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Carlsbad Environmental
Monitoring & Research Center
New Mexico State University

2000 Report
Carlsbad Environmental Monitoring & Research Center

College of Engineering
New Mexico State University

Issued February 22, 2001

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Acronyms and Abbreviations

μBq	microbecquerel
μm	micrometer
AA, AAS	atomic absorption, atomic absorption spectrometry
Ag	silver
Al	aluminum
Am	americium
As	arsenic
Ba	barium
Be	beryllium
Bq	Becquerel
C	centigrade
Ca	calcium
Cd	cadmium
Ce	cerium
CEMRC	Carlsbad Environmental Monitoring & Research Center
CEMRP	Carlsbad Environmental Monitoring and Research Program
CFR	Code of Federal Regulations
cm	centimeter
Cm	curium
Co	cobalt
Cr	chromium
Cs	cesium
Cu	copper
CV	coefficient of variation
DL	detection limit
DOE	U.S. Department of Energy
DRI	Desert Research Institute
Dy	dysprosium
EM	Environmental Monitoring
EML	Environmental Monitoring Laboratory
EPA	U.S. Environmental Protection Agency
Er	erbium
Eu	europium
Fe	iron
FY	fiscal year
g	gram
Gd	gadolinium
Ge	germanium
GPS	global positioning satellite
HCl	hydrochloric acid
$HClO_4$	perchloric acid
HF	hydrofluoric acid
Hg	mercury
HNO_3	nitric acid
hr	hour
IC	ion chromatography
ICP-MS	inductively coupled plasma mass spectrometry

K	potassium
km	kilometer
L	liter
La	lanthanum
LaF_3	lanthanum fluoride
LDBC	"Lie Down and Be Counted"
Li	lithium
m	meter
mb	millibar
MBL	mobile bioassay laboratory
mBq	millibecquerel
MDC	minimum detectable concentration
Mg	magnesium
min	minute
MJ	megajoule
mL	milliliter
mm	millimeter
Mn	manganese
Mo	molybdenum
Na	sodium
NaOH	sodium hydroxide
Nd	neodymium
Ni	nickel
NIST	National Institute of Standards and Technology
NMSU	New Mexico State University
Np	neptunium
ORNL	Oak Ridge National Laboratory
Pb	lead
pH	scale indicating acidity or alkalinity of a substance
PM_{10}	particulate matter smaller than 10 micrometers in aerodynamic diameter
$PM_{2.5}$	particulate matter smaller than 2.5 micrometers in aerodynamic diameter
Pr	praseodymium
PRB	Program Review Board
Pu	plutonium
QA	quality assurance
QAP	quality assurance program
QC	quality control
RIP	Radiochemistry Intercomparison Program
Ru	ruthenium
SAB	Science Advisory Board
Sb	antimony
Sc	scandium
SD	standard deviation
Se	selenium
SE	standard error
sec	second
Sm	samarium
Sn	tin
Sr	strontium
$T_{1/2}$	half-life

Th	thorium
Ti	titanium
TIMS	thermal ionization mass spectrometry
Tl	thallium
TSP	total suspended particulates
U	uranium
UVB	Ultra-Violet B
V	vanadium
W	watt
WERC	Waste-management Education & Research Consortium
WIPP	Waste Isolation Pilot Plant

FORWARD

This report was written, edited and produced collaboratively by the staff of the Carlsbad Environmental Monitoring & Research Center (CEMRC), who are hereby acknowledged for their contributions to the report and the project activities described herein. The first section is an overview of the current program activities, structure, resources and quality assurance. The second section consists of data summaries containing methods and descriptions of results of studies in the WIPP Environmental Monitoring project. Tables presenting data from the WIPP Environmental Monitoring project, and the contents of this report are available for electronic access at http://www.cemrc.org.

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

The cover photograph is the CEMRC lung and whole body radiobioassay system.


Radiochemistry Laboratory


Air sampling station near the WIPP


Experimental unit for radiation measurements of livestock

FORWARD

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Soil column experiment for study of contaminant mobility


Student activities during CEMRC tour


Environmental Chemistry Laboratory


Soil sampling near the WIPP


Colloquium by visiting scientist


Water quality measurement at Brantley Lake


Drinking water sampling

OVERVIEW

Current Program Status

History and Focus

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

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

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

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

- Provide for objective, independent health and environmental monitoring;
- Provide advanced training and educational opportunities;
- Develop improved measurement methods, procedures and sensors; and
- Establish a health and environmental database accessible to all sectors.

Key Activities for Success

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

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

At the end of 1999, staffing reached 28 professional and classified employees. At the end of 2000, the CEMRC employed 29 personnel (Table 1) and two scientific positions were open and under recruitment.

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

In January 1997, the CEMRC was relocated to Light Hall, a new 26,000 ft^2 laboratory and office facility constructed adjacent to the NMSU-Carlsbad campus. The CEMRC's scientific activities are organized into five major areas of specialization, with corresponding assignment of staff roles and responsibilities. Although some of the CEMRC's projects involve only one or two of the program areas, all of the program areas collaborate in carrying out the WIPP Environmental Monitoring project, and this type of integrative research is also applied to some newly funded projects. The five scientific program areas include (1) field sampling, (2) internal dosimetry, (3) informatics and modeling, (4) radiochemistry and (5) environmental chemistry. Detailed descriptions of each program area and associated facilities and instrumentation are presented on the CEMRC web site at http://www.cemrc.org.

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

During 1999-2000, the CEMRC conducted studies in collaboration with the DOE/Carlsbad Area Office (CAO) to quantify the natural radiation background in the WIPP underground. The results of the studies have been used by CAO in efforts to establish the WIPP as a location for new programs by external research groups, capitalizing on the WIPP's low-radiation environment. The CEMRC is one of nine institutions that has partnered with Ohio State University in development of a Center for Nuclear, Neutrino and Astroparticle Physics proposed for development at the WIPP with funding from the National Science Foundation. In addition, the CEMRC has participated with other multi-institution groups in development of three other initiatives for particle physics projects involving the WIPP. These projects include lead investigators from the University of California Los Angeles, Duke University and Stanford University, with 2-5 collaborating institutions for each project.

A Memorandum of Understanding was finalized in 2000 between CEMRC and Health Canada (a ministry of Canada) for collaborative research in health physics. Under this agreement, a series of experiments was conducted for intercomparisons of background radiation of shields and for calibration phantoms used for *in vivo* radiobioassay measurements. A portion of these experiments also involved collaboration with Lovelace Respiratory Research Institute (Albuquerque, New Mexico) and Los Alamos National Laboratory (Los Alamos, New Mexico).

Program needs for external laboratory services declined in 2000, but a few sub-contractual agreements were maintained to provide specific specialized services or analyses (Appendix B). The NMSU Fishery and Wildlife Science Department also continued to provide support to the CEMRC through loan of a boat used in lake sampling activities. With respect to collaborative research, 21 of the publications and presentations by CEMRC staff during 2000 were co-authored with external colleagues, and 14 of the CEMRC's proposed and existing new projects involve collaboration with other departments or institutions.

4. Establish an independent advisory body of scientists to provide expert guidance and consultation to CEMRC staff in the focus areas of CEMRC research.

The Scientific Advisory Board (SAB) for the CEMRC is composed of one scientific expert in each of the CEMRC's five scientific areas of specialization (Appendix C). Each SAB member visited the CEMRC during 2000 to review the individual program areas and provide expert guidance and consultation to the program leaders. Each program leader used the SAB observations and recommendations in structuring specific developmental goals, new experiments and methods improvements. Program leaders provided SAB members with follow-up reports prior to each SAB member's visit during 2000. The term of service for SAB members is two years, and new members for 2000-2001 terms were identified (Appendix C).

The Program Review Board (PRB) for the CEMRC consists of a minimum of three members selected by the NMSU College of Engineering administration (Appendix C). Members of the PRB are directors or former directors of leading environmental research centers with histories of long-term success in sponsored research. Members of the PRB visited the CEMRC as a group during 2000, reviewed the overall operation of the CEMRC, and provided a joint report to the administration. Each year an action plan responding to the review is prepared by the CEMRC director, and a follow-up report is provided to the PRB members prior to their next visit.

5. Establish a program of administration to ensure effective operation of the CEMRC.

Current administrative staff includes a director, a fiscal specialist, a buyer specialist, a project manager, a manager of program development, a quality assurance manager, a word processing specialist, and an administrative secretary. During part of 2000, partial support was also provided for three Waste-management Education & Research Consortium (WERC) administrators at NMSU, to assist in coordination with main campus business and with the WERC educational and research programs.

Cumulative funding from the DOE for the CEMRP totaled approximately $23.8 million through 1 October 2000. Cumulative expenditures by the CEMRP for the same period totaled approximately $23.1 million. Proposed new funding for the 2001 Federal fiscal year is approximately $3.4 million. Combined with carryover funds, the projected CEMRP 2001 budget is approximately $3.9 million.

Formal tracking of CEMRP project schedules and deadlines is conducted for current studies, as noted in later sections. Regularly scheduled work sessions for scientific program planning and problem solving are used to define accountabilities and track progress. Administrative and individual program area staff also have regularly scheduled review and planning sessions. During 2000, significant accomplishments and events were reported in monthly summaries provided to the DOE, NMSU, SAB and PRB.

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

CEMRC staff authored or co-authored 13 presentations at international, national and regional scientific meetings and 18 papers were published, are in press, or have been submitted for publication in peer-reviewed scientific journals and books during 2000 (Appendix D). A cumulative list of publications by CEMRC staff since 1996 is presented on the CEMRC web page.

The CEMRC issued a 1999 report that presented extensive data on radionuclides, non-radioactive constituents and other basic environmental parameters from the WIPP Environmental Monitoring project. This report and other CEMRC information are available via the CEMRC web site, and data tables referenced in this report are also presented on the web site at http://www.cemrc.org.

A notable new feature, “Recent Data for WIPP Environmental Monitoring” was added to the CEMRC Web page during 2000. This feature presents the results from samples collected and analyzed since the most recent CEMRC report. Such results are posted to the site one to three months after sample collection, which represents the most timely data available to the public concerning environmental parameters in the vicinity of the WIPP, and covers aerosols, soils, drinking water, sediment and surface water. Also during 2000, the CEMRC Laboratory Information Management System was upgraded and customized for use with aerosols, soil, drinking water, and surface water samples.

7. Establish regional, national and international outreach and collaboration.

During 2000, the CEMRC hosted 12 colloquia presented by visiting scientists (Appendix E). Each colloquium was advertised locally, resulting in participation by representatives from local scientific, educational, technical and natural resource management organizations, as well as the general public. The CEMRC was involved in many other outreach activities including presentations for local civic and professional groups and exhibits for various school and community events (Appendix F). As described in a later section, over 500 volunteers from the local community have participated in the “Lie Down and Be Counted” project. In addition, CEMRC scientists provided leadership in a variety of professional and scientific organizations and meetings (Appendix G).

During 2000, the CEMRC distributed two issues of its newsletter, *The Monitor*. The newsletters summarized progress achieved in the Lie Down and Be Counted project, described new projects in progress, and provided general information about the CEMRC. Over 2500 copies of each newsletter were distributed to local residents and regular recipients of CEMRC reports.

The CEMRC also entered into a General Agreement with the U.S. Department of Interior, National Park Service to provide a temporary usage area for the National Cave and Karst Research Institute during the Institute’s initial development phases.

8. Procure additional research grants and service contracts from external sources.

CEMRC scientists generated 25 proposals, pre-proposals and contract modifications during 2000 (Appendix H). New funding and amendments were achieved on nine projects totaling over $250,000, six proposals are pending, and ten proposals were not funded. A total of 16 projects (external to the CEMRP) were in progress during 2000, with a combined value over $1.4 million. These projects represent a wide array of activities, and they have resulted in significant expansion and diversification of the scientific program. During 1996-2000, CEMRC has received funding from a total of 16 different federal and private sponsors.

9. Implement programs to offer technical training in specialized research techniques and methodologies and to involve CEMRC resources and personnel in providing educational opportunities for students nationwide.

During 2000, four undergraduate students worked in laboratory aide and technician positions at the CEMRC; these positions provide training and basic skills development relevant to the position assignments. Two CEMRC scientists hold Graduate Faculty appointments at NMSU. CEMRC staff presented two invited seminars for the NMSU Department of Fishery & Wildlife Sciences, and ten major presentations and special programs were provided for student groups (Appendix F).

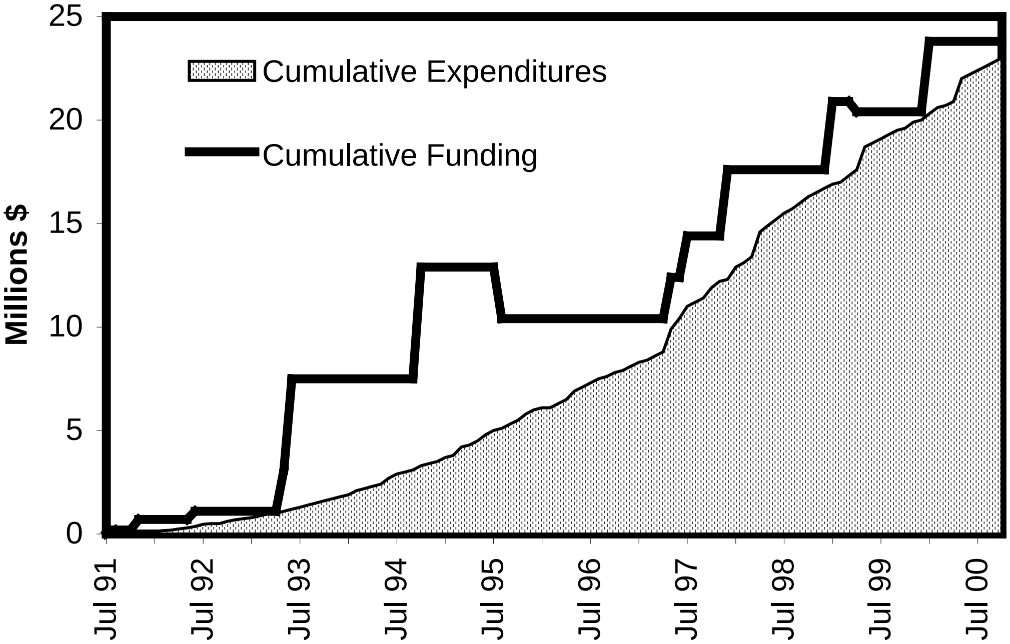


Figure 1. History of CEMRP Funding and Expenditures

Table 1. Listing of CEMRC Staff as of 31 December 2000

Name	Position
Arimoto, Richard	Senior Scientist-Environmental Chemistry
Brown, Becky	Fiscal Specialist II
Castillo, Rick	Technician III-Environmental Chemistry
Chatfield, Randy	Programmer/Analyst I
Conley, Marsha	Director
D’Mura, Gayle	Specialist
Fraire, Joe	Assistant Scientist-Radiochemistry
Ganaway, David	Assistant Scientist-Field Programs
Kirchner, Thomas	Senior Scientist-Informatics & Modeling
Lippis, Joe	Assistant Scientist-Field Programs
Madison, Tom	Project Manager
McCauley, Sharyl	Quality Assurance Manager
Monk, James	Associate Health Physicist
Munoz, Debbie	Administrative Secretary I
Nesbit, Curtis	Associate Health Physicist
Sage, Sondra	Assistant Scientist-Environmental Chemistry
Schloesslin, Carl	Assistant Scientist-Radiochemistry
Schloesslin, Cheryl	Assistant Scientist-Environmental Chemistry
Schoep, David	Science Specialist-Internal Dosimetry
Spruiell, Roy	Programmer/Analyst I
Stevens, Thaddeus	Programmer/Analyst I
Stewart, Barry	Associate Scientist-Radiochemistry
Stroble, Carolyn	Buyer Specialist I
Vasquez, Pam	Laboratory Aide-Environmental Chemistry
Walthall, Mark	Senior Scientist-Environmental Science
Webb, Joel	Manager, Program Development
Yahr, Jim	Assistant Scientist-Field Programs
York, Larry	Technician II-Radiochemistry
Young, Karen	Word Processing Specialist

WIPP Environmental Monitoring Project

Project Concept

As defined in the original grant, the purpose of the WIPP EM project is to establish and maintain independent environmental research and monitoring in the vicinity of the WIPP and to make the results easily accessible to all interested parties. This project was implemented during the WIPP pre-disposal phase, and is now continuing during the operational (disposal) phase. The WIPP EM project is organized and carried out independent of direct oversight by DOE, and the project does not provide data to any regulatory body to meet the compliance demonstration requirements applicable to the WIPP. Analytical results and interpretations from the WIPP EM are published by CEMRC without prior review by DOE.

A detailed description of the WIPP EM concepts, sampling design and baseline studies is presented on the CEMRC web page. The following is a brief summary of 1999-2000 activities for each major environmental medium in the WIPP EM. Mixed waste was first received by the WIPP on 9 September 2000. Since results summarized in this report cover samples collected through June 2000, the results for non-radiological constituents are a continuation of baseline sampling.

Based on the radiological analyses of monitoring phase samples (collected since 26 March 1999) completed to date for area residents and for selected aerosols, soils, drinking water and surface water, there is no evidence of increases in radiological contaminants in the region of the WIPP that could be attributed to releases from the WIPP. In most cases, levels measured in 2000 were within the range of baseline levels measured by CEMRC for the targeted analytes.

Aerosols

Aerosol sampling is conducted at four locations, with samplers operating continuously at each location. The locations include a port inside the WIPP exhaust shaft, a site approximately 0.1 km northwest (downwind) of the WIPP exhaust shaft (On Site station), a site approximately 1 km northwest (downwind) of the WIPP (Near Field station) and a site approximately 19 km southeast (upwind) of the WIPP (Cactus Flats station) (Fig. 2).

Continuous sampling of aerosols was conducted through June 2000 using the same instruments, frequencies and locations as were previously established in the baseline phase. Analyses of all aerosol samples collected through June 2000 for both radiological and non-radiological constituents were completed and are reported herein. Web site posting of results of radiological and non-radiological analyses of aerosol samples collected in the WIPP exhaust shaft (FAS) began in July 1999, and are updated weekly. A summary of these data is also presented herein.

During the period July 2000–June 2001, minor changes are being implemented to improve the aerosol sampling design. These changes include (1) standardizing the height of all sampler intakes at the On Site, Near Field and Cactus Flats stations to 4.3 m, with ≥ l m between sampler intakes and underlying solid surfaces, (2) addition of a high volume TSP sampler at a location approximately 55 km northeast of the WIPP site, in Hobbs, New Mexico, (3) elimination of collection of $PM_{2.5}$ and PM_{10} low-volume samples for inorganic analyses, and (4) modification of low-volume sample collection periods from two, two-day and one three-day cycle each week, to one three-day and one four-day cycle each week.

Soils

Soil sampling is conducted within a 166 km^2 area centered on the WIPP operations facility, and at a comparable area encompassing the Cactus Flats aerosol sampling station. Within each of these two areas, samples are collected at 16 locations positioned in concentric rectangular grids (Fig 2). For baseline studies at each of the 16 locations in each area, samples were collected during 1998 and 1999 at three randomly selected sites within a 50-m x 50-m area centered on the location's reference point. The resulting data represented 96 discrete samples that provided estimates of variability at the small-scale (between samples within a 0.0025 km^2 area), medium-scale (among locations within each 166 km^2 area) and large-scale (between the two sampling areas located approximately 19 km apart).

During 2000, one soil sample was collected at each of the 32 locations during January-February. The limitation of soil sampling to one period annually is based on the assumption that any input of contaminants to surface soils from WIPP releases would occur via aerosol deposition, and since aerosol sampling is conducted continuously, more frequent soil sampling is not warranted unless there was evidence of a contaminant increase in aerosols.

Surface Water and Sediments

The WIPP EM incorporates studies at three reservoirs on the Pecos River, which is the major perennial fresh water system closest to the WIPP that has extensive human usage. The three reservoirs are (1) Brantley Lake, located approximately 64 km northwest of the WIPP, (2) Lake Carlsbad, located in Carlsbad and approximately 40 km northwest of the WIPP and (3) Red Bluff Lake, located approximately 48 km southwest of the WIPP. Results of preliminary studies of selected radionuclides in sediments from Brantley Lake were reported in the CEMRC 1997 Report, and radioanalyses of sediment and surface water samples from all three lakes were reported in the CEMRC 1998 Report. The CEMRC 1999 Report contained results of analyses of the 1999 surface water and sediment samples for non-radiological constituents, analyses of selected alpha-emitting radionuclides in 1998 (baseline) sediment samples, and tests for Pu in 1998 surface water samples.

Radiological analyses of 2000 (monitoring phase) surface water samples were completed and are reported herein. Radiological analyses of 1999 and 2000 sediment samples are in progress and will be reported on the CEMRC web site when completed.

Because of the distance between the WIPP site and these reservoirs, the potential risk of direct contamination of the reservoirs by releases from the WIPP is relatively low compared to other media, and sampling in subsequent years will continue to be conducted once annually in the summer.

Drinking Water

The WIPP EM studies of ground water focus on the major drinking water supplies used by communities in the WIPP region because these are often perceived by the public as a potential route for contaminants to reach humans. Five community supplies of drinking water (representing three major regional aquifers) are included in routine sampling, including Carlsbad, Loving/Malaga, Otis, Hobbs and a secondary source for Carlsbad. One private water well (representing a fourth aquifer) that is located within 16 km of the WIPP is also sampled.

During initial baseline studies during 1996-1998, drinking water samples were subjected to analyses for over 150 analytes, including those that are regulated under the Safe Drinking Water Act, and contaminants known or suspected to be present in the WIPP wastes. Radioanalyses of drinking water conducted during 1997-1998 (previously reported) were unable to detect Pu or Am in any of the samples collected, using traditional alpha spectrometry. Subsequent analyses by thermal ionization mass spectrometry (TIMS) (a more sensitive radioanalytical technique) were also unsuccessful in detecting Pu in any of the water samples. Based on these results, subsequent radiological analyses have applied standard alpha spectroscopy detection limits achievable with 3-L samples. During 2000, drinking water samples were collected in the spring, and results of radiological and non-radiological analyses are reported herein. The six drinking water supplies will continue to be sampled once annually for selected radiological and inorganic testing.

Biota

Studies of biota for the WIPP EM have focused on native vegetation because the vegetation is consumed by beef cattle, and consumption of beef from cattle pastured in the vicinity of the WIPP could serve as an exposure pathway to humans for contaminants released from the WIPP. During baseline studies, vegetation samples were collected from a total of six species of plants that serve as preferred forage species for cattle during at least some portion of the year. During 1997-1998 baseline studies, vegetation was sampled twice annually during the two major periods of new growth for native vegetation (March-May and August-October). Six samples of each of three species (contingent on availability) were collected during each sampling period from selected sites on the sampling grid surrounding the WIPP (which encompasses the Near Field aerosol sampling station). During late summer 1999, the first monitoring phase samples were collected, consisting of a single sample of several grass species from each of the 32 soil sampling locations.

Radiochemical analyses of the baseline and initial monitoring phase samples will be carried out during 2001, followed by web page posting and inclusion in the CEMRC 2001 Report. No additional vegetation sampling is planned to be conducted until spring 2002.

Additional studies are planned to evaluate the effectiveness of expanding the biota sampling for radionuclides to include arthropods. Arthropods were collected at the Cactus Flats station during spring through fall in 1998 (baseline) and at Near Field and Cactus Flats stations during spring through fall in 1999. Comparative radioanalyses of the samples are planned during 2001 to evaluate the effectiveness of this environmental component in long-term monitoring.

Human Population

The "Lie Down and Be Counted" (LDBC) project serves as a component of the WIPP EM that directly addresses the general concern about personal exposure to contaminants shared by residents who live near DOE sites. As in other aspects of the WIPP EM, *in vivo* bioassay testing was used to establish a baseline profile of internally-deposited radionuclides in a sample of local residents. 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. The minimum sample size threshold was achieved for the major categories early in 1998, and continued baseline sampling resulted in radiobioassays completed for 367 individuals before the first receipt of waste at the WIPP, reducing margin of error ranges to a maximum of 5-7% for any category. Radiobioassays of the original volunteer cohort began in July 1999 to achieve a complete cohort recount by July 2001. New volunteers will continue to be recruited each year, with a target of 100 new volunteers annually to establish new study cohorts and replacement of volunteer attrition.

Results of the LDBC project through 1 October 2000 are reported herein, and are updated quarterly on the CEMRC web site.

Meteorological Monitoring

Fully automated meteorological stations are operated by the CEMRC at the Near Field aerosol station and the Cactus Flats aerosol station. Details concerning the sensors and operation of the equipment and a summary of the last year's meteorological patterns are presented herein.

Management of WIPP EM Project

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

The management plan for the WIPP EM incorporates milestones representing significant products and progress, including both routine sampling and analyses and special studies. Key performance indicators that integrate groups of milestones are identified and reviewed annually to serve as metrics of the successful progress of the project. Completion of 2000 key performance indicators is summarized in Appendix I. Eleven indicators were completed on time and four indicators were delayed but completed prior to year-end. Four out of 19 indicators were not completed, with 0-90% progress on each. Key performance indicators for 2001 have been identified to serve as the basis for the 2001 WIPP EM project schedule (Table 2)

Table 2. Key Performance Indicators for 2001

Focus Area	Key Performance Indicator
Aerosols	1. Continue concurrent high-volume and low-volume/dichotomous sampling at current four locations through 2001
	2. Continue collection of daily FAS samples in WIPP exhaust shaft through 2001
Soils	3. Collect samples at current 32 locations during January-February 2001
Meteorology	4. Continue concurrent operation of sampling stations at two current sites through 2001
Drinking water	5. Collect samples from six sources during April-May 2001
Sediment and surface water	6. Collect samples from three reservoirs during June-July 2001
Human studies	7. Complete repeat counts for original volunteer cohort, and initial counts for a minimum of 100 new volunteers
Radioanalyses	8. Complete analyses of subset of pre-2000 vegetation and arthropod samples by October 2001
	9. Complete analyses of soil, aerosol, sediment, surface water and drinking water samples (collected through June 2001) by October 2001
	10. Continue FAS sample analyses to meet weekly and quarterly posting schedule
Non-radiological analyses	11. Complete analyses of representative subset of 2001 low-volume aerosol, soil, sediment, surface water and drinking water samples within three months after each sample collection
	12. Continue FAS sample analyses to meet weekly and quarterly posting schedule
Data management and dissemination	13. Post results of radioanalyses of 2001 and pre-2001 samples within two months after completion of analyses of each set of samples
	14. Post results of non-radiological analyses of 2001 samples within two months after completion of analyses of each set of samples
	15. Issue CEMRC 2000 Report; post report and background data to CEMRC web site by March 2001
	16. Issue newsletters in March and September, 2001
	17. Submit manuscript for publication by March 2001 on baseline characteristics of aerosols

Quality Assurance

The CEMRC is subject to the policies, procedures and guidelines adopted by NMSU, as well as state and federal laws and regulations that govern the operation of the University. The CEMRC has adopted a general quality assurance policy (Appendix J) that includes development and implementation of appropriate standards, performance assessment, quality improvement, provision of infrastructure, professional staff development, personal accountability and commitment to compliance.

The CEMRC's quality assurance policy and implementation plans recognize that there are distinctions between standard analytical activities and experimental research settings. For experimental research settings, there are frequently few if any recognized analytical standards or procedures for the analyses of interest, and a major task is to develop such procedures, or to modify the application of standard procedures for new media. Likewise, research sampling designs are typically unique to the underlying scientific hypotheses, and therefore may not follow any standardized external formats. Therefore, the quality control measures applied to research contrast with those applied in programs driven by regulatory requirements, where the sampling frequency and methodologies and the analytical procedures typically are spelled out by various compliance guidelines.

In the WIPP Environmental Monitoring project, the CEMRC's strategy is to develop a set of independent data for a variety of parameters of interest, frequently using sampling and analyses that are different from those dictated by the regulatory requirements that govern the WIPP's certification and operation. In many cases, these data will target a larger suite of parameters or lower detection limits than are of concern from a regulatory perspective. Although this approach may include some sampling and analyses similar to those conducted by other groups associated with the WIPP, other activities are unique to the CEMRC's projects.

Personnel

Program managers provide training to laboratory and field workers in methodologies, general laboratory protocol and maintenance routines and good safety practices. CEMRC laboratory and technical support staff receive specialized training for operation of specific equipment or systems, generally offered through equipment vendors. To support continued professional development, staff members are also provided opportunities for membership and participation in professional organizations, including attendance at conferences and workshops. Access to current scientific literature is provided through a current publications bulletin, a variety of journal subscriptions and inter-library loans.

Regulatory Compliance

To promote good health and safety practices in the laboratories, the CEMRC maintains a Chemical Hygiene Plan and associated training of personnel, in compliance with the requirements of 29 CFR 1910.1450, "Occupational Exposure to Chemical Hazardous Chemicals in Laboratories." A Hazard Communication Plan and associated training are also maintained for all employees, in compliance with requirements of 29 CFR 1910.200. A Chemical Hygiene Officer and Hazard Communications Coordinator are responsible for management of the chemical and laboratory safety programs, including maintenance of chemical inventories, periodic audits and management of any hazardous wastes generated by laboratory activities.

The CEMRC is a conditionally-exempt small quantity generator of hazardous wastes, as defined and regulated under the Resource Conservation and Recovery Act. Hazardous waste thus generated is disposed of through licensed treatment, storage and disposal facilities. Based on current chemical inventories, the CEMRC is exempt from the reporting requirements in Section 313 of the Emergency Planning and Community Right-to-Know Act. The CEMRC has had no spills of hazardous substances that exceeded the reportable quantity limits under the Comprehensive Environmental Response, Compensation and Liability Act. The CEMRC currently has no air contaminant emissions subject to regulation under the Clean Air Act, and no wastewater discharges subject to regulation under the Clean Water Act beyond normal sanitary sewer discharges.

Use of radioactive materials is governed by the CEMRC's Radioactive Materials License, issued by the New Mexico Environment Department. A Radiation Control Manual and Implementation Plan and associated training are provided for staff who deal with radioactive materials. A Radiation Safety Officer is responsible for management of the radiation safety program, including maintenance of a radioactive materials inventory, periodic radiation contamination surveys, radiation safety audits and management of any radioactive waste generated by laboratory activities. The CEMRC generates a small amount (< 100 lb) of solid, low-level radioactive waste annually, which is disposed of through a licensed commercial disposal facility.

Field Sampling Program Quality Assurance

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 preliminary plans are developed and documented. After the activity is completed, the plan is revised to reflect any departures from the original plan, and documented to file. For most environmental media, the sampling plans combine selected standard procedures with specific adaptations to address scientific objectives of interest. For example, procedures for collection and preservation of samples for compliance with Safe Drinking Water Act requirements are applied to the collection of drinking water and surface water samples, but the locations of sample collection are selected on the basis of other criteria. Likewise, high-volume air samplers are operated to meet an EPA standard of 1.13 m^3min^{-1}, but the frequency of filter replacement is based on optimal loading for radioanalysis.

Sampling procedures used for collection and preparation of environmental samples for the WIPP EM project are described in the individual data summaries that follow. Logbooks are maintained by technical staff in field operations to record locations and other specifics of sample collection, and data on instrument identification, performance, calibration and maintenance. Data generated from field sampling equipment are error-checked by using routine cross checks, control charts and graphical summaries. Original logbooks and field data forms are kept on file in the program manager's office. Most data collected in written form are also entered in electronic files, and electronic copies are cross-checked against the original data forms. All electronic files are backed up daily.

Calibration and maintenance of equipment and analytical instruments are carried out on predetermined schedules coinciding with manufacturer's specifications or modified to adapt to special project needs. Calibrations are either carried out by equipment vendors or by CEMRC personnel using certified calibration standards. Records of calibration and maintenance are maintained in instrument-specific files in the program manager's office.

Environmental Chemistry Program Quality Assurance

The analytical methods employed in the environmental chemistry program at CEMRC are based, when applicable, on various standard procedures (EPA, 1983, M*ethods for Chemical Analysis of Water and Wastes,* EPA/600/4-79-020; EPA, 1997, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*; EPA/SW-846; American Public Health Association, 1981, *Standard Methods for the Examination of Water and Wastewater, 20th Edition*).

For the WIPP EM, an ion chromatograph (IC) was used to determine the concentrations of a suite of major ions in water samples and aqueous extracts of all media sampled during 2000 (Table 3). An atomic absorption spectrometer (AAS) and inductively coupled plasma-mass spectrometer (ICP-MS) were used to analyze aqueous or acid extracts of samples.

For some matrix/analyte combinations, appropriate external standard procedures do not exist, and CEMRC has developed specialized standard procedures to meet the needs of the WIPP EM. A set of standard operating procedures and a formal quality assurance plan have been developed and implemented for the inorganic analyses performed at CEMRC. A summary of the quality assurance/quality control procedures and results for the environmental chemistry program for WIPP EM studies is presented in Appendix K. As part of CEMRC participation in the National Voluntary Laboratory Accreditation Program during 1999-2000, the environmental chemistry laboratory conducted analyses under the InterLaB WatR™ Pollution WP-58 Proficiency Testing Program sponsored by Environmental Resource Associates. Results for 27 of the reported 30 analytes were rated “acceptable”, for an overall rating of “Very Good” (90.3% score).

Radiochemistry Program Quality Assurance

During 2000, the CEMRC radioanalytical program participated in five rounds of the NIST Radiochemistry Intercomparison Program (NRIP) and achieved traceability for 17 of 18 analyte reports. The radioanalytical program also participated in the DOE Environmental Measurement Laboratory Quality Assurance Program (EML QAP), resulting in “acceptable” ratings for 49 results from glass fiber filters, soil, vegetation and water samples.

CEMRC has undertaken an extensive method development and validation project that began in May 1998, with special emphasis on measures necessary to ensure quantification of background levels of ^{239,240}Pu and other actinides. During 2000, new standard procedures were developed and implemented for WIPP EM analyses of high-volume aerosol filters and sediments. Method development will continue for brine and biota during 2001. A formal quality assurance plan was completed and adopted, and a variety of implementing procedures for radioanalyses in the WIPP EM project were also developed and issued. A summary of general quality assurance/quality control procedures used by the radioanalytical program is presented in Appendix L.

In Vivo Radiobioassay Quality Assurance

In vivo radiobioassays are performed in accordance with a formal quality assurance plan and related documentation that were developed to meet the requirements of the Department of Energy Laboratory Accreditation Program (DOELAP) for Radiobioassay. During 2000, CEMRC participated in DOELAP performance testing for ^{238}Pu, ^{238}U, and fission/activation products in lungs, and passed all performance criteria. CEMRC provides *in vivo* radiobioassay services for WIPP radiation workers, and this program received DOELAP certification in 1999.

During 2000, the CEMRC *in vivo* radiobioassay program participated in the Intercomparison Studies *In Vivo* Program administered by Oak Ridge National Laboratory (ORNL). This program provides quarterly testing for ^{137}Cs, ^{60}Co, ^{57}Co, ^{88}Y and ^{133}Ba deposited in whole body. From the 1998 annual report issued in March 2000, (four quarters in total), CEMRC reported values that were within –1.83% to 4.61% of the ORNL known value for all radionuclides (acceptance criteria at –25% to +50%). Results of tests for the first three quarters of 2000 were also verified by ORNL within –2.7% to 1.8% of known values.

External Laboratory Services

With the exception of data for organic carbon content in FAS air filter samples, all analyses presented herein were carried out by CEMRC laboratories. The organic carbon analyses were provided as a courtesy by the Energy and Environmental Engineering Center of the Desert Research Institute in Reno, Nevada.

Table 3. Inorganic Analyses Conducted at CEMRC

Type of Analyte (Instrument)	**Sample Preparation Method by Sample Matrix**			
	Air	**Drinking & Surface Water**	**Soil**	**Sediment**
Anions ([a]IC)	Filter extraction with [b]DI water and isopropanol	Syringe filtration with direct injection	Aqueous extract	Aqueous extract
Cations (IC)	Filter extraction with DI water and isopropanol			
Hydrides (As, Sb, Se) and Hg (Flow Injection [c]AA)		Syringe filtration with direct injection	Total recoverable	Total recoverable
Trace Elements ([d]ICP-MS & AA)	Aqueous extract Total dissolution	Dissolved Total recoverable	Total recoverable	Total recoverable

[a] Ion chromatograph
[b] De-ionized water
[c] Atomic absorption spectrometer
[d] Inductively-coupled plasma mass spectrometer

WIPP ENVIRONMENTAL MONITORING DATA SUMMARIES

Meteorological Conditions in the Vicinity of the WIPP Site

Methods

CEMRC operates two identical meteorological towers at sampling sites in the vicinity of the WIPP (Fig. 2). The Near Field site is approximately 1 km northwest of the WIPP site at an elevation of 1088 m (latitude 32°22’40.385”N; longitude 103°47’55.425”W). The Cactus Flats site is approximately 19 km southeast of the WIPP site at an elevation of 1041 m (latitude 32°13’05.451”N; longitude 103°41’42.583”W).

Each station consists of a 10-meter tower equipped with sensors for temperature, relative humidity, barometric pressure, total solar radiation, Ultra-Violet B (UVB) radiation, wind speed and direction, and vertical wind speed. Data are collected every second, with averaging times of ten minutes. In addition, the maximum wind speed and total precipitation occurring over the 10-min averaging period are recorded.

Temperature, relative humidity and all wind parameters are measured at a height of 10 meters above ground level. Precipitation, barometric pressure, solar radiation and UVB are measured at heights of 0.4, 1, 2, and 3 m, respectively. The barometric pressure sensors are compensated for temperature, but are not referenced to mean sea level. The solar radiation sensors (pyranometers) measure the energy flux per unit area (W m^{-2}) of both direct and diffuse sky radiation. The UVB sensor measures direct and diffuse UVB in the 280-320 nm band.

The data are stored in electronic dataloggers and downloaded twice weekly. Once downloaded, the data are screened for outliers and other anomalies and uploaded to a main database. Performance checks of the sensors are conducted quarterly, and sensors are re-calibrated at the manufacturers’ specified intervals.

This report summarizes meteorological data collected over the 12-month period from December 1999 through November 2000. In addition, data collected at the sites from 1 December 1998 through 30 November 1999 (12 month period) are compared with data from the same time interval during 1999-2000.

Results

For the 2000 sampling period, data recovery exceeded 99% for all sensors, except the wind speed sensor at Near Field, and the UVB sensor at both locations. The Cactus Flats UVB sensor failed in June and was undergoing repairs and recalibration during late June through early August. At Near Field, the wind speed sensor suffered intermittent failures from late March through late July, and the UVB sensor was absent from the station for calibration during late August through mid-October. Other short-term (typically less than one hour) data losses occurred throughout the year due to sensor malfunction, repair, maintenance, and performance testing.

Averaged over the year, winds were from the east and southeasterly direction (E, ESE, SE and SSE quadrants, inclusive) 50% of the time at the Cactus Flats and 52% at the Near Field sites (Fig. 3). However, there were some distinctive seasonal variations in wind direction (Figs. 4-5). Wind direction was highly variable during the winter and spring (December through May) when compared with the summer and fall (June through November). During summer and fall, wind from the southeastern quadrant occurred over 64% of the time, but dropped to less than 41% during the winter and spring. The inter-annual and intra-annual variability in wind direction are important parameters in modeling dispersion pathways for potential airborne releases from the WIPP.

Wind velocities were very similar between sites. Wind velocities (10-min means) were less than 5.4 m s^{-1} over 73% of the time, with speeds frequently from 3.1 to 5.4 m s^{-1}. Calm periods (wind velocities < 0.1 m s^{-1}) occurred less than 1% of the time over the year. Wind velocities > 5.4 m s^{-1} occurred less than 26% of the time, but were more frequent during the spring, and typically came from the west and west-northwest. The highest wind velocities recorded at each site were 27.1 m s^{-1} (62 mph) on 5 September at the Near Field site, and 27.8 m s^{-1} (63 mph) on 24 May at the Cactus Flats site.

Air temperatures at Near Field ranged from –6.1 to 40.4 ^{o}C and from –6.1 to 40.2 ^{o}C at Cactus Flats. The maximum temperatures were recorded on 30 June at Cactus Flats, and 1 July at Near Field. The lowest temperatures were recorded on 26 December 1999 at both locations. The annual mean temperatures were 18.6 ^{o}C at Near Field and 18.2 ^{o}C at Cactus Flats. At both locations, December was the coldest month (mean = 7.4 ^{o}C at Near Field; mean = 7.0 ^{o}C at Cactus Flats) and July was the hottest month (mean = 28.9 ^{o}C at Near Field; mean = 28.5 ^{o}C at Cactus Flats) (Fig. 6).

The annual mean relative humidity at Near Field was 42% and ranged from 5 to 100%. Humidity at the Cactus Flats site was nearly identical to Near Field, averaging 42% and ranging from 4 to 101%. Mean relative humidities were lowest when temperatures peaked in late spring and early summer (Fig. 7). It should be noted that the accuracy of the relative humidity sensors declines at relative humidities below 12% and above 94%, and readings outside these ranges should be interpreted with caution.

Barometric pressure did not exhibit an obvious seasonal trend at either site (Fig. 8). The annual mean was 893.7 mb at Cactus Flats and 898.3 mb at the Near Field site. The apparent 4.6 mb difference between the sites can be attributed to a 41 m difference in elevation. This difference is not significant if corrected using standard barometric conversions that incorporate elevation (U.S. Department of Commerce Weather Bureau, 1963, *Manual of Barometry*, *Vol. 1*, Washington D.C.).

Total solar radiation flux (W m^{-2}) was integrated over daily intervals to calculate total energy received per unit area (MJ m^{-2}). As is typical, solar radiation received at the sites peaked in the summer and was lowest during the winter months (Fig. 9). This pattern is due to a combination of increasing solar radiation intensity, less cloud cover and additional hours of daylight during the summer months. Over the year, the daily total solar radiation ranged from 4 to 64 MJ m^{-2} at Near Field and 4 to 65 MJ m^{-2} at Cactus Flats.

Solar UVB flux (W m^{-2}) was integrated over daily intervals to calculate total energy received per unit area (MJ m^{-2}). The UVB radiation followed a pattern similar to that of the total solar radiation (Fig. 10).

Over the year, a total of 22.0 cm of precipitation was measured on 55 days at Cactus Flats and 26.3 cm of precipitation was measured on 48 days at Near Field (Fig. 11). At both sites, the month of October had the highest number of days on which precipitation was recorded (12 at each location). Both locations recorded the highest precipitation in June, with 9.7 cm at Cactus Flats on June 2, and 13.2 cm at Near Field on June 21.

