2011 Report
Carlsbad Environmental Monitoring & Research Center

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EXECUTIVE SUMMARY

The Carlsbad Environmental Monitoring and Research Center (CEMRC) has measured the levels of radiological and non-radiological constituents in samples of the exhaust air, ambient air, and water collected at and in the vicinity of the U.S. DOE's Waste Isolation Pilot Plant (WIPP) during calendar year 2011. The WIPP facility became operational in March 26, 1999 for the disposal of transuranic waste, and the WIPP received its first mixed waste shipments on September 9, 2000.

The CEMRC has compared these levels to those measured in the pre-operational phase, prior to receipt of waste. Based on these analyses, the CEMRC concludes that:

a) Levels of the measured radiological and non-radiological constituents in the environment around WIPP during calendar year 2011 are not different from the preoperational baseline levels.

b) The measured levels are similar to those measured by other organizations, where direct comparisons can be made.

c) Trace amounts of radionuclides (^{131}I, ^{134}Cs, and ^{137}Cs) from the Fukushima nuclear power plant incident were detected in the station A and ambient air samples collected during March-April 2011. However, it is important to note that all of the radiation levels detected across the United States, including Carlsbad, due to the Fukushima nuclear power plant accident have been very low, well below any level of public or environmental concern.

d) No measurable radiation dose to the public resulted from WIPP-related operations during calendar year 2011, relative to the estimated baseline dose.

Lastly, I would like to acknowledge the following individuals who contributed heavily to the creation of this report: Ms. Sally Ballard, Ms. Adrienne Chancellor, Dr. Anuj Kumar, Mr. Jim Monk, Dr. Ila Pillalamarri, Dr. Punam Thakur, and Ms. Melinda Wilson.

Respectfully submitted,

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Acronyms and Abbreviations

μBq	MicroBecquerel
μm	Micrometer
Ag	Silver
Al	Aluminum
Am	Americium
ANSI	American National Standards Institute
As	Arsenic
ASTM	American Society for Testing and Materials
Ba	Barium
Be	Beryllium
Bq	Becquerel
C	Centigrade
Ca	Calcium
CAM	Continuous Air Monitor
CCP	Central Characterization Project
Cd	Cadmium
Ce	Cerium
CEMRC	Carlsbad Environmental Monitoring & Research Center
CEMRP	Carlsbad Environmental Monitoring & Research Program
CFR	Code of Federal Regulations
CH	Contact-handled
Ci	Curie
cm	Centimeter
Cm	Curium
Co	Cobalt
Cr	Chromium
CRM	Certified Reference Materials
Cs	Cesium
Cu	Copper
DL	Detection Limit
DOE	U.S. Department of Energy
DOE/CBFO	U.S. Department of Energy/Carlsbad Field Office
DOELAP	U.S. Department of Energy Laboratory Accreditation Program
EEG	Environmental Evaluation Group
EC	Environmental Chemistry
EM	Environmental Monitoring
EPA	U.S. Environmental Protection Agency
Er	Erbium
ERA	Environmental Research Associates
Eu	Europium
F	Fluoride
FAS	Fixed Air Samples
Fe	Iron
FP	Field Programs
FWHM	Full-Width, Half-Maximum
g	Gram
GC/MS	Gas Chromatograph/Mass Spectrometer
Gd	Gadolinium
Ge	Germanium

GPS	Global Positioning Satellite
HCl	Hydrochloric acid
$HClO_4$	Perchloric acid
HEPA	High Efficiency Particulate Air
HF	Hydrofluoric acid
Hg	Mercury
HNO_3	Nitric acid
H_2O_2	Hydrogen Peroxide
HPGe	High Purity Germanium
hr	Hour
HSG	Headspace Gas
I	Iodine
IC	Ion Chromatography
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
ID	Internal Dosimetry
IM	Information Management
ISO	International Organization for Standardization
IUPAC	International Union of Pure and Applied Chemistry
K	Potassium
km	Kilometer
L	Liter
La	Lanthanum
LaF_3	Lanthanum Fluoride
LANL	Los Alamos National Labs
lb	Pound
LDBC	"Lie Down and Be Counted"
LCS	Laboratory Control Samples
LFB	Laboratory Fortified Blank
LFM	Laboratory Fortified Matrix
Li	Lithium
LRB	Laboratory Reagent Blanks
m	Meter
MAPEP	Mixed-Analyte Performance Evaluation Program
mb	Millibar
MBL	Mobile Bioassay Laboratory
mBq	MilliBecquerel
MDC	Minimum Detectable Concentration
MDL	Method Detection Limit
Mg	Magnesium
min	Minute
mL	Milliliter
mm	Millimeter
Mn	Manganese
Mo	Molybdenum
M&O	Management and Operations
MTRU	Mixed Transuranic
Na	Sodium
NaOH	Sodium Hydroxide
NCR	Nonconformance
Nd	Neodymium
Ni	Nickel
NIST	National Institute of Standards and Technology

nm	Nanometer
NMED	New Mexico Environment Department
NMSU	New Mexico State University
Np	Neptunium
NRE	Non-Routine Event
NRIP	National Radiochemistry Intercomparison Program
OC	Organic Chemistry
ORNL	Oak Ridge National Laboratory
Pa	Protactinium
Pb	Lead
pH	Scale Indicating Acidity or Alkalinity of a Substance
Ppbv	Parts per Billion Volume
Pu	Plutonium
QA	Quality Assurance
QAP	Quality Assurance Program
QAPD	Quality Assurance Program Document
QC	Quality Control
RC	Radiochemistry
RCRA	Resource Conservation and Recovery Act
RH	Remote-Handled
Ru	Ruthenium
SAB	Science Advisory Board
Sb	Antimony
Sc	Scandium
SD	Standard Deviation
Se	Selenium
SE	Standard Error
sec	Second
SNL	Sandia National Labs
Sr	Strontium
$T_{1/2}$	Half-Life
TCD	Thermal Conductivity Detector
Th	Thorium
Ti	Titanium
Tl	Thallium
TRU	Transuranic
TSP	Total Suspended Particulates
U	Uranium
V	Vanadium
VOC	Volatile Organic Compound
WERC	Waste-management Education & Research Consortium
WHB	Waste Handling Building
WIPP	Waste Isolation Pilot Plant
WIPP-EM	Waste Isolation Pilot Plant Environmental Monitoring
WRES	Washington Regulatory and Environmental Services
WTS	Washington TRU Solutions
XO	Experimental Operations
Y	Yttrium

INTRODUCTION

The Waste Isolation Pilot Plant (WIPP), a U.S. Department of Energy (DOE) facility, is an underground repository located in the remote Chihuahuan desert of southeastern New Mexico near Carlsbad. The facility is designed to dispose of transuranic (TRU) wastes that were generated from research and the production of nuclear weapons at various DOE sites in the U.S. The WIPP facilities consist of above ground buildings and underground mined areas. The underground portion of the WIPP is located 665 meters (2,150 feet) below the surface and is divided in two main areas. The northern part, the experimental operations (XO) area, is a research area and is open to the scientific community, while the much larger southern part comprises the Waste Disposal Area. As shown in Figure 1, the WIPP repository has eight panels, each consisting of seven waste disposal rooms that measure approximately 300 feet (91 meters) long and 33 feet (10 meters) wide. Seven of the planned panels have been excavated; and the first five have been filled with waste, closed, and sealed from ventilation air. Waste disposal is currently in progress in the sixth panel. Generally, three panels are in operation with one already filled with waste and closed (closure mode); the second panel already excavated with waste disposal in progress (waste disposal mode); and the third panel ready for mining (mining mode). Currently, panel 5 is in closure mode, Panel 6 is in waste mode and Panel 7 is in mining mode.

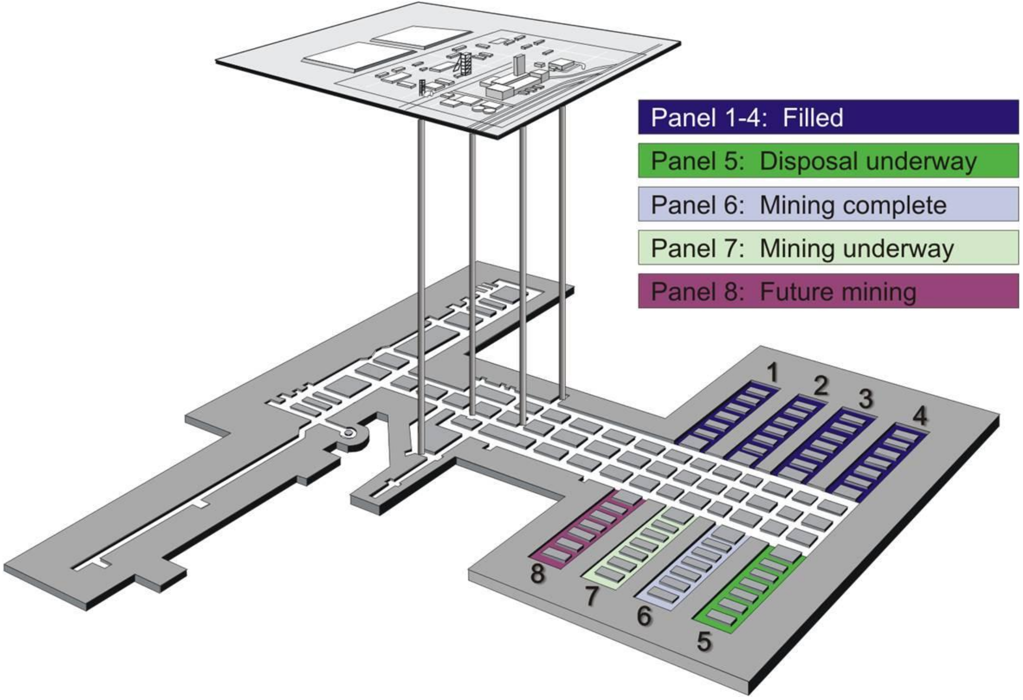

Figure 1. WIPP layout

Two types of TRU wastes are currently stored in the WIPP repository: (1) mixed transuranic waste (MTRU) and (2) non-mixed waste that contain only radioactive elements, mostly plutonium. The TRU waste is subdivided into contact-handled (CH) and remote-handled (RH) waste on the basis of the dose equivalent rate at the surface of the waste container. If the dose is < 200 mrem/h (2 mSv/h), the waste is categorized as CH-TRU waste; otherwise, the categorization is RH-TRU waste. Contact-handled waste (CH TRU Waste) and contact-handled mixed waste (CH TRU mixed waste) do not need additional shielding beyond the waste container. As a result, workers can unload, handle and repack CH waste by touching the waste container directly. Remote-handled waste (RH TRU waste) and remote-handled mixed waste (RH TRU mixed waste) emit higher levels of radiation (surface dose rate from 2mSv/h to 10mSv/h); therefore, remote handling is used as a precaution to ensure worker safety.

Both types of mixed waste contain radioactive and hazardous materials, whereas, non-mixed waste contains only radioactive waste with negligible hazardous characteristics. The first shipment of TRU waste, CH-TRU waste from Los Alamos National Laboratory, arrived at the WIPP on March 26th, 1999 and was disposed underground on the same day. Since opening in March 1999, more than 82,000 cubic meters of legacy TRU waste have been removed from temporary locations around the nation and shipped to WIPP for permanent disposal. Although the waste stored at WIPP contains numerous hazardous and/or radioactive materials, the radionuclides of greatest concern in the WIPP are $^{239+240}$Pu and ^{241}Am, which account for more than 99% of the total radioactivity for most of the 10,000 year regulatory period.

The major objective of the CEMRC monitoring program is to evaluate present, future and sometimes past behavior of radionuclides in the vicinity of the WIPP. The program also has the capabilities to detect radionuclides as quickly as possible in case of accidental releases from within the repository or at the site during waste handling operations. The air, drinking water, surface water, soil, and local population around the WIPP facility as well as air entering and exiting the WIPP underground are analyzed at CEMRC as part of a routine environmental monitoring program. CEMRC has been monitoring the concentration of plutonium (Pu) and americium (Am) in the area around the WIPP sites for many years as isotopes of these elements are the major radioactive constituents in the TRU waste. The source of Pu and Am in and around the WIPP site prior to arrival of the TRU waste at the site can be attributed to: nuclear weapons testing that occurred between the 1950s to1980s, controlled releases from the operation of nuclear power plants and nuclear reprocessing facilities, and nuclear accidents. It has been reported that about 15 pBq of $^{239+240}$ Pu and 0.3 pBq of ^{238}Pu have been globally released into the atmosphere from weapons testing and nuclear power-related incidents, whereas 1.3 pBq of ^{238}Pu was injected into the upper atmosphere from satellite burn-up upon reentry. The Gnome test site, located about 8.8 km southwest of the WIPP site, is also a potential source of radionuclides. At this site a 3.3 kiloton yield nuclear underground detonation was conducted in 1961 as part of the Plowshare Program of the Atomic Energy Commission. The site was decontaminated in 1968-1969 and again in 1978. Despite these clean-up efforts, elevated levels of ^{137}Cs and plutonium have been detected in some of the surface soil samples collected at the Gnome site. These contaminated soils are a potential source of contamination for environmental samples being collected to monitor for potential release of radionuclides from the WIPP and to maintain the integrity of the WIPP project. Therefore, knowledge of the levels and behavior of actinides in the WIPP environment is necessary to assess the radiological and ecological effects of radiation on workers and the general public that live and work around the WIPP site.

In this report, samples collected and analyzed during calendar year 2011 are presented. Results from this program are accessible to the public through this report and the CEMRC website and are used for evaluating the long-term history of these radionuclides to better assess the impact of WIPP (if any) on the local environment. CEMRC believes this aspect of its mission is important since the public needs to know what is truly happening in the environment and what effect, if any, WIPP activities has on their lives and health. Lastly, this type of information is important for assessing the impact of the WIPP on the local environment for public acceptance of this and future waste disposal projects.

OVERVIEW OF THE CEMRC MONITORING PROGRAM

The Carlsbad Environmental Monitoring and Research Center (CEMRC), has performed as an independent, academic-based monitoring facility for the WIPP since 1993. The program was developed in conjunction with the Department of Energy, WIPP management and operations contractor (M&O), state and local government, and regional citizens to monitor the environment in and around the WIPP facility for below background levels of radionuclides and other contaminants of interest to the regional community. The goal is to provide an independent environmental and human health monitoring program to assure area residents that there is no release of radiological contaminates as the result of WIPP-related activities. As defined in the original grant, the project was implemented during the WIPP pre-disposal phase, and is now continuing throughout the operational (disposal) phase. The CEMRC's WIPP environmental monitoring (WIPP-EM) project is organized and carried out independent of direct oversight by DOE. Further, the project does not provide data to any regulatory body to meet the compliance demonstration requirements applicable to the WIPP. Instead, analytical results and interpretations from the WIPP-EM program are published by CEMRC, in the form of an annual report, to inform the citizens of Carlsbad and the surrounding area that there is no evidence of increases in radiological contaminants that can be attributed to releases from the WIPP. The success of such a monitoring program is important in terms of boosting public confidence and enhancing public acceptance; where a locality's "not in my-backyard" attitude could hinder the siting of a nuclear waste repository anywhere in the world.

A detailed description of the CEMRC's WIPP-EM concepts, sampling design, and baseline studies has been presented in previous CEMRC annual reports which are available at the CEMRC website (www.cemrc.org). The following is a summary of the calendar year 2011 activities for the major environmental mediums in the WIPP EM program. It is important to note that the first shipment of TRU nuclear waste was received at the WIPP facility on March 26, 1999; the first mixed waste shipment was received on September 9, 2000; and the first shipment of higher-activity waste (called remote handled or RH waste) was received in the first part of 2007. The results summarized in this report cover samples collected through December 2011.

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, and drinking water, ***there is no evidence of increased radiological contamination in the region of the WIPP that could be attributed to any releases from the WIPP or due to the result of any WIPP-related activities***. Levels of radiological and non-radiological analytes measured in 2011 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 prior to the start of the disposal phase in 1999.

In 2003, CEMRC detected a small quantity of plutonium in a composite aerosol sample from the second calendar quarter. This discovery was corroborated by both Environmental Evaluation Group (EEG) and the M&O contractor Washington Tru Solutions

(WTS) through the analyses of samples that were independently collected and analyzed. The activity level of the plutonium was extremely low and well within historic background levels, but highlighted the ability of the CEMRC's WIPP-EM program to detect radionuclides of interest at any level above the minimum detectable concentration (MDC). Further, CEMRC reported in 2007 a small quantity of plutonium in composite aerosol samples from the first and third quarters. However, further analysis showed that these detections resulted from minor contamination during the gross alpha/beta measurements on filters which has since been corrected. Therefore, no plutonium was detected in 2007 above MDC. However, in 2008, 2009, and 2010, CEMRC again detected a small quantity of plutonium in composite aerosol samples from the first, second, and third quarters respectively all of which were similar to the 2003 detection. The CEMRC detections in 2008, 2009, and 2010 were corroborated by WTS's monitoring activities as well.

The challenges faced by CEMRC during 2011 has been to restructure and optimize the WIPP-EM activities in order to maintain a long-term environmental monitoring program that will contribute to maintaining the public's confidence with respect to the safe operation of the WIPP, to identify missing elements in our understanding of the WIPP environment that are not addressed by the ongoing and proposed long-term monitoring studies, and to initiate research programs to compliment these activities. The sampling schedule for the years 2011-2015 are shown in Table 0.1.

Table 0.1. WIPP-EM Sampling Schedule

(Aerosol sampling includes: Station A, Station B, and Ambient Air)

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

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) need for data validation and verification prior to release, (4) time constraints resulting from sample preparation and analysis procedures, (5) staff turnover resulting from the difficulty in attracting and retaining qualified staff in Carlsbad, (6) fluctuations in funding, and (7) time and resource coordination between and among the other entities in the facility.

Since the WIPP-EM program began, CEMRC has reduced the frequency of sampling of the various media and has reduced the number of target analytes primarily as the result of a decrease in resources over time. Additionally, the justification for this reduction was 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-related activities. Going forward, studies of airborne particulate matter (aerosols) will continue to be a major focus of the CEMRC's environmental monitoring efforts since, in the event that radiological or non-radiological contaminants are released from the WIPP or in the event of a nuclear accident like Fukushima, such contaminants could be rapidly dispersed through the atmosphere and spread throughout the environment. Likewise, monitoring of the public through the Lie Down and Be Counted (LDBC) program is of the utmost importance as humans are the most important target regardless of the transmission vector for contaminants.

Additionally, 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 radiological impacts from the WIPP will be detected through analyses of media other than air and people, CEMRC has determined that there is value in continued monitoring of soils, water (drinking water and surface water) and sediments in some form and frequency. Thus, a program has been implemented, that will be revised annually with input from various stakeholders, in which certain media other than air, people, and drinking water are sampled each year on a rotating basis (see Table 0.1). In 2011, that media was intended to be surface water, and sediments. Unfortunately, the collection of surface water and sediments did not materialize in 2011 due to recurring problems with the CEMRC's boat, a vital piece of equipment needed for this activity. The boat issues have since been resolved; therefore, the collection of surface water and sediment samples are expected to resume in the future.

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

The sampling media for the 2011 environmental monitoring program included airborne particulates (both FAS and ambient air), 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 stream (plutonium ^{238}Pu, $^{239+240}$Pu, and americium ^{241}Am), and major fission products (cesium, ^{137}Cs and cobalt, ^{60}Co). In addition, the CEMRC also analyzed Station A (FAS filters) and drinking water samples for non-radiological constituents. Environmental levels of these radionuclides and inorganics could provide corroborating information on which to base conclusions regarding releases from WIPP facility operations. Table 0.2 summarizes the list of target radionuclides and inorganic constituents along with their type of radiation method of detection and reason for monitoring at the WIPP site.

Table 0.2. Radioactive Nuclides and Non-Radioactive Analytes 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
Key Inorganic Analytes (36 total)	**Symbol**	**Detection Method**	**Reason for Monitoring**
Aluminum	Al	ICP-MS	Likely present in mixed waste
Cadmium	Cd	ICP-MS	Likely present in mixed waste
Magnesium	Mg	ICP-MS	Likely present in mixed waste
Lead	Pb	ICP-MS	Likely present in mixed waste
Thorium	Th	ICP-MS	Likely present in mixed waste
Uranium	U	ICP-MS	Likely present in mixed waste

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 or standard deviation (SD) at the 2 sigma (2 × SD) level, and greater than the minimum detectable concentration (MDC). The MDC is determined by 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.

Aerosols

Aerosol particle sampling is conducted at five locations (listed below) with samplers operating continuously at each location. The locations include a port inside the WIPP exhaust shaft (Station A), a point inside the WIPP exhaust but after the filtration system (Station B), 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 Station B; however, these filters are not currently being analyzed. Depending upon discussions with stakeholders, these samples may be included for analysis in the future once procedures have been developed, tested, and implemented. Results from the analysis of the aerosol samples for 2011 are reported in chapter 1 of this report.

Soils

During 2011, no soil samples were collected or analyzed but as can be seen in Table 0.1, are currently slated to be part of the sampling/analysis schedule for 2012.

Surface Water and Sediments

As mentioned previously, recurring issues with the CEMRC boat prevented the collection of surface water and sediment samples in 2011. However, these media are currently scheduled to be collected for analysis in 2012 as well.

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. During 2011, drinking water samples were collected in the month of July from Carlsbad (Sheep Draw and Double Eagle), Loving, Malaga, Otis, and Hobbs. Results from the analysis of the samples from these well fields for 2011 are reported in chapter 2 of this report.

Human Population

The *Lie Down and Be Counted* (LDBC) project serves as a component of the WIPP-EM program 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 program, *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 and as the number of citizen volunteers for the LDBC continue to decline from previous years. Results of the LDBC project through December 2011 are reported in chapter 3 of this report.

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 the ejection of a particle or ray of ionizing radiation, either an alpha, beta, neutron, or gamma. Sometimes the unit Curie (Ci) is used and is equal to 3.7×10^{10} Bq.

QUALITY ASSURANCE

The CEMRC is subject to the policies, procedures and guidelines adopted by New Mexico State University (NMSU), as well as by 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 processes in research and service to its sponsors. CEMRC technical programmatic areas in 2011 included: Environmental Chemistry (EC), Organic Chemistry (OC), Radiochemistry (RC), Field Programs (FP), Information Management (IM) and Internal Dosimetry (ID). The development and implementation of an independent health and environmental monitoring program has been CEMRC's primary activity since its establishment in 1991.

Project Reporting Requirements

Since its inception, CEMRC's WIPP-EM program has been conducted as a scientific investigation, meaning that these activities are conducted without any compliance, regulatory, or oversight responsibilities. As such, there are no specific requirements for reporting data other than the adoption of good scientific practices. An example of reporting decisions made by CEMRC for this program is whether to correct or not to 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's (DOE/CBFO) Quality Assurance Program Document (QAPD, CAO-94-1012). This effort was in response to the DOE/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 DOE/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/CBFO.

Internal audits were performed during 2011 on the following programmatic areas: Environmental Chemistry, Field Programs, Information Management, Internal Dosimetry, Organic Chemistry, and Document Control. A summary of 2011 audits is reported in Appendix C.

Quality Assurance/ Quality Control for Organic Chemistry

The following audits were conducted on the Organic Chemistry group: A WTS quality assurance (QA) audit was conducted in June 2011 as part of the routine yearly audits for VOCs Confirmatory Monitoring Program including VOC, Hydrogen and Methane sample analysis, and canister cleaning and certification services. The program and process established and implemented by the Organic Chemistry group passed the audit successfully without any findings.

Additionally, a CEMRC internal audit was also conducted on the OC group in July 2011 in compliance with the Center’s QAP. This audit concluded that the OC group continues to operate an effective and responsive program.

Lastly, independent quality assurance samples, true values not known at the time of analysis, were also obtained from an outside source (Wibby Environmental, a Phenomenex Company) in 2011 to verify the performance of the instrumentation and the proficiency of the analyst. The OC group passed the study successfully for all target VOCs. Moreover, analysts were able to identify all other non-target analytes present in the sample.

Quality Assurance/Quality Control for Radioanalyses

Routine quality assurance/quality control activities conducted for radio-analyses include tracking and verification of analytical instrument performance, the use of American Chemical Society certified reagents, the 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 & 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 work day or prior to the counting of 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 to measure the gross alpha/beta on FAS filters, efficiency control charting was performed using ^{239}Pu and ^{90}Sr check sources and checks were made to ensure that α/β cross-talk was within limits.

Additionally, sixty-minute background counts were recorded daily and 20-hour FAS filter blank counts were recorded every two weeks. Lastly, two blanks per week for the FAS program were counted for 20 hours and were used as a background history for calculating results.

For the high purity germanium (HPGe) detector systems, routine background determinations were made 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 position. Blanks counted for 5 days were used as a background history for calculating results.

The radiochemical equations used for the calculation of minimum detection concentration (MDC), standard deviation (SD) are described in Appendix D. The accuracy of the radiochemical analyses was evaluated by analyzing calibration standards, method blanks (tracer blank), and laboratory control samples (LCSs or blank spikes). LCSs are QC samples that check whether the analysis procedure is in control or not. Analysis of LCSs containing the isotopes of interest was performed on a minimum 10% 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.

Laboratory procedural and instrument accuracy was also verified through participation in the DOE Mixed-Analyte Performance Evaluation Program (MAPEP) and National Institute of Standards and Technology - Radiochemistry Intercomparison Program (NIST-NRIP) interlaboratory comparison programs. Under these programs, CEMRC analyzed blind check samples with the analysis results compared against official results measured by the MAPEP and NRIP laboratories. Performance was established by percent bias, calculated as shown in Tables E.1 – E.3. During 2010-2011, CEMRC’s radiochemistry program analyzed MAPEP air filter, water, and soil; MAPEP gross alpha/beta for air filters and water; and NIST-NRIP glass fiber filter, acidified water and soil samples. Isotopes of interest in these performance evaluation programs were $^{233/234}$U, ^{238}U, ^{238}Pu, $^{239+240}$Pu, ^{241}Am and some gamma radionuclides. The analyses were performed using CEMRC’s actinide separation procedures and were treated as a regular sample set to test normal performance. CEMRC’s results were consistently close to the known value. Results from the MAPEP and NIST-NRIP proficiency tests are presented in Appendices D. Only two analysis results, ^{241}Am in MAPEP radiological filter (RdF25) matrix and gross beta activity on filter (GrF25), 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 such as EPA 200.8 and EPA 6020. 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 program and other research projects. Additionally, a CEMRC internal audit was conducted on the EC group in February 2011 in compliance with the Center's QAP. The exit report for the audit maintained that the EC group continues to operate an effective and responsive program. However, because several years had lapsed since the EC group had last been audited; the EC group did receive several findings and observations, a majority of which consisted of documentation-related concerns. Additionally, while many of the findings and observations were corrected during the course of the audit, all findings and observations have since been corrected or addressed, and therefore, the EC group is operating more efficiently as a result of this process.

Calibration checks are performed on all EC balances using NIST traceable weights prior to each use. All pipettes used for quantitative transfer of samples are checked for calibration monthly. All instrumentation is calibrated prior to each sample analysis. All labware not already purchased as "metal free" are acid-cleaned in-house and all reagents used for calibration, sample dilution, and analysis are either purchased as certified trace-metal grade or distilled in-house using a sub-boiling quartz distillation apparatus.

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. Calibration checks are run at the start of each sample analyses and periodically throughout the sample run. Other QC samples checks include, but are not limited to, Laboratory Reagent Blanks (LRBs), Laboratory Fortified Blanks (LFBs), duplicates, and Laboratory Fortified Matrix samples (LFMs). In cases where duplicate aliquots from the original sample were not feasible (such as FAS filters), separate aliquots of the sample extract were analyzed for the duplicate and LFM analyses. All samples and standards for elemental analysis are spiked with an internal standard to determine sensitivity and malfunction during analysis.

Method detection limit (MDL) is determined annually for each analyte as per EC procedures as outlined in 40 Code of Federal Regulations (CFR) Part 136, Appendix B.

Independent quality assurance samples are obtained and analyzed to verify the performance of the instrumentation and the proficiency of the analyst. Annually, blind samples (obtained from an outside source, with true values not known at the time of analysis) are analyzed. 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 MDLs, several analytes often exceed the acceptable range by several percent. Elements commonly falling into this category include aluminum, beryllium, cobalt, and iron, which increases the overall uncertainty of the analyses. Examples of results from a blind sample (from the Environmental Resource Associates [ERA] WatR^{TM} Supply Proficiency Testing Study) for 2011 (the time period in which the 2011 samples were analyzed) are given in Figure D.2 and Table D.4 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 the 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, as well as 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 with electronic copies being crosschecked against the original data forms on a routine basis. All electronic files are backed up daily and paper documents are digitized and backed up monthly.

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 the 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 scheduled for 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, commonly referred to as full-width, half-maximum (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.

Additionally, 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. Table D.1 shows an example of results for the last three quarters of 2010 and the first three quarters of 2011. For all years since CEMRC began participating in the ORNL program, CEMRC has consistently out-performed all other laboratories in this area.

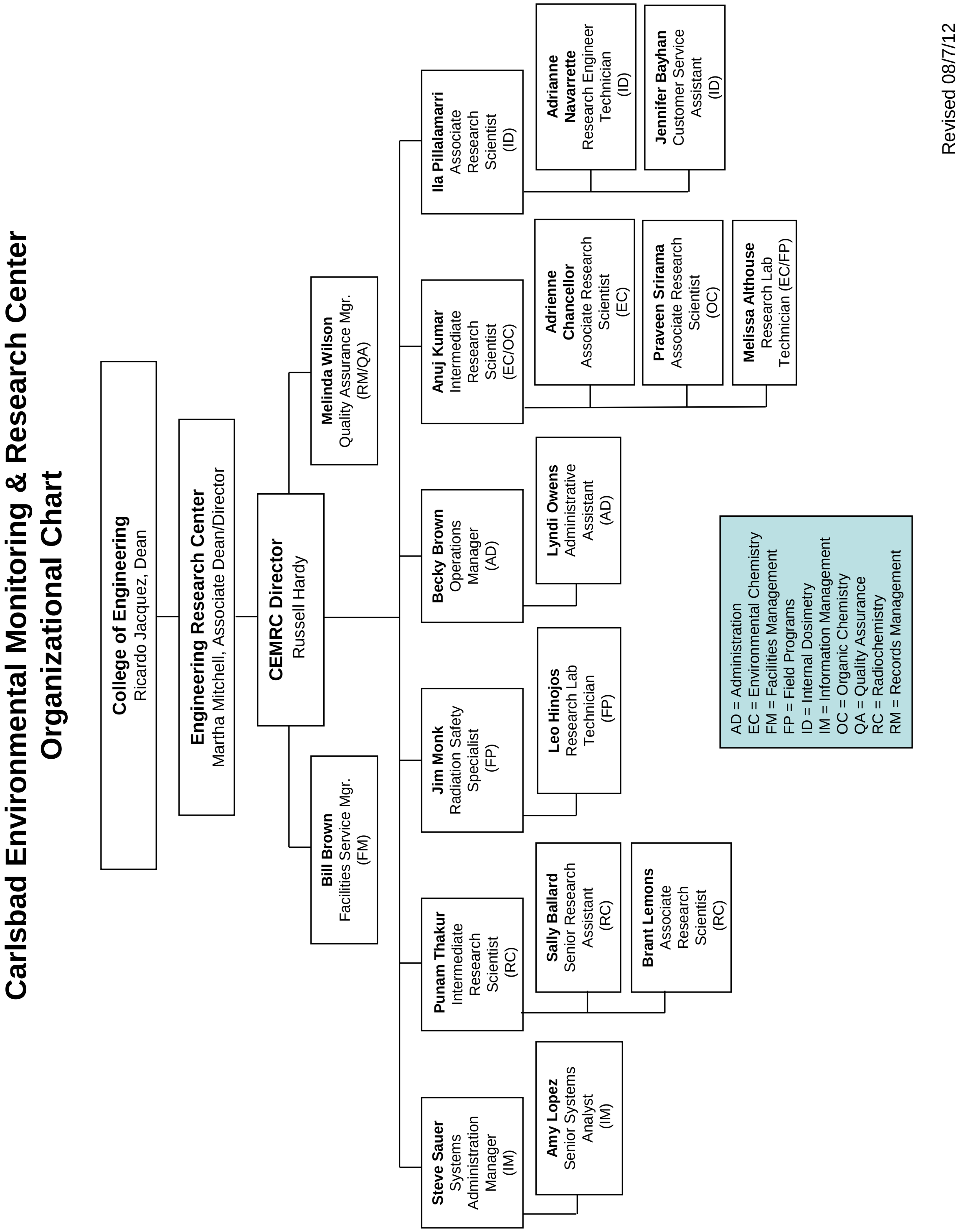

Figure 0.1. CEMRC Organizational Chart

CHAPTER 1

WIPP Exhaust Air Monitoring

Introduction

The WIPP exhaust air from the underground is measured by four monitoring stations referred to as Stations A, B, C, and D. Each station is equipped with at least one skid-mounted particulate air sampler, called a fixed-air sampler (FAS). Station A is an above-ground air sampling platform that is shared by several other environmental monitoring groups. At this station, unfiltered air is exhausted from the repository to the atmosphere. At station B, HEPA (High Efficiency Particulate Air) filters are first used to filter the exhaust from the repository. While in *filtration mode*, stations A and B are mutually exclusive (i.e., when air is exhausted from station A, none is exhausted from station B and vice versa). Both stations A and B sample the same air when operating in the *maintenance bypass*, *reduced*, or *minimum* mode. Station C is used to sample the exhaust from the WHB (Waste Handling Building). Prior to sampling activities at station C, the collective air passes through HEPA filters. Lastly, station D is located at the base of the exhaust shaft and occasionally serves as a back-up skid for station A.

The effluent 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, should radioactive materials be released from the facility, one would expect to detect it at Station A before it is observed in the local population or environment. Therefore, CEMRC has developed procedures and methods to provide a "quick look" (i.e. within a few days when possible) at radioactive materials present in the exhaust air. Under this scenario, 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 sensitivity of the CEMRC WIPP-EM program at Station A was first 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; however, the incident was notable because it demonstrated, for the first time, the ability of the monitoring system to detect a non-routine event. A second incident occurred in the second calendar quarter of 2003 when CEMRC's scientists reported that they had detected a small quantity of plutonium ($^{239+240}$Pu) in a composite aerosol sample. This discovery was later corroborated by both EEG (Environmental Evaluation Group) 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 (DOE) and a briefing presented to the New Mexico Environment Department (NMED). Although the activity was extremely low and well within historic background, it indicated the ability of the monitoring program to detect radionuclides of interest at any level above the MDC. Similarly, trace concentrations of $^{239+240}$Pu, ^{238}Pu and americium (^{241}Am) were detected in February, 2008;

April, 2009; and July, 2010 composite samples by CEMRC scientists. These detections were also corroborated by both WTS and NMED as well. As both ^{238}Pu and $^{239+240}$Pu were detected above MDC, the activity ratios between ^{238}Pu to $^{239+240}$Pu were calculated in order to understand the source of these radionuclides in the WIPP exhaust air samples. The mean ^{238}Pu to $^{239+240}$Pu activity ratio of 0.025±0.004 observed in these samples are consistent with the source being largely related to global fallout. Within global fallout, 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). This 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 to $^{239+240}$Pu activity ratio of 0.03 at mean latitudes of 40^{o}-50^{o} N (UNSCEAR, 1982).

Sample Collection

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 which are available on the CEMRC website www.cemrc.org . In brief, the WIPP air samples for stations A, B, and D are collected on 3.0µm pore size, 47 mm diameter Versapor® membrane filters with the use of a shrouded probe, commonly referred to as a fixed air sampler or FAS. The volume of air sampled at each location varies depending on the sampling location and configuration.

There are actually three shrouded-probe aerosol samplers at Station A (Figure 1.1); these are located on three separate sampling skids referred to as A1, A2 and A3. The airstream sampled by each skid is split among three legs such that three concurrent samples can be collected from each skid. The airflow through the FAS is approximately 170 liters/minute (6.0 cubic feet per minute, cfm). The samples at Station A are typically collected daily except for weekends with weekend samples running from Friday to Monday so that continuous coverage is maintained. Occasionally, however, more than one sample per day is collected if the flow rate on any of the sampler legs drops below 1.8 cfm. Under this scenario, a low-flow alarm on the sampler is activated and the filters are changed. In 2011, a total of 444 filters were collected from Station A. The number of filters collected each year from station A is shown in Figure 1.2.

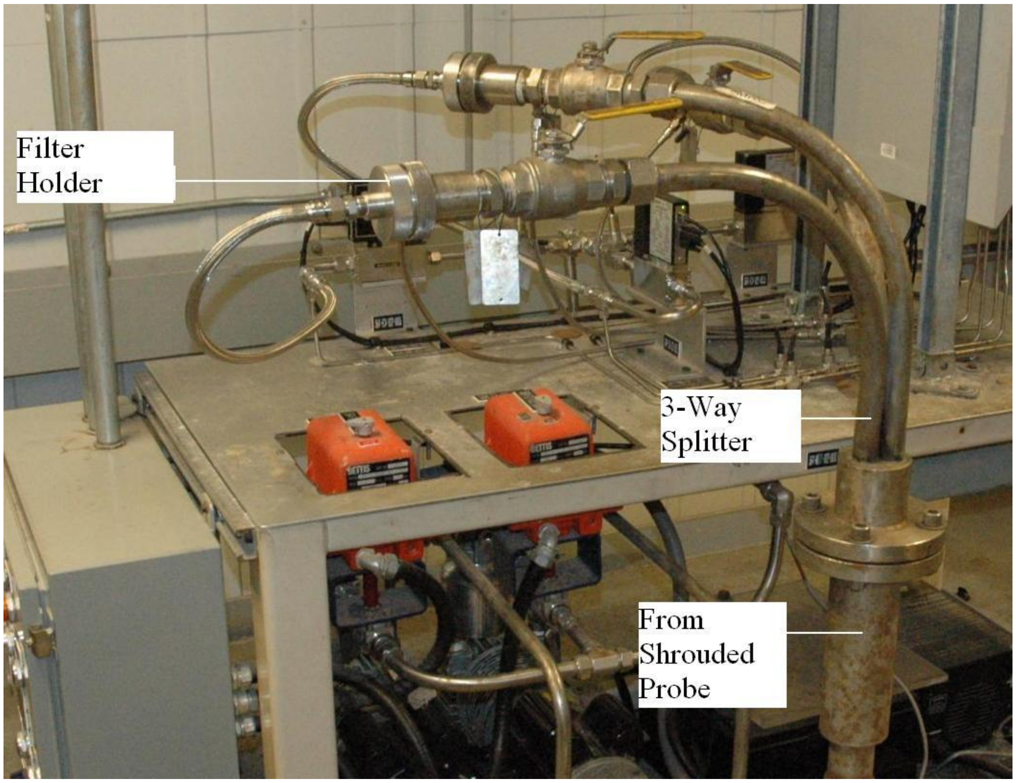

Figure 1.1. Fixed Air Samplers at Station A

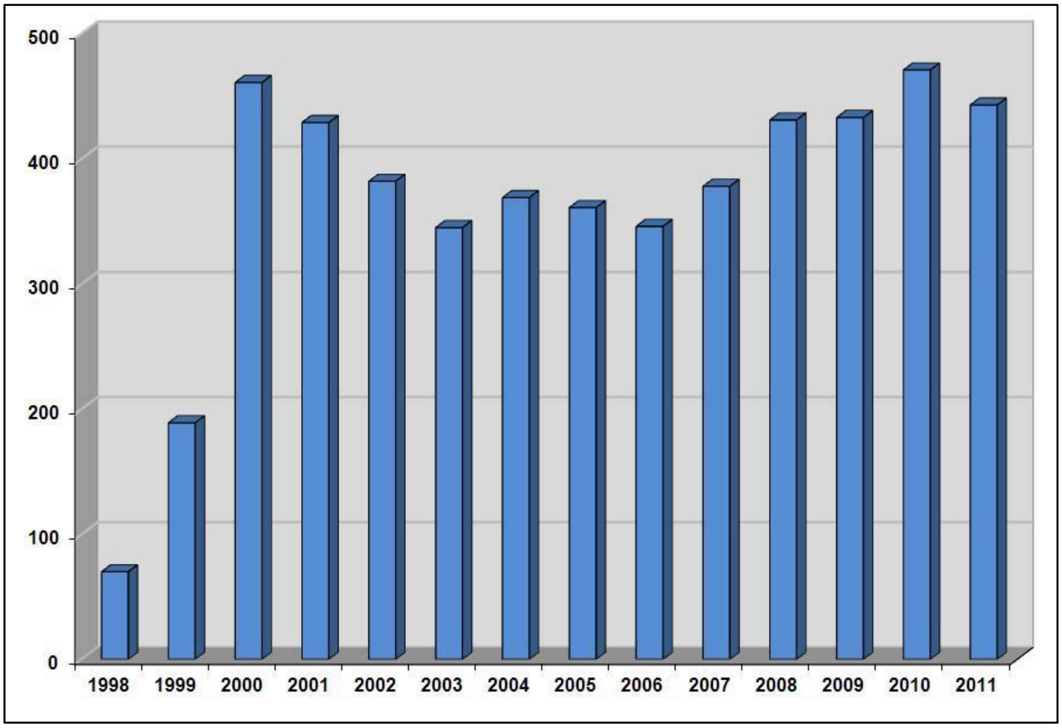

Figure 1.2. Number of FAS Filters Collected from Station A

After the 2003 Pu detection, CEMRC implemented an additional FAS filter, called the Trip Blank, which is a blank filter that accompanies the sample filter throughout the whole process, including transportation to and from the WIPP site as well as being placed on the collector for approximately 15 seconds before being removed and placed in a sealed container. Unlike the laboratory and reagent blanks, the Trip Blank can reflect sampling errors or field contamination that is independent of laboratory procedures and reagents.

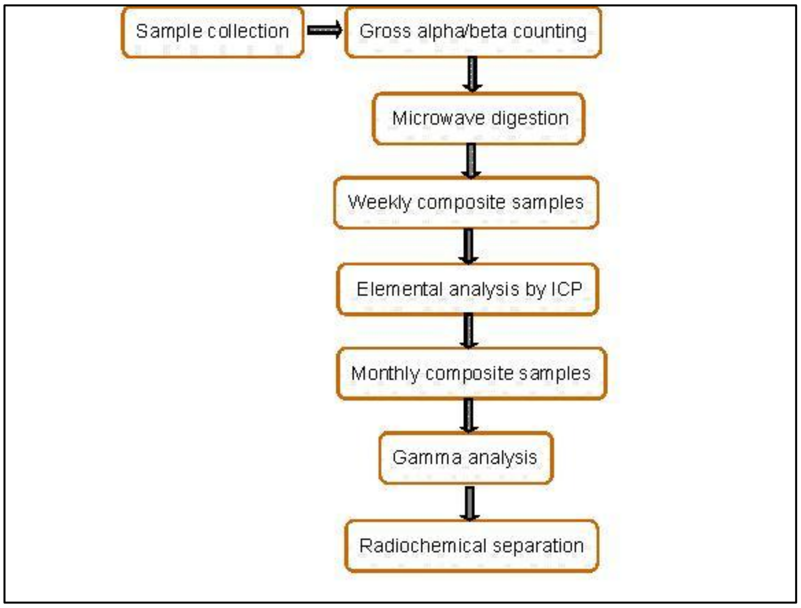

Figure 1.3. Flow Diagram Showing the Handling and Analysis of FAS Filters

Sample Preparation and Analysis

All analyses of the FAS filters are performed according to the methods detailed in the CEMRC document-controlled, standard operating procedures. A simplified scheme of the sample preparation process is shown in Figure 1.3.

Once the samples are collected from the field and returned to the laboratory, the individual filters are desiccated for two days to ensure that any moisture on the filters are evaporated and to ensure a complete decay of daughter products of ^{222}Rn. Once dried, the filters are then weighed to determine mass loadings. Following the desiccating and weighing process, the filters 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. While gross screening analyses are not as accurate nor as precise as more detailed radiochemical separations, 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". Therefore, 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 1,200 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 (2σ warning and 3σ limits) and ensuring that alpha/beta cross-talk are within limits (≤ 0% α into beta and ≤ 0.1% beta into alpha). Sixty-minute background counts are also recorded daily (count must be within the mean background ±3σ) 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 around 25% for alpha and 40% for beta.

Since the levels of radioactivity encountered in environmental samples are typically low, a 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 MDC 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). The flow volume (per cubic meter) and the mass loading (mg) on the monthly composite samples are listed in Table 1.1.

Samples for actinide and inorganic analyses are prepared by using microwave acid digestion in a CEM MARS™ Xpress™ microwave unit according to CEMRC procedures. . Individual FAS filters are placed in separate Teflon vessels and digested at 195'C using an acid matrix consisting of nitric acid, hydrochloric acid, and hydrofluoric acid. A blank filter and Certified Reference Material (CRM) filter are also digested in the same manner for QC-purposes. All acids used in the digestions are concentrated and purified either by using a Milestone Inc. sub-boiling quartz distillation apparatus or purchased as "trace metal" grade. After digestion, the FAS filter solutions are then combined into weekly composites and a small aliquot of each weekly composite is removed for inorganic analysis by inductively-coupled Plasma Mass Spectrometry (ICP-MS).

The weekly composites are then combined into monthly composite samples for the determination of actinide and gamma measurements. The detection and measurement of gamma radionuclides on filter samples are carried out using a low-background, HPGe co-axial detector with a count time of 48 hours. Only one half of the composite sample is normally used for the determination of the actinide activities and the remaining aliquot is archived. The composite sample is evaporated to dryness, and the residue is digested in perchloric acid ($HClO_4$) to destroy the black residue, which consists mostly of diesel exhaust particulates. The actinides are then separated as a group by co-precipitation on iron III oxide ($Fe(OH)_3$). Pu is separated on an anion exchange, AG1-X8 in 8M nitric acid (HNO_3) and purified on a second anion exchange column in 8M hydrochloric acid (HCl). Am and uranium (U) are separated on TRU extraction chromatography column followed by purification of U on an anion exchange column. The samples are then micro-co-precipitated with a neodymium carrier (Nd-carrier) and counted on an alpha spectrometer for 5 days.

The primary purpose of the WIPP-EM plan, including the studies at Station A, has been to compare pre- vs. post-disposal conditions. The WIPP received its first radioactive waste shipments on March 26, 1999. This is considered to be the cut-off date separating the pre-disposal phase from the post-disposal, or operational phase. The first shipment of mixed waste arrived at the WIPP on September 9, 2000. Data for samples collected prior to this date compose a pre-mixed waste baseline for the elemental data, while those collected afterwards are considered operational. In Figures 1.4 through 1.8 and Figures 1.22 through 1.27 discussed in the Radiological and Non-Radiological sections below, data points are distinguished by color for the pre-operational and operational monitoring.

RADIOLOGICAL MONITORING RESULTS

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 1.2, 1.3, and 1.4. Additionally, as shown in Table 1.2, the pre-operational gross alpha activity densities and concentrations were both low compared with the annual mean values for the first five years of operation, but have gone back up above the pre-operational levels during 2007-2011. Gross alpha activities exhibit clear seasonal variability with peaks occurring in the winter (Figures 1.4 and 1.5). 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 2011, 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 2011.

Similar seasonal trends in gross beta data can be seen in Figures 1.6 and 1.7. 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 2011. The beta activity concentration of 58.4 mBq/m^3 observed in 2001 (Table

1.3 and Figure 1.7) is due to contamination released from an under-ground fire extinguisher. Overall beta activities have remained consistent over the years. As shown in Figures 1.6 and 1.7, 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 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 (Figures 1.8) show a trend towards lower sample masses beginning in 2004 and also less scatter in the gravimetric data and then increases again in late 2007 through 2011. The latter point is also evident in Table 1-4, which shows that the relative standard error, i.e. the standard error divided by the arithmetic mean and expressed as a percentage, was ≤ 8% in 2000 and 2003-2009 of the study compared with 10% to 20% in 1999, 2001, 2002, 2010, and 2011. 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 average mass loadings on Station A filters from 1998-2011 are plotted in Figure 1.9 to show the trend.

The weekly and monthly average of gross alpha and gross beta activity concentrations measured in Station A samples from 1998 to 2011 are shown in Figures 1.10 to 1.13. 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 1.14. 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 results of 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. The maximum detectable concentrations of gross alpha and beta as well as aerosol mass loading in Station A filters from 1998 to 2011 are summarized in Table 1.5. 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 1.6. Whenever the word “sample” is used in this section, it should be taken to mean “a monthly composite FAS sample”.

No detectable concentrations of ^{238}Pu, $^{239+240}$Pu or ^{241}Am were detected in any of the 2011 samples. However, a trace amount of cesium (^{134}Cs) and (^{137}Cs) was detected in the March monthly composite samples due to the Fukushima NPP accident in Japan. For more information on this event, see chapter 7 of this report. To confirm the detection of cesium isotopes in the March primary monthly composite sample, the March backup monthly composite sample was also analyzed. The re-analysis of the backup samples also showed a detection of ^{134}Cs and ^{137}Cs. It is important to note that prior to this instance, CEMRC has not detected isotopes of cesium in any of the composite samples since the monitoring operations began in 1998. **Therefore, the detection of Fukushima radionuclides further highlight the sensitivity of the CEMRC analysis and help assure local community constituents that no amount of radionuclide can go undetected by the CEMRC monitoring stations.**

The activity concentrations of $^{239+240}$Pu, ^{238}Pu, ^{241}Am, ^{134}Cs, ^{137}Cs, and cobalt (^{60}Co) measured in the 2011 monthly composite samples are illustrated in Figures 1.15 to 1.20. As shown in Figures 1.18 and 1.19, the activities of the ^{137}Cs and ^{134}Cs isotopes were above detection limits for the month of March, 2011. 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 2011 are shown in Figures 1.21 and 1.22, respectively. An analysis of historical operational data indicates occasional detections of trace amount of $^{239+240}$Pu, ^{238}Pu, ^{241}Am and ^{137}Cs in the exhaust air release from the WIPP. From 2000 until 2011, only ten measurements can be declared as a detection of a radionuclide. These measurements are listed in Table 1.7. For comparison, the values detected above detection limits by WTS are listed in Table 1.8. The consistency between the CEMRC and WTS data further reflects high quality and sensitivity of CEMRC’s monitoring results. However, it should be noted that these activities were extremely low and well below the action level of 37 Bq/m^3 that triggers the Continuous Air Monitors (CAMs) that are distributed throughout the WIPP. The historical average radionuclide concentrations data of $^{239+240}$Pu, ^{238}Pu, ^{241}Am measured by CEMRC from 2000-2011 are summarized in Tables 1.9 to 1.11.

The naturally occurring isotopes of U were detected in all monthly FAS composites in 2011. The average ^{234}U/^{238}U activity ratio of 1.66±0.22 in the WIPP underground air samples indicates the presence of natural U (Table 1.12). ^{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 detections from ^{40}K, no detectable gamma-emitting radio-nuclides were observed during the monitoring period 2011. The minimum, maximum, and average concentrations of radionuclides for the 2011 FAS composite samples are summarized in Table 1.13.

NON-RADIOLOGICAL MONITORING RESULTS

Elemental analyses by Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) are conducted on weekly composites of the filters. As mentioned previously, individual FAS filters were digested using a mixture of strong acids in a CEM MARS™ Xpress™

microwave digestion unit. Blank filters and Certified Reference Material (CRM) filters were also digested in the same manner for QC purposes. All acids used were concentrated and purified either by using a Milestone Inc. sub-boiling quartz distillation apparatus or purchased as “trace-metal” grade.

Weekly composites were then prepared from the digestates of the individual filters and analyzed for a wide-range of elements. A low-resolution Perkin Elmer Elan 6100 ICP-MS was used for the analysis which has a peak resolution of <0.71amu for the mass range reported. The mass calibration value is within 0.1amu of the published true values for the mass range reported. The system was configured with a gem-tip^{TM} cross-flow nebulizer and a Scott spray chamber. All samples were analyzed using a nickel sampler and skimmer cones. Triplicate readings were performed on each digestate, with the average result reported.

The ICP-MS analyses used at CEMRC can provide data for up to ~35 elements in FAS filters, 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. A second set of elements (notably Ag, Li, and Sn) often have variable concentrations in the blank filters which makes their quantification difficult.

Only the following metals will be reported herein: aluminum (Al), cadmium (Cd), magnesium (Mg), lead (Pb), thorium (Th), and uranium (U). Al is of particular 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, Mg, Mn, Sc, and the rare earth elements) It is also the main source of naturally occurring radionuclides, including U, and fallout radionuclides such as Pu and Am. Kirchner, et al. (2002) has also discussed relationships between Al and various radionuclides, both artificial and naturally occurring, in soils. Several potentially toxic elements (i.e., cadmium (Cd), lead (Pb), Th, and U) which 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.

According to the Environmental Protection Agency (EPA), Pb is 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 $\mu g/m^3$ averaged over a rolling 3-month average (US EPA 2012).

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 WIPP receiving the mixed waste in September 2000. **However, there is no evidence of a long-term increase in the concentrations of any of these elements that can be linked to the WIPP operations.**

Time-series plots of the selected trace elemental data from 1998 to the present are exhibited in Figures 1.23 through 1.28. Some data is missing from the elemental data plots because of a sample holding time issue in the fourth quarter of 2004. Furthermore, the data presented in these plots only reflect concentrations above MDC. The MDCs are re-calculated annually, and vary slightly from year to year. The concentrations of Cd, Th, and U regularly hover right around the MDC and in 2009, concentrations for these elements never exceeded the MDC.

During the fourth quarter of 2010 with carry-over into the first quarter of 2011 there was an increase in the mining activity at the WIPP due to additional disposal panel mining as well as mining in the experimental operations (XO) area. The increase in metal concentrations as a result of the increased mining activity for January 2011 could also be augmented by the fact that the winter weather has been noticeably dryer and windier than in recent history.

Additionally, in October 2011, there was an inadvertent release of the fire suppression material, FORAY® in the underground at the WIPP. The affected FAS filter was digested and analyzed separately from the other October 2011 filters to avoid any potential for contaminating the other filters. The results are included along with the 2011 average monthly concentrations for the selected elements shown in Figures 1.29 through 1.34. The material, FORAY®, contains small amounts of Attapulgite Clay (a salt containing Mg, Al, and silicate) in the range of 5-7% by weight so the slightly higher concentrations for these elements compared to the average concentrations for October are expected. While slightly higher concentrations than the monthly October 2011 average were observed for Th and U, they do not exceed pre-operational levels. Additionally, the radiochemical analyses discussed earlier in this chapter confirms that the concentrations of radioactive isotopes for Th and U were well below environmental levels.

Table 1.1. Total Air Flow Volume and Mass Loading Recorded in Monthly Composite Filters in 2011

Month	SID	Air Flow volume (m^3)	Mass Loading (mg)
January	26179	1355.50	1957.29
February	26181	2156.76	509.93
March	26183	2508.77	219.66
March (BU)	27363	1699.21	146.91
April	26185	2390.93	275.83
May	26187	2331.46	277.33
June	26189	2420.25	263.02
June (BU)	27283	2428.54	230.74
July	26191	2460.13	269.82
August	26193	2511.41	181.63
September	26195	2205.54	42.41
October	26197	2430.14	65.26
November	26199	2446.71	143.23
December	26201	2604.79	183.93

BU= Back-up filter

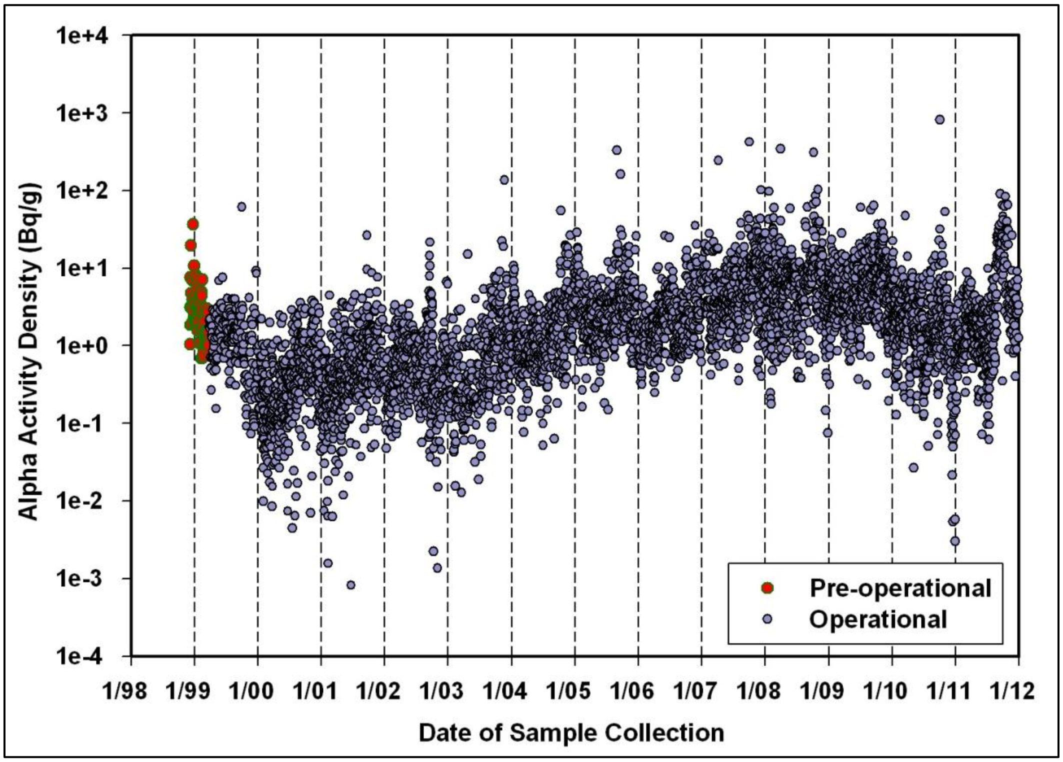

Figure 1.4. Gross Alpha Activity Densities measured in Station A Filters

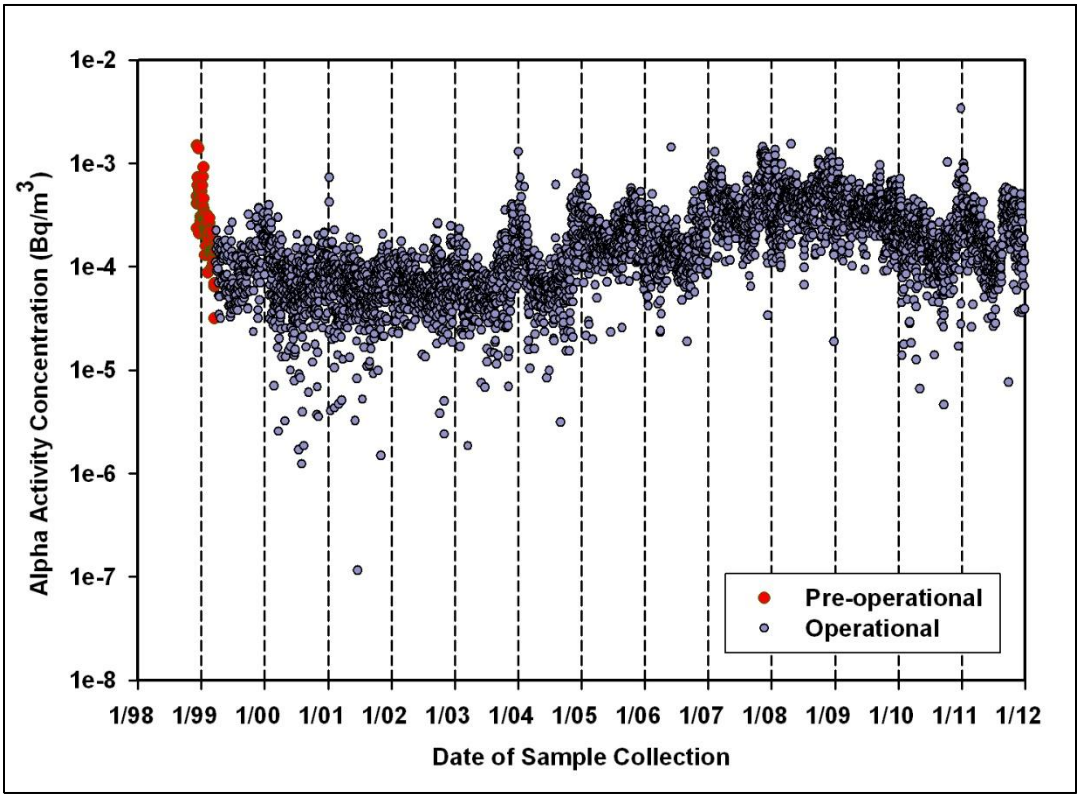

Figure 1.5. Gross Alpha Activity Concentrations measured in Station A Filters

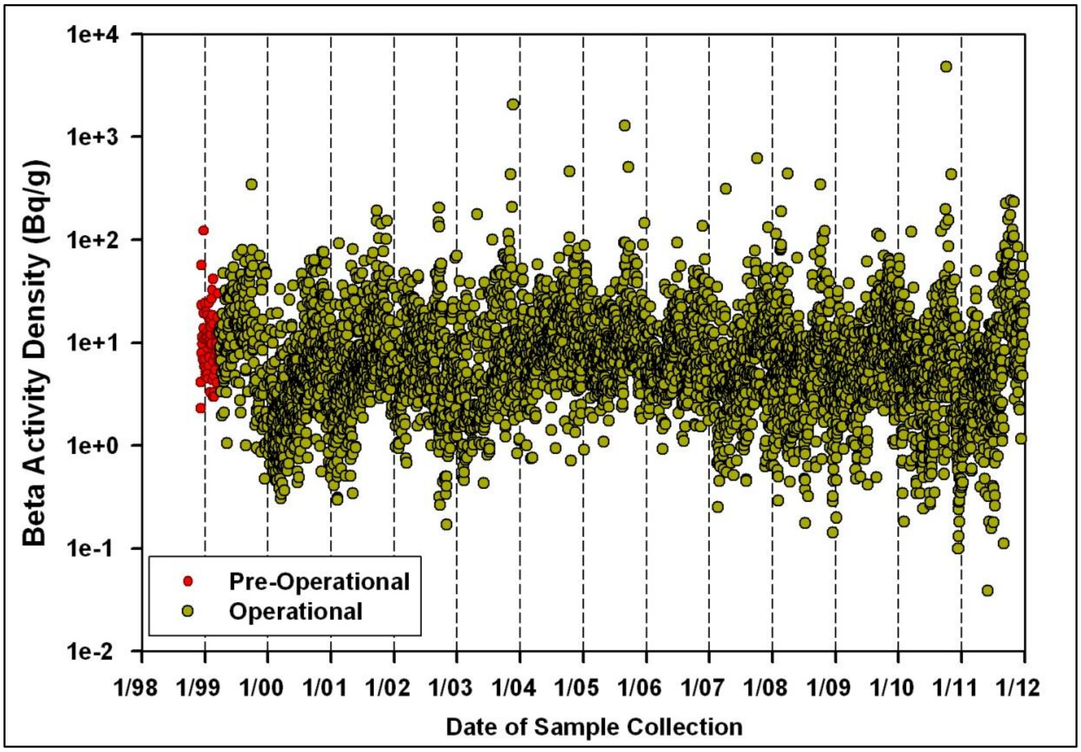

Figure 1.6. Gross Beta Activity Densities measured in Station A Filters

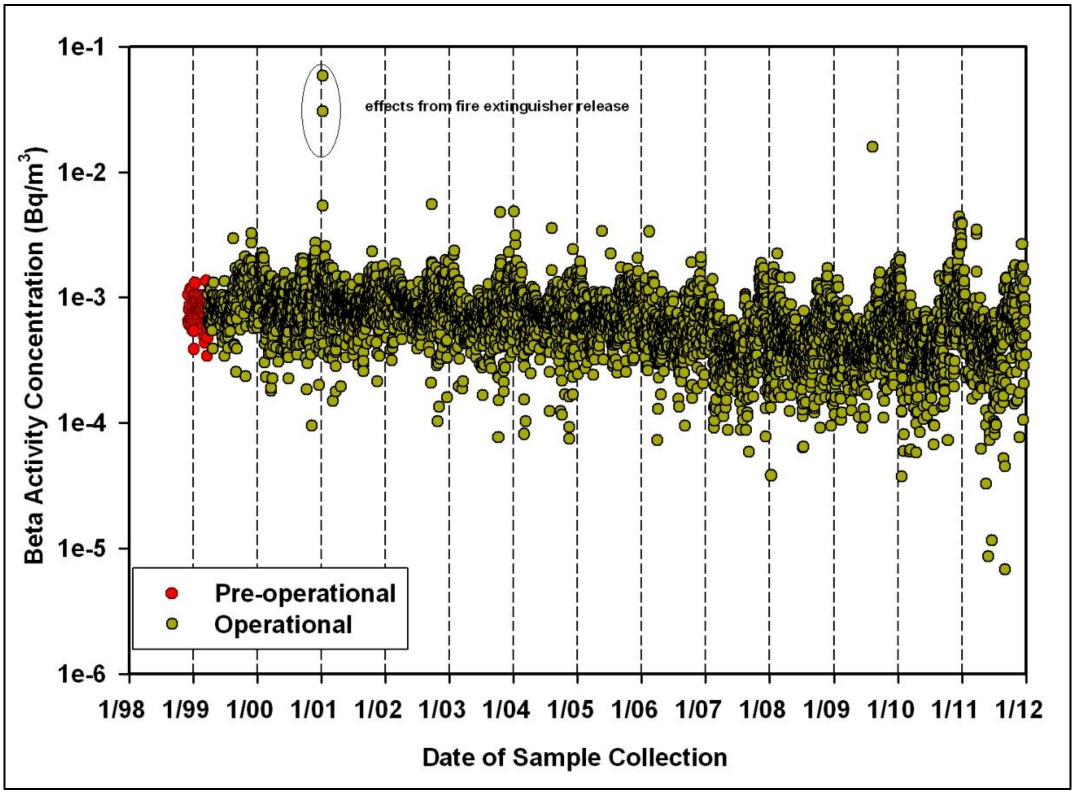

Figure 1.7. Gross Beta Activity Concentrations measured in Station A Filters

Table 1.2. Summary Statistics for Mass Loading and Gross Alpha Analyses of Station A 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
2011	443	7%	5.2	0.49	89.9	7%	0.218	0.007	1.00

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 1.3. Summary Statistics for Mass Loading and Gross Beta analyses of Station A 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
2011	443	7%	13.9	1.33	241	7%	0.55	0.02	3.87

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 1.4. Summary Statistics for Aerosol Mass Loadings on Station A (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
2011	443	176.0	24.5	14.0