Overall, 2000 was a slightly wetter year than 1999. In 1999, a total of 22.7 and 19.6 cm of precipitation was recorded at the Near Field and Cactus Flats sites, respectively. In 2000, 26.3 cm of precipitation was recorded at the Near Field site and 22.0 cm was recorded at the Cactus Flats site. Although 2000 was wetter, mean annual temperatures and relative humidities were approximately the same in both years. Although December 1998, and January, June and August 1999 were warmer when compared to the same months in 1999 and 2000, temperatures were approximately 3 ^{o}C cooler in May 2000, and 2 ^{o}C cooler in July 2000.

Tables presenting meteorological data summarized herein are available on the CEMRC web site at http://www.cemrc.org.

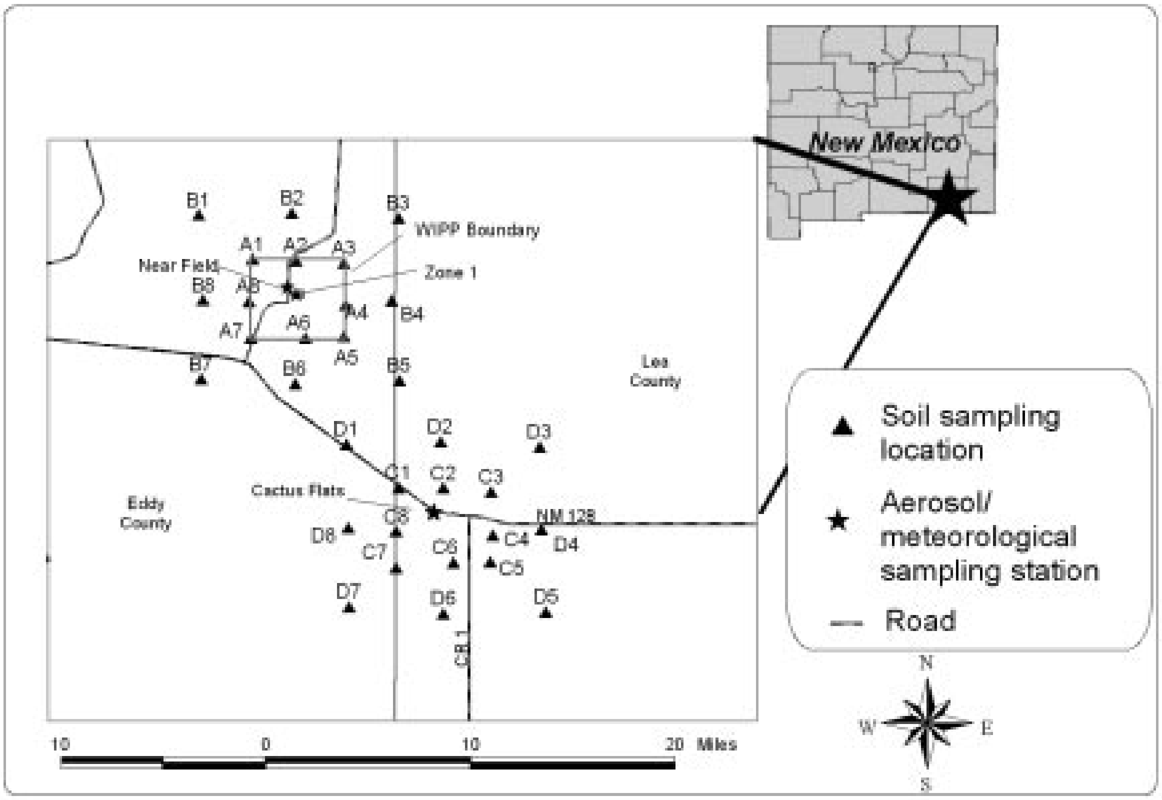
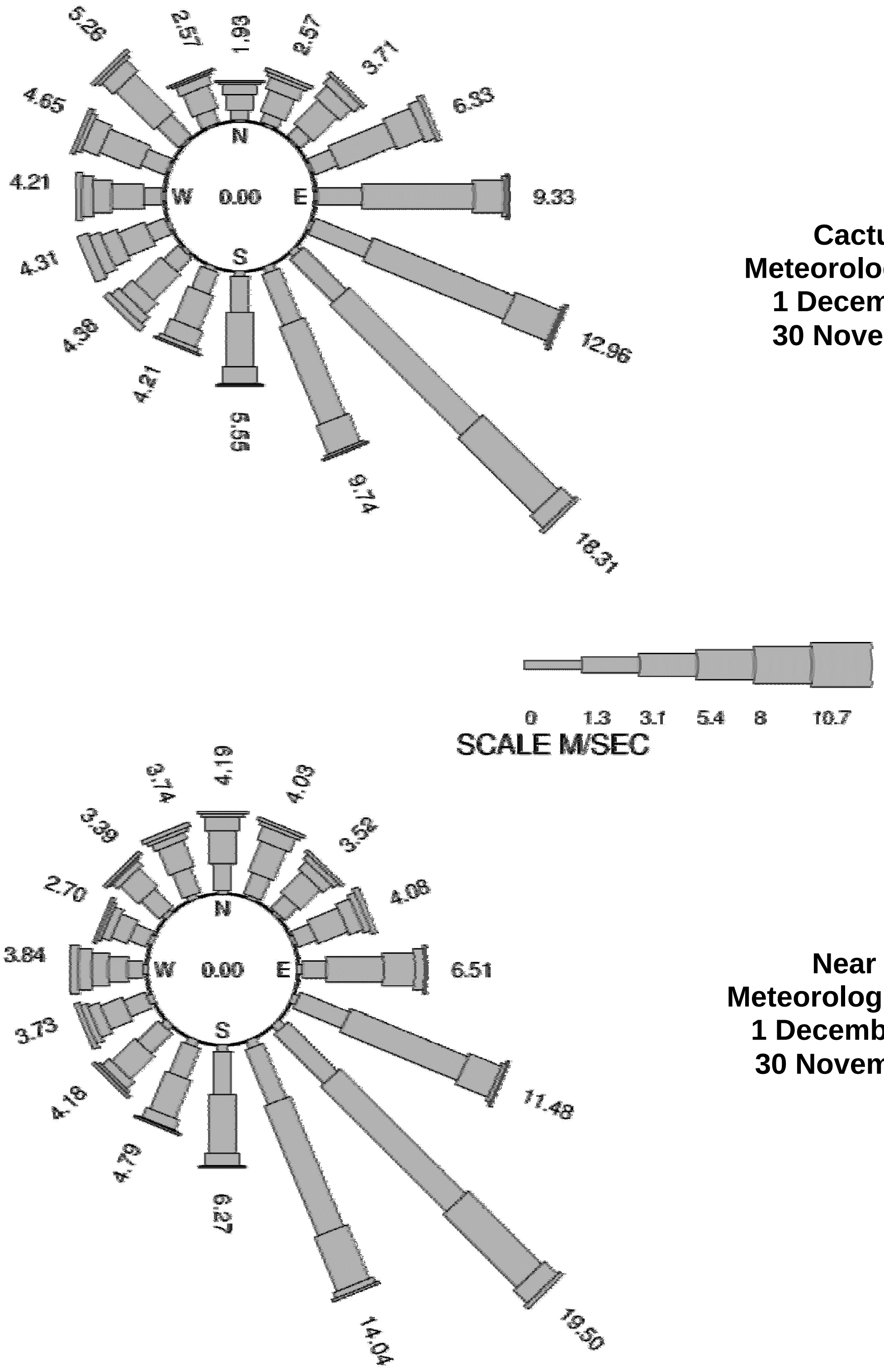


Figure 2. Sampling Locations in the Vicinity of the WIPP

Aerosol sampling and meteorological monitoring is conducted at Near Field and Cactus Flats.

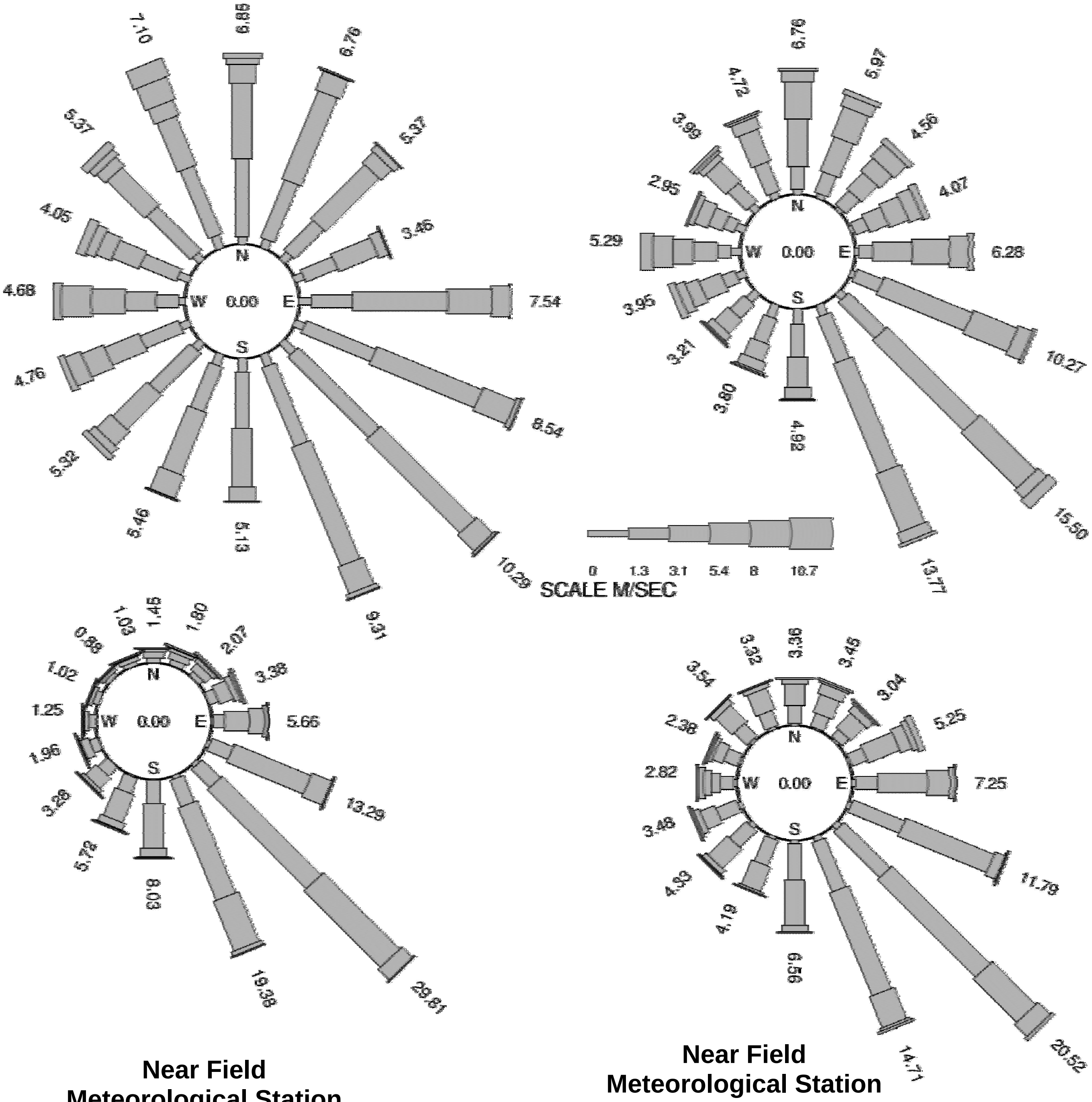


Cactus Flats
Meteorological Station
1 December 1999 -
30 November 2000

Near Field
Meteorological Station
1 December, 1999 -
30 November 2000

Figure 3. Annual Wind Roses for Near Field and Cactus Flats

Value in center of a rose is % time with no recordable wind. Value at outer end of each tube is % time wind blew from the direction of the tube outer opening. Within each tube, segment lengths indicate relative frequency of wind speeds (m sec^{-1}) given on scale.



Near Field Meteorological Station 1 December 1999 - 29 February 2000

Near Field Meteorological Station 1 March, 2000 - 31 May 2000

Near Field Meteorological Station 1 June 2000 - 31 August 2000

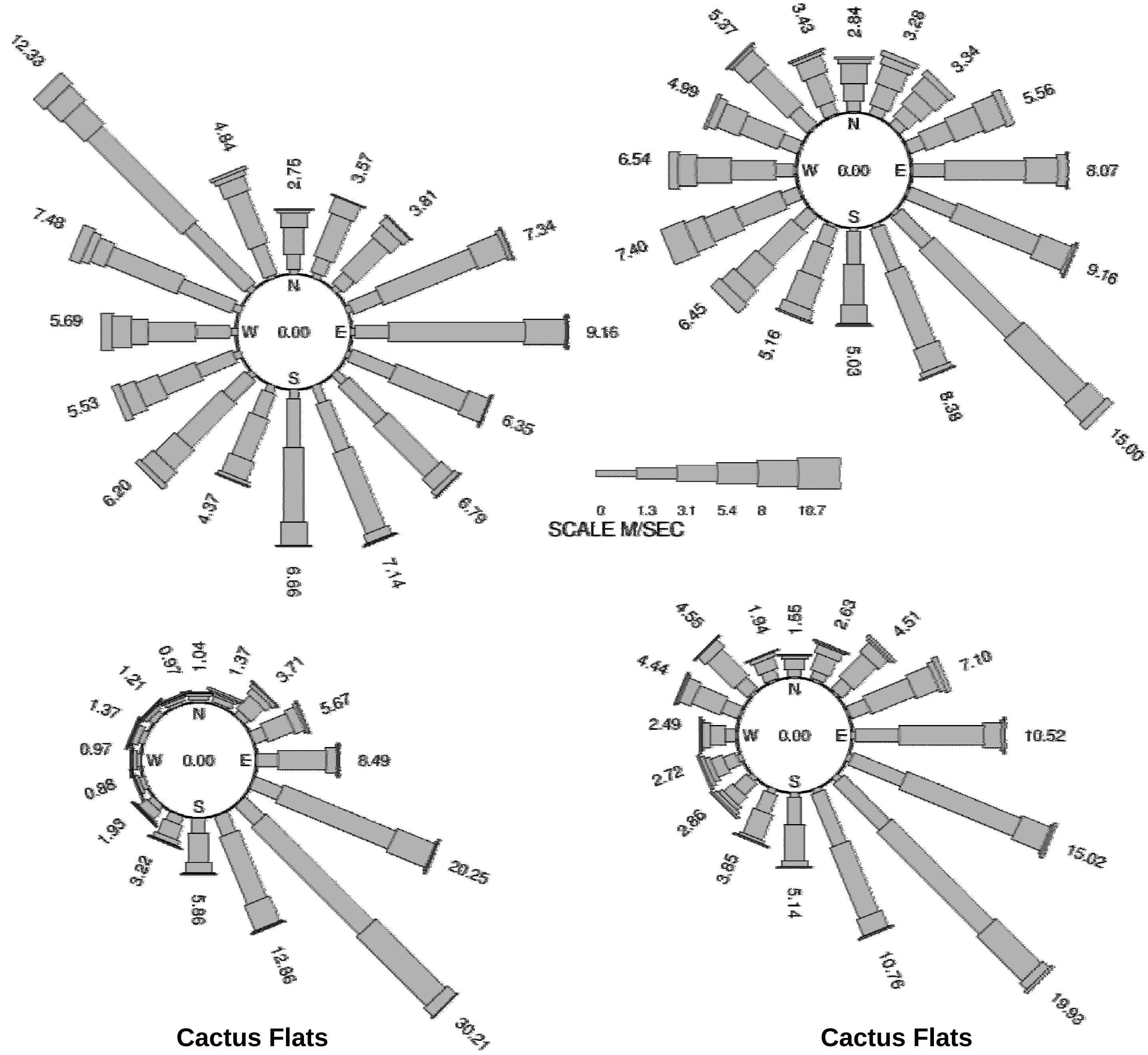
Near Field Meteorological Station 1 September 2000 - 30 November 2000

Figure 4. Seasonal Wind Roses, Near Field

See page 19 for explanation.

Cactus Flats
Meteorological Station
1 December 1999 -
29 February 2000

Cactus Flats
Meteorological Station
1 March 2000 -
31 May 2000



Cactus Flats
Meteorological Station
1 June 2000 -
31 August 2000

Cactus Flats
Meteorological Station
1 September 2000 -
30 November 2000

Figure 5. Seasonal Wind Roses, Cactus Flats
See page 19 for explanation.

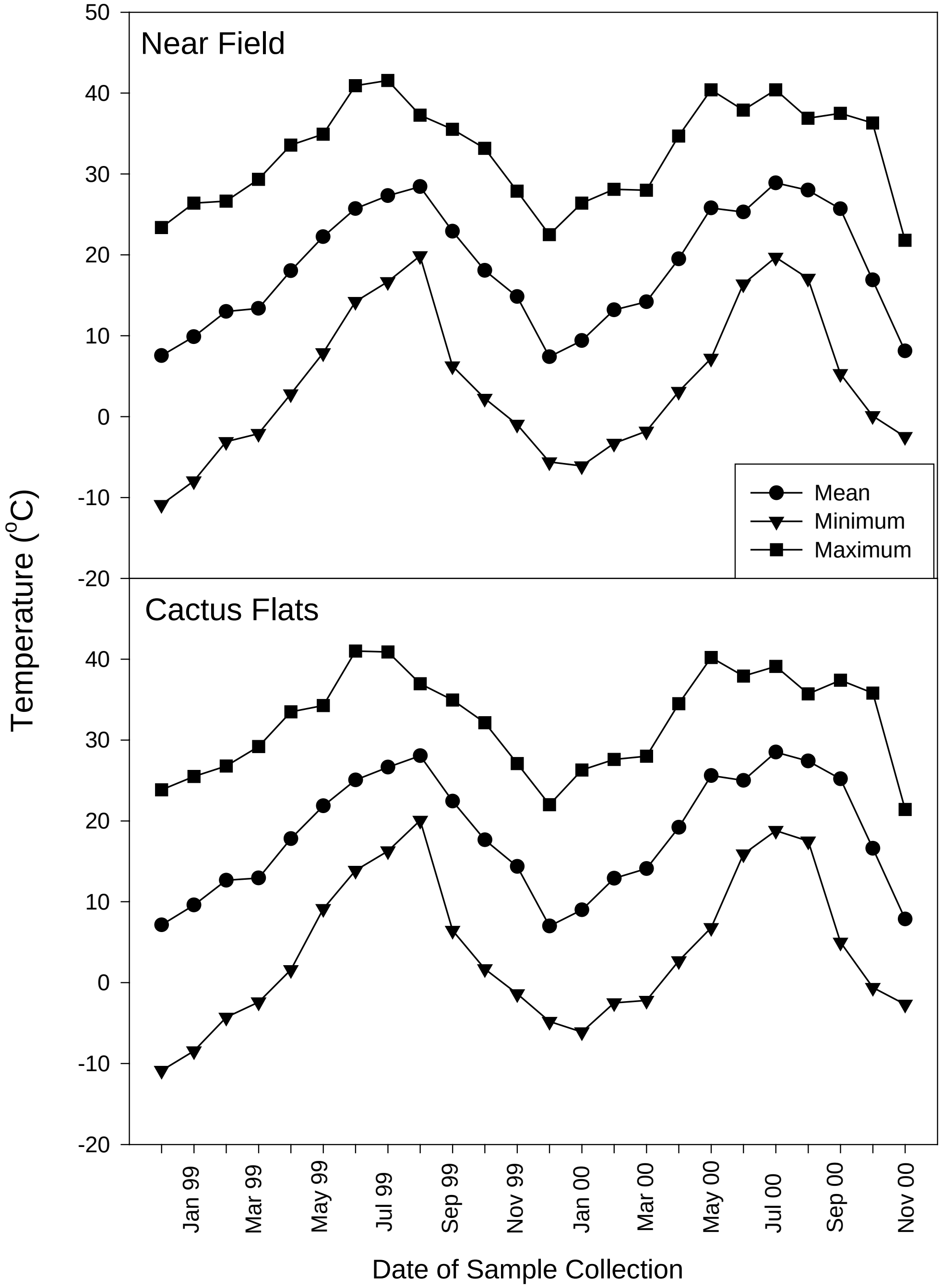


Figure 6. Monthly Mean, Minimum and Maximum Temperature at Near Field and Cactus Flats during December 1998 - November 2000

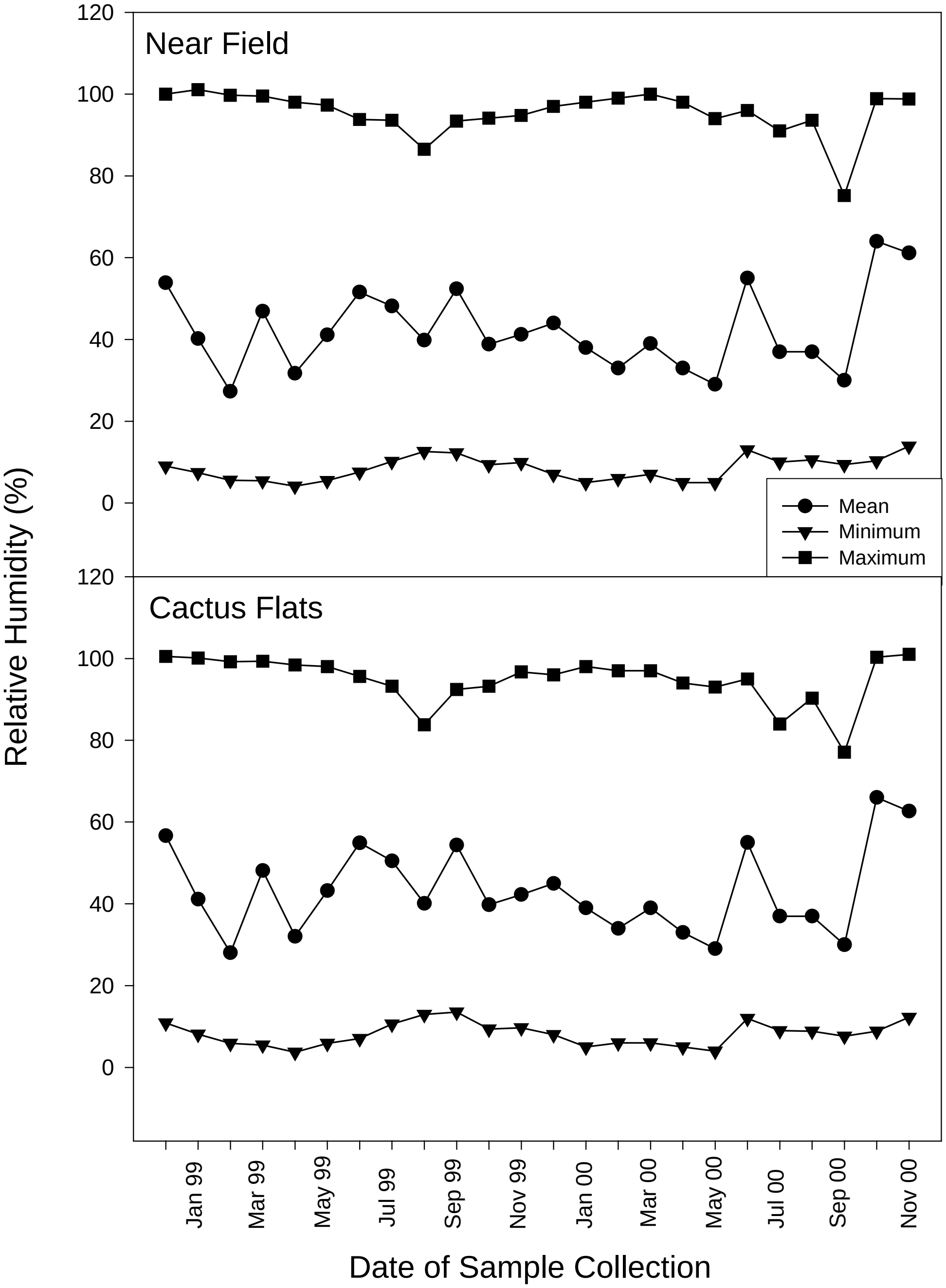


Figure 7. Monthly Mean, Minimum and Maximum Relative Humidity at Near Field and Cactus Flats during December 1998 - November 2000

Relative humidity sensor may have reduced accuracy at < 12% and > 94%.

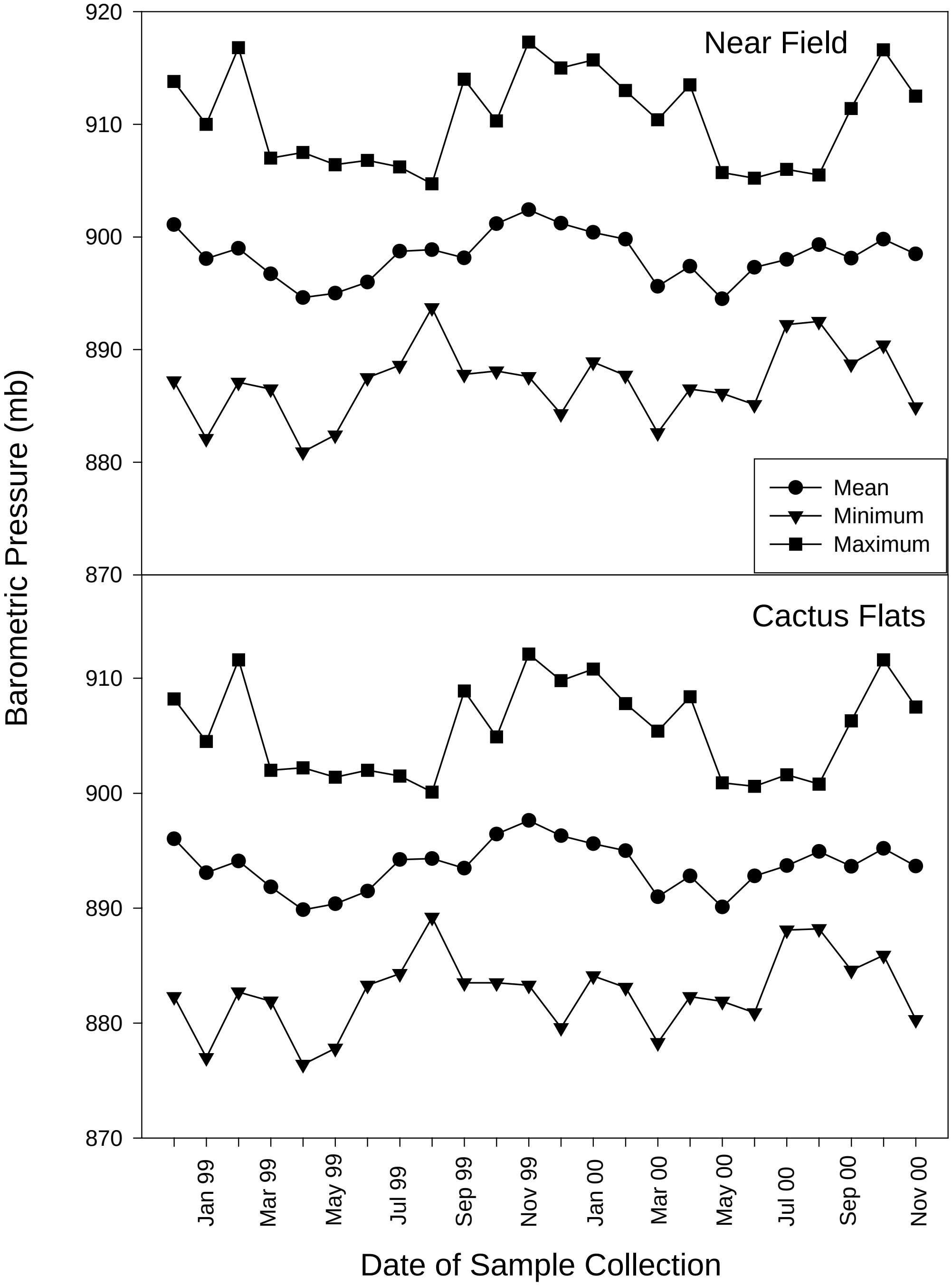


Figure 8. Monthly Mean, Minimum and Maximum Barometric Pressure at Near Field and Cactus Flats during December 1998 - November 2000

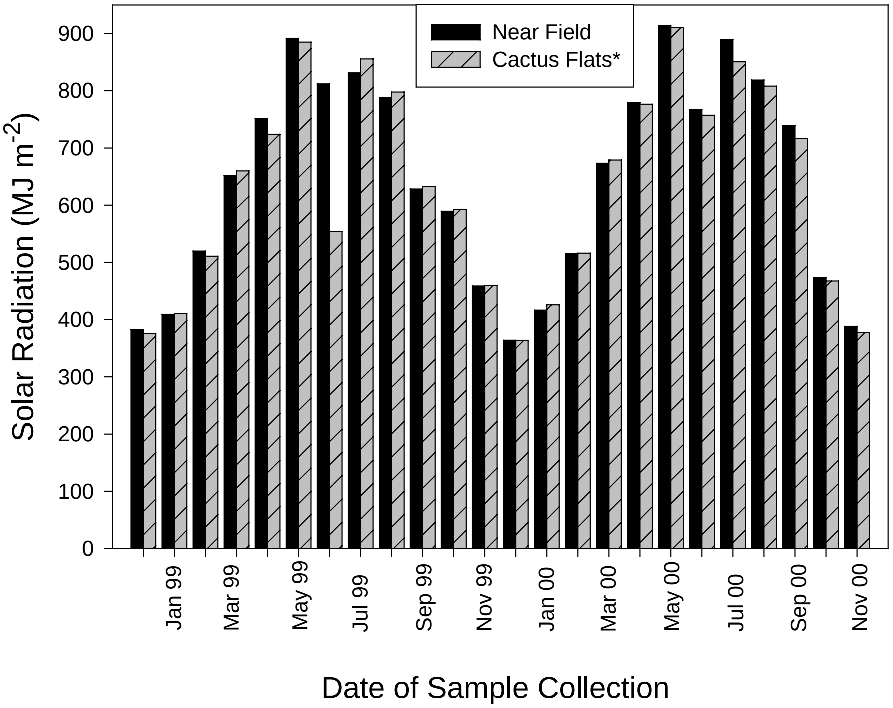


Figure 9. Monthly Total Solar Radiation at Near Field and Cactus Flats during December 1998 - November 2000

*The low value for June 1999 at Cactus Flats resulted when the sensor was damaged by a lightning strike.

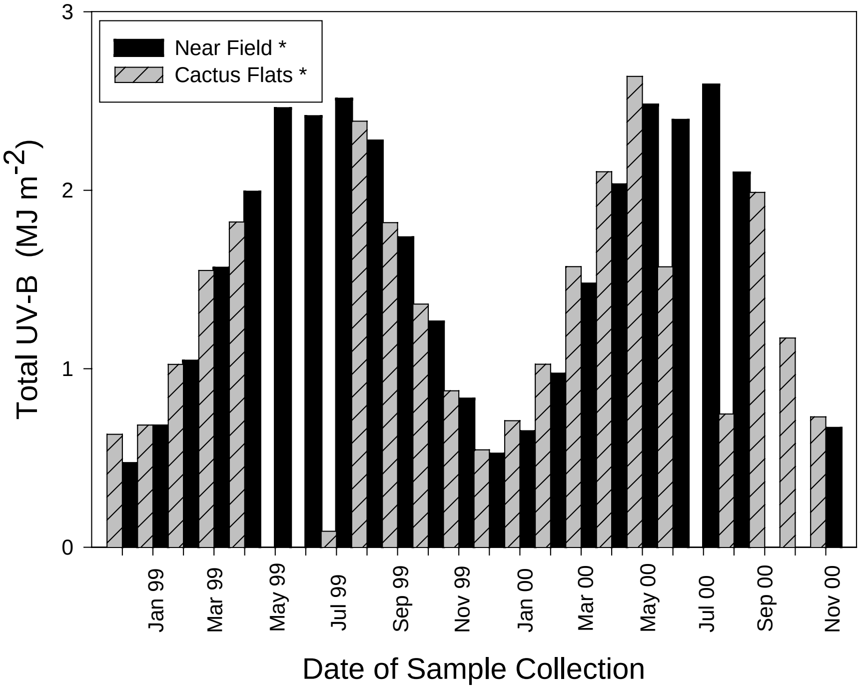


Figure 10. Monthly Total UV-B Radiation at Near Field and Cactus Flats during December 1998 - November 2000

*Cactus Flats sensor inoperative April-July 1999, June-July 2000. Near Field sensor inoperative August-October 2000.

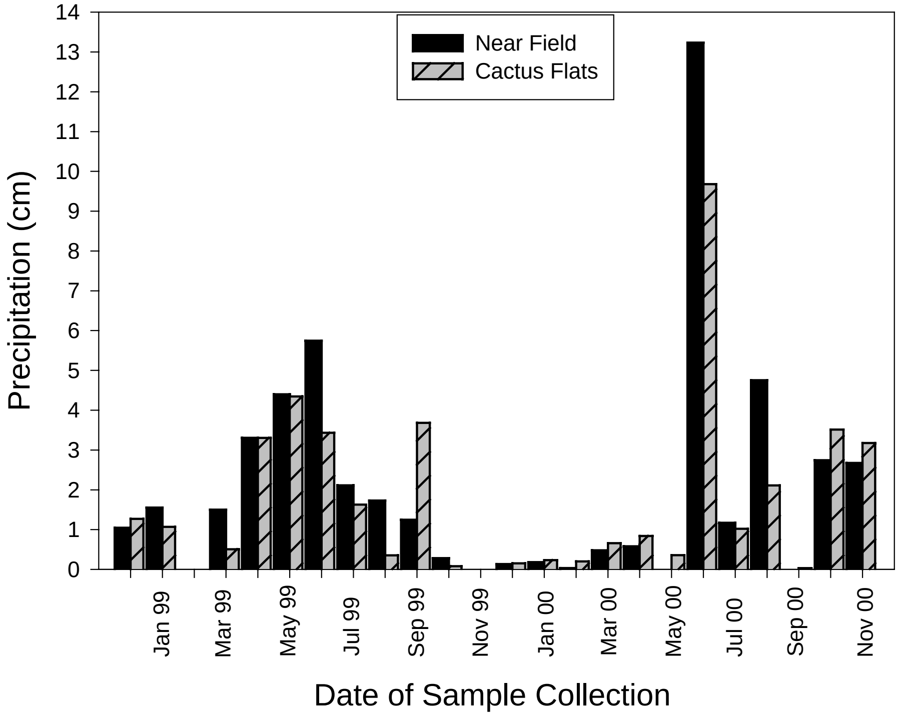


Figure 11. Monthly Total Precipitation at Near Field and Cactus Flats during December 1998 - November 2000

Radionuclides and Inorganics in Ambient Aerosols

Introduction

CEMRC collects and analyzes samples of particulate matter from the atmosphere ("aerosols") as part of its WIPP Environmental Monitoring (EM) project. These atmospheric studies are an important part of the WIPP EM because if a situation arose in which radioactive or chemical contaminants were released from the WIPP, those materials could be rapidly dispersed through the atmosphere and spread throughout the environment. In addition, in such a scenario, the inhalation of aerosol contaminants from the WIPP would represent a potential route of exposure to radionuclides and other chemicals for the local citizenry.

The WIPP EM aerosol studies began prior to March 26, 1999, which is when the first radioactive waste shipment was received at the facility. Baseline samples collected before the receipt of the waste have been used for the first objective of the study, that is, to characterize the background concentrations of selected radionuclides and inorganic substances in the atmosphere of the area surrounding the WIPP. These data also are being used in statistical comparisons to determine whether the concentrations of any of these substances have changed since the WIPP became operational, that is, after shipments of nuclear waste began arriving at the facility. A final objective for the aerosol studies was to investigate the relationships between the concentrations of radioactive and non-radioactive substances in aerosol particles.

This report is one of a series, beginning with the 1998 report, that presents information on actinide concentrations in aerosols resulting from the CEMRC WIPP EM project. The accompanying elemental and aerosol ion analyses complement the radionuclide studies because the inorganic data provide information about the types of aerosols in the atmosphere and how their concentrations have varied over time. In addition, a recent study of soils for the WIPP EM (Kirchner et al., *J. Environ. Rad.*, in press) has demonstrated the complementary nature of the radionuclide and inorganic data by showing that radionuclide activities in soils are correlated with certain elements indicative of crustal materials and environmental pollutants. Furthermore, some of the trace elements being studied (As, Be, Ba, Cd, Cr, Pb, Hg, Se and Ag) are listed as components of the Permitted TRU Mixed Wastes in the WIPP hazardous waste permit (*Waste Acceptance Criteria for the Waste Isolation Pilot Plant*, DOE/WIPP-069, November 8, 1999). Several of these elements are of concern due to possible toxicological effects for humans and ecosystems, but from a practical standpoint, they are also useful as potential chemical tracers of material releases from the WIPP.

Methods

Detailed information regarding the sampling design for the WIPP EM ambient aerosol studies was presented in the CEMRC 1998 and 1999 reports. Briefly, for the radionuclide studies, ambient aerosol samples were collected from three sampling stations (Fig. 2). These high-volume samples were collected on 20 x 25 cm Gelman A/E® glass fiber filters, which were changed when the flow rate dropped to 90% of its original value. As a result, the time intervals for the radionuclide sample collections were variable but typically several weeks in length. At Cactus Flats and Near Field, high-volume samples for the radiochemistry studies were collected for both total suspended particles (TSP) and PM_{10} (particles less than 10 μm, aerodynamic equivalent diameter). At On Site, only TSP samples were collected.

Gravimetric determinations were made for the aerosol masses collected on the high-volume filters. Prior to sampling, new filters were weighed without being desiccated. At the end of the sample collection period, the sample filter holder and filter were returned to the lab where the filter was removed from the holder, folded, and placed in a dessicator for 24 hours. The filters were then reweighed, heat-sealed in plastic, and delivered to the radiochemistry laboratory for analyses. The total mass accumulated on the filter during a sampling period was divided by the total air volume drawn through the filter to calculate the aerosol mass concentration. Activity density was calculated as the activity for each nuclide per unit mass of aerosol material collected. The gravimetric determinations were only made on the high-volume filters because static charge and other technical problems caused the weights of the low-volume filters used for other analytes to vary erratically.

The high-volume samples were analyzed for selected radionuclides, including ^{238}Pu and ^{239,240}Pu. For the radiochemical analyses, entire filters were muffled for 4 hr at 500° C and then spiked with Pu tracers. The samples were dissolved using HF, HCl and $HClO_4$, and the resulting solutions processed by multiple precipitation, co-precipitation, and ion-exchange and/or extraction chromatography steps to separate and purify Pu. The nuclides of interest were then precipitated with LaF_3, deposited onto filters, mounted, and counted using an alpha spectroscopy system.

For the trace element (TE) and ion chromatography (IC) studies, aerosol samples were collected from the same three stations used for radionuclide sampling. Aerosol samples for these studies were collected using low-volume (~ 10 L min^{-1}) systems for collecting TSP, PM_{10} and $PM_{2.5}$ (particulate matter less than 2.5 µm in diameter). Samples for IC analyses were collected on 2-µm pore-size, 47-mm diameter Gelman Teflo® PTFE Teflon® filters while the TE samples were collected on 0.8-µm pore-size, 47-mm diameter cellulose-ester Gelman Metricel® filters. Since February 1998, TE/IC sampling periods of two, two, and three days per week have been used (the filters are replaced on Monday, Wednesday, Friday). The analyses of the filters alternated between TE and IC, with every second sample archived (TE, archive, IC, archive, TE, archive, IC, archive etc.). The results presented here cover the periods from 4 November 1997 to 30 June 2000, and 3 February 1998 to 30 June 2000 for the IC and TE analyses, respectively.

Aerosol filters were prepared for elemental analyses using a microwave digestion system and HNO_3, HCl, and HF. The concentrations of major and trace elements were determined in the aerosol samples by atomic absorption (AA) spectrometry and inductively-coupled plasma mass spectrometry. An inductively-coupled plasma emission spectrometer was used instead of the ICP-MS for analyses prior to January 1999. For the IC analyses, aqueous extracts of the Teflo® filters were determined using an ion chromatography (IC) system equipped with anion or cation columns, using chemical suppression, conductivity detection, and multiple levels of calibration.

Results and Discussion

^{238}Pu was quantified in only two of the 138 samples analyzed. The activity concentrations calculated on a volume basis for these two samples, which were both TSP, were 5.8 and 7.6 nBq m^{-3}. These were collected at the On Site station from 19 November to 20 December, 1999 and at the Cactus Flats station from 10 April to 1 May, 2000, respectively. The corresponding mass concentrations for the samples were 0.11 mBq g^{-1} of aerosol mass (On Site sample) and 0.16 mBq g^{-1} (Cactus Flats sample). As all aerosol samples collected prior to the receipt of waste at the WIPP had ^{2238}Pu activities less than the minimum detectable concentrations, no baseline data for ^{238}Pu are available from CEMRC studies. However, pre-operational data from the Environmental Evaluation Group (EEG), reported in Kenny et al. (1998, *Preoperational Radiation Surveillance of the WIPP Project by EEG during 1993 through 1995,* EEG-67) show ^{238}Pu concentrations ranging from below detection up to 160 nBq m^{-3}, which is roughly 50 times higher than in the two CEMRC samples having quantifiable ^{238}Pu.

^{239,240}Pu was quantified in all 138 samples analyzed. The arithmetic mean volume-based activity concentrations for the PM_{10} samples were 8.9 nBq m^{-3} at Near Field and 12 nBq m^{-3} at Cactus Flats, while the means for the TSP samples over the same time periods were 17, 22, and 18 nBq m^{-3} at Near Field, Cactus Flats, and On Site respectively. Comparisons of the means for the PM_{10} and TSP samples show that the volume-based activity concentrations in the PM_{10} fractions relative to TSP were similar (52% at Near Field and 55% at Cactus Flats).

The mean PM_{10} ^{239,240}Pu activity densities were 0.42 and 0.49 mBq g^{-1} at Near Field and Cactus Flats, respectively. The corresponding mean TSP activity densities were 0.50 (Near Field), 0.59 (Cactus Flats), and 0.34 (On Site) mBq g^{-1}. The percentages of the activity densities for ^{239,240}Pu in the PM_{10} fractions relative to TSP were therefore 84% at Near Field vs. 83% at Cactus Flats.