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

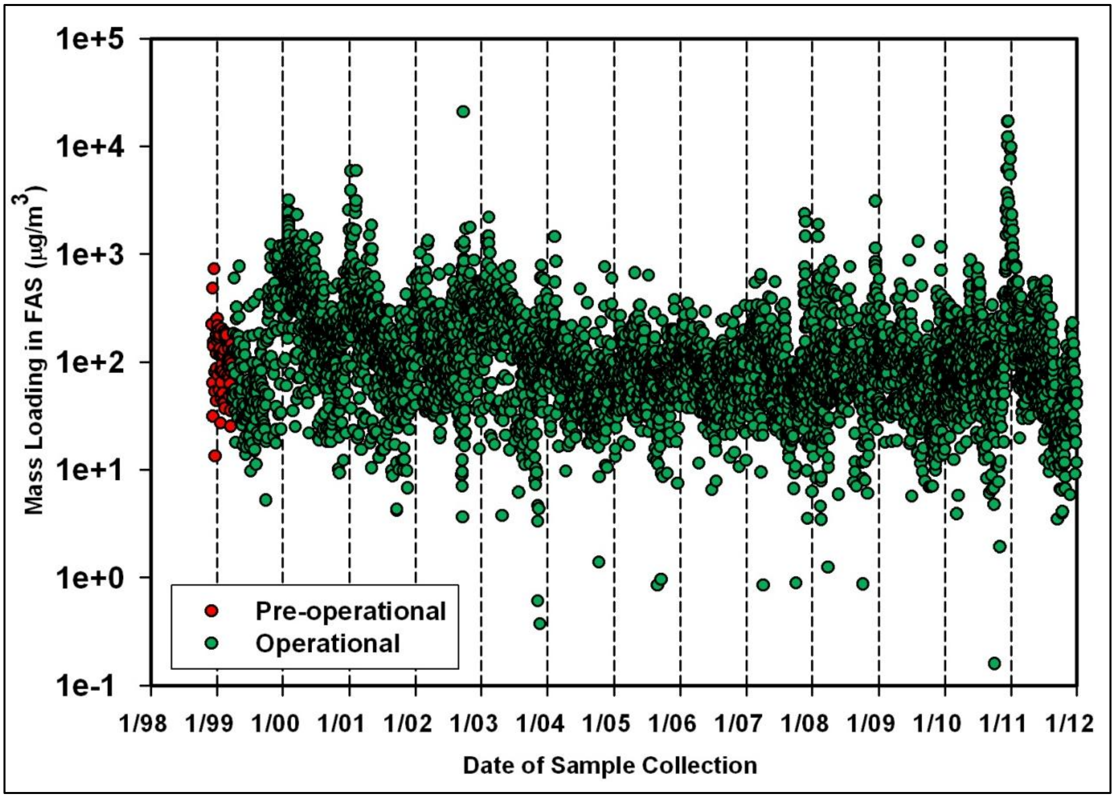

Figure 1.8. Aerosol Mass Loadings on Station A Filters from 1998-2011

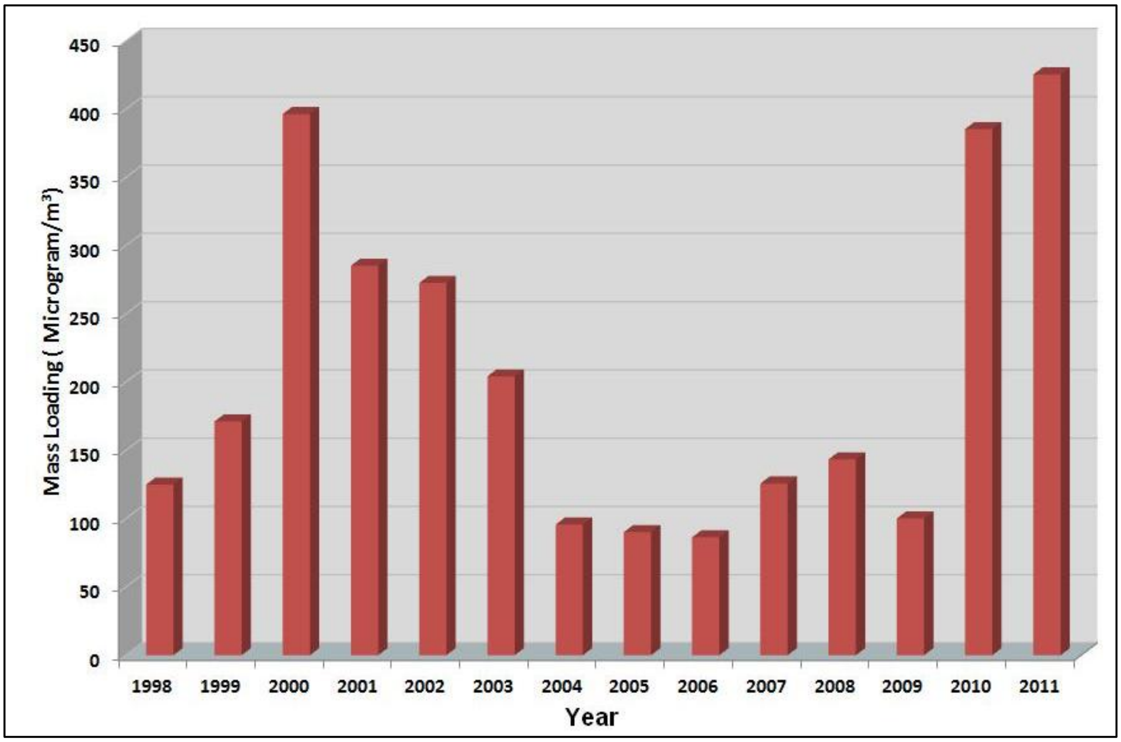

Figure 1.9. Average Mass Loadings on Station A Filters from 1998-2011

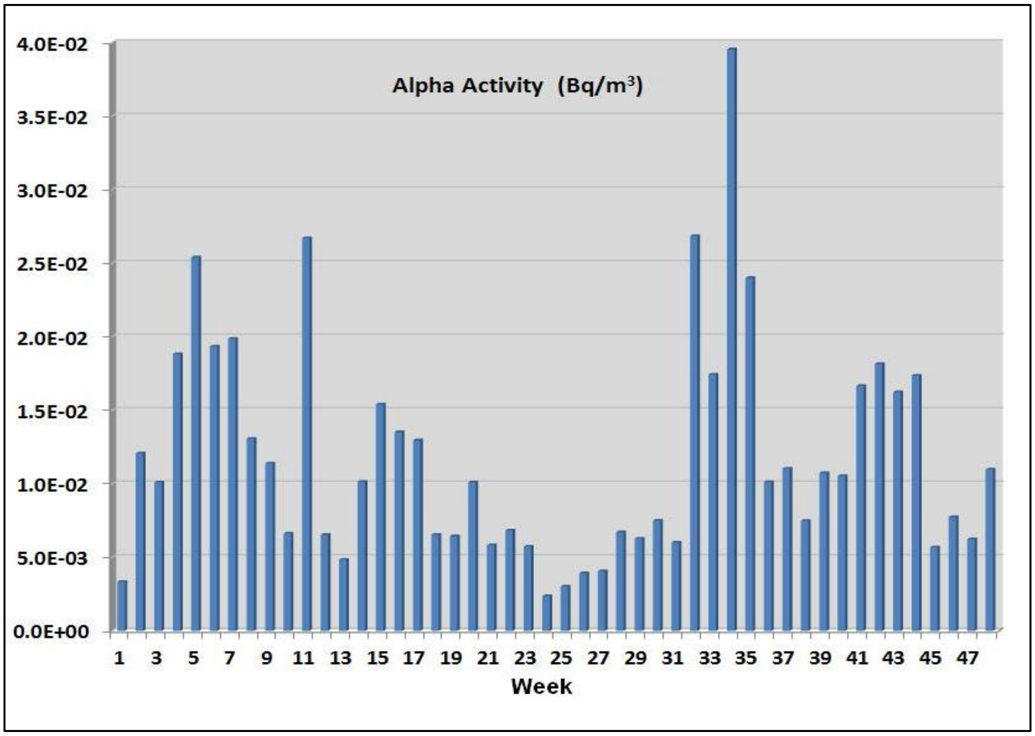

Figure 1.10. Weekly Average Gross Alpha Activity measured in Station A Filters in 2011

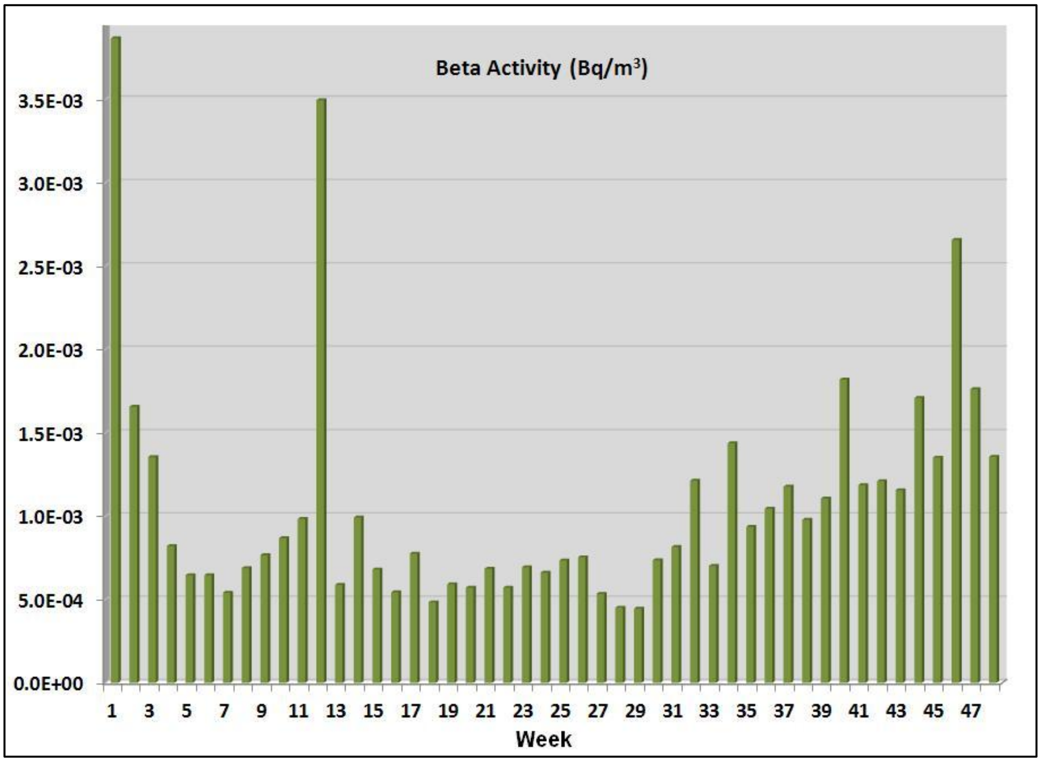

Figure 1.11. Weekly Average Gross Beta Activity measured in Station A Filters in 2011

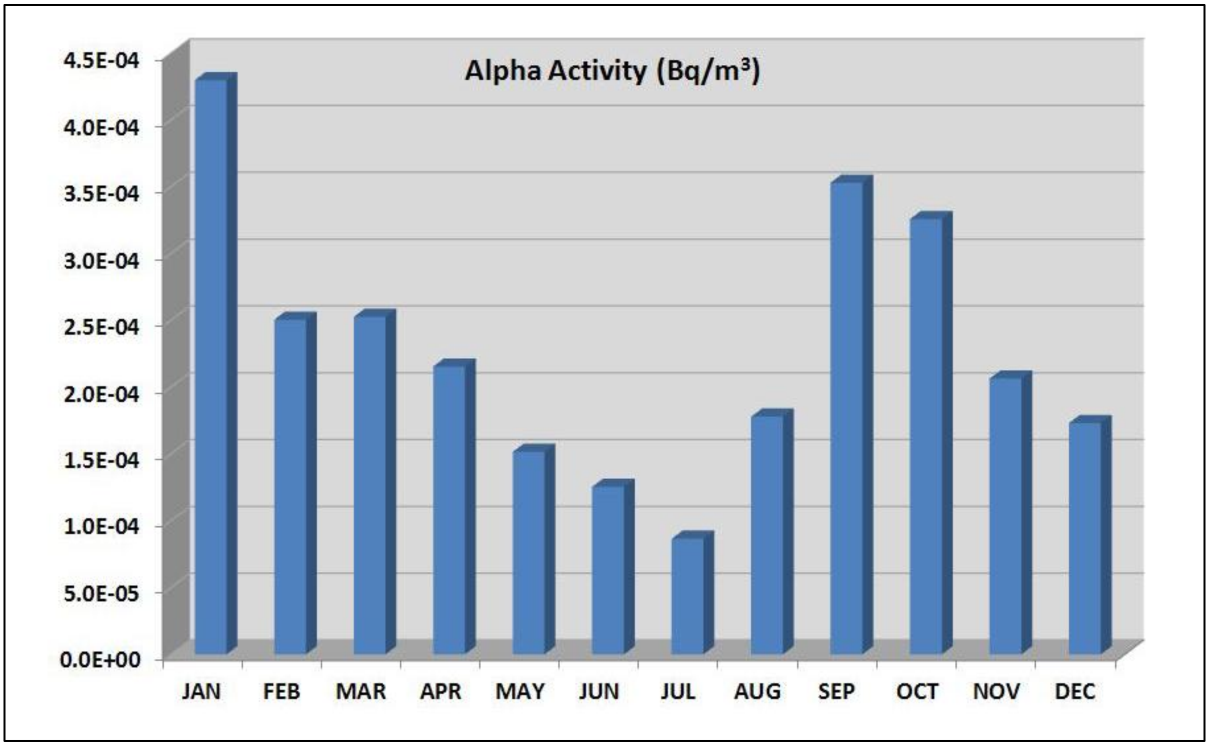

Figure 1.12. Monthly Average Gross Alpha Activity measured in Station A Filters in 2011

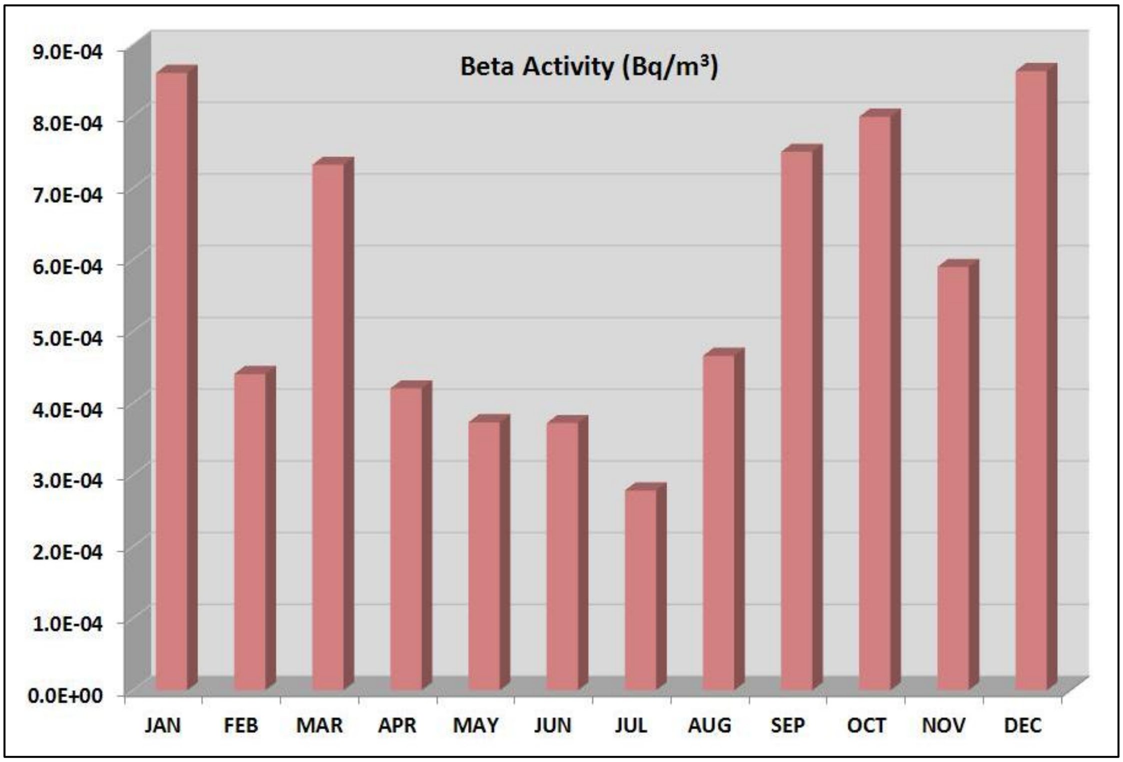

Figure 1.13. Monthly Average Gross Beta Activity measured in Station A Filters in 2011

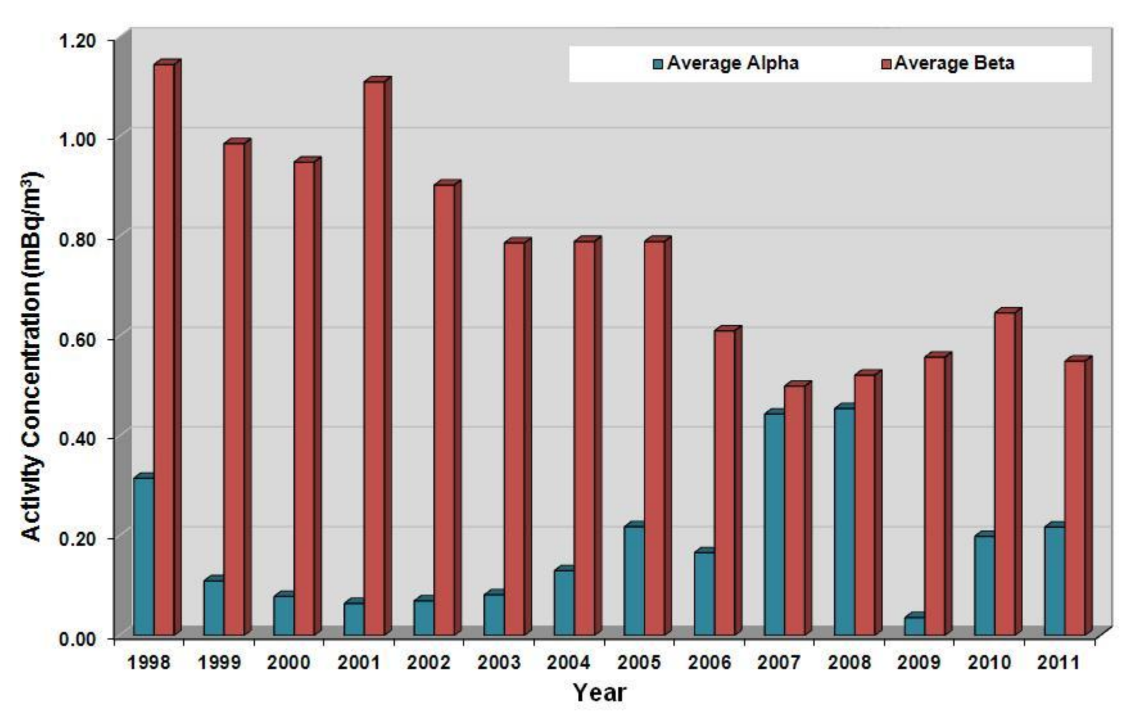

Figure 1.14. Average Annual Gross Alpha and Beta Activity Concentrations in Station A filters

Table 1.5. Summary Statistics of Maximum Gross Alpha and Beta Activities and the Corresponding Mass Loading on Station A Filters from 1998-2011

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
2011	79.0	0.049	0.115	0.049	79.0	0.310	6.27

Table 1.6. Radionuclides concentrations in Monthly Composite Samples Collected from Station A

	Activity Concentration (Bq/m^3)			Activity Density (Bq/g)		
Radionuclide	**Activity**	**SD**	**MDC**	**Activity**	**SD**	**MDC**
January 2011						
^{241}Am	5.35E-08	4.46E-08	1.24E-07	3.70E-05	3.09E-05	8.60E-05
^{238}Pu	8.17E-08	5.89E-08	1.96E-07	5.66E-05	4.08E-05	1.36E-04
$^{239+240}$Pu	1.63E-07	6.93E-08	1.96E-07	1.13E-04	4.80E-05	1.36E-04
^{234}U	2.90E-06	3.24E-07	3.13E-07	2.01E-03	2.24E-04	2.17E-04
^{235}U	2.09E-07	1.39E-07	4.51E-07	1.45E-04	9.62E-05	3.12E-04
^{238}U	2.43E-06	2.97E-07	3.13E-07	1.68E-03	2.05E-04	2.17E-04
^{134}Cs	-4.53E-05	2.46E-05	8.24E-05	-3.14E-02	1.71E-02	5.71E-02
^{137}Cs	-8.89E-06	3.45E-05	1.15E-04	-6.16E-03	2.39E-02	7.94E-02
^{60}Co	-5.43E-06	3.39E-05	1.13E-04	-3.76E-03	2.35E-02	7.81E-02
^{40}K	2.56E-04	3.48E-04	1.15E-03	1.77E-01	2.41E-01	7.97E-01
February 2011						
^{241}Am	-1.13E-08	1.74E-08	7.70E-08	-4.79E-05	7.36E-05	3.26E-04
^{238}Pu	0.00E+00	4.97E-08	2.18E-07	0.00E+00	2.10E-04	9.23E-04
$^{239+240}$Pu	7.27E-08	3.85E-08	1.07E-07	3.07E-04	1.63E-04	4.52E-04
^{234}U	5.10E-07	1.70E-07	4.80E-07	2.16E-03	7.20E-04	2.03E-03
^{235}U	1.26E-07	9.19E-08	3.05E-07	5.32E-04	3.89E-04	1.29E-03
^{238}U	3.17E-07	1.40E-07	4.19E-07	1.34E-03	5.92E-04	1.77E-03
^{134}Cs	-1.00E-04	1.69E-05	5.69E-05	-4.23E-01	7.13E-02	2.41E-01
^{137}Cs	-5.19E-06	2.19E-05	7.29E-05	-2.20E-02	9.28E-02	3.08E-01
^{60}Co	2.55E-06	2.09E-05	6.96E-05	1.08E-02	8.86E-02	2.94E-01
^{40}K	1.65E-04	2.12E-04	7.00E-04	6.98E-01	8.95E-01	2.96E+00
March 2011						
^{241}Am	-6.05E-09	2.67E-08	1.11E-07	-6.91E-05	3.05E-04	1.27E-03
^{238}Pu	4.97E-08	3.93E-08	1.34E-07	5.68E-04	4.49E-04	1.53E-03
$^{239+240}$Pu	3.73E-08	4.48E-08	1.63E-07	4.26E-04	5.12E-04	1.86E-03
^{234}U	4.89E-07	7.21E-08	1.01E-07	5.58E-03	8.23E-04	1.16E-03
^{235}U	2.39E-08	2.39E-08	8.79E-08	2.73E-04	2.73E-04	1.00E-03
^{238}U	2.81E-07	5.48E-08	8.69E-08	3.21E-03	6.26E-04	9.92E-04
^{134}Cs	1.48E-04	1.47E-05	4.48E-05	1.71E+00	1.70E-01	5.18E-01
^{137}Cs	1.09E-04	1.96E-05	6.26E-05	1.24E+00	2.24E-01	7.15E-01
^{137}Cs (BU)	1.70E-04	1.31E-05	4.04E-05	1.96E+00	1.51E-01	4.67E-01
^{60}Co	-4.44E-06	1.80E-05	5.99E-05	-5.07E-02	2.05E-01	6.84E-01
^{40}K	-8.37E-05	1.79E-04	5.97E-04	-9.56E-01	2.04E+00	6.82E+00
April 2011						
^{241}Am	1.93E-09	3.08E-08	1.17E-07	1.67E-05	2.67E-04	1.01E-03
^{238}Pu	6.66E-08	3.54E-08	1.06E-07	5.78E-04	3.07E-04	9.16E-04
$^{239+240}$Pu	1.03E-07	4.43E-08	1.26E-07	8.95E-04	3.84E-04	1.09E-03
^{234}U	6.22E-07	8.71E-08	1.54E-07	5.39E-03	7.55E-04	1.33E-03
^{235}U	6.99E-08	4.13E-08	1.29E-07	6.06E-04	3.58E-04	1.12E-03
^{238}U	4.60E-07	7.49E-08	1.36E-07	3.99E-03	6.49E-04	1.18E-03
^{134}Cs	-8.89E-06	1.05E-05	3.53E-05	-7.71E-02	9.10E-02	3.06E-01
^{137}Cs	5.79E-06	2.39E-05	7.95E-05	5.02E-02	2.07E-01	6.89E-01
^{60}Co	1.77E-05	2.24E-05	7.44E-05	1.53E-01	1.94E-01	6.45E-01
^{40}K	-5.00E-04	2.49E-04	8.47E-04	-4.34E+00	2.16E+00	7.34E+00

Table 1.6. Radionuclides concentrations in Monthly Composite Samples Collected from Station A (continued)

	Activity Concentration (Bq/m^3)			Activity Density (Bq/g)		
Radionuclide	**Activity**	**SD**	**MDC**	**Activity**	**SD**	**MDC**
April BU 2011						
^{241}Am	1.50E-09	2.19E-08	8.06E-08	1.15E-05	1.68E-04	6.18E-04
^{238}Pu	1.12E-08	3.37E-08	1.35E-07	8.63E-05	2.59E-04	1.04E-03
$^{239+240}$Pu	3.37E-08	2.52E-08	8.28E-08	2.59E-04	1.93E-04	6.35E-04
^{234}U	9.26E-07	1.67E-07	2.46E-07	7.10E-03	1.28E-03	1.88E-03
^{235}U	2.16E-07	1.01E-07	2.71E-07	1.66E-03	7.75E-04	2.08E-03
^{238}U	5.28E-07	1.59E-07	4.19E-07	4.05E-03	1.22E-03	3.21E-03
May 2011						
^{241}Am	6.82E-09	3.22E-08	1.19E-07	5.73E-05	2.71E-04	9.99E-04
^{238}Pu	6.40E-08	4.33E-08	1.42E-07	5.38E-04	3.64E-04	1.19E-03
$^{239+240}$Pu	6.27E-08	4.54E-08	1.51E-07	5.27E-04	3.81E-04	1.27E-03
^{234}U	4.24E-07	1.08E-07	2.74E-07	3.57E-03	9.07E-04	2.30E-03
^{235}U	9.75E-08	5.16E-08	1.43E-07	8.19E-04	4.34E-04	1.21E-03
^{238}U	2.67E-07	8.45E-08	2.21E-07	2.24E-03	7.11E-04	1.86E-03
^{134}Cs	-2.72E-05	1.36E-05	4.56E-05	-2.29E-01	1.14E-01	3.83E-01
^{137}Cs	-3.36E-05	2.03E-05	6.77E-05	-2.83E-01	1.70E-01	5.69E-01
^{60}Co	-1.37E-05	1.92E-05	6.41E-05	-1.15E-01	1.61E-01	5.39E-01
^{40}K	-5.14E-05	1.95E-04	6.50E-04	-4.32E-01	1.64E+00	5.47E+00
June 2011						
^{241}Am	4.85E-07	8.02E-08	1.20E-07	4.46E-03	7.38E-04	1.11E-03
^{238}Pu	4.44E-08	4.36E-08	1.57E-07	4.08E-04	4.01E-04	1.44E-03
$^{239+240}$Pu	7.28E-07	1.35E-07	3.05E-07	6.70E-03	1.24E-03	2.80E-03
^{234}U	5.89E-07	9.56E-08	1.30E-07	5.42E-03	8.80E-04	1.20E-03
^{235}U	1.74E-08	5.78E-08	2.28E-07	1.60E-04	5.32E-04	2.10E-03
^{238}U	4.34E-07	8.77E-08	1.68E-07	4.00E-03	8.07E-04	1.55E-03
^{134}Cs	-4.07E-05	1.31E-05	4.43E-05	-3.75E-01	1.21E-01	4.08E-01
^{137}Cs	-2.19E-05	1.92E-05	6.42E-05	-2.01E-01	1.77E-01	5.90E-01
^{60}Co	-7.15E-06	1.81E-05	6.03E-05	-6.58E-02	1.66E-01	5.55E-01
^{40}K	-8.09E-05	1.87E-04	6.23E-04	-7.44E-01	1.72E+00	5.73E+00
June BU 2011						
^{241}Am	6.83E-08	3.54E-08	9.12E-08	7.19E-04	3.73E-04	9.59E-04
^{238}Pu	2.11E-08	3.65E-08	1.38E-07	2.22E-04	3.84E-04	1.45E-03
$^{239+240}$Pu	4.21E-08	4.47E-08	1.58E-07	4.43E-04	4.70E-04	1.66E-03
^{234}U	5.74E-07	9.33E-08	1.62E-07	6.04E-03	9.82E-04	1.71E-03
^{235}U	1.69E-07	5.54E-08	1.13E-07	1.78E-03	5.84E-04	1.19E-03
^{238}U	2.72E-07	7.00E-08	1.62E-07	2.86E-03	7.37E-04	1.70E-03
July 2011						
^{241}Am	2.72E-08	5.57E-08	2.11E-07	2.48E-04	5.08E-04	1.92E-03
^{238}Pu	-5.12E-08	6.16E-08	2.71E-07	-4.67E-04	5.62E-04	2.47E-03
$^{239+240}$Pu	-1.71E-08	6.62E-08	2.71E-07	-1.56E-04	6.03E-04	2.47E-03
^{234}U	8.14E-07	1.17E-07	2.16E-07	7.43E-03	1.07E-03	1.97E-03
^{235}U	-1.61E-08	4.26E-08	1.94E-07	-1.47E-04	3.89E-04	1.76E-03
^{238}U	5.83E-07	9.82E-08	1.83E-07	5.32E-03	8.95E-04	1.67E-03
^{134}Cs	-3.08E-05	1.27E-05	4.29E-05	-2.81E-01	1.16E-01	3.91E-01
^{137}Cs	-5.17E-06	1.89E-05	6.27E-05	-4.71E-02	1.72E-01	5.72E-01
^{60}Co	1.63E-07	1.81E-05	6.03E-05	1.49E-03	1.65E-01	5.50E-01
^{40}K	2.98E-05	1.81E-04	6.01E-04	2.72E-01	1.65E+00	5.48E+00

Table 1.6. Radionuclides concentrations in Monthly Composite Samples Collected from Station A (continued)

	Activity Concentration (Bq/m^3)			Activity Density (Bq/g)		
Radionuclide	**Activity**	**SD**	**MDC**	**Activity**	**SD**	**MDC**
August 2011						
^{241}Am	1.02E-08	2.80E-08	1.00E-07	1.41E-04	3.87E-04	1.39E-03
^{238}Pu	-2.66E-08	3.82E-08	1.77E-07	-3.67E-04	5.29E-04	2.45E-03
$^{239+240}$Pu	-4.07E-08	3.03E-08	1.63E-07	-5.62E-04	4.19E-04	2.25E-03
^{234}U	5.06E-07	6.48E-08	8.13E-08	7.00E-03	8.97E-04	1.12E-03
^{235}U	9.28E-07	3.67E-07	8.53E-07	1.28E-02	5.07E-03	1.18E-02
^{238}U	2.81E-07	5.19E-08	9.86E-08	3.88E-03	7.17E-04	1.36E-03
^{134}Cs	-5.58E-05	1.33E-05	4.51E-05	-7.71E-01	1.84E-01	6.23E-01
^{137}Cs	-1.37E-05	1.87E-05	6.24E-05	-1.90E-01	2.59E-01	8.63E-01
^{60}Co	-1.16E-05	1.80E-05	6.03E-05	-1.61E-01	2.50E-01	8.33E-01
^{40}K	-2.59E-05	1.81E-04	6.02E-04	-3.58E-01	2.50E+00	8.32E+00
September 2011						
^{241}Am	-9.03E-09	3.42E-08	1.39E-07	-4.70E-04	1.78E-03	7.23E-03
^{238}Pu	-2.15E-08	3.04E-08	1.41E-07	-1.12E-03	1.58E-03	7.32E-03
$^{239+240}$Pu	9.74E-08	4.28E-08	1.21E-07	5.06E-03	2.23E-03	6.31E-03
^{234}U	3.97E-07	9.20E-08	2.00E-07	2.07E-02	4.78E-03	1.04E-02
^{235}U	1.39E-08	5.59E-08	2.27E-07	7.25E-04	2.91E-03	1.18E-02
^{238}U	2.75E-07	6.84E-08	1.12E-07	1.43E-02	3.56E-03	5.84E-03
^{134}Cs	-4.84E-05	1.48E-05	5.00E-05	-2.52E+00	7.69E-01	2.60E+00
^{137}Cs	-2.35E-05	2.16E-05	7.21E-05	-1.22E+00	1.12E+00	3.75E+00
^{60}Co	1.82E-06	2.00E-05	6.66E-05	9.47E-02	1.04E+00	3.46E+00
^{40}K	-3.58E-04	2.06E-04	6.91E-04	-1.86E+01	1.07E+01	3.59E+01
October 2011						
^{241}Am	1.83E-08	2.34E-08	7.03E-08	6.80E-04	8.72E-04	2.62E-03
^{238}Pu	3.24E-08	3.25E-08	1.19E-07	1.21E-03	1.21E-03	4.45E-03
$^{239+240}$Pu	1.01E-07	5.68E-08	1.75E-07	3.76E-03	2.12E-03	6.50E-03
^{234}U	3.66E-07	8.11E-08	1.83E-07	1.36E-02	3.02E-03	6.81E-03
^{235}U	1.21E-07	4.79E-08	1.11E-07	4.50E-03	1.78E-03	4.14E-03
^{238}U	4.38E-07	7.92E-08	1.31E-07	1.63E-02	2.95E-03	4.87E-03
^{134}Cs	-4.47E-05	1.33E-05	4.52E-05	-1.67E+00	4.97E-01	1.68E+00
^{137}Cs	-6.75E-05	1.99E-05	6.68E-05	-2.51E+00	7.41E-01	2.49E+00
^{60}Co	-1.44E-05	1.83E-05	6.10E-05	-5.35E-01	6.80E-01	2.27E+00
^{40}K	-2.09E-04	1.89E-04	6.33E-04	-7.79E+00	7.05E+00	2.36E+01
November 2011						
^{241}Am	7.50E-08	3.45E-08	7.65E-08	1.28E-03	5.89E-04	1.31E-03
^{238}Pu	2.18E-08	1.89E-08	2.95E-08	3.72E-04	3.22E-04	5.04E-04
$^{239+240}$Pu	5.45E-08	4.99E-08	1.73E-07	9.31E-04	8.53E-04	2.95E-03
^{234}U	3.77E-07	1.10E-07	2.83E-07	6.45E-03	1.88E-03	4.84E-03
^{235}U	2.35E-08	3.33E-08	6.37E-08	4.02E-04	5.69E-04	1.09E-03
^{238}U	3.58E-07	9.45E-08	2.03E-07	6.11E-03	1.61E-03	3.46E-03
^{134}Cs	-6.75E-05	1.31E-05	4.44E-05	-1.15E+00	2.24E-01	7.58E-01
^{137}Cs	-1.72E-06	2.10E-05	6.98E-05	-2.94E-02	3.59E-01	1.19E+00
^{60}Co	-1.89E-05	1.79E-05	6.00E-05	-3.23E-01	3.06E-01	1.02E+00
^{40}K	-1.04E-04	1.85E-04	6.16E-04	-1.77E+00	3.15E+00	1.05E+01
December 2011						
^{241}Am	2.29E-09	2.42E-08	9.17E-08	3.24E-05	3.43E-04	1.30E-03

Table 1.6. Radionuclides concentrations in Monthly Composite Samples Collected from Station A (continued)

	Activity Concentration (Bq/m3)			Activity Density (Bq/g)		
Radionuclide	**Activity**	**SD**	**MDC**	**Activity**	**SD**	**MDC**
December 2011						
^{238}Pu	-2.07E-08	2.93E-08	1.36E-07	-2.94E-04	4.15E-04	1.92E-03
$^{239+240}$Pu	3.11E-08	3.11E-08	1.12E-07	4.40E-04	4.40E-04	1.58E-03
^{234}U	2.04E-07	6.53E-08	1.63E-07	2.89E-03	9.24E-04	2.31E-03
^{235}U	6.76E-08	4.14E-08	1.24E-07	9.58E-04	5.87E-04	1.76E-03
^{238}U	1.22E-07	4.29E-08	3.67E-08	1.73E-03	6.08E-04	5.20E-04
^{134}Cs	-5.35E-05	4.95E-08	1.32E-07	-7.57E-01	1.71E-01	5.75E-01
^{137}Cs	2.52E-06	1.20E-05	4.06E-05	3.57E-02	2.62E-01	8.67E-01
^{60}Co	-4.86E-05	1.85E-05	6.12E-05	-6.88E-01	2.48E+00	8.25E+00
^{40}K	-1.40E-05	1.75E-04	5.82E-04	-1.98E-01	2.40E-01	8.03E-01
Single filter from October 2011						
^{241}Am	-1.52E-07	1.34E-06	1.34E-06	-1.57E-03	3.32E-03	1.38E-02
^{238}Pu	3.03E-07	1.12E-06	1.12E-06	3.13E-03	3.13E-03	1.15E-02
$^{239+240}$Pu	-1.52E-07	2.53E-06	2.53E-06	-1.56E-03	6.44E-03	2.60E-02
^{234}U	2.96E-06	3.79E-06	3.79E-06	3.05E-02	1.31E-02	3.91E-02
^{235}U	2.26E-06	2.08E-06	2.08E-06	2.33E-02	9.21E-03	2.14E-02
^{238}U	2.43E-06	2.98E-06	2.98E-06	2.51E-02	1.07E-02	3.07E-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

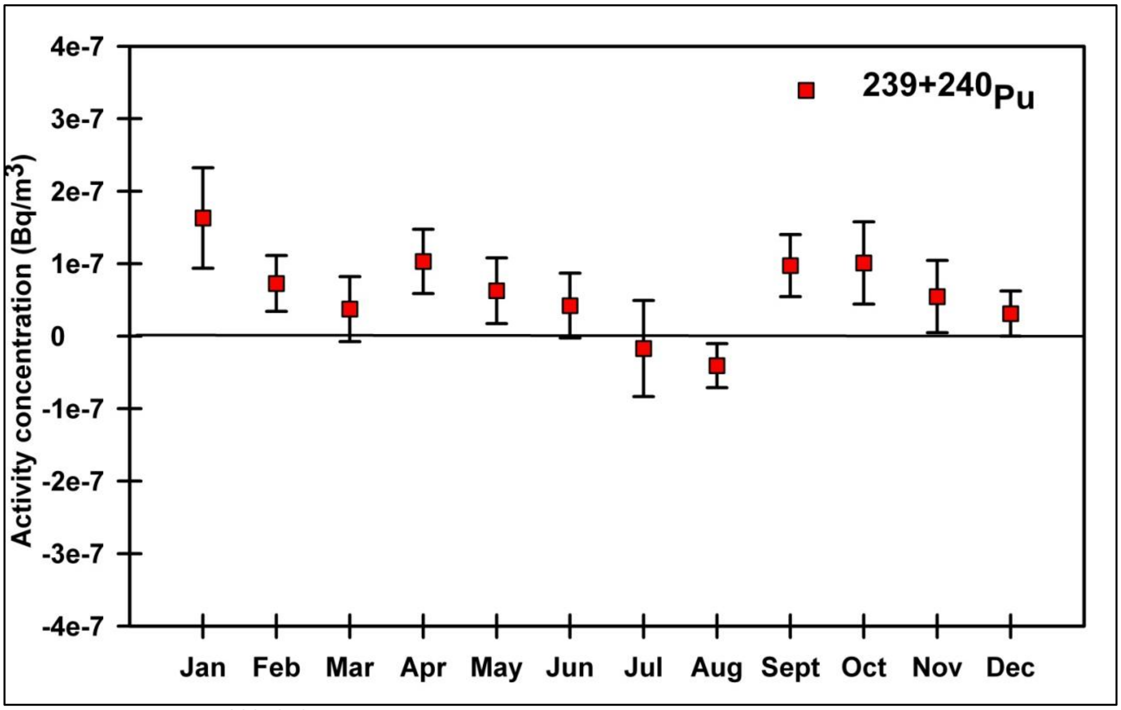

Figure 1.15. $^{239+240}$Pu Concentrations in Station A composites in 2011

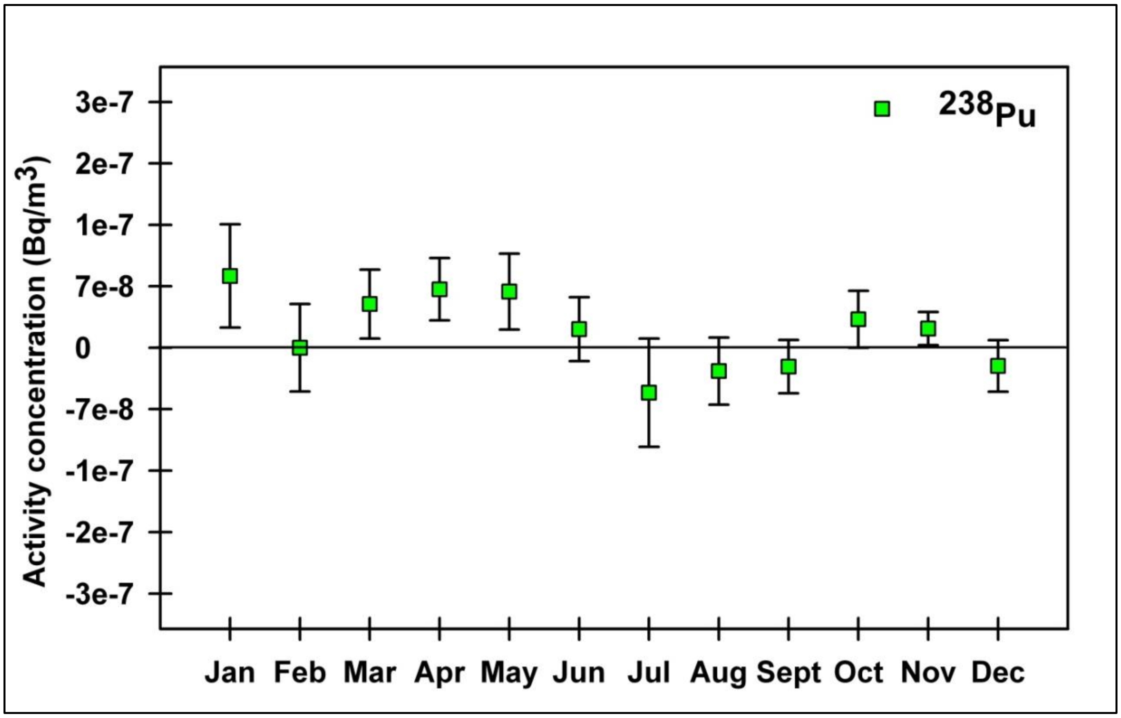

Figure 1.16. ^{238}Pu Concentrations in Station A Composites in 2011

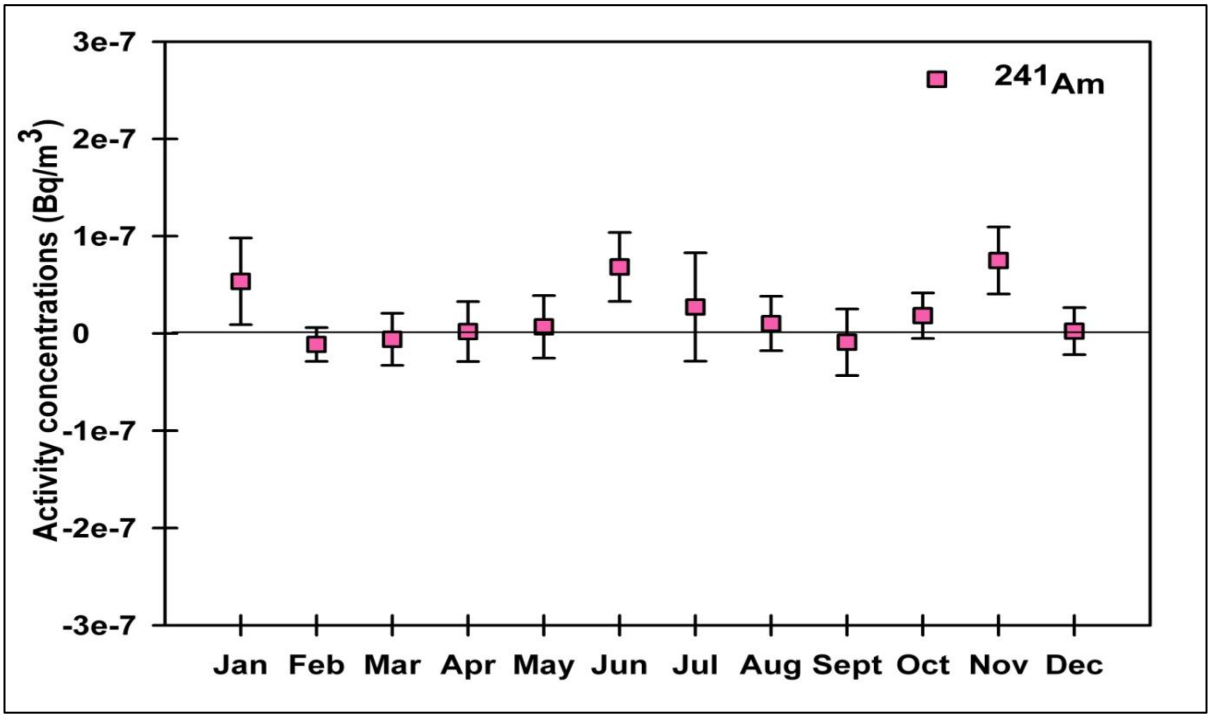

Figure 1.17. ^{241}Am Concentrations in Station A composites in 2011

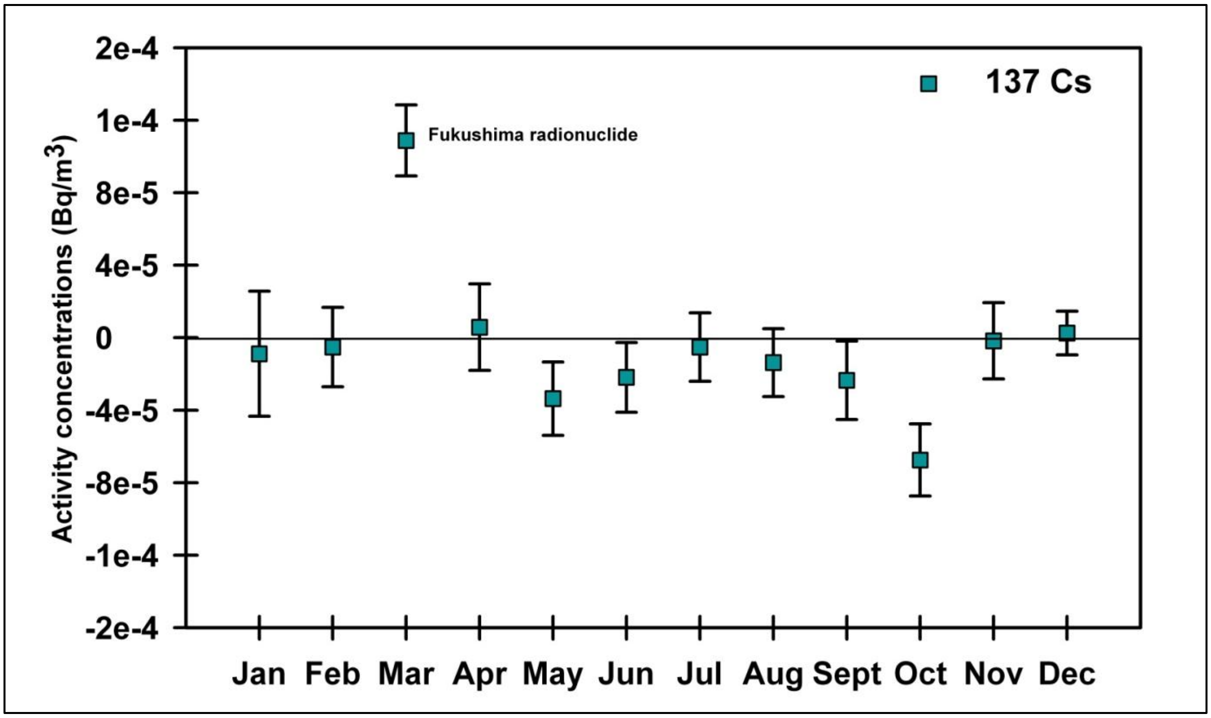

Figure 1.18. ^{137}Cs Concentrations in Station A Composites in 2011

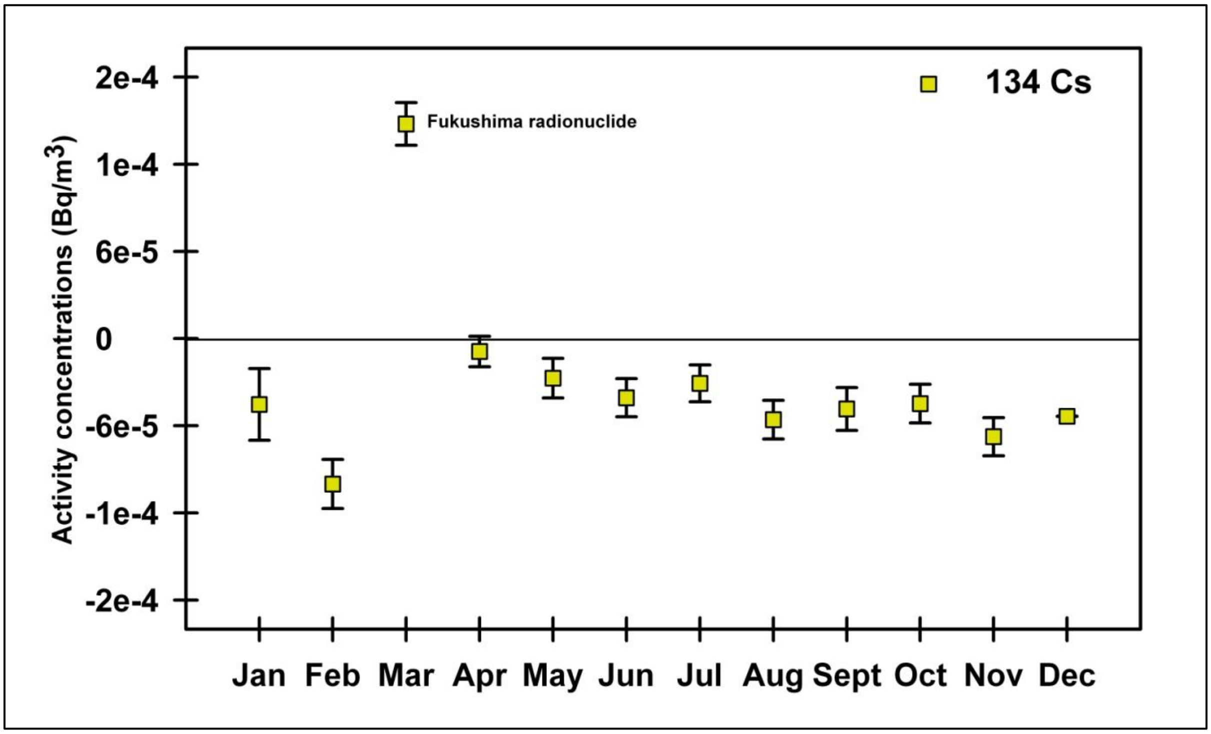

Figure 1.19. ^{134}Cs Concentrations in Station A Composite in 2011

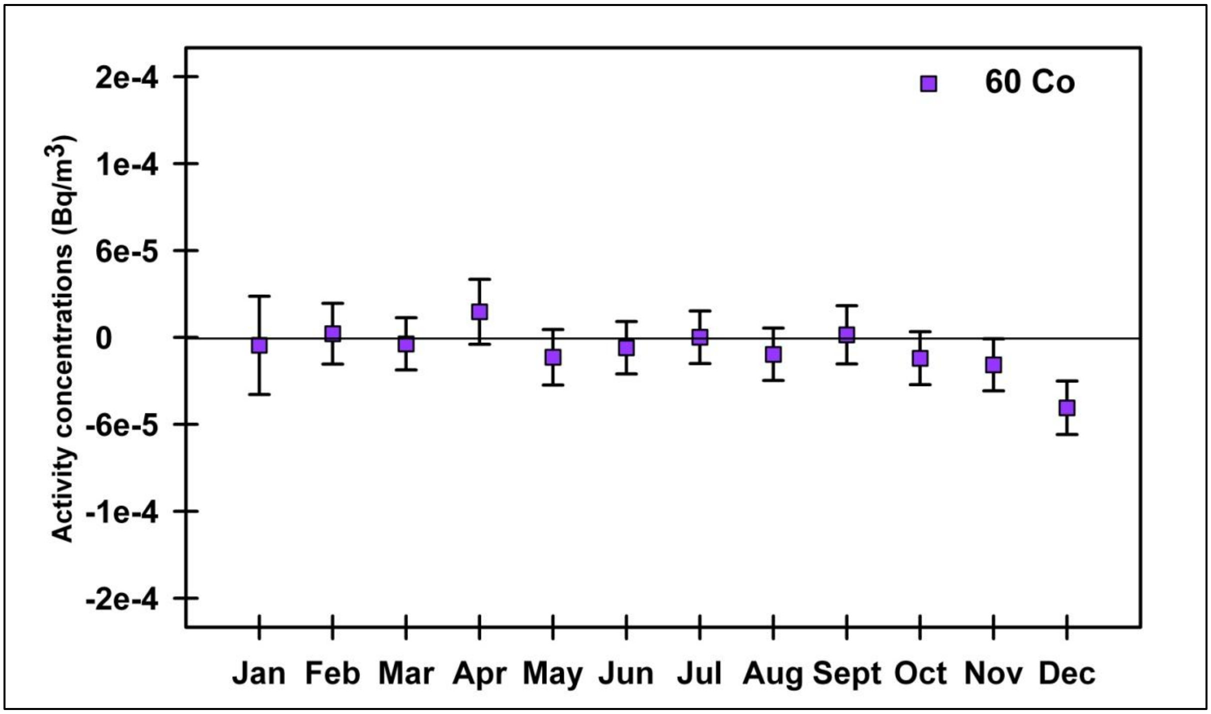

Figure 1.20. ^{60}Co Concentrations in Station A Composite in 2011

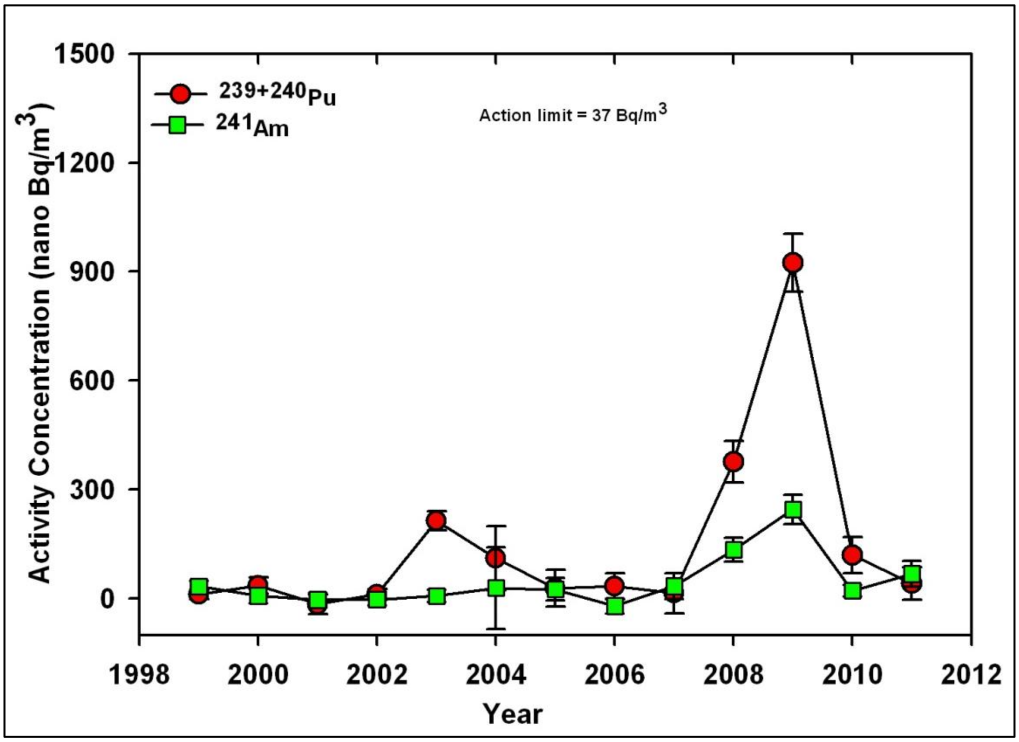

Figure 1.21. Annual Average Activity Concentrations of $^{239+240}$Pu and ^{241}Am in WIPP Exhaust Air from 1998-2011

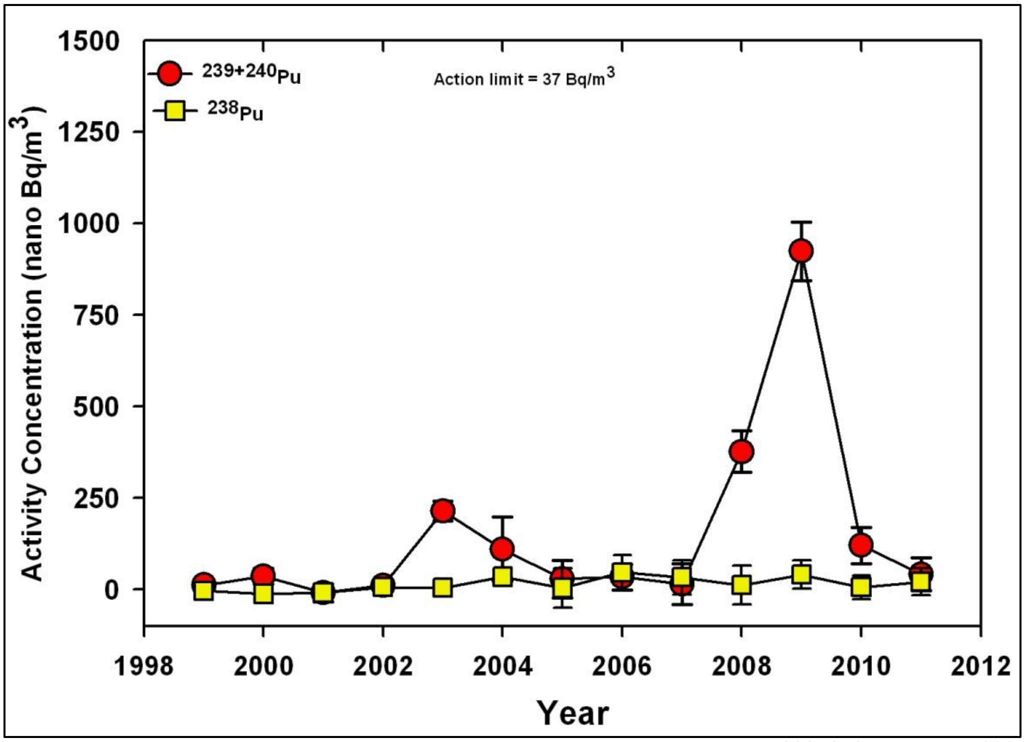

Figure 1.22. Annual Average Activity Concentrations of $^{239+240}$Pu and ^{238}Pu in WIPP Exhaust Air from 1998-2011

Table 1.7. Activities greater than MDC and Uncertainty (2σ) measured by CEMRC during period 1999-2011

Year	Month	Radionuclides	Activity (Bq)	Uncertanity (2σ)	MDC
2003	Mar-Jun	$^{239+240}$Pu	4.76E-03	8.02E-04	2.63E-04
2005	April	^{241}Am	2.72E-04	1.99E-04	2.65E-04
2008	Feb	^{241}Am	6.20E-03	7.92E-04	1.79E-04
2008	Feb	^{238}Pu	7.02E-04	3.52E-04	2.87E-04
2008	Feb	$^{239+240}$Pu	1.78E-02	2.06E-03	2.87E-04
2009	April	^{241}Am	3.53E-03	1.19E-03	3.03E-04
2009	April	^{238}Pu	4.89E-04	2.24E-04	6.61E-05
2009	April	$^{239+240}$Pu	2.13E-02	1.72E-03	6.61E-05
2010	July	$^{239+240}$Pu	2.72E-03	9.04E-04	9.29E-04
2010	July	^{241}Am	4.09E-04	2.48E-04	2.95E-04

Table 1.8. Activities greater than MDC and Uncertainty (2σ) measured by WTS during period 1999-2011

Year	Month	Radionuclides	Activity (Bq)	Uncertanity (2σ)	MDC
2001	Oct	^{241}Am	1.86E-03	1.41E-03	1.52E-03
2003	Jan	^{241}Am	6.85E-04	5.70E-04	3.09E-04
2003	Sep	^{241}Am	4.96E-04	4.51E-04	2.69E-04
2007	Sep	$^{239+240}$Pu	1.71E-03	9.99E-04	4.40E-04
2008	Feb	^{241}Am	4.00E-03	2.53E-03	1.97E-03
2008	Feb	$^{239+240}$Pu	2.20E-02	5.17E-03	1.60E-03
2009*	April	^{241}Am	4.26E-03	1.85E-03	3.23E-03
2009*	April	$^{239+240}$Pu	1.96E-02	4.00E-03	1.83E-03
2010	July	$^{239+240}$Pu	1.88E-03	1.15E-03	5.00E-04

* Re-analyzed resulting in no detection

Table 1.9. Historical Minimum, Maximum, and Average Concentrations of ^{238}Pu (Bq/m^3) measured in Station A

Year	Minimum	Maximum	Average
2000	-3.62E-08	5.35E-09	-1.23E-08
2001	-2.68E-08	1.08E-08	-8.20E-09
2002	-8.22E-09	2.01E-08	6.47E-09
2003	-2.90E-11	8.00E-09	4.26E-09
2004	9.89E-08	2.76E-07	1.70E-07
2005	-5.94E-08	6.01E-08	4.52E-09
2006	-3.57E-08	7.81E-08	1.87E-08
2007	-6.96E-08	6.83E-08	8.97E-09
2008	-8.62E-08	1.50E-07	1.20E-08
2009	-1.42E-08	2.33E-07	4.07E-08
2010	-6.05E-08	7.19E-08	6.65E-09
2011	-5.12E-08	8.17E-08	1.78E-08

Table 1.10. Historical Minimum, Maximum, and Average Concentrations of $^{239+240}$Pu (Bq/m^3) measured in Station A

Year	Minimum	Maximum	Average
2000	2.24E-08	5.86E-08	3.67E-08
2001	-3.34E-08	1.06E-08	-8.83E-09
2002	8.10E-09	1.76E-08	1.23E-08
2003	-7.99E-09	6.39E-07	1.58E-07
2004	3.65E-09	1.25E-07	6.45E-08
2005	-3.82E-08	1.41E-07	3.69E-08
2006	-5.05E-08	1.67E-07	5.82E-08
2007	-2.79E-07	1.09E-07	1.73E-08
2008	8.44E-09	3.81E-06	3.77E-07
2009	-3.48E-08	1.01E-05	9.24E-07
2010	-1.77E-08	1.03E-06	1.28E-07
2011	-4.07E-08	1.63E-07	6.04E-08

Table 1.11. Historical Minimum, Maximum, and Average Concentrations of ^{241}Am (Bq/m^3) measured in Station A

Year	Minimum	Maximum	Average
2000	-1.51E-08	3.17E-08	8.02E-09
2001	-1.70E-08	1.36E-08	-3.5E-09
2002	-2.16E-08	1.35E-09	-6.1E-09
2003	-4.73E-09	1.98E-08	7.72E-09
2004	-9.96E-09	5.12E-08	2.66E-08
2005	-1.94E-08	1.13E-07	3.35E-08
2006	-2.20E-08	7.07E-08	2.84E-08
2007	-2.05E-08	1.08E-07	2.97E-08
2008	-3.72E-08	1.32E-06	1.34E-07
2009	-1.61E-08	1.68E-06	1.88E-07
2010	-4.82E-08	1.54E-07	1.66E-08
2011	-1.13E-08	7.50E-08	1.54E-08

Table 1.12. $^{234}U/^{238}U$ Activity Ratios in Station A Composites in 2011

Month	^{234}U (Bq)	^{238}U (Bq)	$^{234}U/^{238}U$
January	9.862E-02	1.180E-01	1.20
February	2.050E-02	3.298E-02	1.61
March	1.166E-02	9.034E-02	2.92
April	3.299E-02	4.459E-02	1.35
May	1.864E-02	2.97E-02	1.59
June	3.153E-02	2.877E-02	0.91
July	4.303E-02	6.010E-02	1.40
August	1.514E-02	4.363E-02	2.88
September	1.816E-02	2.629E-02	1.45
October	3.192E-02	2.665E-02	0.83
November	2.627E-02	2.770E-02	1.05
December	7.085E-03	1.950E-02	2.75
		Average	**1.66**
		Std Error	**0.22**

Table 1.13. Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Station A Composites in 2011

		Activity Concentration (Bq/m^3)		
Radionuclides		**Conc.**	**SD**	**MDC**
^{241}Am	Minimum	-1.13E-08	1.74E-08	7.03E-08
	Maximum	7.50E-08	5.57E-08	2.11E-07
	Average	1.98E-08	3.23E-08	1.11E-07
^{238}Pu	Minimum	-5.12E-08	1.89E-08	2.95E-08
	Maximum	8.17E-08	6.16E-08	2.71E-07
	Average	1.81E-08	3.95E-08	1.51E-07
$^{239+240}$Pu	Minimum	-4.07E-08	3.03E-08	1.07E-07
	Maximum	1.63E-07	6.93E-08	2.71E-07
	Average	5.89E-08	4.70E-08	1.60E-07
^{234}U	Minimum	2.04E-07	6.48E-08	8.13E-08
	Maximum	2.90E-06	3.24E-07	4.80E-07
	Average	7.02E-07	1.20E-07	2.17E-07
^{235}U	Minimum	-1.61E-08	2.39E-08	6.37E-08
	Maximum	9.28E-07	3.67E-07	8.53E-07
	Average	1.46E-07	8.42E-08	2.45E-07
^{238}U	Minimum	1.22E-07	4.29E-08	3.67E-08
	Maximum	2.43E-06	2.97E-07	4.19E-07
	Average	5.21E-07	1.03E-07	1.94E-07
^{137}Cs	Minimum	-6.75E-05	1.20E-05	4.06E-05
	Maximum	1.09E-04	3.45E-05	1.15E-04
	Average	-5.34E-06	2.10E-05	6.97E-05
^{134}Cs	Minimum	-1.00E-04	4.95E-08	1.32E-07
	Maximum	1.48E-04	2.46E-05	8.24E-05
	Average	-3.13E-05	1.34E-05	4.47E-05
^{60}Co	Minimum	-4.86E-05	1.79E-05	5.99E-05
	Maximum	1.77E-05	3.39E-05	1.13E-04
	Average	-8.50E-06	2.03E-05	6.75E-05
^{40}K	Minimum	-5.00E-04	1.75E-04	5.82E-04
	Maximum	2.56E-04	3.48E-04	1.15E-03
	Average	-8.13E-05	2.07E-04	6.91E-04