It is noteworthy that when calculated on a per unit volume basis, the ^{239,240}Pu activity concentration was lower in the PM_{10}-sized fraction than was aerosol mass. That is, the ratio of the mean ^{239,240}Pu activity concentrations in the PM_{10} size fraction vs. TSP (^{239,240}Pu activity concentration in PM_{10} / ^{239,240}Pu activity concentration in TSP) was less than the corresponding ratio of aerosol masses (mass in PM_{10} fraction/mass in TSP). This relationship held at both Near Field and Cactus Flats. Generally one would expect Pu to be enriched in small particles as has been observed for soils from the study area (Kirchner et al., *op cit.*). While there is no direct evidence for small particle ^{239,240}Pu enrichments in the aerosol data, the results could be explained by the existence of PM_{10} aerosols that contribute to the aerosol mass but contain little or no ^{239,240}Pu. Two likely candidates for the small particle aerosols are major ions, such as nitrate and sulfate, and organic compounds, both of which are often produced through gas-to-particle conversion processes. These results demonstrate the advantages for the WIPP EM of collecting data for non-radioactive substances that provide a context for the distributions of ^{239,240}Pu, and presumably other radionuclides, in the environment. Follow-up studies of the contributions of major ions to mass loadings are planned.

Comparisons between the baseline and operational data were made by testing the differences in the mean values of ^{239,240}Pu for statistical significance through 2-way analysis of variance (2-way ANOVA). For these analyses, the ^{239,240}Pu data were grouped by category (i.e., Baseline vs. Operational) and by sampling site. Separate analyses were conducted for the PM_{10} (Near Field vs. Cactus Flats) and TSP (On Site vs. Near Field vs. Cactus Flats) samples. Parallel statistical analyses were conducted for selected TE and IC constituents as a means of investigating concurrent changes in other types of aerosol particles.

For the PM_{10} samples, neither of the 2-way ANOVAs testing for differences in the mean ^{239,240}Pu activity concentrations or densities (i.e., activities calculated on a volumetric or mass basis) showed any statistically significant differences at a probability for chance occurrence of less than 5% ($p < 0.05$). Therefore, neither the differences in the means for the baseline vs. operational PM_{10} samples nor those in the mean PM_{10} activities for the three different sites were statistically significant.

Two-way ANOVAs for the TSP samples showed that the differences in the mean ^{239,240}Pu activity concentrations among sites were not significant, but the difference between the ^{239,240}Pu activity concentrations for baseline vs. operational samples was marginally significant at $p = 0.021$. It is noteworthy that although not statistically significant, the highest mean activities, both for the baseline and operational samples, were observed at Cactus Flats, the site farthest from the WIPP. Furthermore, related studies show that the soils at Cactus Flats have higher concentrations of many radionuclides, including ^{239,240}Pu than those from Near Field.

For the TSP activity densities, the differences among sites were highly significant ($p < 0.0001$), and as with the activity concentrations, the highest activity densities were observed at Cactus Flats. In contrast to the activity concentrations, the differences in the mean ^{239,240}Pu activity densities for baseline vs. operational samples were clearly not significant ($p = 0.18$).

One explanation for the difference in the mean activity concentrations between the sets of baseline vs. operational samples is a problem related to aliasing in time-series analysis. Strong seasonal cycles are evident in the ^{239,240}Pu data for both TSP and PM_{10}, with higher activity concentrations occurring in spring of each of the three years of available data (Figs. 12 and 13). As a result of these seasonal cycles, and to avoid aliasing, one must ensure that time intervals are properly matched when making comparisons. The baseline data for the radionuclide activities cover almost exactly one year, from 2 February 1998 to 12 February 1999, while the operational data include two of the high-activity spring events. Recalculating the 2-way ANOVA using only the first full year of operational data substantially increases the probability of a chance occurrence for a difference as large as that observed, from $p = 0.021$ to $p = 0.036$.

The EEG has reported data for ^{239}Pu in aerosols on their web site (http://www.rt66.com/~eeg/) that are in good agreement with the CEMRC ^{239,240}Pu data reported here. The EEG results were based on quarterly composites of low-volume samples collected at Artesia, Carlsbad, Hobbs, Loving and three sites at the WIPP. Quarterly data were reported by EEG for 1993, 1994, 1995 and 1998, but data were not posted for all quarters at all sites, and many samples were reported below detection limits (including negative activities). The EEG results represent the average activities for the composite samples grouped by calendar quarter. As might be expected for longer sampling periods, seasonal patterns were less evident in the EEG ^{239}Pu aerosol data than in the CEMRC results, but high relative ^{239}Pu activities were evident for the spring periods at Artesia and Carlsbad. More important and relevant to the CEMRC results, the EEG quarterly data for the pre-operational period, which were also reported in Kenny et al., (*op. cit.*), encompass all of the CEMRC values, including the high values observed at Cactus Flats in 1999.

One explanation for the temporal trends in the ^{239,240}Pu data is that the concentrations of this nuclide vary from year-to-year and that the loadings of various kinds of aerosols were simply higher during the first year of the WIPP operations than during the baseline period. This can be illustrated by examining the temporal trends of other types of aerosols, focusing on data from the low-volume aerosol samples collected coincident with the high-volume samples. For example, the mean aerosol aluminum concentrations, which are an indicator of the loadings of mineral dust in the atmosphere (Duce et al., 1980. *Science* 209, 1522), changed in a manner similar to ^{239,240}Pu (Fig. 14), that is, with strong peaks observed from late winter into spring. A 2-way ANOVA comparing the mean Al concentrations in the TSP samples for one year of baseline vs. one year of operational data (as defined by the receipt of radioactive waste) produced a probability for chance occurrence of 0.014. Such interannual variability in mineral dust concentrations is well documented in the atmospheric sciences literature and differences of this type are influenced both by conditions in the dust source regions (Prospero, J and R. T. Nees, 1986, *Nature* 320, 735) and variations in transport pathways.

The analysis of variance also showed that the mean Al concentrations were not significantly different among sites. More importantly, trends resembling those observed for ^{239,240}Pu (higher concentrations of dust in the operational vs. baseline samples) were observed at all sites. At Cactus Flats, the mean aerosol/Al concentration for the first year of the operational phase (620 ng m^{-3}) was ~ 70% higher than the mean for the baseline samples (360 ng m^{-3}).

Pronounced seasonal cycles also were observed for U, nitrate, and sulfate concentrations in aerosols from all three CEMRC sampling sites (Figs. 14 and 15). These cycles were not exactly coincident, however. In particular, the peak in sulfate concentrations occurred after July whereas the maximum concentrations in the other types of aerosols, including ^{239,240}Pu, were several months earlier. Interannual variability is especially evident in the nitrate data, with much higher concentrations observed in 2000 than in the preceding two years.

A summary of maximum and minimum concentrations for the elemental data is provided as a reference for baseline conditions (Table 4). The first shipment of mixed waste was delivered to WIPP on 9 September 2000, and thus all of the elemental data included in this report can be considered part of the "mixed waste" baseline. Particular attention in future analyses will be given to samples that exceed the maxima observed during this baseline phase.

It is highly improbable that any activities at the WIPP could affect the concentrations of Al, U, nitrate and sulfate over such a vast area, especially since (a) the concentrations of these substances and ^{239,240}Pu were often highest at Cactus Flats, which is ~ 19 km to the southeast and upwind of the WIPP and (b) the seasonal patterns in the four analytes were offset, indicating multiple sources were likely important. A much more compelling explanation for the observed differences between baseline and operational concentrations of ^{239,240}Pu and other inorganic substances is that the aerosol loadings and composition were responding to the ensemble of processes responsible for the production, removal and composition of the aerosols. That is, the concentrations of these substances were affected by trends in the prevailing winds, rainfall, and other factors that favor the generation of dust as well as by those physical forces that lead to the transport and removal of particles from the atmosphere (Tegen, I. and R. Miller, 1998, *J. Geophys. Res*. 103, 25, 975). Finally, perturbation of a magnitude sufficient to affect all of these analytes almost certainly would have been evident in the FAS data, but as discussed elsewhere in this report, no such indications of enhancements of the magnitude needed to affect such changes were found.

Tables presenting the aerosol data summarized herein are available on the CEMRC web site at http://www.cemrc.org.

Table 4. Ranges of Elemental Concentrations (ng m^{-3}) in Aerosols Collected during February 1998 - July 2000

Location:		**Cactus Flats**	**Cactus Flats**	**Cactus Flats**	**Near Field**	**Near Field**	**Near Field**	**On Site**
[a]Sample Type:		**LPM_{10}**	**$LPM_{2.5}$**	**LTSP**	**LPM_{10}**	**$LPM_{2.5}$**	**LTSP**	**LTSP**
	[b]Total N	64	64	82	63	64	73	68
Ag	N	21	15	19	21	20	19	12
	Minimum	1.84E-02	1.74E-02	4.74E-03	1.68E-02	1.47E-02	1.73E-03	1.66E-02
	Maximum	1.62E-01	5.02E-01	4.14E-01	6.43E-01	1.99E+00	1.56E-01	6.23E-02
Al	N	63	51	82	61	52	70	66
	Minimum	5.16E+01	2.33E+01	7.35E+01	6.80E+01	1.45E+01	3.66E+01	5.16E+01
	Maximum	1.43E+03	5.39E+02	1.86E+03	2.31E+03	7.06E+02	2.86E+03	1.44E+03
As	N	3	1	4	4	4	1	1
	Minimum	2.57E+00	3.60E+00	2.52E+00	2.10E+00	1.76E+00	3.77E+00	7.21E-01
	Maximum	3.79E+00	3.60E+00	5.47E+00	4.30E+00	4.44E+00	3.77E+00	7.21E-01
Ba	N	62	48	81	60	52	69	65
	Minimum	9.36E-01	2.15E-01	8.90E-01	6.47E-01	2.59E-01	8.46E-01	1.05E+00
	Maximum	1.39E+01	5.30E+00	3.33E+01	1.84E+01	2.08E+01	2.30E+01	2.71E+01
Be	N	1	1	0	0	0	0	1
	Minimum	9.02E-02	6.39E-02	[c]NA	NA	NA	NA	9.32E-02
	Maximum	9.02E-02	6.39E-02	NA	NA	NA	NA	9.32E-02
Ca	N	62	36	75	55	37	68	65
	Minimum	8.37E+01	7.93E+01	1.54E+02	1.53E+02	6.10E+01	1.24E+02	1.38E+02
	Maximum	1.17E+03	1.01E+03	2.23E+03	1.91E+03	8.33E+02	4.55E+03	5.30E+03
Cd	N	16	14	19	19	28	19	11
	Minimum	4.63E-02	5.92E-02	7.21E-02	6.31E-02	3.43E-02	3.82E-02	9.20E-02
	Maximum	2.92E+00	8.79E+00	1.39E+00	1.92E+00	1.11E+00	2.21E+00	1.56E+00
Ce	N	63	63	82	61	60	70	67
	Minimum	6.00E-02	1.99E-02	4.76E-02	5.04E-02	1.65E-02	1.47E-02	4.07E-02
	Maximum	1.72E+00	3.68E-01	1.90E+00	3.43E+00	9.48E-01	3.99E+00	1.61E+00
Co	N	46	23	56	36	23	48	51
	Minimum	1.32E-01	7.17E-02	2.08E-01	1.27E-01	1.45E-01	1.07E-01	2.08E-01
	Maximum	2.92E+00	8.62E+00	1.29E+01	3.71E+00	2.24E+00	3.10E+00	8.03E+01
Cr	N	5	3	10	8	5	11	10
	Minimum	1.68E+01	8.03E+00	4.45E+00	3.13E+00	9.25E+00	3.22E+00	5.21E+00
	Maximum	6.14E+01	2.38E+02	5.37E+01	5.51E+01	3.59E+01	6.01E+01	4.09E+01
Cu	N	53	39	65	51	39	57	56
	Minimum	4.06E-01	5.16E-01	4.50E-01	4.32E-01	4.02E-01	5.93E-01	4.69E-01
	Maximum	7.80E+00	1.70E+01	1.30E+01	4.81E+01	6.65E+01	4.89E+01	1.34E+01
Dy	N	56	23	79	57	21	61	56
	Minimum	5.86E-03	4.00E-03	4.12E-03	3.84E-03	2.88E-03	5.10E-03	3.84E-03
	Maximum	1.11E-01	2.03E-02	1.41E-01	2.61E-01	8.58E-02	2.94E-01	1.15E-01
Er	N	40	9	66	36	14	47	46
	Minimum	3.97E-03	3.50E-03	6.09E-03	1.16E-03	1.41E-03	5.46E-03	4.10E-03
	Maximum	6.27E-02	1.23E-02	8.81E-02	1.36E-01	6.21E-02	1.66E-01	7.40E-02

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Table 4. Ranges of Elemental Concentrations (ng m^{-3}) in Aerosols Collected during February 1998 - July 2000 (Cont.)

Location:		**Cactus Flats**	**Cactus Flats**	**Cactus Flats**	**Near Field**	**Near Field**	**Near Field**	**On Site**
[a]Sample Type:		**LPM_{10}**	**$LPM_{2.5}$**	**LTSP**	**LPM_{10}**	**$LPM_{2.5}$**	**LTSP**	**LTSP**
Eu	N	26	4	54	24	6	38	39
	Minimum	4.52E-03	3.55E-04	3.02E-03	4.22E-03	2.35E-04	1.97E-03	3.88E-03
	Maximum	2.99E-02	1.05E+01	4.39E-02	5.40E-02	1.42E-02	7.06E-02	4.19E-02
Fe	N	55	36	66	50	30	58	53
	Minimum	3.48E+01	0.00E+00	2.70E+01	1.85E+01	1.22E+01	2.54E+01	2.60E+01
	Maximum	7.61E+02	2.33E+02	8.73E+02	1.19E+03	3.92E+02	1.52E+03	6.88E+02
Gd	N	58	31	79	58	28	64	60
	Minimum	5.91E-03	3.02E-03	5.28E-03	6.06E-03	4.31E-03	5.05E-03	4.82E-03
	Maximum	1.51E-01	3.64E-02	2.60E-01	3.30E-01	9.29E-02	3.54E-01	2.34E-01
Hg	N	7	7	18	6	3	15	14
	Minimum	1.69E-02	4.38E-03	2.21E-03	1.90E-02	4.22E-02	1.07E-02	1.29E-02
	Maximum	2.37E-01	2.47E-01	2.25E-01	1.46E-01	1.43E-01	2.10E-01	1.39E-01
K	N	59	39	77	57	47	68	63
	Minimum	4.85E+01	5.93E+00	3.78E+01	6.08E+01	4.39E+01	4.01E+01	4.16E+01
	Maximum	5.42E+02	2.60E+02	6.30E+02	1.04E+03	4.76E+02	1.23E+03	1.14E+03
La	N	50	46	68	48	45	56	54
	Minimum	5.69E-02	1.68E-02	3.49E-02	3.82E-02	7.04E-03	6.74E-02	2.03E-02
	Maximum	1.67E+00	3.07E+00	1.97E+00	1.59E+00	8.63E-01	7.61E+00	1.46E+00
Li	N	9	6	28	8	1	19	20
	Minimum	1.52E-01	8.59E-01	1.64E-01	1.72E-01	1.65E-01	2.54E-01	2.09E-01
	Maximum	2.18E+00	1.93E+00	2.72E+00	1.86E+00	1.65E-01	1.16E+00	1.08E+00
Mg	N	61	42	79	58	45	69	67
	Minimum	2.12E+01	1.26E+01	9.69E+00	3.04E+01	1.29E+01	1.59E+01	2.52E+01
	Maximum	2.40E+02	1.96E+02	3.64E+02	5.66E+02	1.64E+02	6.69E+02	6.10E+02
Mn	N	62	47	80	63	47	68	65
	Minimum	9.96E-01	4.91E-01	7.87E-01	4.54E-01	4.51E-01	7.12E-01	6.69E-01
	Maximum	1.48E+01	4.55E+00	1.89E+01	3.16E+01	2.75E+01	3.70E+01	1.65E+01
Mo	N	1	3	10	8	1	6	9
	Minimum	4.57E-02	1.22E-01	5.33E-02	6.44E-02	2.13E-02	4.01E-02	4.09E-02
	Maximum	4.57E-02	4.86E+00	8.79E-01	1.26E+01	2.13E-02	3.57E-01	4.75E-01
Na	N	39	15	50	39	17	53	50
	Minimum	5.66E+01	7.46E+01	1.03E+02	6.95E+01	6.75E+01	6.39E+01	8.86E+01
	Maximum	5.35E+02	1.15E+03	3.23E+03	6.91E+02	3.35E+02	2.40E+03	7.34E+02
Nd	N	64	61	82	61	61	70	67
	Minimum	1.18E-02	1.04E-02	1.29E-02	1.61E-02	9.17E-03	9.18E-03	1.19E-02
	Maximum	7.31E-01	1.56E-01	8.40E-01	1.60E+00	3.92E-01	1.75E+00	6.64E-01
Ni	N	18	17	34	18	17	29	34
	Minimum	8.75E-01	1.36E+00	1.16E+00	7.40E-01	6.33E-01	1.02E+00	9.53E-01
	Maximum	3.20E+01	2.32E+01	4.07E+01	8.84E+01	4.92E+01	2.08E+01	5.93E+01
Pb	N	60	52	74	56	57	62	58
	Minimum	2.38E-01	1.44E-01	6.55E-02	2.07E-01	1.17E-01	2.70E-01	1.99E-01
	Maximum	3.38E+00	2.73E+01	2.95E+00	4.18E+00	4.70E+00	4.91E+00	2.05E+00

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Table 4. Ranges of Elemental Concentrations (ng m^{-3}) in Aerosols Collected during February 1998 - July 2000 (Cont.)

Location:		**Cactus Flats**	**Cactus Flats**	**Cactus Flats**	**Near Field**	**Near Field**	**Near Field**	**On Site**
[a]Sample Type:		**LPM_{10}**	**$LPM_{2.5}$**	**LTSP**	**LPM_{10}**	**$LPM_{2.5}$**	**LTSP**	**LTSP**
Pr	N	64	46	81	62	50	69	65
	Minimum	1.05E-02	5.39E-03	1.02E-02	7.34E-03	4.40E-03	1.03E-02	8.03E-03
	Maximum	1.96E-01	4.60E-02	2.29E-01	4.07E-01	1.05E-01	7.57E-01	1.89E-01
Sb	N	14	15	28	16	17	26	25
	Minimum	9.47E-02	4.89E-02	7.96E-02	4.54E-02	4.11E-02	4.37E-02	4.10E-02
	Maximum	5.10E-01	3.13E-01	1.38E+01	3.86E-01	3.12E-01	5.85E-01	7.65E-01
Sc	N	2	0	14	2	0	12	12
	Minimum	1.46E-01	NA	1.56E-01	1.86E-01	NA	2.06E-01	1.66E-01
	Maximum	3.32E-01	NA	1.59E+00	3.50E-01	NA	1.19E+00	1.32E+00
Se	N	0	1	2	1	0	0	1
	Minimum	NA	1.57E+00	4.75E-01	5.73E-01	NA	NA	2.51E+00
	Maximum	NA	1.57E+00	7.94E-01	5.73E-01	NA	NA	2.51E+00
Sm	N	55	20	76	56	23	63	56
	Minimum	6.69E-03	4.40E-03	6.58E-03	5.21E-03	2.58E-03	7.65E-03	5.63E-03
	Maximum	1.38E-01	2.87E-02	1.90E-01	3.08E-01	7.73E-02	3.42E-01	1.44E-01
Sn	N	2	2	3	5	3	3	7
	Minimum	1.98E+01	1.87E+01	1.84E+01	1.24E+01	2.53E+01	1.70E+01	8.05E+00
	Maximum	3.68E+01	6.54E+01	3.15E-01	6.20E+01	9.21E+01	1.01E+02	6.32E+01
Sr	N	59	37	73	52	38	60	61
	Minimum	1.69E-01	1.46E-01	3.15E-01	3.22E-02	1.38E-01	3.19E-01	6.08E-01
	Maximum	5.91E+00	2.92E+00	8.72E+00	1.46E+01	3.58E+00	2.07E+01	9.82E+00
Th	N	61	38	81	58	38	68	60
	Minimum	9.69E-03	4.19E-03	4.65E-03	6.96E-03	5.28E-03	6.41E-03	4.12E-03
	Maximum	2.45E-01	5.71E-02	3.45E-01	5.44E-01	1.43E-01	6.28E-01	2.70E-01
Ti	N	60	28	78	57	30	64	58
	Minimum	6.27E-01	3.81E+00	6.48E+00	5.84E+00	3.25E+00	3.58E+00	7.39E+00
	Maximum	8.43E+01	2.82E+01	9.49E+01	1.43E+02	3.67E+01	1.71E+02	8.11E+01
Tl	N	5	8	10	3	3	8	11
	Minimum	2.48E-02	7.12E-03	1.08E-02	2.12E-02	2.98E-02	1.09E-02	4.07E-03
	Maximum	3.05E-01	1.01E+00	9.04E-02	6.16E-02	7.51E-02	2.53E-01	6.20E-01
U	N	51	11	73	50	13	56	52
	Minimum	5.02E-03	2.35E-03	8.24E-03	4.91E-03	1.71E-03	3.70E-03	2.44E-03
	Maximum	6.76E-02	7.47E-02	1.00E-01	1.07E-01	1.21E-01	1.28E-01	7.40E-02
V	N	22	17	26	19	19	21	24
	Minimum	1.09E+00	1.01E+00	9.93E-01	1.07E+00	1.12E+00	1.16E+00	1.04E+00
	Maximum	2.25E+01	2.01E+01	3.08E+01	3.00E+01	3.15E+01	1.03E+01	2.14E+01
Zn	N	21	19	20	26	21	20	23
	Minimum	4.13E+00	3.72E+00	3.22E+00	5.14E+00	4.46E+00	3.89E+00	2.93E+00
	Maximum	1.88E+02	9.44E+01	1.84E+02	1.10E+02	6.73E+02	7.19E+01	1.62E+02

[a] Sample type: LPM_{10}, $LPM_{2.5}$ and LTSP stand for low-volume PM_{10}, $PM_{2.5}$ and total suspended particle samplers, respectively

[b] N = number of samples, subsequent rows show number of samples above method detection limit

[c] NA = not applicable

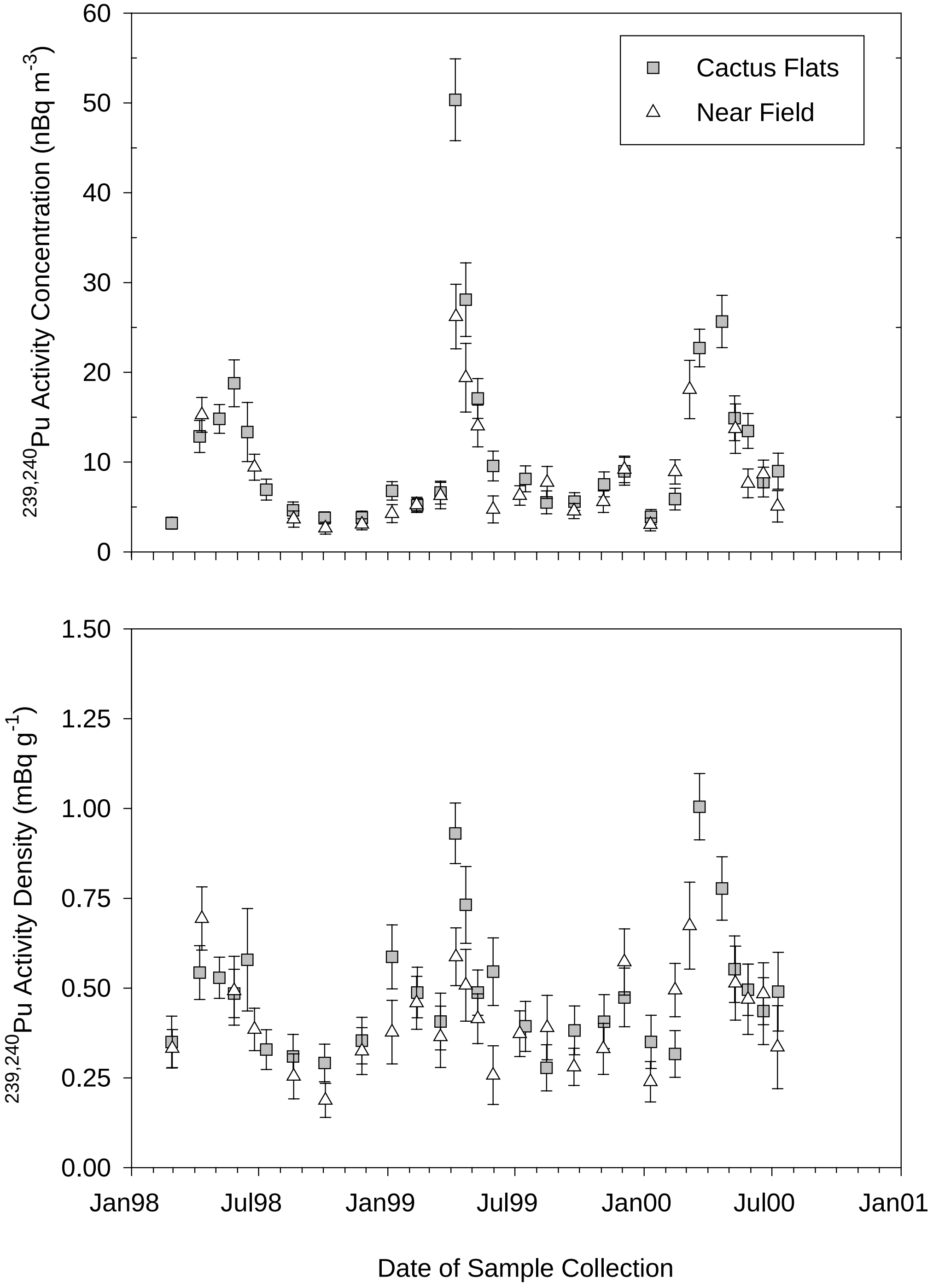

Figure 12. ***^{239,240}Pu Activities for PM_{10} High Volume Aerosol Samples Collected during February 1998 - July 2000***

Error bars show ± one standard deviation based on total radioanalytical uncertainty inventory.

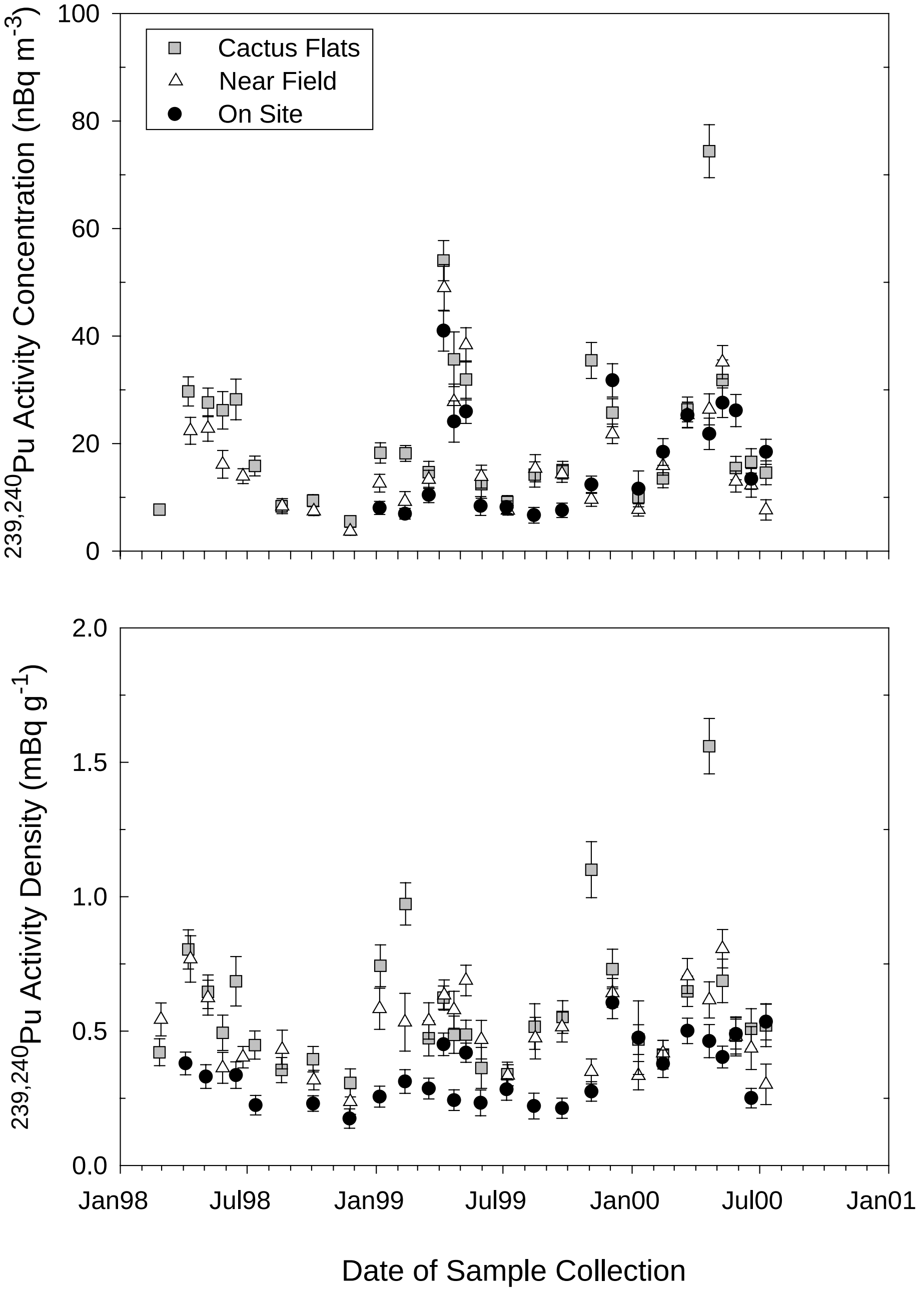

Figure 13. ^{239,240}Pu Activities for TSP High Volume Aerosol Samples Collected during February 1998 - July 2000

Error bars show ± one standard deviation based on total radioanalytical uncertainty inventory.

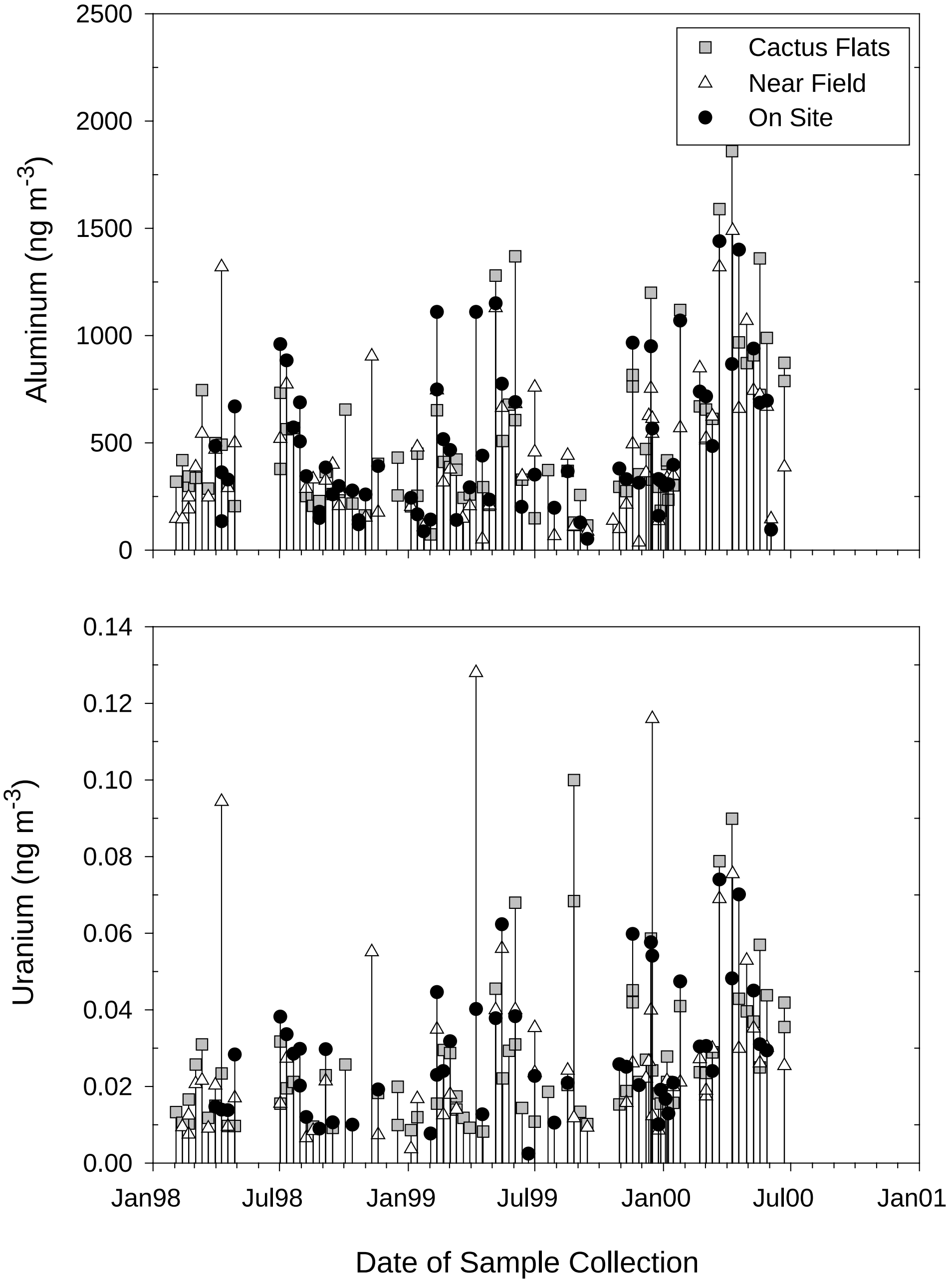

Figure 14. Aluminum and Uranium Concentrations in TSP Aerosol Samples Collected during February 1998 - July 2000

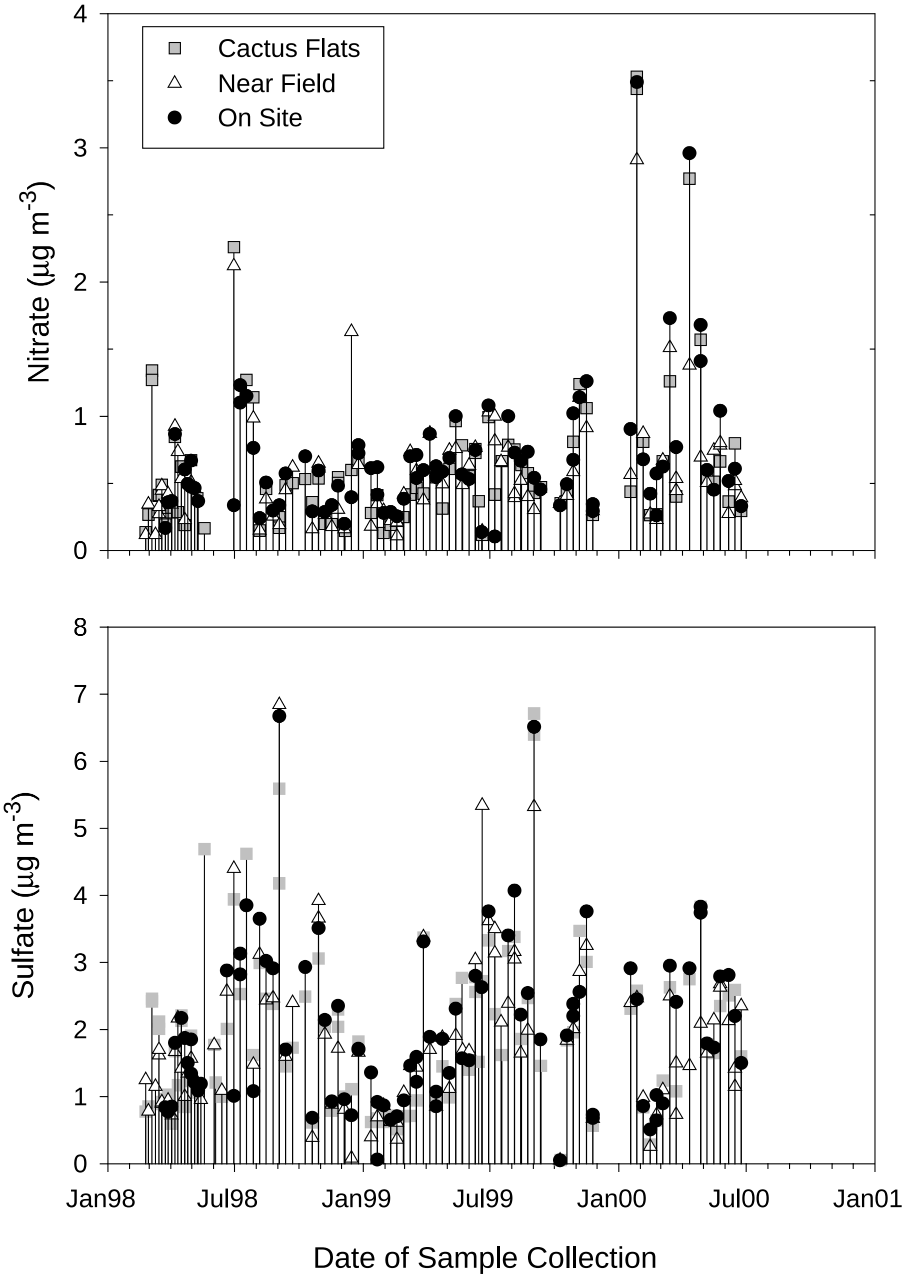

Figure 15. Nitrate and Sulfate Concentrations in TSP Aerosol Samples Collected during February 1998 - July 2000

Radionuclides and Inorganics in WIPP Exhaust Air

Introduction

The CEMRC aerosol sampling program for the WIPP EM is designed to study the pathway that is the most likely route by which contaminants from the WIPP site could become rapidly dispersed in the environment. One facet of this comprehensive program is the monitoring of aerosols in the WIPP exhaust shaft. These samples are collected at a location (Station A) that represents the release point of aerosol effluents from the underground to the environment. CEMRC is interested in obtaining information on air quality from Station A because it provides a means for characterizing a source-term that will be needed for the interpretation of future monitoring results from the WIPP EM. For example, if radioactive or hazardous material was released from the WIPP, we would expect to detect it at Station A before it is observed in the local population or environment. In addition, source-term data collected at Station A would be of critical importance for the determination of public or worker dose in the event of an accident at the WIPP.

Another objective of the sampling program at Station A is to provide a gross check of emissions on a short resolution time-scale (e.g. weeks). For example, many of the WIPP EM analyses require many months to complete once the samples are collected. Such time is needed because of the specificity and sensitivity of the analyses. At Station A, gross monitoring results (less specific and sensitive) are provided within three weeks of sample collection and are used to trigger more detailed investigations if necessary.

Methods

A detailed description of the sampling protocol, aerosol sampler, analytical methods and detection limits are provided in the CEMRC 1999 Report. This report and continually updated results can be found at the CEMRC website (http://www.cemrc.org). In summary, the monitoring program consists of daily aerosol sampling, gravimetric and gross alpha/beta analyses of individual filters, elemental and gamma-ray analysis of weekly filter composites and actinide analysis of quarterly filter composites.

Some changes to effluent sampling and analytical methods were made during this reporting period. Specifically, changes were made to the sampling location within Station A, frequency of sampling and the efficiency calibration used for gross alpha/beta analyses. These changes are described below.

At Station A, there are three shrouded-probe aerosol samplers, located on three separate sampling skids (skids 1-3). On each skid, aerosols are split into three sampling legs such that three concurrent samples can be collected from a single skid. On 15 January 2000, the CEMRC effluent sampling location was moved from skid 2, leg 1 to skid 3, leg 2. This change was made to facilitate more direct data comparisons among all organizations sampling at Station A (CEMRC, Environmental Evaluation Group (EEG) and Westinghouse/MK Ferguson). In addition, all organizations sampling at Station A were having difficulties with low flow rates at the end of sampling periods. It was hypothesized that the problem was the result of increased mass loading due to mining activities. To help resolve this issue, CEMRC (and the other organizations) began changing filters twice daily Monday through Friday, rather than once daily. In most situations, a single filter was still collected over the weekend.

In December 1999, calibration methods for the gross alpha/beta measurements were revised to encompass a larger range of mass deposition. The revised methodology provides a calibration factor for mass loadings ranging from 0.5 to 122 mg (previously 3 to 31 mg). The revised calibration range encompasses all values of mass loading observed to date at Station A.

In addition to routine monitoring, two minor experiments were conducted at Station A in an effort to improve sampling methodologies. The first experiment was conducted to evaluate an alternative filter medium (glass fiber). As previously mentioned, filters were being changed twice daily to accommodate increases in mass loading. This solution is rather labor intensive, and it was hypothesized that a more robust filter medium, with respect to mass loading characteristics, could be identified that would allow the sampling frequency to be reduced (ideally once daily). Incorporating input from EEG and Westinghouse/MK Ferguson, glass fiber was selected as the test medium. The experiment was conducted by collection of concurrent aerosol samples on all three legs of skid 2 during Spring 2000. Aerosols were collected until the flow rate on one leg of the skid dropped to 1.8 ft^3 min^{-1} (set point for each leg is 2.0 ft^3 min^{-1}). When this occurred, the filters on all three legs were changed and the mass loading on each leg was determined. At CEMRC, side by side measurements, comparing the glass fiber to the current Versapore filter, were also performed to evaluate any differences in mass loading. These measurements were performed using PM_{10} low volume aerosol samplers.

A second experiment was conducted in Spring 2000 to evaluate elemental and organic carbon loading on aerosol filters collected at Station A. For these measurements, four 24-hour aerosol samples were collected from skid 2 using quartz fiber filters. These filters were analyzed for organic carbon, high temperature organic carbon and elemental carbon at DRI.

Results and Discussion

Routine Monitoring

Aerosol sampling has been conducted continuously at Station A by CEMRC since 12 December 1998. Monitoring results from 1 July 1999 through 1 July 2000 are discussed herein. Tables presenting aerosol data summarized herein are available on the CEMRC web site at http://www.cemrc.org. For measurements of radioactivity, data reported during the current period are considered operational monitoring, since radioactive waste was received in March 1998. The determination of baseline concentrations of elemental constituents is considered on-going for the purposes of this report, since WIPP had not received any mixed waste (containing both hazardous and radioactive constituents) as of 1 July 2000.

Values of gross alpha activity concentration and density ranged from < MDC (≈ 0.03) to 0.4 mBq m^{-3} and < MDC (≈ 0.4) to 9.2 Bq g^{-1}, respectively. Values of gross beta activity concentration and density ranged from < MDC (≈ 0.07) to 3.3 mBq m^{-3} and < MDC (≈ 1) to 80.1 Bq g^{-1}, respectively. In general, quarterly mean values of gross alpha and beta concentration and density have decreased since the WIPP began receiving waste in March 1998. (Table 5). For gross alpha, such decreases were observed in all operational quarters and the levels of decrease were as much as 74% and 82% per quarter for activity concentration and density, respectively. A similar trend was observed for gross beta. However, mean values of gross beta activity concentration and density did not decrease relative to pre-operational values in the fourth and third quarters of 1999, respectively (although they decreased in all other operational quarters). It is important to note that no single gross alpha or beta result observed during operational monitoring has exceeded the highest value observed during the pre-operational baseline (Table 5).

Similar trends were also observed for daily gross alpha and beta measurements (Figs. 16 and 17). This trend was most notable for measurements of activity density, suggesting the level of radioactivity contained in WIPP aerosol effluents has decreased per unit of airborne particulate mass. This observation was supported by weekly elemental analyses of U and Th (Fig. 18), where the mass concentration of these elements decreased over time, coinciding with decreases in gross alpha and beta radioactivity.

The observed trends may be the result of environmental phenomena, changes in WIPP operational practices or a combination of these factors. The most notable decrease in these measurements appeared to coincide with increased mining activity at the WIPP during the fall of 1999. At that time, the WIPP began excavation of a second panel for mixed waste disposal. Mining activities for the panel were then ongoing for the remainder of this reporting period (through 1 July 2000) and may have resulted in increased salt per unit of aerosol particulate mass, relative to pre-operational conditions. Recent studies (The Next Generation Underground Observatory of the Universe, U.S. DOE Workshop, Carlsbad, NM, June 12-14, 2000) suggest that WIPP salts contain lower amounts of naturally occurring radioactive elements (e.g. U and Th) than crustally derived materials. Within this context, 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.

Another factor that may be contributing to the decrease in radioactive emissions could be an increase in the concentration of carbon aerosols from the burning of fossil fuels (e.g. vehicle exhaust). One would expect vehicle exhaust to be greatest during periods of extensive mining. Aerosol samples collected during May 2000 showed total carbon loading to be greater than 30 $\mu g\ m^{-3}$, which would account for nearly 50% of aerosol mass during this time period. Of the total carbon, greater than 70% was organic, and of this fraction, approximately 80% was high temperature carbon (consistent with vehicle exhaust). Applying similar logic as with salt, an increased proportion of organic carbon may decrease effluent radioactivity per unit mass. It is important to note that these carbon analyses were quite limited and no other data (e.g. non-mining) are available for comparison.

Numerous elemental constituents were observed in weekly composites (Table 6). Greater than 80% of all of the 39 elements were observed in 75-100% of the weekly composites. Tl was the only element not detected in any weekly composite and this element may serve as a useful tracer for future WIPP aerosol studies. Many of the hazardous elements (e.g. Pb, Be, Cd, etc.) expected to be contained in WIPP mixed waste are already present in WIPP aerosol effluents. A high degree of variability in weekly concentrations was observed for most elements, where the ratio between maximum and minimum values frequently exceeded 200 (Table 6). Capturing this level of variability is an essential aspect of baseline characterization and will be important when interpreting monitoring results after mixed waste is received.

For many elements, volumetric concentrations were similar to those reported herein (Radionuclides and Trace Elements in Ambient Aerosols) for the TSP fraction at the On Site sampling location. When making such comparisons, it is important to note that the sampling methodologies (e.g. sampler type, filter type, and sampling frequency) are quite different between the two locations. Therefore, slight differences in concentrations should be interpreted with caution. The volumetric concentrations of several elements were slightly enriched in FAS samples over ambient aerosol samples (factors 3 to 20), which would be expected since mass loading is much greater in WIPP exhaust than surface air. In contrast, the ratios between U concentrations in exhaust air samples and ambient aerosols were near unity. The same was true for Th concentrations. This observation suggests that naturally occurring radioactive material in WIPP effluents are depleted relative to surface air.

Volume concentrations for Sb and Na appeared to be highly enriched (factors of 140 and 200, respectively) relative to surface aerosols as measured at the On Site location. It is doubtful that such large enrichment factors were due to differences in sampling methodology. The enrichment of Na is likely due to an increased concentration of salt in WIPP aerosols when compared to surface aerosols. This finding is consistent with that reported in the CERMC 1999 report. Sb enrichment may be associated with vehicle exhaust emissions, but further investigation is necessary.

With the exception of ^{7}Be, no detectable gamma-emitting radionuclides were observed during this monitoring period. ^{7}Be was detected in approximately 33% of samples, ranging in activity concentration and density from 4 to 13 $mBq\ m^{-3}$ and 16 to 223 $Bq\ g^{-1}$, respectively. For detectable results, mean values (± SE) of activity concentration and density were 7.1 (± 0.4) $mBq\ m^{-3}$ and 49 (± 8) $Bq\ g^{-1}$, respectively. ^{7}Be values during this monitoring period were consistent with those reported in the CEMRC 1999 Report. These results indicate that the aerosols entering through the WIPP air intake eventually reach the exhaust system and are released as exhaust effluents. The presence of ^{7}Be in the exhaust is an indicator of this mechanism because ^{7}Be is a short-lived radionuclide ($T_{1/2}$ = 53 days) that is produced in the stratosphere through spallation of atmospheric gases (not occurring naturally in the WIPP underground). This finding may be of importance because other aerosols containing radionuclides of concern (e.g. Pu, ^{137}Cs) may follow a similar process and be detected in the exhaust in the absence of a WIPP-related contamination event. Therefore, ^{7}Be may be a useful tracer for understanding aerosol residence times in the WIPP.

Naturally occurring U and Th isotopes were detected in quarterly composites during all monitoring quarters with the exception of the fourth quarter of 1999 (Table 7). During this quarter, the U analysis failed due to low recovery, and concentration values were not reported. Elemental analyses of weekly composites showed no unusual changes in U concentrations during this time period. In general, U and Th concentrations have decreased relative to pre-operational values. This decrease was most notable in the first and second quarters of 2000 and is consistent with gross alpha/beta and elemental results reported herein.

For ^{238}Pu, no detectable concentrations were observed in any operational quarter (Table 7). No detectable ^{239,240}Pu or ^{241}Am were observed in the first and second quarters of 2000. Values for ^{239,240}Pu and ^{241}Am were not reported in the second, third and fourth quarters of 1999 due to sample contamination at CEMRC (described in detail in the CEMRC 1999 Report). However, Station A monitoring results reported by the EEG (Gray et al., 2000, *Operational Radiation Surveillance of the WIPP Project by EEG during 1999*, EEG-79), for this time period, showed no activity (at two standard deviations) above zero for ^{239,240}Pu, ^{238}Pu and ^{241}Am. Direct comparison of CEMRC results to those of EEG is difficult, since EEG does not distinguish when analytical results are less than detection limit (e.g. no detectable radioactivity in the sample).

^{234}U results were indistinguishable (at two standard deviations) from those of ^{238}U for activity concentration and density, suggesting secular equilibrium between the two isotopes (Table 7). Such results are expected for many natural sources of U. ^{228}Th activity concentration and density appeared to be enriched by a factor of ≅ 2 in comparison to ^{232}Th, but this effect is not statistically significant at two standard deviations (reported as such in the CEMRC 1999 Report). Investigation into this observation suggests an analytical bias resulting from ^{228}Th introduced into the sample from the decay of ^{232}U added as chemical yield tracer.

Filter Medium Experiment

For the filter medium experiment, 19 side-by-side sampling events using the glass fiber filter were evaluated (57 individual samples). The geometric mean (± SD) of mass loading on the glass fiber filters was 28.8(± 1.7) mg. The geometric mean (± SD) of samples collected on the same skid (previous fall) with the same final flow criteria (1.8 ft^{3} min^{-1}) using the Versapore filter were 8.1 (± 2.1) mg. Although the data are not directly comparable due to differences in sampling time, they suggest that more mass can be sampled using the glass fiber filter. These results were promising and suggested that if the glass fiber filters were utilized, sampling frequency could be decreased.

However, side by side comparisons between the glass fiber and Versapore filters conducted at CEMRC showed that the glass fiber filters collected 42 ± 19% (mean ± SE) less mass in the PM_{10} fraction than did the Versapore filter when sampling the same air. Although not statistically robust, these data suggest that if the glass fiber filters were used at Station A, particles less than 10 μm may be under-sampled relative to the current methodology. In addition, the glass fiber filter has the disadvantage that the filter matrix contains significant levels of U (which is not the case with the Versapore filter), which could make weekly and quarterly U composite analyses extremely difficult, if not impossible. As a result, no effort has been made to switch to glass fiber filters for effluent monitoring at Station A.

The filter medium experiment also provided useful information regarding intra-skid comparability of mass loading and final flow. Concurrent samples were collected on each of the skid’s three legs during 19 sampling events. Ideally, the mass loaded on the filters and the final flow at the time of collection should be identical (within some small deviation) for each leg. Mass loading values between legs of the same skid were more strongly correlated than final flow rate between legs. Correlation coefficients for mass loading between the three legs were 0.92 to 0.97, while correlation coefficients for final flows were 0.28 to 0.64. These values for final flows indicate little to no correlation between legs (for this sample size, anything less than 0.5 is considered no better than random). The lack of correlation may introduce significant uncertainty for metrics involving air volume for this skid.

As previously mentioned, mass loading exhibited better correlation between skid legs. However, from these data the confidence in comparability between legs for a single sampling event would be no greater than 8%. If intra-skid comparability is limited to 8%, it is likely that comparability between skids would be much worse, adding uncertainty to the efficacy of representative sampling at Station A. It is important to note that this discussion is based on limited data, and further investigation is necessary to bound the comparability of effluent sampling at Station A as currently configured.

Table 5. Summary Statistics for Gross Alpha/Beta Analyses of Daily FAS Filters

Gross Emission	**[a]N**	**% ≥ [b]MDC**	**Activity Concentration ($Bq\ m^{-3}$)**				**Activity Density ($Bq\ g^{-1}$)**			
			[c]Mean	**[d]SE**	**[e]Max**	**[f]RPC (%)**	**Mean**	**SE**	**Max**	**RPC (%)**
Pre-Operational Baseline										
Alpha	71	100	3.1E-04	3.1E-05	1.5E-03	NA	3.6E+00	5.8E-01	3.7E+01	NA
Beta	71	100	1.1E-03	9.1E-05	4.9E-03	NA	1.4E+01	1.9E+00	1.2E+02	NA
Operational Monitoring Second Quarter, 1999										
Alpha	65	100	1.1E-04	6.5E-06	2.7E-04	-65	1.7E+00	1.6E-01	7.6E+00	-53
Beta	65	100	8.2E-04	2.3E-05	1.4E-03	-25	1.6E+01	1.6E+00	5.4E+01	14
Operational Monitoring Third Quarter, 1999										
Alpha	70	100	8.5E-05	5.4E-06	3.2E-04	-73	2.6E+00	8.6E-01	9.2E+00	-27
Beta	70	100	9.7E-04	5.3E-05	3.0E-03	-12	2.9E+01	5.1E+00	8.0E+01	107
Operational Monitoring Fourth Quarter, 1999										
Alpha	39	98	1.4E-04	1.3E-05	3.7E-04	-56	8.1E-01	1.4E-01	4.2E+00	-78
Beta	40	100	1.3E-03	9.1E-05	3.3E-03	23	1.1E+01	2.5E+00	7.0E+01	-24
Operational Monitoring First Quarter, 2000										
Alpha	58	44	1.7E-04	1.1E-05	3.9E-04	-44	8.7E-01	2.1E-01	9.2E+00	-76
Beta	121	92	1.1E-03	4.4E-05	2.3E-03	0	3.9E+00	6.6E-01	4.8E+01	-72
Operational Monitoring Second Quarter, 2000										
Alpha	25	19	8.2E-05	6.1E-06	1.4E-04	-74	6.5E-01	1.2E-01	2.5E+00	-82
Beta	118	90	8.1E-04	2.6E-05	1.6E-03	-26	3.9E+00	4.3E-01	3.6E+01	-72

[a]N = number of samples
[b]MDC = minimum detectable concentration
[c]Mean = arithmetic mean
[d]SE = standard error
[e]Max = maximum
[f]RPC = relative percent change calculated as ((observed mean - baseline mean)/baseline mean) * 100

Table 6. Summary Statistics for Elemental Constituents in Weekly FAS Composites Collected during 12 December 1998 – 30 June 2000

Analyte	[a]Frequency of Detection (%)	Volume Concentration (ng m^{-3})				Mass Concentration (ng mg^{-1})			
		[b]Mean	[c]SE	[d]Min	[e]Max	Mean	SE	Min	Max
Ag	83	1.1E-01	2.2E-02	1.8E-02	1.2E+00	8.3E-01	1.1E-01	7.2E-02	4.7E+00
Al	99	7.3E+02	1.0E+02	1.3E+02	7.8E+03	6.2E+03	1.2E+03	3.9E+02	8.9E+04
As	70	1.3E+00	1.3E-01	3.5E-01	4.7E+00	1.2E+01	1.5E+00	1.3E+00	4.1E+01
Ba	100	7.8E+00	4.4E-01	1.5E+00	2.0E+01	6.9E+01	6.5E+00	1.1E+01	3.0E+02
Be	8	2.9E-01	1.4E-01	8.8E-02	9.8E-01	2.9E+00	1.7E+00	3.8E-01	1.1E+01
Ca	100	4.1E+03	9.4E+02	2.4E+02	7.0E+04	2.0E+04	1.4E+03	7.4E+03	6.9E+04
Cd	84	8.9E-01	2.4E-01	8.2E-02	1.5E+01	7.5E+00	1.4E+00	5.4E-01	6.0E+01
Ce	99	7.6E-01	5.0E-02	1.5E-01	2.1E+00	6.7E+00	6.1E-01	4.5E-01	2.5E+01
Co	94	2.8E+00	4.6E-01	3.5E-01	2.4E+01	1.4E+01	1.4E+00	2.4E+00	6.5E+01
Cr	57	6.0E+01	1.5E+01	8.7E+00	6.2E+02	2.6E+02	7.6E+01	3.2E+01	3.3E+03
Cu	100	3.6E+01	2.1E+00	1.2E+01	1.1E+02	3.2E+02	3.0E+01	4.2E+01	1.7E+03
Dy	100	4.7E-02	3.6E-03	1.0E-02	1.6E-01	4.2E-01	4.4E-02	4.0E-02	1.8E+00
Er	96	2.9E-02	2.5E-03	5.1E-03	1.5E-01	2.7E-01	3.1E-02	2.7E-02	1.7E+00
Eu	92	1.5E-02	1.0E-03	3.8E-03	3.7E-02	1.3E-01	1.2E-02	1.8E-02	5.3E-01
Fe	100	8.1E+02	8.4E+01	3.6E+01	5.8E+03	7.3E+03	7.9E+02	1.5E+02	3.1E+04
Gd	99	7.1E-02	5.7E-03	1.4E-02	2.8E-01	6.4E-01	7.2E-02	1.6E-02	3.2E+00
Hg	25	1.3E-01	3.0E-02	3.1E-02	5.7E-01	7.5E-01	1.2E-01	9.8E-02	1.8E+00
K	99	1.3E+03	1.2E+02	8.2E+01	5.4E+03	7.8E+03	4.3E+02	1.5E+03	2.7E+04
La	100	4.6E-01	3.1E-02	8.9E-02	1.3E+00	4.0E+00	3.6E-01	3.4E-01	1.5E+01
Li	78	2.5E+00	2.7E-01	5.8E-01	1.4E+01	1.2E+01	7.0E-01	4.5E+00	3.8E+01
Ma	100	3.4E+01	3.7E+00	1.4E+00	1.4E+02	3.5E+02	5.6E+01	2.9E+00	3.0E+03
Mg	100	2.8E+03	6.8E+02	1.3E+02	5.1E+04	1.2E+04	7.9E+02	3.9E+03	5.0E+04
Mo	66	4.5E+00	1.4E+00	8.2E-01	7.5E+01	2.3E+01	7.8E+00	2.9E+00	4.1E+02
Na	100	6.7E+04	7.6E+03	1.4E+03	2.9E+05	3.5E+05	3.5E+04	4.8E+04	1.6E+06
Nd	100	3.2E-01	2.1E-02	5.9E-02	9.2E-01	2.9E+00	2.7E-01	1.4E-01	1.2E+01
Ni	91	1.8E+01	6.1E+00	1.8E+00	4.2E+02	1.0E+02	3.2E+01	9.1E+00	2.3E+03
Pb	100	6.8E+00	7.7E-01	1.1E+00	4.6E+01	5.8E+01	6.9E+00	4.5E+00	3.3E+02
Pr	100	9.1E-02	5.9E-03	1.8E-02	2.7E-01	8.1E-01	7.5E-02	6.4E-02	3.4E+00
Sa	100	4.6E-01	2.1E-02	1.6E-01	1.2E+00	4.4E+00	4.6E-01	4.9E-01	2.7E+01
Sb	100	3.2E+01	3.3E+00	3.1E+00	2.2E+02	4.5E+02	1.1E+02	1.4E+01	7.7E+03
Se	27	5.3E-01	4.8E-02	3.0E-01	1.1E+00	6.3E+00	9.8E-01	1.0E+00	1.5E+01
Sn	0	[f]NA	NA	NA	NA	NA	NA	NA	NA
Sr	100	7.0E+01	1.9E+01	3.3E+00	1.4E+03	3.1E+02	2.5E+01	1.3E+02	1.4E+03
Th	96	1.2E-01	9.9E-03	2.0E-02	4.8E-01	1.1E+00	1.1E-01	1.0E-01	4.6E+00

Table continued on next page

Table 6. Summary Statistics for Elemental Constituents in Weekly FAS Composites Collected during 12 December 1998 – 30 June 2000 (Cont.)

Analyte	[a]Frequency of Detection (%)	Volume Concentration (ng m^{-3})				Mass Concentration (ng mg^{-1})			
		[b]Mean	[c]SE	[d]Min	[e]Max	Mean	SE	Min	Max
Ti	99	4.5E+01	3.4E+00	9.9E+00	2.1E+02	3.5E+02	3.0E+01	8.3E+01	1.3E+03
Tl	0	NA	NA	NA	NA	NA	NA	NA	NA
U	91	4.9E-02	4.8E-03	8.8E-03	2.4E-01	4.0E-01	5.6E-02	6.6E-02	2.8E+00
V	62	4.2E+00	5.3E-01	1.0E+00	1.7E+01	2.6E+01	2.0E+00	6.9E+00	6.9E+01
Zn	97	2.8E+02	8.5E+01	2.4E+01	4.7E+03	2.7E+03	8.5E+02	1.5E+02	4.9E+04

[a] A total of 77 weekly composites were analyzed during this interval
[b] Mean = arithmetic mean
[c] SE = standard error
[d] Min = minimum
[e] Max = maximum
[f] NA = not applicable

Table 7. Results of Actinide Analyses for Quarterly FAS Composite Samples

Radionuclide	Activity Concentration (Bq m^{-3})				Activity Density (Bq g^{-1})			
	[a]C	[b]SD	[c]MDC	[d]RPC (%)	C	SD	MDC	RPC (%)
Pre-operational Baseline								
^{238}Pu	< MDC	[e]NA	2.4E-08	NA	< MDC	NA	3.0E-04	NA
$^{239, 240}$Pu	< MDC	NA	2.4E-08	NA	< MDC	NA	2.9E-04	NA
^{241}Am	< MDC	NA	5.5E-08	NA	< MDC	NA	6.9E-04	NA
^{228}Th	7.6E-07	5.2E-08	9.7E-08	NA	8.1E-03	5.6E-04	1.2E-03	NA
^{230}Th	7.0E-07	4.9E-08	6.8E-08	NA	7.5E-03	5.3E-04	8.3E-04	NA
^{232}Th	4.9E-07	3.7E-08	3.6E-08	NA	5.2E-03	4.0E-04	4.3E-04	NA
^{234}U	8.9E-07	4.9E-08	3.0E-08	NA	9.5E-03	5.3E-04	3.8E-04	NA
^{235}U	4.1E-08	1.5E-08	2.7E-08	NA	4.4E-04	1.6E-04	3.2E-04	NA
^{238}U	8.5E-07	4.9E-08	2.4E-08	NA	9.1E-03	5.2E-04	3.0E-04	NA
Operational Monitoring Second Quarter, 1999								
^{238}Pu	< MDC	NA	2.4E-08	NA	< MDC	NA	3.0E-04	NA
$^{239, 240}$Pu	[f]NR	NR	NR	NA	NR	NR	NR	NA
^{241}Am	NR	NR	NR	NA	NR	NR	NR	NA
^{228}Th	1.1E-06	7.0E-08	9.7E-08	4.5E+01	1.5E-02	9.6E-04	1.2E-03	85
^{230}Th	5.6E-07	4.6E-08	6.8E-08	-2.0E+01	7.6E-03	6.3E-04	8.3E-04	1.3
^{232}Th	5.8E-07	4.0E-08	3.6E-08	1.8E+01	7.9E-03	5.5E-04	4.3E-04	52
^{234}U	7.3E-07	4.6E-08	3.0E-08	-1.8E+01	9.9E-03	6.2E-04	3.8E-04	4.2
^{235}U	3.3E-08	1.2E-08	2.7E-08	-2.0E+01	4.5E-04	1.6E-04	3.2E-04	2.3
^{238}U	6.1E-07	4.1E-08	2.4E-08	-2.8E+01	8.4E-03	5.6E-04	3.0E-04	-7.7
Operational Monitoring Third Quarter, 1999								
^{238}Pu	< MDC	NA	9.3E-08	NA	< MDC	NA	1.6E-06	NA
$^{239, 240}$Pu	NR	NR	NR	NA	NR	NR	NR	NA
^{241}Am	NR	NR	NR	NA	NR	NR	NR	NA
^{228}Th	6.9E-07	5.4E-08	7.8E-08	-8.9E+00	1.2E-02	9.5E-04	1.4E-03	51
^{230}Th	2.5E-07	4.2E-08	7.8E-08	-6.4E+01	4.5E-03	7.5E-04	1.4E-03	-40
^{232}Th	1.9E-07	2.9E-08	5.4E-08	-6.2E+01	3.3E-03	5.2E-04	9.6E-04	-37
^{234}U	5.1E-07	6.4E-08	7.8E-08	-4.2E+01	9.1E-03	1.1E-03	1.4E-03	-4.3
^{235}U	< MDC	NA	8.5E-08	NA	< MDC	NA	1.5E-03	NA
^{238}U	3.7E-07	5.7E-08	1.1E-07	-5.6E+01	6.6E-03	1.0E-03	1.9E-03	-28
Operational Monitoring Fourth Quarter, 1999								
^{238}Pu	< MDC	NA	2.3E-07	NA	< MDC	NA	8.3E-04	NA
$^{239, 240}$Pu	NR	NR	NA	NA	NR	NR	NA	NA
^{241}Am	NR	NR	NA	NA	NR	NR	NA	NA
^{228}Th	1.2E-06	1.5E-07	3.8E-07	6.0E+01	4.4E-03	5.6E-04	1.4E-03	-45
^{230}Th	1.0E-06	1.6E-07	3.1E-07	4.3E+01	3.6E-03	5.9E-04	1.1E-03	-51
^{232}Th	6.0E-07	9.6E-08	1.8E-07	2.3E+01	2.2E-03	3.5E-04	6.4E-04	-58
^{234}U	NR	NA	NR	NA	NR	NR	NA	NA
^{235}U	NR	NA	NR	NA	NR	NR	NA	NA
^{238}U	NR	NA	NR	NA	NR	NR	NA	NA

Table continued on next page

Table 7. Results of Actinide Analyses for Quarterly FAS Composite Samples (Cont.)

Radionuclide	**Activity Concentration (Bq m^{-3})**				**Activity Density (Bq g^{-1})**			
	[a]C	**[b]SD**	**[c]MDC**	**[d]RPC (%)**	**C**	**SD**	**MDC**	**RPC (%)**
Operational Monitoring First Quarter, 2000								
^{238}Pu	< MDC	NA	7.1E-08	NA	< MDC	NA	1.7E-04	NA
$^{239, 240}$Pu	< MDC	NA	5.6E-08	NA	< MDC	NA	1.3E-04	NA
^{241}Am	< MDC	NA	4.9E-08	NA	< MDC	NA	1.2E-04	NA
^{228}Th	1.2E-06	6.8E-08	9.4E-08	5.8E+01	2.8E-03	1.6E-04	2.2E-04	-65
^{230}Th	5.8E-07	5.0E-08	6.5E-08	-1.7E+01	1.4E-03	1.2E-04	1.5E-04	-82
^{232}Th	4.1E-07	3.7E-08	3.2E-08	-1.5E+01	9.8E-04	8.8E-05	7.6E-05	-81
^{234}U	1.0E-06	7.5E-08	8.0E-08	1.2E+01	2.4E-03	1.8E-04	1.9E-04	-75
^{235}U	1.3E-07	3.9E-08	1.1E-07	2.2E+02	3.1E-04	9.2E-05	2.6E-04	-29
^{238}U	8.6E-07	7.0E-08	7.5E-08	1.5E+00	2.0E-03	1.7E-04	1.8E-04	-7.8E+01
Operational Monitoring Second Quarter, 2000								
^{238}Pu	< MDC	NA	9.3E-08	NA	< MDC	NA	4.1E-04	NA
$^{239, 240}$Pu	< MDC	NA	7.5E-08	NA	< MDC	NA	3.3E-04	NA
^{241}Am	< MDC	NA	6.0E-08	NA	< MDC	NA	2.6E-04	NA
^{228}Th	4.9E-07	7.1E-08	1.5E-07	-3.5E+01	2.2E-03	3.1E-04	6.7E-04	-7.3E+01
^{230}Th	4.0E-07	6.4E-08	1.1E-07	-4.3E+01	1.8E-03	2.8E-04	4.7E-04	-7.7E+01
^{232}Th	2.3E-07	4.3E-08	8.8E-08	-5.3E+01	1.0E-03	1.9E-04	3.8E-04	-8.0E+01
^{234}U	6.3E-07	6.9E-08	8.1E-08	-2.9E+01	2.8E-03	3.0E-04	3.6E-04	-7.1E+01
^{235}U	< MDC	NA	8.1E-08	NA	< MDC	NA	3.5E-04	NA
^{238}U	5.0E-07	6.3E-08	1.0E-07	-4.2E+01	2.2E-03	2.8E-04	4.5E-04	-7.6E+01

[a] C = concentration
[b] SD = standard deviation
[c] MDC = minimum detectable concentration
[d] RPC = relative percent change, calculated as ((observed value - baseline value)/baseline value) * 100
[e] NA = not applicable
[f] NR = data not reported

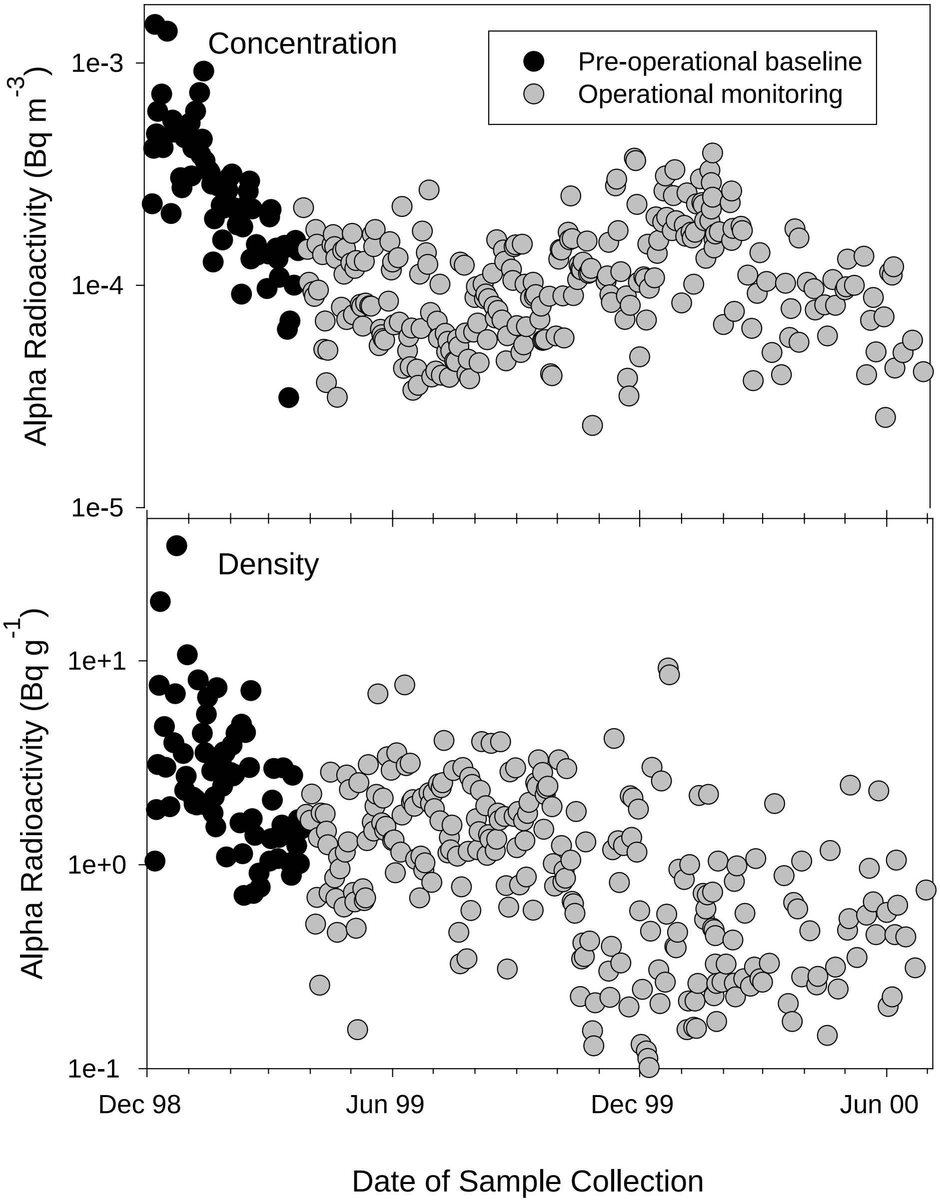

Figure 16. Alpha Emitting Radioactivity in FAS Samples Collected during December 1998 - July 2000

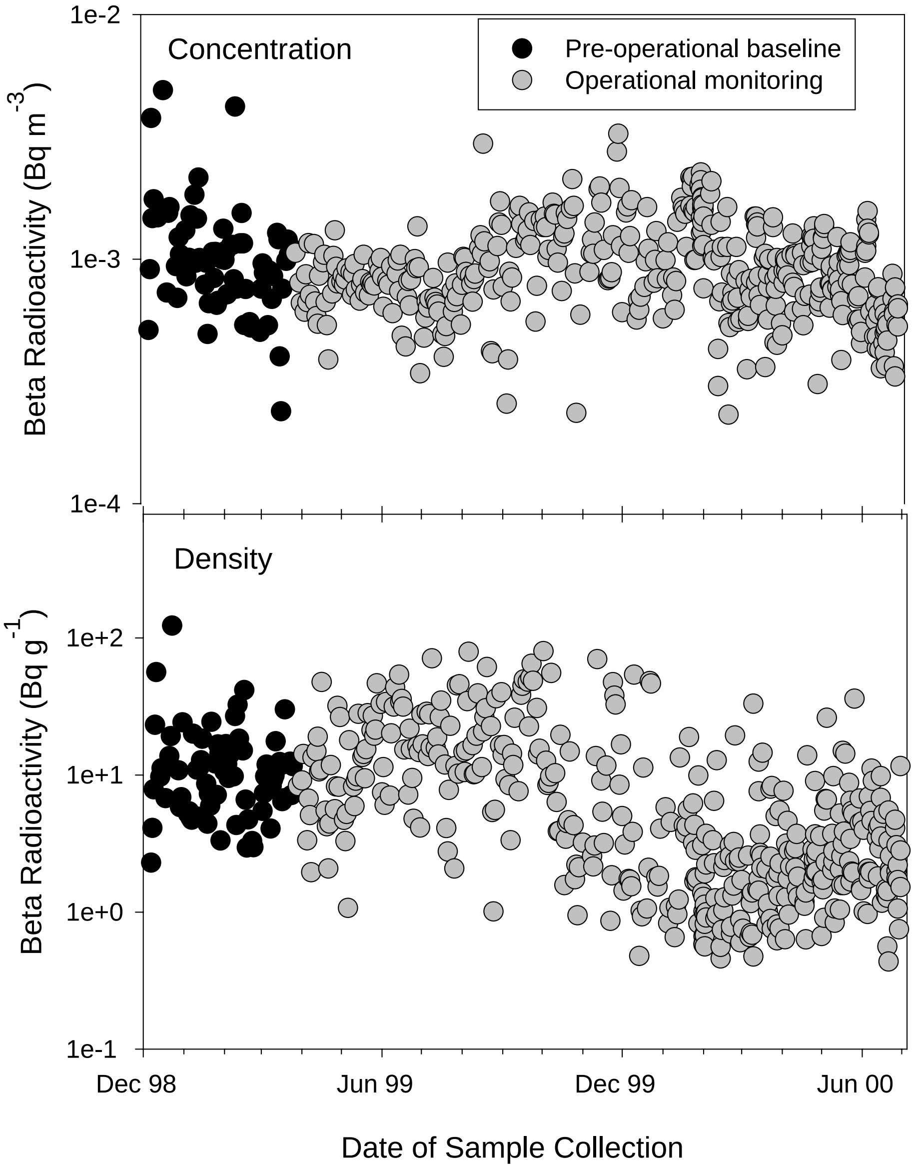

Figure 17. Beta Emitting Radioactivity in FAS Samples Collected during December 1998 - July 2000

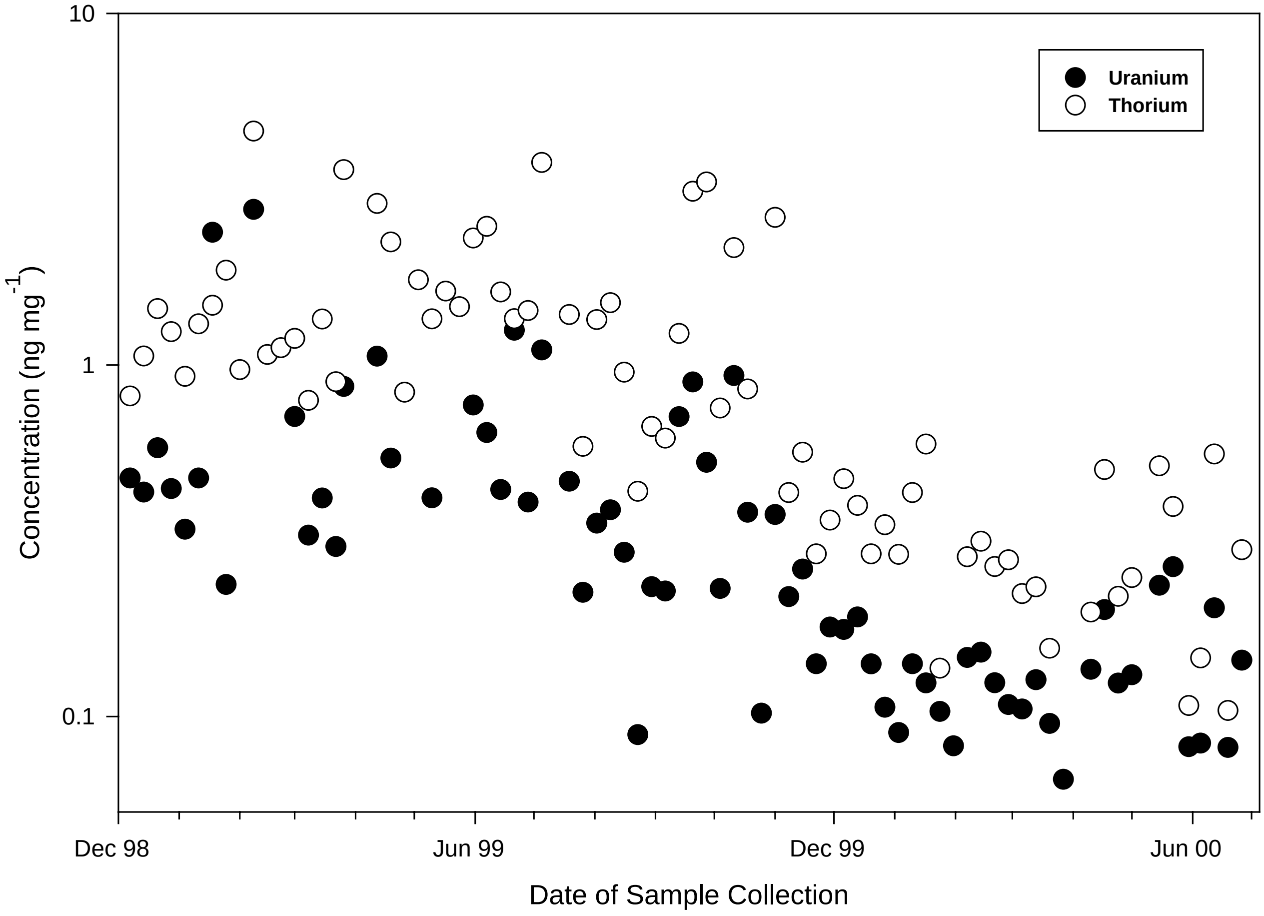

Figure 18. Radioactive Elemental Constituents Released as Aerosols in the Exhaust from the WIPP

Surface Soil Radionuclides and Inorganic Chemicals

Introduction

Results reported herein are from soil samples collected during 1999 and 2000 from a grid of 16 locations surrounding the WIPP site (the Near Field grid) and a grid of 16 locations approximately 12 miles southeast of the WIPP (the Cactus Flats grid, Fig. 2). The 2000 soil samples were collected prior to the arrival of the first mixed waste shipments at WIPP. Thus, the data for the non-radioactive analytes represent a continuation of the baseline monitoring study whereas the radionuclide data for the 2000 soil samples are results from the first monitoring phase. Measurements presented herein were made by CEMRC on the 2000 soil samples for ^{234}U, ^{235}U, ^{238}U, ^{230}Th, ^{232}Th, ^{228}Th and ^{239,240}Pu, ^{137}Cs, ^{208}Tl, ^{212}Pb, ^{212}Bi, ^{214}Pb, ^{228}Ac, ^{234m}Pa, ^{241}Am, ^{40}K, ^{60}Co and ^{7}Be. The natural radionuclides ^{208}Tl, ^{212}Bi, ^{214}Pb and ^{212}Pb are measured after allowing for ingrowth and their concentrations do not represent natural levels in the environment. However, the activity of ^{214}Pb can be used to estimate the original environmental concentration of ^{226}Ra. The activity of ^{208}Tl, ^{212}Bi and ^{212}Pb can be used to estimate activities of other members of the thorium series. Results are also presented for 45 non-radiological analytes measured using ICP-MS, AAS and IC.

One finding presented in the CEMRC 1999 Report was that there were significant differences in many analyte concentrations between the Near Field and Cactus Flats grids. Differences in soil texture were identified as a possible cause for these observations. Therefore, soil texture analyses were conducted on the 2000 soil samples to review these relationships.

Methods

The 16 sampling locations constituting each grid are distributed over approximately 16,580 hectares. In both 1998 and 1999 at each of the 32 locations (grid nodes), soil was collected from three randomly selected sites within a 50-m radius of the selected reference point. In 2000, one sample was collected at each of the 32 grid nodes. Four additional field duplicates were collected at randomly selected reference points each year. Individual sampling sites were selected on the basis of relatively flat topography, minimum surface erosion and minimum surface disturbance by human or livestock activity. At each sampling site, approximately 20 g of soil were removed using a plastic trowel from near the center of each of two 25-cm x 25-cm areas and placed in a plastic bag for inorganic analyses. In addition, approximately 8 L of soil were collected from within the two sampling areas to a depth of approximately 2 cm for radionuclide analyses. Soil samples were excavated using a trowel and placed in plastic bags for transport and storage. Sampling equipment was cleaned between samples.

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

Gamma spectroscopy analysis was conducted using high purity Ge (HPGe) detector systems for 2-3 days. A set of soil matrix standards was prepared using NIST traceable solutions and used to establish matrix-specific calibration and counting efficiencies.

Separate ~ 10-g aliquots of soil were used for actinide analyses. These aliquots were heated in a muffle furnace to combust organic material and spiked with a radioactive tracer to allow determination of the efficiency of extraction. They then underwent dissolution with HF and HCl followed by NaOH fusion of the insoluble residues. Multiple precipitation, co-precipitation and ion-exchange and/or extraction chromatography procedures were then used to separate and purify the desired elements. The elements of interest were then precipitated with LaF_3, deposited onto filters, mounted and counted on an alpha spectroscopy system. A summary of QA/QC for radioanalyses is presented in Appendix L.

Soil sample aliquots of 0.1 g were analyzed by AAS for As and Se using the soil collected from near the center of the sampling areas. These samples were neither sieved nor ground to prevent potential contamination by metals. ICP-MS was used to analyze samples for Ag, Al, Ba, Be, Ca, Cd, Ce, Co, Cr, Cu, Dy, Er, Eu, Fe, Gd, Hg, K, La, Li, Mg, Mn, Mo, Na, Ni, Pb, Pr, Sb, Sc, Sm, Sn, Sr, Th, Ti, Tl, U, V and Zn. The lower detection limits for both of these systems are in the low parts per billion range (Appendix K). Soil samples were analyzed by IC for chloride, fluoride, nitrate, nitrite, phosphate and sulfate. A summary of QA/QC methods for inorganic analyses is presented in Appendix K. The mean concentrations of these analytes reported herein for soils include only those values that are above detection levels. Thus, some estimates of the mean may be biased toward larger values. Sn and Na are also omitted from the statistical analyses because the level of the analytes in laboratory blanks approached and sometimes exceeded the levels measured in the samples, thus making the interpretation of their concentrations problematic.

Two aliquots of each sample collected in 2000 were air-dried, passed through a 2-mm sieve and analyzed by CEMRC for soil texture using the pipette method (Gee, G. W. and J. W. Bauder, 1986, Particle-size Analysis. In Klute, A. (ed.) *Methods of Soil Analysis. Part I. Physical and Mineralogical Methods-Agronomy Monograph no. 9*. American Society of Agronomy, Madison, WI). These analyses produced data for the percentages of sand, silt and clay in the soils.