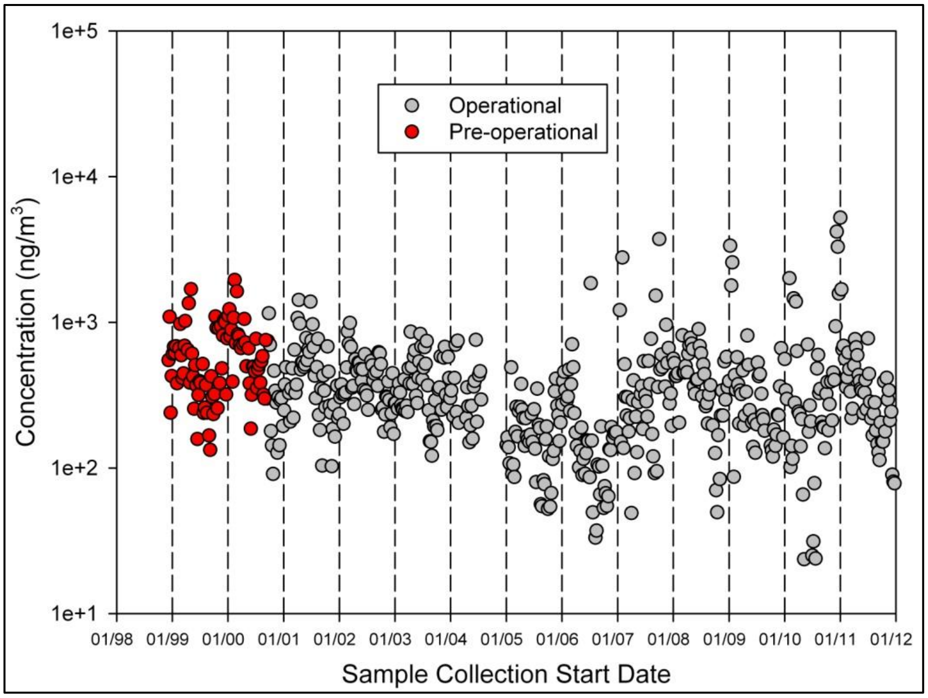

Figure 1.23. Concentrations of Al in WIPP Exhaust Air from 1998 - 2011

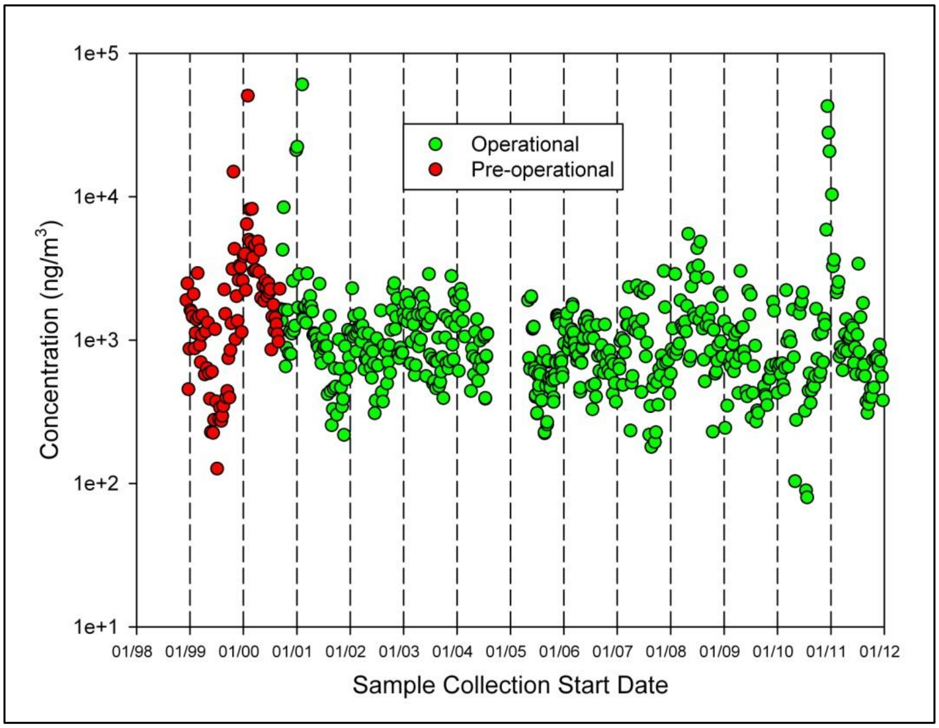

Figure 1.24. Concentrations of Mg in WIPP Exhaust Air from 1998 - 2011

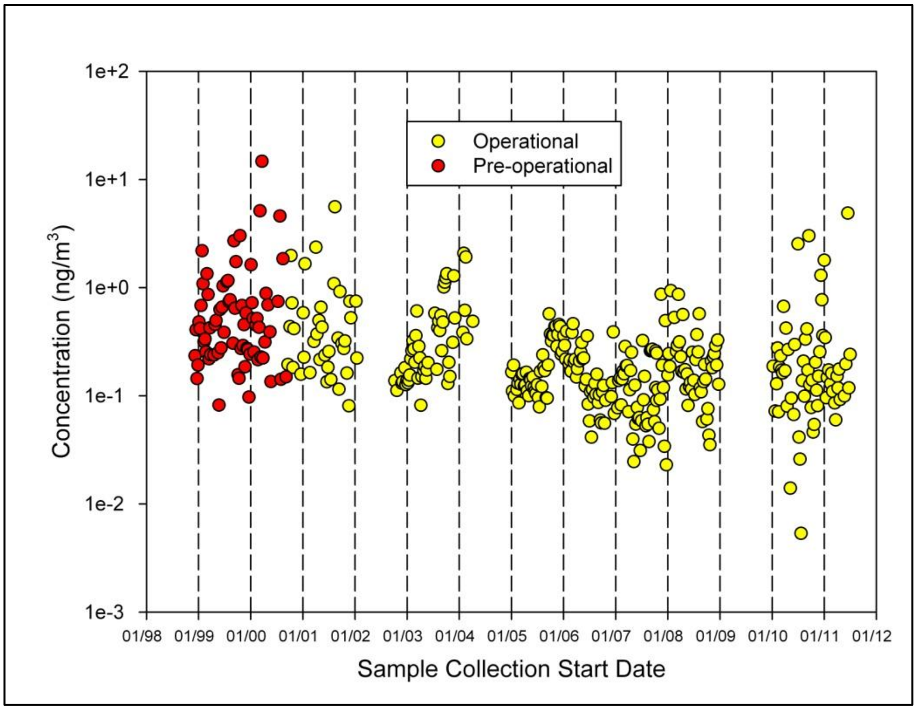

Figure 1.25. Concentrations of Cd in WIPP Exhaust Air from 1998 - 2011

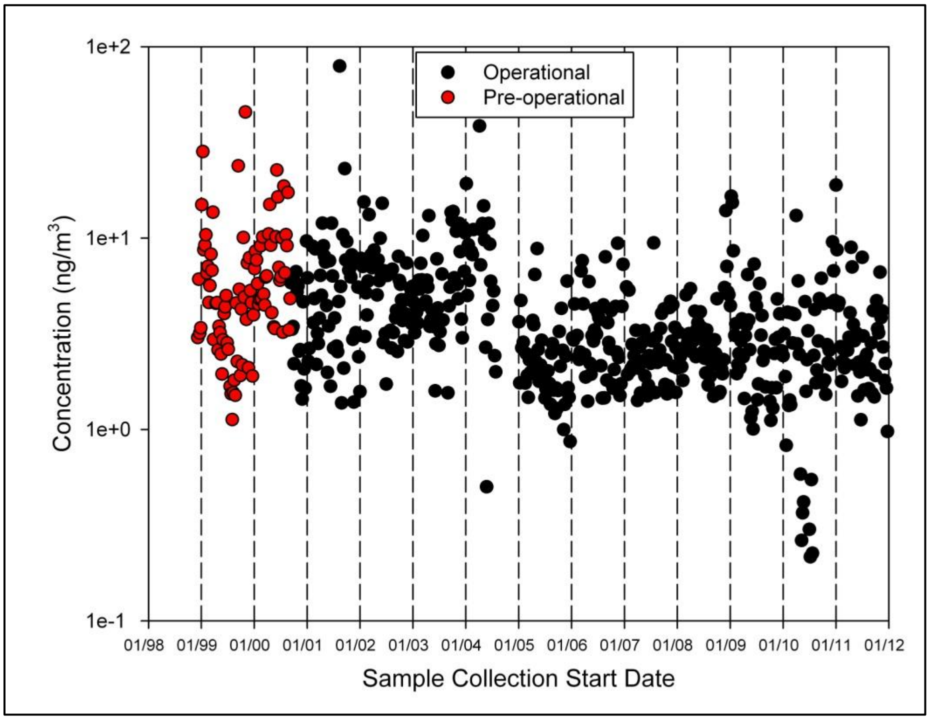

Figure 1.26. Concentrations of Pb in WIPP Exhaust Air from 1998 - 2011

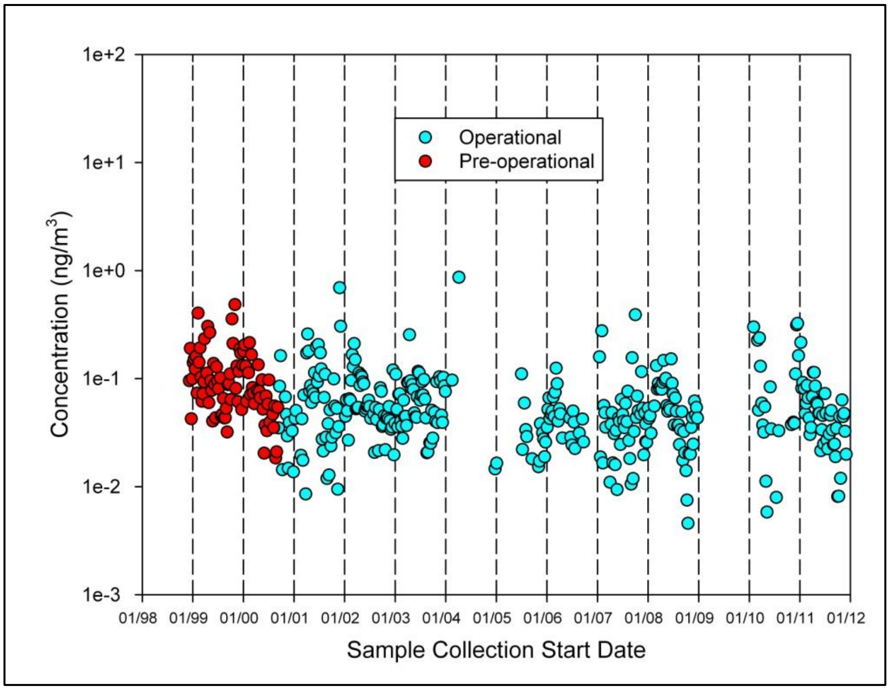

Figure 1.27. Concentrations of Th in WIPP Exhaust Air from 1998 - 2011

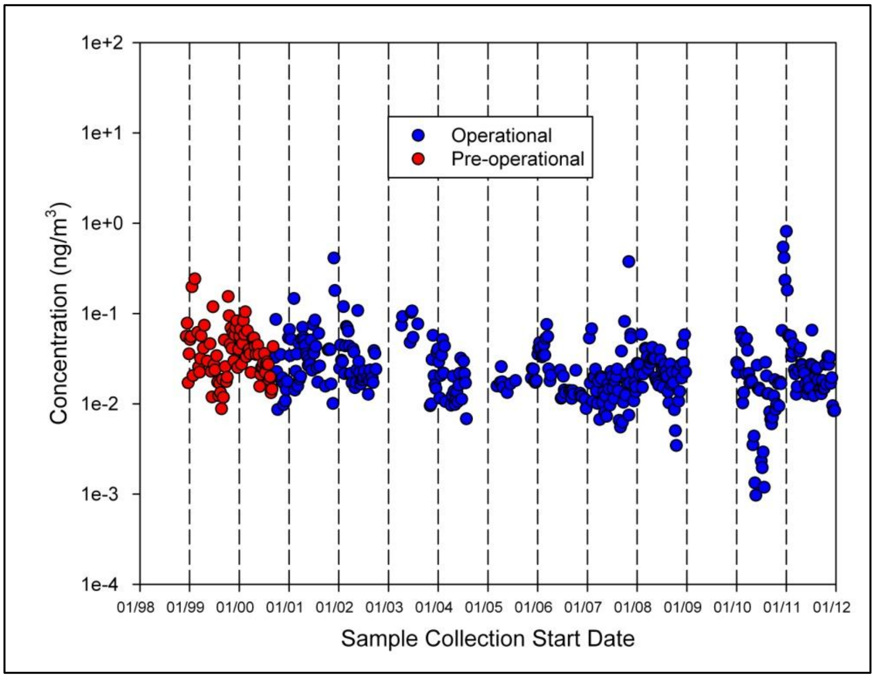

Figure 1.28. Concentrations of U in WIPP Exhaust Air from 1998 - 2011

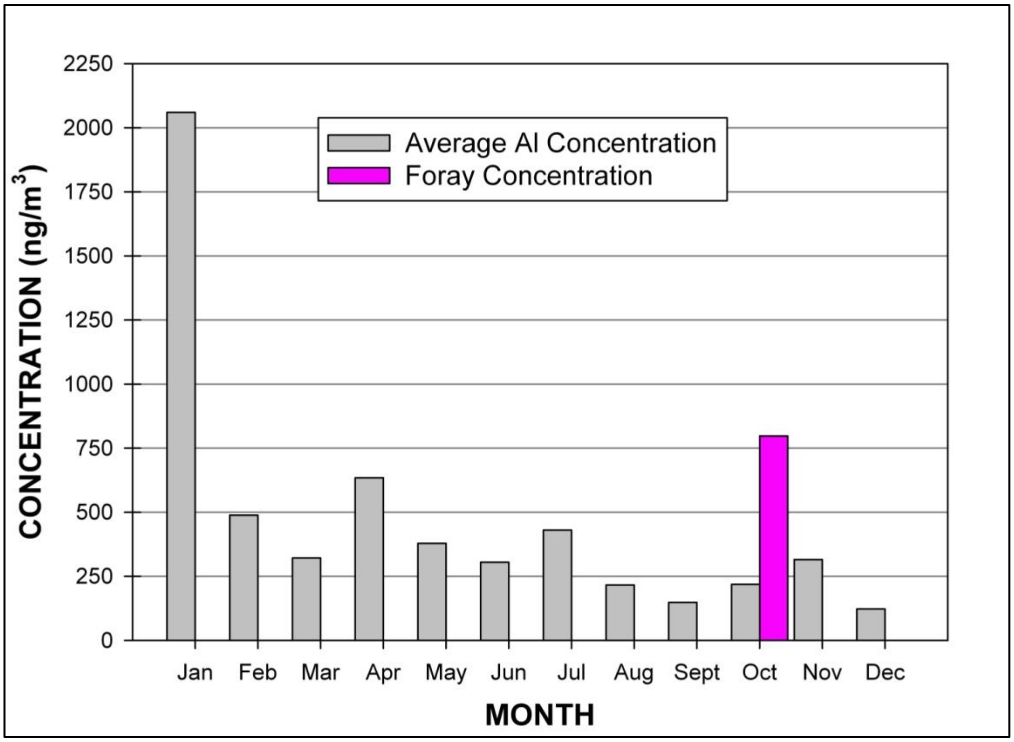

Figure 1.29. Monthly Average Concentrations of Al for 2011

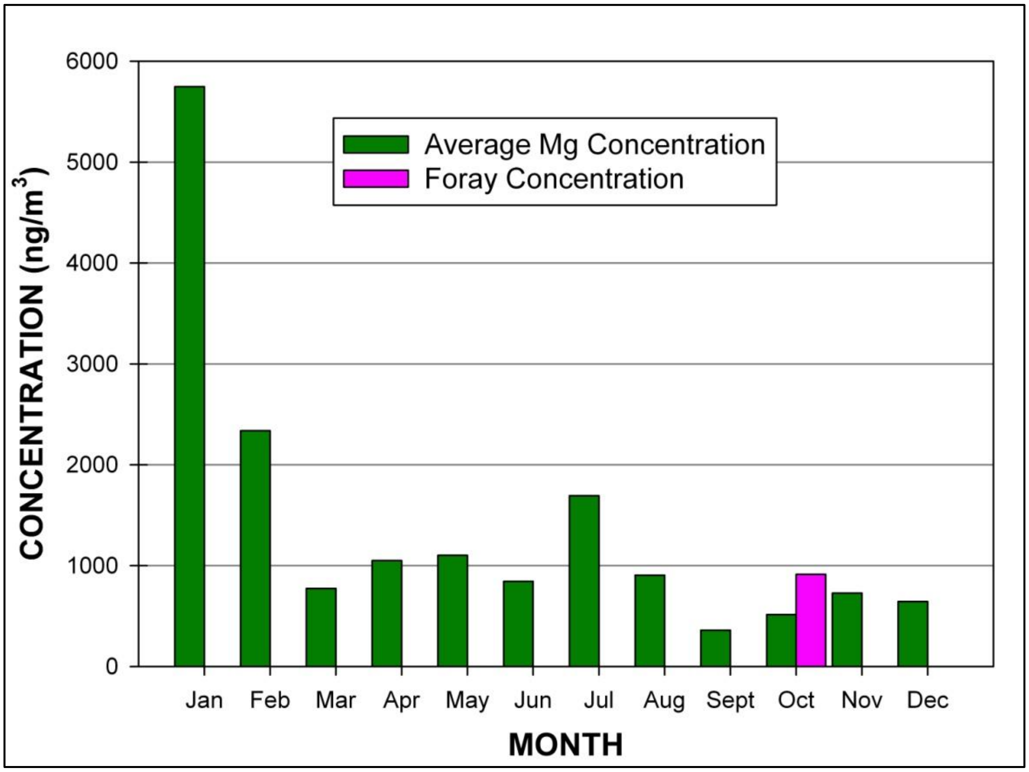

Figure 1.30. Monthly Average Concentrations of Mg for 2011

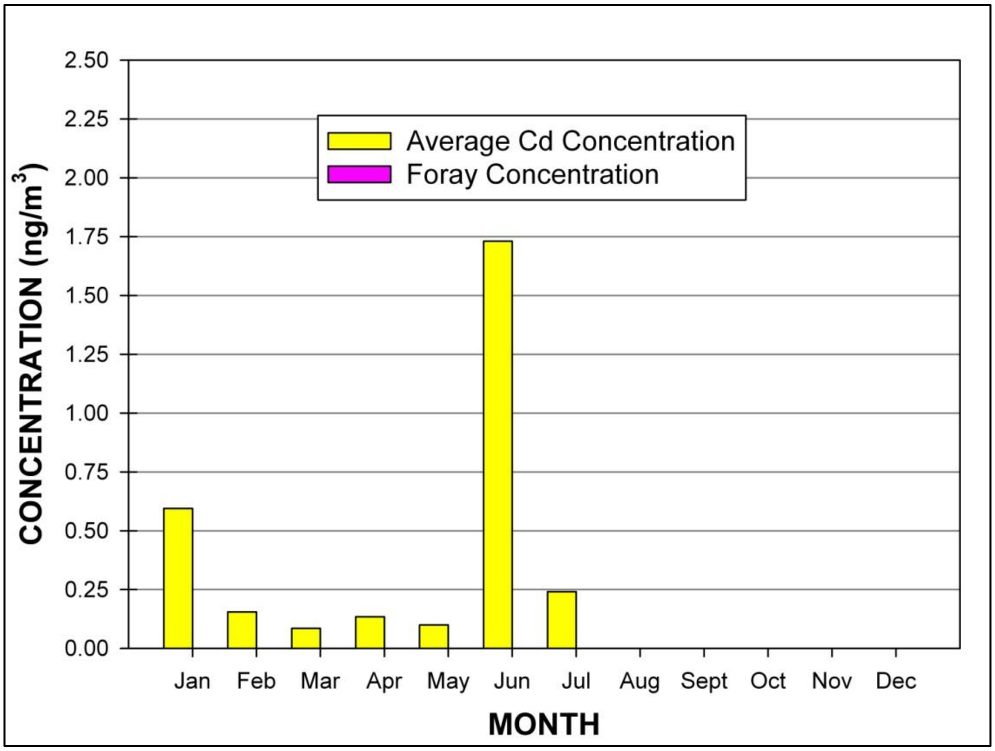

Figure 1.31. Monthly Average Concentrations of Cd for 2011

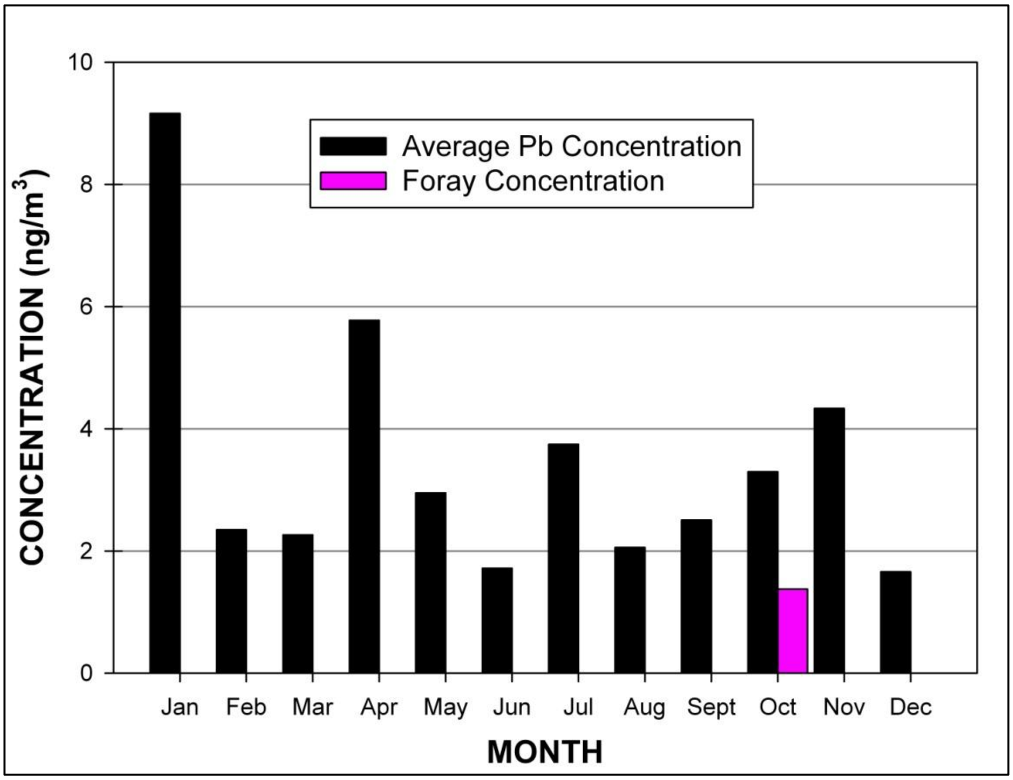

Figure 1.32. Monthly Average Concentrations of Pb for 2011

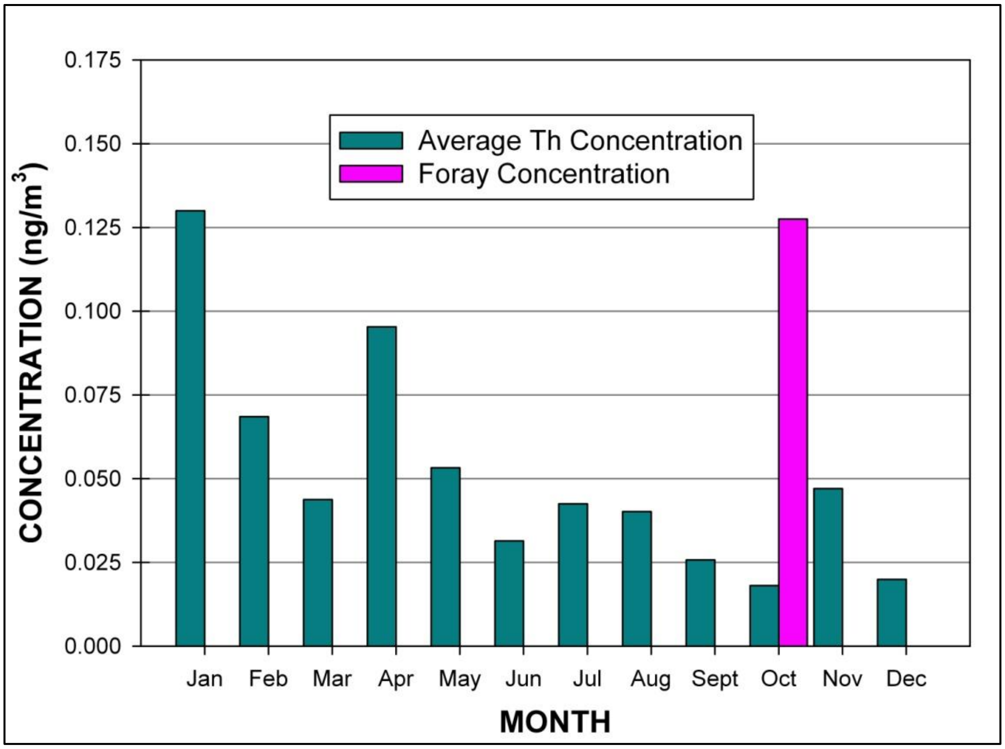

Figure 1.33. Monthly Average Concentrations of Th for 2011

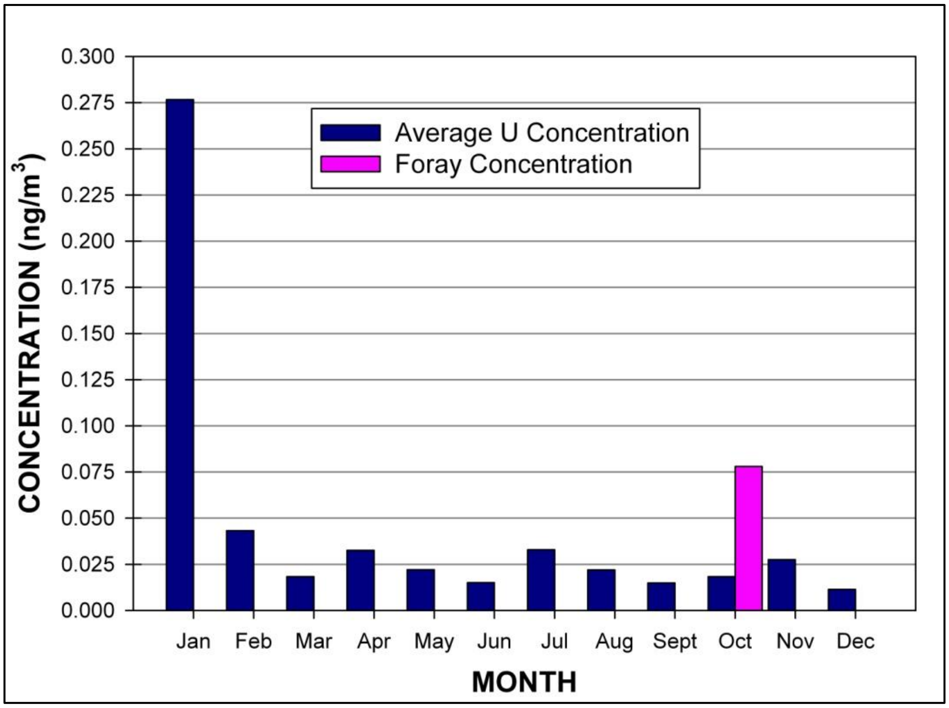

Figure 1.34. Monthly Average Concentrations of U for 2011

CHAPTER 2

Monitoring Drinking Water from Selected Sources

Introduction

Routine testing of public drinking water supplies helps to assure the public that health and environmental standards are met and seeks to identify any changes in water quality which might have a negative impact on public health and the environment. During 2011, water samples were collected for CEMRC environmental monitoring studies from six drinking water sources in the region of the WIPP including the community water supplies of Carlsbad, Loving, Otis, Hobbs, and Malaga. The drinking water wells in the vicinity of the WIPP provide water primarily for livestock, industrial usage by oil and gas production operations, and monitoring studies conducted by various groups.

Aquifers in the region surrounding the WIPP include Dewey Lake, Culebra-Magenta, Ogallala, 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 Ogallala aquifer, while the Loving, Malaga, and Otis supply wells are drawn from deposits that are hydraulically linked to the flow of the Pecos River. The source for a private well sampling site is a well seven miles southwest of the WIPP. This water is drawn from the Culebra aquifer, however, this sampling site has been dry since before 2001.

CEMRC began collecting drinking water samples for radiochemical analyses in 1997 and inorganic analyses on drinking water samples commenced in 1998. The results for the five drinking water sources from Carlsbad, Loving, Otis, Hobbs, and WIPP (Double Eagle) have been reported annually since 2001. Drinking water samples were not collected during 2004 and 2006. In addition, this is the first year that drinking water has been sampled from the site in Malaga. Summaries of methods, data, and results from previous samplings were reported in earlier CEMRC reports and can be found on the CEMRC website (www.cemrc.org). Present results as well as the results of previous analyses of drinking water were consistent for each source across sampling periods, and were below levels specified under the Safe Drinking Water Act.

Analyses reported herein for are for 2011 drinking water samples. These samples were analyzed for radionuclides including alpha and gamma emitting radionuclides of interest to the WIPP. In addition, inorganic studies were performed separately and include elemental analysis as well as analysis for mercury. ***The 2011 monitoring results show no increase in the levels of radionuclides or inorganics that could be attributed to WIPP-related activities***.

Sampling, Sample Preparation, and Measurements

All drinking water samples were processed according to CEMRC protocols for the collection, handling, and preservation of drinking water. The following samples were taken from each sampling location: (1) 8L for gamma and alpha analyses, (2) 1L for elemental analyses, (3) 1L for anion tests, and (4) 500mL for mercury analysis. None of the samples were filtered before analysis. Current methods used for the various analyses are summarized in Table 2.1. Basic information about contaminants in drinking water is listed in Table 2.2 (US-EPA, 2012).

For radioactive analyses, two aliquots were taken from each 8L sample: (a) 3L for gamma analyses and (b) 1L for alpha analyses. Both aliquots were acidified to approximately pH = 2 with nitric acid upon collection to avoid losses through microbial activity and adsorption onto the vessel walls. The first aliquot was transferred to 3L Marinelli beakers for the measurement of the gamma-emitting radionuclides potassium (^{40}K), cobalt (^{60}Co), and cesium (^{137}Cs), by gamma spectroscopy using a high purity germanium (HPGe) detector. Before collecting the measurements, the gamma system was calibrated for energy and efficiency to enable both qualitative and quantitative analysis of the water samples. The energy and efficiency calibrations were carried out using a mixed standards material from Eckert and Ziegler, Analytics (GA) in the energy range between 60 to 2000keV for a 3L Marinelli geometry. The counting time for each sample was 48 hours.

The second, 1L aliquot, was used for alpha analysis of uranium (U) and transuranic radionuclides. Tracers consisting of uranium, americium, and plutonium (^{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. Next, the samples were heated to dryness again in preparation for isotopic separation. The separation process began with co-precipitation of the target isotopes and corresponding tracers with an iron carrier followed by ion exchange and chromatographic separations of the individual radionuclides. Finally, the separated radionuclides were micro-precipitated using lanthanum fluoride (LaF_3) and deposited onto planchets for counting uranium/transuranics by alpha spectroscopy.

For elemental analysis, the 1L samples were preserved in a 1% nitric acid solution during sample collection. Samples from Otis, Malaga, and Hobbs were diluted using a similar nitric acid matrix prior to analysis by ICP-MS due to the elevated calcium (Ca) and sodium (Na) levels in these samples. All other 1L samples were analyzed directly. For Mercury analysis, the 500mL samples were preserved with a bromomonochloride solution and analyzed directly by ICP-MS. For each type of inorganic analyses, aliquots were blank-corrected after the application of dilution factors. As per CEMRC procedure, only concentrations above laboratory MDC values are reported.

As per CEMRC procedure, each 1L sample used for anion analysis was refrigerated immediately upon arrival and analyzed within 48 hours of collection. No preservatives were added to the samples used for anion analysis. At this time the results of the anion analyses are not currently being reported. However, anion analysis has continued to be performed on all collected drinking water samples as per the CEMRC procedure.

RADIOLOGICAL MONITORING RESULTS

Table 2-3 shows the activity concentrations for radionuclides of ^{234}U, ^{235}U, and ^{238}U; ^{238}Pu, $^{239+240}$Pu; ^{241}Am; ^{137}Cs; ^{60}Co; and ^{40}K in regional drinking water samples from 2011. The alpha radionuclides, ^{238}Pu, $^{239+240}$Pu, and ^{241}Am have not been detected in any of the drinking water samples above the MDC since monitoring commenced in 1997. The federal and state action level for gross alpha emitters, which includes isotopes of Pu and U, is 15pCi/L (0.56Bq/L). This level is over 10,000 times the MDCs used at CEMRC.

Isotopes of naturally occurring uranium were detected in all the drinking water samples in 2011 as shown in Table 2-3. Natural uranium is a mixture of three alpha-emitting isotopes (^{234}U, ^{235}U, and ^{238}U). They have long half-lives, $t_{1/2}$, that allow them to be transported to water supplies. The ^{238}U isotope has a $t_{1/2}$ of 4.5×10^9 years (99.285% natural abundance), ^{235}U has a $t_{1/2}$ of 7.04×10^8 years (0.71% natural abundance), and ^{234}U with a $t_{1/2}$ of 2.24×10^5 years (0.0053% natural abundance; Neghabian et al, 1991). Thus, natural abundances of isotopes and the half-lives give 12.2, 0.6, and 12.2mBq/μg of natural uranium for ^{238}U, ^{235}U, and ^{234}U respectively, or 25mBq/μg in total (Hess et al, 1985). Combined, these isotopes of uranium are found in the earth's crust with a natural abundance of 4×10^{-4} % (Hursh et al, 1973); in rocks and minerals such as granite, metamorphic rocks lignite, monazite sand; phosphate deposits as well as in uranium minerals such as uraninite, carnotite and pitchblende. It is also present as a trace element in coal, peat, asphalt and in some phosphate fertilizers at a level of about 100μg/g or 2.5Bq/g (Hess et al, 1985). All these sources can come in contact with water which influences the amount of natural uranium present in our drinking water. The natural level of uranium in water can also be enhanced due to human activity. For example, the increased concentration of natural radionuclides in water can be caused by the intensive use of phosphate fertilizers in agriculture. Phosphate fertilizers contain uranium which can leach from the soil to nearby rivers and lakes (Fleischer, 1980; UNSCEAR, 1982).

Measured values for the drinking water samples collected around the WIPP site during 2011 ranged between 10.9-239mBq/L for ^{238}U, 1.22-39.0mBq/L for ^{235}U, and 25.3-154mBq/L for ^{234}U. The average activity concentrations of ^{234}U, ^{235}U, and ^{238}U in drinking water from the five sources are presented in Figure 2.1. These uranium concentrations are well below the reference concentration level for radiological protection, i.e. 3.0Bq/L. They are also below the EPA Action level of 0.56 Bq/L and within the range expected in waters from this region. The greatest variations appear in the amounts of ^{235}U. The low concentration of ^{235}U in the 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 were found in Otis water. Figure 2.2 shows the total uranium concentration at each location.

It has been reported that the activity of natural water from ^{234}U is higher than that of ^{238}U. The ^{234}U/^{238}U activity ratio usually ranges between 1.0 and 3.0 (Cherdynstev et al, 1971; Gilkeson et al, 1982). According to the most recent reports, the fixed mass ratio and fixed activity ratios are still used for reporting the activity of natural uranium. The isotopic composition of natural uranium activities are 48.9, 2.2, and 48.9 %, respectively (IAEA, 1989). In radiochemical equilibrium, natural activity ratios are typically unity for ^{234}U/^{238}U and 0.045 for ^{235}U/^{238}U (Pimple et al, 1992). However, many studies looking at ^{238}U and ^{234}U in natural bodies of water indicate that these isotopes do not occur in equilibrium and that, with a few exceptions, waters typically contain more ^{234}U than ^{238}U (Cothern et al, 1983; Skwarzec et al, 2002). Higher activity of ^{234}U in water is the result of the ^{234}U atom displacement from the crystal lattice. The recoil atom, ^{234}U, is liable to be oxidized to the hexavalent stage and can be leached into the water phase more easily than its parent nuclide ^{238}U. The oxidation of U(IV) to U(VI) is an important step in leaching, because compounds containing U(VI) have a higher solubility due to the formation of strong complexes between uranyl and carbonate ions (UNSCEAR, 1977). All U(IV) compounds of uranium are practically insoluble.

The average activity ratio of ^{235}U and ^{238}U in the water samples collected around the WIPP site ranged from 0.036-0.072 (Average = 0.054) which is close to the value 0.045 for uranium reported in nature. The ^{235}U/^{238}U ratio in environmental samples differing from the natural ratio results from anthropogenic nuclear activities. Figure 2.3 shows the average ^{234}U/^{238}U ratios. The results of the activity ratios in this study compared very well with data observed in other countries as shown in Table 2.4. The calculated ^{234}U/^{238}U activity ratio varies between 2.33 to 2.96 which means that two isotopes are not in radioactive equilibrium. The historical activity concentrations of ^{234}U, ^{235}U and ^{238}U measured at well sites in the region of the WIPP site are summarized in Tables 2.5 to 2.9. The historical concentrations of transuranic elements like Plutonium and Americium, (^{238}Pu, $^{239+240}$Pu, and ^{241}Am) are shown in Figures 2.4 through 2.11.

It is important to note that after more than ten years of monitoring, isotopes of ^{238}Pu, $^{239+240}$Pu, and ^{241}Am have never been detected above MDC in any of the samples collected from well sites around the WIPP site. However, the levels of uranium detected in regional drinking water are very low and the activity ratio indicates its presence in drinking water is most likely from natural sources. For most people in the world, the intake of uranium through food is around 1μg/day. The worldwide average of dietary uranium is estimated at 1.3μg/day from which the portion from drinking water is 0.2μg/day (UNSCEAR, 2001). Thus drinking water is not usually the main source of ingested uranium.

NON-RADIOLOGICAL MONITORING RESULTS

The CEMRC analyzes samples from the six regional drinking water sources for over 30 different inorganic elements. The results are summarized in Tables 2.10 through 2.15. MDC values are determined annually and are reported as described in the current CEMRC procedure. The results exhibited in these Tables are not used in assessing regulatory compliance. However, the CEMRC results for drinking water from the Carlsbad (Sheep Draw) and WIPP (Double Eagle) locations agree well with measurements for the same elements published by the City of Carlsbad (City of Carlsbad Municipal Water System, 2011).

The 2011 inorganic drinking water measurements exhibit a high level of consistency with past results providing a useful characterization of each source. Figures 2.12 through 2.16 compare the history of select inorganic analytes measured in drinking water collected from the surrounding area of WIPP including Carlsbad (Sheep Draw), WIPP (Double Eagle), Loving, Hobbs, and Otis. Only the selected inorganics (listed in Table 2.2) which have been detected regularly above MDCs are shown in these figures. Historical comparisons show that differences of a factor of two or three between one set of successive years is common, as it is for all natural water systems. Additionally, there has been no noticeable increase in the inorganic levels found in the regional drinking water after the WIPP site started accepting mixed waste in August of 2000. It should be noted that drinking water sampling did not take place during the 2004 and 2006 years due to a change in sampling frequency.

Minerals are a natural part of all water sources. The amount of inorganic materials in drinking water is determined primarily by local geology and topography, but it can be influenced by urban storm water runoff, industrial or domestic wastewater discharges, oil and gas production, mining, and/or farming, etc. The city of Andrews, TX, has naturally occurring levels of Arsenic and Fluoride in their drinking water (City of Andrews, 2011). The drinking water from this part of TX is supplied from the Ogallala and Dockum formations which are also accessed by the WIPP (Double Eagle) and Hobbs communities. Indeed the concentrations of Arsenic measured at the Double Eagle and Hobbs sites are higher than the drinking water for other sampling locations around the WIPP site (most of which have concentrations below MDC) as shown in Figure 2.17. However, the levels determined for Double Eagle and Hobbs are still below the EPA limit of 10µg/L (0.01mg/L) for Arsenic as listed in Table 2.2. Figure 2.17 also includes comparisons of selected analytes which were measured above the corresponding MDC.

The WIPP site is located in the Delaware Basin of New Mexico, the second largest region of the greater Permian Basin. This 600-meter deep salt basin was formed during the Permian Era approximately 250 million years ago when an ancient Sea once covering the area evaporated and left behind a nearly impermeable layer of salt. Over time this salt layer was covered by 300 meters of soil and rock (Kerr, 1999; Weeks, 2011). The Permian Basin is now a major source of potassium salts (potash), which are mined from bedded deposits of sylvite and langbeinite (Alto, 1965). Sylvite is potassium chloride (KCl) in its natural mineral form while langbeinite is a potassium magnesium sulfate mineral ($K_2Mg_2(SO_4)_3$). Langbeinite ore occurs in evaporated marine deposits in association with carnallite, halite and sylvite (Mereiter, 1979; NBS Mono 1968; Palache, 1951;). Therefore, it is to be expected that through leaching and other natural processes, the water in this region should contain significant quantities of potassium (K), magnesium (Mg) and, of course, sodium (Na). Figure 2.18 summarizes the concentrations of common salts measured in the areas surrounding the WIPP site. Currently there are no EPA regulations for salts like K, Mg, and Na in drinking water.

The highest concentration of the measured metals found in the drinking water of this area is Calcium (Ca) for each of the sites sampled around the WIPP (Figure 2.18). This is likely due to the natural limestone deposits found along the edge of the Delaware Basin which once existed as the Capitan Reef during the Permian Era. Limestone is a sedimentary rock composed largely of the minerals calcite and aragonite, which are different crystal forms of calcium carbonate ($CaCO_3$). Limestone leaching creates the stalactites and stalagmites found in the infamous Carlsbad Caverns, located approximately 18 miles southwest of Carlsbad, NM and a likely source of Calcium (Ca) in the drinking water in the area.

Table 2.1. Drinking Water Parameters, Methods, and Detection Levels used to Analyze Samples from all Locations

Method/ Parameters	Analytes of Interest	Typical Detection Limits
Gross alpha/beta EPA 900.0	(Under Development)	0.037-0.11Bq/L*
Gamma emitters	^{60}Co, ^{137}Cs and ^{40}K	0.03-1.0Bq/L*
Alpha emitters	$^{239+240}$Pu, ^{238}Pu, ^{241}Am, ^{234}U, ^{238}U, ^{235}U	0.001-0.002Bq/L*
Elemental analysis EPA 200.8	Over 30 different metals	Varies by element**
Anions EPA 300.0	F^-, Cl^-, Br^-, NO_2^-, NO_3^-, PO_4^{3-}, SO_4^{2-}	Not currently reported**
Mercury EPA 200.8	Hg	0.0089µg/L**

* Detection limits may vary depending on sample volume, solid concentrations, counting system and time.

** Detection limits are determined annually.

Table 2.2. Basic Information about Drinking Water Contaminants from the EPA

Contaminant	Minimum Contaminants Level	Potential Health Effects from Long-term Exposure	Sources of Drinking Water Contaminants
Radium-226, Radium-228 (combined)	5pCi/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	15pCi/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, U	30µg/L (as of 12/08/03)	Increased risk of cancer; kidney toxicity	Erosion of natural deposits.
Antimony, Sb	0.006mg/L	Increase in blood cholesterol; decrease in blood sugar	Discharge from petroleum refineries; fire retardants; ceramics; electronics; solder
Arsenic, As	0.010mg/L (as of 01/23/06)	Skin damage or problems with circulatory systems, and may have increased risk of cancer.	Erosion of natural deposits; runoff from orchards; runoff from glass & electronics production wastes.
Barium, Ba	2mg/L	Increase in blood pressure	Discharge of drilling wastes; discharge from metal refineries; erosion of natural deposits
Beryllium, Be	0.004mg/L	Intestinal lesions	Discharge from metal refineries and coal-burning factories; discharge from electrical, aerospace, and defense industries.
Cadmium, Cd	0.005mg/L	Kidney damage	Corrosion of galvanized pipes; erosion of natural deposits; discharge from metal refineries; runoff from waste batteries and paints.
Chromium, Cr (total)	0.1mg/L	Allergic dermatitis	Discharge from steel and pulp mills; erosion of natural deposits.
Copper, Cu	1.3mg/L	**Short term exposure**: gastrointestinal distress. **Long term exposure**: liver or kidney damage. People with Wilson's Disease should consult their doctor	Corrosion of household plumbing systems; erosion of natural deposits
Lead, Pb	0.015mg/L	**Infants and children**: delays in physical or mental development; children could show slight deficits in attention span and learning abilities. **Adults**: kidney problems; high blood pressure	Corrosion of household plumbing systems; erosion of natural deposits
Mercury, Hg	0.002mg/L	Kidney damage	Erosion of natural deposits; discharge from refineries; runoff from landfills and croplands
Selenium, Se	0.05mg/L	Hair or fingernail loss; numbness in fingers or toes; circulatory problems	Discharge from petroleum refineries; erosion of natural deposits; discharge from mines
Thallium, Tl	0.002mg/L	Hair loss; changes in blood; kidney, intestine, or liver problems	Leaching from ore-processing sites; discharge from electronics, glass, and drug factories

Table 2.3. Radionuclide Activity Concentrations in Drinking Water in 2011

Location/sample collection date	Radionuclide	Activity[a] Bq/L	SD[b] (Bq/L)	MDC[c] (Bq/L)
Carlsbad 07/11/2011	$^{239+240}$Pu	0.00E+00	1.05E-05	4.60E-05
	^{238}Pu	0.00E+00	1.21E-05	5.14E-05
	^{241}Am	2.05E-05	1.66E-05	5.30E-05
	^{234}U	2.83E-02	7.13E-04	8.42E-05
	^{235}U	7.83E-03	8.27E-04	7.49E-04
	^{238}U	1.09E-02	3.40E-04	7.81E-05
	^{137}Cs	8.63E-03	3.66E-02	1.21E-01
	^{40}K	1.34E-01	3.58E-01	1.19E+00
	^{60}Co	7.93E-03	1.70E-02	7.88E-02
Hobbs 07/13/2011	$^{239+240}$Pu	3.18E-06	9.79E-06	4.14E-05
	^{238}Pu	-4.27E-06	1.13E-05	5.13E-05
	^{241}Am	3.50E-07	9.24E-06	3.50E-05
	^{234}U	1.04E-01	3.01E-03	2.65E-04
	^{235}U	2.60E-03	2.44E-04	2.59E-04
	^{238}U	4.50E-02	1.45E-03	2.64E-04
	^{137}Cs	4.99E-03	3.65E-02	1.21E-01
	^{40}K	1.19E-02	3.62E-01	1.20E+00
	^{60}Co	-9.76E-03	1.76E-02	8.25E-02
Double Eagle 07/13/2011	$^{239+240}$Pu	1.30E-05	1.30E-05	4.67E-05
	^{238}Pu	-8.62E-06	1.37E-05	6.12E-05
	^{241}Am	-8.38E-06	1.15E-05	5.05E-05
	^{234}U	4.80E-02	8.52E-04	7.26E-05
	^{235}U	1.12E-03	8.45E-05	5.57E-05
	^{238}U	1.86E-02	4.06E-04	8.75E-05
	^{137}Cs	4.80E-02	8.52E-04	7.26E-05
	^{40}K	1.12E-03	8.45E-05	5.57E-05
	^{60}Co	1.86E-02	4.06E-04	8.75E-05
Otis 07/11/2011	$^{239+240}$Pu	2.93E-05	1.49E-05	4.34E-05
	^{238}Pu	1.76E-05	1.39E-05	4.75E-05
	^{241}Am	5.13E-06	1.10E-05	3.84E-05
	^{234}U	1.54E-01	2.77E-03	1.45E-04
	^{235}U	1.19E-02	6.48E-04	2.94E-04
	^{238}U	2.39E-01	4.85E-03	5.81E-04
	^{137}Cs	-1.45E-02	3.66E-02	1.22E-01
	^{40}K	6.90E-01	3.52E-01	1.15E+00
	^{60}Co	-7.77E-03	1.70E-02	7.97E-02

* Values are overestimated because of poor separation.

[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

Table 2.3. Radionuclide Activity Concentrations in Drinking Water in 2011 (continued)

Location/sample collection date	Radionuclide	Activity[a] Bq/L	SD[b] (Bq/L)	MDC[c] (Bq/L)
Loving 07/11/2011	$^{239+240}$Pu	3.00E-05	1.29E-05	3.16E-05
	^{238}Pu	6.90E-06	1.08E-05	4.25E-05
	^{241}Am	-1.86E-05	9.63E-06	5.04E-05
	^{234}U	7.64E-02	1.12E-03	4.14E-05
	^{235}U	2.04E-02*	1.29E-03	5.66E-04
	^{238}U	2.57E-02	4.56E-04	7.22E-05
	^{137}Cs	-1.21E-03	3.66E-02	1.21E-01
	^{40}K	2.53E-01	3.65E-01	1.21E+00
	^{60}Co	-7.79E-03	1.72E-02	8.02E-02
Loving (DUP) 07/11/2011	$^{239+240}$Pu	1.35E-05	1.35E-05	4.83E-05
	^{238}Pu	8.91E-06	1.27E-05	4.83E-05
	^{241}Am	5.52E-06	1.12E-05	3.93E-05
	^{234}U	7.50E-02	1.53E-03	1.13E-04
	^{235}U	3.90E-02*	2.62E-03	1.49E-03
	^{238}U	1.09E-01	2.72E-03	7.57E-04
	^{137}Cs	-7.35E-03	3.65E-02	1.21E-01
	^{40}K	4.05E-01	3.58E-01	1.18E+00
	^{60}Co	4.70E-02	1.63E-02	7.37E-02
Malaga 07/12/2011	$^{239+240}$Pu	8.75E-06	1.64E-05	6.17E-05
	^{238}Pu	-2.51E-06	1.55E-05	6.40E-05
	^{241}Am	8.77E-06	1.27E-05	4.32E-05
	^{234}U	1.38E-01	2.92E-03	9.02E-05
	^{235}U	2.56E-03	1.75E-04	1.47E-04
	^{238}U	5.34E-02	1.25E-03	1.33E-04
	^{137}Cs	-3.32E-02	3.68E-02	1.22E-01
	^{40}K	4.38E-01	3.51E-01	1.16E+00
	^{60}Co	8.62E-03	1.76E-02	8.01E-02

* Values are overestimated because of poor separation.

[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

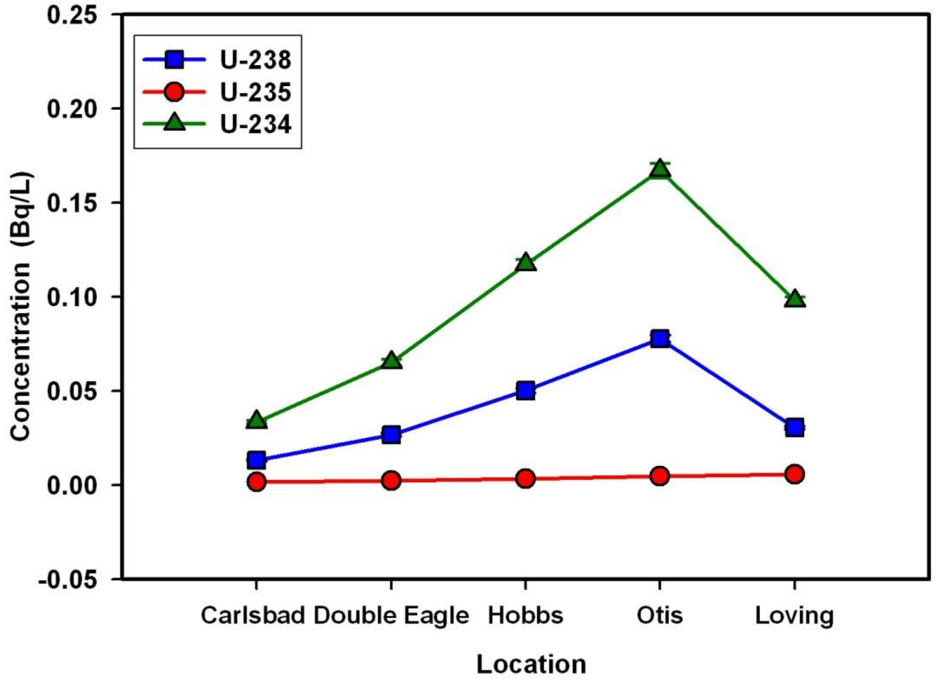

Figure 2.1. Average ^{234}U, ^{235}U, and ^{238}U concentrations (Bq/L) in Regional Drinking Water

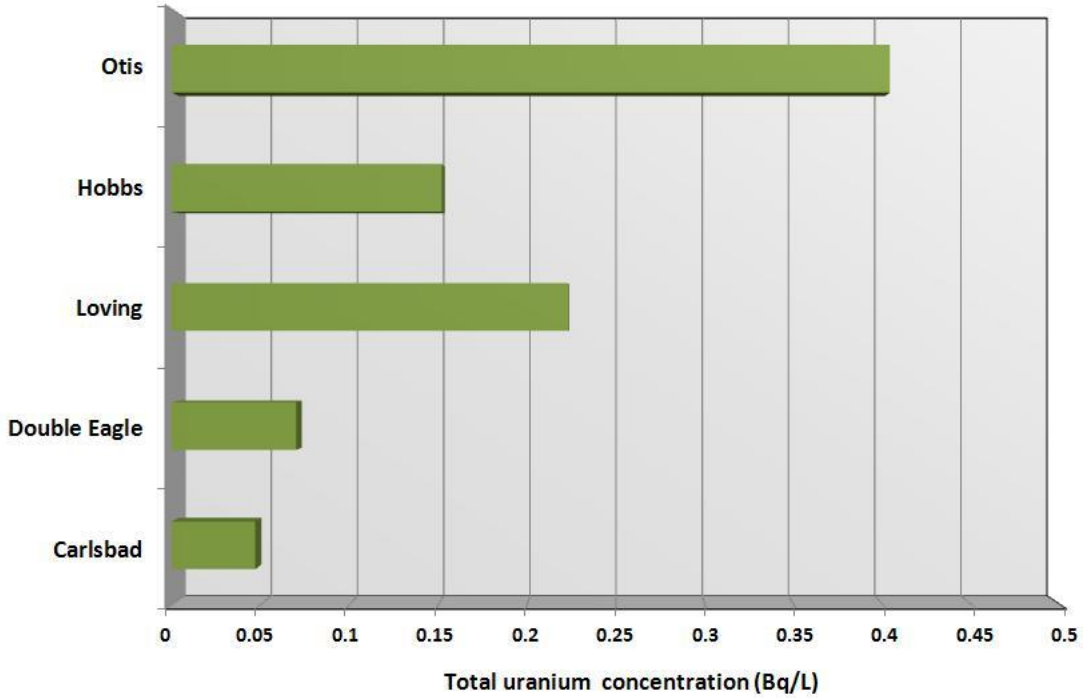

Figure 2.2. Total Uranium Concentrations in Bq/L in Regional Drinking Water Collected in 2011

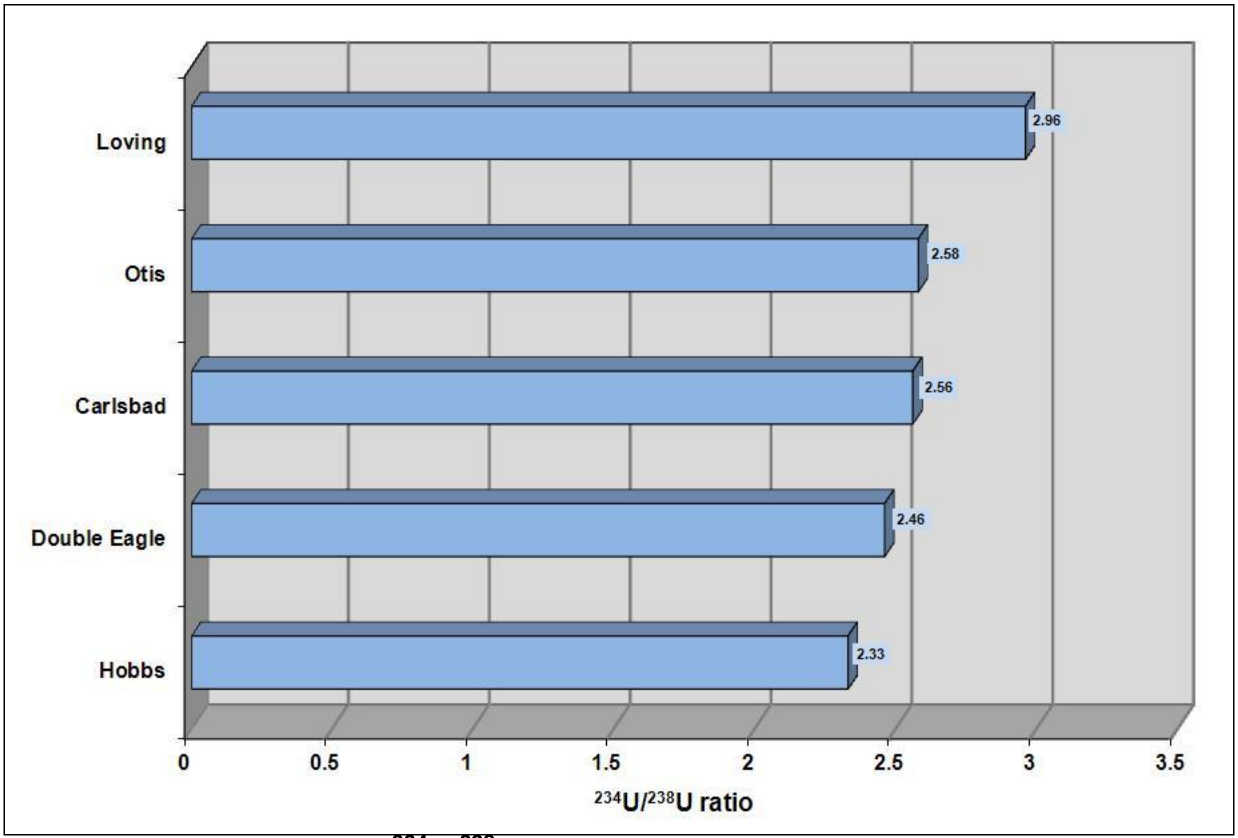

Figure 2.3. Average $^{234}U/^{238}U$ Activity Ratio in Regional Drinking Water from 1998 - 2011

Table 2.4. Comparison of Activity Concentration Ratios of $^{234}U/^{238}U$ and $^{235}U/^{238}U$ 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	2.56	0.072	Present work
Double Eagle	Drinking water	2.46	0.060	Present work
Hobbs	Drinking water	2.33	0.058	Present work
Otis	Drinking water	2.58	0.050	Present work
Loving	Drinking water	2.96	0.036	Present work
Malaga	Drinking water	2.58	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.