Multivariate analysis of variance (MANOVA) was used to test for differences between the Cactus Flats and Near Field grids across inorganic analytes and soil particle size. MANOVA was also used to test for differences between 1999 and 2000, with Tukey's Honest Significant Difference Test used to identify differences between means of individual analytes. Chloride, Hg, Na, nitrite, Sn, Se, Tl and V were eliminated from the MANOVA for the 1999 data because those analytes had a preponderance of values below detection levels. Because of the lower number of samples collected in 2000 as compared to 1999 (36 versus 100, respectively), MANOVA could not be conducted using all of the analytes. Therefore the inorganic analytes were assigned to the following groups: anions (chloride, fluoride, nitrate, phosphate and sulfate), lanthanides (Ce, Dy, Er, Eu, Gd, La, Nd, Pr, Sm, Th and U) and other metals (Ag, Al, As, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Li, Mg, Mn, Mo, Ni, Pb, Sb, Sc, Sr, Ti, Tl, V and Zn). The analytes nitrite, Se and Hg were not included in the analyses of the 2000 soils because too few measurements were above detection levels.

MANOVA was used to test for differences between grids and between years (1998 and 2000) in the radionuclides. The radionuclides ^{241}Am, ^{234m}Pa, ^{234}U, ^{235}U and ^{238}U were not included in these analyses due to the number of non-detect values.

Correlations of the concentrations of radionuclides to soil texture classes and to concentrations of Al and Pb were computed using Pearson correlation coefficients.

Reproducibility of the measurements for the non-radiological measurements was determined from comparing five sets of laboratory duplicates. Relative Percent Differences (RPDs) were computed for all pairs for which the measurements were greater than the Minimum Detectable Concentration (MDC). The RPD is calculated as

$$RPD = 2\frac{|c_i - c_2|}{c_1 + c_2}\times 100\%$$

where c_i is the concentration of the ith duplicate. The RPD is the difference divided by the mean of two values expressed as a percent.

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

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

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

Results and Discussion

Particle-Size Analysis

Differences between the Near Field and Cactus Flats grids in concentrations of many analytes were documented in the 1999 CEMRC Report. These differences were postulated to arise from the preferential association of many analytes with fine (silt and clay) soil particles combined with a differential in soil texture between the two grids. The particle-size analysis for the 1998 soils employed the hydrometer method. The 2000 soils were analyzed using the pipette analysis because it provides greater accuracy than the hydrometer method. The average relative percent difference between duplicate aliquots was 6% for clay, 16% for silt and < 1% for sand. The differences in reproducibility by particle-size fraction are due in part to the predominance of sand in the soils. MANOVA on the texture data for the 2000 soil samples confirmed that there are significant ($p < 0.0001$) differences between the grids in soil texture. The mean percentages of clay (4.54) and of silt (3.64) particles in the soils on the Cactus Flats grid are greater than those on the Near Field grid (2.98 and 1.91 for clay and silt, respectively).

Reproducibility of Measurements

The average RPDs for the non-radiological analytes excluding Sn and Na ranged from 7% to 70% (Table 8). The maximum RPD values ranged from 12% to 170%. The RPDs reflect the uncertainty in estimated concentrations due to variability in analysis and heterogeneity in the samples. Heterogeneity in the non-radiological samples was probably high because of the relatively small aliquots analyzed and because the samples were not ground. The average RPD value is appropriate for estimating the reproducibility on the average of several samples, whereas the maximum RPD is a conservative estimate of the uncertainty in reproducibility that could be observed on any single measurement.

The measurements of radionuclides in laboratory duplicates were generally in good agreement. RPDs ranged between 1% and 47%. RPDs hold meaning only when the RERs are relatively low, i.e. when the differences do not fall within the range of analytical uncertainty. The maximum RER was 0.21 for the radionuclides measured by gamma analysis. The RERs for the actinides measured by alpha spectroscopy were 5.16 for ^{228}Th, 2.71 for ^{230}Th, 3.40 for ^{232}Th, 1.29 for ^{234}U, 0.65 for ^{235}U, 0.23 for ^{238}U, 2.74 for ^{239,240}Pu and 1.13 for ^{241}Am. The RERs for the gamma-emitting radionuclides compare well to the RERs determined for gamma measurements in Evans et al. (2000, *Waste Isolation Pilot Plant 1999 Site Environmental Report*, DOE/WIPP-00-2225). Evans et al. compared duplicates only for the actinides ^{233,234}U and ^{238}U because their other actinide measurements were below detection limits. The maximum CEMRC RERs for ^{233,234}U and ^{238}U (1.29 and 0.23, respectively) were similar to those reported by Evans et al.

Analyses of Variance

MANOVA showed a significant ($p < 0.0001$) effect of year on the concentrations of the inorganic analytes. The concentrations of the inorganic analytes in the 1999 soils are similar to those measured in the 1998 soils, with only Ag and Tl showing significantly different concentrations (higher and lower, respectively) in 1999 as compared to 1998. However, concentrations of 11 analytes (Ag, Al, As, Cr, Fe, K, Li, Mg, Mn, phosphate, and U) in the 2000 soils showed higher values than 1998 concentrations whereas the concentration of Tl was significantly lower in 2000 as compared to 1998 (Figs. 19 and 20). Cd had a significantly higher concentration in 1999 than in 2000.

It is believed that most of these differences between years are due to changes in the sample preparation procedures. In 2000 the digestion procedure was modified to use a microwave instead of a hotplate, as had been used in the 1998 and 1999 analyses. The microwave appears to be much more effective in dissolving some analytes. However, the lower concentration of Tl in 1999 and 2000 as compared to 1998 and of Cd in 2000 as compared to 1999 cannot be explained by this change in methodology.

The average MDC for radionuclides in soils determined by alpha spectroscopy was ≈ 0.1 mBq g^{-1}. The average MDC for radionuclides determined by gamma spectrometry was ≈ 1.3 mBq g^{-1}. MANOVA showed a significant ($p < 0.001$) year effect on radionuclide concentrations as well. However, there were no significant differences between years in the concentrations of the individual radionuclides and those differences were relatively small. The largest relative percent difference (RPD) between the adjusted means from the MANOVA was 11% for ^{137}Cs. Most of the radionuclides showed lower concentrations in 2000 than in 1998, with only ^{228}Ac and ^{212}Bi showing slightly higher values. Concentrations of ^{239,240}Pu were nearly identical between years. Thus the year effect identified in the MANOVA probably arises from relatively consistent but small differences between years. Given that (1) the uncertainty on individual measurements ranged between 1.6% and 44% of the reported values, (2) these uncertainties cannot be considered in the MANOVA, (3) there were no significant differences between years in the mean concentrations of any radionuclide and (4) the data from the Fixed Air Sampler in the exhaust shaft showed no indications of a release, it seems unlikely that the between-year differences are associated with the receipt of waste at the WIPP.

Results of the MANOVA on the 1999 soil samples showed that there were significant ($p < 0.0001$) differences between the two grids, and that the Cactus Flats grid generally had higher concentrations of metals than at the Near Field grid (Table 9). Of the analytes, 27 (Ag, Al, Ba, Be, Cd, Ce, Co, Cr, Cu, Dy, Er, Eu, Fe, Gd, K, La, Li, Mn, Mo, Nd, Pb, Pr, Sm, Sr, Th, Ti, and U) showed significantly ($p < 0.05$) higher concentrations on the Cactus Flats grid as compared to the Near Field grid. Nitrate showed a significantly lower concentration on the Cactus Flats grid.

MANOVA showed a significant ($p < 0.0001$) grid effect on the lanthanide analytes in the 2000 soil samples (Table 10). All of the lanthanides had significantly ($p < 0.05$) greater concentrations in the Cactus Flats soils than in the Near Field soils. MANOVA showed that there was no significant grid effect on the anions, although chloride and sulfate individually showed significantly higher concentrations on the Near Field grid as compared to the Cactus Flats grid. MANOVA also did not show a grid effect on the non-lanthanide metal concentrations, although individually Al, Ba, Be, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Ni, Pb, Sc, Ti, V and Zn showed significantly ($p < 0.05$) higher concentrations on the Cactus Flats grid than on the Near Field grid.

Grid effects were significant ($p < 0.05$) for the 2000 radionuclide concentrations. The concentrations of nine radionuclides (^{228}Ac, ^{212}Bi, ^{214}Bi, ^{212}Pb, ^{214}Pb, ^{228}Th, ^{230}Th, ^{232}Th, and ^{208}Tl) were significantly higher on the Cactus Flats grid than on the Near Field grid (Table 10). Grid effects on the combined 1998 and 2000 data were also significant ($p < 0.0001$). All radionuclides except ^{40}K showed significantly higher concentrations on the Cactus Flats grid than on the Near Field grid. These same patterns were observed in baseline studies presented in the CEMRC 1999 Report and in Kirchner et al. (*J. Environ. Rad.*, in press).

Correlation With Soil Texture

The 2000 soil data also show that the concentrations of many analytes are correlated with the proportion of fine (silt + sand) particles in the soil. Of the non-radiological analytes, Al, As, Ba, Be, Ca, Ce, Co, Cr, Cu, Dy, Er, Eu, Fe, Gd, Hg, K, La, Li, Mg, Mn, Mo, Nd, Ni, Pb, Pr, Sc, Sm, Sr, Th, Ti, Tl, U, V and Zn showed significant ($p < 0.05$) positive correlations with the proportion of fine particles in the soil samples. All of the radionuclides except ^{235}U showed significant ($p < 0.01$) positive correlations with the proportion of fine particles in the soils (Table 11). In the case of ^{235}U, interference from spectral tailing of the ^{234}U peak is likely to have introduced uncertainty into the measurements and thus degraded the correlation. These radionuclides also showed significant ($p < 0.01$) positive correlations with the concentrations of Al and Pb. In all cases soil texture was a better predictor of radionuclide concentrations than was Al. For example, the proportion of fine particles accounted for 35% of the variability in ^{239,240}Pu, whereas Al only accounted for 26% of the variability. Lead was a better predictor than soil texture for the isotopes of Pu, Am and U but not for the Th isotopes. The concentration of Pb accounted for 64% of the variability in ^{239,240}Pu as compared with 35% for soil texture.

The importance of soil texture on the dynamics of many soil analytes was described in the CEMRC 1999 Report. Many metals, including radionuclides, are known to have an affinity for small particles in the soil (Muller, R. N. and D. G. Sprugel, 1977, *Health Physics* 33, 405; Muller, R. N. and G. T. Tisue, 1977, *Soil Science* 124, 191; Watters et al., 1983, *Radiochima Acta* 32, 89; Little, C. A., 1980, J. *Environ. Qual.* 9, 350; Tamura, T., 1975, *J. Environ. Qual.* 4, 350). The aluminosilicates and hydrated oxides of clays usually account for the major adsorptive component of soils and hence affect the binding of radionuclides (Wild, A., 1994, *Soils and the Environment*. Cambridge University Press; Whicker, F. W. and V. Schultz, 1982, *Radioecology: Nuclear Energy and the Environment. Vol. II*. CRC Press).

Clay content also affects the infiltration rate of soils. Infiltration can deplete the inventory of contaminants in the surface layer of soil, with sandy soils generally having greater infiltration rates than clay soils. However, a simple relationship between vertical transport rates and soil texture should not be expected because macropores such as root channels and soil cracks are unlikely to form in sandy soils. Macropore flow is recognized as an extremely important mechanism in the leaching of contaminants in unsaturated soils (Luxmoore, R. J., 1991, In Gish, T. J., & A. Schirmohammadi (eds.), *Preferential Flow. Proc. Natl. Symp.*, Chicago, IL. 16-17 Dec. 1991. St. Joseph, MI , Am. Soc. Agric. Eng.,). Litaor et al. (1998, *J. Environ. Rad.* 38, 17.) concluded that most of the vertical transport of ^{239,240}Pu and ^{241}Am in the top 20 cm of soils at the Rocky Flats Environmental Technology site (Colorado, USA) was associated with infiltration of suspended and colloidal matter, and they implicated macropore flow following heavy rain as an important mechanism for moving Pu and Am deep into the soil. Thus clays in soils, through their adsorptive properties and by their effects on infiltration rates, can impact the vertical movement of many radionuclides and hence influence surface concentrations.

Comparison to Other Studies

The mean activity concentrations of ^{137}Cs, ^{234}U, ^{235}U, ^{238}U, and ^{40}K in CEMRC 2000 samples fell within the ranges reported by Evans et al., (*op. cit.*). The maximum ^{239,240}Pu concentration (0.40 mBq g^{-1}) was within the range reported by Kenny et al. (1995, *Radionuclide Baseline in Soil Near Project Gnome and the Waste Isolation Pilot Plant*, EEG-58) at the WIPP (0-0.74 mBq g^{-1}) and was lower than background concentrations found at Hueston Woods and Urbana, Ohio (0.7-1.0 mBq g^{-1}) (Alberts et al., 1980, *J. Environ. Qual.* 9, 592) and at a series of 15 locations between Ft. Collins and Colorado Springs, Colorado (0.6-1.7 mBq g^{-1}) (Hodge et al., 1996, *Chemosphere* 32, 2067). Evans et al. (*op. cit.*) detected neither ^{239,240}Pu nor ^{241}Am in surface soils.

These results demonstrate that significant variability in background levels of soil contaminants and constituents can occur in areas having relatively low variability in soil texture. The high correlations of the radionuclides and many of the non-radioactive metals to the percentages of silt and clay in the soil explains much of the between-sample variability. Actinides can form strong complexes with oxygen-containing ligands (Beal, G. W. and B. Allard, 1981, In Tewari, P. H. (ed.), *Adsorption from Aqueous Solutions*, Plenum Press, New York; Allard, B., 1982, In Edlestein, N. M. (ed.), *Actinides in Perspective*, Pergamon Press, Oxford). Actinides also form complexes with humic molecules and these can be significantly more stable than their complexes with simple inorganic ligands (Livens, F. R. and D. L. Singleton, 1991, *J. Environ. Rad.* 13, 323), although subject to a significant concentration effect (Hummel et al., 1999, *Radiochima Acta* 84, 111). Therefore, the affinity of ^{239,240}Pu for fine soil particles could also be due to organic material in the silt fractions. The radionuclides in the 2000 soil samples also showed significant correlations with Al and Pb, as was noted in the CEMRC 1999 Report for the 1998 data.

These data also suggest that the variability in concentrations across locations may arise from a redistribution of naturally occurring radionuclides and fallout-contaminated fine soil particles or from a greater degree of entrapment of the contaminants in the upper layer of the soil. Radionuclides deposited as fallout, such as ^{137}Cs and ^{239,240}Pu, would be expected to show a decrease in concentration with depth. Soil profile analyses would be expected to help elucidate the dynamics of radionuclide contaminants in soil. However, the soil profile concentrations presented in Evans et al. (*op. cit.*) do not demonstrate a consistent pattern of concentration of radionuclides with respect to depth within the top 10 cm of soil. The collection of additional soil profile data is expected to help determine the underlying causes for the differences observed between the Near Field and Cactus Flats grids.

Tables presenting soil data summarized herein are available on the CEMRC web site at http://www.cemrc.org.

Table 8. Mean and Maximum Relative Percent Differences for Inorganic Analytes in Soils

Analyte	Mean [a]RPD (%)	Maximum RPD (%)	Analyte	Mean RPD (%)	Maximum RPD (%)
Ag	22.0	54.9	Mo	36.2	124.3
Al	12.7	33.0	Na	95.1	382.3
As	15.4	46.6	Nd	15.6	32.6
Ba	12.9	26.7	Ni	18.5	30.0
Be	26.9	110.0	Pb	11.1	23.9
Ca	8.5	17.7	Pr	16.3	31.8
Cd	51.4	167.3	Sb	24.8	100.4
Ce	17.9	37.9	Sc	12.9	25.8
Co	18.4	50.6	Se	70.4	170.1
Cr	13.0	30.2	Sm	15.7	31.0
Cu	14.2	47.3	Sn	-12.2	29.1
Dy	15.9	28.9	Sr	13.1	32.9
Er	15.7	26.5	Th	25.6	53.5
Eu	14.5	25.7	Ti	18.5	40.7
Fe	14.1	31.4	Tl	38.2	159.7
Gd	17.7	34.4	U	15.5	29.7
Hg	49.8	130.6	V	16.4	27.4
K	8.0	15.1	Zn	7.4	12.1
La	15.6	30.3	Chloride	49.4	103.5
Li	8.7	15.6	Nitrate	20.2	34.2
Mg	12.8	25.3	Phosphate	17.4	39.7
Mn	11.1	24.2	Sulfate	13.6	25.6

[a] $RPD = 2\frac{|c_i - c_2|}{c_1 + c_2} \times 100\%$, where c_1 and c_2 are concentrations in the duplicate samples

Table 9. Summary Statistics for Inorganic Analytes in Soil Samples Collected in 1999

		Near Field			Cactus Flats		
Analyte	**Units**	**[a]N**	**[b]Mean**	**Range**	**N**	**Mean**	**Range**
Ag	mg kg^{-1}	43	1.4E-02	5.7E-03 - 3.3E-02	38	2.2E-02	5.7E-03 - 3.3E-02
Al	mg kg^{-1}	50	2.1E+03	1.6E+02 - 5.0E+03	49	2.7E+03	1.6E+02 - 5.0E+03
As	mg kg^{-1}	51	9.6E-01	5.0E-01 - 1.9E+00	43	1.2E+00	5.0E-01 - 1.9E+00
Ba	mg kg^{-1}	51	2.0E+01	8.1E+00 - 5.1E+01	49	2.7E+01	8.1E+00 - 5.1E+01
Be	mg kg^{-1}	49	1.1E-01	4.8E-02 - 2.6E-01	49	1.4E-01	4.8E-02 - 2.6E-01
Ca	mg kg^{-1}	45	4.9E+02	1.7E+02 - 2.0E+03	33	8.1E+02	1.7E+02 - 2.0E+03
Cd	mg kg^{-1}	47	5.5E-02	3.0E-02 - 1.4E-01	42	8.0E-02	3.0E-02 - 1.4E-01
Chloride	mg kg^{-1}	35	1.7E+00	6.0E-01 - 1.4E+01	46	1.1E+00	6.0E-01 - 1.4E+01
Co	mg kg^{-1}	49	6.6E-01	3.2E-01 - 1.7E+00	50	8.7E-01	3.2E-01 - 1.7E+00
Cr	mg kg^{-1}	50	3.0E+00	1.6E+00 - 6.9E+00	50	4.1E+00	1.6E+00 - 6.9E+00
Cu	mg kg^{-1}	48	1.8E+00	8.4E-01 - 4.2E+00	50	2.3E+00	8.4E-01 - 4.2E+00
Fe	mg kg^{-1}	38	2.2E+03	2.3E+02 - 4.3E+03	37	3.9E+03	2.3E+02 - 4.3E+03
Hg	mg kg^{-1}	30	3.3E-03	1.4E-03 - 1.6E-02	40	3.1E-03	1.4E-03 - 1.6E-02
K	mg kg^{-1}	49	5.8E+02	2.2E+02 - 1.4E+03	48	7.2E+02	2.2E+02 - 1.4E+03
La	mg kg^{-1}	50	2.9E+00	1.6E+00 - 6.0E+00	49	4.0E+00	1.6E+00 - 6.0E+00
Li	mg kg^{-1}	50	1.8E+00	7.8E-01 - 5.0E+00	50	2.2E+00	7.8E-01 - 5.0E+00
Mg	mg kg^{-1}	49	4.6E+02	1.7E+02 - 1.1E+03	41	5.0E+02	1.7E+02 - 1.1E+03
Mn	mg kg^{-1}	50	3.9E+01	1.7E+01 - 8.5E+01	49	5.2E+01	1.7E+01 - 8.5E+01
Mo	mg kg^{-1}	49	7.8E-02	4.0E-02 - 1.5E-01	43	1.1E-01	4.0E-02 - 1.5E-01
Na	mg kg^{-1}	8	7.9E+01	6.5E+01 - 1.2E+02	6	7.1E+01	6.5E+01 - 1.2E+02
Ni	mg kg^{-1}	47	1.7E+00	4.7E-01 - 4.8E+00	40	1.8E+00	4.7E-01 - 4.8E+00
Nitrate	mg kg^{-1}	52	1.3E+01	1.2E+00 - 7.0E+01	55	8.6E+00	1.2E+00 - 7.0E+01
Nitrite	mg kg^{-1}	6	1.7E-01	1.0E-01 - 2.3E-01	15	2.9E+00	1.0E-01 - 2.3E-01
Pb	mg kg^{-1}	48	2.8E+00	1.4E+00 - 5.6E+00	49	3.9E+00	1.4E+00 - 5.6E+00
Phosphate	mg kg^{-1}	52	5.4E+00	3.1E-01 - 1.3E+01	54	6.3E+00	3.1E-01 - 1.3E+01
Sb	mg kg^{-1}	38	5.6E-02	2.1E-02 - 2.3E-01	42	5.7E-02	2.1E-02 - 2.3E-01
Se	mg kg^{-1}	4	1.4E-01	1.3E-01 - 1.4E-01	5	1.5E-01	1.3E-01 - 1.4E-01
Sr	mg kg^{-1}	49	3.3E+00	1.5E+00 - 7.4E+00	48	4.4E+00	1.5E+00 - 7.4E+00
Sulfate	mg kg^{-1}	52	3.8E+00	7.9E-01 - 1.4E+01	55	4.6E+00	7.9E-01 - 1.4E+01
Th	mg kg^{-1}	49	1.1E+00	5.6E-01 - 2.3E+00	49	1.5E+00	5.6E-01 - 2.3E+00
Ti	mg kg^{-1}	49	5.8E+01	2.9E+01 - 1.8E+02	49	7.4E+01	2.9E+01 - 1.8E+02
U	mg kg^{-1}	50	9.0E-02	4.7E-02 - 2.2E-01	50	1.1E-01	4.7E-02 - 2.2E-01
V	mg kg^{-1}	45	4.1E+00	2.0E+00 - 1.3E+01	33	5.1E+00	2.0E+00 - 1.3E+01
Zn	mg kg^{-1}	48	1.1E+01	2.8E+00 - 4.0E+01	50	1.2E+01	2.8E+00 - 4.0E+01

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

Table 10. Summary Statistics for Analytes in Soil Samples Collected in 2000

		Near Field			Cactus Flats		
Analyte	**Unit**	**[a]N**	**[b]Mean**	**Range**	**N**	**Mean**	**Range**
Ag	mg kg^{-1}	18	1.4E-02	7.3E-03 - 4.3E-02	18	1.8E-02	6.6E-03 - 6.1E-02
Al	mg kg^{-1}	18	3.7E+03	1.8E+03 - 6.0E+03	18	5.3E+03	2.4E+03 - 9.2E+03
As	mg kg^{-1}	18	1.4E+00	7.4E-01 - 3.6E+00	18	2.0E+00	1.0E+00 - 4.0E+00
Ba	mg kg^{-1}	18	2.1E+01	1.0E+01 - 4.2E+01	18	3.0E+01	1.8E+01 - 4.3E+01
Be	mg kg^{-1}	18	1.3E-01	8.7E-02 - 2.4E-01	18	1.8E-01	9.2E-02 - 2.5E-01
Ca	mg kg^{-1}	18	9.0E+02	3.5E+02 - 5.7E+03	18	8.2E+02	2.8E+02 - 2.3E+03
Cd	mg kg^{-1}	18	5.6E-02	2.0E-02 - 2.9E-01	18	5.8E-02	2.8E-02 - 9.6E-02
[c]Ce	mg kg^{-1}	18	6.1E+00	4.0E+00 - 9.0E+00	18	8.1E+00	4.9E+00 - 1.4E+01
[d]Chloride	mg kg^{-1}	18	5.7E+00	1.0E+00 - 2.0E+01	18	2.3E+00	-5.9E-01 - 5.9E+00
Co	mg kg^{-1}	18	7.3E-01	4.2E-01 - 1.3E+00	18	9.7E-01	5.3E-01 - 1.7E+00
Cr	mg kg^{-1}	18	4.2E+00	2.6E+00 - 5.3E+00	18	5.3E+00	3.1E+00 - 8.6E+00
Cu	mg kg^{-1}	18	1.5E+00	7.3E-01 - 2.5E+00	18	2.0E+00	1.0E+00 - 3.2E+00
[c]Dy	mg kg^{-1}	18	3.0E-01	2.0E-01 - 4.8E-01	18	4.3E-01	2.6E-01 - 6.8E-01
[c]Er	mg kg^{-1}	18	1.5E-01	9.7E-02 - 2.3E-01	18	2.1E-01	1.2E-01 - 3.4E-01
[c]Eu	mg kg^{-1}	18	1.0E-01	6.4E-02 - 1.9E-01	18	1.5E-01	9.4E-02 - 2.3E-01
Fe	mg kg^{-1}	18	3.7E+03	1.8E+03 - 5.3E+03	18	5.3E+03	3.1E+03 - 7.7E+03
[d]Fluoride	mg kg^{-1}	18	5.9E-01	-9.2E-02 - 2.2E+00	18	7.4E-01	2.5E-01 - 1.5E+00
[c]Gd	mg kg^{-1}	18	6.7E-01	4.2E-01 - 1.0E+00	18	9.3E-01	4.9E-01 - 1.7E+00
Hg	mg kg^{-1}	13	4.8E-03	3.5E-03 - 1.0E-02	17	5.2E-03	3.3E-03 - 8.4E-03
K	mg kg^{-1}	18	8.0E+02	5.4E+02 - 1.3E+03	18	1.1E+03	3.9E+02 - 2.7E+03
[c]La	mg kg^{-1}	18	3.3E+00	2.2E+00 - 4.7E+00	18	4.7E+00	3.1E+00 - 7.5E+00
Li	mg kg^{-1}	18	3.7E+00	2.4E+00 - 5.2E+00	18	4.8E+00	2.2E+00 - 6.8E+00
Mg	mg kg^{-1}	18	5.8E+02	3.9E+02 - 1.1E+03	18	7.5E+02	3.2E+02 - 1.7E+03
Mn	mg kg^{-1}	18	4.7E+01	2.7E+01 - 7.7E+01	18	6.6E+01	3.4E+01 - 1.3E+02
Mo	mg kg^{-1}	18	1.0E-01	5.6E-02 - 1.9E-01	18	1.3E-01	8.4E-02 - 2.2E-01
[c]Nd	mg kg^{-1}	18	3.1E+00	2.0E+00 - 4.6E+00	18	4.4E+00	2.9E+00 - 7.0E+00
Ni	mg kg^{-1}	18	2.0E+00	1.1E+00 - 3.3E+00	18	2.4E+00	1.2E+00 - 4.2E+00
[d]Nitrate	mg kg^{-1}	18	1.8E+01	5.7E+00 - 4.5E+01	18	1.0E+01	3.2E+00 - 4.2E+01
Nitrite	mg kg^{-1}	5	2.3E-01	8.6E-02 - 4.4E-01	2	2.5E-01	2.4E-01 - 2.7E-01
Pb	mg kg^{-1}	18	2.8E+00	1.6E+00 - 4.5E+00	18	4.0E+00	2.6E+00 - 6.0E+00
[d]Phosphate	mg kg^{-1}	18	7.1E+00	3.6E+00 - 1.1E+01	18	6.3E+00	2.6E+00 - 1.2E+01
[c]Pr	mg kg^{-1}	18	8.6E-01	5.5E-01 - 1.2E+00	18	1.2E+00	7.9E-01 - 1.9E+00
Sb	mg kg^{-1}	18	6.2E-02	3.1E-02 - 1.0E-01	18	7.8E-02	9.7E-03 - 1.4E-01
Sc	mg kg^{-1}	18	5.7E-01	3.4E-01 - 1.0E+00	18	7.8E-01	3.8E-01 - 1.3E+00
Se	mg kg^{-1}	10	1.2E+00	6.1E-02 - 5.6E+00	15	7.5E-01	6.2E-02 - 5.0E+00
[c]Sm	mg kg^{-1}	18	5.7E-01	3.7E-01 - 8.5E-01	18	8.1E-01	5.3E-01 - 1.3E+00
Sr	mg kg^{-1}	18	4.2E+00	2.6E+00 - 8.7E+00	18	5.0E+00	2.5E+00 - 9.0E+00
[d]Sulfate	mg kg^{-1}	18	1.3E+01	5.2E+00 - 3.5E+01	18	6.4E+00	4.1E+00 - 1.2E+01
[c]Th	mg kg^{-1}	18	1.1E+00	7.6E-01 - 1.8E+00	18	1.7E+00	1.1E+00 - 2.4E+00

Table continued on next page

Table 10. Summary Statistics for Analytes in Soil Samples Collected in 2000 (Cont.)

		Near Field			Cactus Flats		
Analyte	**Unit**	**[a]N**	**[b]Mean**	**Range**	**N**	**Mean**	**Range**
Ti	mg kg^{-1}	18	6.0E+01	2.7E+01 - 9.1E+01	18	8.1E+01	3.5E+01 - 1.9E+02
Tl	mg kg^{-1}	18	5.2E-02	2.8E-02 - 1.4E-01	18	6.2E-02	3.0E-02 - 1.2E-01
[c]U	mg kg^{-1}	18	1.2E-01	7.5E-02 - 2.0E-01	18	1.6E-01	9.8E-02 - 2.3E-01
V	mg kg^{-1}	18	5.5E+00	3.9E+00 - 7.5E+00	18	7.1E+00	4.5E+00 - 9.1E+00
Zn	mg kg^{-1}	18	7.1E+00	3.4E+00 - 1.2E+01	18	9.8E+00	5.2E+00 - 1.5E+01
^{137}Cs	mBq g^{-1}	17	3.8E+00	7.2E-01 - 6.9E+00	18	4.8E+00	8.1E-01 - 1.1E+01
^{208}Tl	mBq g^{-1}	18	2.7E+00	1.8E+00 - 3.8E+00	18	3.4E+00	2.7E+00 - 4.6E+00
^{212}Bi	mBq g^{-1}	18	9.3E+00	6.4E+00 - 1.3E+01	18	1.2E+01	8.3E+00 - 1.5E+01
^{212}Pb	mBq g^{-1}	18	8.3E+00	5.9E+00 - 1.2E+01	18	1.1E+01	8.4E+00 - 1.4E+01
^{214}Bi	mBq g^{-1}	18	8.1E+00	5.5E+00 - 1.1E+01	18	1.0E+01	7.5E+00 - 1.3E+01
^{214}Pb	mBq g^{-1}	18	8.4E+00	6.3E+00 - 1.1E+01	18	1.0E+01	7.8E+00 - 1.4E+01
^{228}Ac	mBq g^{-1}	18	8.8E+00	6.3E+00 - 1.2E+01	18	1.2E+01	8.5E+00 - 1.6E+01
^{40}K	mBq g^{-1}	18	2.2E+02	1.4E+02 - 2.8E+02	18	2.2E+02	1.5E+02 - 2.8E+02
^{241}Am	mBq g^{-1}	15	4.5E-02	1.5E-02 - 8.5E-02	18	6.3E-02	2.7E-02 - 1.0E-01
^{239,240}Pu	mBq g^{-1}	18	1.4E-01	3.9E-02 - 3.9E-01	22	1.8E-01	3.5E-02 - 4.0E-01
^{228}Th	mBq g^{-1}	15	8.7E+00	6.2E+00 - 1.5E+01	19	1.2E+01	5.5E+00 - 1.7E+01
^{230}Th	mBq g^{-1}	15	8.8E+00	6.6E+00 - 1.3E+01	19	1.2E+01	5.3E+00 - 1.6E+01
^{232}Th	mBq g^{-1}	15	8.3E+00	5.8E+00 - 1.4E+01	19	1.1E+01	5.2E+00 - 1.6E+01
^{234}U	mBq g^{-1}	6	7.0E+00	5.3E+00 - 8.6E+00	8	8.1E+00	7.2E+00 - 9.2E+00
^{235}U	mBq g^{-1}	6	4.1E-01	2.7E-01 - 6.0E-01	9	4.3E-01	3.7E-01 - 5.3E-01
^{238}U	mBq g^{-1}	6	7.2E+00	5.4E+00 - 8.9E+00	11	8.1E+00	7.1E+00 - 9.4E+00

[a]N = number of samples > MDC

[b]Mean = arithmetic mean

[c]Included in lanthanide group for MANOVA

[d]Included in anion group for MANOVA. Nitrite excluded because of low number of concentrations > MDC

Table 11. Mean Concentrations of Radionuclides and Correlations with Soil Texture, Al and Pb in Soils Collected from Near Field and Cactus Flats Grids in 2000

	Activity Concentration			**Correlation Coefficients (r)**		
Analyte	**[a]Mean (mBq g^{-1})**	**[b]SE (mBq g^{-1})**	**[c]N**	**Concentration of Al**	**Concentration of Pb**	**% Fine Soil Particles**
^{228}Ac	1.0E+01	3.8E-01	36	0.80	0.90	0.92
^{241}Am	5.5E-2	4.0E-3	33	0.57	0.80	0.66
^{212}Bi	1.1E+01	3.5E-01	36	0.66	0.81	0.75
^{214}Bi	9.1E+00	3.1E-01	36	0.79	0.90	0.89
^{137}Cs	4.3E+00	3.6E-01	35	0.50	0.81	0.62
^{40}K	2.2E+02	6.2E+00	36	0.62	0.73	0.69
^{212}Pb	9.5E+00	3.5E-01	36	0.80	0.93	0.93
^{214}Pb	9.4E+00	2.9E-01	36	0.78	0.91	0.89
^{239,240}Pu	1.6E-01	1.5E-02	41	0.48	0.78	0.57
^{228}Th	1.0E+01	5.1E-01	34	0.80	0.85	0.91
^{230}Th	1.0E+01	5.0E-01	34	0.79	0.84	0.91
^{232}Th	9.9E+00	4.9E-01	34	0.79	0.86	0.91
^{208}Tl	3.1E+00	1.1E-01	36	0.80	0.90	0.91
^{234}U	7.6E+00	2.8E-01	14	0.72	0.86	0.77
^{235}U	4.2E-01	2.2E-02	15	[d]*0.41*	*0.40*	*0.39*
^{238}U	7.8E+00	2.5E-01	17	0.71	0.80	0.78

[a] Mean = arithmetic mean
[b] SE = standard error of mean
[c] N = number of samples > MDL
[d] Italicized values are not significant. All others are significant at $p < 0.01$

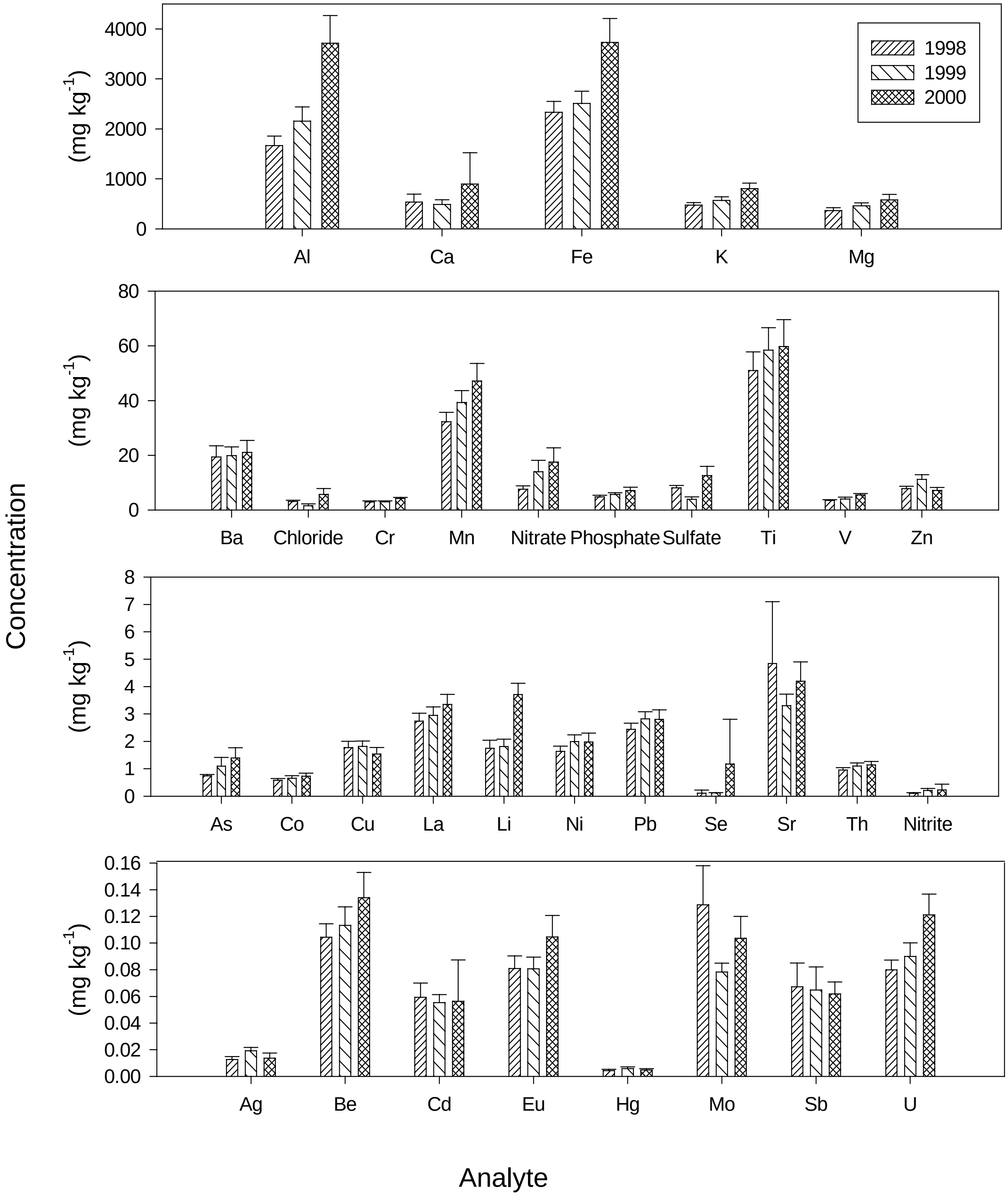

Figure 19. Mean Concentrations of Inorganic Analytes in Soil Samples from Near Field Grid Collected during 1998 - 2000

Error bars show upper 95% confidence intervals for concentrations.

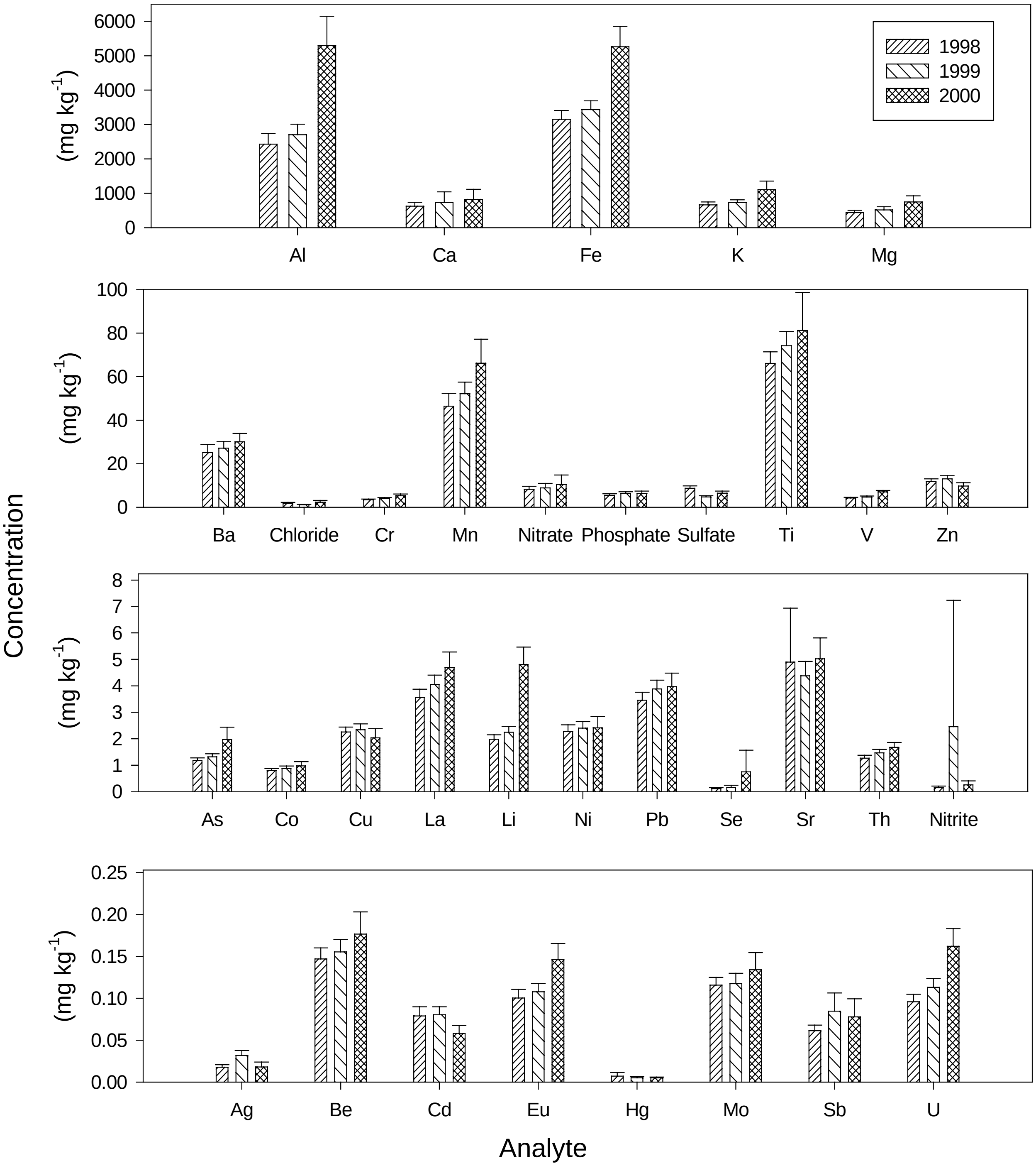

Figure 20. Mean Concentrations of Inorganic Analytes in Soil Samples from Cactus Flats Grid Collected during 1998 - 2000

Error bars show upper 95% confidence intervals for concentrations.

Radionuclides and Inorganics in Surface Water and Sediments at Selected Reservoirs

Introduction

As part of the WIPP EM project, surface water and sediments are routinely sampled from three regional reservoirs situated on the Pecos River. Brantley Lake and Red Bluff Reservoir were selected for sampling because they are impoundments located "upstream" and "downstream", respectively, relative to surface and ground water flows from the area immediately surrounding the WIPP site (Figs. 21 and 22). Both reservoirs support a warm-water fishery and are used for irrigation, livestock watering, wildlife habitat and recreation. Lake Carlsbad is an impounded section of the Pecos River within the city of Carlsbad (Fig. 23) that is used extensively by the local population for recreational warm-water fishing, boating and swimming.