Table 2.5. Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) measured in Carlsbad Drinking Water

Year	^{234}U	^{235}U	^{238}U
1998	3.34E-02	7.52E-04	1.35E-02
1999	2.94E-02	6.99E-04	1.14E-02
2000	2.81E-02	8.12E-04	1.08E-02
2001	3.15E-02	9.68E-04	1.21E-02
2002	3.02E-02	7.97E-04	1.26E-02
2003	2.90E-02	5.52E-04	1.05E-02
2005	2.75E-02	1.54E-03	1.11E-02
2007	NR	NR	NR
2008	7.73E-02	3.09E-03	3.18E-02
2009	2.48E-02	3.57E-04	9.24E-03
2010	2.99E-02	5.64E-04	1.17E-02
2011	2.83E-02	7.83E-03	1.09E-02

NR = not reported

Table 2.6. Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) measured in Double Eagle Drinking Water

Year	^{234}U	^{235}U	^{238}U
1998	NR	NR	NR
1999	6.19E-02	1.35E-04	2.32E-02
2000	5.40E-02	1.38E-04	2.19E-02
2001	4.10E-02	1.22E-04	1.74E-02
2002	4.16E-02	1.01E-04	1.77E-02
2003	4.25E-02	8.89E-05	1.61E-02
2005	5.83E-02	1.43E-04	2.48E-02
2007	NR	NR	NR
2008	1.86E-01	4.31E-04	7.94E-02
2009	6.97E-02	7.55E-04	2.89E-02
2010	4.89E-02	1.36E-04	2.01E-02
2011	4.80E-02	8.45E-05	1.86E-02

NR = not reported

Table 2.7. Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) measured in Hobbs Drinking Water

Year	^{234}U	^{235}U	^{238}U
1998	NR	NR	NR
1999	8.81E-02	2.46E-03	3.86E-02
2000	9.06E-02	2.34E-03	3.99E-02
2001	7.52E-02	2.59E-03	3.32E-02
2002	9.40E-02	2.37E-03	4.05E-02
2003	1.30E-01	2.51E-03	4.61E-02
2005	9.82E-02	2.68E-03	4.27E-02
2007	NR	NR	NR
2008	2.87E-01	1.18E-02	1.31E-01
2009	8.94E-02	1.99E-03	3.86E-02
2010	1.04E-01	2.23E-03	4.59E-02
2011	1.04E-01	2.60E-03	4.50E-02

NR = not reported

Table 2.8. Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) measured in Otis Drinking Water

Year	^{234}U	^{235}U	^{238}U
1998	1.29E-01	2.73E-03	4.67E-02
1999	1.50E-01	2.85E-03	5.30E-02
2000	1.44E-01	2.97E-03	5.16E-02
2001	1.62E-01	3.30E-03	6.01E-02
2002	1.47E-01	3.34E-03	5.34E-02
2003	1.34E-01	2.56E-03	4.81E-02
2005	1.17E-01	2.60E-03	4.36E-02
2007	NR	NR	NR
2008	3.89E-01	1.35E-02	1.53E-01
2009	1.47E-01	3.80E-03	5.35E-02
2010	1.54E-01	2.66E-03	5.41E-02
2011	1.54E-01	1.19E-02	2.39E-01

NR = not reported

Table 2.9. Historical Activity Concentrations of ^{234}U, ^{235}U and ^{238}U (Bq/L) measured in Loving Drinking Water

Year	^{234}U	^{235}U	^{238}U
1998	NR	NR	NR
1999	8.15E-02	1.66E-03	2.63E-02
2000	8.38E-02	1.63E-03	2.59E-02
2001	8.05E-02	1.61E-03	2.48E-02
2002	8.82E-02	1.63E-03	2.83E-02
2003	7.91E-02	1.35E-03	2.40E-02
2005	8.13E-02	1.42E-03	2.64E-02
2007	NR	NR	NR
2008	2.56E-01	5.15E-03	7.71E-02
2009	7.42E-02	1.26E-03	2.22E-02
2010	8.00E-02	1.20E-03	2.49E-02
2011	7.50E-02	3.90E-02	2.57E-02

NR = not reported

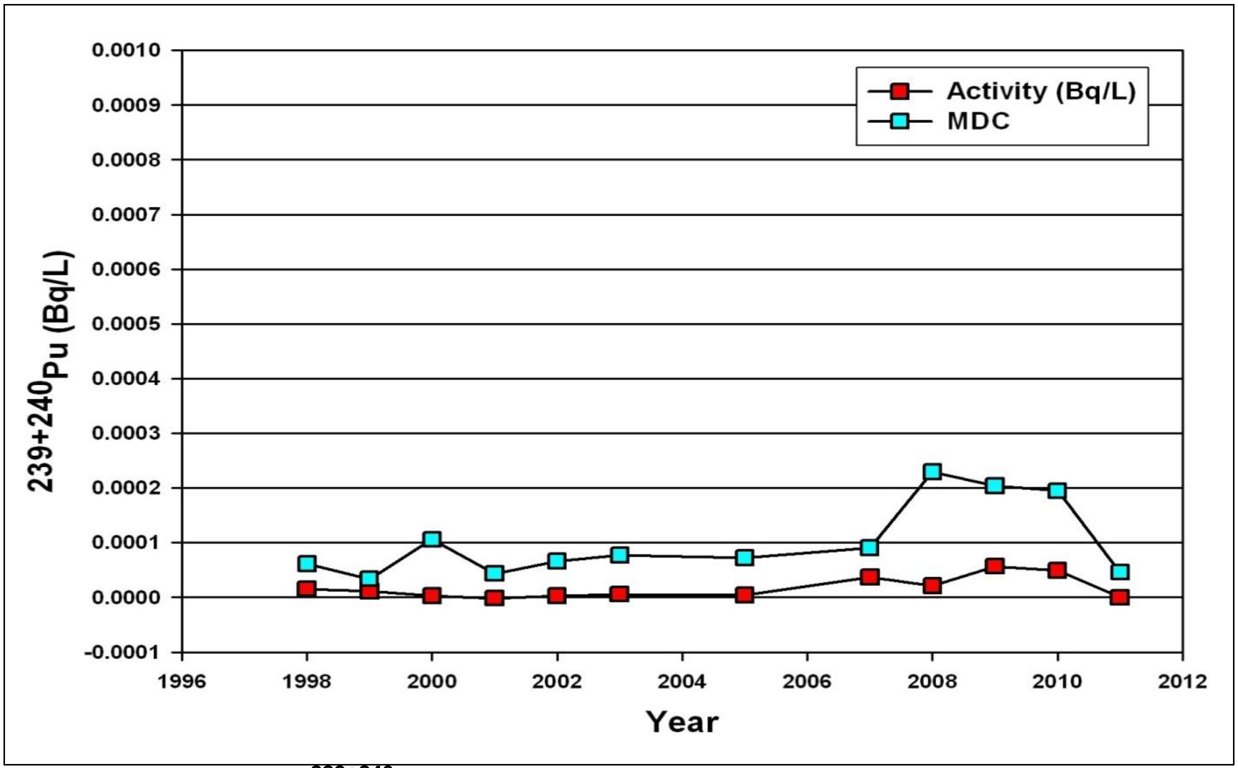

Figure 2.4. $^{239+240}$**Pu in Carlsbad Drinking Water from 1998-2011**

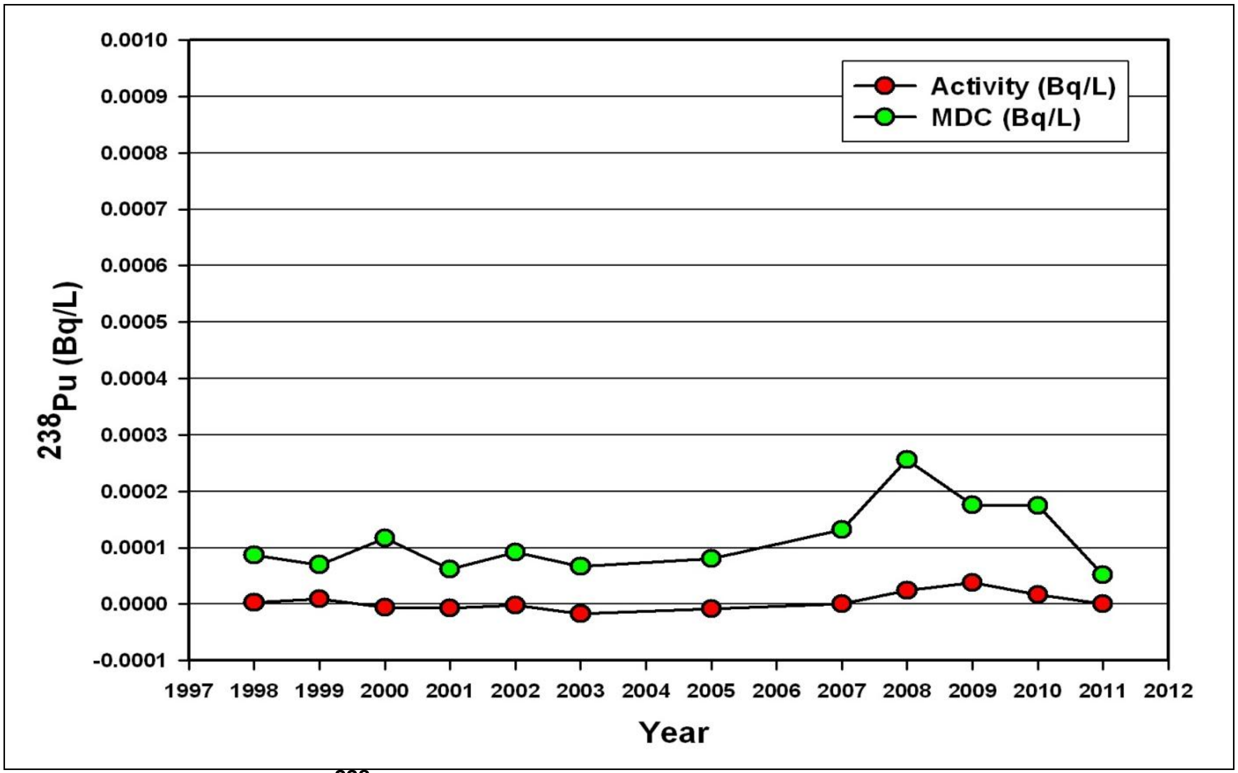

Figure 2.5. ^{238}**Pu in Carlsbad Drinking Water from 1998-2011**

EPA action level for all alpha emitters is 15pCi/L (0.56 Bq/L)

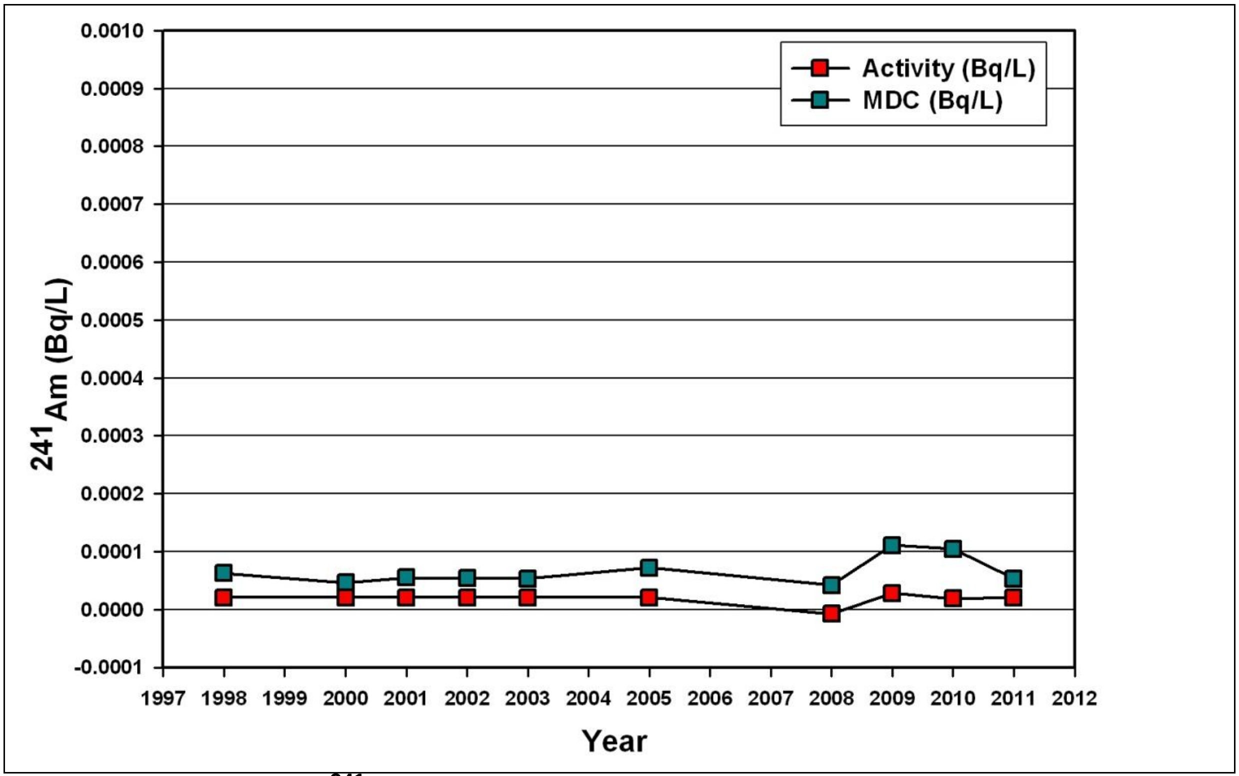

Figure 2.6. ^{241}Am in Carlsbad Drinking Water from 1998-2011

EPA action level for all alpha emitters is 15pCi/L (0.56 Bq/L)

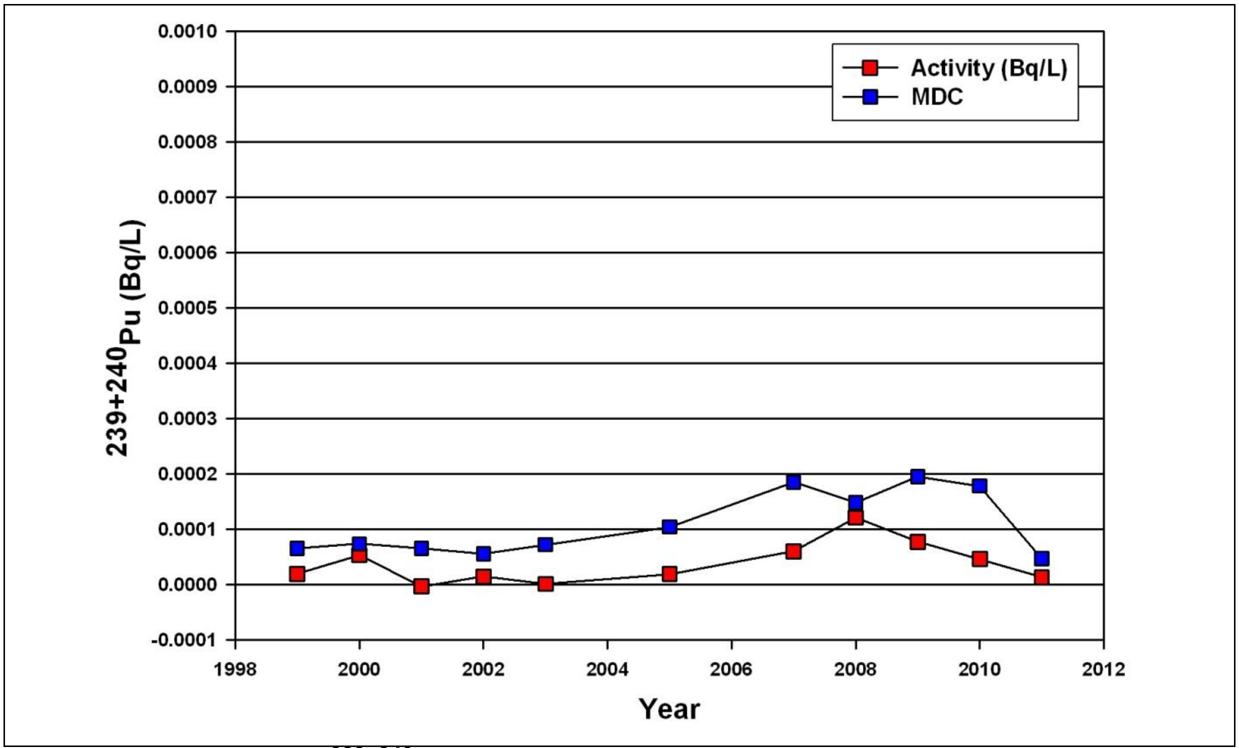

Figure 2.7. $^{239+240}$Pu in Hobbs Drinking Water from 1998-2011

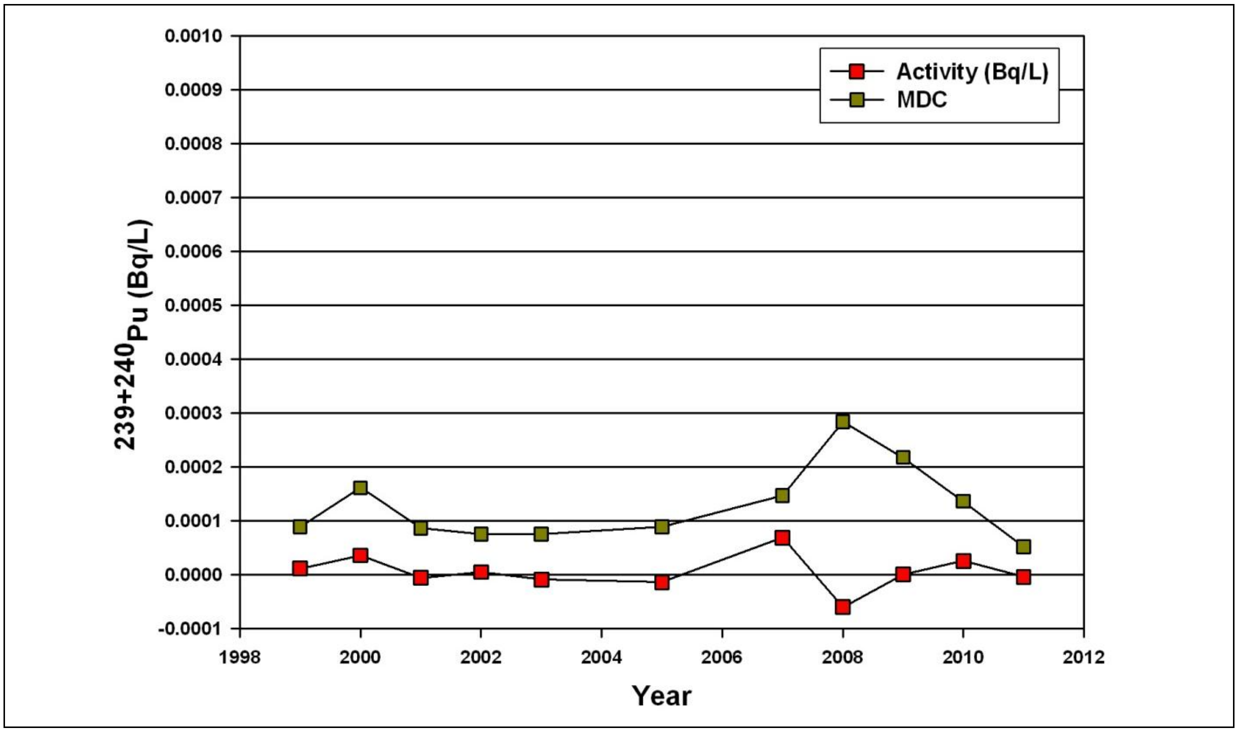

Figure 2.8. ^{238}Pu in Hobbs Drinking Water from 1998-2011

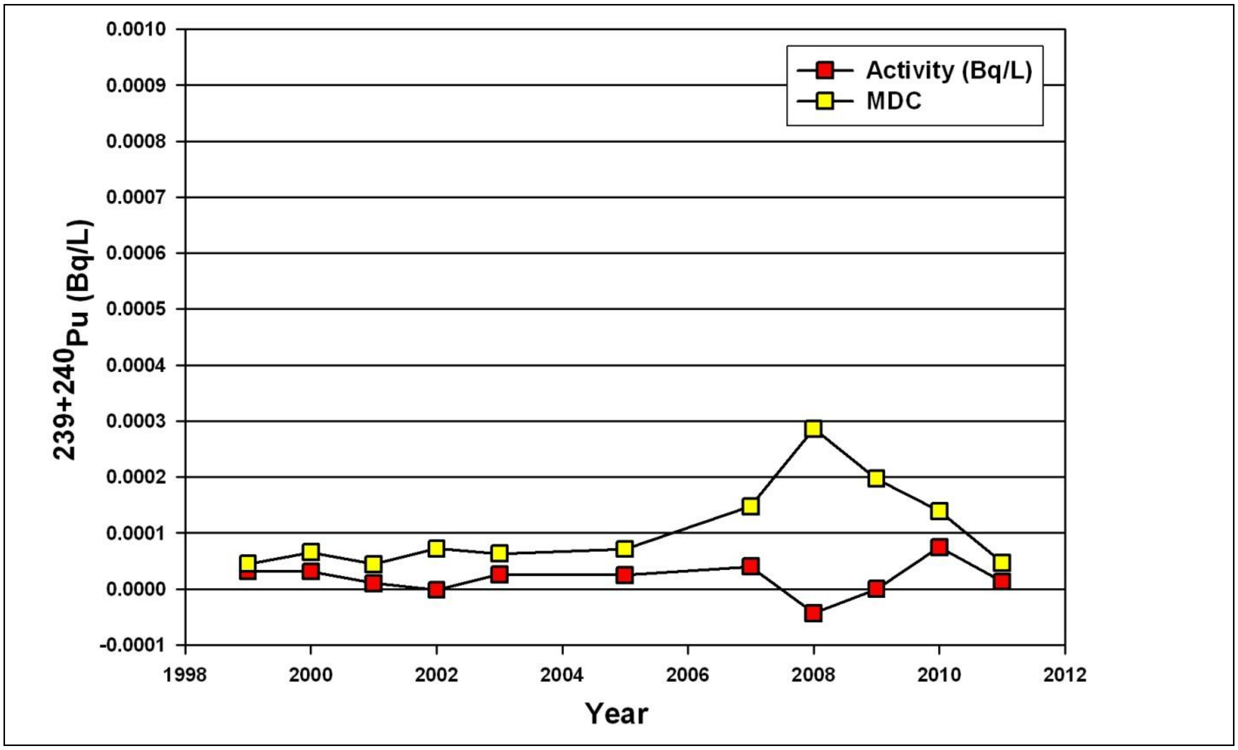

Figure 2.9. $^{239+240}$Pu in Double Eagle Drinking Water from 1998-2011
EPA action level for all alpha emitters is 15pCi/L (0.56 Bq/L)

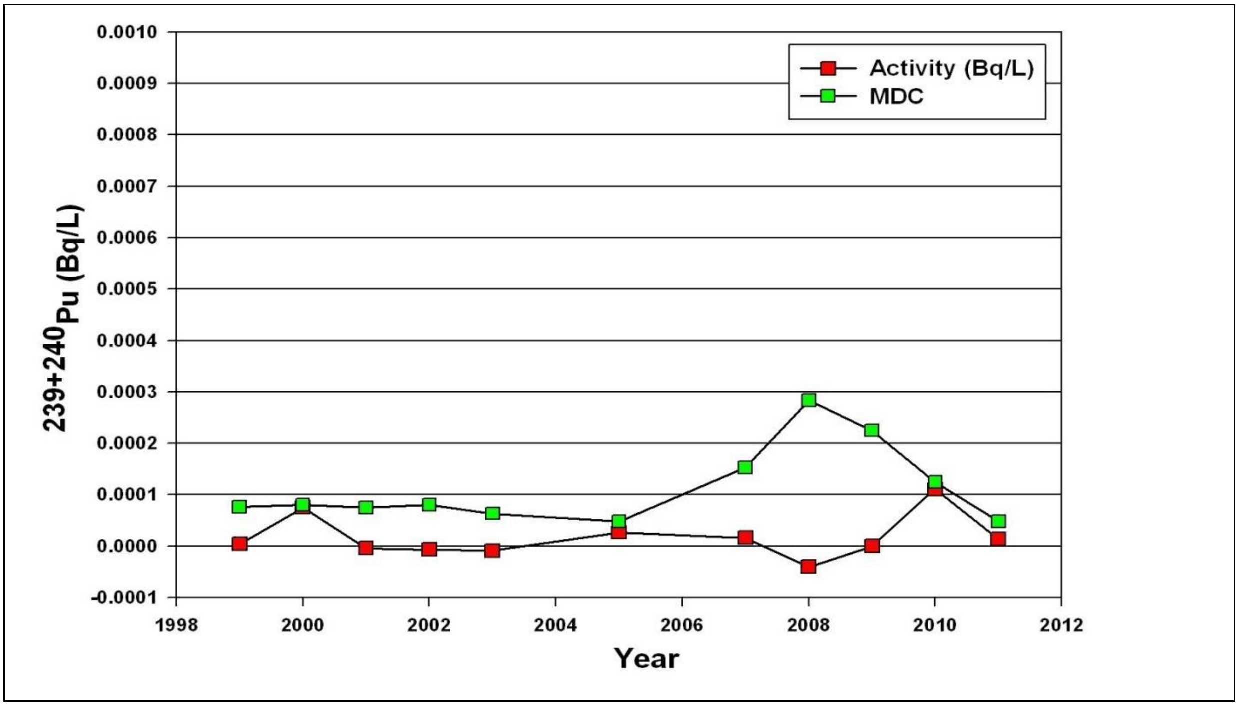

Figure 2.10. $^{239+240}$Pu in Loving Drinking Water from 1998-2011

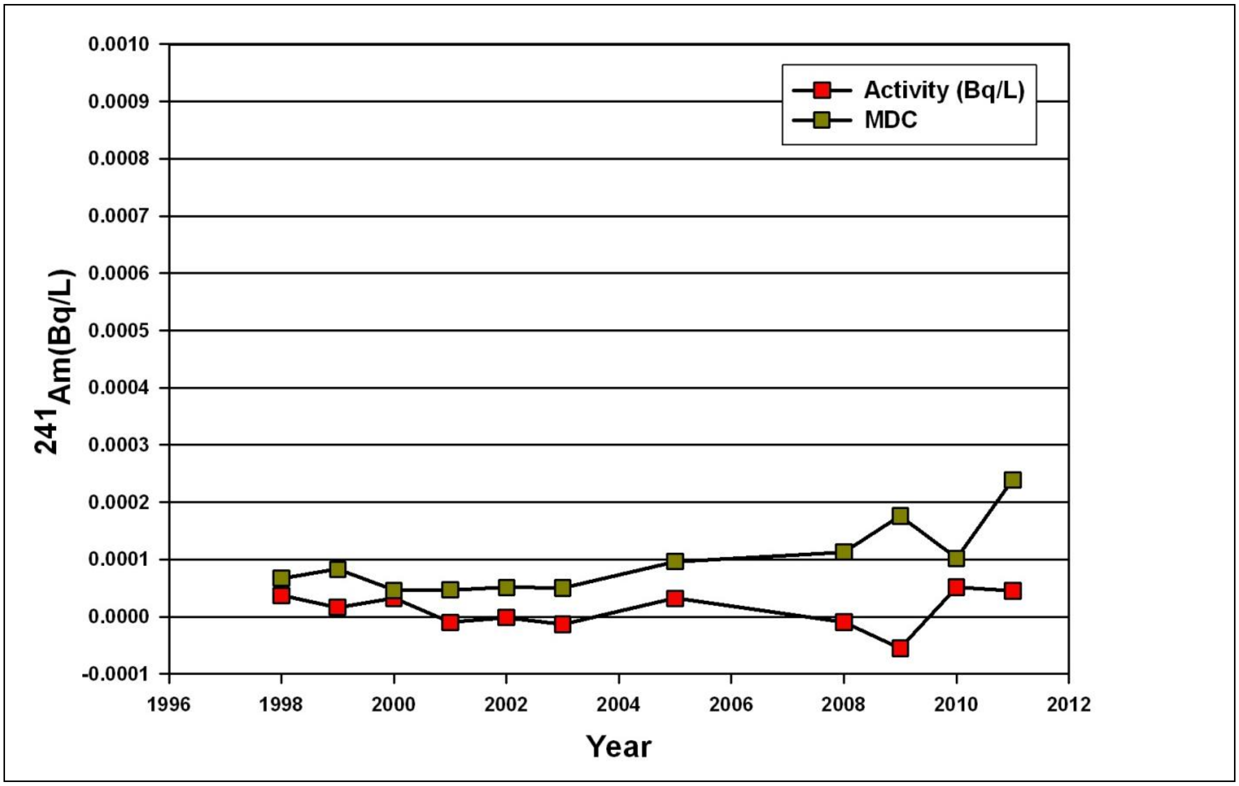

Figure 2.11. ^{241}Am in Otis Drinking Water from 1998-2011

Table 2.10. Measured Concentration of Selected Inorganic Analytes in Carlsbad Drinking Water from 1998 - 2011

Carlsbad							
1998-2010					2011		
EL[1]	**N[2]**	**N_{DET}[2]**	**Min[3]**	**Max[3]**	**MDC[4] (µg/L)**	**Blank Conc. (µg/L)**	**Sample Conc. (µg/L)[5]**
Ag	9	1	1.75E-02	1.75E-02	3.10E-03	3.85E-03	<MDC
Al	11	4	2.34E+00	4.11E+01	9.80E-01	2.24E-01	1.83E+00
As	11	8	2.94E-01	1.42E+00	1.30E+00	5.57E-01	<MDC
B	3	3	2.89E+01	4.44E+01	N/A	N/A	N/A
Ba	9	9	6.64E+01	8.19E+01	3.20E-02	3.72E-03	7.26E+01
Be	9	N/A	N/A	N/A	5.00E-02	-2.82E-02	<MDC
Ca	5	5	6.54E+04	7.26E+04	3.17E+02	-3.39E+01	5.90E+04
Cd	9	N/A	N/A	N/A	2.80E-01	-1.82E-01	<MDC
Ce	9	2	8.31E-03	3.42E-02	8.10E-03	7.40E-05	<MDC
Co	11	7	8.80E-02	3.41E-01	4.50E-03	-1.99E-04	1.04E-01
Cr	11	8	1.24E+00	6.96E+00	1.60E-01	5.29E-02	2.11E+00
Cu	11	9	1.30E+00	1.67E+01	5.80E-01	5.56E-03	5.21E+00
Dy	10	N/A	N/A	N/A	1.70E-03	8.35E-04	3.56E-03
Er	10	1	3.38E-03	3.38E-03	3.20E-03	1.63E-04	3.32E-03
Eu	9	5	1.35E-02	2.42E-02	3.10E-03	9.45E-04	1.90E-02
Fe	7	3	7.10E-01	2.24E+02	1.01E+01	5.19E+00	2.02E+02
Ga	1	1	3.25E+00	3.25E+00	N/A	N/A	N/A
Gd	8	N/A	N/A	N/A	2.40E-03	1.20E-03	3.80E-03
Hg	3	N/A	N/A	N/A	8.90E-03	1.04E-02	<MDC
K	9	9	1.04E+03	3.56E+03	1.62E+01	1.75E+01	1.32E+03
La	9	4	8.45E-03	4.42E-02	3.90E-03	9.23E-04	5.81E-03
Li	7	7	5.14E+00	7.87E+00	4.90E-02	3.58E-02	8.86E+00
Mg	8	8	3.14E+04	3.47E+04	7.30E+00	4.93E-02	2.73E+04
Mn	11	7	5.50E-02	2.04E+00	1.20E-01	4.44E-03	2.58E-01
Mo	9	8	7.03E-01	1.22E+00	N/A	N/A	N/A
Na	10	10	8.16E+03	9.94E+04	3.57E+01	2.67E-01	2.03E+04
Nd	10	N/A	N/A	N/A	8.40E-03	6.85E-04	<MDC
Ni	11	9	1.01E+00	3.14E+00	1.20E-01	-1.26E-03	2.69E+00
P	3	2	1.61E+01	2.29E+01	6.30E+00	-2.05E+00	1.87E+01
Pb	10	7	1.68E-01	1.44E+00	1.20E-01	1.41E-04	2.63E-01
Pr	10	N/A	N/A	N/A	2.30E-03	2.10E-04	3.72E-03
Sb	10	4	3.00E-02	1.99E-01	1.30E-02	1.15E-02	3.66E-02
Sc	8	7	1.32E+00	3.03E+00	N/A	N/A	N/A
Se	8	6	-8.83E-02	1.22E+00	4.10E+00	1.73E+00	<MDC
Si	6	6	5.31E+03	6.87E+03	7.10E+00	-4.69E+00	6.51E+03
Sr	10	10	2.61E+02	4.59E+02	1.30E+00	2.94E-03	3.60E+02
Th	8	1	1.76E-02	1.76E-02	3.20E-03	1.42E-03	6.32E-03
Tl	9	9	8.97E-02	1.62E-01	2.50E-03	-4.84E-04	1.13E-01
U	10	10	8.21E-01	1.05E+00	2.20E-03	1.69E-04	9.23E-01
V	11	11	3.54E+00	5.80E+00	1.20E-01	1.96E-02	4.86E+00
Zn	11	10	2.13E+00	1.52E+01	1.60E+00	-9.85E-04	6.94E+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] Concentrations below the MDC are reported as <MDC;
N/A = Not Applicable

Table 2.11. Measured Concentration of Selected Inorganic Analytes in Double Eagle Drinking Water from 1998 - 2011

Double Eagle							
1998-2010					2011		
EL[1]	**N[2]**	**N_{DET}[2]**	**Min[3]**	**Max[3]**	**MDC[4] (µg/L)**	**Blank Conc. (µg/L)**	**Sample Conc. (µg/L)[5]**
Ag	10	2	3.62E-03	1.78E-01	3.10E-03	3.85E-03	<MDC
Al	11	5	2.57E+00	7.22E+01	9.80E-01	2.24E-01	1.93E+00
As	11	10	4.43E+00	7.80E+00	1.30E+00	5.57E-01	7.26E+00
B	3	3	2.98E+01	8.55E+01	N/A	N/A	N/A
Ba	9	9	3.82E+01	1.25E+02	3.20E-01	3.72E-03	1.03E+02
Be	9	1	3.63E-02	3.63E-02	5.00E-02	-2.82E-02	<MDC
Ca	6	6	4.49E+04	5.61E+04	3.17E+02	-3.39E+01	4.15E+04
Cd	9	1	1.87E-02	1.87E-02	2.80E-01	-1.82E-01	<MDC
Ce	10	2	3.63E-03	3.22E-02	8.10E-03	7.40E-05	<MDC
Co	11	7	6.48E-02	1.12E+00	4.50E-03	-1.99E-04	8.21E-02
Cr	11	10	1.29E+00	3.25E+01	1.60E-01	5.29E-02	1.62E+00
Cu	11	10	8.09E-01	5.69E+00	5.80E-01	5.56E-03	1.57E+00
Dy	11	N/A	N/A	N/A	1.70E-03	8.35E-04	<MDC
Er	11	N/A	N/A	N/A	3.20E-03	1.63E-04	<MDC
Eu	10	6	1.68E-02	2.86E-02	3.10E-03	9.45E-04	2.86E-02
Fe	7	5	3.01E-02	9.32E+02	1.01E+01	5.19E+00	1.39E+02
Ga	1	1	4.46E+00	4.46E+00	N/A	N/A	N/A
Gd	10	N/A	N/A	N/A	2.40E-03	1.20E-03	<MDC
Hg	2	N/A	N/A	N/A	8.90E-03	1.04E-02	<MDC
K	9	9	2.31E+03	2.94E+04	1.62E+01	1.75E+01	2.22E+03
La	10	5	1.19E-02	6.26E-02	3.90E-03	9.23E-04	<MDC
Li	8	8	9.97E+00	1.90E+01	4.90E-02	3.58E-02	1.55E+01
Mg	8	8	8.51E+03	1.25E+04	7.30E-01	4.93E-02	8.64E+03
Mn	11	9	2.30E-01	6.04E+00	1.20E-01	4.44E-03	2.22E-01
Mo	9	9	1.42E+00	6.70E+00	N/A	N/A	N/A
Na	10	10	3.84E+03	4.04E+04	3.57E+01	2.67E-01	2.48E+04
Nd	11	N/A	N/A	N/A	8.40E-03	6.85E-04	<MDC
Ni	11	10	8.00E-01	4.03E+00	1.20E-01	-1.26E-03	1.61E+00
P	3	1	1.04E+01	1.04E+01	6.30E+00	-2.05E+00	<MDC
Pb	10	9	2.56E-01	4.21E+00	1.20E-01	1.41E-04	1.25E+00
Pr	11	1	9.05E-04	9.05E-04	2.30E-03	2.10E-04	<MDC
Sb	10	6	2.41E-02	1.39E-01	1.30E-02	1.15E-02	3.27E-02
Sc	8	7	1.40E+00	6.59E+00	N/A	N/A	N/A
Se	8	6	-4.16E-02	3.53E+00	4.10E+00	1.73E+00	5.30E+00
Si	6	6	7.37E+03	1.81E+04	7.10E+00	-4.69E+00	1.53E+04
Sr	10	10	5.06E+01	5.53E+02	1.30E+00	2.94E-03	5.35E+02
Th	9	3	2.07E-03	1.36E-02	3.20E-03	1.42E-03	<MDC
Tl	10	2	-1.23E-02	4.84E-02	2.50E-03	-4.84E-04	<MDC
U	11	11	1.17E+00	2.38E+00	2.20E-03	1.69E-04	1.77E+00
V	11	11	7.71E+00	3.26E+01	1.20E-01	1.96E-02	2.77E+01
Zn	11	10	1.46E+00	1.25E+01	1.60E+00	-9.85E-04	2.52E+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] Concentrations below the MDC are reported as <MDC;
N/A = Not Applicable

Table 2.12. Measured Concentration of Selected Inorganic Analytes in Hobbs Drinking Water from 1998 - 2011

Hobbs							
1998-2010					**2011**		
EL[1]	**N**[2]	**N_{DET}**[2]	**Min**[3]	**Max**[3]	**MDC**[4] **(µg/L)**	**Blank Conc. (µg/L)**	**Sample Conc. (µg/L)**[5]
Ag	10	2	3.86E-03	1.04E-01	6.20E-03	3.85E-03	<MDC
Al	11	8	3.03E+00	1.14E+02	1.96E+00	2.24E-01	5.48E+00
As	11	10	4.51E+00	7.37E+00	2.60E+00	5.57E-01	8.56E+00
B	3	3	1.41E+02	1.97E+02	N/A	N/A	N/A
Ba	9	9	5.83E+01	6.52E+01	6.40E-02	3.72E-03	6.79E+01
Be	9	1	5.39E-02	5.39E-02	1.00E-01	-2.82E-02	<MDC
Ca	6	6	7.79E+04	9.20E+04	3.17E+03	-3.39E+01	7.63E+04
Cd	9	N/A	N/A	N/A	5.60E-01	-1.82E-01	<MDC
Ce	10	6	5.10E-03	3.56E-02	1.62E-02	7.40E-05	1.68E-02
Co	11	8	9.78E-02	3.61E-01	9.00E-03	-1.99E-04	1.93E-01
Cr	11	10	6.44E-01	1.13E+01	3.20E-01	5.29E-02	1.48E+00
Cu	11	10	1.06E+00	6.93E+00	1.16E+00	5.56E-03	3.05E+00
Dy	11	1	4.18E-03	4.18E-03	3.40E-03	8.35E-04	<MDC
Er	11	N/A	N/A	N/A	6.40E-03	1.63E-04	<MDC
Eu	10	6	1.31E-02	1.97E-02	6.20E-03	9.45E-04	1.68E-02
Fe	7	5	3.64E+01	4.44E+02	2.02E+01	5.19E+00	2.58E+02
Ga	1	1	2.56E+00	2.56E+00	N/A	N/A	N/A
Gd	10	N/A	N/A	N/A	4.80E-03	1.20E-03	<MDC
Hg	2	N/A	N/A	N/A	8.90E-03	1.04E-02	<MDC
K	9	9	2.32E+03	2.52E+04	3.24E+01	1.75E+01	2.11E+03
La	10	5	1.25E-02	5.01E-02	7.80E-03	9.23E-04	<MDC
Li	8	8	2.65E+01	3.18E+01	9.80E-02	3.58E-02	3.21E+01
Mg	8	8	1.92E+04	2.67E+04	7.30E+01	4.93E-02	1.90E+04
Mn	11	10	3.79E-01	3.62E+00	2.40E-01	4.44E-03	1.63E+00
Mo	9	9	2.46E+00	3.31E+00	N/A	N/A	N/A
Na	10	10	4.97E+03	5.80E+04	3.57E+02	2.67E-01	3.98E+04
Nd	11	3	3.01E-03	1.28E-02	1.68E-02	6.85E-04	<MDC
Ni	11	11	1.08E+00	4.78E+00	2.40E-01	-1.26E-03	3.15E+00
P	3	2	2.44E+01	2.53E+01	1.26E+01	-2.05E+00	1.76E+01
Pb	10	8	9.44E-02	1.19E+00	2.40E-01	1.41E-04	7.43E-01
Pr	11	1	1.57E-03	1.57E-03	4.60E-03	2.10E-04	<MDC
Sb	10	6	3.88E-02	7.02E-02	2.60E-02	1.15E-02	7.78E-02
Sc	8	8	3.06E+00	1.05E+01	N/A	N/A	N/A
Se	8	6	-1.70E-01	6.23E+00	8.20E+00	1.73E+00	1.23E+01
Si	6	6	2.41E+04	2.86E+04	1.42E+01	-4.69E+00	2.42E+04
Sr	10	10	7.89E+01	1.06E+03	1.30E+01	2.94E-03	1.10E+03
Th	9	2	2.29E-03	4.56E-03	6.40E-03	1.42E-03	<MDC
Tl	9	3	9.45E-03	2.31E-02	5.00E-03	-4.84E-04	<MDC
U	11	11	2.90E+00	3.98E+00	4.40E-03	1.69E-04	4.30E+00
V	11	11	3.11E+01	3.71E+01	2.40E-01	1.96E-02	3.46E+01
Zn	11	9	8.44E-01	4.37E+00	3.20E+00	-9.85E-04	<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] Concentrations below the MDC are reported as <MDC;
N/A = Not Applicable

Table 2.13. Measured Concentration of Selected Inorganic Analytes in Loving Drinking Water from 1998 - 2011

Loving							
1998-2010					2011		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Ag	11	4	2.55E-03	2.17E-01	3.10E-03	3.85E-03	<MDC
Al	11	6	3.76E+00	3.76E+02	9.80E-01	2.24E-01	1.43E+00
As	11	8	7.82E-01	2.34E+00	1.30E+00	5.57E-01	2.01E+00
B	3	3	7.55E+01	1.12E+02	N/A	N/A	N/A
Ba	9	9	2.86E+01	3.47E+01	3.20E-02	3.72E-03	3.36E+01
Be	9	1	9.35E-02	9.35E-02	5.00E-02	-2.82E-02	<MDC
Ca	6	6	6.71E+04	1.00E+05	3.17E+02	-3.39E+01	7.04E+04
Cd	9	N/A	N/A	N/A	2.80E-01	-1.82E-01	<MDC
Ce	10	3	9.74E-04	2.53E-01	8.10E-03	7.40E-05	<MDC
Co	11	8	1.02E-01	4.04E-01	4.50E-03	-1.99E-04	1.19E-01
Cr	11	9	1.12E+00	7.44E+00	1.60E-01	5.29E-02	2.42E+00
Cu	11	9	1.80E+00	5.59E+00	5.80E-01	5.56E-03	1.20E+00
Dy	11	N/A	N/A	N/A	1.70E-03	8.35E-04	<MDC
Er	11	N/A	N/A	N/A	3.20E-03	1.63E-04	<MDC
Eu	10	6	7.00E-03	1.01E-02	3.10E-03	9.45E-04	9.91E-03
Fe	7	4	3.60E+00	2.57E+02	1.01E+01	5.19E+00	2.18E+02
Ga	1	1	1.26E+00	1.26E+00	N/A	N/A	N/A
Gd	10	2	2.15E-03	1.04E-02	2.40E-03	1.20E-03	<MDC
Hg	2	N/A	N/A	N/A	8.90E-03	1.04E-02	<MDC
K	9	9	1.85E+03	1.98E+04	1.62E+01	1.75E+01	1.69E+03
La	10	4	6.66E-03	2.22E-02	3.90E-03	9.23E-04	<MDC
Li	8	8	1.66E+01	1.96E+01	4.90E-02	3.58E-02	2.03E+01
Mg	8	8	3.05E+04	4.21E+04	7.30E+00	4.93E-02	3.02E+04
Mn	11	8	1.43E-02	1.77E+00	1.20E-01	4.44E-03	<MDC
Mo	9	8	1.28E+00	1.81E+00	N/A	N/A	N/A
Na	10	10	2.33E+03	2.82E+04	3.57E+01	2.67E-01	2.12E+04
Nd	11	1	3.37E-03	3.37E-03	8.40E-03	6.85E-04	<MDC
Ni	11	10	1.19E+00	3.38E+00	1.20E-01	-1.26E-03	2.87E+00
P	3	2	2.53E+01	3.37E+01	6.30E+00	-2.05E+00	2.46E+01
Pb	10	7	1.73E-01	1.67E+00	1.20E-01	1.41E-04	<MDC
Pr	11	N/A	N/A	N/A	2.30E-03	2.10E-04	<MDC
Sb	10	5	3.51E-02	1.84E-01	1.30E-02	1.15E-02	3.78E-02
Sc	8	7	1.91E+00	4.72E+00	N/A	N/A	N/A
Se	8	6	-2.89E+00	1.51E+00	4.10E+00	1.73E+00	<MDC
Si	6	6	8.54E+03	1.09E+04	7.10E+00	-4.69E+00	9.23E+03
Sr	10	10	7.60E+01	9.37E+02	1.30E+00	2.94E-03	7.85E+02
Th	9	2	5.69E-03	7.38E-03	3.20E-03	1.42E-03	<MDC
Tl	10	2	2.24E-03	4.32E-02	2.50E-03	-4.84E-04	<MDC
U	11	11	1.98E+00	2.30E+00	2.20E-03	1.69E-04	2.16E+00
V	11	11	1.11E+01	1.44E+01	1.20E-01	1.96E-02	1.34E+01
Zn	11	10	4.13E+00	2.01E+01	1.60E+00	-9.85E-04	8.60E+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] Concentrations below the MDC are reported as <MDC;
N/A = Not Applicable

Table 2.14. Measured Concentration of Selected Inorganic Analytes in Otis Drinking Water from 1998 - 2011

Otis							
1998-2010					**2011**		
EL[1]	**N[2]**	**N_{DET}[2]**	**Min[3]**	**Max[3]**	**MDC[4] (μg/L)**	**Blank Conc. (μg/L)**	**Sample Conc. (μg/L)[5]**
Ag	9	1	2.63E-02	2.63E-02	1.55E-02	3.85E-03	<MDC
Al	11	3	5.74E+00	1.06E+03	4.90E+00	2.24E-01	<MDC
As	11	8	6.53E-01	5.72E+00	6.50E+00	5.57E-01	<MDC
B	3	3	1.46E+02	2.39E+02	N/A	N/A	N/A
Ba	9	8	1.35E+01	1.75E+01	1.60E-01	3.72E-03	1.75E+01
Be	9	N/A	N/A	N/A	2.50E-01	-2.82E-02	<MDC
Ca	5	5	2.42E+05	3.83E+05	3.17E+03	-3.39E+01	2.43E+05
Cd	9	N/A	N/A	N/A	1.40E+00	-1.82E-01	<MDC
Ce	9	1	2.75E-02	2.75E-02	4.05E-02	7.40E-05	<MDC
Co	11	8	1.31E-01	9.51E-01	2.25E-02	-1.99E-04	4.56E-01
Cr	11	9	8.76E-01	6.67E+00	8.00E-01	5.29E-02	2.34E+00
Cu	11	9	2.43E+00	6.02E+00	2.90E+00	5.56E-03	4.37E+00
Dy	10	1	3.39E-03	3.39E-03	8.50E-03	8.35E-04	<MDC
Er	10	N/A	N/A	N/A	1.60E-02	1.63E-04	<MDC
Eu	9	3	3.42E-03	9.48E-03	1.55E-02	9.45E-04	<MDC
Fe	7	6	2.87E+00	1.02E+03	5.05E+01	5.19E+00	8.34E+02
Ga	1	1	6.54E-01	6.54E-01	N/A	N/A	N/A
Gd	9	N/A	N/A	N/A	1.20E-02	1.20E-03	<MDC
Hg	2	N/A	N/A	N/A	8.90E-03	1.04E-02	<MDC
K	9	9	2.74E+03	4.01E+03	8.10E+01	1.75E+01	2.85E+03
La	9	2	3.36E-03	6.30E-03	1.95E-02	9.23E-04	<MDC
Li	7	7	3.74E+01	6.79E+01	2.45E-01	3.58E-02	4.41E+01
Mg	8	8	5.16E+04	1.08E+05	7.30E+01	4.93E-02	8.10E+04
Mn	11	5	1.78E-01	2.32E+00	6.00E-01	4.44E-03	<MDC
Mo	9	8	2.25E+00	3.13E+00	N/A	N/A	N/A
Na	10	10	1.16E+03	1.97E+05	3.57E+02	2.67E-01	1.14E+05
Nd	10	3	4.80E-03	3.97E-02	4.20E-02	6.85E-04	<MDC
Ni	11	9	2.45E+00	1.11E+01	6.00E-01	-1.26E-03	1.03E+01
P	3	3	4.54E+01	1.32E+02	3.15E+01	-2.05E+00	8.64E+01
Pb	9	5	1.08E-01	5.04E-01	6.00E-01	1.41E-04	<MDC
Pr	10	N/A	N/A	N/A	1.15E-02	2.10E-04	<MDC
Sb	9	5	3.50E-02	4.10E-01	6.50E-02	1.15E-02	9.83E-02
Sc	8	6	2.57E+00	5.35E+00	N/A	N/A	N/A
Se	8	6	-2.43E-02	1.19E+00	2.05E+01	1.73E+00	<MDC
Si	6	6	9.83E+03	1.39E+04	3.55E+01	-4.69E+00	9.30E+03
Sr	10	10	3.31E+01	4.62E+03	1.30E+01	2.94E-03	3.60E+03
Th	8	2	1.19E-03	2.67E-02	1.60E-02	1.42E-03	<MDC
Tl	9	1	-6.30E-03	-6.30E-03	1.25E-02	-4.84E-04	<MDC
U	10	10	3.73E+00	5.88E+00	1.10E-02	1.69E-04	5.07E+00
V	11	10	1.05E+01	1.29E+01	6.00E-01	1.96E-02	1.10E+01
Zn	11	8	1.54E+00	1.64E+01	8.00E+00	-9.85E-04	9.15E+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] Concentrations below the MDC are reported as <MDC;
N/A = Not Applicable

Table 2.15. Measured Concentration of Selected Inorganic Analytes in Malaga Drinking Water from 1998 - 2011

Malaga							
1998-2010					2011		
EL[1]	N[2]	N_{DET}[2]	Min[3]	Max[3]	MDC[4] (µg/L)	Blank Conc. (µg/L)	Sample Conc. (µg/L)[5]
Ag	N/A	N/A	N/A	N/A	1.55E-02	3.85E-03	<MDC
Al	N/A	N/A	N/A	N/A	4.90E+00	2.24E-01	<MDC
As	N/A	N/A	N/A	N/A	6.50E+00	5.57E-01	<MDC
B	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ba	N/A	N/A	N/A	N/A	1.60E-01	3.72E-03	1.66E+01
Be	N/A	N/A	N/A	N/A	2.50E-01	-2.82E-02	<MDC
Ca	N/A	N/A	N/A	N/A	3.17E+03	-3.39E+01	2.41E+05
Cd	N/A	N/A	N/A	N/A	1.40E+00	-1.82E-01	<MDC
Ce	N/A	N/A	N/A	N/A	4.05E-02	7.40E-05	<MDC
Co	N/A	N/A	N/A	N/A	2.25E-02	-1.99E-04	8.57E-01
Cr	N/A	N/A	N/A	N/A	8.00E-01	5.29E-02	1.95E+00
Cu	N/A	N/A	N/A	N/A	2.90E+00	5.56E-03	3.66E+00
Dy	N/A	N/A	N/A	N/A	8.50E-03	8.35E-04	<MDC
Er	N/A	N/A	N/A	N/A	1.60E-02	1.63E-04	<MDC
Eu	N/A	N/A	N/A	N/A	1.55E-02	9.45E-04	<MDC
Fe	N/A	N/A	N/A	N/A	5.05E+01	5.19E+00	8.94E+02
Ga	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Gd	N/A	N/A	N/A	N/A	1.20E-02	1.20E-03	<MDC
Hg	N/A	N/A	N/A	N/A	8.90E-03	1.04E-02	<MDC
K	N/A	N/A	N/A	N/A	8.10E+01	1.75E+01	2.57E+03
La	N/A	N/A	N/A	N/A	1.95E-02	9.23E-04	<MDC
Li	N/A	N/A	N/A	N/A	2.45E-01	3.58E-02	4.39E+01
Mg	N/A	N/A	N/A	N/A	7.30E+01	4.93E-02	6.98E+04
Mn	N/A	N/A	N/A	N/A	6.00E-01	4.44E-03	<MDC
Mo	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Na	N/A	N/A	N/A	N/A	3.57E+02	2.67E-01	7.53E+04
Nd	N/A	N/A	N/A	N/A	4.20E-02	6.85E-04	<MDC
Ni	N/A	N/A	N/A	N/A	6.00E-01	-1.26E-03	1.04E+01
P	N/A	N/A	N/A	N/A	3.15E+01	-2.05E+00	5.64E+01
Pb	N/A	N/A	N/A	N/A	6.00E-01	1.41E-04	<MDC
Pr	N/A	N/A	N/A	N/A	1.15E-02	2.10E-04	<MDC
Sb	N/A	N/A	N/A	N/A	6.50E-02	1.15E-02	<MDC
Sc	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Se	N/A	N/A	N/A	N/A	2.05E+01	1.73E+00	<MDC
Si	N/A	N/A	N/A	N/A	3.55E+01	-4.69E+00	9.12E+03
Sr	N/A	N/A	N/A	N/A	1.30E+01	2.94E-03	3.80E+03
Th	N/A	N/A	N/A	N/A	1.60E-02	1.42E-03	<MDC
Tl	N/A	N/A	N/A	N/A	1.25E-02	-4.84E-04	<MDC
U	N/A	N/A	N/A	N/A	1.10E-02	1.69E-04	5.38E+00
V	N/A	N/A	N/A	N/A	6.00E-01	1.96E-02	8.70E+00
Zn	N/A	N/A	N/A	N/A	8.00E+00	-9.85E-04	1.52E+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] Concentrations below the MDC are reported as <MDC;
N/A = Not Applicable

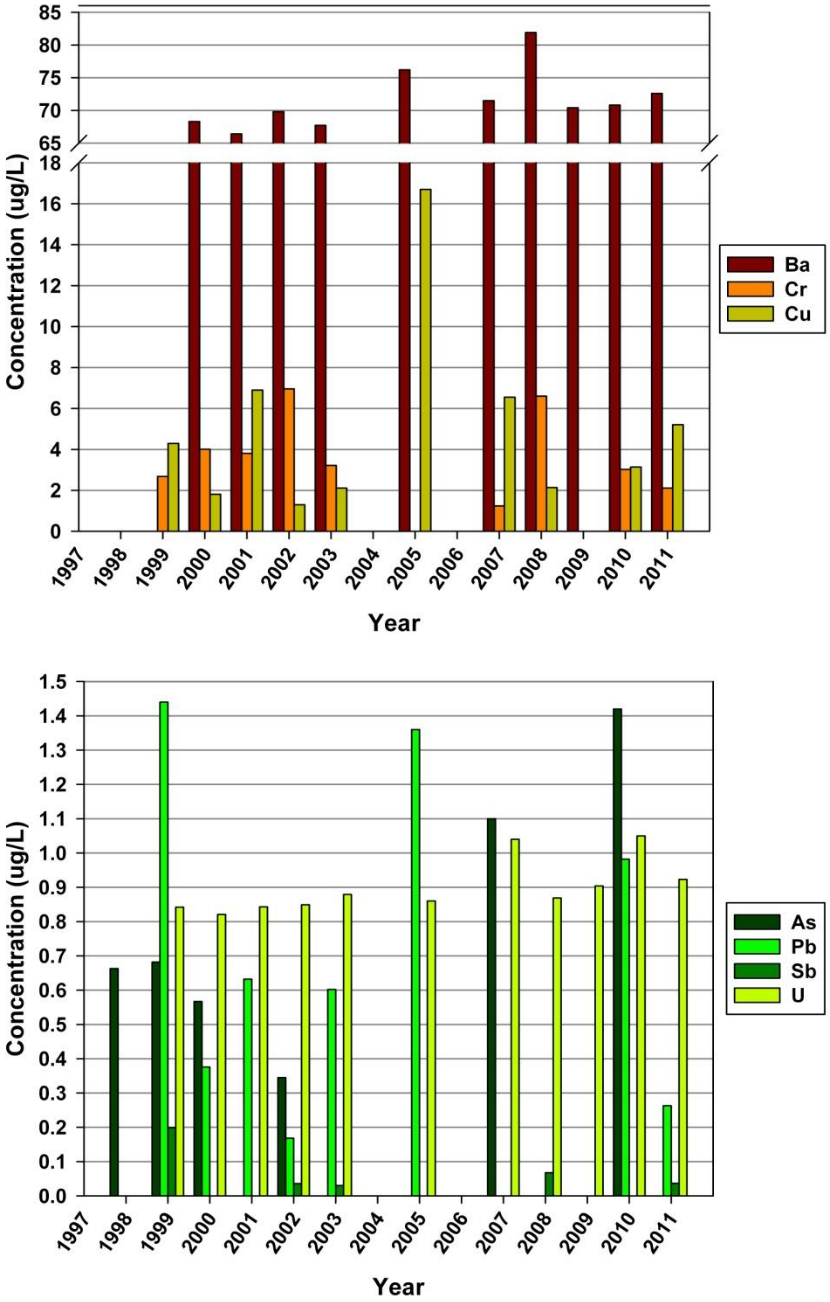

Figure 2.12. Concentrations (µg/L) of Select Inorganic Analytes Measured in Carlsbad Drinking Water from 1998 - 2011

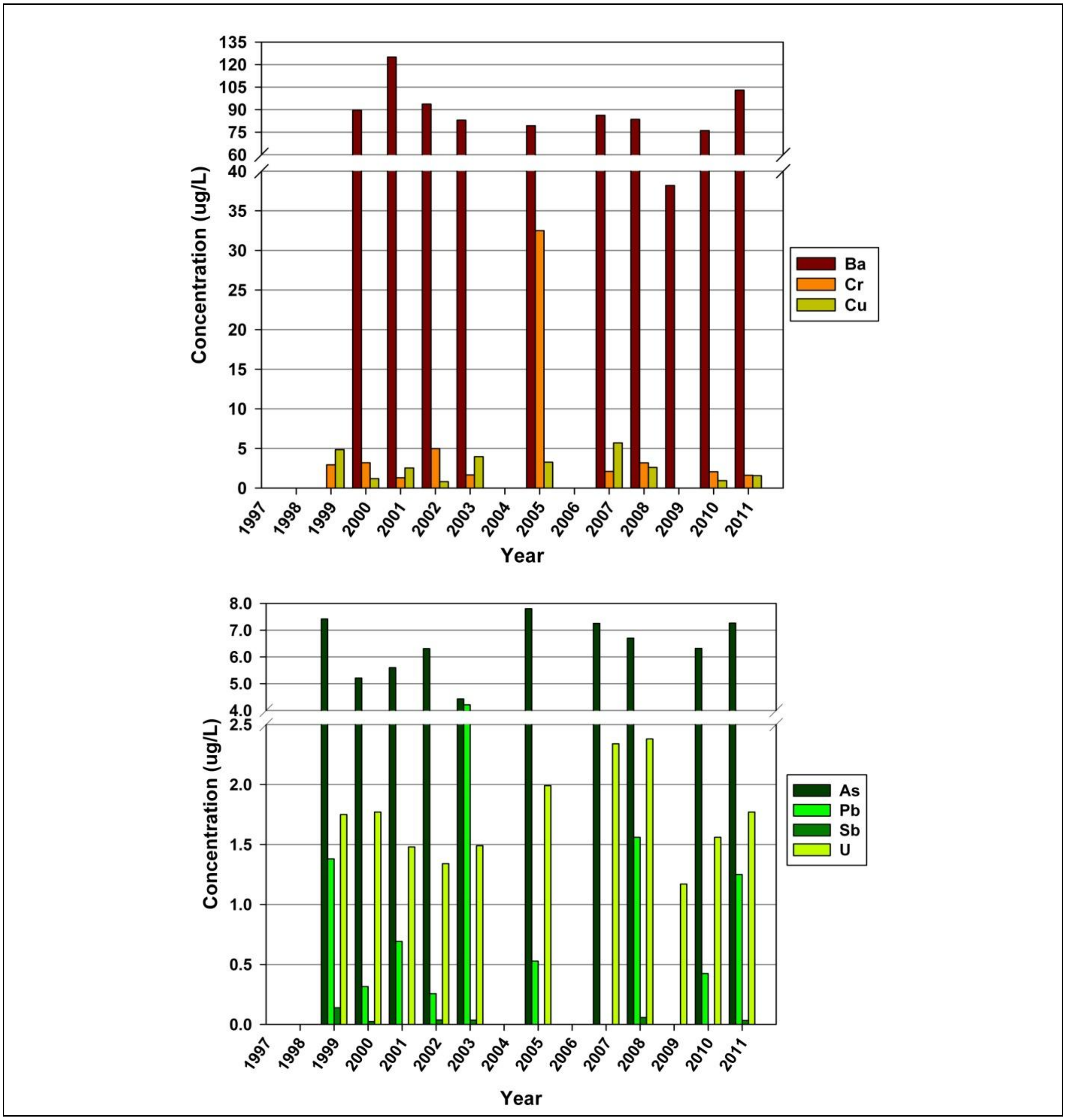

Figure 2.13. Concentrations (µg/L) of Select Inorganic Analytes Measured Near the WIPP site (Double Eagle) from 1998 - 2011

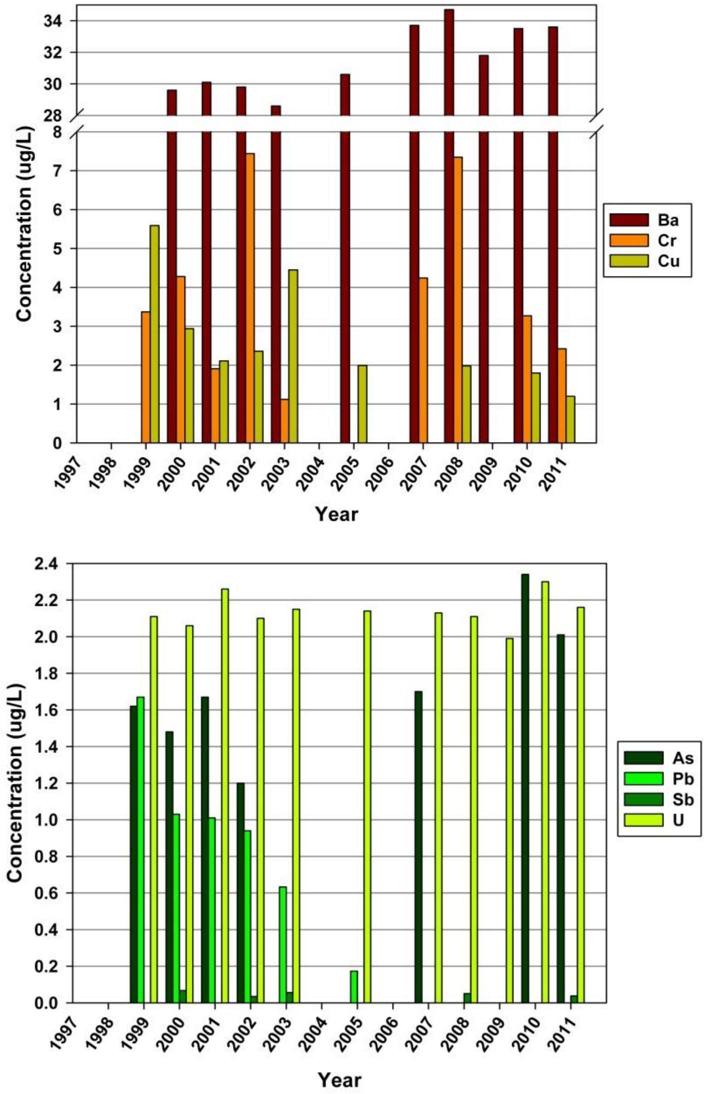

Figure 2.14. Concentrations (µg/L) of Select Inorganic Analytes Measured in Loving Drinking Water from 1998 - 2011

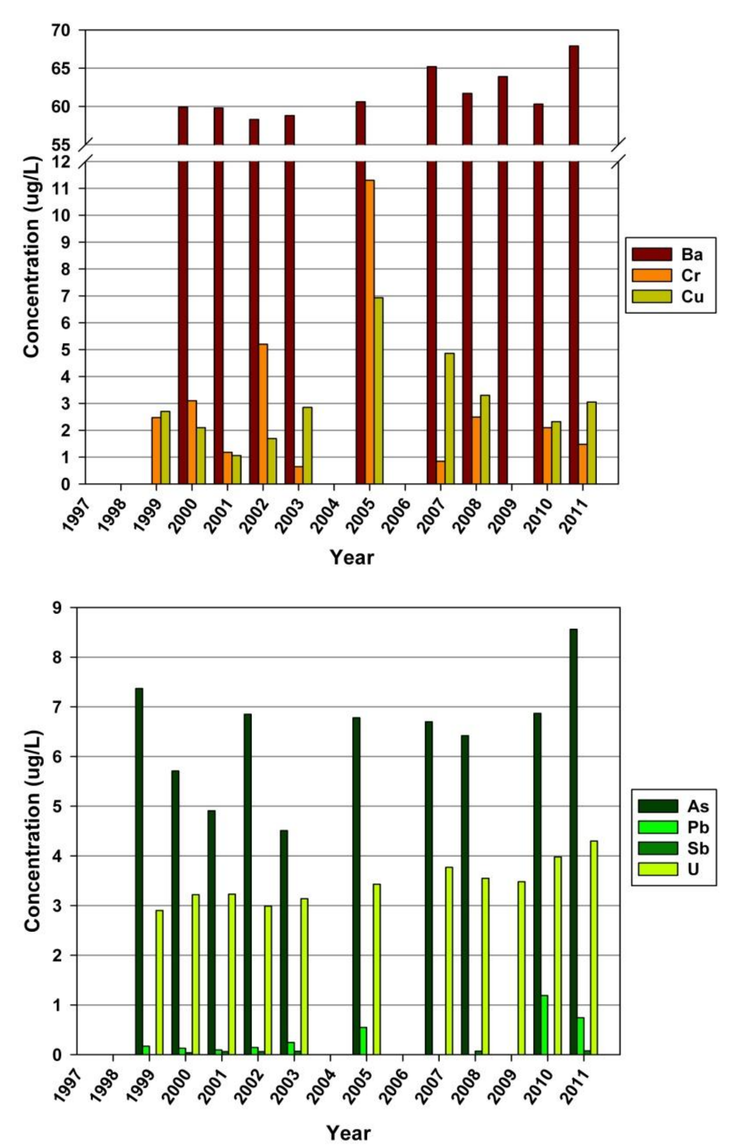

Figure 2.15. Concentrations (µg/L) of Select Inorganic Analytes Measured in Hobbs Drinking Water from 1998 - 2011

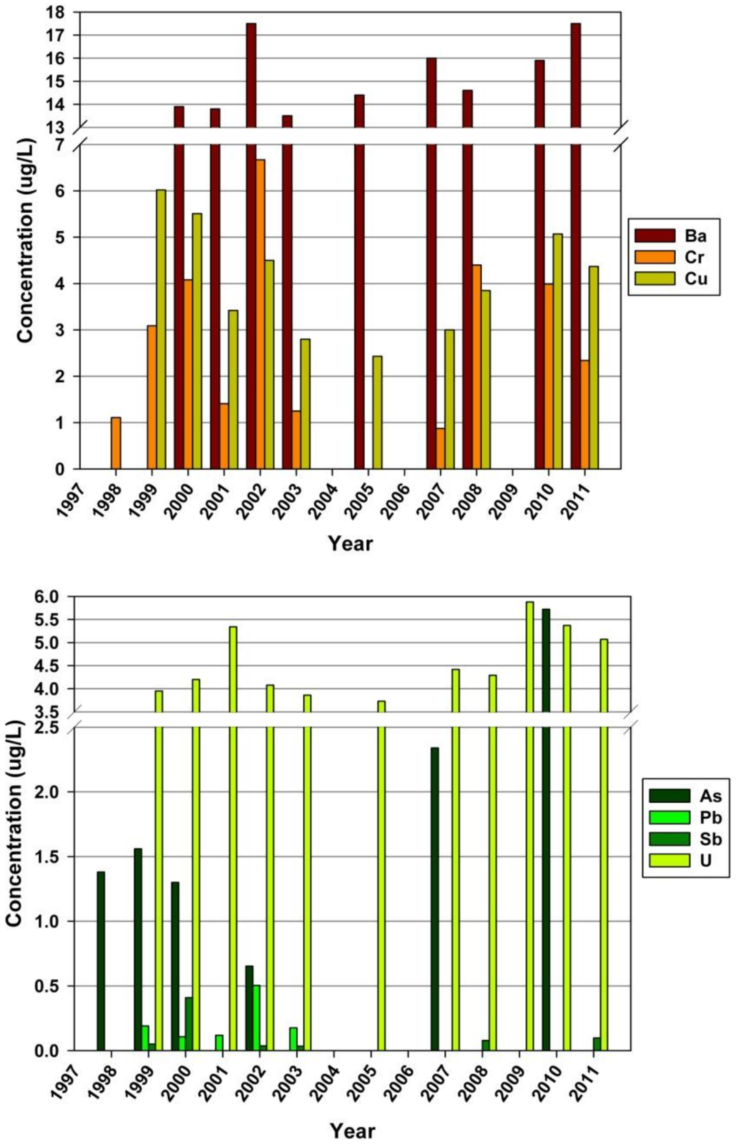

Figure 2.16. Concentrations (µg/L) of Select Inorganic Analytes Measured in Otis Drinking Water from 1998 - 2011

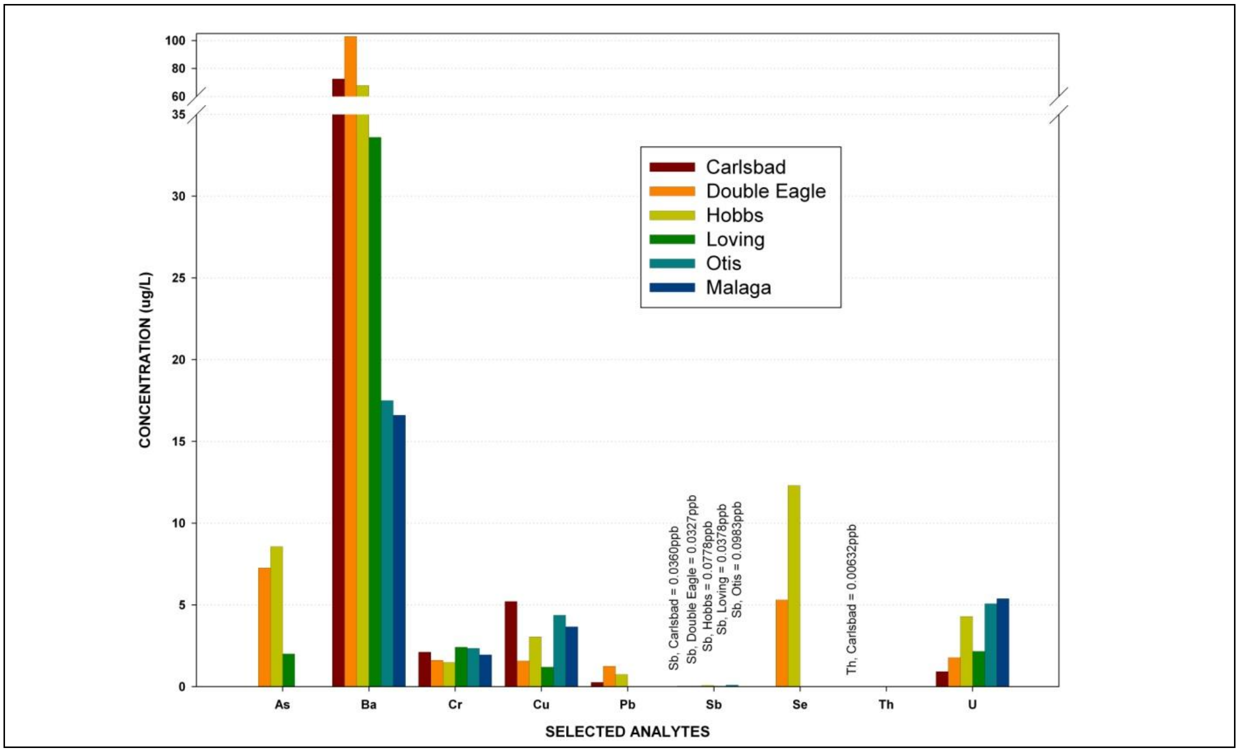

Figure 2.17. Select Analytes with Measured Concentrations >MDC in 2011 Drinking Water

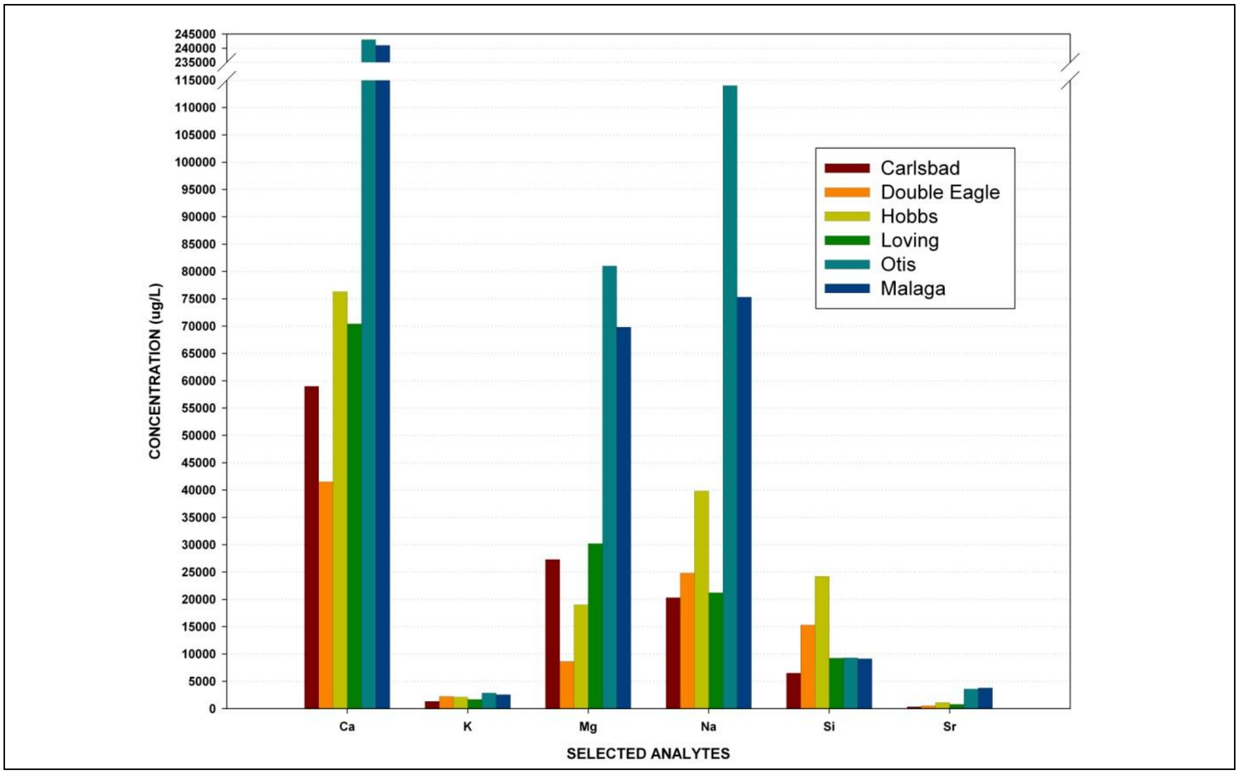

Figure 2.18. Concentrations of Common Salts in 2011 Drinking Water

CHAPTER 3

Whole Body and Lung *In Vivo* Measurement of Occurrence of Radionuclides in Residents of Carlsbad, New Mexico, and the Surrounding Area

Introduction

Citizen volunteers from the Carlsbad, New Mexico and the surrounding 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 within a 100-mile radius 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, 2011) 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 Carlsbad Environmental Monitoring and Research Center (CEMRC) 1998 Report. In addition, the status of the project and results are available on the CEMRC website (www.cemrc.org).

The CEMRC LDBC program is accredited through the Department of Energy Laboratory Accreditation Program (DOELAP) which maintains the competency of dosimetry measurement laboratories through performance evaluation test measurements, calibration inter-comparisons, and site assessments, to assure that the performance of personnel performing dosimetry and radiobioassay measurements meet the standards of Title 10, Code of Federal Regulations, Part 835, “Occupational Radiation Protection,” and related requirements and guidance. The CEMRC Internal Dosimetry (ID) lung and whole body counting laboratory has been DOELAP accredited since 1999.

Bioassay Results

As of December 31, 2011, 986 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 “operational phase” 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 environmental monitoring program. Figure 3.1 shows the number of male, female and total voluntary participants counted, by year, during the period 7/21/1997 to 12/31/2011.

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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.

While not part of the LDBC program, CEMRC has also performed over 3,495 counts on radiation-trained workers in the region including WIPP; Waste Control Specialists (WCS) of Andrews, Texas; and the Nuclear Enrichment Facility (NEF) of Eunice, New Mexico.

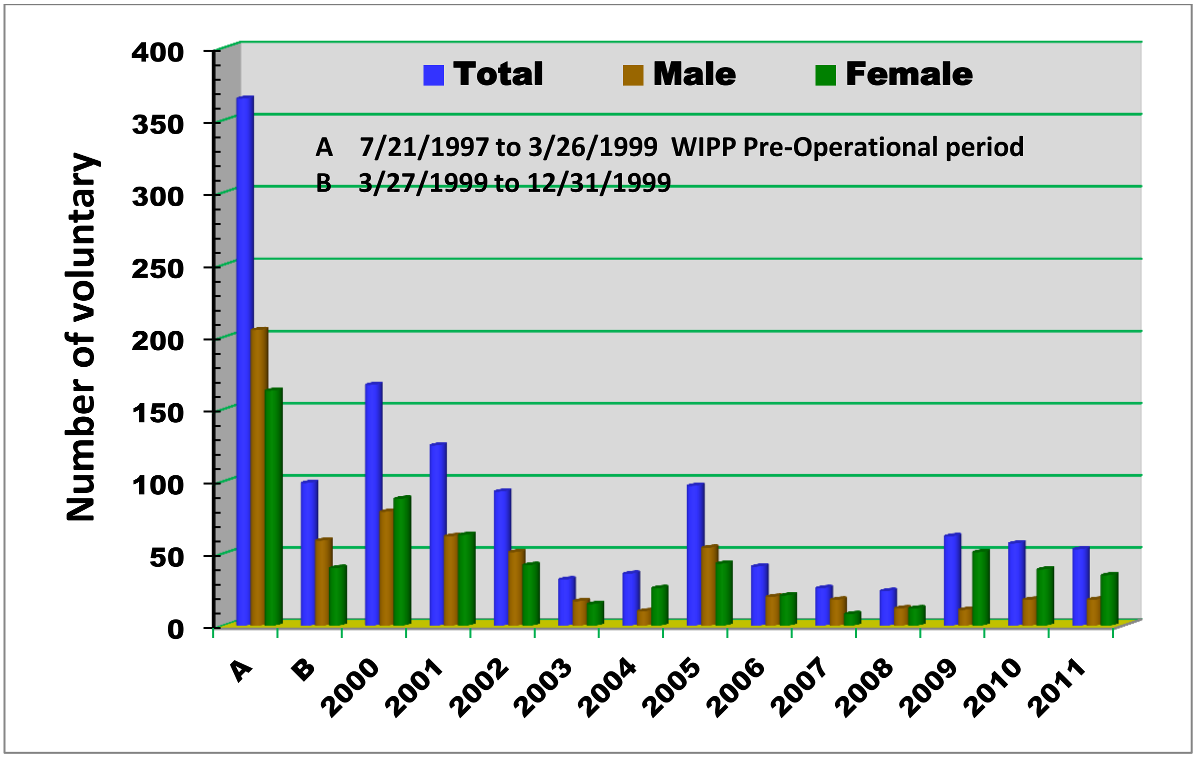

Figure 3.1. Number of LDBC voluntary participants (total and by gender) counted during the period 1997 – 2011

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 2010 census for citizens living in Carlsbad. The largest deviation between the LDBC cohort and 2010 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**.

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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.

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 years 2009/2010, 2010/2011 and 2011/2012, which coincide with the current DOELAP three-year accreditation period. 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 shielded 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 = 912), 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.

^{40}K results were positive for all participants through December 2011 and ranged from 925 to 5559 Bq per person with an overall average (± Std. Err.) of 2481 (± 23) Bq per person. Such results are expected since K is an essential biological element contained primarily in muscle. ^{40}K, the radioactive isotope, is the theoretical constant fraction of all naturally occurring K. ^{40}K average value (± Std. Err.), was 3065 (± 27) Bq per person for males, which was significantly greater ($p < 0.0001$) than that of females, which was 1902 (± 18) Bq per person. This result was expected since; in general, males tend to have larger body sizes and greater muscle content than females.

Detectable ^{137}Cs is present in 22 % (20.8% to 23.1% with 95% confidence level for baseline and operational monitoring counts through December 2011) of citizens living in the Carlsbad area. These results are in the same range with findings previously reported in CEMRC reports and elsewhere (Webb and Kirchner, 2000). Detectable ^{137}Cs body burdens ranged from 4.9 to 77.5 Bq per person with an overall average (± Std. Err.) of 10.2 (± 0.3) Bq per person. The average ^{137}Cs body burden (± Std. Err.), was 11.0 (± 0.7) Bq for males per person, which was greater ($p = 0.002$) than that of females, which was 8.7 (± 0.3) Bq per person. Reports such as CEMRC Reports; Webb and Kirchner, 2000; provide initial correlation studies of detectable ^{137}Cs with parameters like age, ethnicity, European travel, gender, consumption of wild game, nuclear medical treatments, radiation work history, and smoking. A follow-up analysis of 15 years of data is in progress to determine if any relationships between any of these factors are related to higher activities of ^{137}Cs.

^{40}K and ^{137}Cs results of LDBC voluntary participants through December 2011 are shown in figures 3.2 – 3.5.

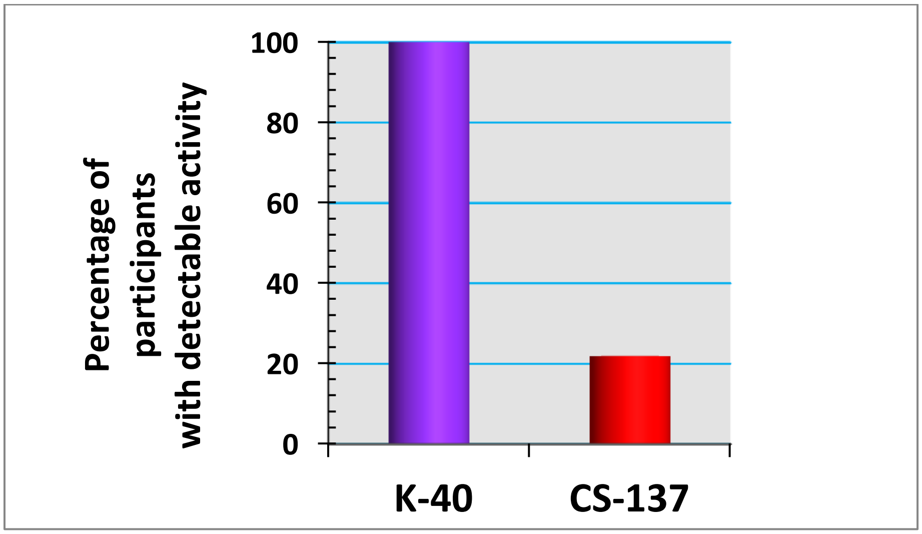


Figure 3.2. Percentage of voluntary participants with detectable ^{40}K and ^{137}Cs activities through December 2011

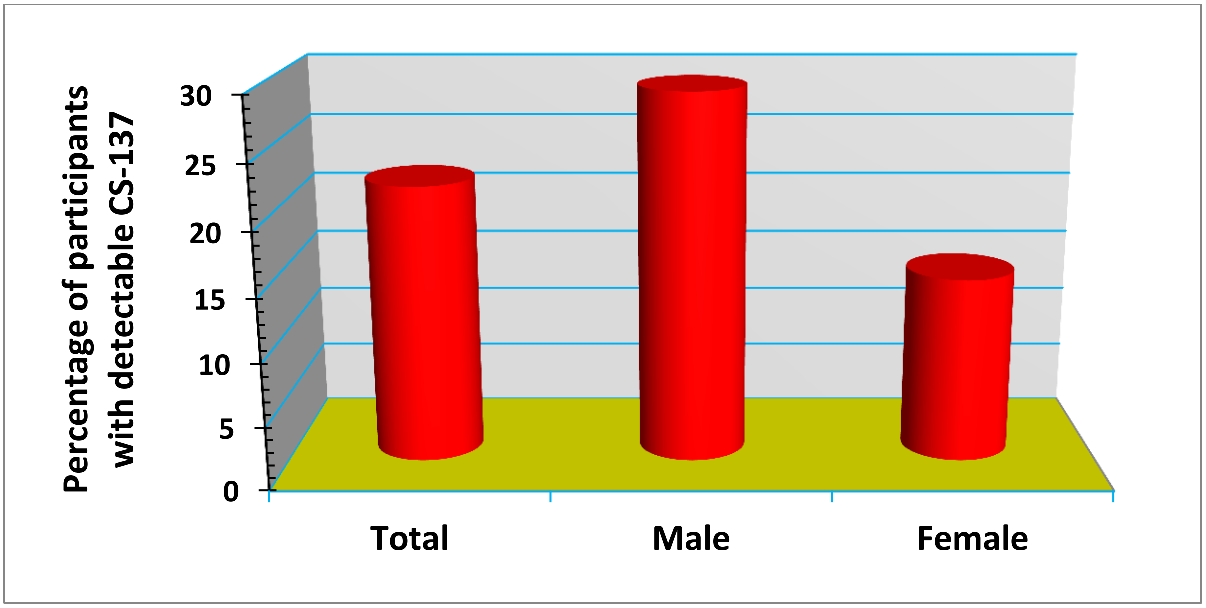


Figure 3.3. Percentage of voluntary participants with detectable ^{137}Cs activity through December 2011 (This figure displays the total percentage of participants with ^{137}Cs activity and the percentage of participants with ^{137}Cs activity by gender).

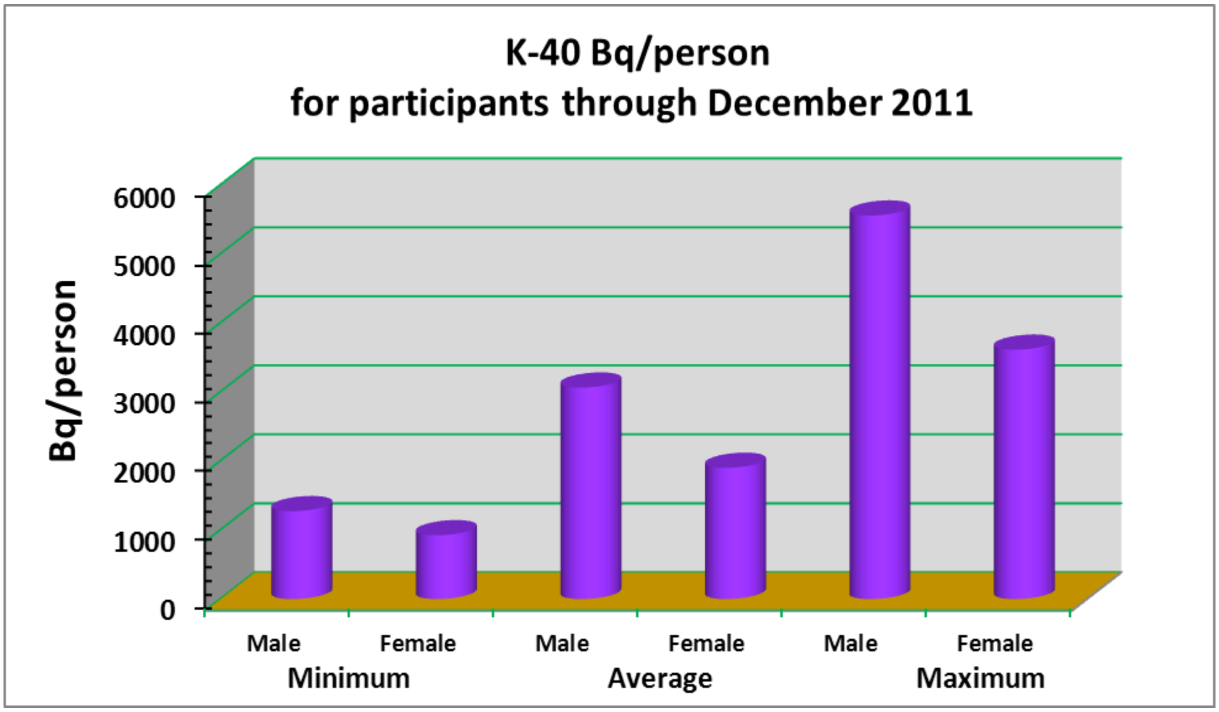


Figure 3.4. Minimum, average, and maximum ^{40}K activity for participants, separated by gender, through December 2011

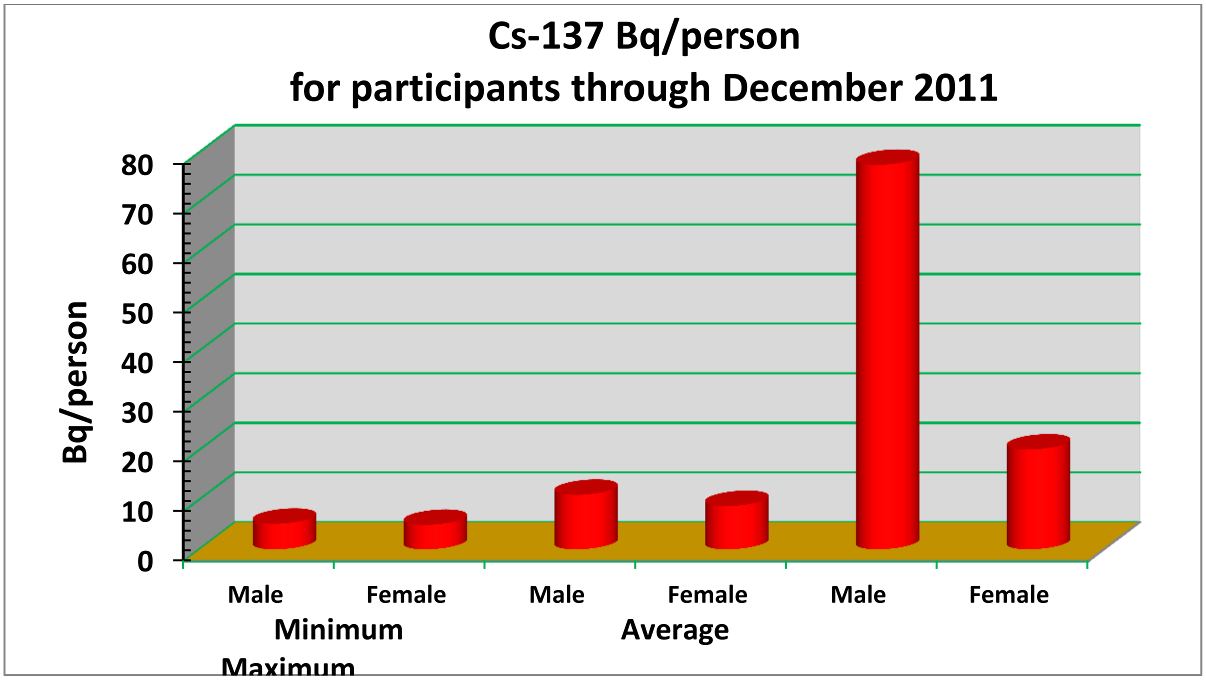


Figure 3.5. Minimum, average, and maximum ^{137}Cs activity for participants, separated by gender, through December 2011

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. This shows the necessity of further research and procedural set up to enhance the detection capability.

These results, particularly with no significant variation in the percentage of public participants with detectable levels of plutonium, suggest that there have been no observable effects from WIPP.

Table 3.1. Demographic Characteristics of the "Lie Down and Be Counted" Population Sample through December 31, 2011

Characteristic		2011 Sample Group[a] (margin of error)	[b]Census, 2010 New Mexico	[c]Census, 2010 US
Gender	Male	46.5% (44.9 to 48.0%)	49.4%	49.1%
	Female	53.5% (52.0 to 55.1%)	50.6 %	50.9%
Ethnicity	Latino	20.2% (18.9 to 21.4%)	46.3 %	16.3 %
	Non-Latino	79.8% (78.6 to 81.1%)	53.7 %	83.7%
Age 65 years or over		26.1% (24.7 to 27.4%)	19.6 %	13.0%
Currently or previously classified as a radiation worker		7.6% (6.8 to 8.4%)	[d]NA	[d]NA
Consumption of wild game within 3 months prior to count		20.7% (19.4 to 22.0%)	NA	NA
Medical treatment other than X-rays using radionuclides		7.5% (6.7 to 8.3%)	NA	NA
European travel within 2 years prior to the count		4.2% (3.6 to 4.8%)	NA	NA
Current smoker		15.8% (14.7 to 16.9%)	NA	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://2010.census.gov/2010census/popmap/ipmtext.php?fl=35 US Census 2010, New Mexico State.

[c] http://www.census.gov/prod/cen2010/briefs/c2010br-03.pdf US Census 2010, US.

[d] NA = not available.

Table 3.2. Minimum Detectable Activities

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 3-2. Minimum Detectable Activities (continued)

2011-2012 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	0.22	0.30	0.34	0.46	0.64	0.89
Ce-144	133.50	0.49	0.57	0.72	0.79	1.02	1.34	1.76
Cf-252	19.20	19.09	34.70	84.51	121.18	315.90	891.15	2454.73
Cm-244	18.10	17.16	35.01	93.70	139.72	402.23	1264.15	3875.50
Eu-155	105.30	0.26	0.33	0.43	0.48	0.63	0.85	1.15
Np-237	86.50	0.45	0.59	0.78	0.87	1.16	1.60	2.19
Pu-238	17.10	17.52	41.27	121.80	190.25	611.99	2179.54	7529.31
Pu-239	17.10	43.60	102.69	303.04	473.35	1522.65	5422.77	18733.21
Pu-240	17.10	17.13	40.34	119.05	185.96	598.18	2130.37	7359.48
Pu-242	17.10	20.66	48.67	143.62	224.33	721.62	2569.98	8878.10
Ra-226	186.10	1.81	1.94	2.40	2.61	3.26	4.16	5.28
Th-232 via Pb-212	238.60	0.15	0.17	0.21	0.23	0.29	0.37	0.48
Th-232	59.00	31.88	41.97	55.90	62.88	85.81	120.21	166.78
Th-232 via Th-228	84.30	4.43	5.87	7.67	8.61	11.57	15.92	21.77
U-233	440.30	0.65	0.76	0.92	0.99	1.23	1.53	1.91
U-235	185.70	0.11	0.12	0.15	0.16	0.20	0.26	0.33
Nat U via Th-234	63.30	1.49	1.99	2.65	2.97	4.04	5.64	7.80

Radionuclides Deposited in the Whole Body

Radionuclide	Energy (keV)	MDA (nCi)
Ba-133	356	0.80
Ba-140	537	1.55
Ce-141	145	1.70
Co-58	811	0.37
Co-60	1333	0.36
Cr-51	320	4.61
Cs-134	604	0.36
Cs-137	662	0.43
Eu-152	344	1.66
Eu-154	1275	0.97
Eu-155	105	3.84
Fe-59	1099	0.68
I-131	365	0.49
I-133	530	0.43
Ir-192	317	0.56
Mn-54	835	0.46
Ru-103	497	0.41
Ru-106	622	3.36
Sb-125	428	1.38
Th-232 via Ac-228	911	1.29
Y-88	898	0.38
Zn-65	1116	1.13
Zr-95	757	0.60

Table 3.3. "Lie Down and Be Counted" Results through December 31, 2011

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 2011) N = 912**
		% of Results ≥ [b]L_C	**% of Results ≥ L_C**
^{241}Am	Lung	5.2 (4.0 to 6.4)	4.4 (3.7 to 5.1)
^{144}Ce	Lung	4.6 (3.5 to 5.7)	4.0 (3.3 to 4.6)
^{252}Cf	Lung	4.1 (3.1 to 5.1)	5.8 (5.1 to 6.6)
^{244}Cm	Lung	5.7 (4.5 to 7.0)	5.0 (4.2 to 5.7)
^{155}Eu	Lung	7.1 (5.8 to 8.4)	5.2 (4.5 to 5.9)
^{237}Np	Lung	3.6 (2.6 to 4.5)	3.7 (3.1 to 4.4)
^{210}Pb	Lung	4.4 (3.3 to 5.4)	6.4 (5.6 to 7.2)
Plutonium Isotope	Lung	5.7 (4.5 to 7.0)	5.5 (4.8 to 6.2)
[d] ^{232}Th via ^{212}Pb	Lung	34.2 (31.7 to 36.6)	32.2 (30.7 to 33.7)
^{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)	5.3 (4.6 to 6)
^{233}U	Lung	5.7 (4.5 to 7.0)	8.9 (8 to 9.8)
^{235}U/^{226}Ra	Lung	10.7 (9.0 to 12.3)	11.9 (10.8 to 12.9)
Natural Uranium via ^{234}Th	Lung	5.2 (4.0 to 6.4)	6.2 (5.4 to 6.9)
^{133}Ba	Whole Body	3.6 (2.6 to 4.5)	3.0 (2.4 to 3.5)
^{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)	4.8 (4.1 to 5.5)
^{58}Co	Whole Body	4.4 (3.3 to 5.4)	2.9 (2.3 to 3.4)
[d] ^{60}Co	Whole Body	54.6 (52.0 to 57.2)	25.7 (24.3 to 27.1)
^{51}Cr	Whole Body	5.7 (4.5 to 7.0)	4.0 (3.3 to 4.6)
^{134}Cs	Whole Body	1.6 (1.0 to 2.3)	2.6 (2.1 to 3.2)
^{137}Cs	Whole Body	28.4 (26.1 to 30.8)	19.3 (18.0 to 20.6)
^{152}Eu	Whole Body	7.4 (6.0 to 8.7)	6.3 (5.5 to 7.1)
^{154}Eu	Whole Body	3.8 (2.8 to 4.8)	3.1 (2.5 to 3.6)
^{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)	5.9 (5.2 to 6.7)
^{131}I	Whole Body	5.2 (4.0 to 6.4)	4.3 (3.6 to 5)
^{133}I	Whole Body	3.3 (2.3 to 4.2)	4.0 (3.3 to 4.6)
^{192}Ir	Whole Body	4.1 (3.1 to 5.1)	4.1 (3.4 to 4.7)
^{40}K	Whole Body	100.0 (100.0 to 100.0)	100.0 (100.0 to 100.0)
[d] ^{54}Mn	Whole Body	12.3 (10.6 to 14.0)	12.3 (11.3 to 13.4)
^{103}Ru	Whole Body	2.2 (1.4 to 3.0)	1.8 (1.3 to 2.2)
^{106}Ru	Whole Body	4.4 (3.3 to 5.4)	4.3 (3.6 to 5.0)
^{125}Sb	Whole Body	5.2 (4.0 to 6.4)	4.4 (3.7 to 5.1)
^{232}Th via ^{228}Ac	Whole Body	34.7 (32.2 to 37.2)	25.9 (24.5 to 27.4)
^{88}Y	Whole Body	7.7 (6.3 to 9.0)	6.2 (5.4 to 7)
^{95}Zr	Whole Body	6.6 (5.3 to 7.9)	3.9 (3.2 to 4.5)

[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, Hydrogen and Methane

Introduction

The WIPP Hazardous Waste Facility Permit, issued by the New Mexico Environment Department (NMED) under the Resource Conservation and Recovery Act (RCRA), mandates the monitoring of nine volatile organic compounds (VOCs) in ambient air in the WIPP underground to assure that their respective concentrations of concern are not exceeded. Additional compounds consistently detected in ambient air samples in the underground may be added to the list of compounds of interest. The current lists of compounds of interest and additional requested compounds are presented in Tables 4.2 and 4.3 respectively.

VOC 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). Under this plan, Washington Regulatory and Environmental Services (WRES) personnel collect ambient air samples in six liter passivated canisters and deliver for analysis to CEMRC in weekly batches.

CEMRC first began analysis of samples for the Confirmatory VOCs Monitoring Plan in April 2004. The program was established and successfully audited by the WTS quality assurance (QA) group prior to acceptance of actual samples and has since been audited at yearly intervals. Initially, 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). Later, CEMRC purchased an Entech 7100 Preconcentrator for use as the sample concentration and introduction system, and 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 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 in order to prepare for the analysis of headspace gas (HSG) samples collected from waste drums required under the WIPP Permit. 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 purchased 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 project in July 2005, it was decided 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 allowed 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 program 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, 2008, 2009, and 2010, CEMRC analyzed a total of 749, 608, 571, and 711 samples for VOCs and 182, 254, 339, and 441 samples, respectively, for hydrogen and methane. In 2011, CEMRC analyzed a total of 615 samples for VOCs and 398 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 at low 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 transferring the sample through three consecutive cryogenic traps at different controlled temperatures. This results in very low detection limits unattainable without cryogenic preconcentration.

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

For 2011, 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 4.1 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 required sampling from closed rooms within the current panel until the entire panel is full. Therefore, the WIPP Hazardous Waste Facility permit now refers to both Repository VOCs Monitoring and Disposal Room Monitoring.

Table 4.2 summarizes the nine permit-specified target compounds and their required reporting limits for different types of samples. In early 2011, nine other compounds were requested to be included in the list of target analytes as “Additional Requested Analytes”. ‘m-Xylene’ & ‘p-Xylene’ co-elute together as a single compound so they are reported as ‘p,m-Xylene’. Table 4.3 lists the additional analytes and their required reporting limits.

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 GC/MS. The sampling system incorporates three autosamplers in series to allow for the analysis of two complete batches of six 6L samples per run. Samples from the autosamplers pass through heated transfer lines into two injection loops attached to an automated valve for simultaneous injection into the GC. The VOC screening results are used to determine pre-analysis dilutions required for analysis by Method TO-15. The hydrogen and methane analysis results are reported in separate data packages from the VOCs results.

Laboratory Precision

Laboratory Control Sample (LCS) and LCS-Duplicate are analyzed at a rate of once per batch, or once each ten samples, whichever is applicable, to verify instrument calibration and quantitative analytical accuracy. LCS is a standard that contains 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 LCS % recovery must be within ± 40% for all target and additional requested compounds. The relative percentage deviation (RPD) must be 25% or less for all target and additional requested compounds. The Laboratory achieved the precision limit for all the target compounds. Figures 4.1-4.4 show an example of laboratory precision through LCS % recovery and RPD for one of the target VOC analytes (Carbon Tetrachloride) and Hydrogen.

Results and Discussion

The OC lab analyzed a total of 1,013 samples in 2011. All of the samples were analyzed and reported in a timely manner under an extensive quality assurance (QA) / quality control (QC) program. The 1,013 samples consisted of 615 samples for VOCs measurement (571 routine air samples, 44 blank and recovery gas samples) and 398 samples for hydrogen and methane analysis. All of these samples achieved more than 99% completeness. Blank and recovery gas samples were collected by Shaw Environmental and were part of the sampler cleaning and certification program. The blank and recovery samples were analyzed in expedited turnaround batches (7 calendar days) at various times throughout the years.

In addition, 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 were submitted in hardcopy in the EPA Contract Laboratory Program format. An electronic report in the client’s specified format was also provided for each batch. Hardcopy and electronic reports for hydrogen and methane analyses were submitted in the formats specified by the client. Lastly, copies of batch reports and all QA records associated with these analyses were 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 in this report. However, 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. As a result, the 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 and is seeking additional contracts to fully utilize the lab’s capabilities.

Table 4.1. CEMRC Procedures for Confirmatory Volatile Organic Compounds Monitoring Program

Procedure Number	Procedure Title
OC-PLAN-001	Quality Assurance Project Plan for Analysis of Volatile Organic Compounds and/or Hydrogen and Methane in Canister Samples
OC-PROC-002	Preparation of Canisters and Sample Trains for Ambient Air Sampling
OC-PROC-003	Gas Chromatography-Mass Spectrometry Analysis of Vol Organic Compounds (VOCs) in Ambient Air from Caniste PPBV Concentration Levels
OC-PROC-004	Preparation of Calibration Standards in Specially Prepared Canisters for Analysis by Gas Chromatography/Mass Spectrometry
OC-PROC-005	Data Validation and Reporting of Volatile Organic Compounds from Gas Chromatography/Mass Spectrometry Analysis of Ambient Air in Canisters for the WIPP Volatile Organic Compound Monitoring Plan
OC-PROC-006	Receipt, Control, and Storage of Gas Samples in Passivated Canisters
OC-PROC-009	Analysis of Hydrogen and Methane in Passivated Canisters Using Gas Chromatography with Thermal Conductivity Detection

Table 4.2. 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 4.3. Additional Requested Compounds for WIPP Confirmatory Volatile Organic Compounds Monitoring Program

Compound	Repository Sample Reporting Limit (ppbv)	Closed Room Sample Reporting Limit (ppbv)
Benzene	2	500
Trichloroethylene	2	500
Tetrachloroethylene	5	500
Chloromethane	2	500
trans-1,2-Dichloroethylene	2	500
1,2,4-Trimethylbenzene	2	500
p,m-Xylene	5	500
Trichloromonofluoromethane	2	500

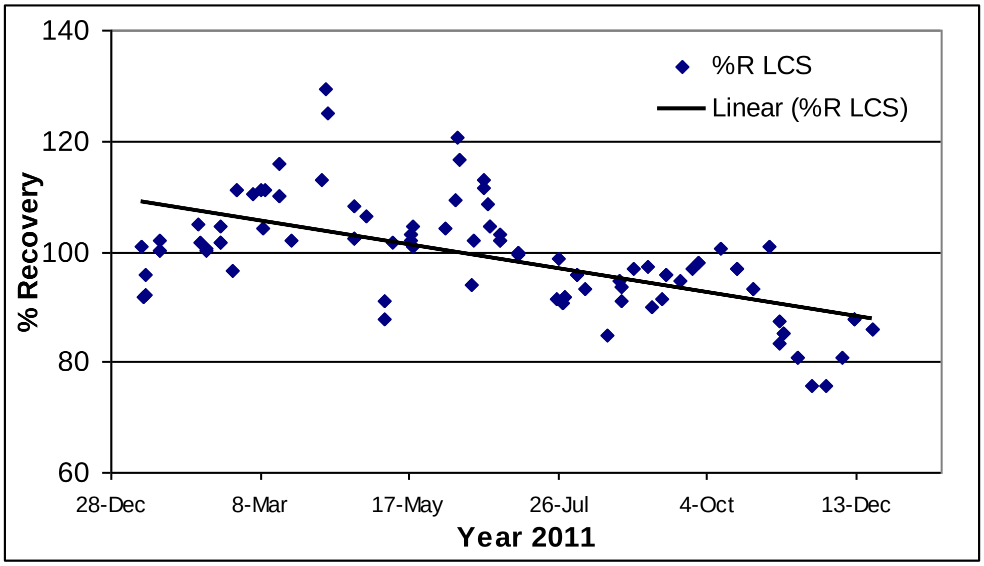


Figure 4.1. Percent Recovery of Carbon Tetrachloride in LCS (Recovery range: 60-140%)

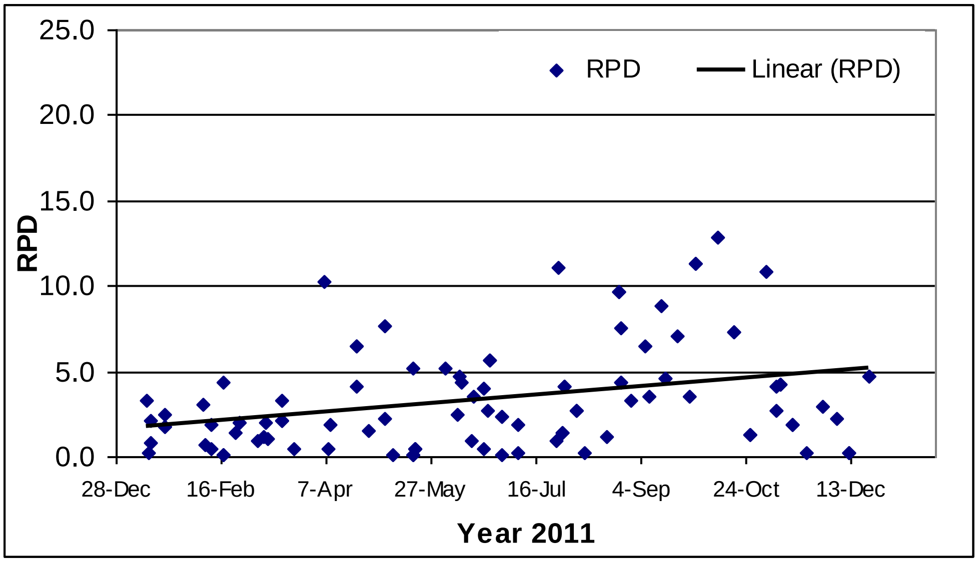


Figure 4.2. Relative Percent Deviation (RPD) between LCS and LCS-Duplicate for Carbon Tetrachloride (RPD range: 25%)

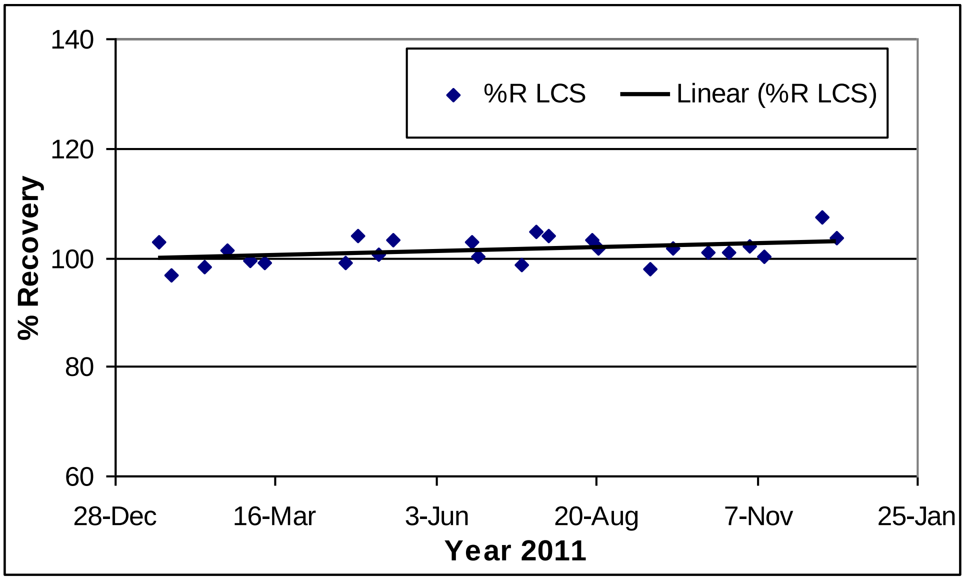


Figure 4.3. Percent Recovery of Hydrogen in LCS (Recovery range: 60-140%)

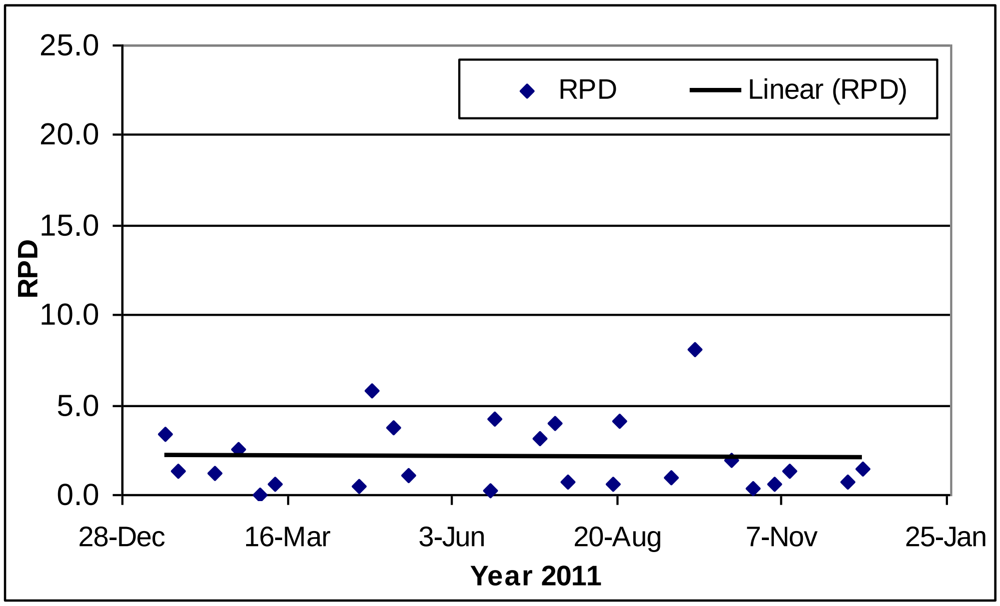


Figure 4.4. Relative Percent Deviation (RPD) between LCS and LCS-Duplicate for Hydrogen (RPD range: 25%)

CHAPTER 5

Ambient Aerosol Studies for the WIPP-EM

Introduction

The CEMRC ambient aerosol monitoring studies focus on both man-made and naturally-occurring radionuclides, with special emphasis given to plutonium (Pu) and americium (Am) as isotopes of these elements are the major radioactive constituents in the TRU waste stored at the WIPP. In fact, the vast majority of radionuclides within TRU waste are ^{239}Pu, ^{240}Pu and ^{241}Am, which account for more than 99% of the total radioactivity for most of the 10,000-year regulatory period. In this context, the variation in concentrations of these two radionuclides in the WIPP environment is important not only because they are the main component of the WIPP wastes, but also because of their global background activity. Atmospheric nuclear tests have been the major source of radiological contamination to date in the global 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 (UNSCEAR 2000).

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. Summaries of the WIPP-EM aerosol studies have been included in prior CEMRC Annual Reports since 1997, and two articles specifically based on the WIPP-EM aerosol research program have been published in peer-reviewed journals (Arimoto et al. 2002 and 2005).

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 (UNSCEAR, 2000). At present, almost all plutonium being introduced into the atmosphere can be found in the surface soil. As a result, plutonium can migrate vertically at various rates depending on meteorological conditions, physiochemical properties of soil, and human activity. It can also be taken up by plants or be re-suspended into the air with eroded soil particles. The importance of resuspension in recycling radionuclides from the soil back into the atmosphere has been pointed out in many publications (Rosner et al., 1997; Pavlotskaya et al., 1994; Arimoto et al., 2005; Sehmel, 1987).

Additionally, in the Carlsbad area, where WIPP is located, there is a potential local source of anthropogenic radioactivity from an underground nuclear test conducted during the Plowshare project. One particular test occurred in 1961 at the Gnome site, about 8.8 km southwest of the WIPP site, when an underground test of a 3.3-kiloton ^{239}Pu device vented radioactive materials to the surface (USAEC, 1973). Clean-up efforts at this site have been carried out in several campaigns since that time, and the surface contamination is now well below any risk-based action levels. However, ^{137}Cs and plutonium have been detected in some samples of surface soils at the Gnome site (Kenney 1995). 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. Consequently, it is very important to understand factors controlling the distribution of contaminants in the WIPP area.

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 of this report.

METHODS

Ambient Air Sampling Stations

Ambient aerosols are collected using high volume samplers, commonly referred to as “hivols,”, which have a flow rate of ~1.13 $m^3\ min^{-1}$ and are located at three (3) sites in and around the WIPP facility. 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. One particular site, the cactus flats station, was used as a reference location because it represents a reasonable compromise based on these considerations. The locations of the three (3) air sampling stations are depicted in Figure 5.1. The high volume sampler utilized for ambient aerosol monitoring, filter holder and the type of filter used to collect total suspended particles (TSP) are shown in Figures 5.2 and 5.3.

The three (3) hivol stations are designated as follows:

- **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.

Sampling Background

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 previous CEMRC reports starting in 1998. 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 the PM_{10} samplers was based on the overall objective of the WIPP-EM program, 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 a site in Hobbs over a period of approximately a year and a half, but the sampling there was discontinued in April 2002 since 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.

In addition, operational aspects of the ambient aerosol component of the WIPP-EM program have changed since the 2003 Annual Report with Whatman 41 sampling beginning on 1/4/2007. These 8 inch by 10 inch filters are being used on Hi-Q Hi-Vol HVP-4300AFC samplers. These samplers are located at sites 107 (Near Field) and 108 (Cactus Flats) 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.

Prior to 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. However, the WIPP-EM program underwent a major restructuring in FY 2002 and afterwards, sampling for the non-radiological aerosol analytes was done using dichots exclusively. Further, in November 2004, the collection of aerosols by dichots was discontinued.

Sample Preparation

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 hours of heating in a muffle furnace at 500° C to drive 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 each filter is digested with a strong acid mixture of $HCl+HF+HClO_4$. Subsequently, the actinides are separated as a group by co-precipitation on $Fe(OH)_3$. Pu isotopes are separated and purified using a two -column anion exchange resin (AG1-X8, Bio-Rad, 100-200 mesh), while TRU chromatography columns are used for the separation of Am. The samples are then micro-co-precipitated using a Nd-carrier, 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. Additionally, a known amount of tracer (^{242}Pu, ^{243}Am or ^{232}U) is added to determine the actinide recovery in each sample. Typical chemical recoveries are in the range of “40-80%” for Pu and of “90-105%” for Am. For counting times of 72,000 min, the detection limits of $^{239+240}$Pu, ^{238}Pu and ^{241}Am are $2.6x10^{-9}$, $3.9x10^{-9}$ and $3.1x10^{-9}$ Bq/m^3, respectively.

Data Reporting

The activities of the actinides in the air samples are reported as *activity concentration* (Bq/m^3) and *activity density* (Bq/g). *Activity concentration* is calculated as the activity of radionuclides detected in bequerels (Bq) divided by the volume of air in cubic meters, while *activity density* is calculated as the nuclides activity divided by the aerosol mass in grams collected on the filter.

RESULTS AND DISCUSSION

Average air concentrations of actinides in the aerosol samples during the period from 1998 to 2011 are summarized in Table 5.2. The average air concentrations of actinides after WIPP became operational are not statistically different than those measured prior to waste disposal operations. 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 (station 108) in 1999 and 2000, at On Site (station 106) in 2004, and at Near field (station 107) in 2008 exhibited slightly higher $^{239+240}$Pu activity concentrations as well as densities (Figure 5.4 and 5.5) than surrounding data points. The observed seasonality in Pu activity concentration is attributed to the resuspension of contaminated soil dust plus the local precipitation to some extent. Studies conducted prior to the end of the atmospheric weapons testing showed that Pu activities varied seasonally, being highest in spring and summer because of the springtime enhanced transportation of radioactive aerosols from the stratosphere to troposphere. However, with the cessation of nuclear weapons tests and considering the fact that the residence time of Pu in the atmosphere is on the order of a year, the stratospheric deposition of radionuclides, including Pu, is no longer a dominant factor for the Pu concentration in air. Additionally, the Chernobyl nuclear power plant accident that occurred in April 1986 did not bring significant amounts of Pu to this area. Therefore, resuspension is assumed to be the main source of Pu in the aerosol samples around the WIPP.

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 2011.

A time series plot for ^{241}Am activity concentrations and densities are presented in (Figure 5.6 and 5.7). The activity concentrations of ^{241}Am in the high-volume samples closely tracked those of $^{239+240}$Pu. As a result, a strong correlation exists between ^{241}Am and $^{239+240}$Pu activity concentrations (R^2 = 0.69, 0.71 and 0.69, 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 5.8 - 5.10).

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 satellites such as SNAP-9A (Hardy, 1973)

The average activity concentration (activity per unit volume air sampled) for $^{239+240}$Pu ranges from 5.5-18.3 nBq/m^3 at On Site, 4.9-19.4 nBq/m^3 at Near Field, 2.3-20.3 nBq/m^3 at Cactus Flat. For ^{241}Am the average activity concentrations ranged from 1.9-5.4 nBq/m^3 for On Site station, 1.4-5.2 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 (5.11-5.13). In 2011, 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 0.26-0.41 mBq/g at On Site, 0.26-0.77 mBq/g at Near Field, 0.23-0.59 mBq/g at Cactus Flats (Figures 5.14-5.16) while that of ^{241}Am ranged from 0.08-0.16 mBq/g for On Site, 0.06-0.23 mBq/g for Near Field and 0.10-0.38 mBq/g for Cactus Flats.

The plutonium activity concentration and density are usually higher in Cactus Flats samples with the activity following the order: Cactus Flat>Near Field>On Site. In contrast to actinide data, the aerosol mass loadings follows the trend: On Site (37.3±17.0 μg/m^3)> Cactus Flat (29.2±14.3 μg/m^3) > Near Field (27.1±12.3 μg/m^3). As a result, the aerosol mass loadings at On Site were generally the highest of the three stations with comparable data sets (Table 5.2 and Figure 5.17). 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 the Cactus Flats or Near Field stations (Table 5.2). The combination of $^{239+240}$Pu and gravimetric 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 generated by construction dust or the mining of salt from underground operations.

The concentrations of $^{239+240}$Pu, ^{238}Pu, ^{241}Am, ^{137}Cs, ^{134}Cs, ^{60}Co and ^{40}K measured in ambient aerosol samples collected during 2011 are presented in Figures 5.18 - 5.24. The minimum, maximum, and average concentrations of radionuclides for all sampling locations combined are reported in Tables 5.3, 5.4 and 5.5. As can be seen in the tables, ^{238}Pu, $^{239+240}$Pu, and ^{241}Am were detected in some samples. Additionally, 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. However, there was no significant difference in the concentrations of ^{40}K among locations. Lastly, ^{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. The detections of ^{137}Cs and ^{134}Cs in the samples collected during March -April, 2011 are attributed to the Fukushima Nuclear accident in Japan and not from the WIPP related operations. For more information on the Fukushima accident, see chapter 7 of this report.

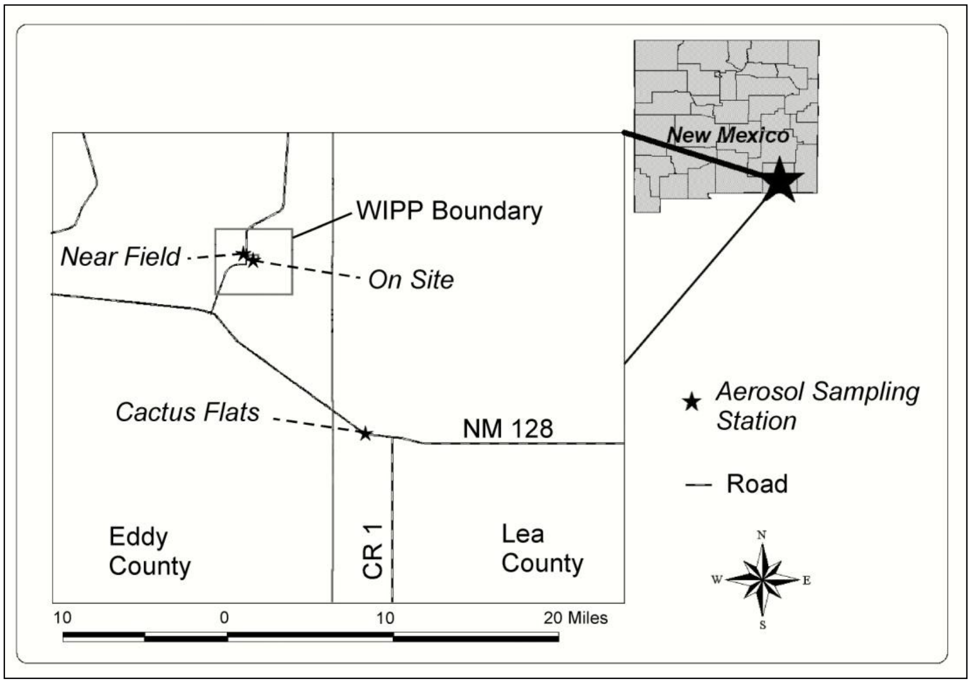


Figure 5.1. WIPP-EM Ambient Aerosol Sampling Locations

Figure 5.2. High Volume Air sampler for TSP Monitoring around the WIPP Site

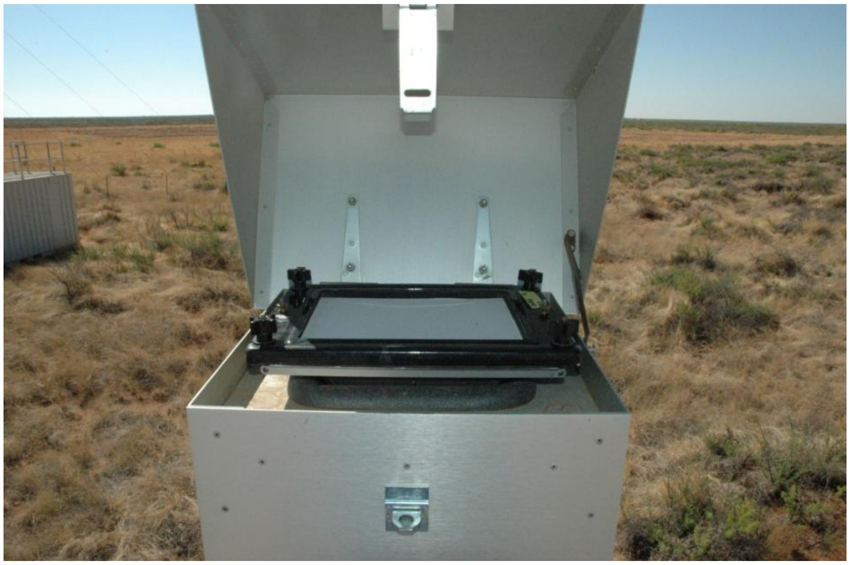


Figure 5.3. Aerosol Sampling Filter Holder
Filter Type Used: 8×10 inches Glass Fiber

Table 5.1. Aerosol Sampling Status for the WIPP-EM

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

[a] Sampler types are as follows: PM_{10}-Shrouded Probe = particles greater than 10 µm diameter (50% cut-size) TSP-HI VOL = High Volume Total Suspended Particles.

[b] Samples are changed when the flow drops to 90% of original for the 2-stage pumps.

[c] TSP-HI VOL Whatman 41 Filters are collected at Cactus Flats and Near Field.

Table 5.2. Summary Statistics for Aerosol Mass Loadings and Actinide Activities in High Volume Aerosol Samples Around WIPP Site

Station		Cactus Flats	Near Field	On Site
Type of Sample		**TSP**	**TSP**	**TSP**
Number of Samples		130	132	132
Aerosol Mass, micrograms per cubic meter	N	130	132	132
	Mean	29.18	27.13	37.26
	StdDev	14.29	12.26	17.04
^{241}Am Activity Concentration, Bq/m^3	N	56	54	60
	Mean	6.33E-09	4.94E-09	1.26E-07
	StdDev	5.22E-09	3.91E-09	9.43E-07
^{241}Am Activity Density, Bq/g	N	56	54	60
	Mean	2.55E-04	1.88E-04	5.40E-03
	StdDev	2.41E-04	1.10E-04	4.10E-02
^{134}Cs Activity Concentration, Bq/m^3	N	2	3	0
	Mean	8.73E-06	1.12E-05	9.26E-06
	StdDev	4.75E-05	5.96E-05	4.72E-05
^{134}Cs Activity Density, Bq/g	N	2	3	0
	Mean	2.64E-01	3.28E-01	2.21E-01
	StdDev	1.49E+00	1.79E+00	1.16E+00
^{137}Cs Activity Concentration, Bq/m^3	N	3	3	1
	Mean	1.28E-05	1.48E-05	2.08E-05
	StdDev	5.19E-05	6.58E-05	6.32E-05
^{137}Cs Activity Density, Bq/g	N	3	3	1
	Mean	3.75E-01	4.27E-01	4.99E-01
	StdDev	1.64E+00	1.98E+00	1.55E+00
^{60}Co Activity Concentration, Bq/m^3	[a]N	0	0	0
	Mean	N/A	N/A	1.48E-06
	StdDev	N/A	N/A	8.72E-06
^{60}Co Activity Density, Bq/g	N	0	0	0
	Mean	N/A	N/A	4.94E-02
	StdDev	N/A	N/A	2.66E-01
^{40}K Activity Concentration, Bq/m^3	N	0	0	0
	Mean	N/A	1.21E-05	3.18E-06
	StdDev	N/A	1.51E-05	1.42E-05
^{40}K Activity Density, Bq/g	N	0	0	0
	Mean	N/A	3.42E-01	9.64E-02
	StdDev	N/A	4.23E-01	3.58E-01
^{238}Pu Activity Concentration, Bq/m^3	N	9	2	10
	Mean	6.13E-09	2.42E-09	2.98E-09
	StdDev	1.14E-08	2.14E-09	1.47E-09
^{238}Pu Activity Density, Bq/g	N	9	3	10
	Mean	2.69E-04	9.15E-05	8.24E-05
	StdDev	5.45E-04	9.35E-05	3.30E-05

Table 5.2. Summary Statistics for Aerosol Mass Loadings and Actinide Activities in High Volume Aerosol Samples Around WIPP Site (continued)

Station		**Cactus Flats**	**Near Field**	**On Site**
Type of Sample		**TSP**	**TSP**	**TSP**
Number of Samples		130	132	132
$^{239+240}$Pu Activity Concentration, Bq/m^3	N	91	109	106
	Mean	1.61E-08	1.39E-08	1.36E-08
	StdDev	1.31E-08	9.88E-09	8.81E-09
$^{239+240}$Pu Activity Density, Bq/g	N	91	110	108
	Mean	5.35E-04	5.18E-04	3.63E-04
	StdDev	2.15E-04	2.37E-04	1.90E-04
^{234}U Activity Concentration, Bq/m^3	N	31	31	29
	Mean	2.78E-06	2.89E-06	3.04E-06
	StdDev	1.16E-06	1.37E-06	1.38E-06
^{234}U Activity Density, Bq/g	N	31	31	29
	Mean	7.87E-02	8.07E-02	6.63E-02
	StdDev	2.34E-02	2.39E-02	2.21E-02
^{235}U Activity Concentration, Bq/m^3	N	31	31	29
	Mean	1.53E-07	1.83E-07	1.67E-07
	StdDev	8.17E-08	1.78E-07	8.47E-08
^{235}U Activity Density, Bq/g	N	31	31	29
	Mean	4.20E-03	4.82E-03	3.66E-03
	StdDev	1.41E-03	3.77E-03	1.56E-03
^{238}U Activity Concentration, Bq/m^3	N	31	31	29
	Mean	2.68E-06	2.78E-06	2.98E-06
	StdDev	1.13E-06	1.31E-06	1.30E-06
^{238}U Activity Density, Bq/g	N	31	31	29
	Mean	7.59E-02	7.77E-02	6.50E-02
	StdDev	2.16E-02	2.30E-02	2.07E-02

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

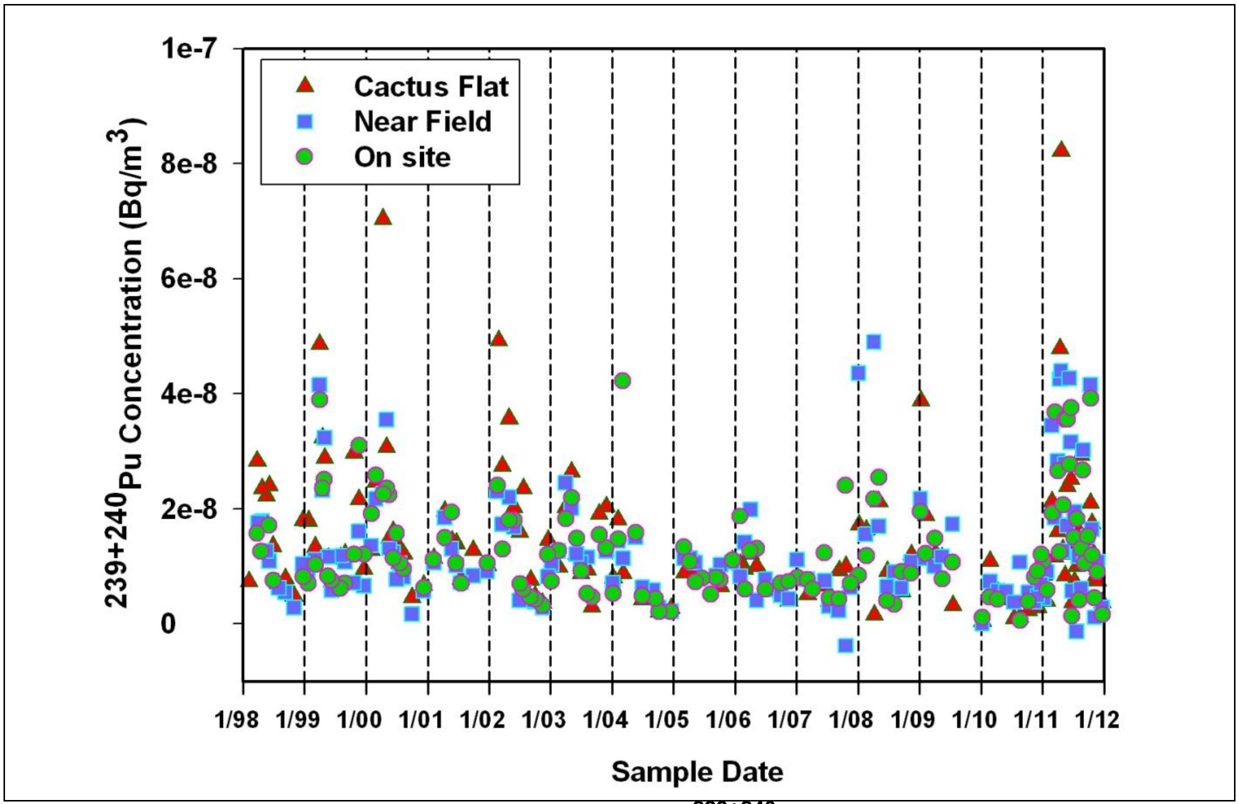


Figure 5.4. High Volume Ambient Aerosol $^{239+240}$Pu Activity Concentrations

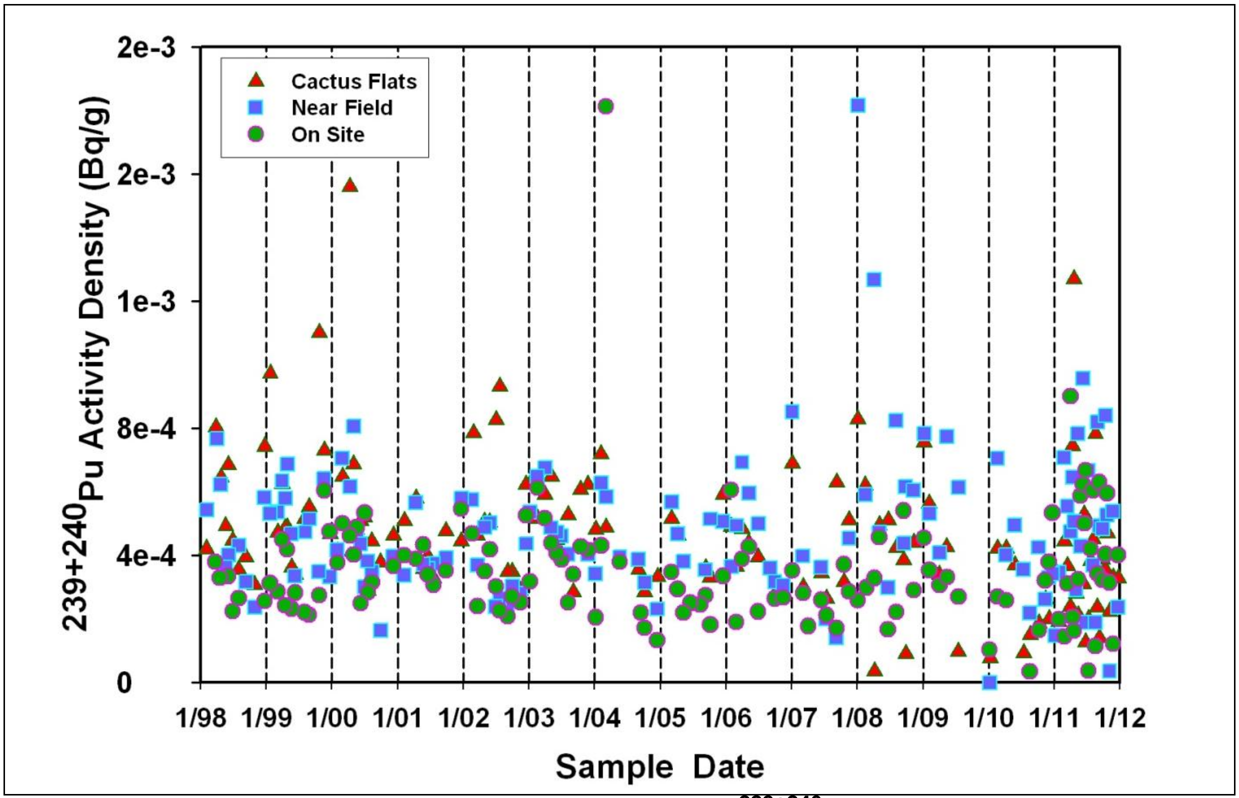


Figure 5.5. High Volume Ambient Aerosol $^{239+240}$Pu Activity Densities

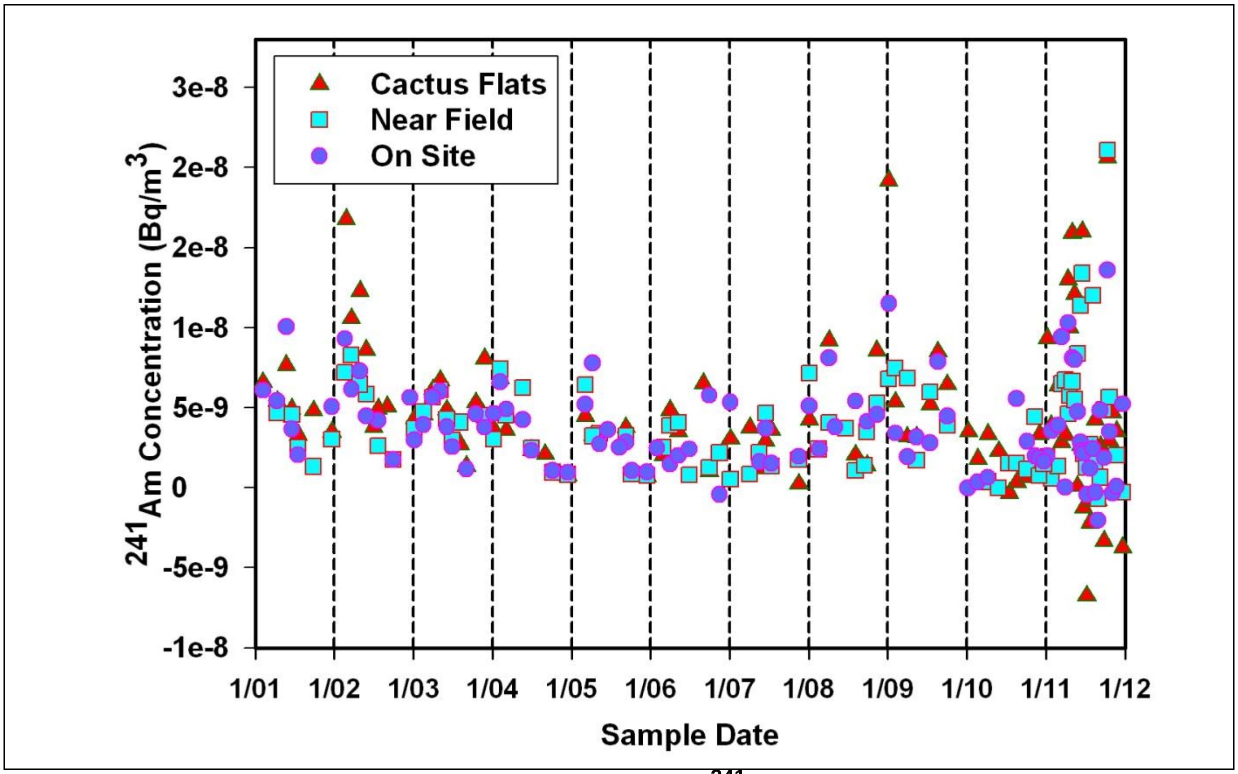


Figure 5.6. High Volume Ambient Aerosol ^{241}Am Activity Concentrations

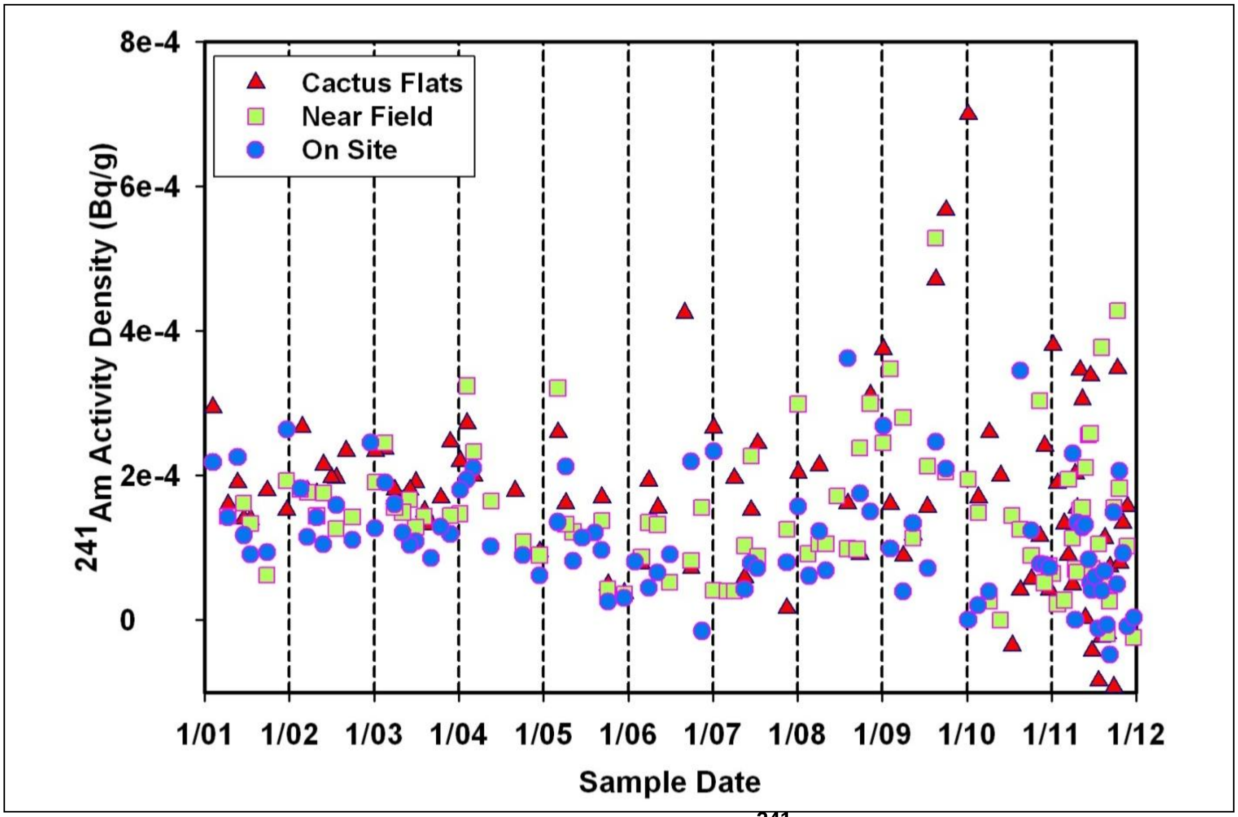


Figure 5.7. High Volume Ambient Aerosol ^{241}Am Activity Densities

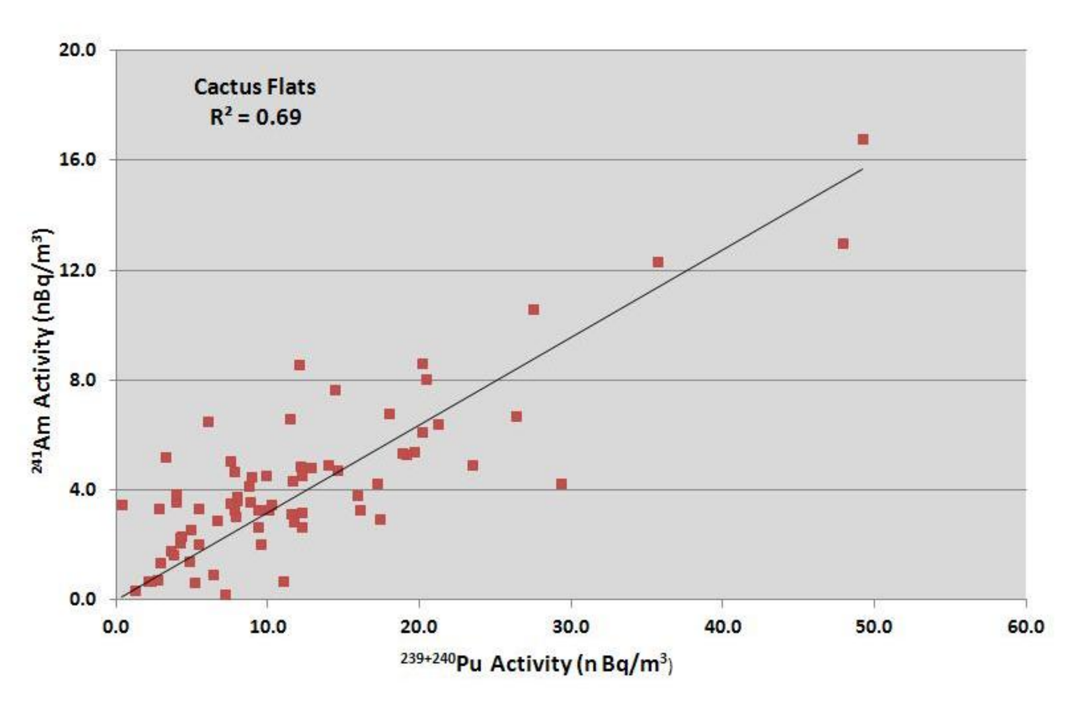


Figure 5.8. Correlation between $^{239+240}$Pu and ^{241}Am Activity Concentrations in Aerosol Samples Collected from Cactus Flats Stations