In 1997, a pilot study of the surface water and sediments in Brantley Lake was conducted, in which 15 sediment and three surface water samples were collected during March and April and three additional water samples in September. A summary of the sample analyses was included in the 1997 CEMRC Report. In 1998, 24 sediment and 17 surface water samples were collected from Brantley Lake, Lake Carlsbad and Red Bluff Reservoir. These included 12 sediment samples and 11 surface water samples collected during January-April and the remaining samples (12 sediment and 6 surface water) collected during August-October. The results of actinide, elemental, inorganic and selected organic analyses of the first set of samples collected in 1998 were reported in the 1998 CEMRC Report. In 1999, six surface water and 12 sediment samples were collected from the three reservoirs during June and July and again in May and June of 2000.

Analyses reported herein summarize the baseline results for radiological constituents in regional surface water and results from the first monitoring phase samples collected in 1999 and 2000. A summary of baseline and monitoring phase measurements of gamma-emitting radionuclides in sediments is also presented. The baseline summary for inorganic analyses is updated to include the latest surface water and sediment measurements.

Results from monitoring phase radiological analyses of alpha-emitting radionuclides in sediments collected during 1999 and 2000 are scheduled for completion and posting on the CEMRC web site in February 2001.

Methods

Sediment and surface water samples were collected during May-June 2000 from previously selected sites within each reservoir. Four site locations at each lake were identified using sonar and a combination of triangulation to known shoreline locations and GPS coordinates established during the 1998 and 1999 sampling seasons. These locations fall within the deep basins of each reservoir (Figs. 21, 22, and 23). Deep basins were chosen for sampling to minimize the disturbance and particle mixing effects of current and wave action that occur at shallower depths. Also, many of the analytes of interest tend to concentrate in the fine sediments that settle in the deep reservoir basins; thus, measurements from these areas would typically represent the highest levels that might be expected for a given reservoir.

Sediments were collected using an Eckman dredge. The thickness of the sediment collected ranged from 5 to 10 cm. Excess water was decanted from the sediment. Approximately 5 L of sediment was sealed in a pre-cleaned plastic bucket in the field and transported to CEMRC for preparation prior to analyses.

In the laboratory, the sediment samples were air-dried, pulverized to pass a 2-mm sieve, homogenized and split into aliquots for radiochemical, inorganic and particle-size analyses. Samples destined for radiochemical analyses were dried at 105° for 24 hours and pulverized in a jar mill prior to analysis. Particle-size analysis was conducted using the pipette method (Gee, G. W. and J. W. Bauder, 1986, Particle-size Analysis. In Klute, A. (ed.), *Methods of Soil Analysis. Part I. Physical and Mineralogical Methods-Agronomy Monograph No. 9.* American Society of Agronomy, Madison, WI).

Surface water was collected at one location within each reservoir in 1999 and 2000. The surface water samples were collected in the same general area as the sediment samples. At each sampling location, one sample was collected from the surface (~ 0.5 to 1 m depth) and a second sample from approximately 0.5 to 1 m above the sediment bed.

In the laboratory, surface water samples collected for radiological analyses were vacuum-filtered to 0.2 μm and acidified with HNO_3 to a pH < 2. A 3-L aliquot was removed for analysis of alpha and gamma-emitting radionuclides. Alpha-emitting radionuclides analyzed in surface water and sediment samples included ^{241}Am, ^{238}Pu, ^{239,240}Pu, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, ^{235}U, and ^{238}U. Gamma-emitting radionuclides included ^{228}Ac, ^{241}Am ^{7}Be, ^{212}Bi, ^{213}Bi, ^{214}Bi, ^{144}Ce, ^{249}Cf, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{40}K, ^{233}Pa, ^{234m}Pa, ^{212}Pb, ^{214}Pb, ^{106}Rh, ^{125}Sb, and ^{208}Tl.

Surface water samples collected for elemental analyses (1-L each) were prepared according to the applicable EPA standard methods for the instrumentation used. Inorganic analyses were determined by IC, ICP-MS and AAS, with methods described elsewhere in this report. Inorganic analytes included Ag, Al, As, Ba, Be, Ca, Cd, Ce, Co, Cr, Cu, Dy, Er, Eu, Fe, Gd, Hg, K, La, Li, Mg, Mn, Mo, Na, Nd, Ni, Pb, Pr, Sb, Sc, Se, Sm, Sn, Sr, Th, Ti, Tl, U, V, Zn, chloride, fluoride, nitrate, phosphate and sulfate.

Results and Discussion

Comparison of Baseline and Monitoring Phase Radiological Analyses of Surface Water

Activity concentrations measured for ^{241}Am, ^{238}Pu, and $^{239,\ 240}$Pu were below the respective MDCs for each analyte in all filtered surface water samples collected in 1998, 1999 and 2000 from all three reservoirs. MDC ranges for CEMRC analyses were 0.049-0.105 mBq L^{-1} for ^{241}Am, 0.047-0.239 mBq L^{-1} for ^{238}Pu, and 0.030-0.168 mBq L^{-1} for ^{239,240}Pu. Unfiltered surface water samples collected in Brantley Lake and Red Bluff Reservoir in 1998 were analyzed by Los Alamos National Laboratory for ^{239}Pu using thermal ionization mass spectroscopy (TIMS). ^{239}Pu was not detected at MDC's of 1.3 μBq L^{-1} for the Brantley Lake sample and 2.2 μBq L^{-1} for the Red Bluff Reservoir sample.

In comparison, a detectable quantity of ^{241}Am (2.56 mBq L^{-1}) was reported by Westinghouse Waste Isolation Division (WID) in a surface water sample having a high level of suspended sediment that was collected from the Pecos River near Artesia in 1997 (approximately 65 km northwest of WIPP) (1998, *Waste Isolation Pilot Plant Annual Site Environmental Report Calendar Year 1997,* DOE/WIPP 98-2225). A higher ^{241}Am value of 3.05 mBq L^{-1} was reported for a sample collected from the Pecos River near Carlsbad during 1993-1995 by EEG (Kenny et al., 1998, *Preoperational Radiation Surveillance of the WIPP Project by EEG during 1993 through 1995*, EEG-67).

A detectable quantity of ^{238}Pu was reported by WID for a surface water sample collected from a stock tank approximately 16 km southwest of the WIPP in 1998 (1.07 mBq L^{-1}) (1999, *Waste Isolation Pilot Plant Site Environmental Report for 1998*, DOE/WIPP 99-2225). The same sample contained an activity concentration for ^{241}Am of 1.66 mBq L^{-1}. It was noted in the WID report that this sample had a high level of suspended sediment. In contrast to CEMRC and EEG sampling procedures, WID did not filter surface water samples. The inclusion of suspended sediment could possibly be a source of the ^{241}Am and ^{238}Pu occasionally detected in WID samples, but this does not explain the ^{241}Am observation by EEG (Kenny et al., *op. cit.*). ^{241}Am and ^{238}Pu were not detected in surface water samples collected by WID in 1999 (2000, *Waste Isolation Pilot Plant 1999 Site Environmental Report*, DOE/WIPP 00-2225). MDCs were not presented for the cited ^{241}Am values reported by EEG, and MDCs were only presented for the most recent ^{241}Am and ^{238}Pu values reported by WID. However, the observed values for both radioisotopes are at least 20 times higher than MDCs achieved for surface water samples analyzed by CEMRC, so any similar activity concentrations in CEMRC samples would have been easily detectable.

Maximum activity concentrations for ^{234}U, ^{235}U and ^{238}U (Table 12) increased in the monitoring phase ($N \leq 4$) relative to the baseline phase ($N \leq 2$) for samples collected from Brantley Lake and Lake Carlsbad, but a similar trend was not apparent in the Red Bluff samples. The activity concentration ranges for the same isotopes across lakes, by year (Fig. 24) ($N \leq 6$), showed no significant difference between baseline and monitoring phases, considering the 95% confidence intervals of the radioanalytical uncertainty. The lower activity concentrations (minimum values) measured for the baseline data may be the result of prolonged holding times for the baseline samples prior to analyses, during which adsorption of analytes to container walls may have occurred.

Activity concentrations reported by WID in surface waters for ^{234}U from 1997-1999 ranged from < MDC to 274 mBq L^{-1} (WID, 1997, *op. cit.*; WID, 1998, *op. cit.*; WID, 1999, *op. cit.*). A similar range for ^{234}U activity concentrations was reported by CEMRC for surface water samples from 1998-2000 ranging from 70 to 214 mBq L^{-1}. The upper ranges of values reported by CEMRC for ^{235}U and ^{238}U were also comparable to upper ranges reported for these analytes by WID. EEG did not include uranium radioisotopes among analytes measured in surface water samples collected during 1993-1999 (Kenny et al., 1998, *op. cit.*; Kenny et al., 1999, *Preoperational Radiation Surveillance of the WIPP Project by EEG from 1996-1998*, EEG-73; Gray et al., 2000, *Operational Radiation Surveillance of the WIPP Project by EEG during 1999*, EEG-79).

^{228}Th was detected in all surface water samples collected from 1998-2000. However, a positive bias is present in the reported ^{228}Th activity concentrations that results from the addition of a ^{232}U tracer during analyses. ^{232}Th was detected only in samples from Red Bluff Reservoir during the baseline phase and in samples from Brantley Lake and Red Bluff Reservoir during the monitoring phase.

For surface water samples collected during May and June of 2000, ^{40}K was the only gamma-emitting radionuclide determined at activity concentrations above MDC, and it was only detected in samples from Red Bluff Reservoir (1.22–1.26 Bq L^{-1}). These levels were not significantly different from those determined in samples collected in 1998.

Comparison of Gamma-emitting Radionuclides in Baseline and Monitoring Phase Sediment Samples

Sediment samples collected from three regional reservoirs during 1998-2000 were analyzed by gamma spectroscopy for ^{228}Ac, ^{241}Am, ^{7}Be, ^{212}Bi, ^{213}Bi, ^{214}Bi, ^{144}Ce, ^{249}Cf, ^{60}Co, ^{134}Cs, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{40}K, ^{233}Pa, ^{234m}Pa, ^{212}Pb, ^{214}Pb, ^{106}Rh, ^{125}Sb and ^{208}Tl. Those analytes having activity concentrations < MDC in all samples included: ^{241}Am, ^{213}Bi, ^{144}Ce, ^{249}Cf, ^{60}Co, ^{134}Cs, ^{152}Eu, ^{154}Eu, ^{233}Pa, ^{106}Rh, and ^{125}Sb.

Comparison of minimum and maximum activity concentrations of gamma-emitting radionuclides determined for sediment samples collected during the monitoring phase (1999 and 2000) and baseline phase (spring and fall of 1998) reflected no increase in any of the analytes with the possible exception of ^{7}Be (Table 13). Activity concentrations of ^{7}Be were < MDC in all samples collected in 1998 and 2000. However, ^{7}Be was detected in 6 of the 12 sediment samples collected in 1999, with at least one sample in each reservoir having detectable activity. Activity concentrations were only slightly above the MDC in all 6 samples.

In most cases there were no significant differences among sampling periods for ^{137}Cs and ^{40}K (Figs. 25 and 26). However, activity concentrations for both analytes were substantially lower in Lake Carlsbad relative to Brantley Lake and Red Bluff Reservoir. Activity concentrations of ^{137}Cs for samples collected from Brantley Lake in 2000 were lower than in samples collected in the two sampling periods of 1998, demonstrating the magnitude of variation in ^{137}Cs that could be expected in future sampling. No analyses of comparable sediment samples for ^{137}Cs have been reported by WID or EEG.

Baseline Non-Radiological Analyses of Surface Water and Sediments

As no mixed (hazardous + radioactive) wastes had been received for deposition at the WIPP prior to collection of the 2000 samples, the data presented herein for inorganics represent a continuation of baseline characterization studies (1998, 1999, and 2000). Summaries for future sampling and analyses will include comparisons of monitoring phase data with baseline data.

To date, 18 surface water samples (six from each reservoir) have been analyzed for a suite of inorganic compounds (Ag, Al, As, Ba, Be, Ca, Cd, Ce, Co, Cr, Cu, Dy, Er, Eu, Fe, Gd, Hg, K, La, Li, Mg, Mn, Mo, Na, Nd, Ni, Pb, Pr, Sb, Sc, Se, Sm, Sn, Sr, Th, Ti, Tl, U, V, Zn, chloride, fluoride, nitrate, phosphate and sulfate). The majority of analytes were detected in each of the samples collected from each sampling period with the exceptions of Ag, Be, Cd, Hg, Sn, Tl, nitrate, and phosphate (Table 14). Be was detected in samples collected from Red Bluff Reservoir but not in Lake Carlsbad or Brantley Lake. Nitrates were detected in Lake Carlsbad and Red Bluff Reservoir but not in Brantley Lake. Hg has not been detected in Lake Carlsbad to date, but was measured above detection limits in Brantley Lake and Red Bluff Reservoir.

To date, 36 sediment samples (12 from each reservoir) have been analyzed for the same suite of inorganic constituents as surface water samples. Most of the analytes were detected in all of the sediment samples from the three reservoirs (Table 15) with the exceptions of fluoride, nitrate and phosphate. Analyses of fluoride failed because of interference of soluble organics extracted from the sediments. As was the case with surface water, nitrate was detected in sediments from Lake Carlsbad and Red Bluff Reservoir, but not in Brantley Lake. Phosphate was detected in Lake Carlsbad sediments, but not in any samples from Brantley Lake or Red Bluff Reservoir.

Particle-size analyses for sediment samples collected in 2000 illustrate the fine particle-size nature of the sediment in the deep basin of each reservoir (Fig. 27). The maximum sand fraction in Brantley Lake and Red Bluff Reservoir was 2.7%. Lake Carlsbad ranged in sand content from 2.3% to 23.6%. The variation in clay content among the lake sediments was more extreme. Sediments from Brantley Lake had the highest clay composition (66.1%-71.3%). Sediments from Red Bluff Reservoir were intermediate in clay (40.3%-48.5%), while Lake Carlsbad sediments had the lowest clay contents (25.2%-29.0%). The coarse nature of the sediments from Lake Carlsbad might be expected considering the relatively shallow depths from which the sediments were collected in this reservoir (3.0 to 3.4 m). The sediment sampling depths from Brantley Lake and Red Bluff Reservoir are substantially deeper (12.2 to 13.3 m and 12.3 to 12.6 m, respectively). As Brantley Lake and Red Bluff Reservoir are both substantially larger and deeper than Lake Carlsbad, it would be expected that a higher degree of particle segregation would occur in the deep basins of these water bodies.

The contrast in clay content of Lake Carlsbad relative to Brantley Lake and Red Bluff Reservoir follows the general pattern of activity concentrations of ^{137}Cs and ^{40}K previously noted, with the exception of ^{137}Cs activity concentrations observed in Brantley Lake. A significant positive correlation ($r = 0.87$, $p < 0.001$) was observed between ^{40}K activity concentration (a naturally occurring radioisotope) and percent clay in samples from all three reservoirs, but there was no significant correlation between percent clay and activity concentration of ^{137}Cs (a nuclear fission product). However, if samples from Brantley Lake are excluded, there is a significant positive correlation ($r = 0.96$, $p < 0.001$) between percent clay and ^{137}Cs in samples from the other two lakes. These patterns may result at least partially from the differences in age and history of the reservoirs. Lake Carlsbad and Red Bluff Reservoir have been receiving sediment throughout the nuclear era, while Brantley Lake is relatively new, and has been receiving nuclear-era sediment for only approximately 10 years. However, Brantley Lake has received some level of sediment input via the breached dam of an adjacent older reservoir (McMillan) that predated the nuclear era by 50 years (constructed in 1893). Thus Brantley Lake sediments may incorporate a large pre-nuclear age sediment contribution that would be free of ^{137}Cs, thus diluting the representation of this radioisotope. An association between fine particulates and radionuclides has also been observed in soil samples (CEMRC 1999 Report and this report).

Comparison of baseline to monitoring phase levels of radionuclides in surface water and sediment samples collected within the Pecos River valley revealed no detectable increases above those typical of natural variation. The saline nature of Red Bluff Reservoir relative to Brantley Lake and Lake Carlsbad is apparent from the elevated concentrations of inorganic constituents as well as radionuclides determined in surface water samples. This pattern of salinity is not apparent in sediments, but the association of some radionuclides with higher clay content is clear.

Tables presenting the surface water and sediment data summarized herein are available on the CEMRC web site at http://www.cemrc.org.

Table 12. Range of Activity Concentrations for Uranium Isotopes in Surface Water Samples Collected from Three Regional Reservoirs during 1998 - 2000

Analyte	Activity Concentration ($Bq\ L^{-1}$)					
	1998 - Baseline			1999 & 2000 - Monitoring		
	[a]N	[b]Min	[c]Max	N	Min	Max
	Brantley Lake					
^{234}U	2	6.99E-02	7.54E-02	4	1.06E-01	1.68E-01
^{235}U	2	1.83E-03	1.94E-03	4	2.80E-03	4.88E-03
^{238}U	2	3.80E-02	3.89E-02	4	5.32E-02	7.86E-02
	Lake Carlsbad					
^{234}U	2	1.13E-01	1.16E-01	4	1.19E-01	1.88E-01
^{235}U	2	2.69E-03	2.74E-03	4	2.65E-03	5.03E-03
^{238}U	2	5.66E-02	5.71E-02	4	5.55E-02	9.10E-02
	Red Bluff Reservoir					
^{234}U	2	2.13E-01	2.14E-01	4	1.42E-01	2.04E-01
^{235}U	2	5.56E-03	5.78E-03	4	3.25E-03	6.44E-03
^{238}U	2	1.06E-01	1.06E-01	4	7.09E-02	1.01E-01

[a] N = number of samples; only samples > MDC included in calculations
[b] Min = minimum activity concentration above MDC
[c] Max = maximum activity concentration above MDC

Table 13. Range of Activity Concentrations for Selected Gamma-Emitting Radionuclides in Sediment Samples Collected from Three Regional Reservoirs during 1998 - 2000

Radionuclide	**Activity Concentration (Bq g^{-1})**					
	1998 - Baseline			**1999 & 2000 - Monitoring**		
	[a]N	**[b]Min**	**[c]Max**	**N**	**Min**	**Max**
	Brantley Lake					
^{228}Ac	8	3.21E-02	4.76E-02	8	2.73E-02	4.13E-02
^{7}Be	0	[d] < MDC	< MDC	2	1.14E-02	1.54E-02
^{212}Bi	8	3.32E-02	4.97E-02	8	2.92E-02	4.41E-02
^{214}Bi	8	2.70E-02	4.20E-02	8	1.92E-02	2.86E-02
^{137}Cs	8	7.33E-03	9.00E-03	8	4.80E-03	9.00E-03
^{40}K	8	4.72E-01	6.21E-01	8	3.90E-01	5.41E-01
^{234m}Pa	3	4.20E-02	4.44E-02	3	4.09E-02	7.62E-02
^{212}Pb	8	3.19E-02	4.56E-02	8	2.84E-02	3.83E-02
^{214}Pb	8	2.82E-02	4.40E-02	8	2.04E-02	2.95E-02
^{208}Tl	8	1.01E-02	1.42E-02	8	8.77E-03	1.24E-02
	Lake Carlsbad					
^{228}Ac	8	1.70E-02	2.76E-02	8	1.68E-02	2.48E-02
^{7}Be	0	< MDC	< MDC	4	8.07E-03	2.46E-02
^{212}Bi	8	1.52E-02	2.92E-02	8	1.61E-02	2.86E-02
^{214}Bi	8	1.94E-02	2.87E-02	8	1.85E-02	2.76E-02
^{137}Cs	8	2.48E-03	5.19E-03	8	3.06E-03	5.00E-03
^{40}K	8	2.75E-01	4.51E-01	8	2.90E-01	4.29E-01
^{234m}Pa	0	< MDC	< MDC	0	< MDC	< MDC
^{212}Pb	8	1.63E-02	2.58E-02	8	1.59E-02	2.48E-02
^{214}Pb	8	1.93E-02	2.80E-02	8	1.93E-02	2.76E-02
^{208}Tl	8	5.04E-03	8.28E-03	8	4.80E-03	7.99E-03
	Red Bluff Reservoir					
^{228}Ac	8	2.33E-02	3.38E-02	8	2.69E-02	3.41E-02
^{7}Be	0	< MDC	< MDC	1	1.01E-02	1.01E-02
^{212}Bi	8	2.54E-02	3.91E-02	8	2.69E-02	4.22E-02
^{214}Bi	8	2.48E-02	3.46E-02	8	2.69E-02	3.50E-02
^{137}Cs	8	4.88E-03	1.11E-02	8	8.08E-03	9.78E-03
^{40}K	8	4.08E-01	4.55E-01	8	4.22E-01	4.76E-01
^{234m}Pa	4	5.04E-02	1.00E-01	6	4.41E-02	7.21E-02
^{212}Pb	8	1.99E-02	3.50E-02	8	2.73E-02	3.38E-02
^{214}Pb	8	2.56E-02	3.59E-02	8	2.79E-02	3.55E-02
^{208}Tl	8	6.96E-03	1.07E-02	8	8.70E-03	1.12E-02

[a] N = number of samples; only samples > MDC included in calculations
[b] Min = minimum sample concentration above MDC
[c] Max = maximum sample concentration above MDC
[d] MDC = minimum detectable concentration

Table 14. Range of Concentrations for Baseline Inorganic Constituents in Surface Water Samples Collected during 1998 - 2000 from Three Regional Reservoirs

Analyte	Concentration (mg L^{-1})								
	Brantley Lake			Lake Carlsbad			Red Bluff Reservoir		
	[a]N	[b]Min	[c]Max	N	Min	Max	N	Min	Max
Ag	1	1.11E-05	1.11E-05	0	[d]< MDL	< MDL	0	< MDL	< MDL
Al	5	5.20E-02	4.89E-01	6	6.65E-02	3.77E-01	2	1.91E-02	6.53E-02
As	6	1.09E-03	7.43E-03	6	1.11E-03	2.37E-03	6	1.77E-03	4.97E-03
Ba	6	1.91E-02	7.50E-02	6	1.75E-02	3.36E-02	6	4.69E-02	9.57E-02
Be	0	< MDL	< MDL	0	< MDL	< MDL	3	3.29E-05	5.96E-05
Ca	6	8.69E+01	5.00E+02	6	2.06E+02	3.34E+02	6	2.90E+02	4.98E+02
Cd	0	< MDL	< MDL	1	8.99E-05	8.99E-05	0	< MDL	< MDL
Ce	5	3.61E-05	4.63E-04	4	8.08E-05	4.16E-04	4	3.93E-05	9.77E-05
Co	6	1.64E-04	6.75E-03	6	1.67E-03	1.18E-02	6	1.38E-03	6.01E-03
Cr	4	6.27E-04	2.08E-03	4	6.12E-04	2.19E-03	5	4.59E-04	2.24E-03
Cu	4	4.69E-03	8.06E-03	6	2.59E-03	1.13E-02	6	6.73E-03	8.70E-03
Dy	4	5.79E-06	2.40E-05	4	6.67E-06	3.51E-05	2	4.01E-06	4.13E-06
Er	3	3.52E-06	2.16E-05	3	9.19E-06	1.51E-05	3	2.08E-06	8.33E-06
Eu	6	5.60E-06	3.35E-05	4	6.54E-06	1.81E-05	6	1.45E-05	3.43E-05
Fe	5	5.30E-02	3.68E-01	6	7.60E-02	3.96E+00	3	6.40E-02	8.23E-02
Gd	4	7.34E-06	5.26E-05	4	9.10E-06	4.84E-05	6	4.22E-06	1.51E-05
Hg	1	3.60E-07	3.60E-07	0	< MDL	< MDL	2	2.36E-07	2.72E-07
K	6	1.30E+00	7.65E+00	5	5.31E+00	6.55E+00	6	1.70E+01	2.67E+01
La	4	1.95E-05	1.82E-04	2	4.29E-05	2.21E-04	5	2.84E-05	7.40E-05
Li	5	5.89E-03	7.76E-02	3	6.01E-02	7.75E-02	6	5.14E-02	9.47E-02
Mg	6	1.68E+01	1.63E+02	6	7.31E+01	1.51E+02	6	1.12E+02	1.82E+02
Mn	5	3.61E-03	6.55E-01	5	1.84E-02	6.65E-02	6	1.22E-02	2.72E-01
Mo	6	1.07E-03	3.83E-03	6	1.17E-03	3.36E-03	6	3.00E-03	4.92E-03
Na	6	4.70E+01	8.85E+02	6	2.48E+02	4.48E+02	6	6.21E+02	1.20E+03
Nd	5	1.70E-05	2.18E-04	4	3.79E-05	2.31E-04	4	1.45E-05	3.12E-05
Ni	6	2.51E-03	2.91E-02	4	4.60E-03	2.28E-02	6	1.35E-02	2.87E-02
Pb	2	2.88E-04	6.78E-04	3	6.38E-04	2.65E-03	2	7.76E-04	9.74E-04
Pr	4	5.20E-06	5.87E-05	2	1.11E-05	5.66E-05	3	5.44E-06	8.10E-06
Sb	4	2.53E-04	4.40E-04	0	< MDL	< MDL	6	2.47E-04	6.58E-04
Sc	2	2.61E-03	4.00E-03	2	3.60E-03	3.88E-03	2	2.58E-03	2.63E-03
Se	2	2.83E-04	3.75E-04	4	4.66E-04	6.10E-04	3	8.85E-04	9.20E-04
Sm	4	7.57E-06	5.85E-05	2	1.69E-05	6.12E-05	4	2.26E-05	3.80E-05
Sn	0	< MDL	< MDL	0	< MDL	< MDL	0	< MDL	< MDL
Sr	6	1.00E+00	7.40E+00	6	3.07E+00	5.95E+00	6	4.59E+00	8.81E+00
Th	5	7.62E-06	8.69E-05	4	1.52E-05	6.01E-05	5	1.25E-05	1.97E-05
Ti	6	6.97E-02	7.70E-01	4	3.69E-01	5.45E-01	6	5.77E-01	7.90E-01
Tl	1	4.81E-05	4.81E-05	2	1.20E-04	1.35E-04	0	< MDL	< MDL
U	6	1.17E-03	7.93E-03	4	3.78E-03	9.17E-03	6	4.71E-03	9.50E-03

Table continued on next page

Table 14. Range of Concentrations for Baseline Inorganic Constituents in Surface Water Samples Collected during 1998 - 2000 from Three Regional Reservoirs (Cont.)

Analyte	**Concentration (mg L^{-1})**								
	Brantley Lake			**Lake Carlsbad**			**Red Bluff Reservoir**		
	[a]N	**[b]Min**	**[c]Max**	**N**	**Min**	**Max**	**N**	**Min**	**Max**
V	6	2.22E-03	5.90E-03	6	6.13E-03	9.30E-03	6	2.48E-03	5.65E-03
Zn	2	1.09E-02	1.12E-02	4	6.12E-03	1.73E-02	2	6.40E-03	1.09E-02
Chloride	6	5.25E+02	2.20E+03	6	6.81E+02	1.06E+03	6	1.61E+03	2.19E+03
Fluoride	6	1.54E+00	3.13E+00	6	1.49E+00	1.12E+00	4	4.05E-01	3.77E+00
Nitrate	0	< MDL	< MDL	6	4.95E+00	6.53E+00	1	2.38E+00	2.38E+00
Phosphate	0	< MDL	< MDL	0	< MDL	< MDL	1	5.68E+00	5.68E+00
Sulfate	6	1.35E+02	2.61E+03	6	1.37E+03	2.01E+03	6	2.33E+03	2.44E+03

[a] N = number of samples above MDL

[b] Min = minimum sample concentration above MDL

[c] Max = maximum sample concentration above MDL

[d] MDL = method detection limit

Table 15. Range of Concentrations for Baseline Inorganic Constituents in Sediment Samples Collected during 1998 - 2000 from Three Regional Reservoirs

Analyte	Concentration (mg kg^{-1})								
	Brantley Lake			Lake Carlsbad			Red Bluff Reservoir		
	[a]N	[b]Min	[c]Max	N	Min	Max	N	Min	Max
Ag	12	5.90E-02	9.44E-02	12	5.83E-02	1.22E-01	12	7.68E-02	1.11E-01
Al	12	1.86E+04	3.88E+04	12	7.64E+03	1.94E+04	12	1.20E+04	2.67E+04
As	12	3.94E+00	5.77E+00	12	2.36E+00	4.51E+00	12	4.39E+00	5.54E+00
Ba	12	1.82E+02	2.70E+02	12	1.12E+02	1.77E+02	12	2.33E+02	3.45E+02
Be	12	4.62E-01	1.54E+00	12	3.30E-01	8.87E-01	12	5.01E-01	8.92E-01
Ca	12	8.62E+04	1.70E+05	12	1.04E+05	2.29E+05	12	1.28E+05	2.04E+05
Cd	12	2.71E-01	4.32E-01	12	3.09E-01	7.58E-01	12	3.88E-01	4.89E-01
Ce	12	2.55E+01	3.93E+01	12	1.30E+01	2.59E+01	12	1.90E+01	3.20E+01
Co	12	7.28E+00	1.09E+01	12	3.00E+00	6.43E+00	12	6.27E+00	7.53E+00
Cr	12	1.67E+01	3.32E+01	12	9.11E+00	2.39E+01	12	1.08E+01	2.53E+01
Cu	12	1.33E+01	1.72E+01	12	1.00E+01	2.28E+01	12	1.15E+01	1.88E+01
Dy	12	1.32E+00	2.61E+00	12	8.07E-01	1.91E+00	12	1.11E+00	2.59E+00
Er	12	6.30E-01	1.27E+00	12	3.96E-01	9.74E-01	12	5.40E-01	1.35E+00
Eu	12	5.28E-01	1.33E+00	12	2.89E-01	7.63E-01	12	4.24E-01	1.13E+00
Fe	12	1.60E+04	2.57E+04	12	7.53E+03	1.72E+04	12	1.26E+04	1.94E+04
Gd	12	2.36E+00	6.65E+00	12	1.32E+00	3.96E+00	12	1.89E+00	5.33E+00
Hg	12	1.17E-02	2.47E-02	12	2.24E-02	6.00E-02	12	1.75E-02	3.54E-02
K	12	3.42E+03	8.72E+03	12	1.70E+03	4.68E+03	12	2.93E+03	7.95E+03
La	12	1.24E+01	1.97E+01	12	6.91E+00	1.33E+01	12	1.00E+01	1.52E+01
Li	12	1.79E+01	3.08E+01	12	8.06E+00	2.28E+01	12	1.12E+01	2.66E+01
Mg	12	1.26E+04	2.34E+04	12	9.81E+03	1.95E+04	12	1.01E+04	1.24E+04
Mn	12	4.05E+02	6.97E+02	12	2.59E+02	4.81E+02	12	4.04E+02	5.33E+02
Mo	12	9.50E-01	1.69E+00	8	4.43E-01	1.08E+00	12	8.59E-01	3.14E+00
Na	12	1.38E+03	6.04E+03	12	1.07E+03	5.64E+03	12	3.79E+03	8.19E+03
Nd	12	1.25E+01	2.19E+01	12	6.86E+00	1.42E+01	12	1.08E+01	1.85E+01
Ni	12	2.11E+01	3.87E+01	12	1.19E+01	3.86E+01	12	1.75E+01	3.86E+01
Pb	12	9.94E+00	1.64E+01	12	9.53E+00	4.41E+01	12	9.37E+00	1.63E+01
Pr	12	3.35E+00	5.93E+00	12	1.78E+00	3.82E+00	12	2.70E+00	4.84E+00
Sb	9	6.63E-02	2.23E-01	8	6.74E-02	2.34E-01	8	8.13E-02	1.73E-01
Sc	4	2.13E+00	2.22E+00	4	1.49E+00	3.03E+00	4	3.80E+00	4.03E+00
Se	12	1.07E+00	2.51E+00	12	1.25E+00	2.87E+00	12	1.90E+00	2.83E+00
Sm	12	2.56E+00	4.87E+00	12	1.41E+00	3.09E+00	12	2.06E+00	4.23E+00
Sn	4	1.52E+00	1.72E+00	4	1.28E+00	3.75E+00	4	1.34E+00	5.43E+00
Sr	12	3.76E+02	7.76E+02	12	3.83E+02	9.00E+02	12	2.84E+02	7.50E+02
Th	12	2.34E+00	8.09E+00	12	1.31E+00	4.70E+00	12	2.13E+00	6.44E+00
Ti	12	1.44E+02	3.90E+02	12	2.27E+02	4.20E+02	12	2.68E+02	5.50E+02
Tl	7	1.26E-01	1.78E+00	8	3.31E-01	1.96E+00	4	3.27E-01	4.08E-01

Table continued on next page

Table 15. Range of Concentrations for Baseline Inorganic Constituents in Sediment Samples Collected during 1998 - 2000 from Three Regional Reservoirs (Cont.)

Analyte	Concentration (mg kg^{-1})								
	Brantley Lake			Lake Carlsbad			Red Bluff Reservoir		
	[a]N	[b]Min	[c]Max	N	Min	Max	N	Min	Max
U	12	1.29E+00	2.27E+00	12	9.18E-01	1.89E+00	12	1.66E+00	4.13E+00
V	12	2.92E+01	4.68E+01	12	1.57E+01	3.23E+01	12	2.27E+01	4.04E+01
Zn	12	4.84E+01	6.61E+01	12	5.62E+01	1.28E+02	12	4.47E+01	1.08E+02
Chloride	12	1.57E+03	1.18E+04	12	7.20E+02	1.07E+04	12	3.76E+03	1.80E+04
Fluoride	0	[d] < MDL	< MDL	0	< MDL	< MDL	0	< MDL	< MDL
Nitrate	0	< MDL	< MDL	4	2.70E+00	1.25E+02	4	1.93E+01	1.02E+02
Phosphate	0	< MDL	< MDL	3	5.99E+00	2.99E+01	0	< MDL	< MDL
Sulfate	12	4.03E+03	1.13E+04	12	1.80E+03	2.45E+04	12	6.09E+03	1.29E+04

[a]N = number of samples above MDL
[b]Min = minimum sample concentration above MDL
[c]Max = maximum sample concentration above MDL
[d]MDL = method detection limit

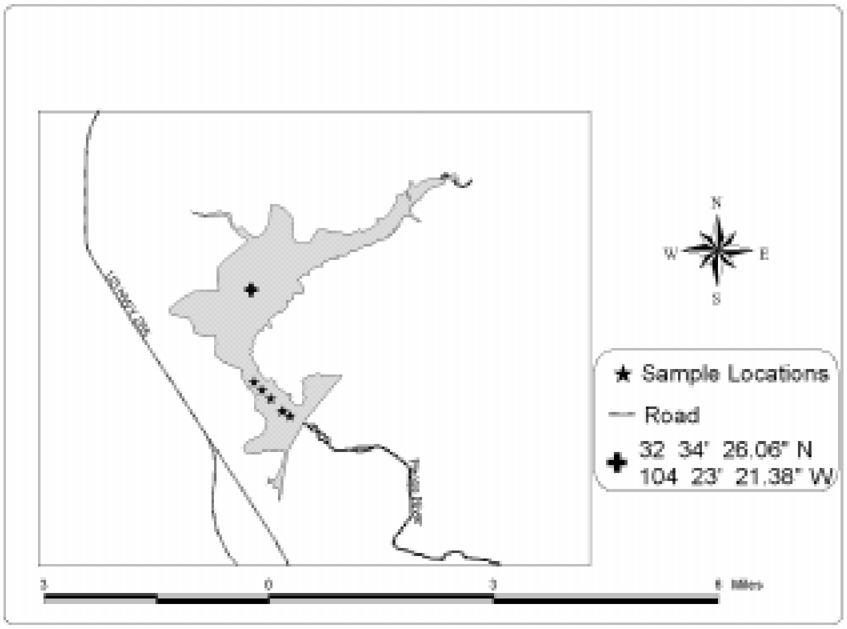

Figure 21. Surface Water and Sediment Sampling Locations at Brantley Lake

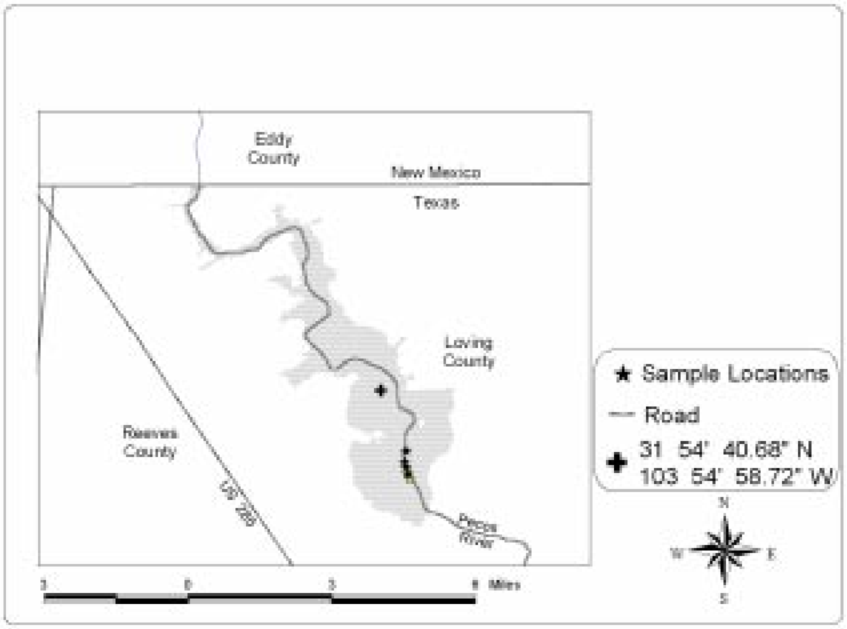

Figure 22. Surface Water and Sediment Sampling Locations at Red Bluff Reservoir

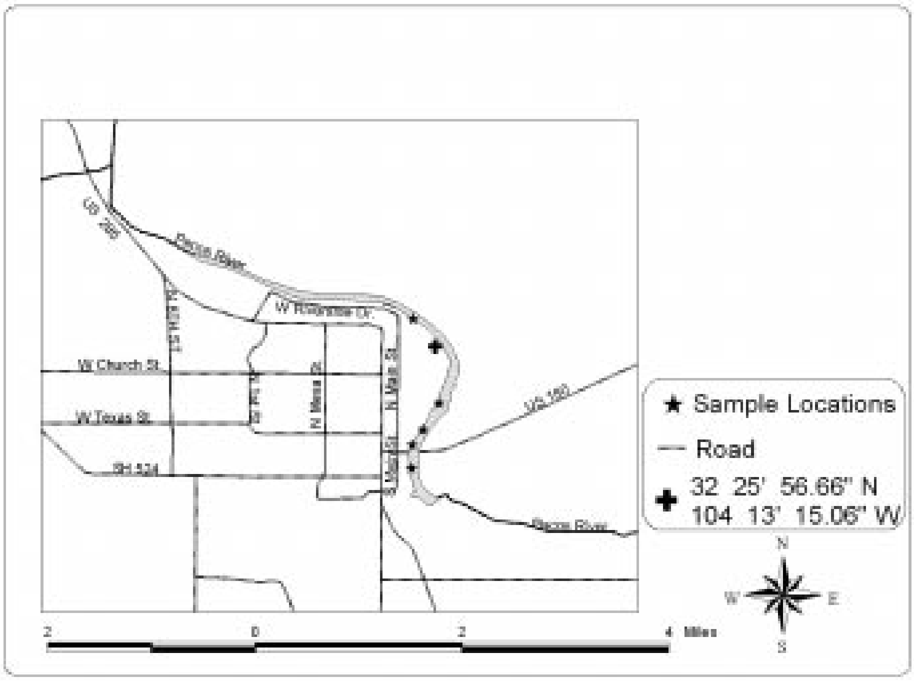

Figure 23. Surface Water and Sediment Sampling Locations at Lake Carlsbad

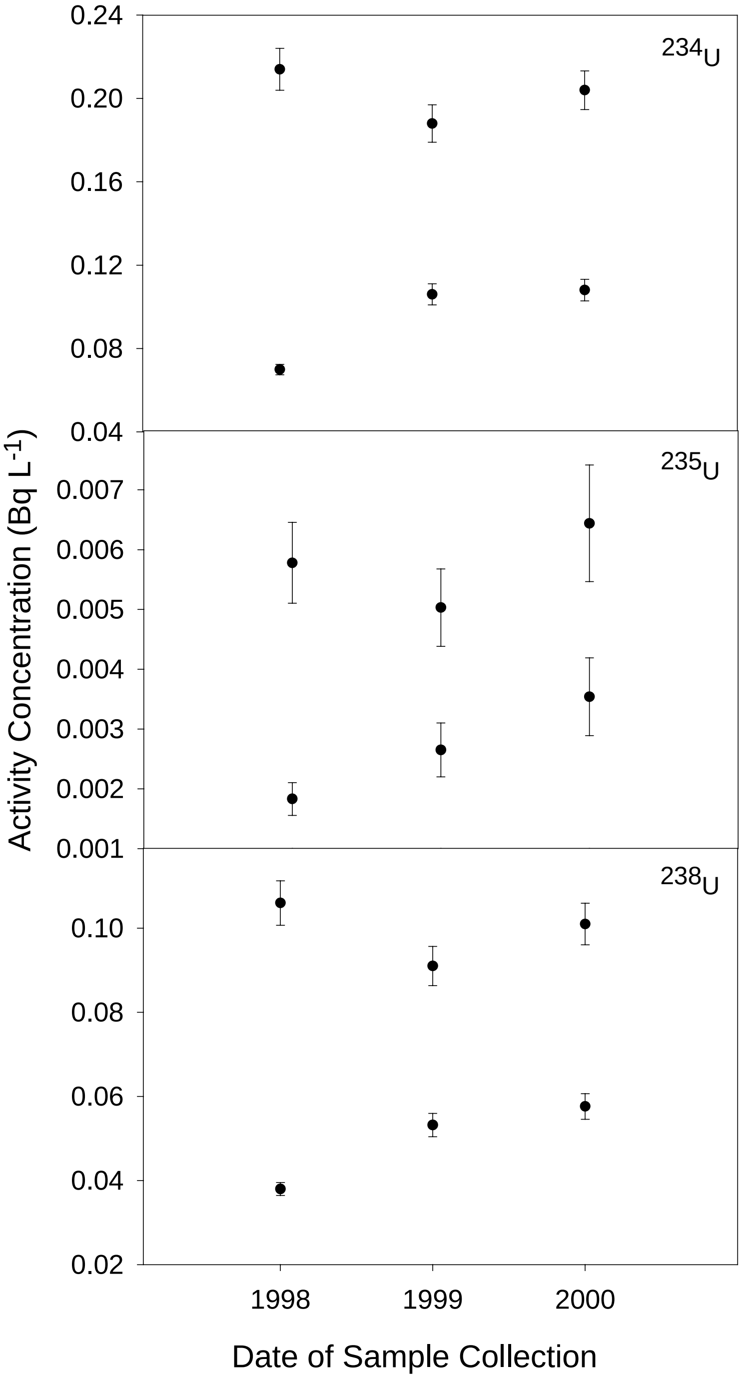

Figure 24. Range in Activity Concentrations for Uranium Isotopes in Surface Water Samples Collected from Three Regional Reservoirs during 1998 - 2000

Error bars represent the total radioanalytical uncertainty at the 95% confidence interval.