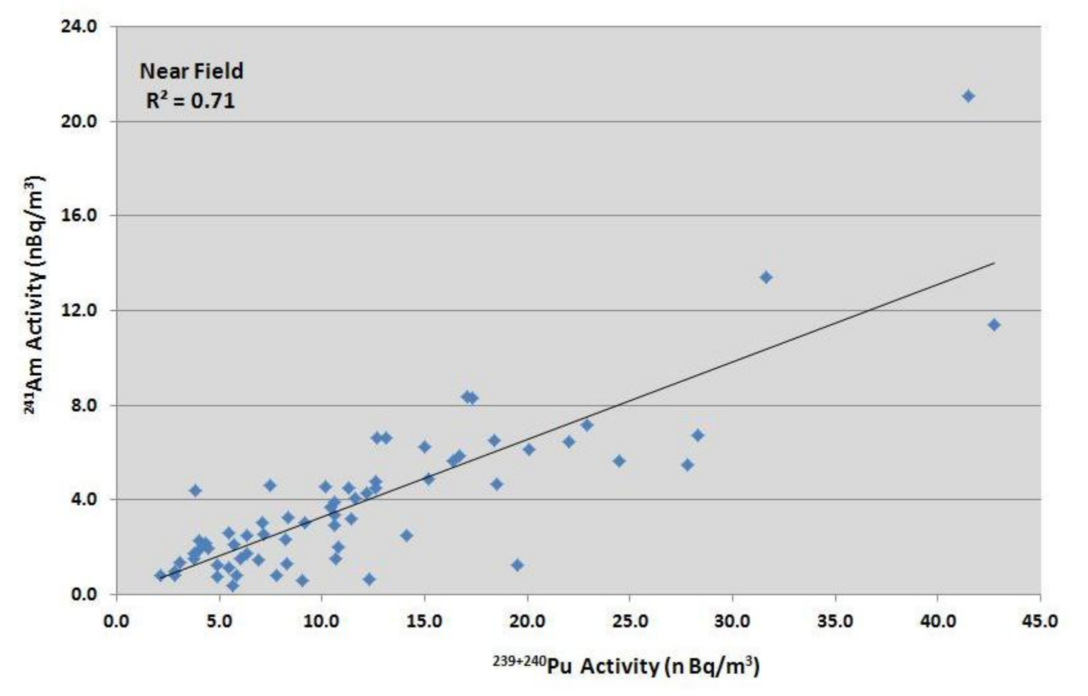


Figure 5.9. Correlation between ^{241}Am and $^{239+240}$Pu Activity Concentrations in Aerosol Samples Collected from Near Field Stations

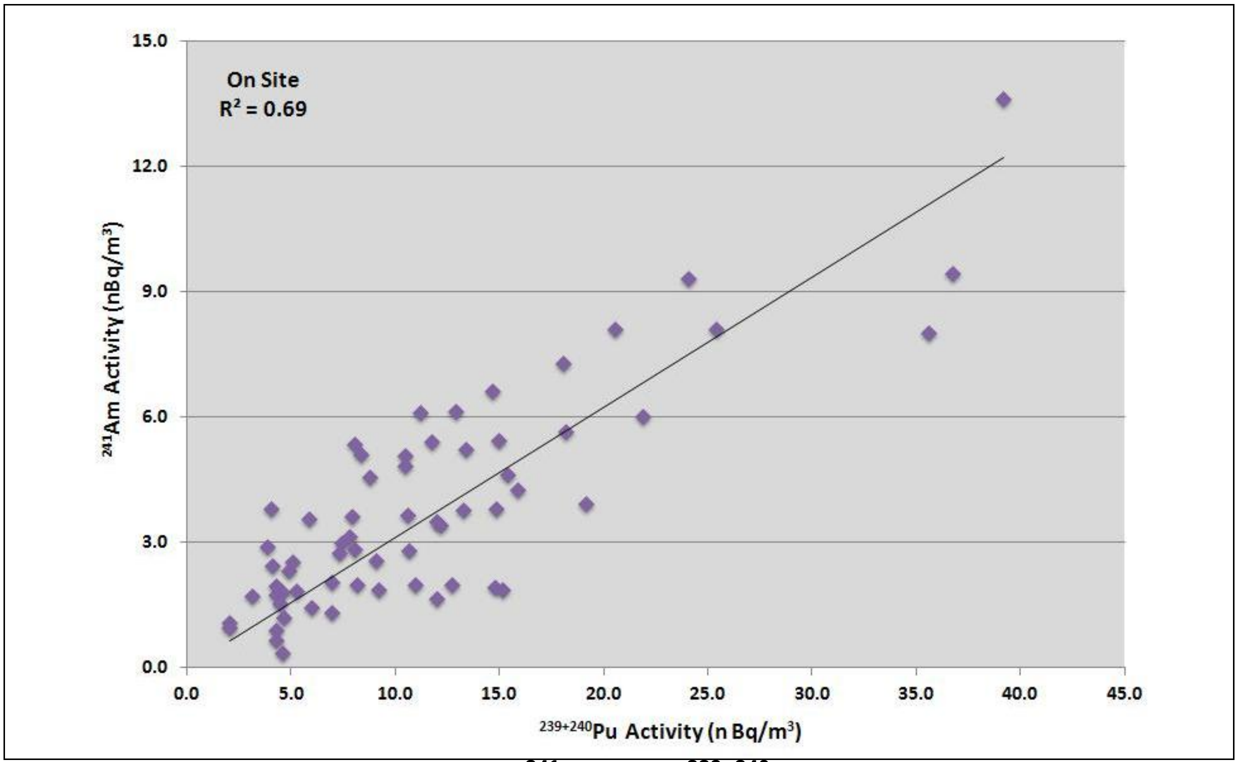


Figure 5.10. Correlation between ^{241}Am and $^{239+240}$Pu Activity Concentrations in Aerosol Samples Collected from On Site Stations

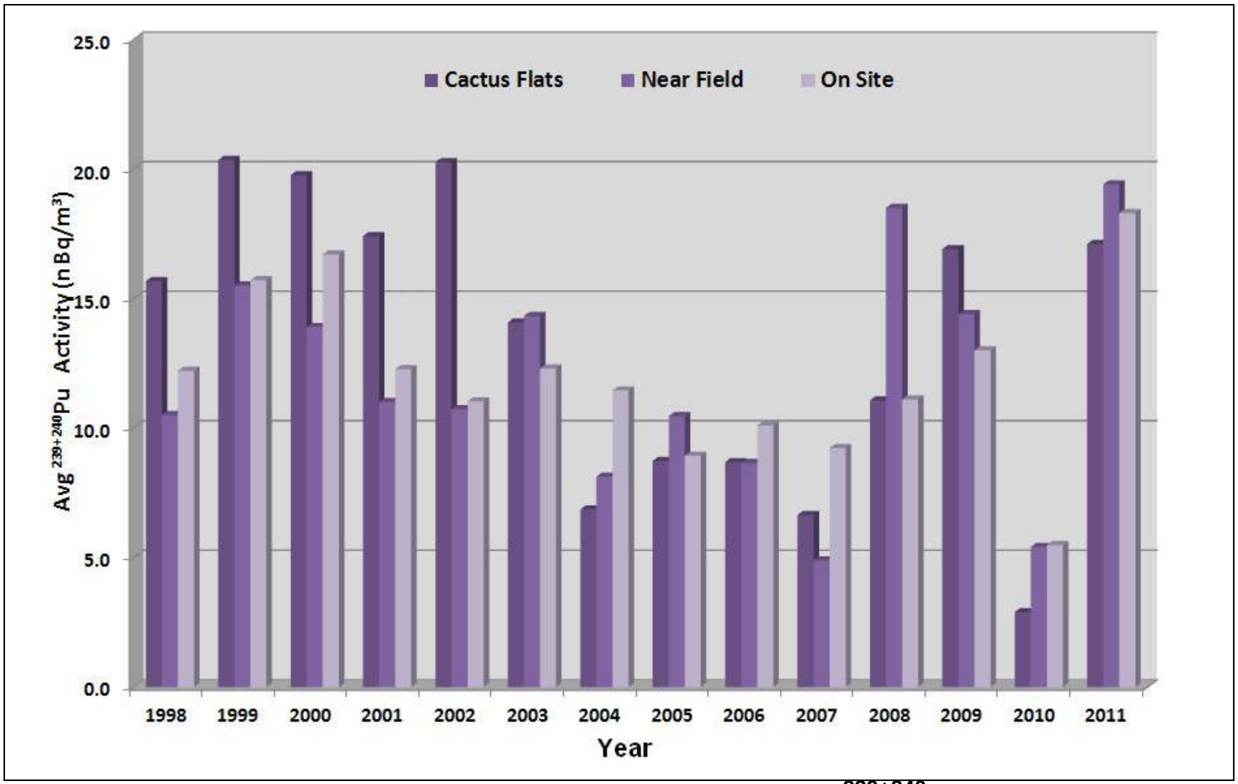


Figure 5.11. Average High Volume Ambient Aerosol $^{239+240}$Pu Activity in the Vicinity of WIPP Site

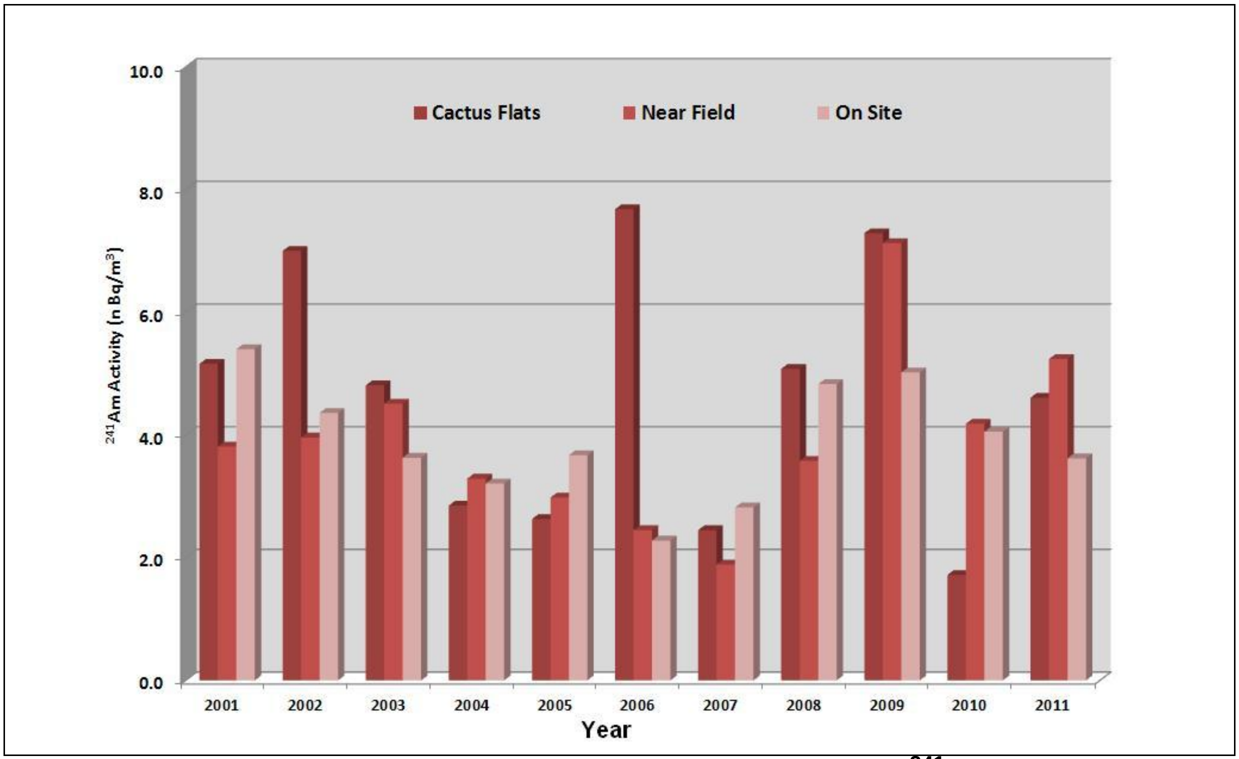


Figure 5.12. Average High Volume Ambient Aerosol ^{241}Am Activity Concentrations in the Vicinity of the WIPP Site

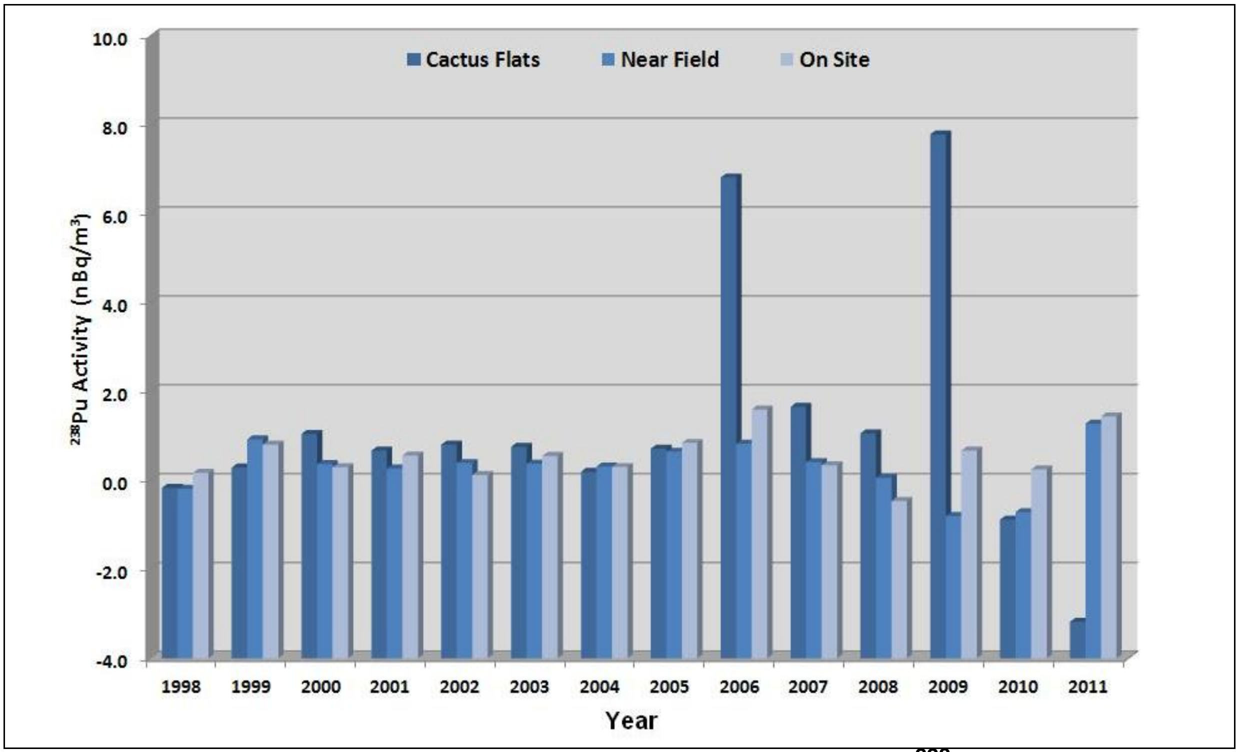


Figure 5.13. Average High Volume Ambient Aerosol ^{238}Pu Activity Concentrations in the vicinity of the WIPP Site

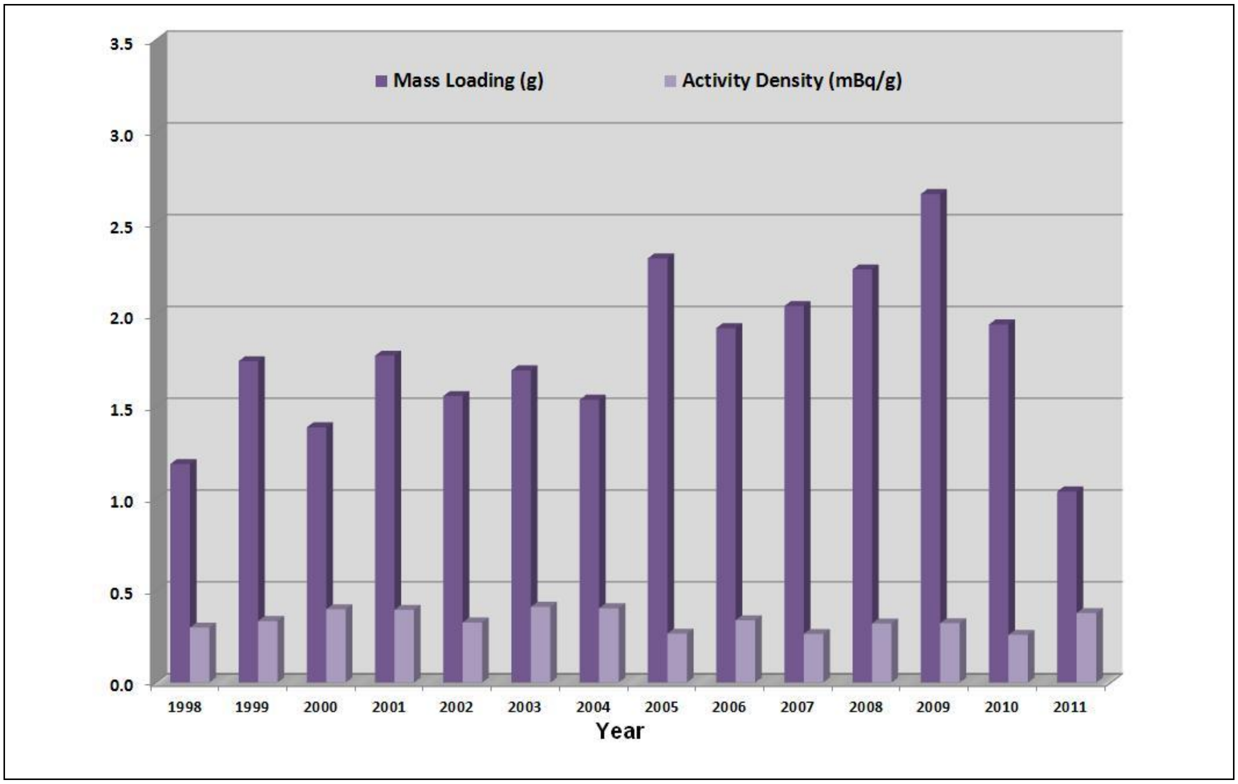


Figure 5.14. Average High Volume Ambient Aerosol Mass Loading and $^{239+240}$Pu Activity Density at On Site Station

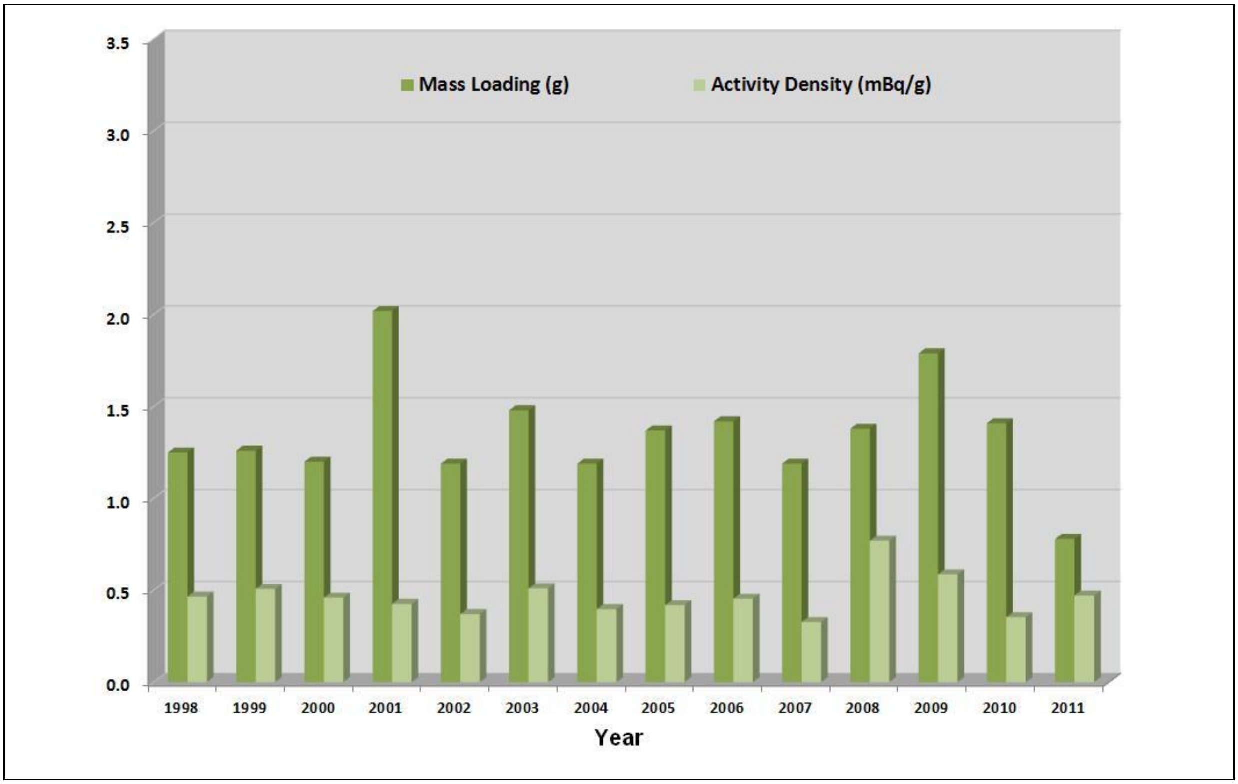


Figure 5.15. Average High Volume Ambient Aerosol Mass Loading and $^{239+240}$Pu Activity Density at Near Field Station

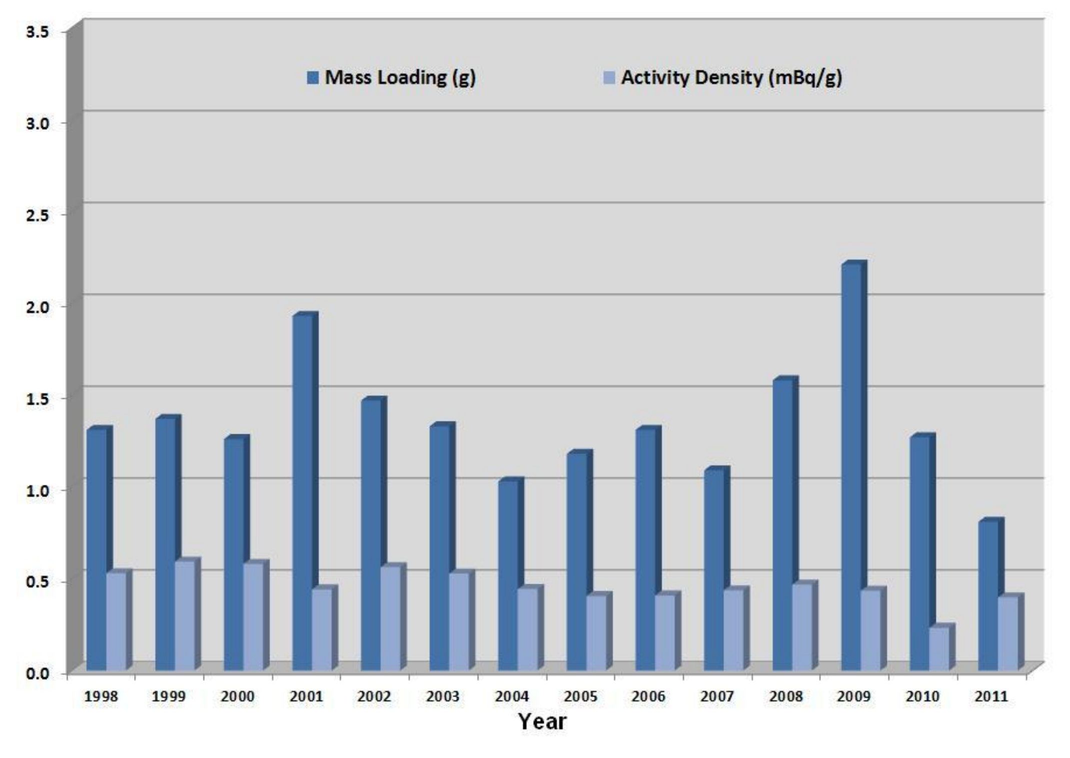


Figure 5.16. Average High Volume Ambient Aerosol Mass Loading and $^{239+240}$Pu Activity Density at Cactus Flats Station

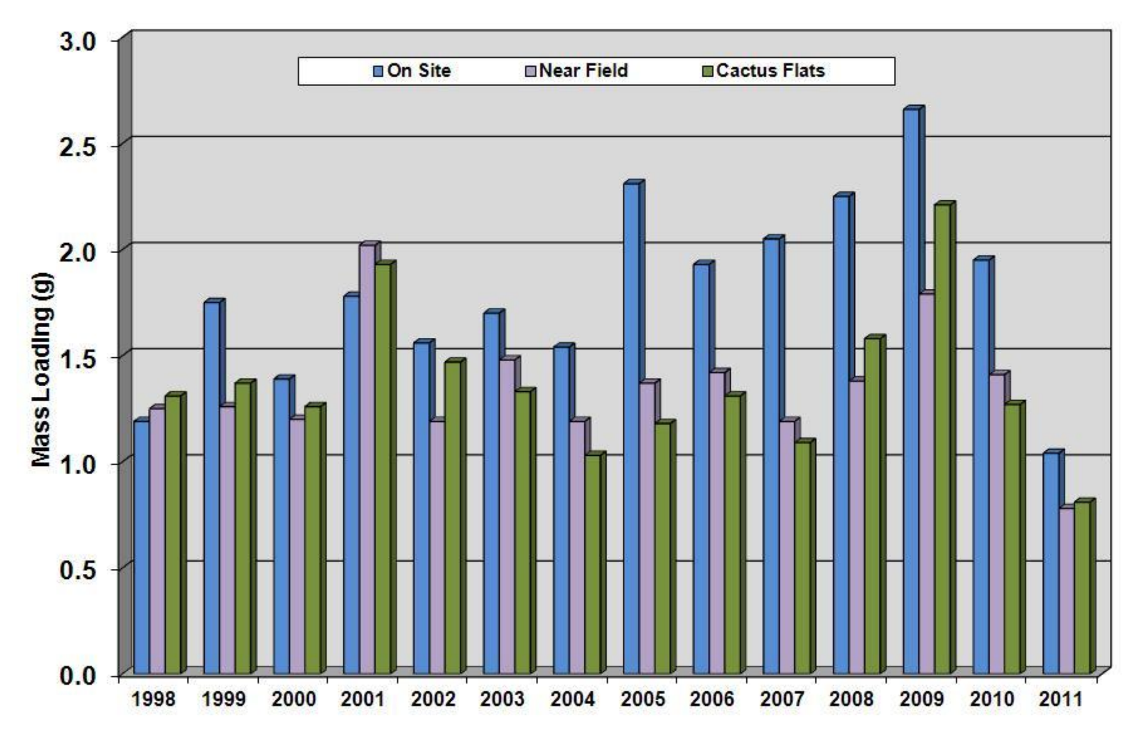


Figure 5.17. Average Ambient Aerosol Mass Loading in Aerosol Air Filters near the WIPP Site

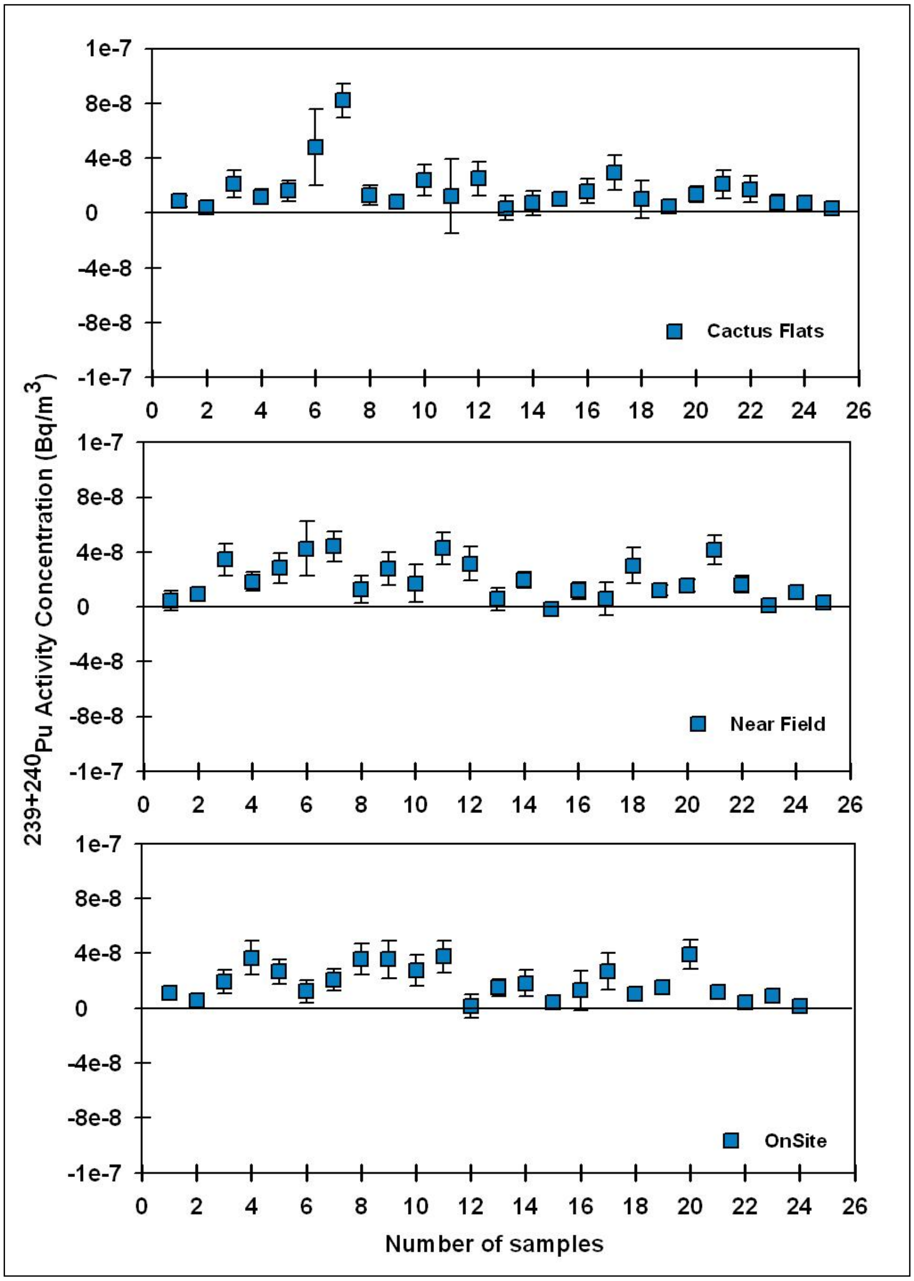


Figure 5.18. $^{239+240}$Pu Concentrations in Aerosol Filters Collected in 2011

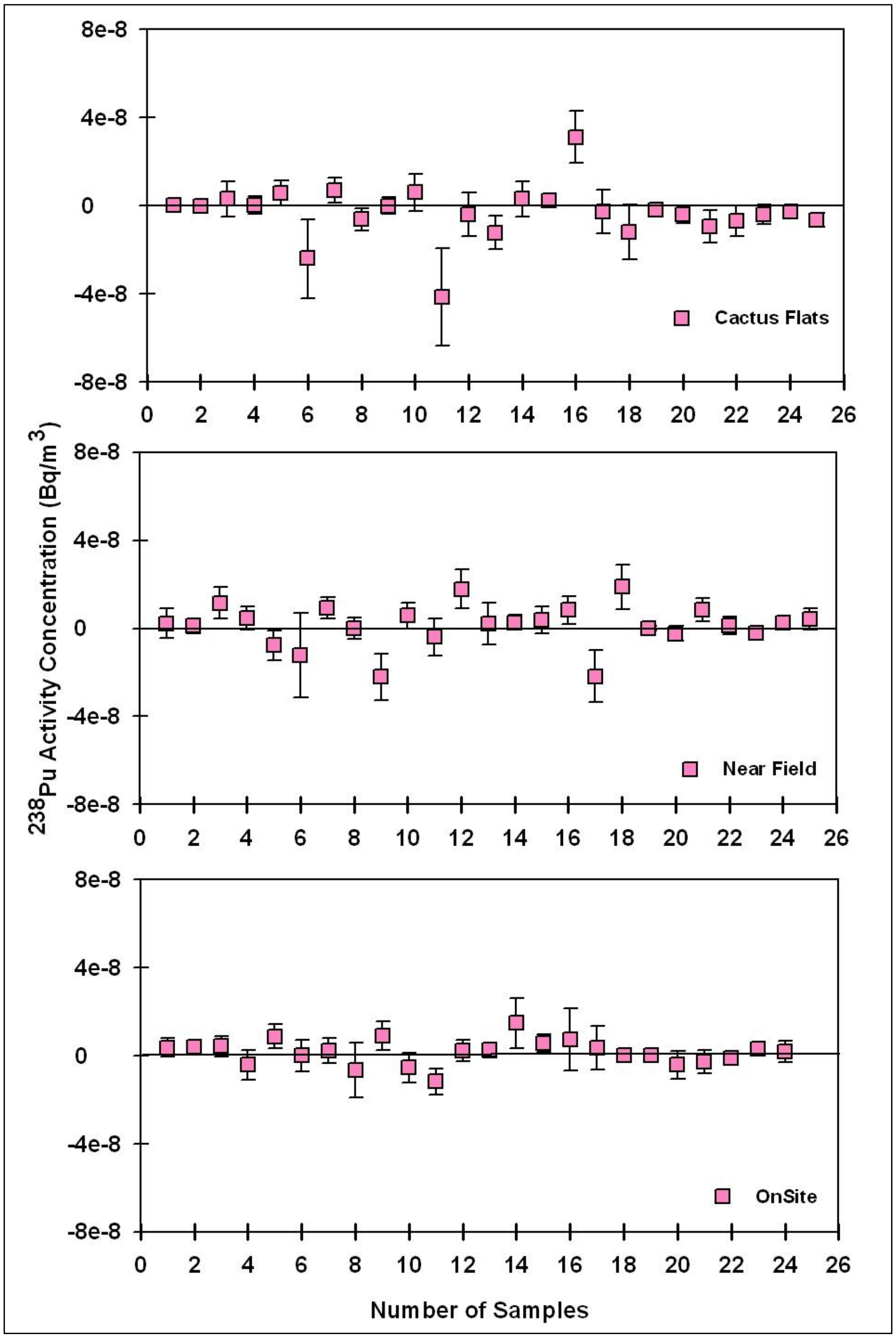


Figure 5.19. ^{238}Pu Concentrations in Aerosol Filters Collected in 2011

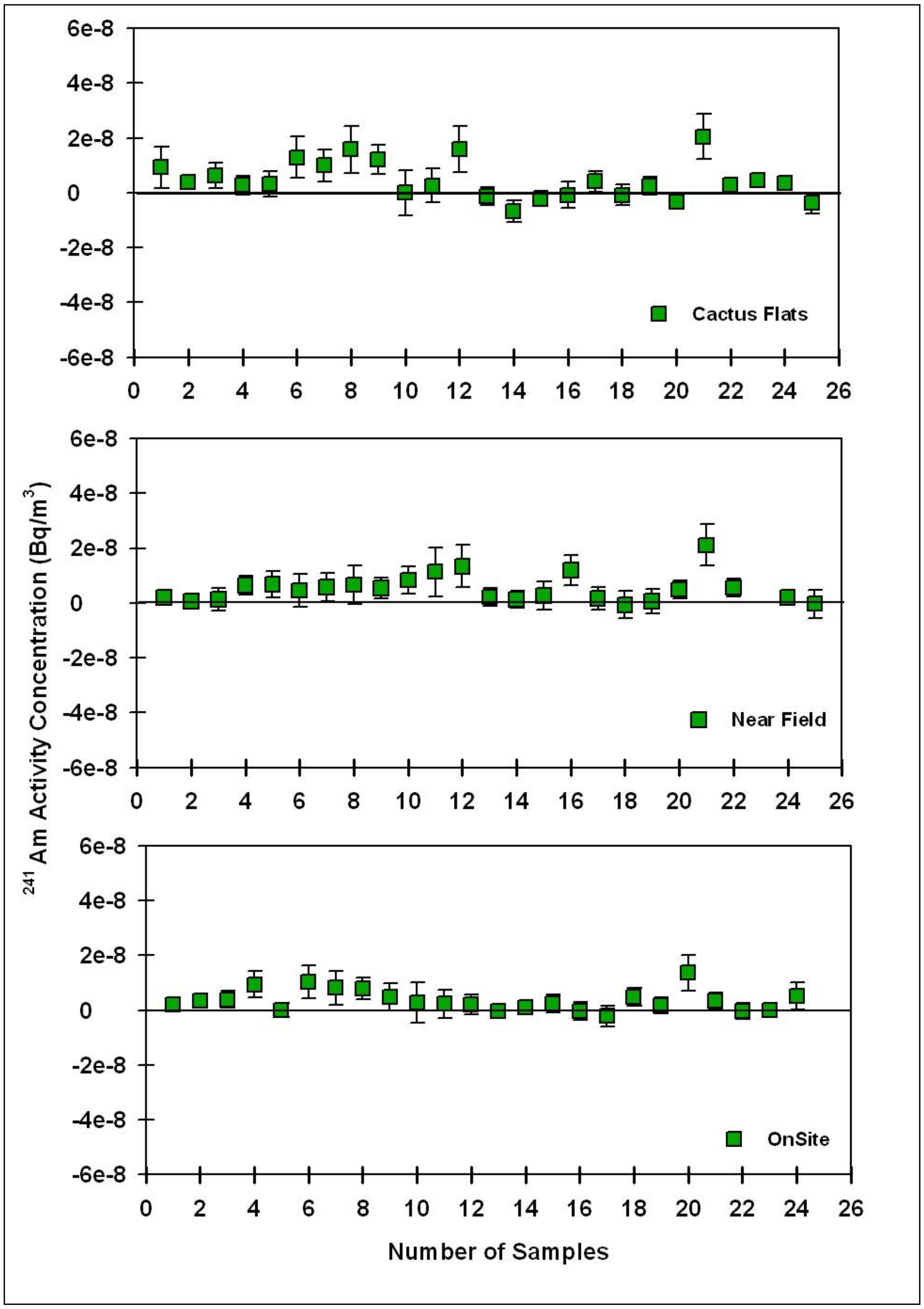


Figure 5.20. ^{241}Am Concentrations in Aerosol Filters Collected in 2011

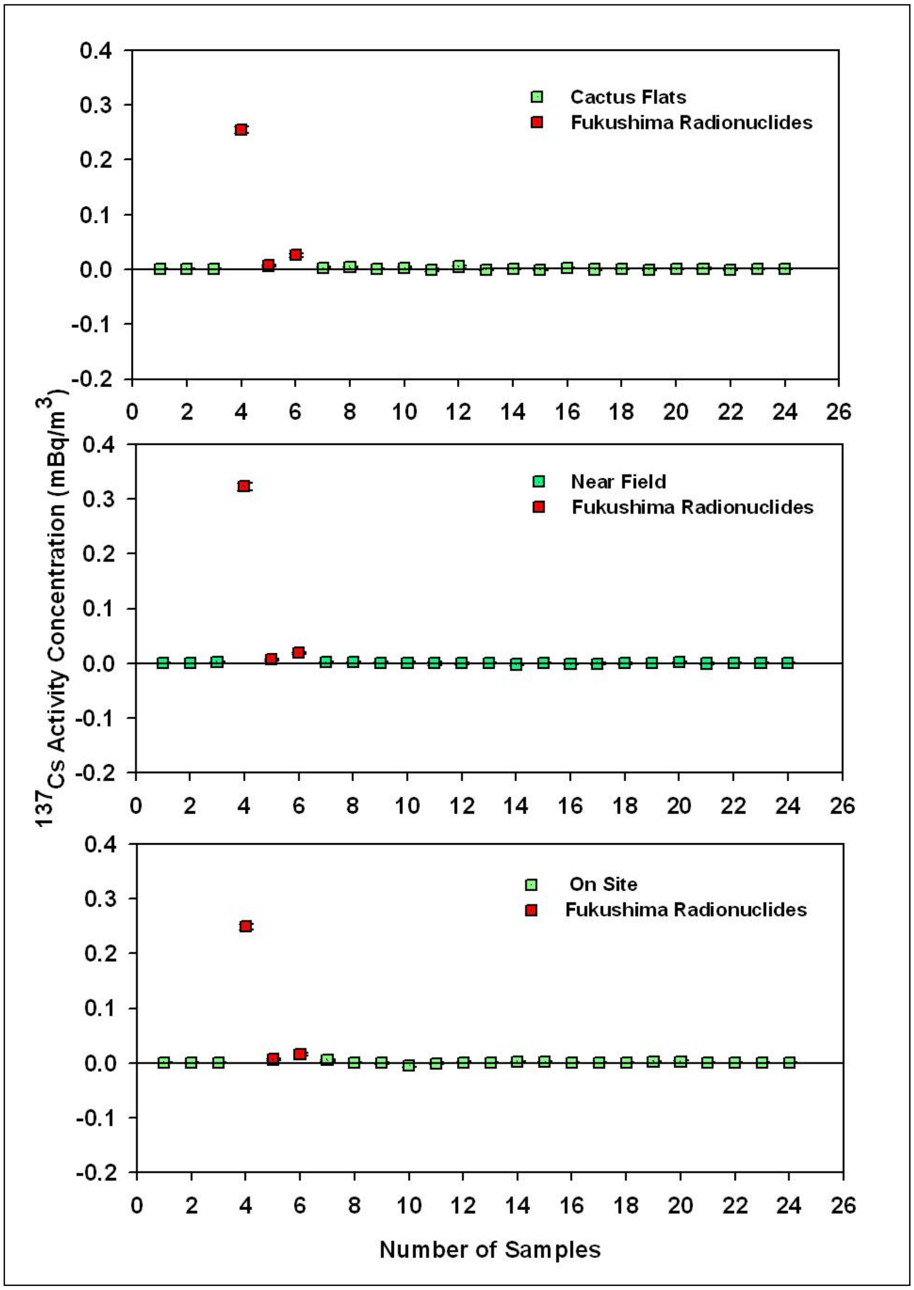


Figure 5.21. ^{137}Cs Concentrations in Aerosol Filters Collected in 2011

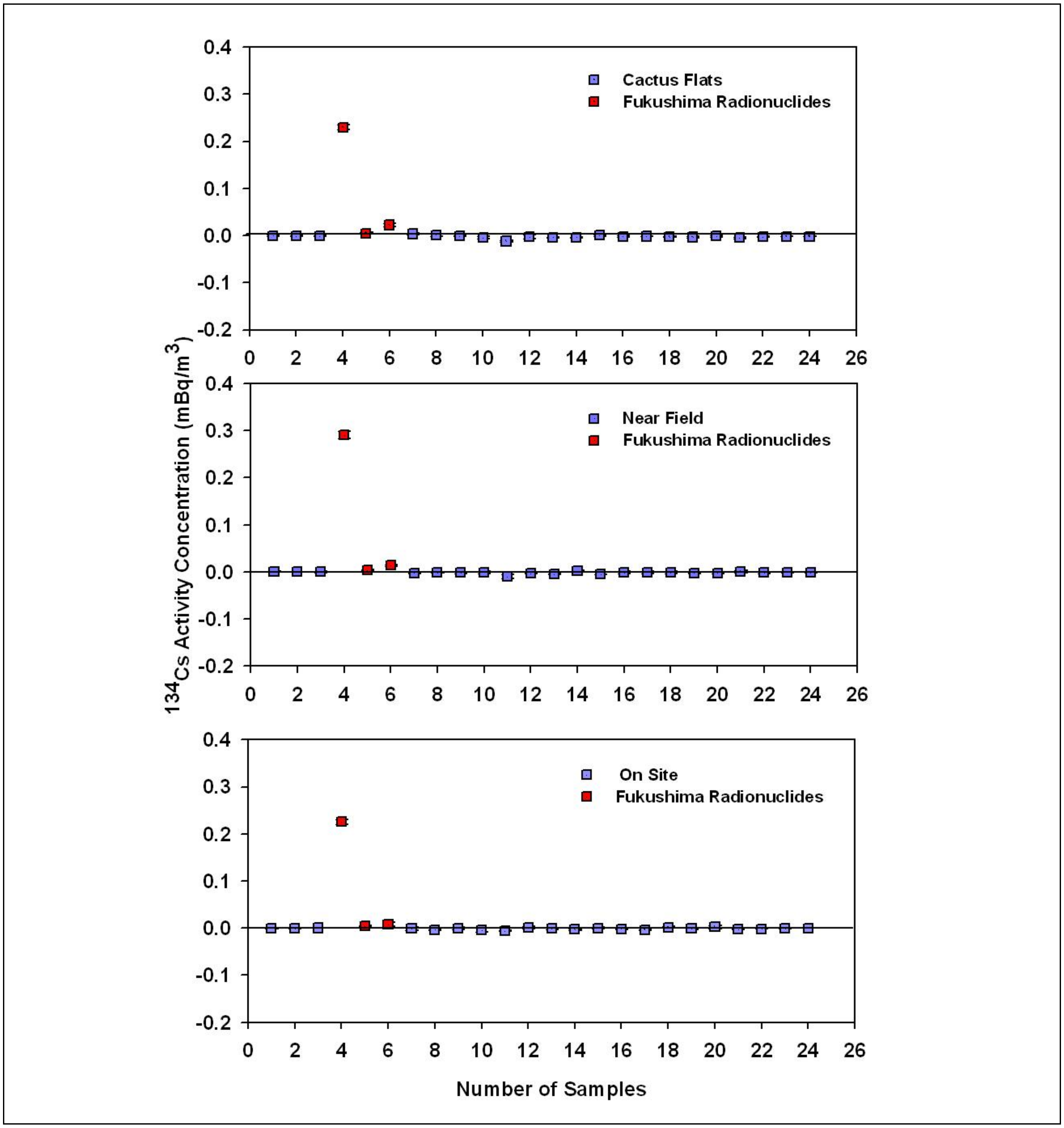


Figure 5.22. ^{137}Cs Concentrations in Aerosol Filters Collected in 2011

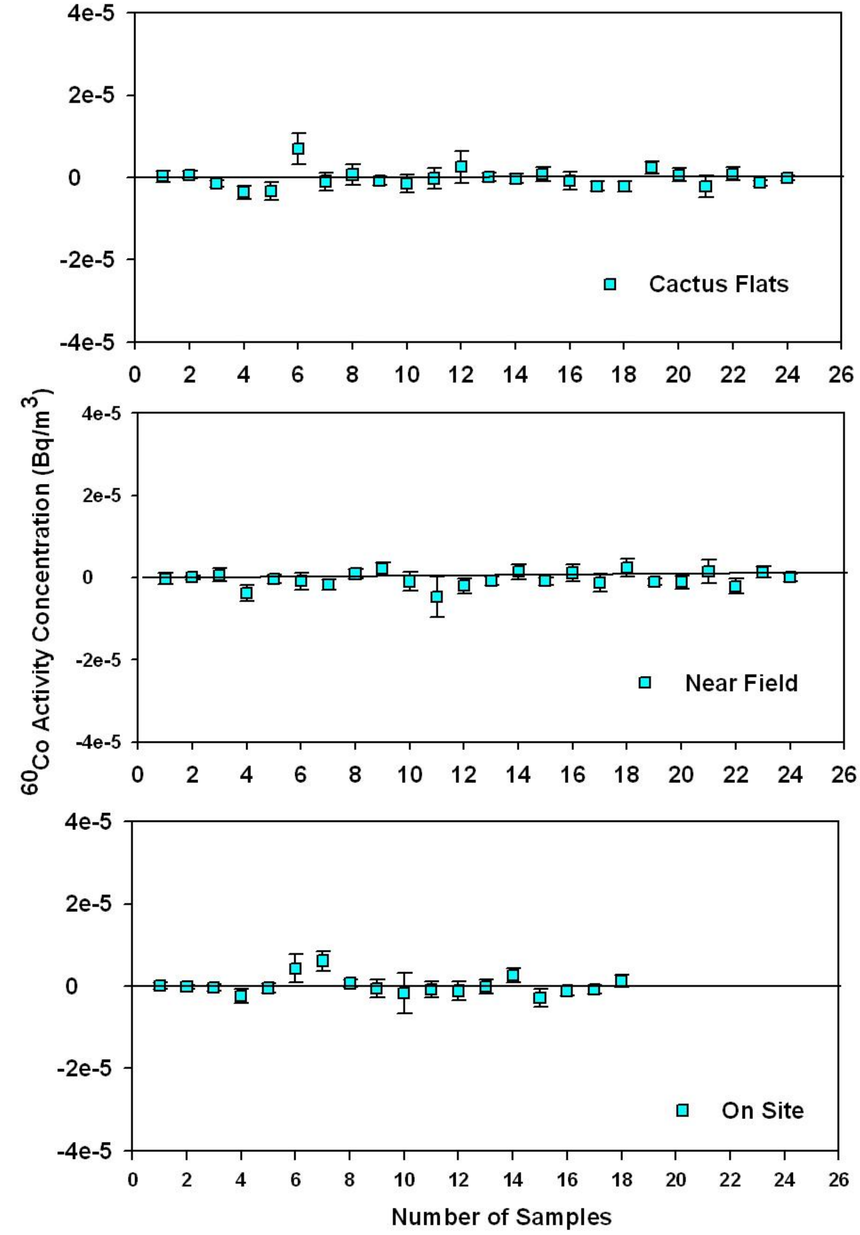


Figure 5.23. ^{60}Co Concentrations in Aerosol Filters Collected in 2011

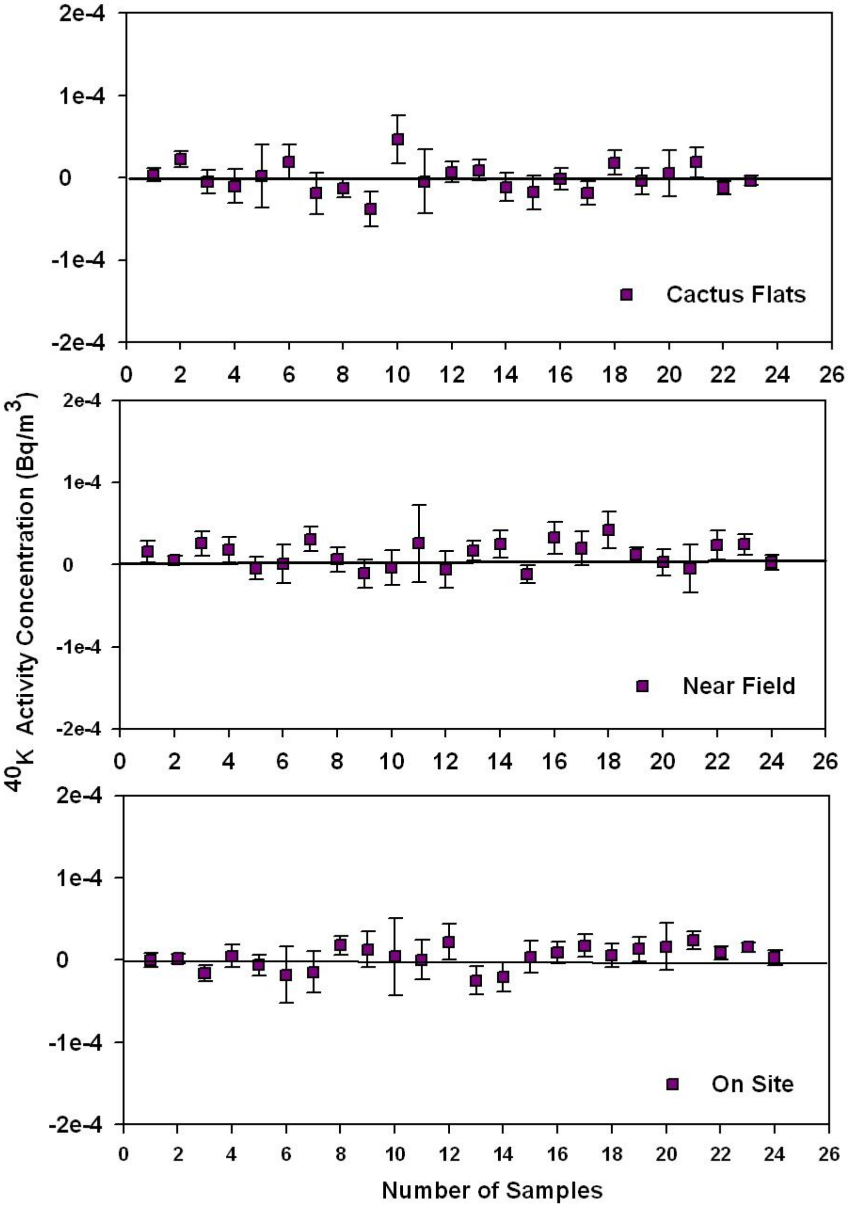


Figure 5.24. ^{40}K Concentrations in Aerosol Filters Collected in 2011

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

Table 5.3. Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filters at On Site Station (continued)

Radionuclide		Concentration	SD	MDC
	2009			
^{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
	2011			
^{241}Am	Minimum	-2.04E-09	1.75E-09	3.13E-09
	Maximum	1.36E-08	7.51E-09	2.63E-08
	Average	3.62E-09	3.81E-09	1.12E-08
^{238}Pu	Minimum	-1.19E-08	1.87E-09	5.99E-09
	Maximum	1.46E-08	1.41E-08	5.48E-08
	Average	1.44E-09	5.96E-09	2.40E-08
$^{239+240}$Pu	Minimum	1.37E-09	2.45E-09	5.38E-09
	Maximum	3.92E-08	1.44E-08	5.24E-08
	Average	1.83E-08	8.14E-09	2.26E-08

Table 5.3. Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filters at On Site Station (Continued)

Radionuclide		**Concentration**	**SD**	**MDC**
	2011			
^{234}U	Minimum	1.99E-07	6.17E-10	-1.02E-07
	Maximum	4.73E-06	1.02E-07	-7.64E-09
	Average	1.53E-06	3.29E-08	-3.57E-08
^{235}U	Minimum	8.79E-10	-1.61E-09	-1.46E-08
	Maximum	2.62E-07	1.35E-08	3.31E-08
	Average	8.16E-08	4.60E-09	6.29E-09
^{238}U	Minimum	-9.01E-08	-1.03E-08	-1.33E-07
	Maximum	3.92E-06	7.91E-08	-1.81E-08
	Average	1.11E-06	1.91E-08	-4.86E-08
^{134}Cs	Minimum	-5.82E-06	3.32E-07	1.12E-06
	Maximum	2.26E-04	5.72E-06	1.62E-05
	Average	9.26E-06	1.76E-06	5.30E-06
^{137}Cs	Minimum	-5.82E-06	3.32E-07	1.12E-06
	Maximum	2.49E-04	5.72E-06	1.62E-05
	Average	2.08E-05	1.59E-06	4.62E-06
^{60}Co	Minimum	-2.49E-05	4.45E-07	1.49E-06
	Maximum	2.37E-05	4.70E-05	1.57E-04
	Average	1.48E-06	5.08E-06	1.69E-05
^{40}K	Minimum	-2.49E-05	5.27E-06	1.75E-05
	Maximum	2.37E-05	4.70E-05	1.57E-04
	Average	3.18E-06	1.74E-05	5.78E-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

Table 5.4. Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filters at Near Field Station (continued)

Radionuclide		*Concentration*	*SD*	*MDC*
	2009			
	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
	2011			
^{241}Am	Minimum	-7.04E-10	1.10E-09	3.62E-09
	Maximum	2.11E-08	8.99E-09	2.64E-08
	Average	5.24E-09	4.63E-09	1.34E-08
^{238}Pu	Minimum	-2.21E-08	1.24E-09	6.17E-09
	Maximum	1.88E-08	1.92E-08	8.54E-08
	Average	1.28E-09	6.46E-09	2.56E-08
$^{239+240}$Pu	Minimum	-1.34E-09	2.58E-09	3.16E-09
	Maximum	4.40E-08	2.01E-08	5.62E-08
	Average	1.94E-08	8.69E-09	2.41E-08
^{234}U	Minimum	4.85E-07	7.46E-09	-8.68E-08
	Maximum	4.26E-06	7.43E-08	-9.78E-09
	Average	1.51E-06	3.34E-08	-3.57E-08

Table 5.4. Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filters at Near Field Station (continued)

Radionuclide		**Concentration**	**SD**	**MDC**
	2011			
^{235}U	Minimum	-4.26E-09	-1.26E-09	-2.07E-08
	Maximum	7.55E-07	5.01E-08	8.34E-08
	Average	1.08E-07	7.09E-09	1.08E-08
^{238}U	Minimum	1.16E-07	-1.38E-08	-1.06E-07
	Maximum	3.44E-06	5.23E-08	-9.29E-09
	Average	1.00E-06	1.79E-08	-4.80E-08
^{134}Cs	Minimum	-9.81E-06	3.30E-07	1.10E-06
	Maximum	2.90E-04	7.22E-06	1.63E-05
	Average	1.12E-05	1.85E-06	5.45E-06
^{137}Cs	Minimum	-2.07E-06	4.20E-07	1.39E-06
	Maximum	3.23E-04	6.78E-06	1.06E-05
	Average	1.48E-05	1.52E-06	4.31E-06
^{60}Co	Minimum	-4.76E-06	4.50E-07	1.50E-06
	Maximum	2.36E-06	4.88E-06	1.64E-05
	Average	-4.37E-07	1.71E-06	5.69E-06
^{40}K	Minimum	-1.15E-05	5.16E-06	1.70E-05
	Maximum	4.23E-05	4.69E-05	1.56E-04
	Average	1.21E-05	1.74E-05	5.77E-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

Table 5.5. Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filters at Cactus Flats Station (continued)

Radionuclide		***Concentration***	***SD***	***MDC***
	2009			
	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
	2011			
^{241}Am	Minimum	-6.76E-09	1.78E-09	4.41E-09
	Maximum	2.06E-08	8.57E-09	3.44E-08
	Average	4.61E-09	4.77E-09	1.51E-08
^{238}Pu	Minimum	-4.15E-08	1.65E-09	2.98E-09
	Maximum	3.12E-08	2.21E-08	1.18E-07
	Average	-3.18E-09	7.12E-09	3.14E-08
$^{239+240}$Pu	Minimum	3.70E-09	2.33E-09	4.56E-09
	Maximum	8.21E-08	2.77E-08	1.06E-07
	Average	1.71E-08	9.26E-09	2.91E-08

Table 5.5. Minimum, Maximum, and Average Radionuclide Concentrations (Bq/m^3) in Aerosol Filters at Cactus Flats Station (continued)

Radionuclide		**Concentration**	**SD**	**MDC**
	2011			
^{234}U	Minimum	4.44E-07	6.75E-09	-8.42E-08
	Maximum	3.30E-06	1.06E-07	-1.48E-08
	Average	1.42E-06	3.28E-08	-3.72E-08
^{235}U	Minimum	-7.74E-09	-3.02E-09	-6.94E-09
	Maximum	2.60E-07	1.67E-08	4.41E-08
	Average	7.41E-08	4.31E-09	6.58E-09
^{238}U	Minimum	-1.43E-07	-1.18E-08	-1.17E-07
	Maximum	2.97E-06	7.98E-08	-4.72E-09
	Average	9.35E-07	1.76E-08	-4.62E-08
^{134}Cs	Minimum	-1.18E-05	3.69E-07	1.26E-06
	Maximum	2.30E-04	5.79E-06	1.33E-05
	Average	8.73E-06	1.81E-06	5.46E-06
^{137}Cs	Minimum	-9.00E-07	4.27E-07	1.41E-06
	Maximum	2.55E-04	5.42E-06	8.91E-06
	Average	1.28E-05	1.50E-06	4.36E-06
^{60}Co	Minimum	-3.67E-06	4.54E-07	1.52E-06
	Maximum	6.90E-06	3.82E-06	1.27E-05
	Average	-2.30E-07	1.73E-06	5.77E-06
^{40}K	Minimum	-3.83E-05	5.52E-06	1.84E-05
	Maximum	4.66E-05	3.87E-05	1.30E-04
	Average	-4.48E-07	1.80E-05	6.01E-05

CHAPTER 6

Impact of Fukushima Nuclear Power Plant Accident

Introduction

On March 11, 2011 a massive 9.0 earthquake and ensuing tsunami struck the northern coast of Honshu-island, Japan and severely damaged the electric system of the Fukushima-Daiichi Nuclear Power Plant (NPP; Figure 6.1). The structural damage to the plant disabled the reactor's cooling system resulting in hydrogen explosions on March 12 and 14 in the Unit 1 and 3 reactors, respectively. On March 15 other explosions occurred in the Unit 4 reactor building and the Unit 2 reactor. Subsequent fires and possible partial core meltdowns released radioactive fission products into the atmosphere. The atmospheric release from the crippled Fukushima NPP started on March 12, 2011 with a maximum release phase from March 14 to 17. The radioactivity released was dominated by volatile fission products including isotopes of the noble gases xenon (^{133}Xe) and krypton (85Kr), iodine (131I, 132I), cesium (134Cs, 136Cs, 137Cs), and tellurium (132Te). The non-volatile radionuclides such as isotopes of strontium and plutonium are believed to have remained largely inside the reactor although there is evidence of a release of plutonium into the environment (Zheng et al, 2012). Although the Japanese Government and the Tokyo Electric Power Company (TEPCO) adopted a series of measures, the accident gradually became a level 7 nuclear event on the INES (International Nuclear Event Scale) due to high radiation released in the first few days. The release from the Fukushima Daiichi NPP was significant, but due to the transit time and significant dilution of the radioactivity in the atmosphere as the contaminated air mass was transported across the across the Pacific toward the North American and European continents, the levels of radioactivity measured were extremely small and not of concern from a public health point of view.