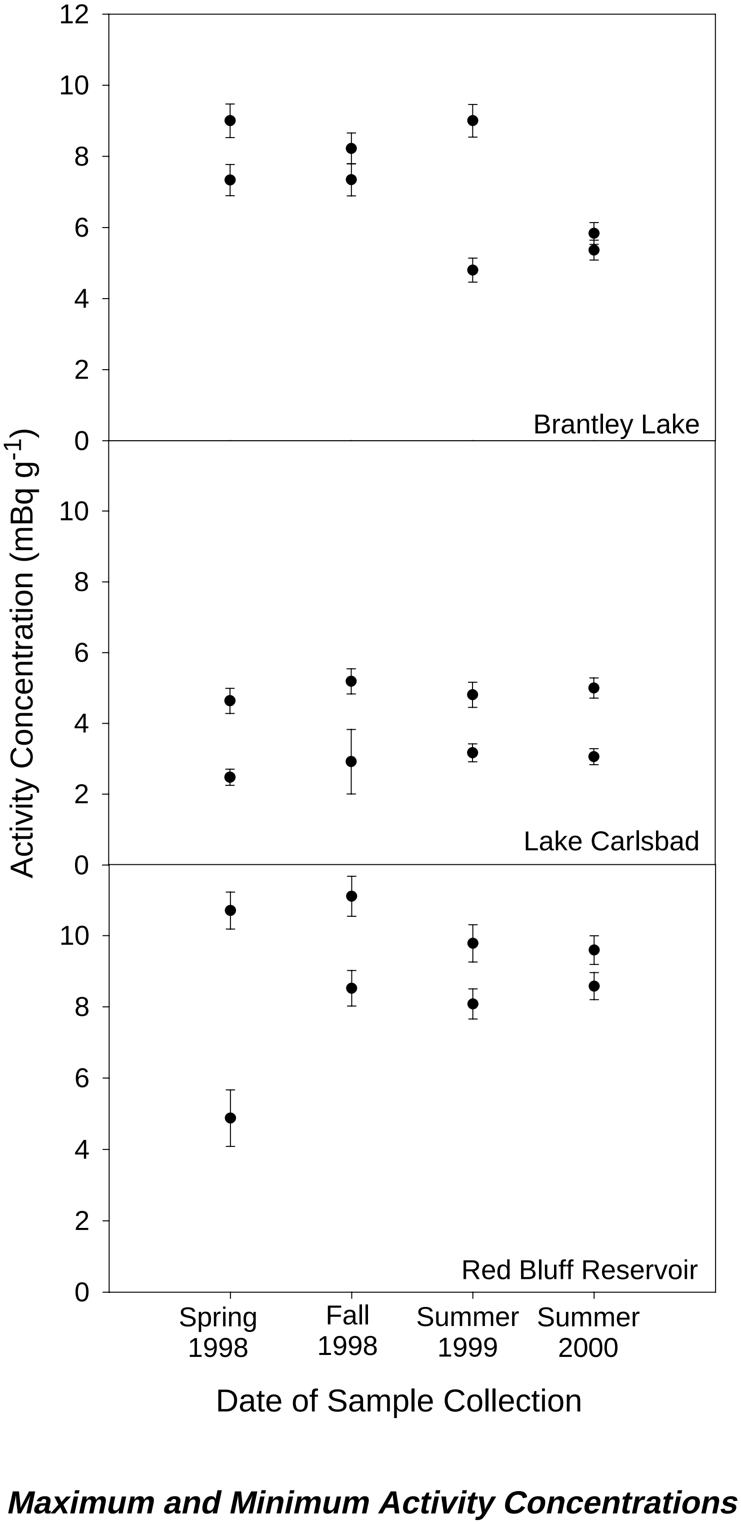

Figure 25. Maximum and Minimum Activity Concentrations for ^{137}Cs in Sediment Samples Collected from Three Regional Reservoirs during 1998 - 2000

Error bars represent the total radioanalytical uncertainty at the 95% confidence interval.

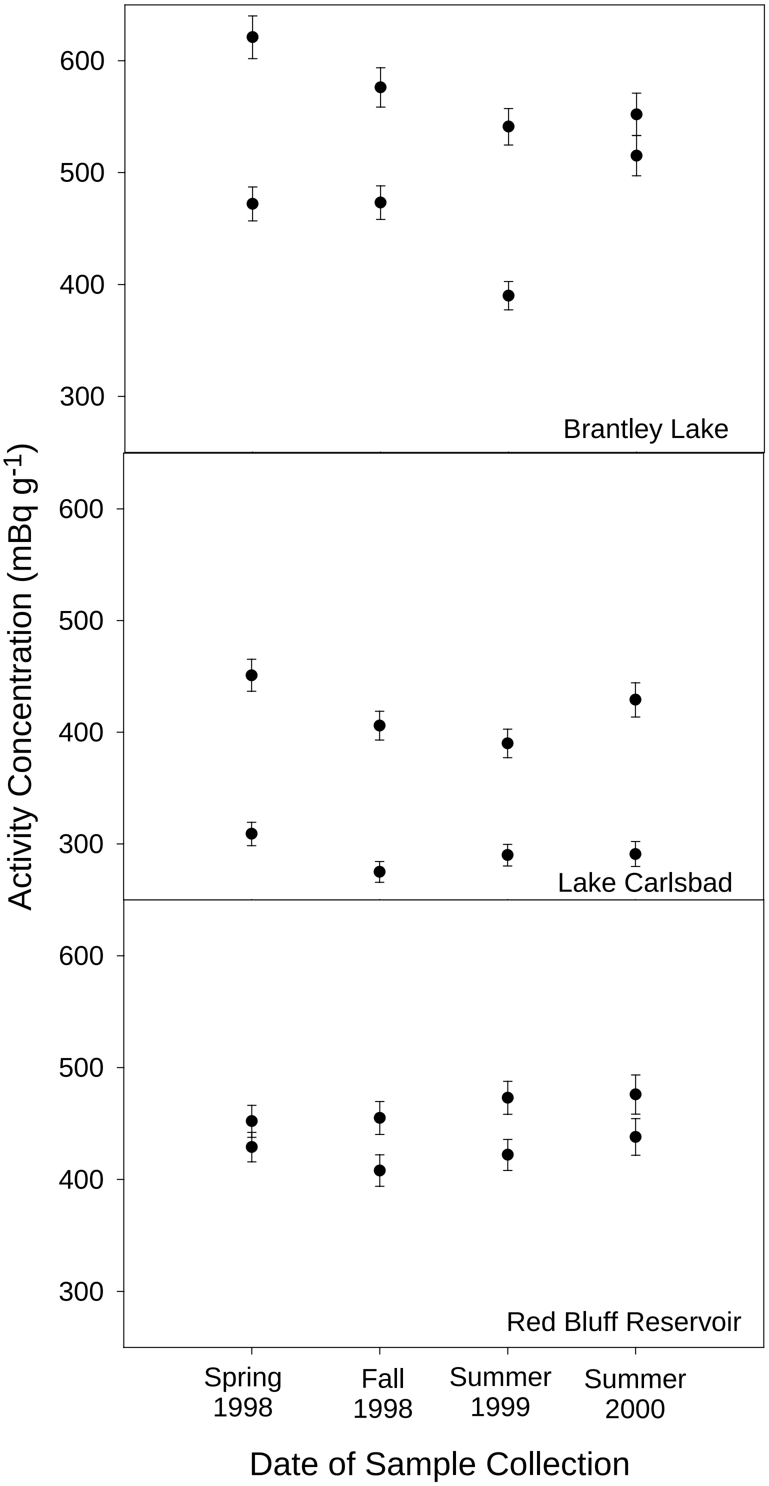

Figure 26. Maximum and Minimum Activity Concentrations for ^{40}K in Sediment Samples Collected from Three Regional Reservoirs during 1998 - 2000

Error bars represent the total radioanalytical uncertainty at the 95% confidence interval.

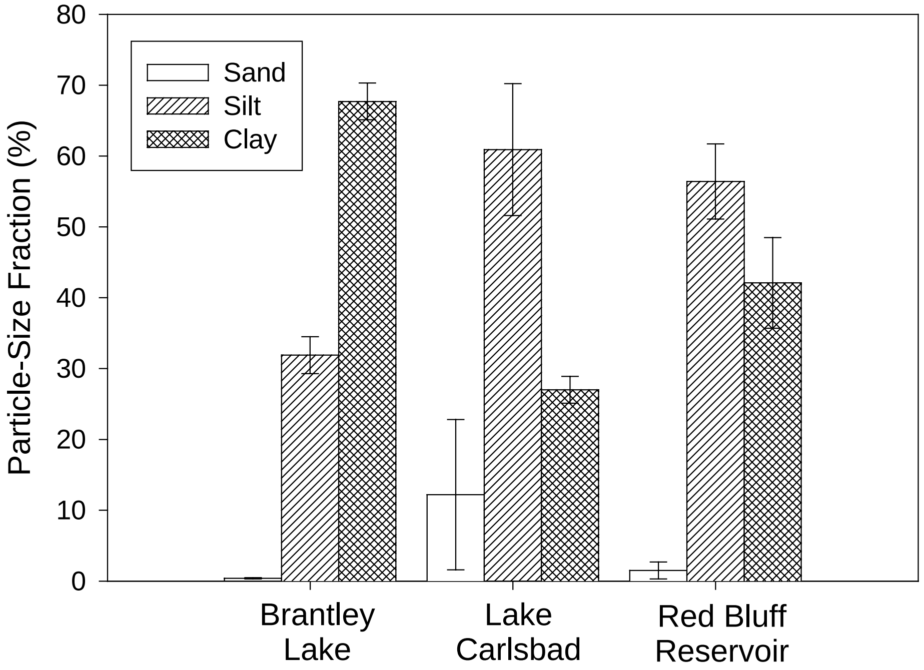

Figure 27. Mean Particle-Size Fractions for Sediment Samples Collected in 2000 from Three Regional Reservoirs

Lines bracket ranges in particle-size fraction among the four individual samples from each reservoir.

Radionuclides and Inorganics in Selected Drinking Water Sources

Introduction

The water wells in the immediate vicinity of the WIPP site provide water primarily for livestock, industrial usage by oil and gas production operations, and monitoring studies conducted by various groups. In March 2000, water samples were collected for CEMRC environmental monitoring studies from six sources in the region of the WIPP. The sources included the community water supplies of Carlsbad, Loving, Otis, and Hobbs; the water supply for the WIPP site (Double Eagle); and one private well.

Aquifers in the region surrounding the WIPP include Dewey Lake, Culebra-Magenta, Ogalalla, Dockum, Pecos River alluvium and Capitan Reef. The main Carlsbad water supply is the Sheep Draw well field whose primary source is the Capitan Reef aquifer. The Hobbs and WIPP-Double Eagle water supplies are drawn from the Ogalalla aquifer, while the Loving/Malaga and Otis supply wells draw from deposits that are hydraulically linked to the flow of the Pecos River. The source for the sampling site designated as Private Well #2 is a well seven miles southwest of the WIPP; this water is drawn from the Culebra aquifer.

The 2000 drinking water samples were collected after WIPP began receiving radioactive waste (March 1999), but before the WIPP began receiving mixed waste (September 2000). Therefore, this summary represents monitoring phase data for radionuclides in drinking water but continues the baseline phase for non-radiological constituents.

CEMRC began collecting drinking water samples in 1997, and summaries of methods, data and results from previous sampling were reported in the CEMRC 1997, 1998 and 1999 reports (available at http://www.cemrc.org). The results of previous analyses of drinking water were generally consistent for each source across sampling periods, with few organic contaminants detected and inorganic substances mostly below levels specified under the Safe Drinking Water Act.

Methods

All 2000 samples were collected according to EPA protocols for the collection, handling and preservation of drinking water as follows: (1) 4 L for radiological analyses, (2) 1 L for elemental analyses and (3) 1 L for anion tests. None of the samples were filtered before analysis, but a portion of the 4-L sample was transferred to a 3-L Marinelli beaker for gamma spectroscopy analyses. The 2000 samples were collected at the same six locations as the 1999 samples.

CEMRC performed non-radiological analyses of drinking water samples using IC, ICP-MS and AAS. Instrumentation, general methods and QA/QC results are presented in Appendix K. CEMRC did not test the 2000 drinking water samples for organic constituents because of low concentrations and consistent results in prior analyses performed by an external laboratory.

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

Results and Discussion

Radiological

No radionuclides were measured above MDC in 2000 samples as measured by gamma spectroscopy targeting 11 naturally occurring and 12 anthropogenic gamma-emitters. Four naturally occurring actinides (^{234}U, ^{235}U, ^{238}U, and ^{228}Th) were detected via alpha spectroscopy in all of the samples from each location. However, measured levels of ^{228}Th are considered largely an artifact of the use of ^{232}U as a tracer during the radioanalytical process. (^{232}U decays to ^{228}Th, resulting in a positive bias in ^{228}Th measurements).

The uranium isotope activity concentrations in 2000 water samples were quite similar to the 1999 and 1998 samples, with the greatest variations appearing in ^{235}U measurements. Measured values for samples collected during 2000 were 28-510 mBq L^{-1} for ^{234}U, 0.81-12 mBq L^{-1} for ^{235}U, and 11-200 mBq L^{-1} for ^{238}U. Across all years, the highest levels of all three uranium isotopes were measured in samples from Private Well #2, and lowest levels were measured in samples from Carlsbad (Table 16). Across all years, ^{234}U concentrations were 3.2-3.4 times greater than ^{238}U in samples from Loving, and 2.4-2.8 times greater in samples from the other five drinking water sources. Enrichment of ^{234}U at these levels is common in drinking water produced from underground sources (Eisenbud, M. and T. Gesell, 1997, *Environmental Radioactivity*, Academic Press, San Diego).

For ^{235}U, the levels measured in 2000 were higher than in both 1998 and 1999 (3-27%) for samples from Carlsbad, Double Eagle and Otis, and higher than the 1998 sample from Hobbs. Similar or lower levels of ^{235}U were measured in 2000 samples from Loving and Private Well #2 as compared to samples from 1998. For ^{234}U, the 2000 samples from Hobbs, Loving and Otis were higher than levels measured in 1998. For Carlsbad, Double Eagle, and Private Well #2, the ^{234}U levels measured in 2000 samples were lower (2-15%) than in 1998 and 1999 samples. For ^{238}U, the 2000 samples from Double Eagle, Hobbs, Loving and Otis were higher (5-11%) than in 1998, but values for Carlsbad and Private Well #2 were lower (5-21%) than in 1998.

Excluding measurements from Private Well #2, the ranges and ratios of all three uranium isotopes measured in CEMRC samples during 1998-2000 were similar to values from 1992 samples from Carlsbad, Double Eagle and Loving reported by EEG (Kenny, J.W., 1994, *Preoperational Radiation Surveillance of the WIPP Project by EEG during 1992*, EEG-54). No comparable data for community drinking water sources have been generated in recent years by Westinghouse Waste Isolation Division (WID), the WIPP management and operating contractor. However, analyses have been reported by WID for samples from a single "fresh" water well near the WIPP site. In general, CEMRC values for ^{238}U and ^{234}U in samples from Private Well #2 are 60-120% higher, respectively, than those reported for the fresh water well samples collected during 1997-1999 by WID (1998, *Waste Isolation Pilot Plant Annual Site Environmental Report Calendar Year 1997*, DOE/WIPP 98-2225; 1999, *Waste Isolation Pilot Plant Site Environmental Report for 1998*, DOE/WIPP 99-2225; 2000, *Waste Isolation Pilot Plant 1999 Site Environmental Report*, DOE/WIPP 00-2225). With the exception of a measurement of 0.014 mBq L^{-1} for a 1998 sample, ^{235}U values reported by WID from this well are 3-4 times lower than for the nearest source tested by CEMRC (Private Well #2).

The levels and ratios measured by CEMRC for these naturally occurring radionuclides are typical of natural variations in ground water (Cothern, C.R. and W.L. Lappenbusch, 1983, *Health Physics* 45, 89; Luo et al., 2000, *Geochim. Cosmochim*. 64, 867), and agree well with the few directly comparable values reported from studies in the region. Overall the CEMRC measurements are more consistent through time for each source than the cited annual measurements reported by WID. It is important to note that the quantification of ^{235}U by alpha spectroscopy may be impacted by tailing from the ^{234}U spectral region. In particular, higher measured levels of ^{235}U that are accompanied by lower measured levels of ^{234}U (such as in the Carlsbad and Double Eagle samples) should therefore be interpreted with caution. As previously noted, values for samples collected in 1998 are believed to have been affected by storage of the samples for > 12 months prior to analyses. Despite acidification, such prolonged storage may have allowed U adsorption to the containers, producing a low bias in measured U.

Of the 18 uranium isotope measurements in 2000 samples, 11 were higher than in 1998 samples. Of these, only three values (^{238}U for

Double Eagle, Loving and Otis) were above 2 SD (counting error) of the matching 1998 value. The highest of these elevated ^{238}U values (0.052 mBq L^{-1} for ^{238}U in the Otis sample) is still less than half of the highest ^{238}U values reported by WID for the fresh water well near the WIPP site. Based on the comparisons as summarized, other relevant scientific information and results of analyses of other media reported herein, CEMRC concludes that the higher levels of some uranium isotopes in the 2000 drinking water samples from some sources represent a combination of natural variation and analytical artifact, and are not the result of releases from the WIPP.

Pu was not detected in any 2000 drinking water samples. Results of previous tests using thermal ionization mass spectrometry revealed no Pu in samples from the same six drinking water sources (reported in the CEMRC 1999 Report).

Non-Radiological Results

Measurements of inorganic analytes produced by CEMRC from the six drinking water sources showed little variation between years for each source. Differences of > 100% between one set of successive years at a single location have been recorded for Ag, Co, Cu, Pb, Th, Zn, nitrate and fluoride. For five inorganic analytes (Fe, La, Mn, Nd and Sb) differences > 100% in successive years have been recorded in samples from two or more sources.

With the exception of these instances, the 1998-2000 measurements exhibit a high level of consistency that provides a useful characterization of each source (Table 17). Private Well #2 exhibited the highest levels of Sr, Na, Mg, K, Cu, Co and Ca, and samples from Otis ranked second highest for measured levels of these analytes. Private Well #2 also had the highest levels of Zn and total U (measured by ICP-MS), while measured levels of Ba were lowest for Private Well #2 and Otis. Total nitrates (not reduced to N) were highest in samples from Otis (19-22 μg L^{-1}) and Loving (17-23 μg L^{-1}). Across all years, samples from Loving were highest in measured Pb levels (1.0-1.4 μg L^{-1}), while Hg was detected only in samples from Hobbs (0.009-0.014 μg L^{-1}). Measured As levels were highest in samples from Hobbs (5.6-6.5 μg L^{-1}) and Double Eagle (5.2-6.6 μg L^{-1}), and these measurements suggest that these drinking water sources would exceed any As standard $\leq$ 5 μg L^{-1} as has been recently considered for adoption by EPA.

As in previous years, measured levels of chloride and sulfate exceeded reference levels (secondary maximum contaminant levels) in the 2000 samples from Private Well #2 and Otis. Reference levels for Fe and Mn were also exceeded in the 2000 samples from Private Well #2.

These results are not appropriate for use in assessing of regulatory compliance, due to sample collection locations and other methodological details. However, it is noteworthy that the CEMRC results for Carlsbad and Double Eagle drinking water collected during 1998-2000 generally agreed well with measurements published by the City of Carlsbad Municipal Water System (*1999 Annual Consumer Report on the Quality of Tap Water; 1998 Annual Consumer Report on the Quality of Tap Water)* and with measurements published by the Otis Water User Co-Op (*Annual Water Quality Report*, 1999). As noted in the CEMRC 1999 Report, CEMRC values for nitrates are higher than those reported by Carlsbad and Loving, because the city-reported values are actually total N, rather than total nitrates.

Tables presenting drinking water data summarized herein are available on the CEMRC web site at http://www.cemrc.org.

Table 16. Range of Activity Concentrations and Interannual Comparisons for Uranium Isotopes Measured in Drinking Water during 1998 - 2000

Location	Analyte	Activity Concentration ($Bq\ L^{-1}$)		[a]RPC (%)	
		[b]Minimum	[c]Maximum	2000:1998	2000:1999
Carlsbad	^{234}U	2.8E-02	3.3E-02	-15	-3
	^{235}U	7.0E-04	8.1E-04	8	16
	^{238}U	1.1E-02	1.4E-02	-21	0
Double Eagle	^{234}U	5.4E-02	6.2E-02	-2	-13
	^{235}U	1.1E-03	1.4E-03	27	27
	^{238}U	2.0E-02	2.3E-02	10	-4
Hobbs	^{234}U	8.5E-02	9.1E-02	3	7
	^{235}U	2.2E-03	2.5E-03	5	-8
	^{238}U	3.8E-02	4.0E-02	5	3
Loving	^{234}U	8.2E-02	8.5E-02	2	-1
	^{235}U	1.5E-03	1.7E-03	-6	7
	^{238}U	2.4E-02	2.6E-02	8	0
Private Well #2	^{234}U	5.1E-01	5.3E-01	-2	-4
	^{235}U	1.1E-02	1.2E-02	0	9
	^{238}U	2.0E-01	2.1E-01	-5	-5
Otis	^{234}U	1.3E-01	1.5E-01	8	-7
	^{235}U	2.7E-03	3.0E-03	11	3
	^{238}U	4.7E-02	5.3E-02	11	-2

[a] RPC = relative percent change; for 2000:1998 = ((2000 concentration –1998 concentration) / 1998 concentration) * 100%; for 2000:1999 = ((2000 concentration –1999 concentration) / 1999 concentration) * 100%

[b] Minimum activity concentration measured in three consecutive annual samples

[c] Maximum activity concentration measured in three consecutive annual samples

Table 17. Range of Concentrations of Selected Inorganic Analytes in Drinking Water Samples Collected during 1998 - 2000

Analyte	Unit	Minimum/Maximum Concentrations by Location								
		Carlsbad			Double Eagle			Hobbs		
		[a]N	[b]Min	[c]Max	N	Min	Max	N	Min	Max
Ag	μg L^{-1}	1	1.6E-02	1.6E-02	1	2.8E-02	2.8E-02	2	3.5E-03	4.0E-03
Al	mg L^{-1}	2	4.4E-03	3.0E-02	2	4.6E-03	7.0E-03	2	5.1E-03	1.0E-02
As	μg L^{-1}	3	5.4E-01	5.7E-01	3	5.2E-00	6.6E-00	3	5.6E-00	6.5E-00
Ba	μg L^{-1}	3	6.8E+01	7.4E+01	3	6.8E+01	9.0E+01	3	5.7E+01	6.4E+01
Be	μg L^{-1}	0	[d]NA	NA	1	3.6E-02	3.6E-02	1	5.4E-02	5.4E-02
Ca	mg L^{-1}	3	6.1E+01	7.9E+01	3	4.5E+01	5.5E+01	3	7.0E+01	8.5E+01
Cd	μg L^{-1}	1	6.6E-03	6.6E-03	2	2.2E-03	4.0E-03	1	1.4E-02	1.4E-02
Co	μg L^{-1}	2	1.5E-01	3.4E-01	3	9.3E-02	1.4E-01	3	1.7E-01	3.6E-01
Cr	μg L^{-1}	3	3.0E-01	4.0E-00	3	2.9E-00	3.5E-00	3	2.3E-00	3.1E-00
Cu	μg L^{-1}	2	1.8E-00	3.9E-00	3	1.2E-00	3.8E-00	3	1.9E-00	2.1E-00
Fe	mg L^{-1}	1	4.3E-03	4.3E-03	2	4.2E-03	9.0E-03	3	4.3E-03	3.6E-02
Hg	μg L^{-1}	0	NA	NA	0	NA	NA	3	9.0E-03	1.4E-02
K	mg L^{-1}	3	1.3E-00	2.9E-00	3	2.7E-00	3.5E-00	3	2.4E-00	2.9E-00
La	μg L^{-1}	2	1.4E-02	4.4E-02	3	1.4E-02	6.3E-02	3	1.3E-02	5.0E-02
Li	μg L^{-1}	2	7.3E-00	7.9E-00	3	1.8E+01	1.9E+01	3	2.9E+01	3.2E+01
Mg	mg L^{-1}	3	3.0E+01	3.4E+01	3	1.1E+01	1.1E+01	3	2.0E+01	2.1E+01
Mn	μg L^{-1}	3	5.5E-02	3.2E-01	3	2.3E-01	3.1E-01	3	2.5E-01	6.7E-01
Mo	μg L^{-1}	3	7.0E-01	1.2E-00	3	1.5E-00	2.3E-00	3	2.6E-00	2.7E-00
Na	mg L^{-1}	3	2.0E+01	9.9E+01	3	3.1E+01	3.8E+01	3	4.0E+01	4.9E+01
Ni	μg L^{-1}	2	1.9E-00	2.1E-00	3	1.1E-00	1.5E-00	3	1.6E-00	2.5E-00
Pb	μg L^{-1}	2	3.8E-01	1.5E-00	3	3.2E-01	1.4E-00	3	9.4E-02	1.7E-01
Sb	μg L^{-1}	1	2.4E-01	2.4E-01	2	1.9E-02	2.4E-02	2	3.9E-02	4.7E-02
Sn	μg L^{-1}	0	NA	NA	1	2.8E-01	2.8E-01	0	NA	NA
Sr	μg L^{-1}	3	3.5E+02	4.6E+02	3	5.0E+02	5.3E+02	3	7.9E+02	9.2E+02
Th	μg L^{-1}	1	2.5E-02	2.5E-02	2	5.7E-03	3.0E-02	2	4.6E-03	4.6E-03
Tl	μg L^{-1}	2	1.2E-01	1.5E-01	0	0.0E+01	0.0E+01	1	4.9E-02	4.9E-02
U	μg L^{-1}	2	8.2E-01	8.5E-01	3	1.7E-00	1.8E-00	3	3.0E-00	3.4E-00
V	μg L^{-1}	3	3.8E-00	4.7E-00	3	1.8E+01	2.7E+01	3	2.2E+01	3.6E+01
Zn	μg L^{-1}	3	4.6E-00	1.5E+01	3	1.5E-00	4.2E-00	3	8.4E-01	3.4E-00
Nitrate	mg L^{-1}	3	3.5E-00	5.9E-00	3	1.1E+01	1.4E+01	3	1.7E+01	2.0E+01
Chloride	mg L^{-1}	3	1.5E+01	1.9E+02	3	2.6E+01	3.7E+01	3	6.3E+01	9.4E+01
Fluoride	mg L^{-1}	3	2.2E-01	7.8E-01	3	5.0E-01	1.0E-00	3	6.2E-01	1.3E-00
Sulfate	mg L^{-1}	3	8.1E+01	1.2E+02	3	4.1E+01	5.7E+01	3	1.0E+02	1.4E+02

Table continued on next page

Table 17. Range of Concentrations of Selected Inorganic Analytes in Drinking Water Samples Collected during 1998 - 2000 (Cont.)

Analyte	Unit	Minimum/Maximum Concentrations by Location								
		Private Well #2			Otis			Loving		
		[a]N	[b]Min	[c]Max	N	Min	Max	N	Min	Max
Ag	μg L^{-1}	3	4.6E-03	3.6E-02	1	2.6E-02	2.6E-02	2	3.3E-03	5.6E-03
Al	mg L^{-1}	2	4.6E-03	9.1E-03	1	3.5E-03	3.5E-03	2	3.6E-03	5.0E-03
As	μg L^{-1}	3	2.0E-00	2.3E-00	3	1.2E-00	1.5E-00	3	1.2E-00	1.6E+00
Ba	μg L^{-1}	3	8.5E-00	9.2E-00	3	1.4E+01	1.8E+01	3	2.9E+01	3.2E+01
Be	μg L^{-1}	2	1.1E-01	1.9E-01	0	NA	NA	1	9.4E-02	9.4E-02
Ca	mg L^{-1}	3	4.4E+02	5.9E+02	3	2.4E+02	2.5E+02	3	7.8E+01	9.4E+01
Cd	μg L^{-1}	3	9.2E-02	1.1E-01	1	6.9E-03	6.9E-03	2	1.0E-02	1.6E-02
Co	μg L^{-1}	3	1.0E-00	1.4E-00	2	3.9E-01	5.1E-01	3	1.5E-01	6.4E-01
Cr	μg L^{-1}	3	3.1E-00	3.8E-00	3	8.6E-01	4.1E-00	3	2.3E-00	4.3E+00
Cu	μg L^{-1}	3	5.2E-00	1.0E+01	2	4.4E-00	5.5E-00	3	2.4E-00	4.7E+00
Fe	mg L^{-1}	3	6.6E-01	8.1E-01	2	5.1E-03	1.2E-02	1	2.2E-03	2.2E-03
Hg	μg L^{-1}	0	NA	NA	0	NA	NA	0	NA	NA
K	mg L^{-1}	3	8.2E-00	8.3E-00	3	3.2E-00	3.9E-00	3	1.9E-00	2.5E+00
La	μg L^{-1}	3	1.4E-02	2.2E-02	1	2.9E-03	2.9E-03	3	6.8E-03	2.2E-02
Li	μg L^{-1}	3	1.8E+02	2.1E+02	2	4.7E+01	4.9E+01	3	1.7E+01	2.0E+01
Mg	mg L^{-1}	3	1.4E+02	1.7E+02	3	8.3E+01	9.1E+01	3	3.5E+01	4.1E+01
Mn	μg L^{-1}	3	3.1E+01	8.0E+01	2	1.7E-01	2.5E-01	2	5.2E-02	6.8E-02
Mo	μg L^{-1}	3	3.3E+01	3.8E+01	2	2.4E-00	2.7E-00	3	1.4E-00	1.6E+00
Na	mg L^{-1}	3	2.1E+02	2.7E+02	3	9.6E+01	1.1E+02	3	1.9E+01	2.3E+01
Ni	μg L^{-1}	3	1.4E+01	2.0E+01	2	7.2E-00	7.4E-00	3	2.2E-00	2.7E+00
Pb	μg L^{-1}	3	9.5E-02	1.8E-01	2	1.1E-01	2.1E-01	3	1.0E-00	1.7E+00
Sb	μg L^{-1}	2	2.2E-02	9.1E-02	2	4.0E-02	4.1E-01	2	6.8E-02	2.5E-01
Sn	μg L^{-1}	0	NA	NA	0	NA	NA	0	NA	NA
Sr	μg L^{-1}	3	5.6E+03	7.9E+03	3	2.8E+03	2.9E+03	3	6.5E+02	8.3E+02
Th	μg L^{-1}	2	4.1E-03	6.0E-03	2	6.6E-03	2.7E-02	2	3.7E-03	1.1E-02
Tl	μg L^{-1}	3	2.2E-01	3.6E-01	0	NA	NA	1	5.1E-02	5.1E-02
U	μg L^{-1}	3	1.4E+01	1.7E+01	2	4.2E-00	4.2E-00	3	2.0E-00	2.1E+00
V	μg L^{-1}	3	1.1E+01	1.9E+01	3	9.4E-00	1.2E+01	3	9.2E-00	1.3E+01
Zn	μg L^{-1}	3	2.2E+01	3.9E+01	2	4.4E-00	1.1E+01	3	4.8E-00	7.8E+00
Nitrate	mg L^{-1}	3	1.4E-00	3.8E-00	3	1.9E+01	2.2E+01	3	1.7E+01	2.3E+01
Chloride	mg L^{-1}	3	4.6E+02	5.0E+02	3	2.7E+02	3.9E+02	3	1.6E+01	2.9E+01
Fluoride	mg L^{-1}	3	1.4E-00	2.1E-00	3	5.5E-01	1.3E-00	3	2.5E-01	6.0E-01
Sulfate	mg L^{-1}	3	1.9E+03	2.5E+03	3	6.4E+02	7.5E+02	3	1.4E+02	2.0E+02

[a]N = number of samples > MDL
[b]Min = minimum measured concentration in three consecutive annual samples
[c]Max = maximum measured concentration in three consecutive samples
[d]NA = all samples below MDL for analyte

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

Introduction

Citizen volunteers from the Carlsbad, New Mexico area were monitored for internally deposited radionuclides through a project entitled "Lie Down and Be Counted" (LDBC). This project is provided as an outreach service to the public to support education about naturally occurring and man-made radioactivity present in people who live in the vicinity of the WIPP. The data collected prior to the opening of the WIPP facility (26 March 1999) serve as a baseline for comparisons with periodic follow-up measurements that are slated to continue throughout the 35-year operational phase of the WIPP. It is important to note that these data represent an interim summary (through 1 October 2000) of an ongoing study.

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

Results

As of 1 October 2000, 500 individuals had participated in the LDBC project. At the time the WIPP opened, 367 individuals had been measured using the *in vivo* protocol. This group of 367 measurements constitutes the pre-operational baseline to which subsequent results are compared. Counts performed after the opening of the WIPP are considered to be a part of the operational monitoring phase of the WIPP EM. Recounts of the original cohort began in July 1999, and 98 recounts had been performed through 1 October 2000. In addition, 133 new volunteers have participated in the program since 1 October 1999. These new volunteers form an additional baseline cohort for future comparisons.

Demographic characteristics (Table 18) of the current LDBC cohort are statistically unchanged from those reported in the CEMRC 1999 Report, and are generally consistent with those reported in the 1990 census for citizens living in Carlsbad. The largest deviations reported in the 1999 report between the LDBC cohort and 1990 census were the over-sampling of males and under-sampling of Hispanics. Since that time, slight improvements have been made with respect to the percent of males and Hispanics represented, but Hispanics are still 50% under-sampled relative to the 1990 census. During 2001, demographic characteristics of the LDBC project will be compared to results of the 2000 census, which will provide a more accurate representation of the current population. 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.

As discussed in detail in the CEMRC 1998 Report and elsewhere (Webb et al., 2000, *Radiat. Prot. Dosim.* 89, 183), 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). For the baseline measurements (N = 367), 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 ^{212}Pb, ^{235}U / ^{226}Ra, ^{60}Co, ^{137}Cs, ^{40}K, ^{54}Mn, ^{232}Th via ^{228}Ac and ^{65}Zn (Table 19). As discussed in detail in the 1998 report, five of these (^{232}Th via ^{212}Pb, ^{60}Co, ^{40}K, ^{54}Mn (^{228}Ac interference) and ^{232}Th (via ^{228}Ac) are part of the shield-room background and positive detection is expected at low frequency. ^{40}K is a naturally occurring isotope of an essential biological element, so detection in all individuals is expected. ^{137}Cs and ^{235}U / ^{226}Ra are not components of the shielded room background and were observed at frequencies greater than the 95% confidence interval for the false positive error rate (discussed in more detail later). It is interesting that no result above L_C has been observed for ^{65}Zn in the baseline or monitoring phase. It is unlikely that this result is a statistical anomaly, since results greater than L_C were observed for all other radionuclides. This observation suggests an abnormality in the analysis algorithm at that photon energy and further investigation is underway.

For the operational monitoring counts (Table 19, N = 226), 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 years), and the content within the shield has decreased via decay by approximately 45% since the baseline phase of monitoring. The ^{232}Th (via ^{228}Ac) results were unexpected and further investigation is necessary to explain this observation.

The margin of error could not be calculated for the ^{103}Ru percentage because the sample size of the operational monitoring counts was too small at the time of this summary. When sufficient operational monitoring counts are performed, the margin of error will be calculated. In addition, margins of error can not be calculated for percentages of 100 and 0 (^{40}K and ^{65}Zn, respectively), applying binomial statistics, since these percentages represent non-binomial data.

It is important to note that 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.

^{40}K results were positive for all participants (n = 500), ranging from 1088 to 4462 Bq per person with an overall mean (± SE) of 2868 (± 40) Bq per person. Such results are expected since K is an essential biological element contained primarily in muscle, and a theoretical constant fraction of all naturally occurring K is the radioactive isotope ^{40}K. The mean ^{40}K value for males (± SE), was 3474 (± 41) Bq per person, which was significantly greater ($p < 0.0001$) than that of females, which was 2156 (± 34) 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 26.1 ± 3.5% (95% confidence level, baseline and operational monitoring counts) of citizens living in the Carlsbad area. These results are consistent with findings previously reported in CEMRC 1998 and 1999 reports and elsewhere (Webb, J. L. et al., 2000, loc. cit.). Detectable ^{137}Cs body burdens ranged from 5.2 to 62.9 Bq per person with an overall mean (± SE) of 10.4 (± 0.5) Bq per person. The mean ^{137}Cs body burden for males (± SE), was 11.1 (± 0.7) Bq per person, which was significantly greater ($p = 0.02$) than that of females, which was 8.9 (± 0.4) Bq per person. As previously reported (CERMC 1998 Report; CEMRC 1999 Report; Webb, J. L. et al., 2000, loc. cit.) the presence of ^{137}Cs was independent of ethnicity, age, radiation work history, consumption of wild game, nuclear medical treatments and European travel. Occurrence of detectable ^{137}Cs was associated with gender, where males had higher prevalence of ^{137}Cs relative to females. Presence of ^{137}Cs was also associated with smoking (where smokers had a higher prevalence relative to non-smokers). It is likely that the association with gender is related to the tendency for larger muscle mass in males than in females, as supported by the ^{40}K results. The association of ^{137}Cs with smoking could be related to the presence of fallout ^{137}Cs in tobacco, decreased pulmonary clearing capability in smokers, or other as yet unidentified factors, and further study is warranted.

As reported in the CEMRC 1998 and 1999 reports, the percentage of results greater than L_C for ^{235}U / ^{226}Ra (12%) are significantly (although slightly) higher than the distribution-free confidence interval for a 5% random false positive error rate (1 to 9%). 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. However, further study, possibly involving *in vitro* bioassay for the two radionuclides (the nuclides can be distinguished via alpha spectrometry), is needed. No additional investigations into this observation were conducted during this reporting period.

Table 18. Demographic Characteristics of the "Lie Down and Be Counted" Population Sample through 1 October 2000

Characteristic		2000 Sample Group ([a]margin of error)	1999 Sample Group	[b]Census, 1990
Gender	Male	54.0% (49.6 to 58.4%)	56.6%	48.0%
	Female	46.0% (41.6 to 50.4%)	43.4%	52.0%
Ethnicity	Hispanic	13.6% (10.6 to 16.6%)	12.9%	33.4%
	Non-Hispanic	83.6% (80.4 to 86.8%)	84.2%	63.0%
	Other	2.8% (1.2 to 4.4%)	2.9%	3.6%
Age 60 or older		25.2% (21.4 to 29.0%)	24.8%	33.7%
Currently or previously classified as a radiation worker		5.8% (3.8 to 7.8%)	4.9%	[c]NA
Consumption of wild game within last 3 months		17.6% (14.2 to 21.0%)	15.3%	NA
Medical treatment, other than x-rays, using radionuclides		8.8% (6.2 to 11.4%)	9.0%	NA
European travel within the last 2 years		3.8% (2.0 to 5.6%)	3.9%	NA
Current smoker		14.6% (11.4 to 17.8%)	14.6%	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] United States Department of Commerce, Economics and Statistics Administration, Bureau of the Census. *1990 Census of Population*. Washington, DC: US Government Printing Office
[c] NA = not available

Table 19. "Lie Down and Be Counted" Results through 1 October 2000

Radionuclide	*In Vivo* Count Type	Baseline Counts (prior to 27 March 1999) [a]N = 367	Operational Monitoring Counts (27 March 1999 – 1 October 2000) N = 226	
		% of Results ≥ [b]L_C	% of Results ≥ L_C	[c]Margin of Error (%)
^{241}Am	Lung	5	4	1 to 7
^{144}Ce	Lung	5	3	0 to 6
^{252}Cf	Lung	4	8	4 to 12
^{244}Cm	Lung	6	6	2 to 10
^{155}Eu	Lung	7	4	1 to 7
^{237}Np	Lung	4	3	0 to 6
^{210}Pb	Lung	4	8	4 to 12
Plutonium Isotope	Lung	6	4	1 to 7
[d] ^{232}Th via ^{212}Pb	Lung	34	37	30 to 45
^{232}Th	Lung	5	6	2 to 10
^{232}Th via ^{228}Th	Lung	4	6	2 to 10
^{233}U	Lung	6	9	4 to 13
^{235}U / ^{226}Ra	Lung	11	12	7 to 17
Natural Uranium via ^{234}Th	Lung	5	8	4 to 12
^{133}Ba	Whole Body	4	5	1 to 8
^{140}Ba	Whole Body	5	3	0 to 6
^{141}Ce	Whole Body	4	5	1 to 8
^{58}Co	Whole Body	4	4	1 to 7
[d] ^{60}Co	Whole Body	55	36	29 to 43
^{51}Cr	Whole Body	6	4	1 to 7
^{134}Cs	Whole Body	2	4	1 to 7
^{137}Cs	Whole Body	28	23	16 to 29
^{152}Eu	Whole Body	7	4	1 to 7
^{154}Eu	Whole Body	4	2	0 to 5
^{155}Eu	Whole Body	4	4	1 to 7
^{59}Fe	Whole Body	4	7	3 to 11
^{131}I	Whole Body	5	2	0 to 5
^{133}I	Whole Body	3	4	1 to 7
^{192}Ir	Whole Body	4	4	1 to 7
^{40}K	Whole Body	100	100	[e]NC
[d] ^{54}Mn	Whole Body	12	11	6 to 16
^{103}Ru	Whole Body	2	1	NC
^{106}Ru	Whole Body	4	4	1 to 8

Table continued on next page

Table 19. "Lie Down and Be Counted" Results through 1 October 2000 (Cont.)