First commissioned in 1971, the Fukushima-Daiichi NPP consists of six boiling water reactors (BWR) or units operated by TEPCO (Table 6.1 and Figure 6.2). When operational, it provided a total of 4.7 gigawatts of electrical power making this facility one of the 15 largest nuclear power installations in the world. At the time of the quake, 3 of the units (reactors 1-3) were operating while the other 3 (reactors 4-6) were in a state of cold shutdown for periodic maintenance [8]. The reactors 1-3 shut down automatically after the earthquake, and emergency generators came online to stabilize electronic controls and coolant systems. Although the Fukushima-Daiichi NPP was designed to withstand waves of up to 5.7 meters, the flooding and destruction that resulted from 14 meter waves as a result of the earthquake induced tsunami disabled emergency generators required to cool the reactors. As a result, the cooling system stopped working triggering the severe chain reaction of accidents at the Fukushima-Daiichi NPP. The high temperature turned most of the internal coolant water into steam, which in turn exposed the fuel rods to air. In order to avoid a total meltdown of the fuel rods, operators of the plants tried to inject coolant water from external sources (first sea water and later fresh water). Unfortunately, the injected coolant water turned into stream and further increased the pressure inside the reactor vessels. Operators had to vent radioactive gases into the air in an attempt to reduce mounting pressure inside the reactor vessels which resulted in hydrogen gas explosions and a release of radioactivity into the environment. Coolant water that did not escape the vessel, in the form of steam, accumulated at the bottom of the reactors. These radioactive waters either leaked or were discharged into the Pacific Ocean. Despite these attempts, the fuel rods in units 1, 2 and 3 were reported to have experienced serious damage and possible total meltdown (TEPCO 2011; CNN 2011).

Background

Japan is one of the world's top consumers of nuclear energy. The country's 17 nuclear plants, boasting 55 reactors in total, provided about 30 % of the country's total 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 back to the 1960s and are of a design known as boiling water reactors (BWR; Figure 6.3). A controlled nuclear reaction produced by fuel rods containing pellets of enriched uranium creates heat used to make steam that turns turbines in order to produce electricity. The flow of water into and out of the plant serves to cool the reactors. Given its geographic location, the planning for earthquakes and tsunamis is highly developed in Japan; however, the 9.0 earthquake and the giant waves that followed it overwhelmed the reactors' safety systems. As a result, in addition to power being disrupted by the earthquake in the area surrounding the Fukushima-Daiichi NPP, the waves from the earthquake-induced tsunami poured over the sea wall surrounding the plant thereby disabling the power plant's back-up diesel generators.

In response to the Japanese nuclear incident, the CEMRC accelerated and increased sampling frequency and analysis of airborne constituents in and around the WIPP site to confirm that there were no harmful levels of radiation reaching the U.S. from Japan and to better inform the public about any level of radiation detected. This report covers the first three months of air radiation monitoring following the Fukushima nuclear disaster in 2011 and is intended to inform a wider public about the exact time and nature of the arrival of fission products to the Carlsbad area. CEMRC recorded the first arrival of airborne fission products 131I, 132Te, 134Cs and 137Cs in Carlsbad, NM, USA in the air filter which was exposed from March 14-April 01, 2011. A description of the radioactive nuclides emitted by the Fukushima NPP, their half-lives, and the analytical techniques used to detect them are listed in Tables 6.2 and 6.3 respectively. Additionally, the concentrations of radioactivity detected in the Carlsbad, NM region are listed in Table 6.4 and Figure 6.4. Lastly, Figures 6.2 through 6.21 show the concentrations of radioactivity detected at various places around the world from the Fukushima NPP accident.

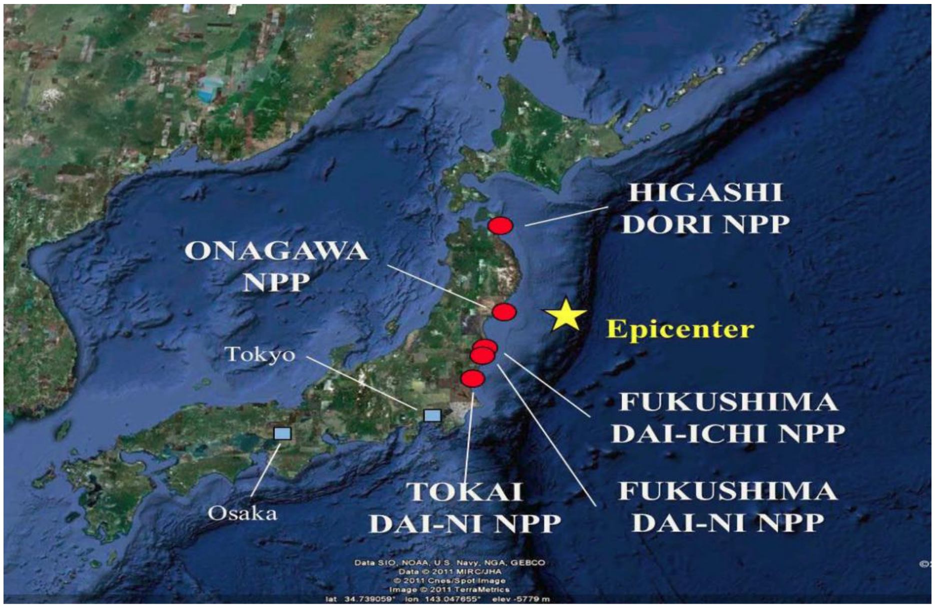
From a public health standpoint, the isotopes of 131I and 137Cs are of most interest because if high concentrations of 131I are inhaled or ingested, the radioactive iodine can concentrate in the thyroid and thereby increase the risk for cancer in that organ. Additionally, cesium is chemically similar to potassium and 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, leading 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. CEMRC saw decreasing radiation levels during April and May, 2011. Since May 2011, sample analyses have predominantly shown no detections of radionuclides associated with the Japanese nuclear incident. The activity of 131I measured was at least a factor of ~1,500 below the limit given by the Environmental Protection Agency (EPA) of 3.7 Bq/m3.

The average dose received by the public from nuclear power is 0.0002 millisievert per year (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 averaging over 15 mSv/yr 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 mSv. However, there is no evidence of increased cancers or other health problems arising from these abnormally-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 6.1. 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



Source: IAEA (2011)

Figure 6.1. Nuclear Power Plant Sites in Japan Affected by the Great East Japan Earthquake

Source: Google Earth

Figure 6.2. Layout of the Fukushima Daiichi NPP site

Inside the Fukushima Daiichi Reactors

The Fukushima Daiichi reactors are GE boiling water reactors (BWR) of an early (1960s) design supplied by GE, Toshiba and Hitachi, with what is known as a Mark I containment type. Reactors 1-3 became operational in 1971-75. Reactor power is 460 MWe for unit 1, 784 MWe for units 2-5, and 1,100 MWe for unit 6.

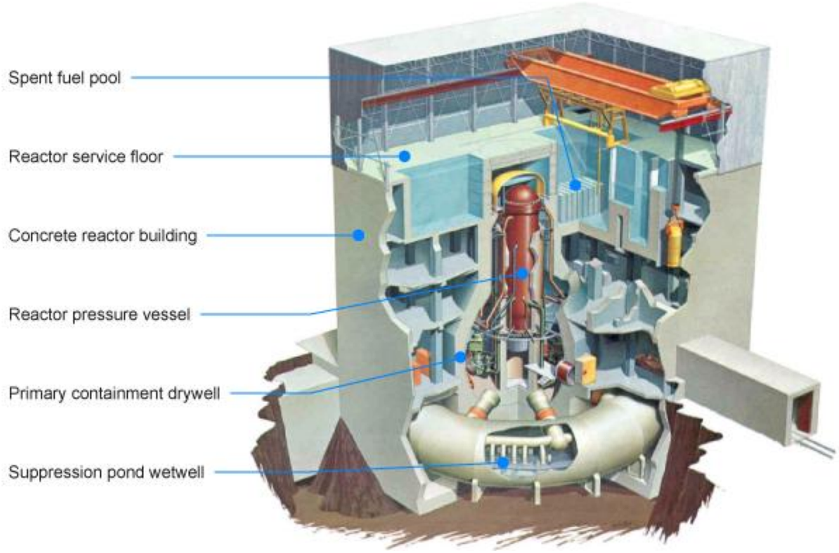


Figure 6.3. BWR rector at Fukushima Daiichi NPP

Nuclear reactor basics

A nuclear reactor utilizes the process of nuclear fission to generate energy. This involves splitting a heavy nucleus, e.g. uranium-235, into two (fission) fragments plus two or three neutrons resulting in a release of energy. Over 80% of the energy released in a fission event appears as the kinetic energy of the fission products. These fission products generate heat by colliding with surrounding atoms. Further heat arises through stopping/absorbing: (i) the neutrons and gamma rays released during fission and (ii) the radiation emitted by the fission products. Heat is removed during normal power operation by generating steam in the reactor vessel and then using that steam to drive a turbine to produce electrical energy. When the reactor is shutdown, the core will still continue to generate decay heat (from the decaying fission products).

The heat is removed by dumping the steam created directly to a condenser where it is converted back into water. The resulting water is pumped out of the condenser with a series of pumps and back to the reactor vessel and the cycle starts again (US-NRC, 2011). Thus nuclear reactors must be cooled, using electrical pumps to circulate a water coolant, even when they are shutdown. ‘Cold shutdown’ means that three conditions have been established: the reactor pressure vessel’s temperature is less than 100^{o} C, the release of radioactive materials from the primary containment vessel is under control and public radiation exposure by additional release is being significantly contained.

Table 6.2. Properties of Radionuclides Detected following the Fukushima Nuclear Accident outside Japan

Radionuclide	Half-lives	Comments
Te-132	3.2 days	Short-lived volatile fission product
I-131	8.02 days	Short-lived volatile fission product
La-140	1.68 days	Decay product of Ba-140
I-132	2.3 hours	Decay product of Te-132
Cs-134	2.07 years	long-lived volatile fission product
Cs-136	13.1 days	Short-lived volatile fission product
Cs-137	30.2 years	long-lived volatile fission product
Xe-133	5.24 days	Noble gas

Table 6.3. Analytical techniques used and typical minimum detectable activities

Measurements	Samplers type	Analytical techniques	Typical MDC 24 hour count
Gamma emitters	High volume air filter	HPGe detector	1-7×10^{-6} Bq/m^3
Gamma emitters	Low volume air filter	HPGe detector	1.5×10^{-5} Bq/m^3
Iodine -131 (gas)	Activated charcoal filter	HPGe detector	1×10^{-3} Bq/m^3
La-140	High volume air filter	HPGe detector	2-20× Bq/m^3
Xe-133*	Noble gas sampler	HPGe detector	200×10^{-6} Bq/m^3
Gamma emitters	Milk	HPGe detector	0.3Bq/L
Gamma emitters	Rain water	HPGe detector	1 Bq/L

Table 6.4. Concentration of Airborne Fission Products (Bq/m^3) Measured In the vicinity of the 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 = No Detect

Fukushima Radionuclides in North American Continent

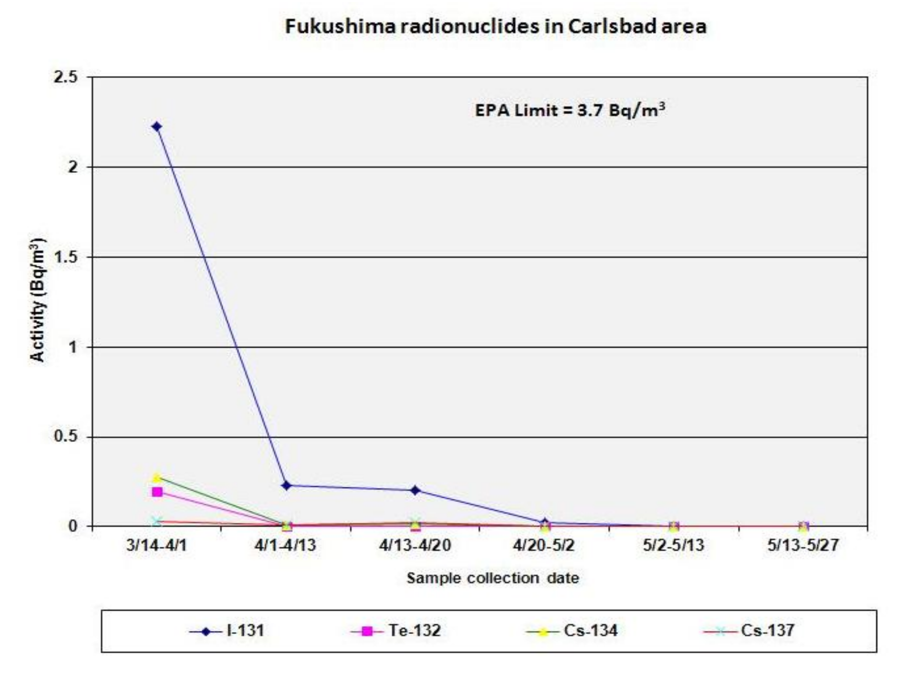


Figure 6.4. Concentration of Airborne Cesium and Iodine (mBq/m^3) Measured Between March 15, 2011 – May 27, 2011

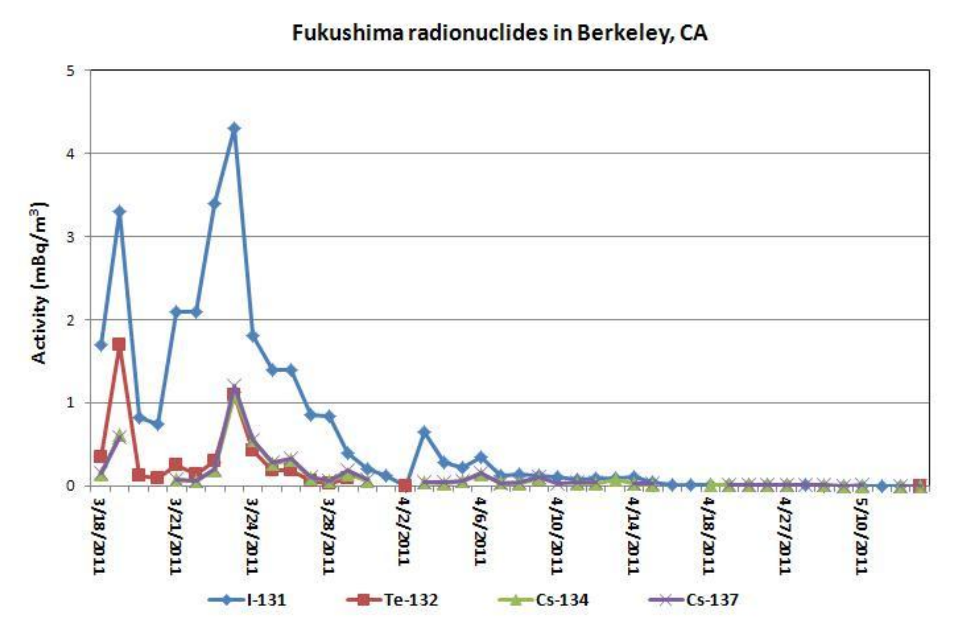


Figure 6.5. Concentration of Airborne Cesium and Iodine (mBq/m^3) Measured in Berkeley, CA

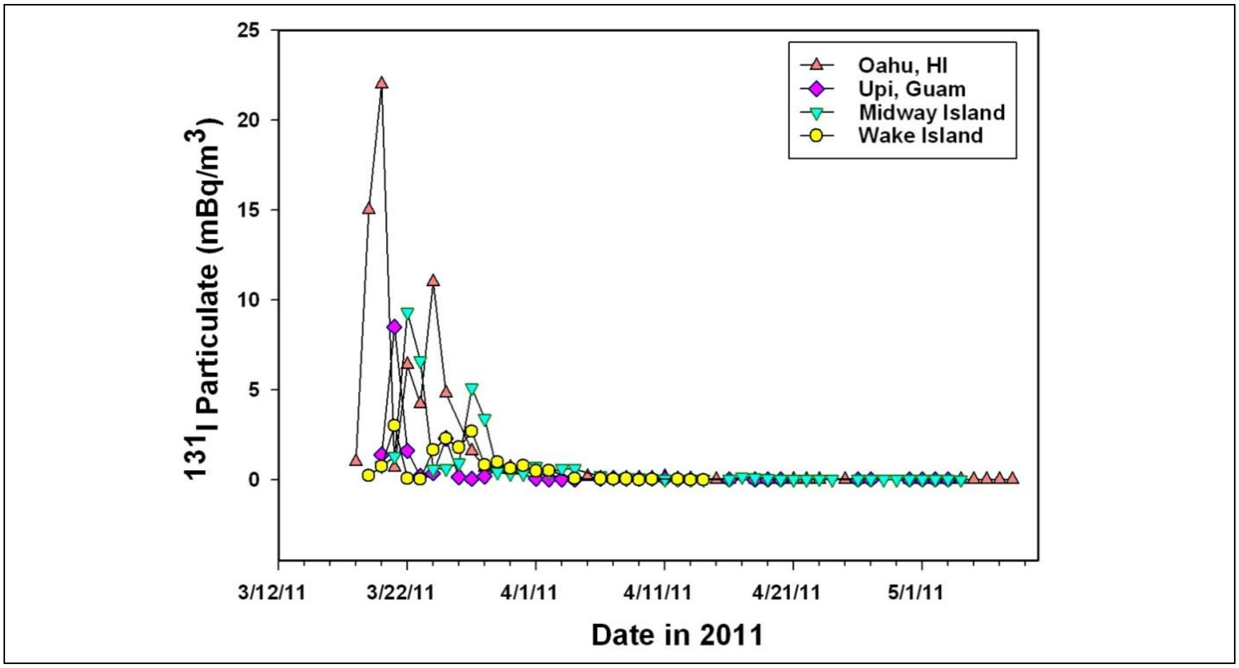


Figure 6.6. Concentration of Airborne I-131(mBq/m^3) Measured in Pacific Islands

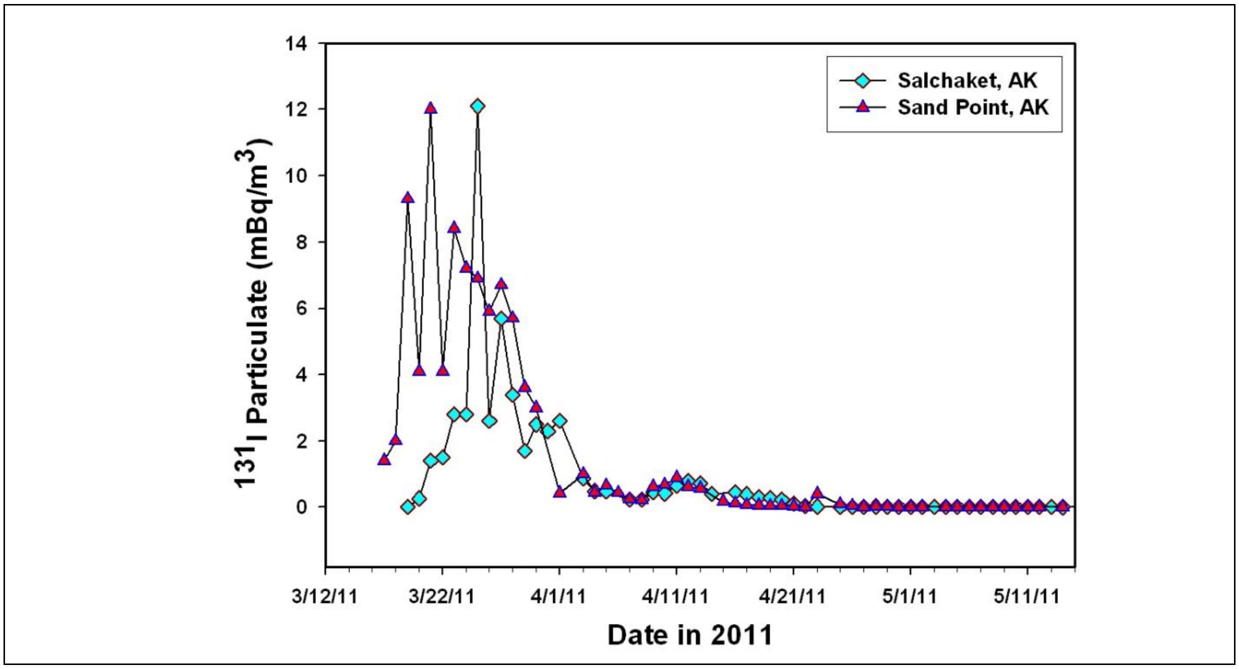


Figure 6.7. Concentration of Airborne I-131(mBq/m^3) Measured in Alaska

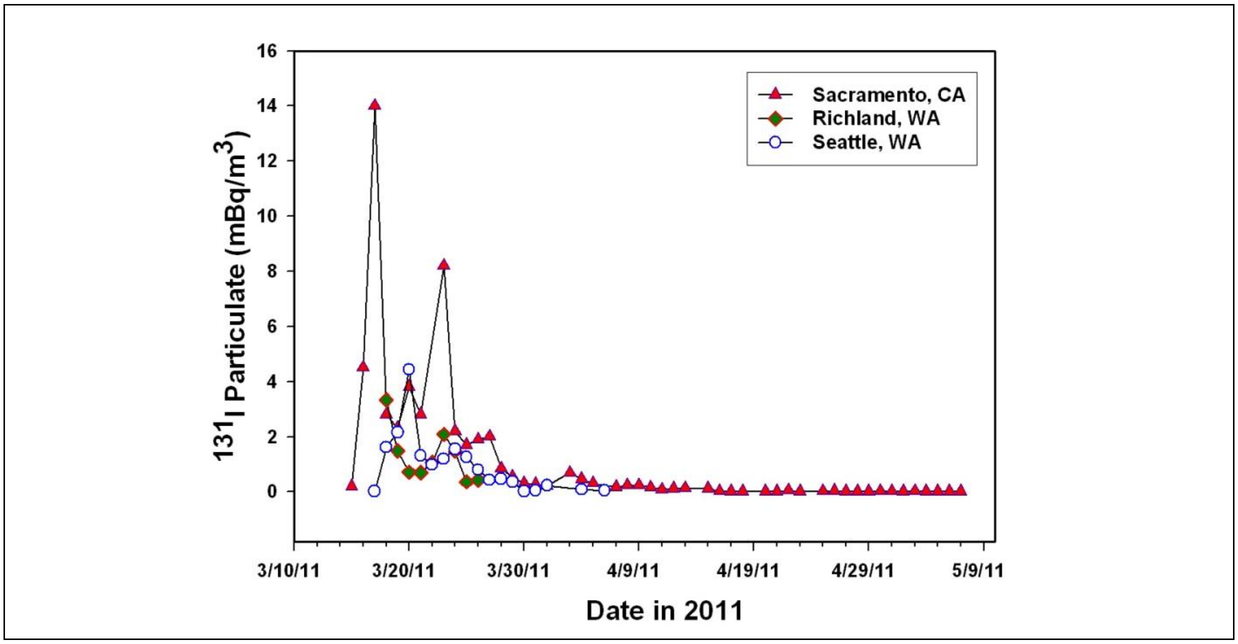


Figure 6.8. Concentration of Airborne I-131(mBq/m^3) Measured in west coast of the United States

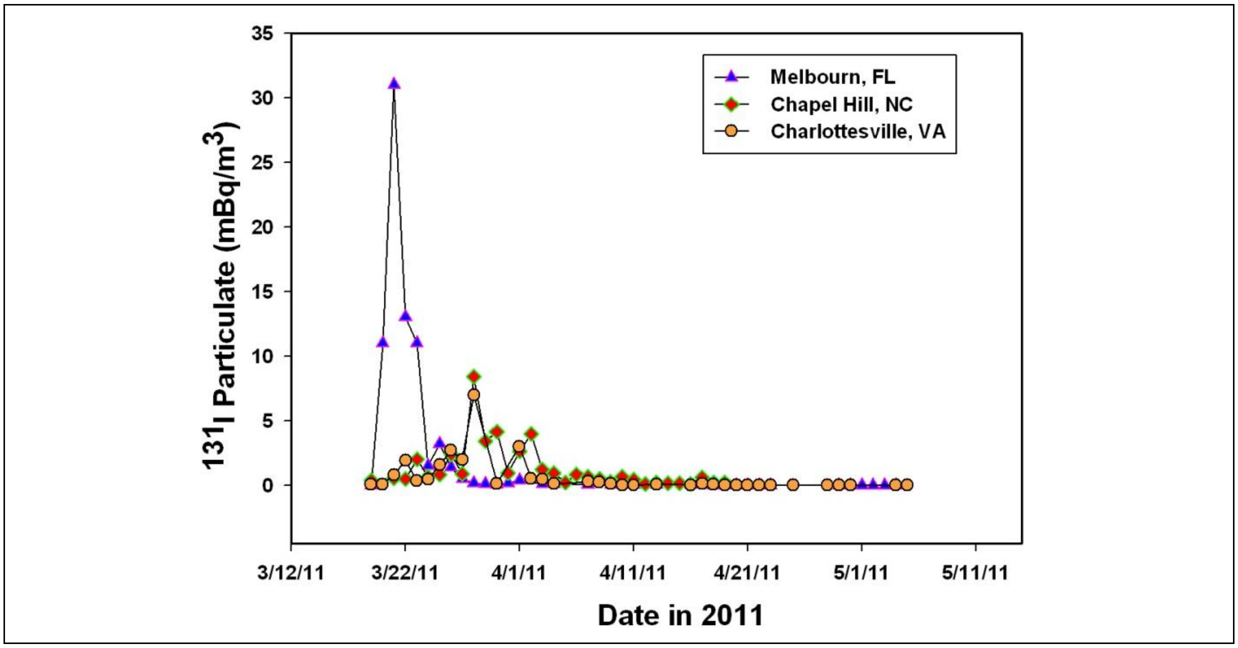


Figure 6.9. Concentration of Airborne I-131(mBq/m^3) Measured in East coast of the United States

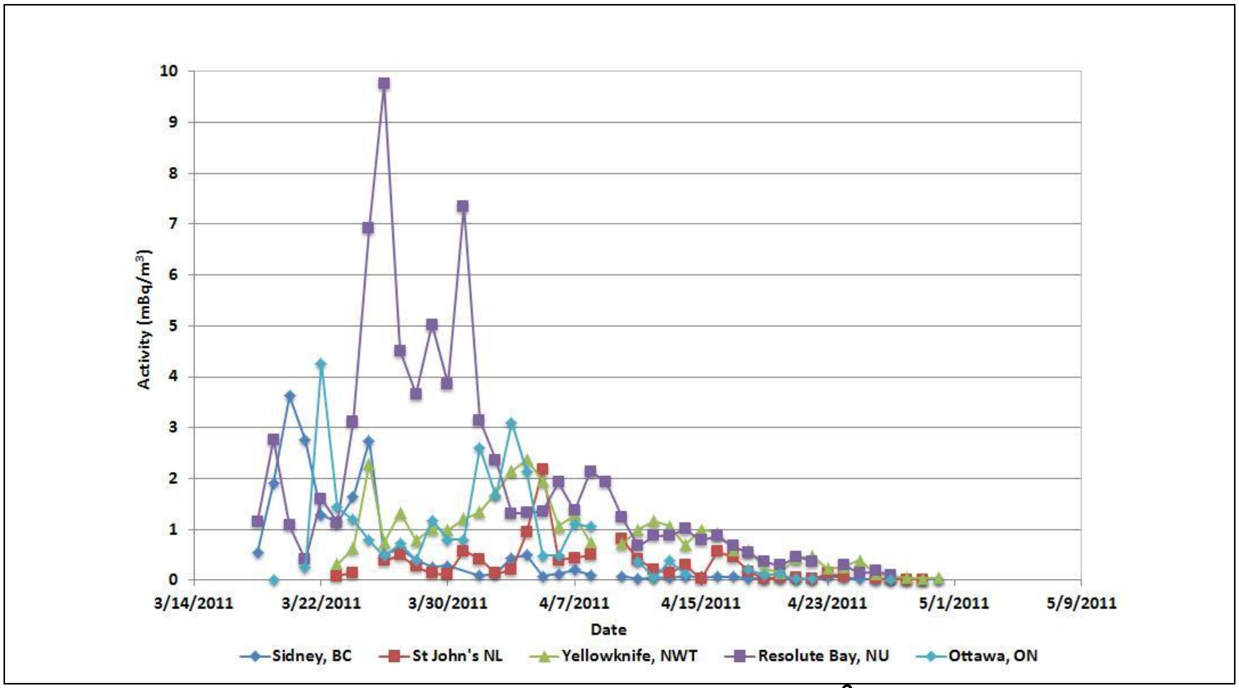


Figure 6.10. Concentration of Airborne I-131(mBq/m^3) Measured in Canada

Fukushima Radionuclides in Europe

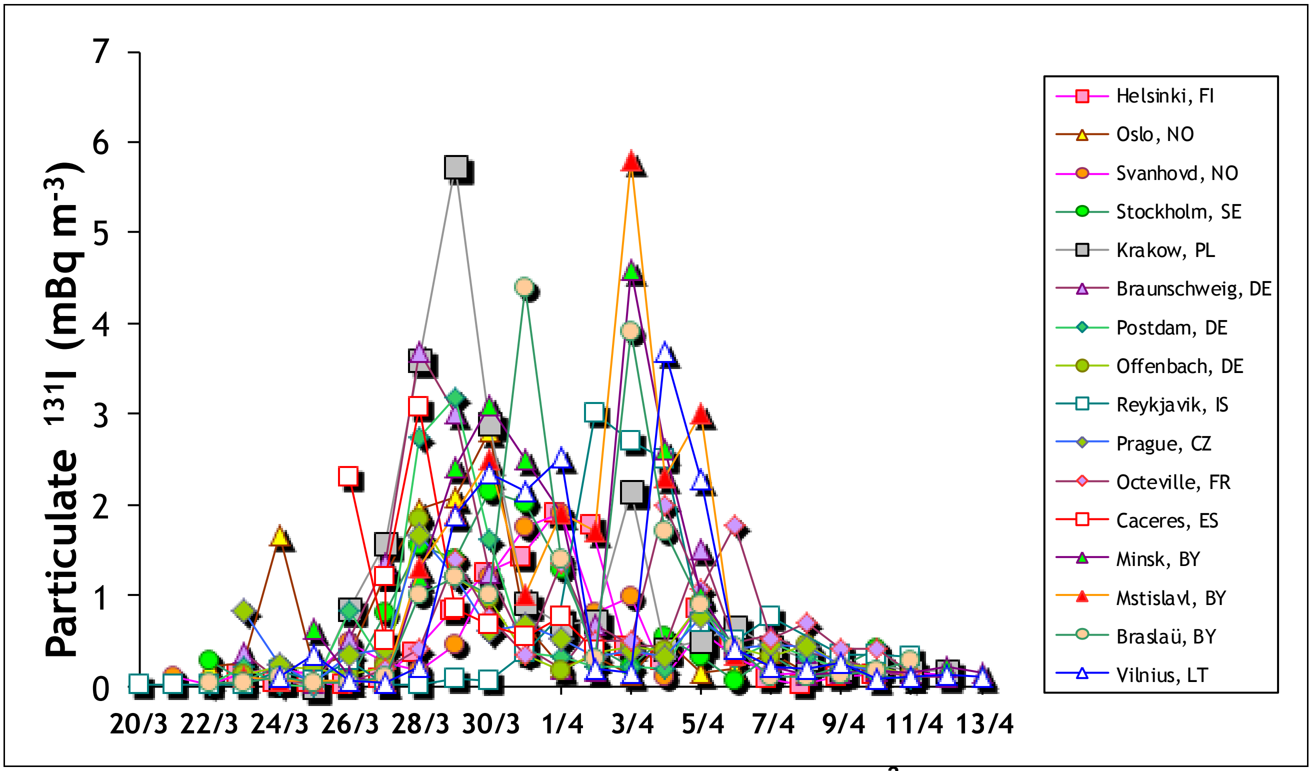


Figure 6.11. Concentration of Airborne I-131(mBq/m^3) Measured in western and central Europe

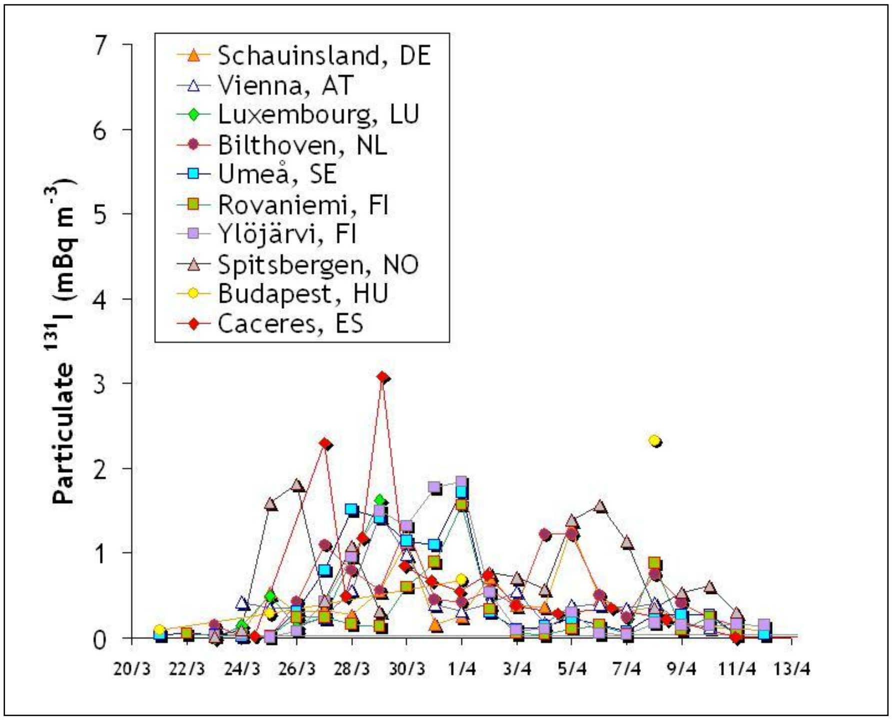


Figure 6.12. Concentration of Airborne I-131(mBq/m^3) Measured in western and central Europe

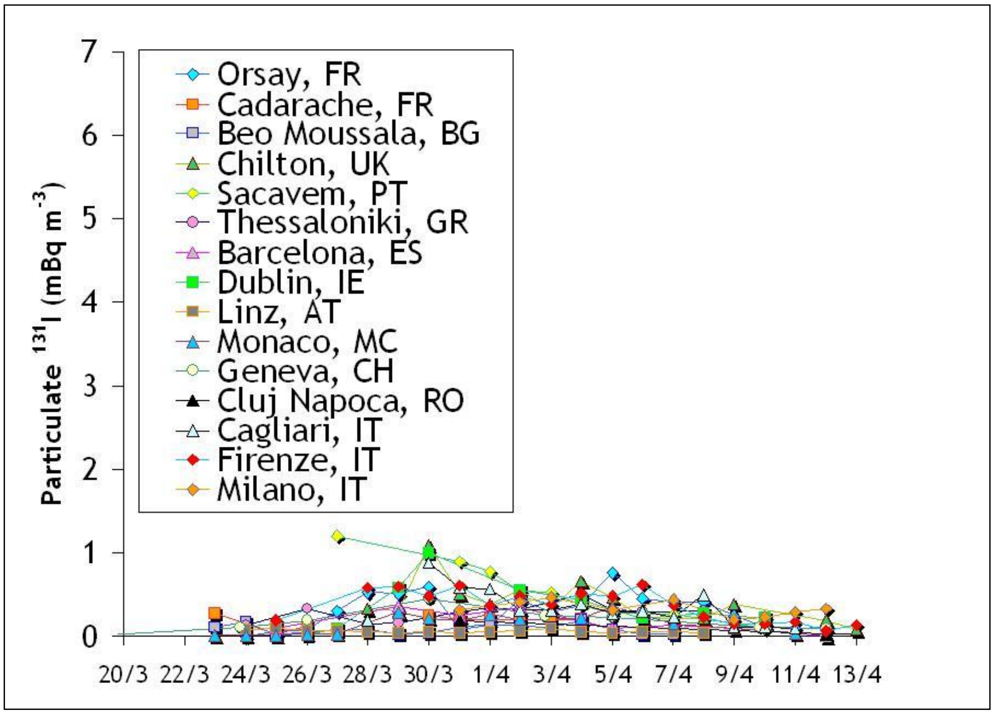


Figure 6.13. Concentration of Airborne I-131(mBq/m^3) Measured in southern Europe

Fukushima Radionuclides in Asia

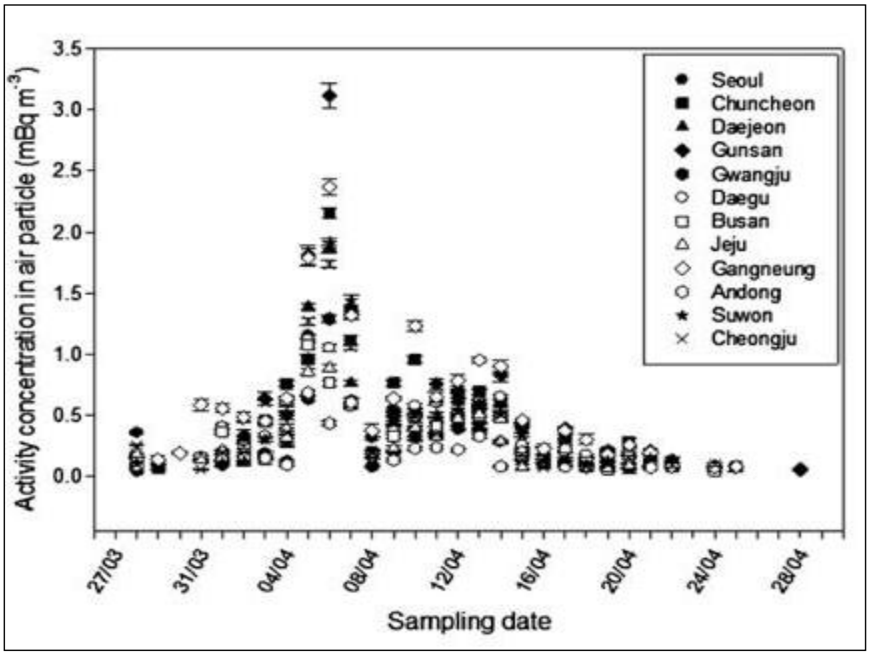


Figure 6.14. Concentration of Airborne I-131(mBq/m^3) Measured in South Korea

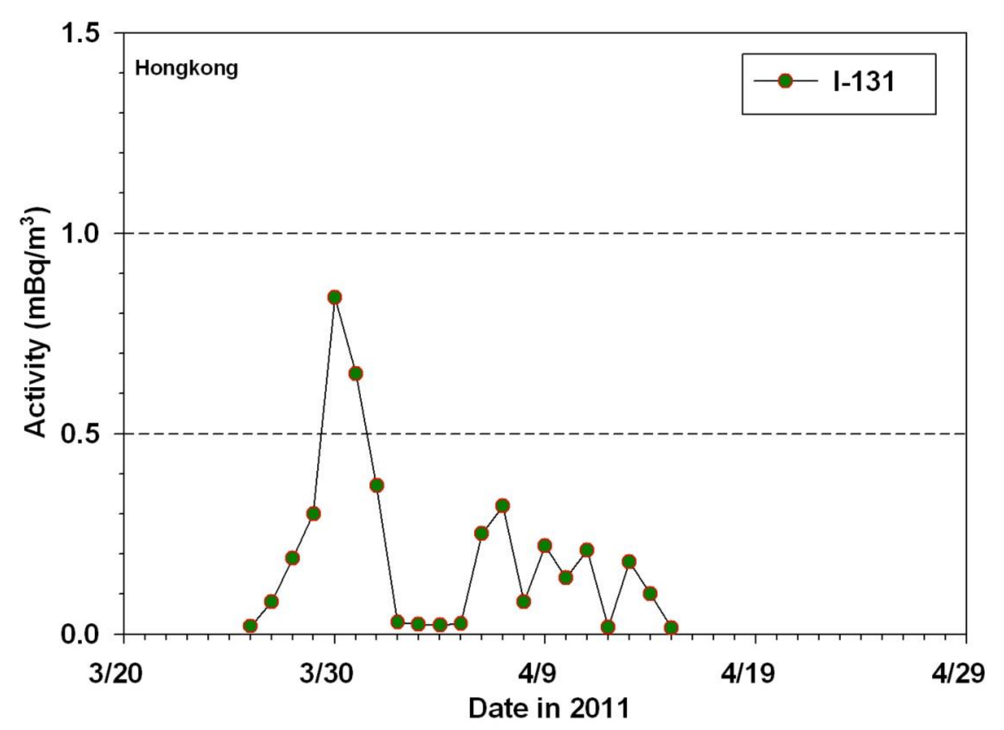


Figure 6.15. Concentration of Airborne I-131(mBq/m^3) Measured in Hongkong

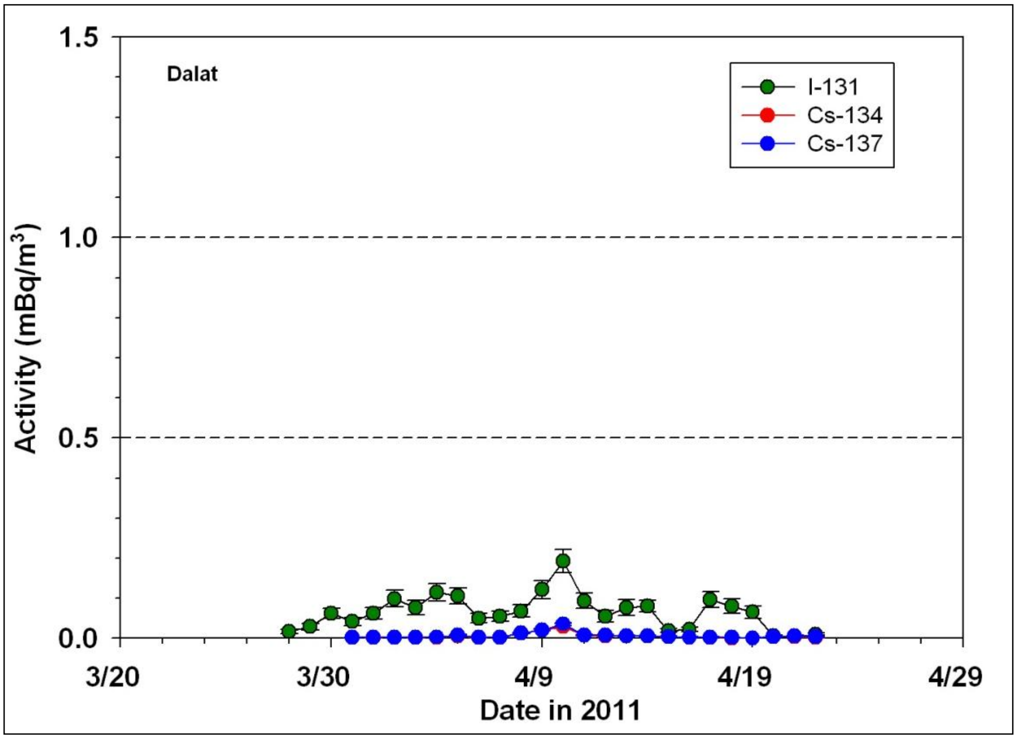


Figure 6.16. Concentration of Airborne I-131, Cs-134 and Cs-137 (mBq/m^3) Measured in Dalat, Vietnam

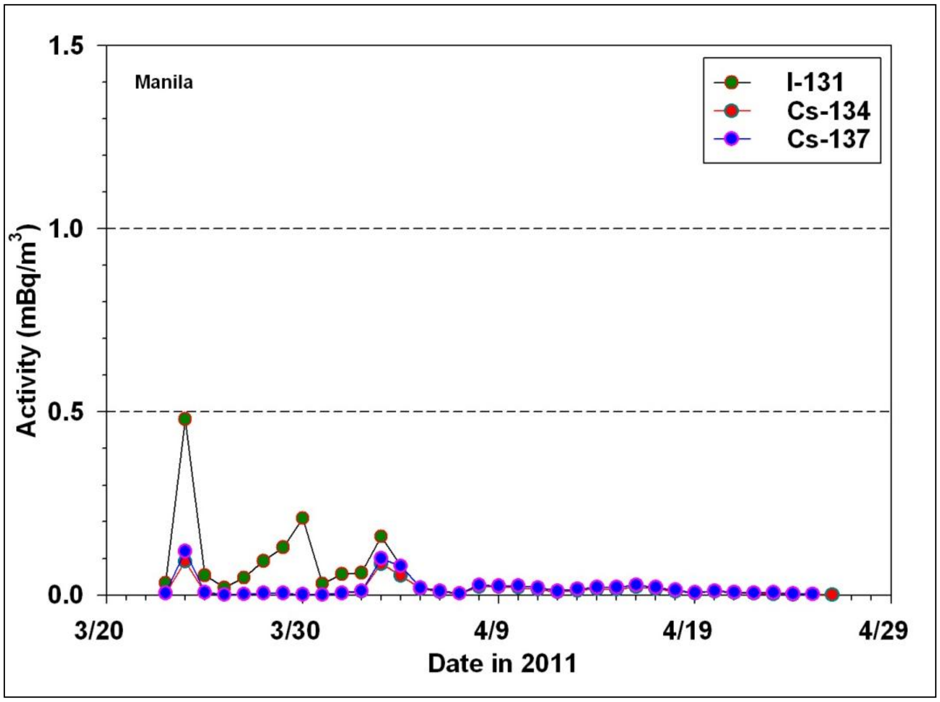


Figure 6.17. Concentration of Airborne I-131, Cs-134, and Cs-137 (mBq/m^3) Measured in Manila, Philippines

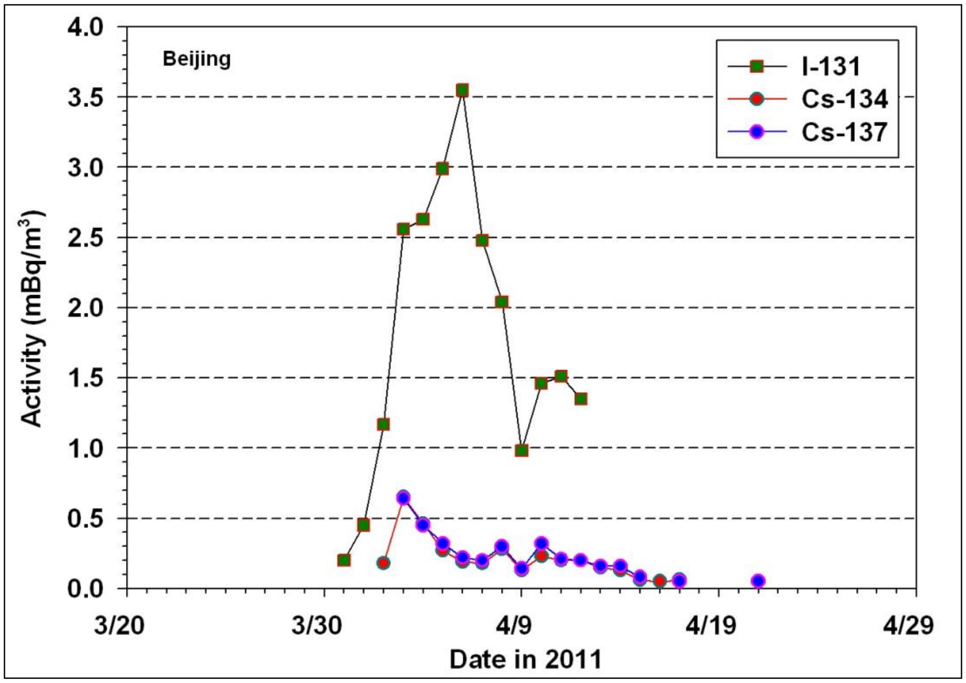


Figure 6.18. Concentration of Airborne I-131, Cs-134, and Cs-137 (mBq/m^3) Measured in Beijing, China

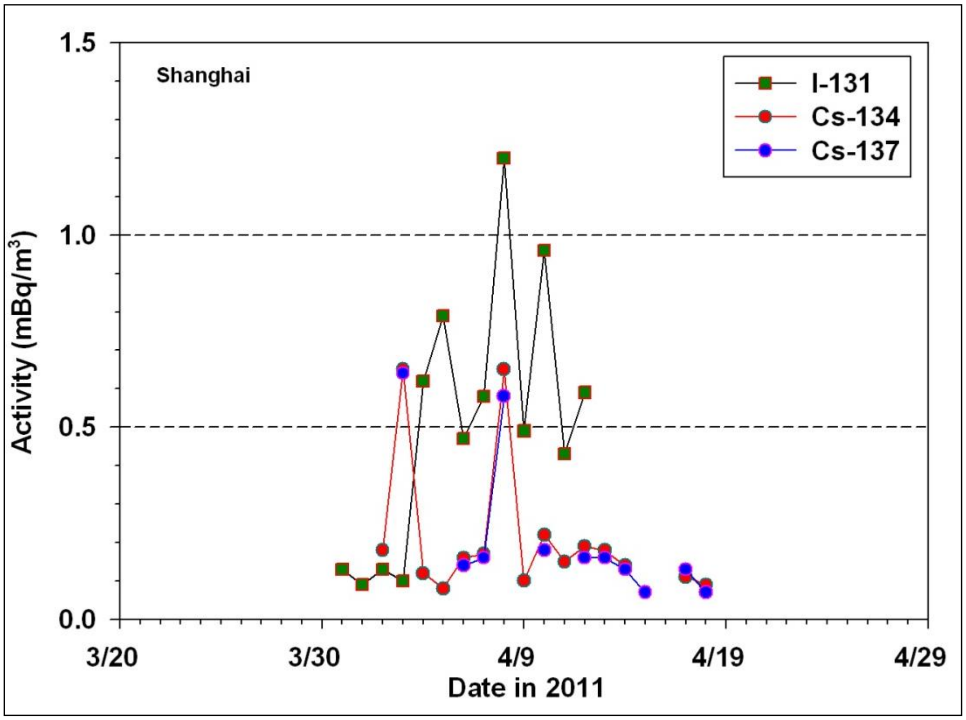


Figure 6.19. Concentration of Airborne I-131, Cs-134, and Cs-137 (mBq/m^3) Measured in Shanghai, China

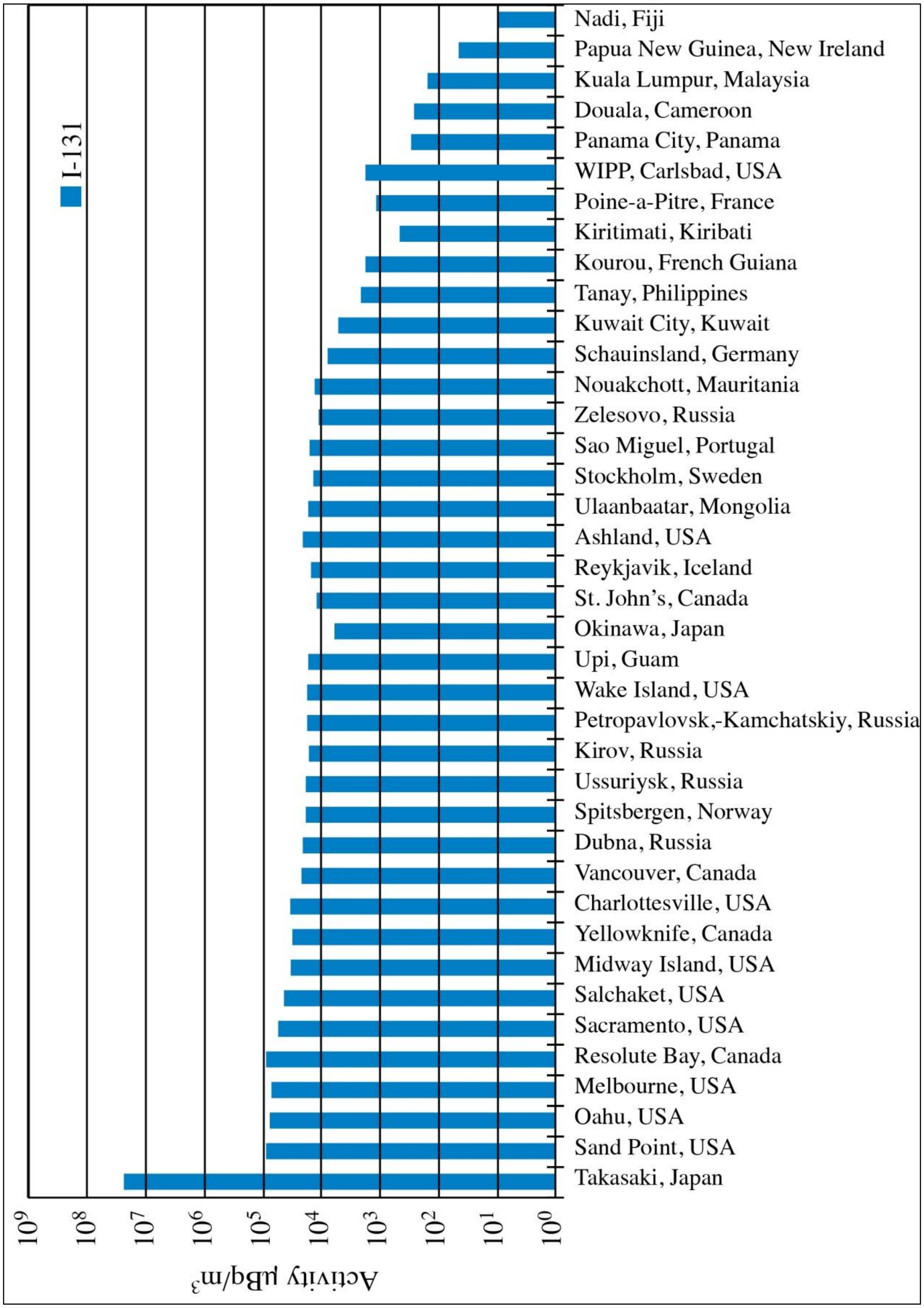


Figure 6.20. Concentration of Airborne I-131 (μBq/m^3) Measured by CTBTO monitoring stations around the world

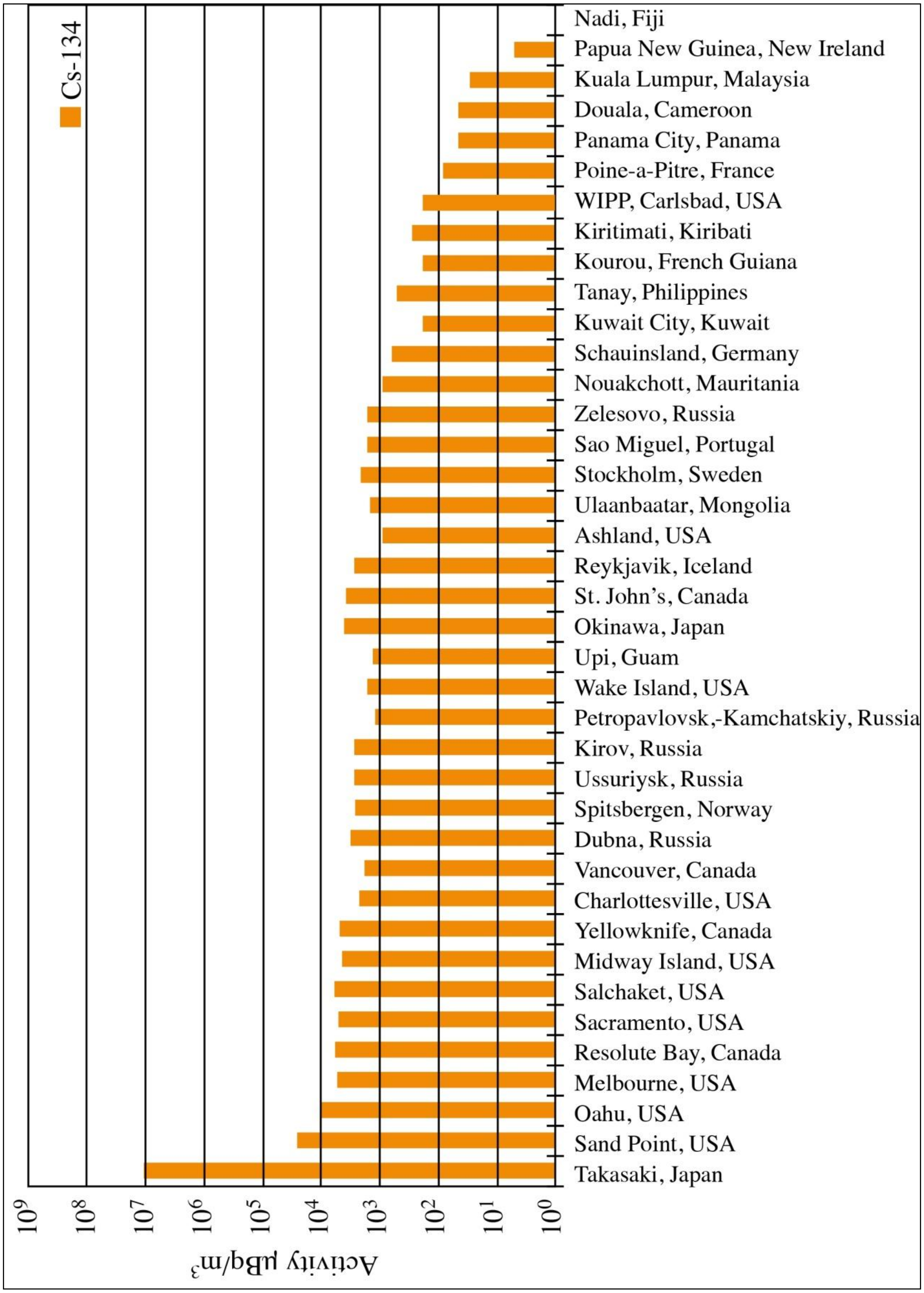


Figure 6.21. Concentration of Airborne Cs-134 ($\mu Bq/m^3$) Measured by CTBTO monitoring stations around the world.

Conclusion

This chapter provides an overview of the radionuclides measured across the northern hemisphere. Air monitoring across the northern hemisphere was increased following the first reports of atmospheric releases from the Fukushima-Daiichi NPP. It is important to note that all of the radiation levels detected outside Japan have been very low, well below any level of public and environmental concern. As of April 13, 2011 the average level of radioactivity picked up by the stations worldwide continued to decline, which is also due to the relatively short half-lives of ^{131}I (8 days) and ^{133}Xe (5.2 days). While the Fukushima radionuclides were detectable in the Northern hemisphere as far as China and the Philippines, countries outside Japan received very little deposition of radionuclides from the accident.

CHAPTER 7

An External Review of the CEMRC Quality Assurance Plan

Introduction

At the request of Interim Director Dr. George Mulholland, personnel from the Sandia National Laboratories (SNL) Carlsbad Office conducted a high-level external review of the governing quality assurance (QA) controlled documents for the Carlsbad Environmental Monitoring and Research Center (CEMRC) during the month of August, 2011.

The primary purpose of the review was to compare the CEMRC Quality Assurance Plan (QAP) and the CEMRC QA program procedures against the governing Washington TRU Solutions Quality Assurance Program (WP 13-1). In addition, SNL representatives also conducted a brief review of the technical program procedures for the Environmental Chemistry (EC), Organic Chemistry (OC), Radiochemistry (RC), Field Programs (FP), Informatics and Modeling (IM), and Internal Dosimetry (ID) functional areas to ensure that they met CEMRC QAP requirements for implementing procedures. Lastly, SNL representatives conducted a site visit of CEMRC laboratory areas, inspected records and controlled documents, and interviewed staff members in accordance with the review.

Results

The SNL review concluded that the CEMRC Quality Assurance Program adequately addressed the requirements of WP 13-1 Washington TRU Solutions LLC Quality Assurance Program Description. In addition, it was determined that the elements addressed in the CEMRC Quality Assurance Plan (CP-QAP-004) were satisfactorily implemented and effective. Lastly, SNL representatives stated that all CEMRC department managers were very knowledgeable of the work being conducted and were very conscientious of CEMRC QA requirements including applicable QA records produced during audit activities.

Recommendations and Observations

Observation 1: SNL reviewers stated that there is a contradiction between CP-PROC-012 (Nonconformances and Non-Routine Events) which states that a trend analysis will be performed annually and WP-13 which states that a trend analysis will be performed semi-annually.

Following a conversation with CEMRC personnel, this contradiction will not be addressed as CEMRC personnel believe that an annual trend analysis of nonconformances or non-routine events is sufficient given the low number of NCRs/NREs issued on an annual basis.

Recommendation 1: For procedures RC-PROC-001 (Calibration, Operation, & Maintenance of Canberra Intrinsic-Germanium Coaxial Gamma Spectrometers and Intrinsic-Germanium Well Gamma Spectrometers) section 3.2 (Liquid Sample Calibration) and RC-PROC-008 (Calibration, Operation, And Maintenance of a Canberra Oasis Alpha Spectrometer Using ORTEC Alphavision Software) section 3.3.13(Detector Background Determination), SNL reviewers stated that the procedure and acceptance criteria were not adequately defined.

CEMRC personnel stated that they will review and revise the procedures during their next regularly scheduled review cycle.

Recommendation 2: SNL reviewers stated that procedure RC-PROC-009 (Calculating Alpha Spectroscopy Analysis Results) did not contain a safety section per the requirements of CP-QAP-004.

CEMRC personnel stated that they will review and revise the procedure during its next regularly scheduled review cycle.

Recommendation 3: SNL reviewers stated that procedure RC-PROC-027 (Determination of Americium and Plutonium in 10-gram Sample of Soil) did not contain an appendices or QA section per the requirements of CP-QAP-004.

CEMRC personnel stated that they will review and revise the procedure during its next regularly scheduled review cycle.

All other observations and recommendations made by SNL personnel were corrected during the course of the review.

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 financial assistance grant entitled "Carlsbad Environmental Monitoring and Research Program" (CEMRP) from the DOE to NMSU. The CEMRP was initially 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 Washington TRU Solutions (WTS) and Los Alamos National Labs (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 reinstated 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. In 2008, the Louisiana Energy Service's (LES) Nuclear Enrichment Facility (NEF) in Eunice began developing a program with CEMRC. Dr. James Conca served as Director of the CEMRC until August 2010. In September 2010, Dr. George Mulholland became interim director of CEMRC until January 2012. In January 2012, Mr. Russell Hardy was named as the Director or CEMRC and still holds the Director position as of December 2012.

Temporary office accommodations for the CEMRC initially were provided at the NMSU-Carlsbad campus 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 permanent facility. 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 the 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 with the unit returning 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 to 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-related performance assessments with respect to actinide elements in brine under repository conditions. The renovation was completed in 2006. Subsequently, other laboratory improvements occurred in 2006 such as the building of a new volatile organic compound (VOC) laboratory and the replacement of most of the ventilation system. These improvements were jointly funded by DOE, WTS and CEMRC. Additionally, a new sector-field mass spectrometry laboratory for uranium analysis was completed at CEMRC in 2008. Lastly, replacement of major portions of the facility began in 2008 and will continue to 2012, 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 activity levels.

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), managed by Dr. Abbas Ghassemi. In 2011, CEMRC, WERC, and SWTDI were reorganized within the College of Engineering and now each report to the Associate Dean for Engineering Research, Dr. Martha Mitchell.

APPENDIX B: RECENT PUBLICATIONS

Author	Title	Publisher/Conference
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
P. Thakur, J. L. Conca, G. R. Choppin	Complexation studies of Cm(III),Am(III), and Eu(III) with linear and cyclic carboxylates and polyaminocarboxylates.	**J. Coordination Chemistry**, vol. 64, p. 3214–3236, 2011.
P. Thakur, Y. Xiong, M. Borkowski, G. R. Choppin	Improved Thermodynamic Model for Interaction of EDTA with Trivalent Actinides and Lanthanide	**Geochim Cosmochim Acta (under review)**
P. Thakur, J.L. Conca and G.R. Choppin, C. J. Dodge and A. J. Francis	Complexation Thermodynamics and Structural Studies of Trivalent Actinide and Lanthanide complexes with DTPA, MS-325 and HMDTPA,	**Radiochim Acta (In Press**)
Kumar, A.	VOC emissions and ozone formation from spraying solvent-based pesticides.	**2nd world Congress on Analytical and Bioanalytical Techniques, San Francisco, CA, December 16-17, 2011. (Conference Presentation)**

APPENDIX C: PERFORMANCE TESTS AND AUDITS

Below are summaries of external and internal audits, and results for three performance tests; one for Whole Body Dosimetry (Table C.1, Table C.2, and Figure C.1), one for Environmental Chemistry Inorganic analysis (Figure C.2), and two for radiochemical analyses (Tables C.3 and C.5). Table C.4 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 D.4).

Table C.3 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 two analysis results, which were for ^{241}Am in the filter matrix and gross beat activity in filter, did not meet the acceptance criteria.

Table C.5 shows NIST results for filters, water and soil. 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 ≤ 10%.

CEMRC MANAGEMENT ASSESSMENT QUALITY ASSURANCE REPORT

January 1, 2011 – December 31, 2011

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, 2011 through December 31, 2011.

Currently, there are 70 active procedures under the CEMRC Controlled Document Program. These procedures are scheduled for review every two years. Thirty-four vendors are currently qualified.

An external audit was conducted during the past year on two CEMRC programmatic areas: Organic Chemistry and Internal Dosimetry. In June 2011, Washington TRU Solutions (WTS) audited the Volatile Organic Compound Monitoring Program (Organic Chemistry) and the In-Vivo Radiobioassay Program (Internal Dosimetry). The audit led to recertification of each program with no findings and two 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 nine CEMRC programmatic areas in 2011. Eleven non-routine events (NREs) and two nonconformances (NCRs) were recorded for most recent assessment. All NREs have been closed with the exception of one (NRE 113011RB43), which is to be closed when the WBC detector 10 is repaired and returned from Canberra. Both NCRs have been closed. As with the previous annual assessment, none of the incidents involved implementation of a center-wide procedure. It should also be noted that NREs and NCRs, 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.

Table C.1. Blind Check Study for Internal Dosimetry Department 2010/2011 by the Oak Ridge National Laboratory (ORNL) Inter-comparison Studies In-vivo Program

Inter-comparison Studies In-vivo Program Report

Carlsbad Environmental Monitoring & Research Center

2nd Quarter Calendar Year 2010

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	96.92 +/ - 4.85	98.27 +/- 4.91	1.4
Co-60	325.24 +/- 16.26	328.17 +/- 16.41	0.90
Co-57	109.99 +/- 5.50	109.89 +/- 5.49	- 0.09
Y-88	70.08 +/- 3.50	70.13 +/- 3.51	0.07
Ba-133	369.97 +/- 18.50	370.10 +/- 18.51	0.04

3rd Quarter Calendar Year 2010

Set I

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	141.4 +/- 7.1	144.11 +/- 7.21	1.9
Co-60	216.1 +/- 10.8	217.85 +/- 10.89	0.8
Co-57	75.7 +/- 3.8	75.46 +/- 3.77	- 0.3
Y-88	60.2 +/- 3.0	60.07 +/- 3.00	- 0.2
Ba-133	269.7 +/- 13.5	273.60 +/- 13.68	1.4

4th Quarter Calendar Year 2010

Set A

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	180.0 +/- 9.0	182.23 +/- 9.11	1.2
Co-60	151.2 +/- 7.6	152.77 +/- 7.64	1.0
Co-57	88.7 +/- 4.4	90.64 +/- 4.53	2.2
Y-88	50.2 +/- 2.5	50.05 +/- 2.50	- 0.3
Ba-133	175.9 +/- 8.8	180.57 +/- 9.03	2.7

Table C.1. Blind Check Study for Internal Dosimetry Department 2010/2011 by the Oak Ridge National Laboratory (ORNL) Inter-comparison Studies In-vivo Program (Continued)

1st Quarter Calendar Year 2011

Set D

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	113.8 +/- 5.7	115.47 +/- 5.77	1.5
Co-60	125.4 +/- 6.3	126.98 +/- 6.35	1.3
Co-57	60.5 +/- 3.0	60.99 +/- 3.05	0.8
Y-88	Not Available	Not Available	N/A
Ba-133	213.1 +/- 10.7	215.45 +/- 10.77	1.1

2nd Quarter Calendar Year 2011

Set B

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	76.8 +/- 3.8	77.45 +/- 3.87	0.8
Co-60	95.5 +/- 4.8	96.27 +/- 4.81	0.8
Co-57	55.5 +/- 2.8	57.69 +/- 2.88	3.9
Y-88	Not Available	Not Available	N/A
Ba-133	160.7 +/- 8.0	162.29 +/- 8.11	1.0

3rd Quarter Calendar Year 2011

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	160.7 +/- 8.0	162.00 +/- 8.10	0.8
Co-60	80.0 +/- 4.0	80.38 +/- 4.02	0.5
Co-57	130.7 +/- 6.5	137.33 +/- 6.87	5.1
Y-88	Not Available	Not Available	N/A
Ba-133	101.4 +/- 5.1	120.20 +/- 5.11	0.8

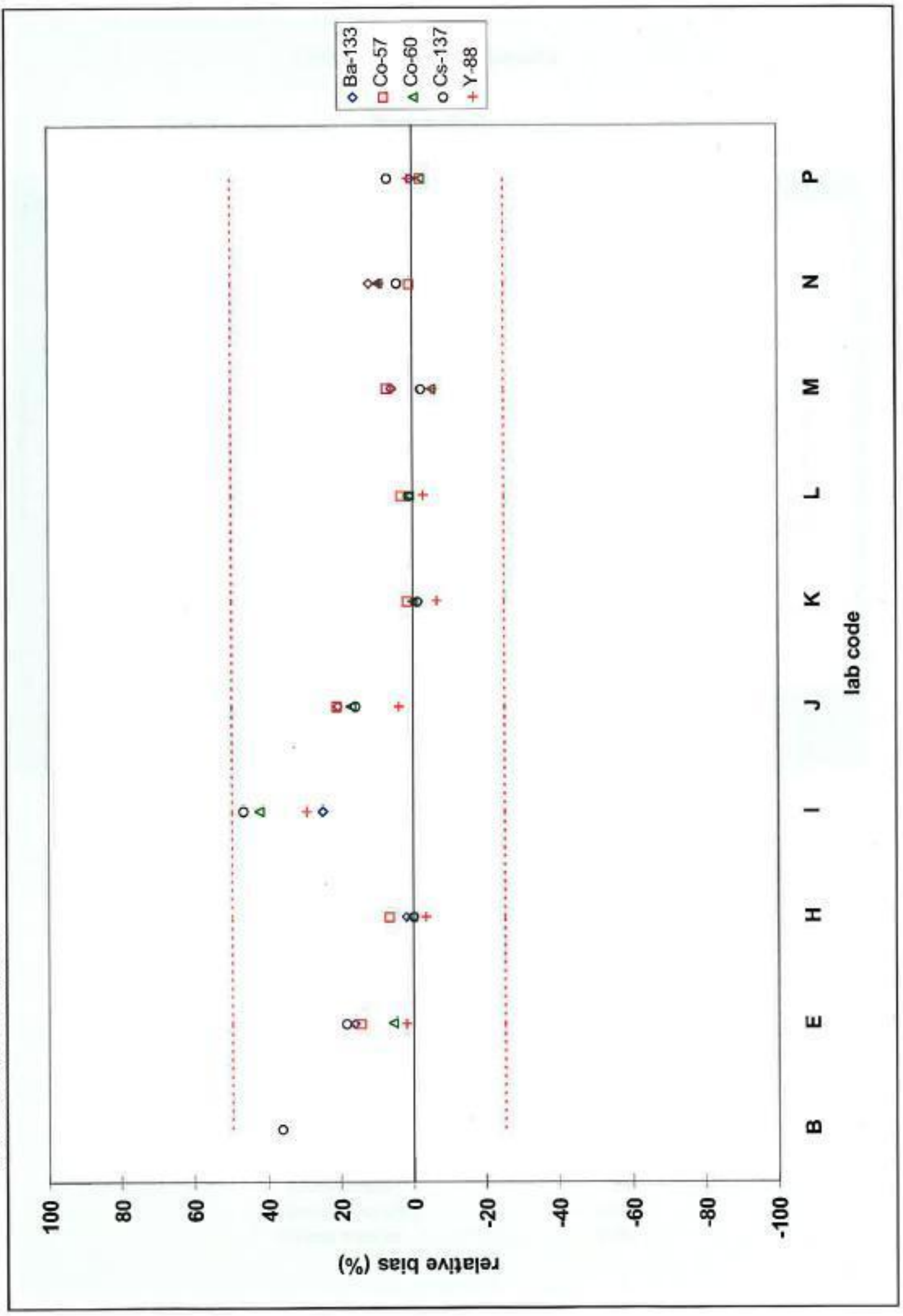
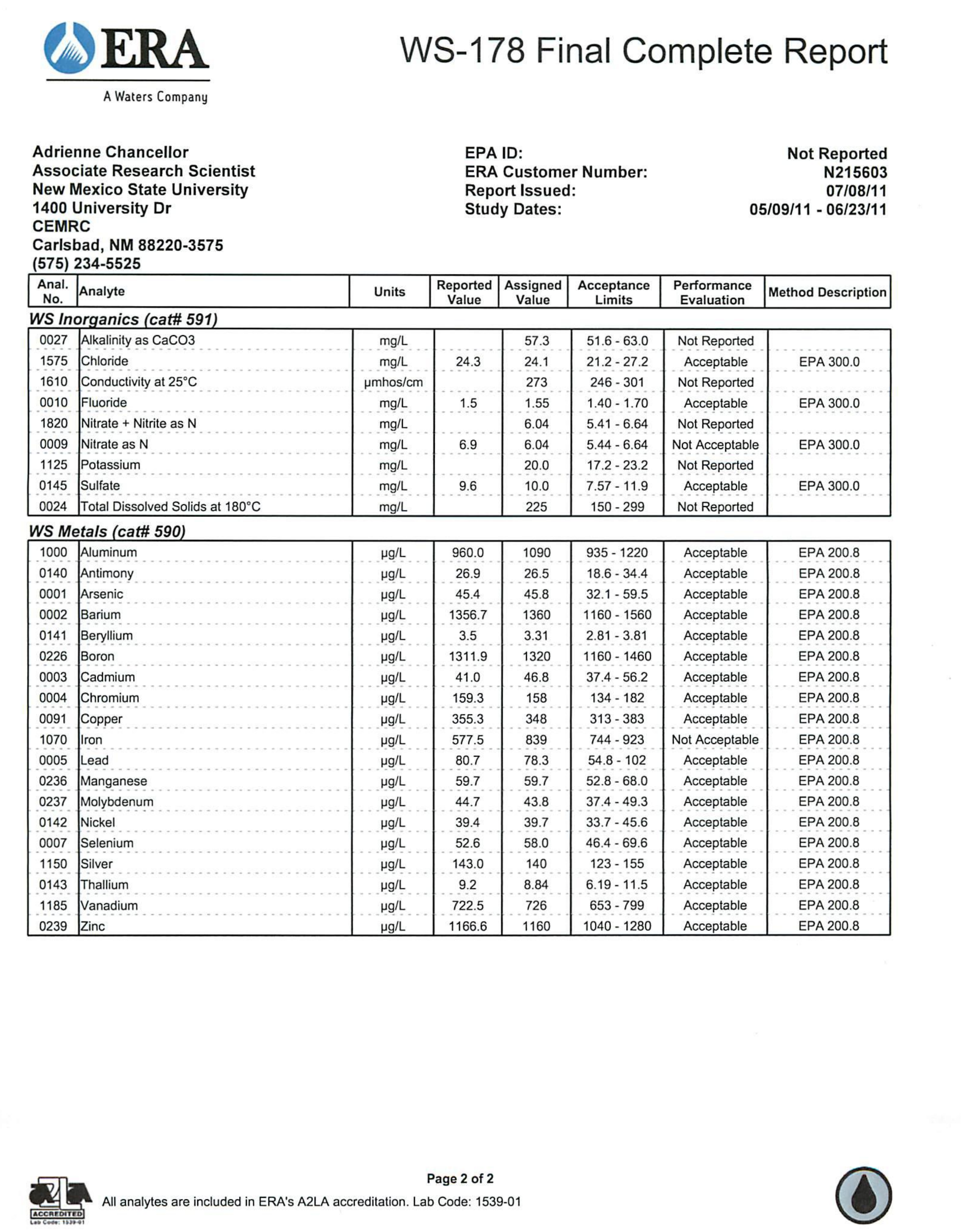


Figure C.1. Comparison of Results for Ten Internal Dosimetry Laboratories in the U.S. During 2011 by the ORNL Intercomparison Studies In-vivo Program
CEMRC is Lab L. For all years that CEMRC has participated in the ORNL program, CEMRC has consistently performed better than all other labs in this area.

Table C.2. Quality Assurance/Quality Control for Internal Dosimetry 2011 Audits

Agency	Date	Conclusion	Reason
Oak Ridge National Laboratory, Inter-comparison Studies Program	Quarterly	Pass	External QC
WTS	May 7, 2011 – May 9, 2011	No findings 2 observations Pass	Annual
Sandia National Laboratories	August 2011 - March 2012	No observations Satisfactory Performance	External Review



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 $CaCO_3$	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

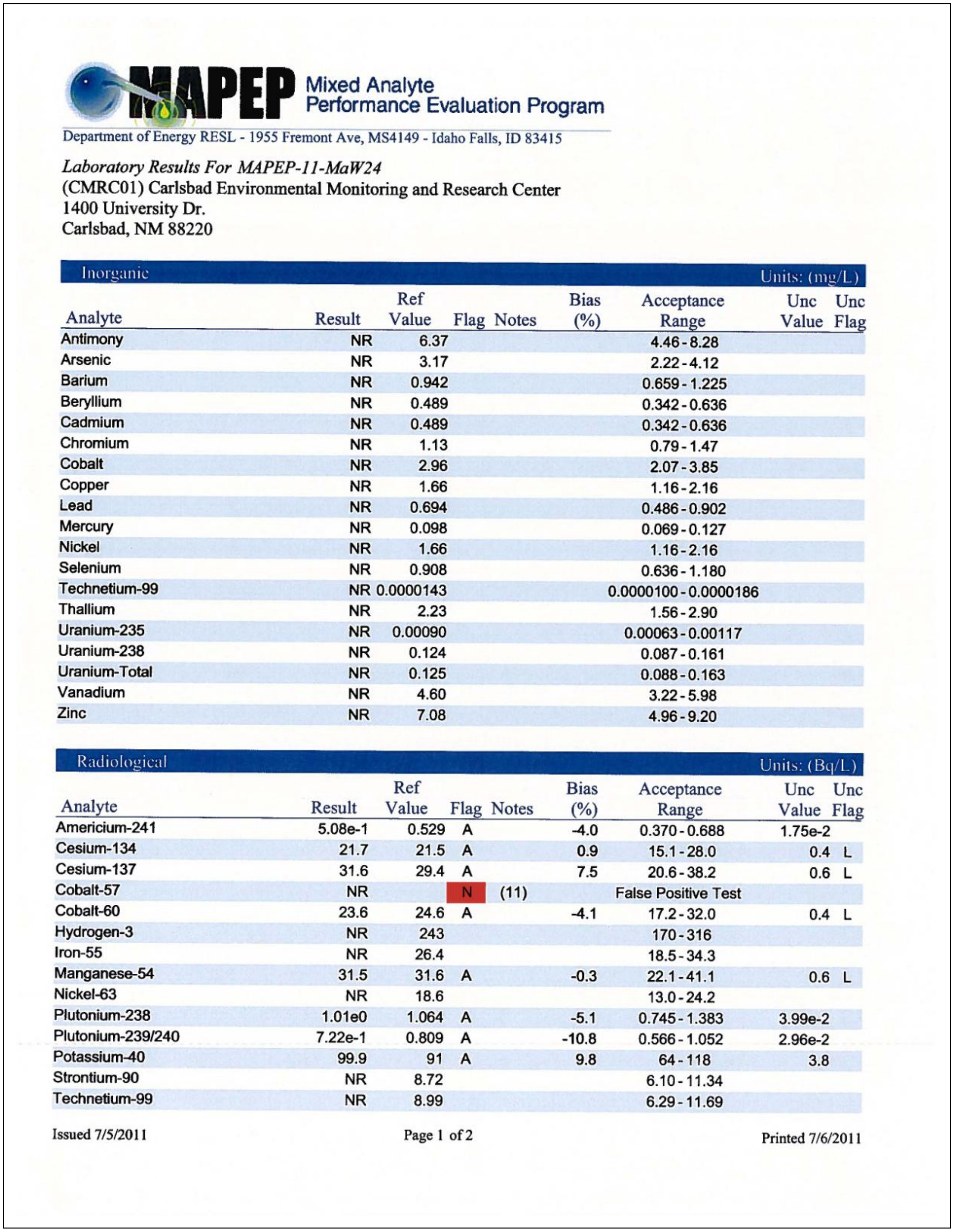
Page 2 of 2

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

Figure C.2. Blind Check 2011 Environmental Chemistry Inorganic Analyses

Table C.3. Radiochemistry MAPEP 2011 Intercomparison Results

The full MAPEP reports are available at http://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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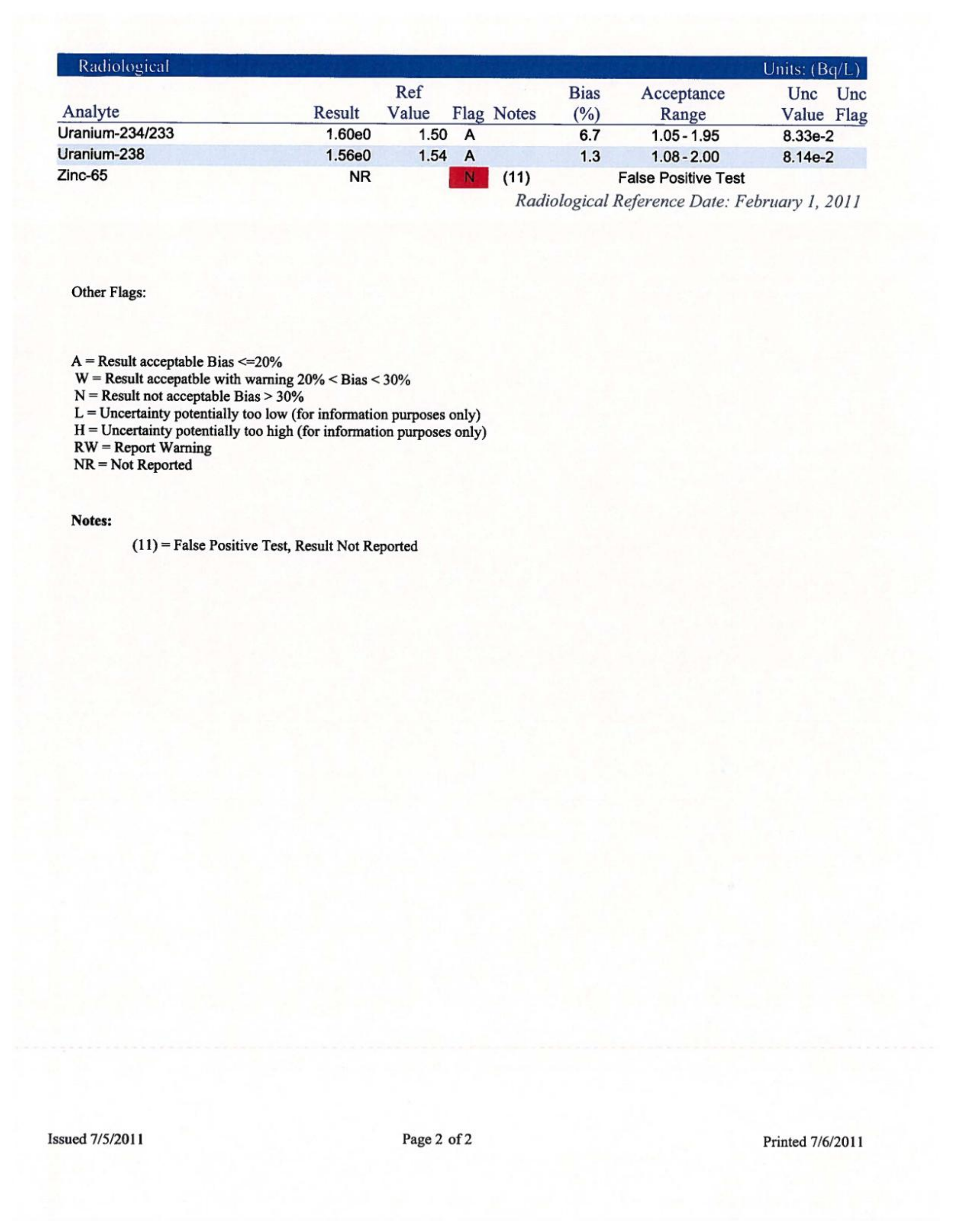
Table C.3. Radiochemistry MAPEP 2011 Intercomparison Results
(continued)



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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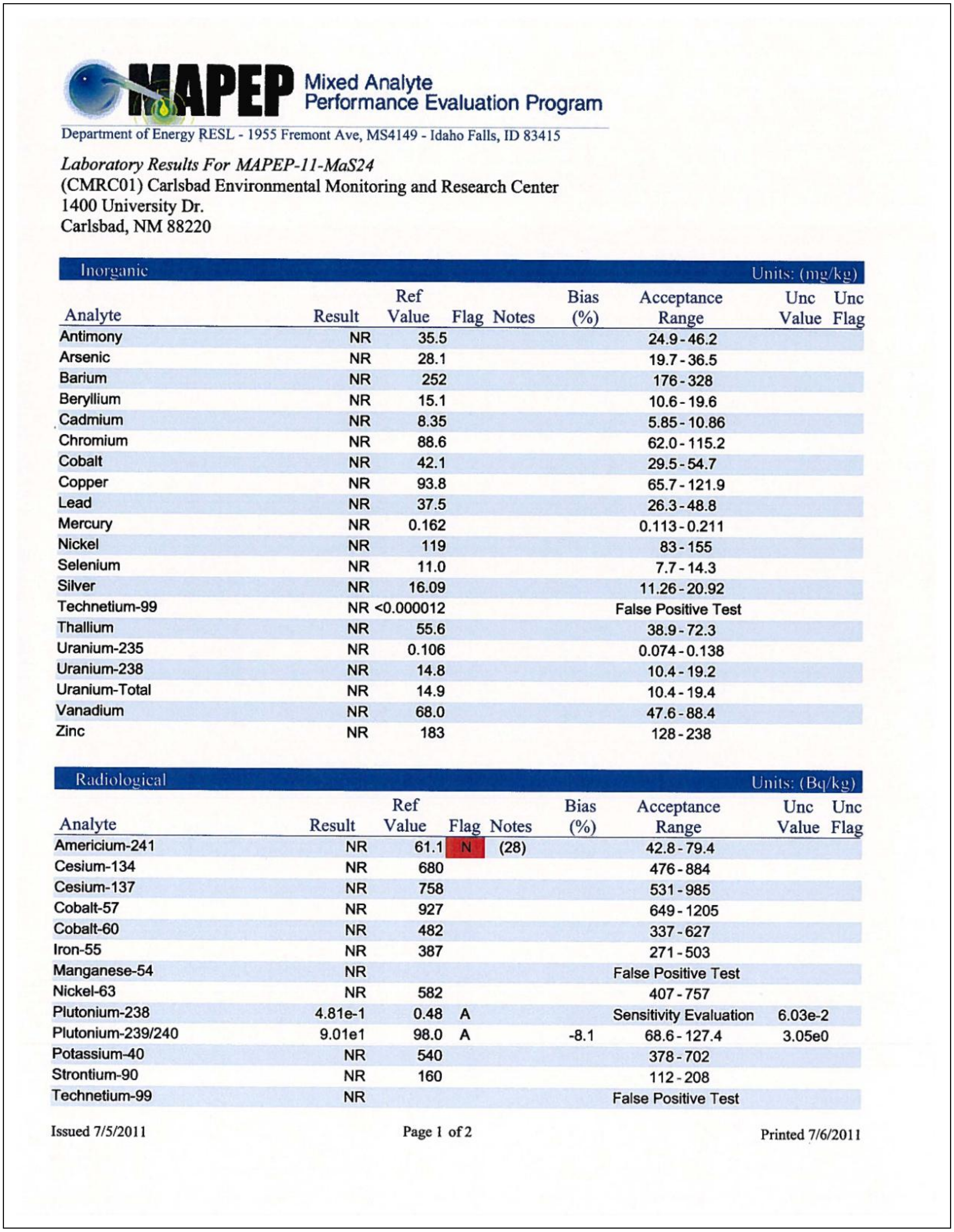
Table C.3. Radiochemistry MAPEP 2011 Intercomparison Results
(continued)



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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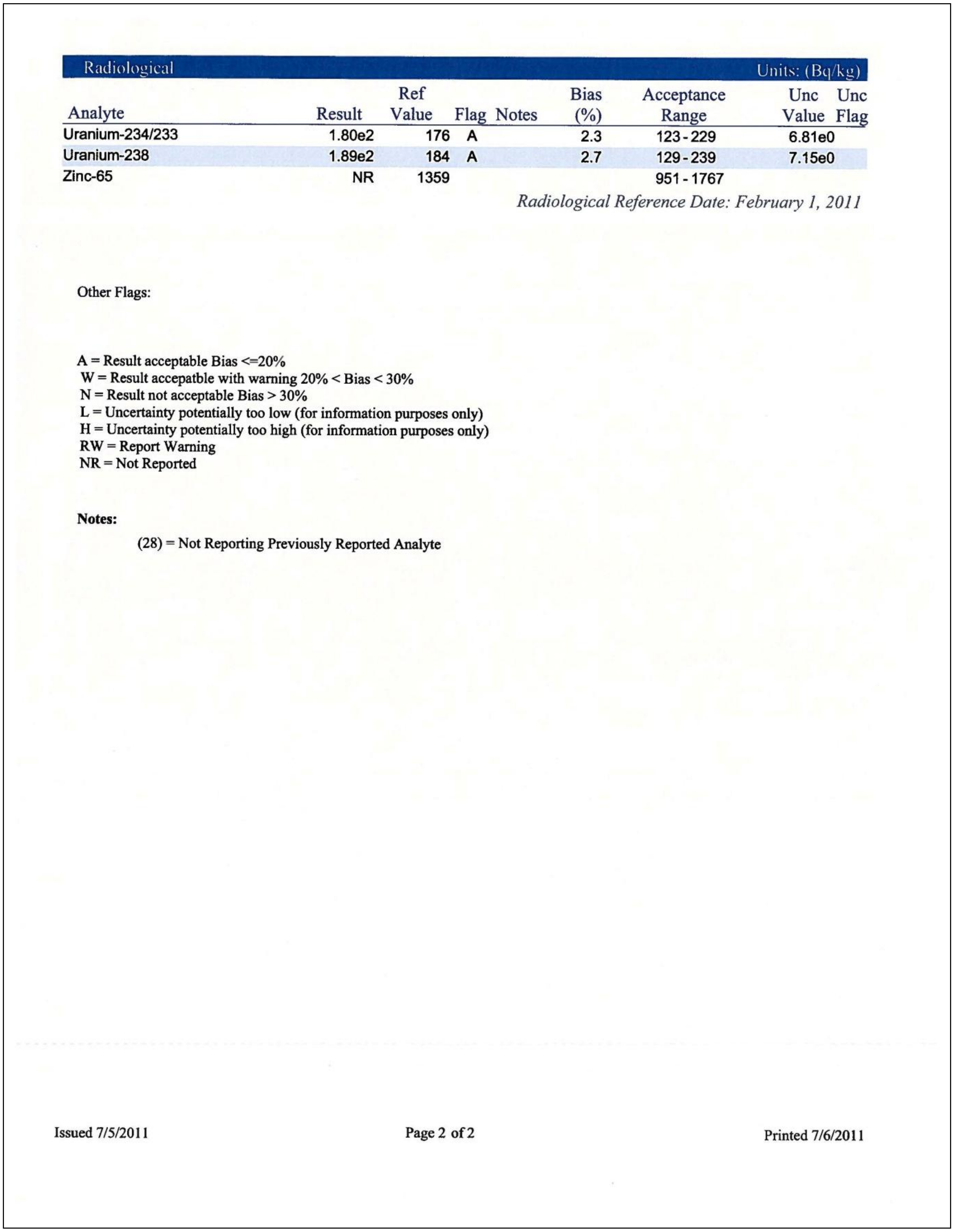
Table C.3. Radiochemistry MAPEP 2011 Intercomparison Results
(continued)



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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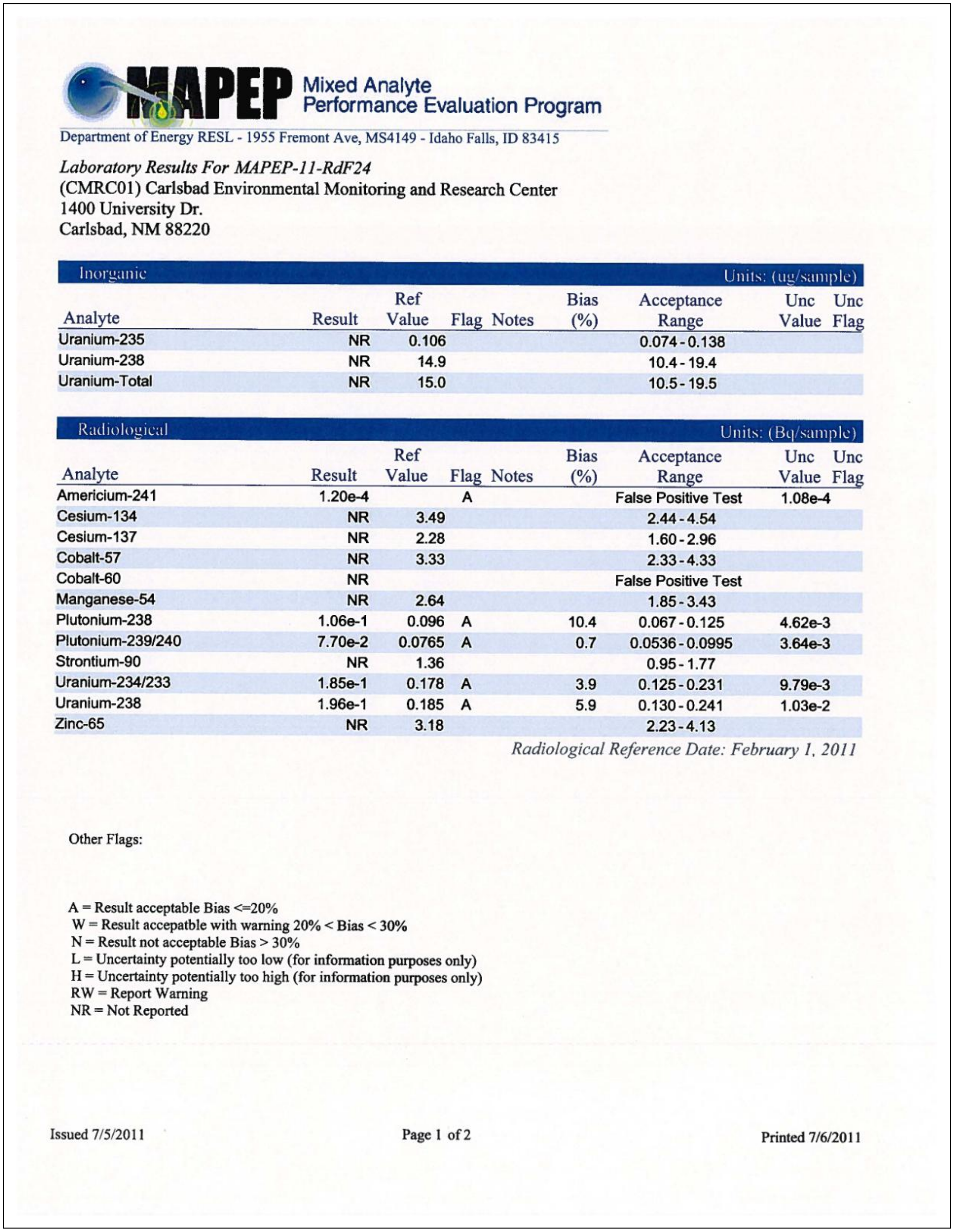
Table C.3. Radiochemistry MAPEP 2011 Intercomparison Results
(continued)



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

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Table C.3. Radiochemistry MAPEP 2011 Intercomparison Results
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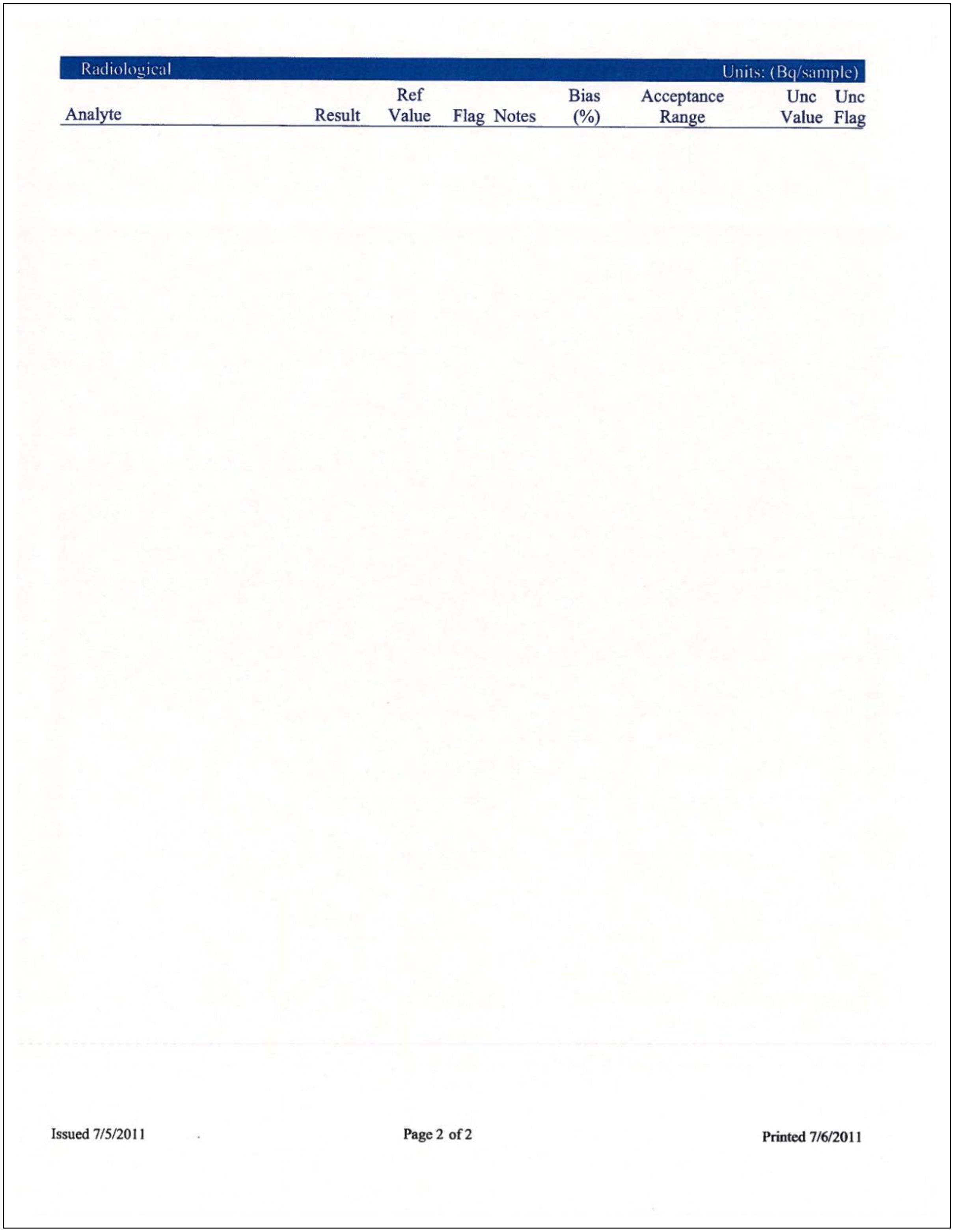

Radiological

Units: (Bq/sample)

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

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Table C.3. Radiochemistry MAPEP 2011 Intercomparison Results
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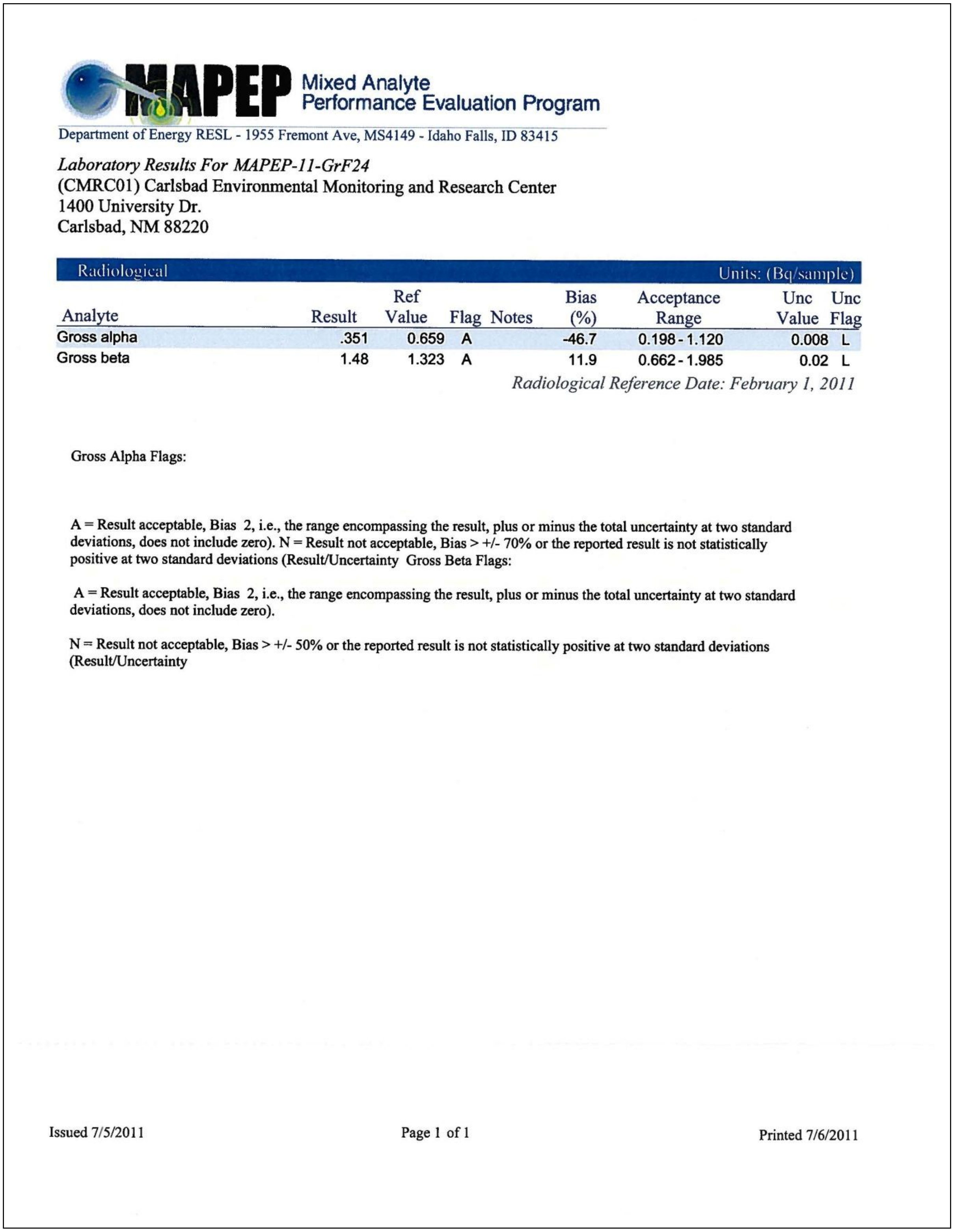

MAPEP Mixed Analyte Performance Evaluation Program

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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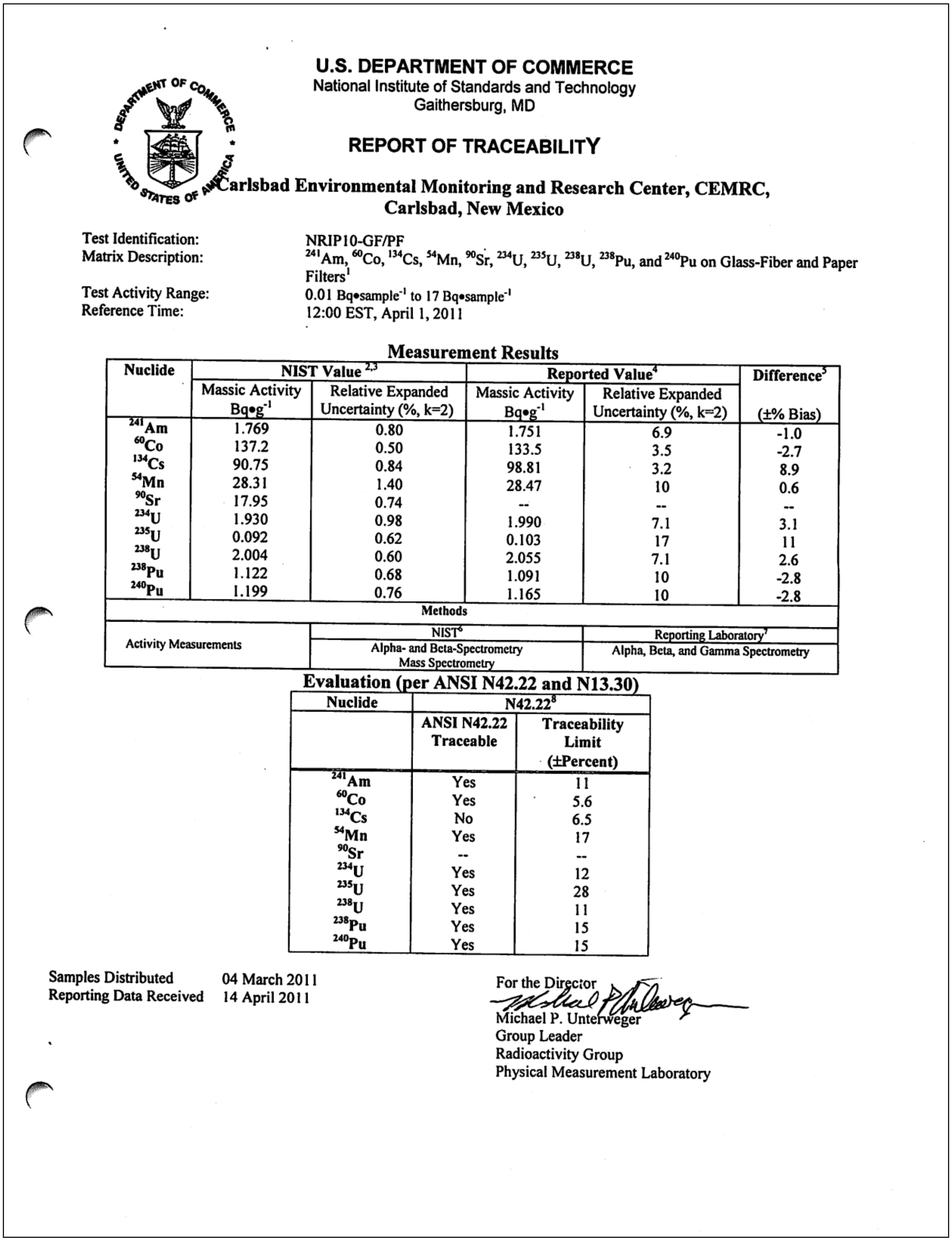
Table C.4. Example of the Daily Performance Tests for ICP-MS

Sample Daily Performance Data of the Elan 6100 ICP-MS for April-May 2011

	Acceptable Ranges		**04/11/2011**			**04/19/2011**		
	Criteria for Net Intensity Mean of 5 replicate readings	**Required Relative Standard Deviation (%)**	**Measured Intensity Mean**	**Relative Standard Deviation**	**Performance Evaluation**	**Measured Mean Intensity**	**Relative Standard Deviation**	**Performance Evaluation**
Be	>1,000	0.0 - 5.0%	4,280.6	0.8	Acceptable	4,245.4	1.3	Acceptable
Mg	>18,000	0.0 - 5.0%	46,140.6	0.8	Acceptable	53,327.6	2.2	Acceptable
In	>120,000	0.0 - 5.0%	423,919.1	2.0	Acceptable	508,895.4	1.4	Acceptable
Pb	>60,000	0.0 - 5.0%	221,326.1	2.0	Acceptable	259,494.6	1.1	Acceptable
Ba	<900,000	0.0 - 5.0%	351,480.0	2.6	Acceptable	393,169.6	1.1	Acceptable
Ba++	≤ 10.0%	N/A	1.4%	N/A	Acceptable	1.9%	N/A	Acceptable
Ce	<900,000	0.0 - 5.0%	450,526.5	1.5	Acceptable	499,283.6	1.2	Acceptable
CeO	≤ 5.0%	N/A	2.3%	N/A	Acceptable	2.6%	N/A	Acceptable
Bkgd	≤ 25.0	N/A	9.2	N/A	Acceptable	7.6	N/A	Acceptable

	Acceptable Ranges		**05/05/2011**			**05/26/2011**		
	Criteria for Net Intensity Mean of 5 replicate readings	**Required Relative Standard Deviation (%)**	**Measured Intensity Mean**	**Relative Standard Deviation**	**Performance Evaluation**	**Measured Mean Intensity**	**Relative Standard Deviation**	**Performance Evaluation**
Be	>1,000	0.0 - 5.0%	3,910.7	1.6	Acceptable	5,219.8	1.0	Acceptable
Mg	>18,000	0.0 - 5.0%	56,279.1	1.4	Acceptable	66,657.8	1.4	Acceptable
In	>120,000	0.0 - 5.0%	564,532.0	1.9	Acceptable	600,156.1	1.3	Acceptable
Pb	>60,000	0.0 - 5.0%	293,780.5	1.4	Acceptable	290,668.6	1.1	Acceptable
Ba	<900,000	0.0 - 5.0%	491,111.4	0.7	Acceptable	463,212.3	1.2	Acceptable
Ba++	≤ 10.0%	N/A	1.6%	N/A	Acceptable	1.7%	N/A	Acceptable
Ce	<900,000	0.0 - 5.0%	644,538.0	0.9	Acceptable	592,542.6	0.9	Acceptable
CeO	≤ 5.0%	N/A	2.4%	N/A	Acceptable	2.6%	N/A	Acceptable
Bkgd	≤ 25.0	N/A	9.2	N/A	Acceptable	6.4	N/A	Acceptable

Table C.5. 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/PF
Matrix Description:	^{241}Am, ^{60}Co, ^{134}Cs, ^{54}Mn, ^{90}Sr, ^{234}U, ^{235}U, ^{238}U, ^{238}Pu, and ^{240}Pu on Glass-Fiber and Paper Filters[1]
Test Activity Range:	0.01 Bq•sample^{-1} to 17 Bq•sample^{-1}
Reference Time:	12:00 EST, April 1, 2011

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	1.769	0.80	1.751	6.9	-1.0
^{60}Co	137.2	0.50	133.5	3.5	-2.7
^{134}Cs	90.75	0.84	98.81	3.2	8.9
^{54}Mn	28.31	1.40	28.47	10	0.6
^{90}Sr	17.95	0.74	--	--	--
^{234}U	1.930	0.98	1.990	7.1	3.1
^{235}U	0.092	0.62	0.103	17	11
^{238}U	2.004	0.60	2.055	7.1	2.6
^{238}Pu	1.122	0.68	1.091	10	-2.8
^{240}Pu	1.199	0.76	1.165	10	-2.8

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

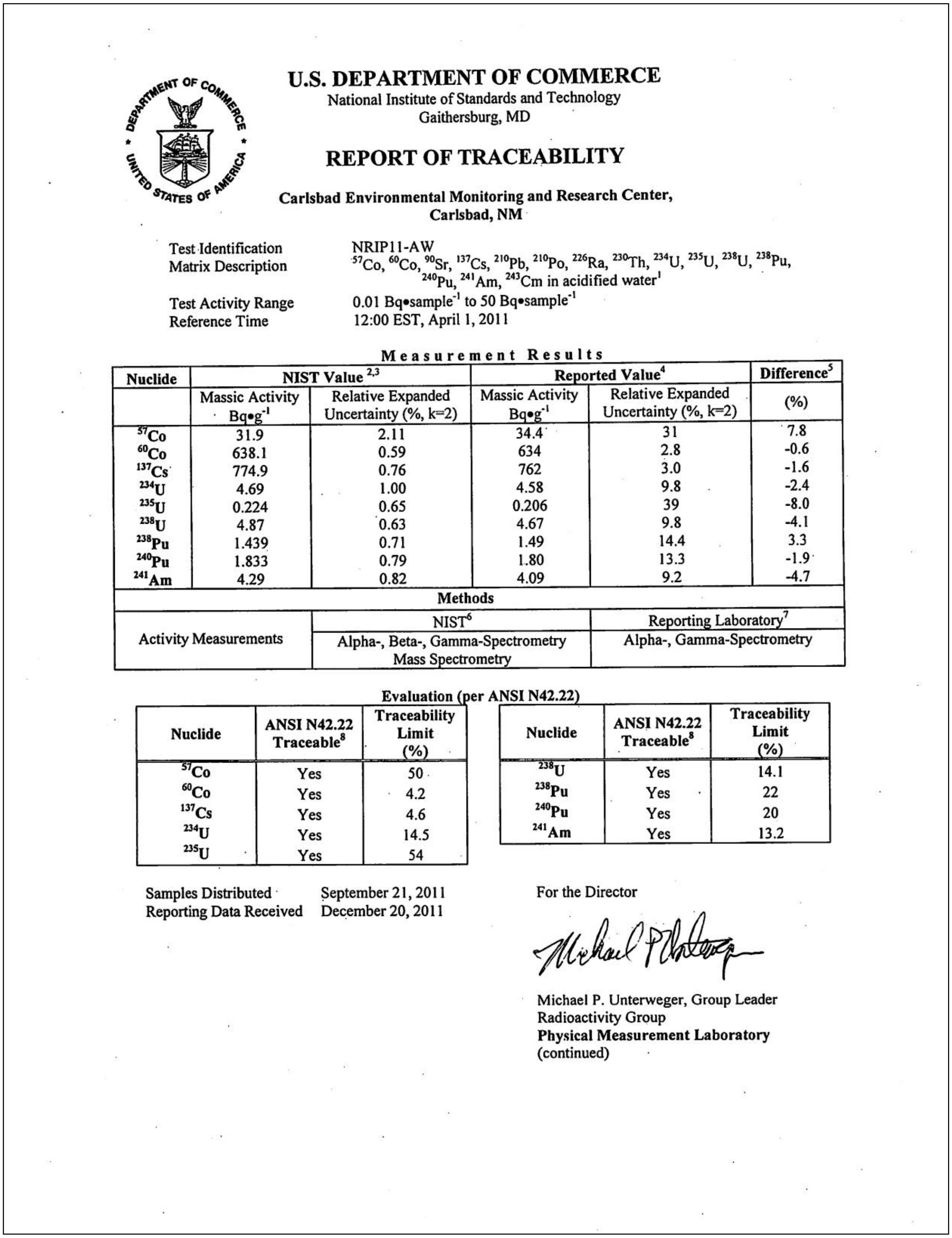
Evaluation (per ANSI N42.22 and N13.30)

Nuclide	N42.22[8]	
	ANSI N42.22 Traceable	Traceability Limit (±Percent)
^{241}Am	Yes	11
^{60}Co	Yes	5.6
^{134}Cs	No	6.5
^{54}Mn	Yes	17
^{90}Sr	--	--
^{234}U	Yes	12
^{235}U	Yes	28
^{238}U	Yes	11
^{238}Pu	Yes	15
^{240}Pu	Yes	15

Samples Distributed	04 March 2011
Reporting Data Received	14 April 2011

For the Director
Michael P. Unterweger
Group Leader
Radioactivity Group
Physical Measurement Laboratory

Table C.5. 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	NRIP11-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 in acidified water[1]
Test Activity Range	0.01 Bq•sample^{-1} to 50 Bq•sample^{-1}
Reference Time	12:00 EST, April 1, 2011

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	31.9	2.11	34.4	31	7.8
^{60}Co	638.1	0.59	634	2.8	-0.6
^{137}Cs	774.9	0.76	762	3.0	-1.6
^{234}U	4.69	1.00	4.58	9.8	-2.4
^{235}U	0.224	0.65	0.206	39	-8.0
^{238}U	4.87	0.63	4.67	9.8	-4.1
^{238}Pu	1.439	0.71	1.49	14.4	3.3
^{240}Pu	1.833	0.79	1.80	13.3	-1.9
^{241}Am	4.29	0.82	4.09	9.2	-4.7

Methods

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

Evaluation (per ANSI N42.22)

Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{57}Co	Yes	50
^{60}Co	Yes	4.2
^{137}Cs	Yes	4.6
^{234}U	Yes	14.5
^{235}U	Yes	54

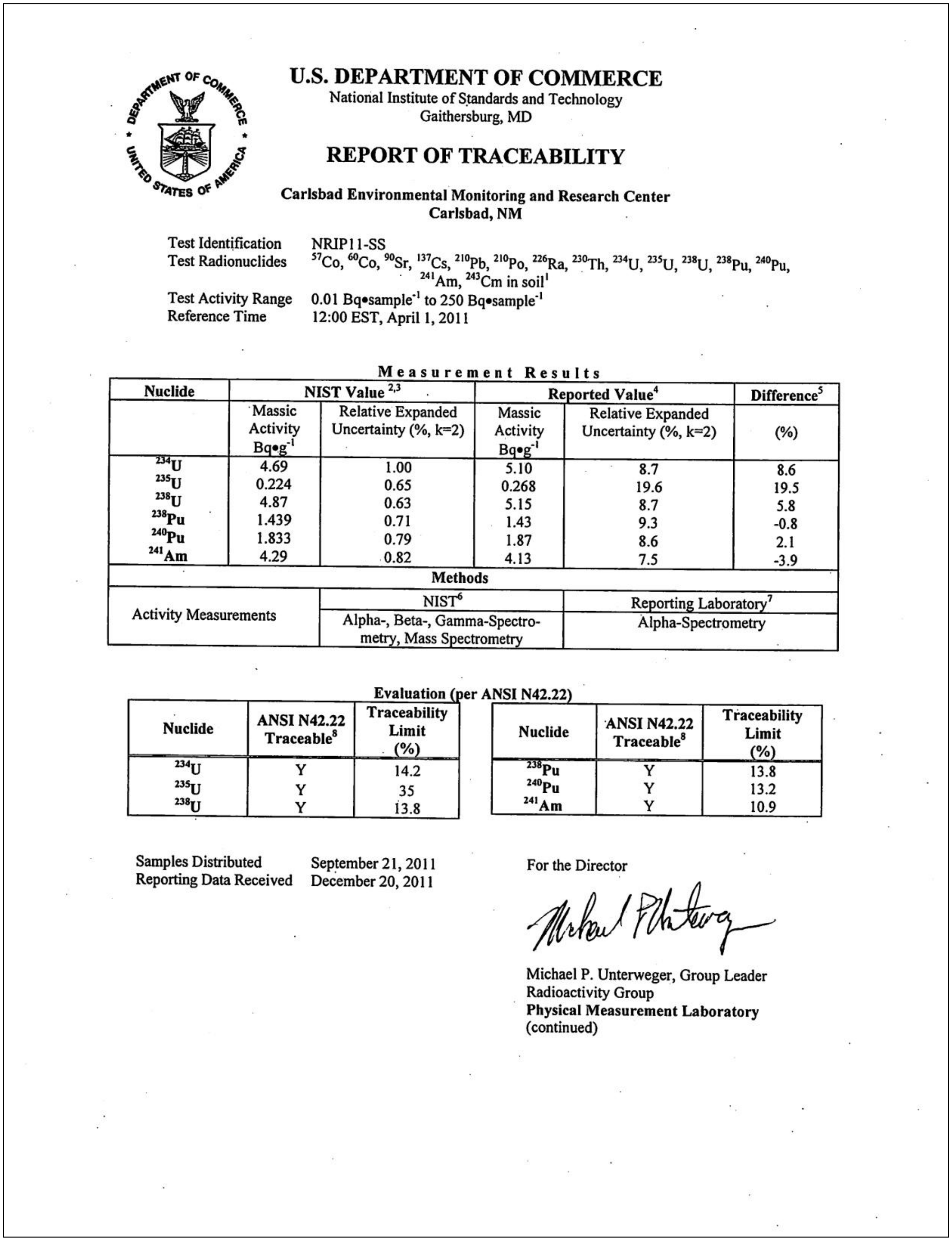
Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{238}U	Yes	14.1
^{238}Pu	Yes	22
^{240}Pu	Yes	20
^{241}Am	Yes	13.2

Samples Distributed	September 21, 2011
Reporting Data Received	December 20, 2011

For the Director

Michael P. Unterweger, Group Leader
Radioactivity Group
Physical Measurement Laboratory
(continued)

Table C.5. 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	NRIP11-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 in soil[1]
Test Activity Range	0.01 Bq•sample^{-1} to 250 Bq•sample^{-1}
Reference Time	12:00 EST, April 1, 2011

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)	(%)
^{234}U	4.69	1.00	5.10	8.7	8.6
^{235}U	0.224	0.65	0.268	19.6	19.5
^{238}U	4.87	0.63	5.15	8.7	5.8
^{238}Pu	1.439	0.71	1.43	9.3	-0.8
^{240}Pu	1.833	0.79	1.87	8.6	2.1
^{241}Am	4.29	0.82	4.13	7.5	-3.9

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	14.2
^{235}U	Y	35
^{238}U	Y	13.8

Nuclide	ANSI N42.22 Traceable[8]	Traceability Limit (%)
^{238}Pu	Y	13.8
^{240}Pu	Y	13.2
^{241}Am	Y	10.9

Samples Distributed	September 21, 2011
Reporting Data Received	December 20, 2011

For the Director

Michael P. Unterweger, Group Leader
Radioactivity Group
Physical Measurement Laboratory
(continued)

APPENDIX D: 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 non-detection while accepting a 5 percent probability of erroneously deciding that a positive quantity of a radionuclide is present in an appropriate blank sample. This method assures that any claimed MDC has at least a 95 percent chance of being detected. It is possible to achieve a very low level of detection by analyzing a large sample size and counting for a very long time. CEMRC uses the following equation for calculating the MDCs for each radionuclide in various sample matrices:

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

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_{blank} = Blank count time

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

Standard Deviation (SD)

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

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

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 D.1. % Chemical Recovery of Tracers in FAS Samples

Radionuclide	*Minimum*	*Maximum*	*Average*	*SD*
^{243}Am	41.00	100.65	91.00	13.8
^{242}Pu	52.42	100.85	81.18	14.1
^{232}U	34.89	99.56	67.56	19.3

Table D.2. % Chemical Recovery of Tracers in Drinking Water Samples

Radionuclide	*Minimum*	*Maximum*	*Average*	*SD*
^{243}Am	89.07	96.25	92.43	3.2
^{242}Pu	84.38	89.60	86.66	2.0
^{232}U	23.05	79.24	54.66	19.4

Table D.3. % Chemical Recovery of Tracers in Ambient Aerosol Samples

Radionuclide	*Minimum*	*Maximum*	*Average*	*SD*
^{243}Am	27.79	84.32	103.04	16.4
^{242}Pu	25.53	99.55	60.78	21.9
^{232}U	35.07	95.74	69.37	13.8

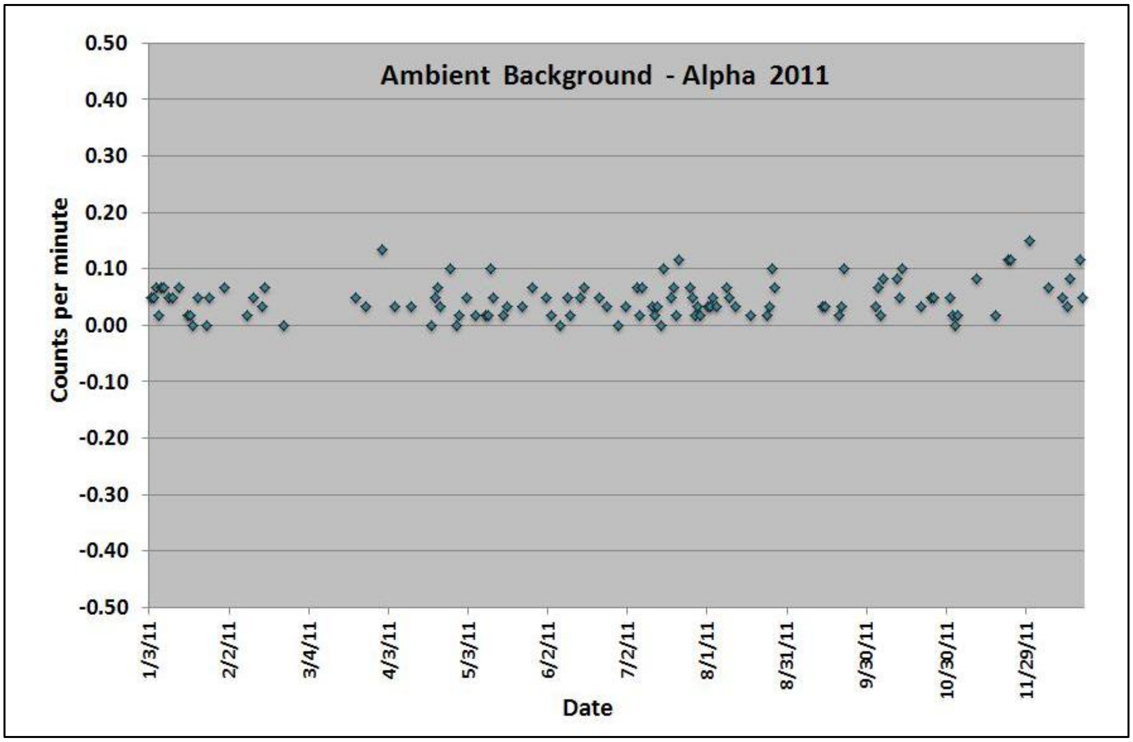


Figure D.1. Sixty Minutes Alpha Ambient Background Count for the PIC-MPC 9604 Gross Alpha and Beta Counter

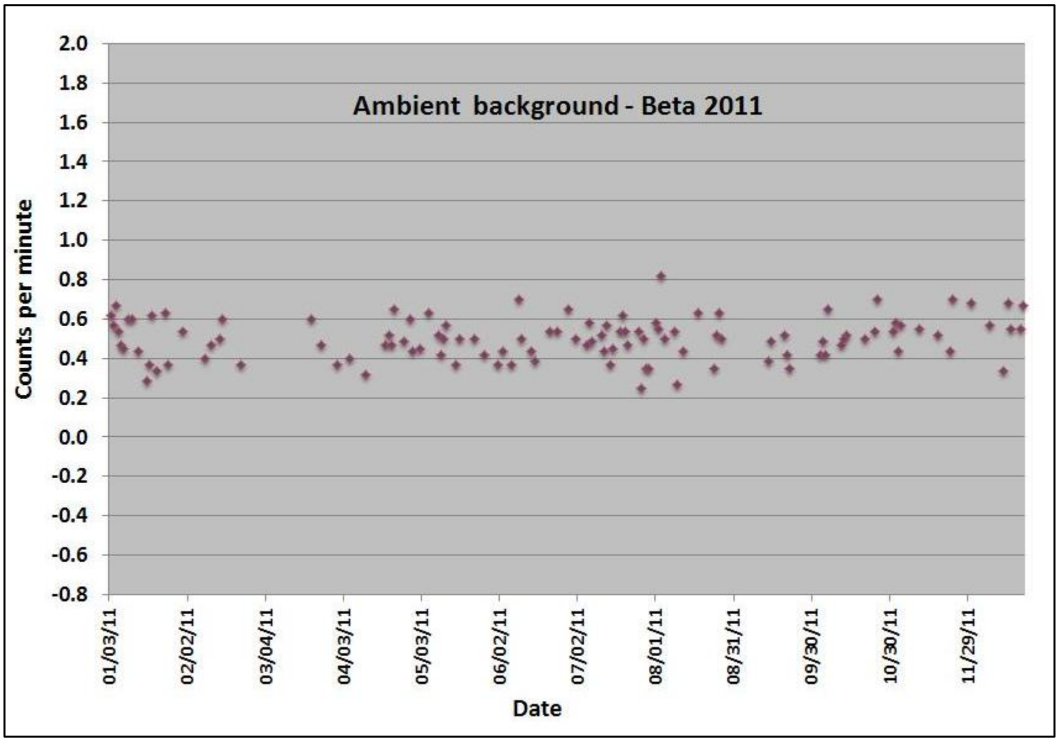


Figure D.2. Sixty Minutes Beta Ambient Background Count for PIC-MPC 9604 Gross Alpha and Beta Counter

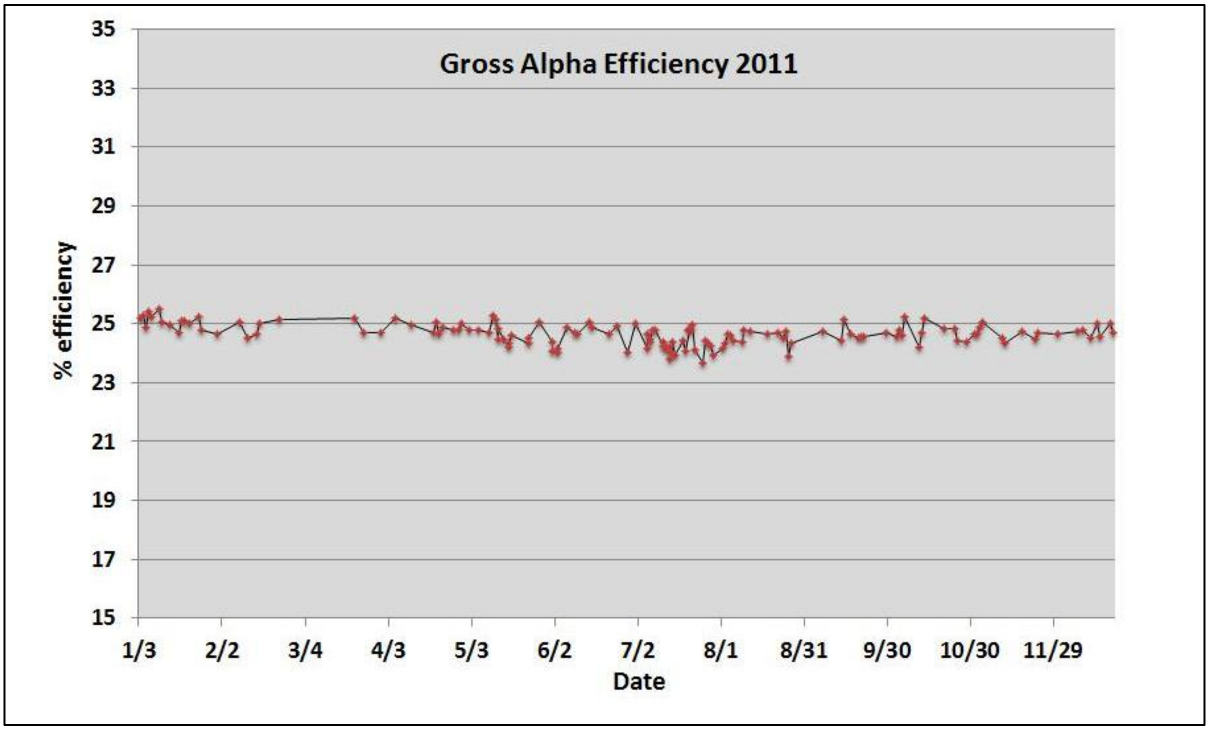


Figure D.3. Control Chart of Daily Alpha Efficiency of the PIC-MPC 9604 Gross Alpha and Beta Counter

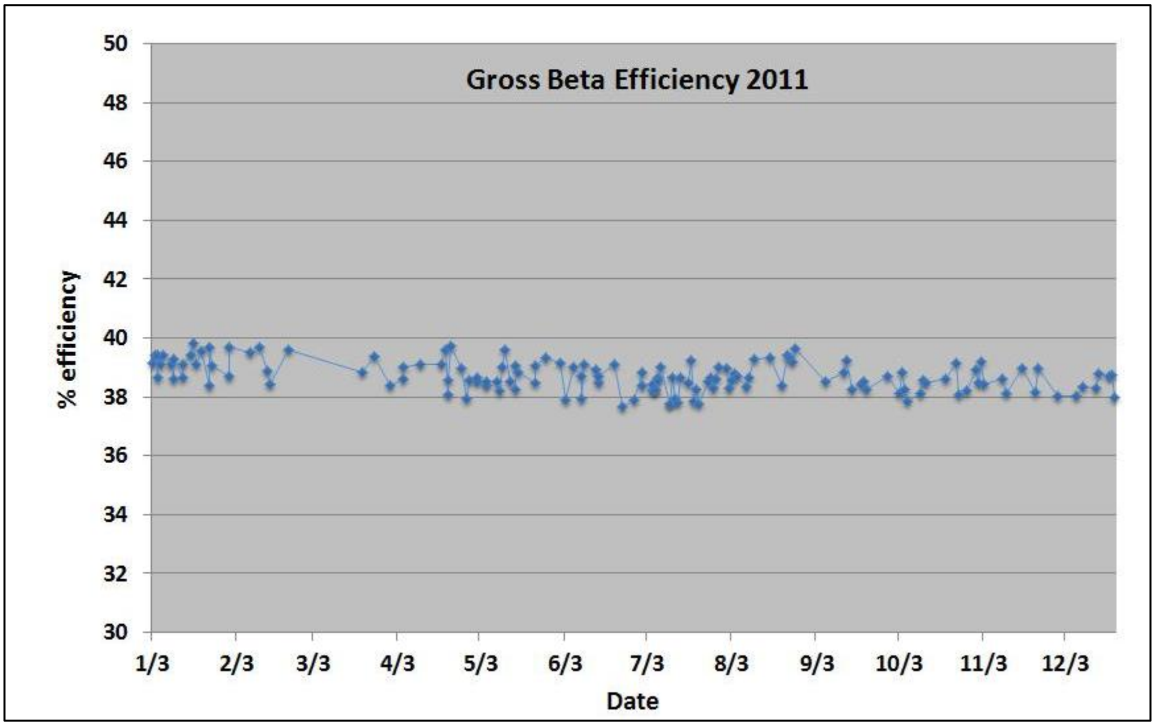


Figure D.4. Control Chart of Daily Beta Efficiency of the PIC-MPC 9604 Gross Alpha and Beta Counter

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