Radionuclide	*In Vivo* Count Type	Baseline Counts (prior to 27 March 1999) [a]N = 367	Operational Monitoring Counts (27 March 1999 – 1 October 2000) N = 226	
		% of Results ≥ [b]L_C	% of Results ≥ L_C	[c]Margin of Error (%)
^{125}Sb	Whole Body	5	4	1 to 7
^{232}Th via ^{228}Ac	Whole Body	35	24	17 to 30
^{88}Y	Whole Body	8	6	2 to 10
^{65}Zn	Whole Body	0	0	NC
^{95}Zr	Whole Body	7	4	1 to 7

[a] N = number of individuals

[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 complete replication of this experiment, one would expect the confidence interval to include the true population percentage 95% of the time, 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

[e] NC = not calculated; the margin of error cannot be calculated for the observed percentage because the sample size for operational monitoring counts is as yet too small; when sufficient counts are performed, the margin of error will be calculated; the margin of error for ^{40}K cannot be calculated since this radionuclide is present in all individuals

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, New Mexico, and the surrounding region; NMSU; the Carlsbad Department of Development; the New Mexico Congressional Delegation; the New Mexico Radioactive and Hazardous Materials Committee; Westinghouse Electric Corporation; and the U.S. Department of Energy (DOE). The CEMRC was established with a grant entitled "Carlsbad Environmental Monitoring and Research Program" (CEMRP) from DOE to NMSU. The CEMRP initially was funded for $27 million over a seven year period (1991–1998). Subsequently, the grant was increased to almost $33 million to support operations of the program until 2008.

Dr. Rohinton (Ron) K. Bhada served as Project Director for the CEMRP during 1991-1999. Dr. Donald J. Fingleton served as Director of the CEMRC during 1991-1996. In 1996, Dr. Fingleton was named Director of Laboratory Development, and Dr. Marsha Conley became Director of Operations. Dr. Fingleton was transferred to a position with WERC in 1997, and Dr. Conley became Director. Mr. Joel Webb was named Manager of Program Development in 1998. Dr. Conley was named CEMRP Project Director in 1999.

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

In addition to work associated with design and construction of buildings for the CEMRC, a variety of other developmental projects were undertaken to support the CEMRC's scientific activities. In 1993, design began for the Mobile Bioassay Laboratory (MBL) that would complement the facilities planned for the new CEMRC building. Construction of the MBL began in 1994, and the unit was completed and delivered to Carlsbad in 1996. An application for a Radioactive Material License was prepared and submitted to the New Mexico Environment Department, and the license was issued in 1996.

In 1999, CEMRC was separated from WERC and is now a division reporting directly to the Dean of Engineering at NMSU. However, CEMRC continues to conduct various collaborative activities with WERC.

Appendix B. Subcontracts for Technical Assistance during 2000

Subcontractor	Scope of Work
Battelle Memorial Institute, Pacific Northwest Division	Fabrication of lung sets for *in vivo* bioassay
[a]Texas A&M Experiment Station	Collection of aerosol samples
[a]Electronic Counter Corporation	Instrument design & engineering
[a]Texas A&M Research Foundation	Measurements of organic nitrogen in aerosol samples
National Institute of Standards & Technology	Intercomparison services for radioanalyses
Oak Ridge National Laboratory, Intercomparison Studies Program	Intercomparison services for *in vivo* radiobioassay
[a]University of Rhode Island/Urszula Tomza	Neutron activation analysis, gamma-ray spectroscopy

[a]Collaborative work not funded through CEMRP

Appendix C. Members of Scientific Advisory Board (SAB) and Program Review Board (PRB)

Member/Term of Service	Affiliation
Stanley I. Auerbach, Ph.D. (PRB) / 1998-2000	Director Emeritus, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee
John M. Briggs, Ph.D. (SAB) / 2000-present	Associate Professor, Department of Plant Biology, Arizona State University, Tempe, Arizona
Paul M. Bertsch, Ph.D. (SAB) / 2000-present	Director, Savannah River Ecology Laboratory, University of Georgia, Aiken, South Carolina
Judith Chow, Ph.D. (SAB) / 2000-present	Research Professor, Desert Research Institute, Reno, Nevada
George M. Hidy, Ph.D. (PRB) / 2000-present	Consultant, Envair/Aerochem President (past), Desert Research Institute, Las Vegas, Nevada
Gary H. Kramer, Ph.D. (SAB) / 2000-present	Head, Human Monitoring Laboratory, Radiation Protection Bureau, Health Canada, Ottawa, Ontario, Canada
David E. Reichle, Ph.D. (PRB) / 2000-present	Associate Director Emeritus, Life Sciences and Environmental Technologies, Oak Ridge National Laboratory, Oak Ridge, Tennessee
Michael H. Smith, Ph.D. (PRB) / 1998-2000	Director Emeritus and Professor, Savannah River Ecology Laboratory, University of Georgia, Aiken, South Carolina
Shawki A. Ibrahim, Ph.D. (SAB) / 2000-present	Professor, Department of Radiological Health Sciences, Colorado State University, Ft. Collins, Colorado

Appendix D. Professional Presentations and Publications during 2000

Author	Title	Publisher/Conference
Arimoto, R.	Sources and composition of aerosol particles	Handbook of Atmospheric Chemistry, submitted
Arimoto, R.	Eolian dust and climate: relationships to sources, transport, and deposition	Earth Science Reviews, submitted
Arimoto, R., J. Greenlee, S. Sage, R. Okrasinski, C. Schloesslin and W. Gutman	Fugitive dust sampling and source characterization	2000 Southwest Center for Environmental Research and Policy Border Conference, Juarez, Mexico
Arimoto, R., A.S. Nottingham, J. Webb, and C.A. Schloesslin	Non-sea salt sulfate and other aerosol constituents at the South Pole during ISCAT	Geophysical Research Letters, submitted
Arimoto, R., W. Balsam and C.A. Schloesslin	Visible spectroscopy of atmospheric dust collected on filters: iron-bearing minerals	American Geophysical Union, Fall Meeting, San Francisco, California
Burnett, W.C., J. Christoff, B. Stewart, T. Winters and P. Wilbur	Reliable gross alpha-/beta-particle analysis of environmental samples via liquid scintillation counting	Radioactivity & Radiochemistry 11:26-44
Conley, M., R. Arimoto, T.B. Kirchner, L. Litinskey, D. Schoep, M. Walthall, J.L. Webb and S. B. Webb	Public access to environmental monitoring at waste sites – an experiment in progress	Waste Management 2000, Tucson, Arizona
Davis, D., M. Buhn, J. Nowak, G. Chen, R. Arimoto, A. Hogan, F. Eisele, L. Mauldin, D. Tanner, R. Shetter, B. Lefer and P. McMurry	Unexpected high levels of NO observed at the South Pole	Geophysical Research Letters, submitted
Guelle, W., Y. Balkanski, M. Schulz, B. Marticorena, G. Bergametti, C. Moulin, R. Arimoto and K.D. Perry	Modeling the atmospheric distribution of mineral aerosol: comparison with ground measurements and satellite observations for yearly and synoptic time scales over the North Atlantic	Journal of Geophysical Research 105:1997-2012
Huang, S.R., R. Arimoto, and K.A. Rahn	Sources and source variations for aerosol at Mace Head, Ireland	Atmospheric Environment, in press
Johnson, S.R., D.D. Breshears and T.B. Kirchner	Multi-pathway, multi-site contaminant transport: assessing vertical migration, wind erosion and water erosion at semiarid DOE sites	45th Annual Meeting Health Physics Society, Denver, Colorado

Table continued on next page

Appendix D. Professional Presentations and Publications during 2000 (Cont.)

Author	Title	Publisher/Conference
Kirchner, T.B.	Multi-pathway, multi-site contaminant transport: assessing vertical migration, wind erosion and water erosion at semiarid DOE sites	45th Annual Meeting Health Physics Society, Denver, Colorado
Kirchner, T.B.	Evolutionary consequences of skewed body distributions of body size	Ecological Society of America, 85th Annual Meeting, Snowbird, Utah
Kirchner, T.B.	Multi-pathway, multi-site contaminant transport: assessing vertical migration, wind erosion and water erosion at semiarid DOE sites	45th Annual Meeting Health Physics Society, Denver, Colorado
Kirchner, T.B., J.L. Webb, S.B. Webb, R. Arimoto, D.A. Schoep and B. Stewart	Variability in background levels of surface soil radionuclides in the vicinity of the Waste Isolation Pilot Plant	Journal of Environmental Radioactivity, in press
Kramer, G.H., M.A. Lopez and J. Webb	A joint HML-CIEMAT-CEMRC project: testing a function to fit counting efficiency of a lung counting germanium detector array to muscle equivalent chest wall thickness and photo energy using a realistic torso phantom	Radiation Protection Dosimetry 92:323-327
Litinskey, L.	Environmental quality system development within the university structure	U.S. Environmental Protection Agency 19th Annual National Conference on Managing Environmental Quality Systems, Albuquerque, New Mexico
Malek, M., T.G. Hinton and S.B. Webb	Comparative uptake pathways of ^{137}Cs and ^{90}Sr in cabbage grown near Chernobyl	Journal of Environmental Radioactivity, in press
Maring, H., D.L. Savoie, M.A. Izaguirre, C. McCormick, R. Arimoto, J.M. Prospero and C. Pilinis	Aerosol physical and optical properties and their relationship to aerosol composition in the free troposphere at Izana, Canary Island during July 1995	Journal of Geophysical Research 105:14677-14700
Orcutt, K.M., F. Lipshultz, K. Gundersen, R. Arimoto, A.F. Michaels, A.H. Knap and J.R. Gallon	Seasonal pattern and significance of N_2 fixation by *Trichodesmium* spp. at the Bermuda Atlantic Time-series Study (BATS) site	Deep Sea Research II Special Issue: Nitrogen Fixation by *Trichodesmium* in the Sargasso Sea, in press
Schoep, D.A., J.L. Webb, R. Arimoto, T.B. Kirchner, S.B. Webb, P.M. Walthall and M.R. Conley	Monitoring of radioactive and inorganic aerosols in exhaust air released from the Waste Isolation Pilot Plant	45th Annual Meeting, Health Physics Society, Denver, Colorado

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Appendix D. Professional Presentations and Publications during 2000 (Cont.)

Author	Title	Publisher/Conference
Stegman, P.M., R. Arimoto, and U. Tomza	Correspondence between SeaWiFS-derived aerosol optical thickness and aerosol concentrations determined at surface sites in the North Atlantic	Journal of Geophysical Research, submitted
Tomza, U., R. Arimoto and B.J. Ray	Filter color as an indicator of aerosol composition	Atmospheric Environment, in press
Uematsu, M. and R. Arimoto	The East Asian/North Pacific Regional Experiment (APARE)	IGACtivities Newsletter 20:2-3
Webb, J. and G.H. Kramer	An evaluation of germanium detectors employed for the measurement of radionuclides deposited in lungs using an experimental and Monte Carlo approach	Health Physics, in press
Webb, J., R. Nelson and D. Schoep	The effect of a 657-meter cosmic ray shield on *in vivo* measurement sensitivity for radionuclides deposited in lungs	Lung Counting Workshop, Idaho Falls, Idaho
Webb, J. and G.H. Kramer	An evaluation of germanium detectors employed for the measurement of radionuclides deposited in lungs using an experimental and Monte Carlo approach	Lung Counting Workshop, Idaho Falls, Idaho
Webb, J. and T.B. Kirchner	An evaluation of *in vivo* sensitivity via public monitoring	Radiation Protection Dosimetry 89:183-191
Webb, J., M. Gadd, F. Bronsen and O. Tench	An evaluation of recent lung counting technology	Radiation Protection Dosimetry 89:325-332
Webb, J. and G.H. Kramer	An evaluation of germanium detectors employed for the measurement of radionuclides deposited in lungs using an experimental and Monte Carlo approach	45th Annual Meeting Health Physics Society, Denver, Colorado
Webb, S.B., S.A. Ibrahim, F.W. Whicker	Inventory estimate of ^{239}Pu in soils east of Rocky Flats, Colorado	Technology 7:497-507
Whicker, J.J., D.D. Breshears, P.T. Wasiolek, R. Tavani, D. Schoep and T.B. Kirchner	Effects of episodic high-wind events and fire on resuspension rates: measurements near the Waste Isolation Pilot Plant	45th Annual Meeting Health Physics Society, Denver, Colorado
Zhang, X.Y., R. Arimoto, Z.S. An, J.J. Cao and D. Wang	Atmospheric dust aerosol over the Tibetan Plateau	Journal of Geophysical Research-Atmospheres, in press

Appendix E. Guest Colloquia

Topic	Presenter
Paleoclimatic interpretations of the Chinese loess sequence: evidence from changes in iron oxides	Bill Balsam, Professor, Geology, University of Texas at Arlington
Globalization and analytical needs for the 21st century	Jon Broadway, Manager, International Corps on the Environment, Auburn University-Montgomery
Seeing the sun from deep underground (the physics of neutrinos from the nuclear reactions that power our sun and their detection)	Todd Haines, Los Alamos National Laboratory
Plutonium distribution and behavior in man and the environment: an overview	Shawki Ibrahim, Associate Professor, Radiological Health Sciences, Colorado State University
Easter red cedar expansion into native tallgrass prairie: patterns and processes	John Briggs, Associate Professor, Plant Biology, Arizona State University
Urban and regional air pollution: current research and future outlook	Judith Chow, Research Professor, Atmospheric Sciences Division, Desert Research Institute
Radiation resistance of concrete and of sodium chloride	Zbigniew Zagorski, Professor, Institute of Nuclear Chemistry and Technology, Warsaw, Poland
Distribution and effects of radioisotopes on small mammals at Chornobyl	Michael Smith, Director Emeritus and Professor, Savannah River Ecology Laboratory, University of Georgia,
Radiochemical procedures in use at IAEA Laboratories for anthropogenic alpha and beta-emitting radionuclides in environmental samples	Josue Moreno-Bermudez, Environmental Radiochemist, International Atomic Energy Agency, Seibersdorf, Austria
Aqueous diffusion in repository systems – the role of volumetric water	James Conca, Los Alamos National Laboratory/Carlsbad Operations
Monte Carlo simulations, how we can investigate the impossible	Gary Kramer, Head, Human Monitoring Laboratory, Radiation Protection Bureau, Health Canada
Chemical speciation of radionuclides in environmental samples from microspectroscopic techniques	Paul Bertsch, Director, Savannah River Ecology Laboratory, University of Georgia

Appendix F. Major Tours, Public Presentations, Exhibits and Other Outreach

Group/Activity
Next Generation U.S. Underground Science Facility Workshop participants - tour and presentation
National Central University, Chung-Li, Taiwan - invited lecture
NMSU Department of Fishery & Wildlife Sciences - invited seminars (2)
Carlsbad Altrusa Club - presentation and tour
Epsilon Sigma Alpha, Beta Rho Chapter - presentation and tour
Carlsbad Historical Society - presentation
Blodgett Street Baptist Adult Seniors program - presentation
American Association of University Women Senior Honors Luncheon - presentation
Winona State University (Winona, Minnesota) - invited seminar
16th of September Celebration, Carlsbad - exhibit
Carlsbad Community Health and Safety Fair 2000 - exhibit
NMSU-Carlsbad Junior/Senior Day - presentation
NMSU-Carlsbad Career Expo 2000 - presentations
NMSU-Carlsbad Alliance for Minority Participation program - tour
Carlsbad Sportsman's Club - presentation and tour
Rotary Club of Carlsbad - presentation
Carlsbad Municipal Schools, Chihuahuan Desert Laboratory project - presentations and tours
Carlsbad Municipal Schools, Alta Vista Leyva Middle School, 6th grade classes - tour and program
Carlsbad Municipal Schools, Sunset Elementary Science Fair - exhibit
Carlsbad Municipal Schools, Joe Stanley Smith Elementary Science Fair - exhibit
Carlsbad Municipal Schools, Pate Elementary Science Fair - exhibit
Universidad Autonoma de Juarez, Environmental Science students - presentation and tour
Nye County, Nevada city/county representatives - tour and presentation
American Association of University Women - presentation
Cochiti Pueblo Environmental Protection Office representatives - tour and presentation
Texas Wind Power Company (Austin, Texas) - provided wind measurement data from CEMRC
Japan Nuclear Fuel Ltd. and Japanese Aomori Prefectural Institute of Public Health and Environment representatives - tour and presentation
Border EcoWeb Internet site (www.borderecoweb.sdsu.edu) - section added featuring CEMRC

Appendix G. Leadership Participation by CEMRC Staff in Professional Functions

Function	CEMRC Staff/Role
ACE-Asia	R. Arimoto, Member, Executive Committee
International Global Atmospheric Chemistry/Asia Pacific Regional Experiment, Tokyo, Japan	R. Arimoto, Member, Executive Committee and Technical Session Chair
American Geophysical Union, Journal of Geophysical Research-Atmospheres	R. Arimoto, Associate Editor
National Aeronautics and Space Administration, Transport and Chemical Evolution over the Pacific program, Washington, D.C.	R. Arimoto, Member, Review Panel
National Aeronautics and Space Administration	R. Arimoto, Recipient, Group Achievement Award as member of Global Tropospheric Experiment Pacific Exploratory Mission to the Western Pacific
Institute of Earth Environment, Xi'an, China	R. Arimoto, invited lecture "Atmospheric haze, dust fluxes and fine particle controls"
Korea Meteorological Administration, Seoul, Korea	R. Arimoto, invited lecture "ACE-Asia and aerosol characterization"
U.S. Geological Service Upper Midwest Environmental Sciences Center, LaCrosse, Wisconsin	M. Conley, invited lecture "Where environmental science and public information meet – an experiment in progress"
Applications of Probability and Statistics in Health Physics, Short Course, Ft. Collins, Colorado	T.B. Kirchner, invited lecture "Uncertainty analysis"
American National Standards Institute, HPS N13.25, Internal Dosimetry Programs for Plutonium Exposure – Minimum Requirements	J. Webb, Member, Standards Committee Working Group
45th Annual Meeting Health Physics Society, Denver, Colorado	J. Webb, Chair, Technical Session
Health Canada, Environmental Health Directorate Radiation Protection Bureau	J. Webb, Technical Lead, Memorandum of Understanding for scientific cooperation
American Institute of Biological Sciences and U.S. Army Research and Materiel Command, Gulf War Related Illness research program, Toxicity of Militarily-Relevant Heavy Metals panel	S.B. Webb, Review Panel Member

Appendix H. New Project Development

Proposal/Bid Title	PI(s)	Sponsor	Funding/ Term	Status
An investigation of sulfur chemistry in the Antarctic troposphere	R. Arimoto (with Georgia Institute of Technology and others)	National Science Foundation	$160,000, 1998-2002	Funded, in progress
Mineral dust and radionuclides over the North Atlantic	R. Arimoto (with Texas A&M University)	National Science Foundation	$270,428, 1997-2001	Amended, in progress
Characterization of ambient particulate matter in the Paso del Norte region	R. Arimoto (with NMSU Physical Science Laboratory and others)	Southwest Center for Environmental Research and Policy (with funding from U.S. Environmental Protection Agency)	$27,843, 1999-2001	Funded, in progress
Determination of Be and U in aqueous extracts of contaminated soils	R. Arimoto	NMSU Cooperative Fish and Wildlife Research Unit (with funding from DOE)	$5,618, 1999-2000	Completed
Ambient air quality issues related to confined animal operations	R. Arimoto (with Texas Agricultural Extension Service and others)	U.S. Department of Agriculture, National Research Initiative Competitive Grants Program	$49,976, 1999-2001	Funded, in progress
Collaborative research: aerosol characterization experiment (ACE)-Asia surface network implementation, operations, and coordination	R. Arimoto (with University of Virginia and others)	National Science Foundation	$139,968, 2000-2004	Funded, in progress
Collaborative research: multiphase chemical processing of Asian outflow air over the northwestern Pacific Ocean during spring	R. Arimoto (with Massachusetts Institute of Technology and others)	National Science Foundation	$69,409, 2000-2002	Submitted, not funded
Collaborative research: integrated studies of morphological, chemical optical, and radiative properties of multi-component aerosols containing mineral dust in the ACE-Asia region	R. Arimoto (with University of Hawaii and others)	National Science Foundation	$148,923, 2000-2004	Submitted

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Appendix H. New Project Development (Cont.)

Proposal/Bid Title	PI(s)	Sponsor	Funding/ Term	Status
Air deposition of mercury and other airborne pollutants in an arid environment	R. Arimoto (with NMSU Cooperative Fish and Wildlife Research Unit and others)	Southwest Center for Environmental Research and Policy (with funding from U.S. Environmental Protection Agency)	$12,537, 2000-2002	Funded, in progress
Significance and suppression of air emissions from open-lot cattle-feeding facilities: a Great Plains research and technology-transfer partnership	R. Arimoto (with Texas Agricultural Extension Service and others)	U.S. Department of Agriculture	$49,856, 2000-2002	Submitted, not funded
Determination of uranium content in human hair	R. Arimoto (with J. Webb)	Freeborn & Peters/Moye, Giles, O'Keefe, Vermire & Gorrell, LLP	$8,500, 2000	Funded, in progress
Determination of nickel content in digested rodent lung tissue	R. Arimoto (with J. Webb)	Lovelace Respiratory Research Institute	$4,600, 2000	Funded, in progress
Source identification for energy-related atmospheric pollution in the southwestern USA using a new technique-positive matrix factorization	R. Arimoto	New Mexico Institute of Mining and Technology (with proposed funding from DOE)	$30,181, 2000-2001	Collaboration commitment submitted, not funded
Effects of depleted uranium on amphibian health	R. Arimoto	NMSU Cooperative Fish and Wildlife Research Unit (with funding from DOE)	$8,000, 2000-2001	Funded, in progress
Proposal to establish the U.S. Department of Energy Waste Isolation Pilot Plant Environmental Research Park	M. Conley	DOE/Carlsbad Area Office	No request for funding	Submitted
General Agreement to establish the National Cave & Karst Research Institute	M. Conley	U.S. Department of Interior National Park Service and NMSU	No funding	Adopted

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Appendix H. New Project Development (Cont.)

Proposal/Bid Title	PI(s)	Sponsor	Funding/ Term	Status
Long-term risk from actinides in the environment: modes of mobility	T. Kirchner (with Los Alamos National Laboratory and others)	DOE Office of Environmental Management	$89,900, 1997-2001	Funded, in progress
Long-term risk from actinides in the environment II: assessment tools for mobility thresholds	T. Kirchner (with Los Alamos National Laboratory and others)	DOE Office of Environmental Management	$95,998, 2000-2003	Submitted, not funded
Component based construction and testing of ecological models	T. Kirchner (with NMSU Department of Computer Science and others)	National Science Foundation	$240,607, 2000-2003	Submitted
Limnological monitoring: Brantley Dam Reservoir	M. Walthall	U.S. Department of Interior, Bureau of Reclamation	$83,363, 1997-2003	Amended, in progress
Quarterly collection of environmental samples	M. Walthall (with J. Webb)	Envirocare of Texas, Inc.	$9,102, 2000-2001	Submitted, not funded
Lung & whole body *in vivo* radiobioassay measurements	J. Webb	Waste Control Specialists, Inc.	$233,414, 1997-2001	Amended, in progress
In vivo radiobioassay measurements for WIPP personnel	J. Webb	Westinghouse Electric Company	$299,000, 1998-2001	Amended, in progress
^{210}Pb - A biomarker for exposure of people to radon in indoor environments	J. Webb	Lovelace Respiratory Research Institute	$116,182, 2000-2002	Pre-proposal submitted, not funded
Human radon exposure estimate using an *in vivo* biomarker	J. Webb	Lovelace Respiratory Research Institute (with proposed funding from National Institutes of Health)	$117,721, 2001-2004	Collaboration commitment submitted
Internal dose assessments from historical radiation worker records	J. Webb	MJW Corporation	$10,000, 1999-2000	Amended, in progress

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Appendix H. New Project Development (Cont.)

Proposal/Bid Title	PI(s)	Sponsor	Funding/ Term	Status
Radiobioassay measurements of New Mexico Environment Department Hazardous and Radioactive Materials Bureau employees	J. Webb	New Mexico Environment Department	$10,000, 2000-2001	Submitted
The cow counter: technology for the measure of radio-contaminants and fat-free lean content in livestock	J. Webb (with NMSU Department of Animal and Range Sciences)	Waste-management Education and Research Consortium (with funding from DOE)	$169,860, 1999-2000	First phase completed, proposal submitted for second phase, not funded
Center for nuclear, neutrino and astroparticle physics	J. Webb (with Ohio State University and others)	National Science Foundation	$229,344, 2001-2006	Collaboration commitment submitted
Memorandum of Understanding	J. Webb	Health Canada and NMSU	No funding	Adopted
Analytical scientific support for the Los Alamos National Laboratory, Carlsbad Office, actinide chemistry and repository science program	J. Webb (with B. Stewart, R. Arimoto and M. Walthall)	Los Alamos National Laboratory	$250,000, 2000-2001	Submitted
Actinide chemistry & repository science laboratory initiative	J. Webb (with M. Conley)	DOE	$7,072,767, 2000-2008	Submitted
Analysis of quarterly environmental samples	S. Webb (with J. Webb)	Envirocare of Texas, Inc.	$17,470, 2000-2001	Submitted, not funded
Radiochemical, chemical and physical characterization of radioactive particles in the environment	S. Webb	International Atomic Energy Agency	No funding	Submitted, not selected

Appendix I. Status of Completion of 2000 Key Performance Indicators

1. Concurrent high-volume and low-volume aerosol sampling at three locations through 2000. **[Completed]**

2. Collection of daily FAS samples in WIPP exhaust shaft through 2000. **[Completed]**

3. Collection of soil samples at current 32 locations during January-February 2000. **[Completed]**

4. Concurrent operation of meteorological sampling stations at two sites through 2000. **[Completed]**

5. Collection of drinking water samples at six sources during March-April 2000. **[Completed]**

6. Collection of sediment and surface water samples from three reservoirs during June-July 2000. **[Completed]**

7. Collection of vegetation samples from six locations during fall 2000. **[No collection due to failure to complete analyses of archived samples from 1997-1999]**

8. Completion of repeat counts for half of original volunteer cohort and initial counts for a minimum of 100 new volunteers. **[Through 1 October 2000, bioassays completed for 98 of original volunteer cohort and 133 new volunteers since first waste receipt at WIPP; 500 volunteer participants measured since project initiation]**

9. Radioanalyses of all pre-2000 aerosol, sediment, surface water, drinking water and vegetation samples by October 2000 **[Analyses of all pre-2000 aerosol, surface water, and drinking water samples completed; alpha spectroscopy analyses of pre-2000 sediment samples delayed to February 2001; analyses of pre-2000 vegetation samples delayed to August 2001]**

10. Radioanalyses of soil, aerosol, sediment, surface water and drinking water samples collected through June 2000 by October 2000 **[Analyses of all 2000 soil, aerosol, sediment, surface water and drinking water samples completed, except alpha spectroscopy of 2000 sediment samples, which is delayed to February 2001]**

11. Radioanalyses of FAS sample analyses to meet weekly and quarterly posting schedule. **[Completed]**

12. Non-radiological (trace element inorganic) analyses of representative subset of 2000 low-volume aerosol, soil, sediment, surface water and drinking water samples within three months after each sample collection. **[Completed]**

13. Non-radiological (trace element inorganic) analyses of FAS samples to meet weekly and quarterly posting schedule **[Completed]**

14. Post results of radioanalyses of 2000 and pre-2000 samples within two months after completion of analyses [**Postings of analytical results for 2000 and pre-2000 samples were delayed, averaging three months after completion of analyses]**

15. Post results of non-radiological analyses of 2000 samples within two months after completion of each set of samples. **[Postings of analytical results for 2000 samples were delayed, averaging three months after completion of analyses]**

16. Issue CEMRC 1999 Report and post report and background data to CEMRC web site by March 2000. **[Completed]**

17. Issue newsletters in March and September 2000. **[Spring newsletter issued in March 2000; Fall newsletter issued in October 2000]**

18. Submit manuscript for publication by February 2000 on baseline characteristics of soils. **[Delayed, submitted April 2000, accepted for publication in Journal of Environmental Radioactivity]**

19. Submit manuscript for publication by July 2000 on baseline characteristics of aerosols. **[Delayed due to delayed completion of radioanalyses of pre-2000 aerosol samples, rescheduled for February 2001]**

Appendix J. CEMRC Quality Assurance Policy

The Carlsbad Environmental Monitoring & Research Center (Center) is a division of the College of Engineering, New Mexico State University (NMSU). The Center is subject to the policies, procedures and guidelines adopted by NMSU, as well as state and federal laws and regulations that govern the operation of the university. Subject to limitations specified by state law, NMSU is legally responsible for the operations and products of the Center. In addition to the general goals, mission and standards of NMSU, the Center adheres to the following principles:

- A quality system will be maintained to ensure that sponsor requirements are consistently met and carried out in accordance with recognized standards as identified and adopted by each programmatic area. The goal of the quality system will be continuous improvement in the processes composing the Center's activities in research and service.

- Standards of quality assurance and quality control incorporating standard scientific methods will be developed and implemented that are appropriate to the objectives and functions of specific projects and programmatic areas.

- Methods for performance assessment and quality improvement will be used throughout the Center in keeping with policies and procedures of NMSU, and with protocols adopted for specific projects and programmatic areas to ensure that all applicable quality objectives are met and maintained.

- Personnel, equipment and facilities will be provided to achieve adopted project objectives and quality standards, subject to the limitations of fiscal and other applicable constraints.

- Personnel will be provided access to written and verbal guidance, training and other professional development to support continuous improvement within all programmatic areas, subject to the limitations of fiscal and other applicable constraints.

- Personnel will be held accountable for their actions related to protection of employees, the public, and the environment, in carrying out projects and other activities, in compliance with all applicable laws and regulations.

- Employees are responsible for personal compliance with policies, procedures and other guidance adopted for purposes of quality control, fiscal accounting, and other management objectives.

Appendix K. Quality Assurance/Quality Control for Inorganic Analyses

As noted elsewhere in this report, the analytical methods employed for inorganic analyses in the environmental chemistry program at CEMRC are based, when applicable, on various standard procedures (EPA, 1983, *Methods for Chemical Analysis of Water and Wastes,* EPA/600/4-79-020; EPA, 1997, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, EPA/SW-846; American Public Health Association, 1981, *Standard Methods for the Examination of Water and Wastewater*, *15th Edition*). For some matrix/analyte combinations, appropriate external standard procedures do not exist, and for those cases, specialized procedures have been developed to meet the needs of the WIPP EM and other research projects.

Instrumentation

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

Elemental analyses employed an atomic absorption spectrometer (AAS) with a computer-controlled Perkin-Elmer 5100PC atomic absorption unit with Zeeman background correction. Samples are introduced into the AAS by aspiration through an air/acetylene flame, by vaporization in a heated graphite furnace, by flow-injection via a heated quartz cell, or through an unheated quartz cell (for Hg). Additional inorganic analyses were performed using a Perkin-Elmer Elan 6000 inductively-coupled plasma mass spectrometer (ICP-MS). The two instruments used for the elemental analyses are complementary; AAS is more sensitive than the ICP-MS for some elements, especially for the hydride elements (As, Se and Hg), but compared with the ICP-MS, the AAS has a narrower linear range, requires more operator effort for calibration and operation, and has a much lower sample throughput.

General Quality Control

Several analytes are readily determined by more than one of the three instruments used at CEMRC, and this facilitates intra-laboratory comparisons as summarized below. Some of these internal QC comparisons are also summarized in other sections of this report that deal with specific media.

Independent quality assurance samples are obtained and analyzed to verify the performance of the instrumentation and the proficiency of the analyst. Both blind samples (obtained from an outside source, with true values not known at the time of analysis) and reference samples (obtained from an outside source or prepared internally, with true values known at the time of analysis) are used to perform this function. Regular QC verifications and batch QC provide records of sample performance data. Copies of the analytical data and performance results are maintained in the environmental chemistry instrument laboratory. The laboratory also carried out several informal inter-laboratory comparisons, and participated in two formal intercomparison studies in 2000.

Calibrations are verified with a standard obtained from a source different from that used for the procurement of the primary calibration standards. The calibration standards and the verification standards used at CEMRC are, where possible, traceable to NIST. A calibration blank is analyzed at the beginning of each workday when samples will be run, after every ten samples, and at the end of the day. To pass the calibration verification, blank results must be less than the minimum detectable level or ± 3 standard deviations (SD) of control limits. Analysis of a blank and a standard are performed at a frequency of 10% during analytical runs, and these are repeated at the close of each analytical run to verify continued calibration validity. Batch quality control samples are counted as samples in determining the 10% frequency, but the continuing check samples are not counted as samples in determining the 10% frequency.

Various types of field blanks, check solutions and laboratory fortified (spiked) samples are analyzed along with the samples as part of the QA/QC procedures. These vary somewhat among matrices and analyses as described in more detail below. In addition, when feasible, duplicate samples (both field and laboratory duplicates) are processed to evaluate reproducibility and sample homogeneity. Control charts for each matrix have been established, and ± 3 SD limits have been determined for future reference. Control charts are used to track the performance of the instrument and the sample preparation procedures. Similarly, spike recoveries are calculated, tracked, and reported along with the analytical data.

Beginning in January 2000, Method Detection Limits (MDLs) were determined using a procedure outlined in 40 CFR 136, Appendix B. Briefly, this involves processing and analyzing seven replicates of a low level standard as though they were samples. The standard deviations of the replicate analyses are multiplied by 3.14 to obtain the MDLs. For previous reports, the MDLs for metals were determined by replicate analyses of prepared blanks, as outlined by the instrument manufacturers. In some cases, this change produced improved limits of detection (note the filter detection limits for V, Cr, Zn Sr, Sb, etc.)(Tables K1 and K2). In other cases, the change caused the limits to increase (e.g., drinking water for Cu and Ba).

The use of a closed microwave digestion system for the preparation of the surface water, soil and sediment also contributed to better method detection limits for some analytes (Zn, Na, K, Mg, Al, Fe, and Ca) in these matrices. It should be noted however, that the method used in 2000 for determining detection level does not address the problem of a systematic bias (such as background filter contamination). Therefore, it is possible to have a high level of precision without an accompanying high level of accuracy. In situations where this happens, the MDL obtained by this method may not accurately represent the true limit of detection.

The environmental chemistry laboratory participated in the InterLaB WatR^{TM} Pollution WP-58 Proficiency Testing Program sponsored by Environmental Resource Associates. Overall, the lab received a "Very Good" rating, with a laboratory score of 90.3% (Table K3). Calcium and ortho-phosphate results were flagged "Not Acceptable" and magnesium results were flagged "Check for Error". A comparison of ICP-MS calibration standards to other known standards indicated that the calibration standards were high for calcium and magnesium. New standards were purchased from another source and the problem was resolved. New IC calibration standards were also purchased. After calibration with the new standards, the phosphate test sample was rerun and found to be within acceptance limits.

Quality Control for Analyses by IC

For IC 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.

Fluoride was not determined in sediments due to co-eluting organic peaks; method development is in progress to determine whether it will be possible to correct for this. QC samples included Laboratory Reagent Blanks (LRB), with one LRB prepared for each sample batch (normally a set of ten samples). LRB results below MDL are considered acceptable (Tables K4 and K5). LRB results higher than MDL must be subtracted from sample results. For aerosol filter analyses, some LRB results indicated reagent blank contamination for nitrate. Sources of blank contamination were traced to some laboratory personal protective equipment and various containers. More rigorous cleaning methods were employed to reduce contamination on these items. Laboratory Fortified Matrix (LFM) samples were also used for QC, with one LFM analysis per batch. Results from analyses of LFMs are used to calculate matrix spike recoveries, with recoveries of 70-130% considered acceptable. As prescribed by EPA Method 300.0, chloride and sulfate LFM values for surface water samples and chloride and sulfate LFM values in sediments were not reported because the concentration of the fortification was less than 25% of the background concentration (Table K6).

One duplicate analysis was performed for each sample batch. When available, duplicate aliquots of some field samples were analyzed. In cases where duplicate aliquots from the original sample were not feasible (such as aerosol filters), separate aliquots of the sample extract were analyzed. The relative percent difference (RPD) between the sample and the duplicate was calculated, with a difference of < 20% (or an absolute difference of ± MDL for samples less than five times the MDL) considered acceptable (Table K7).

A Laboratory Fortified Blank (LFB) was prepared and analyzed with each sample batch, using a spiked ultrapure water sample for aerosol filters and water samples, and certified reference materials (CRM) for soils and sediments. Recoveries of 85-115% were considered acceptable for aerosol filters, and water samples(Table K8). The CRM for soils and sediments was “Anions in Soils” from Environmental Research Associates (ERA) in Arvada, Colorado. Because there is no existing standard reference method for extracting soils or sediments for anion analysis, the results obtained by different methods may not be directly comparable. Recoveries for fluoride and phosphate were lower than desirable on CRM samples for soils (average recovery 73% and 67%, respectively), indicating a possible negative bias for fluoride and phosphate for this matrix. Fluoride and chloride recoveries for CRM samples from sediments were also low (average recovery 67% and 79%, respectively), indicating a negative bias for fluoride and chloride results from sediment samples. During 2000, matrix spikes were added to soil and sediment samples prior to extraction. This change resulted in lower recoveries for fluoride and phosphate than in previous years when the spikes were added after sample extraction. The standard procedure for future analyses will employ spiking after extraction.

Low-volume aerosol filters were also analyzed by IC for five cations with overall acceptable results (Table K9). Acceptance limits for each QC parameter were the same as previously described.

Quality Control for Elemental Analyses by ICP-MS and AAS

For elemental analyses, sets of quality control samples comparable to those previously described for the IC analyses were included with each sample batch. Detailed performance results for all QC measures are not presented here due to the number of elements that are determined by ICP-MS and AAS. For all media (aerosol filters, water, soils, and sediments) ICP-MS and AAS values were reported relative to the method detection limit as determined by the method outlined at 40 CFR 136, Appendix B. Digestion QC samples were analyzed at a frequency of 10% relative to samples. The digestion QC control parameters used for the evaluation of metals in aerosol filters included laboratory reagent blank (LRB) filters and vendor-supplied certified reference filters. Due to limitations in sample quantities, duplicate and post digestion spike analyses could not be performed for the ICP-MS and AAS analyses of aerosol samples.

The digestion QC parameters used for the evaluation of metals in water, soils, and sediments were based on EPA Contract Laboratory Program (1994, U.S. EPA Contract Laboratory Program (CLP) National Functional Guidelines for Inorganic Data Review, EPA 540/R-94013) and SW-846 methods (EPA, 1997, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, EPA/SW-846). No comparable control parameters presently exist for aerosol samples. The EPA CLP sets a required detection limit for metals referred to as the CRDL (Contract Required Detection Limit). The CRDL is used in determining acceptance criteria for blanks and duplicates. Due to the limited scope of analytes monitored in the CLP program, and the relatively high detection limit requirements, it is common practice in commercial laboratories to establish Practical Quantitation Limits (PQLs) which are used in the same manner as CRDLs for non-EPA projects. The PQL is obtained by multiplying the Method Detection Limit (MDL) by five. For drinking water, surface water, soils, and sediments, PQLs were calculated to evaluate precision based on the analysis of duplicate samples.

For aerosol samples, unused cellulose ester filters were used as LRB samples. LRB results above the MDL were subtracted from each associated batch of sample results because the LRB results were greater than the MDL for many of the analytes studied. Analysis of reagent digests have shown inherent contamination in the cellulose ester filters for some analytes (Ca, Cr, Cu, Mg, Ni, and Pb), while others (Al, Ba, Co, Hg, and La) are introduced in trace amounts by the reagents used for digestion. A cellulose ester CRM ("Trace Metals on Filter Media" from High Purity Standards in Charleston, South Carolina) was also used for QC of aerosol sample analysis. Mean recoveries for all analytes were within ± 15% of the manufacturer's established true values for all analytes except Se. The average recovery for Se was 78%, and therefore a negative bias is assumed to be present in reported values for Se in aerosol samples.

For FAS samples, unused Versapore® filters were used as laboratory reagent blank samples. LRB results above the MDL were subtracted from each associated batch of sample results because they were greater than the MDL for several of the analytes studied. Analysis of reagent digests showed inherent contamination in the Versapore filters for Cr, Cu, K, La, Mg, Na, Nd, Ni, Pb, Sm and V, while Be, Cd, Dy, Gd were introduced in trace amounts by the reagents during digestion. A cellulose ester CRM ("Trace Metals on Filter Media" from High Purity Standards in Charleston, South Carolina) was used for QC of the FAS samples. Mean recoveries for all analytes were within ± 15% of the manufacturer's established true values, with the exception of Cu (77%). The filter fortified by High Purity Standards has a much lower Cu background than the Versapore filter and the Cu level contained in the Versapore filters is significant compared to the fortification level, therefore when blank subtraction is performed the CRM recovery is biased low.

Four standard QC measures were used in association with analyses of drinking water and surface water samples. Ultrapure water was used for LRB samples, and average concentrations were less than the MDLs for all analytes except Al, Cr, Fe, Li, Pb, Sb, Sn, Sr, Th, and Ti in drinking water samples and Be, La, Mn and Zn in surface water. All results were corrected for blank bias. A LFB was prepared by adding a known quantity of each analyte of interest to ultrapure water. All analytes for drinking water and surface water preparation were recovered within the 85-115% limits as specified by EPA methods.

LFM samples were also used for QC in analyses of water samples, with all recoveries within a 70%-130% acceptance window, with the exception of Ba in surface water (31%). In compliance with the EPA CLP, the results for Ba must be considered estimates and are possibly biased low. When evaluating LFM results, the concentration of the analyte in the sample must also be considered. If the concentration of the fortification is less than 25% of the background concentration, the recovery of the LFM is not reported. A duplicate digestion analysis of water samples was also performed to demonstrate reproducibility, but a slight modification of the EPA CLP program was used for acceptance determination. If the sample result were less than the PQL, a ± PQL control limit was used. If the sample result were greater than the PQL, a ± 20% RPD control limit was used. All duplicate results were within these modified acceptance limits.

For soils and sediments, LRB samples of prepared ultrapure water were compared to MDLs to determine if contamination was introduced during sample preparation. LRB results were within acceptance limits for soils with the exception of Al, Ba, Ca, Cd, Cr, Co, Cu, Fe, La, K, Mg, Mn, Na, Ni, Pb, Sb, Sn, Sr and Zn, which were above the MDL. The sample measurements were at least ten times higher than the LRB results for all analytes except Ca, Cd, Cr, Cu, Na, Ni Sb, Sn and Zn. The contaminant effects on the measurements are considered negligible for analytes with sample concentrations greater than 10 times the blank level. Sample results were corrected for bias by reagent blank subtraction for all analytes with LRBs above the MDL, regardless of sample concentration.

Sediment LRB results were less than the MDL with the exception of Al, Ba, Ca, Co, Cu, Cr, Fe, Gd, Hg, K, La, Li, Mg, Mn, Nd, Ni, Pb, Sb, Sr, Ti and Zn. The elemental concentrations of all analytes in the sediment samples were 10 times the level in the blanks with the exception of Sb in all sediment samples and Hg in four of the sediment samples. Results for Sb and Hg in these samples may be biased high. For samples with results greater than ten times the blank levels, the contaminant effects on measurements in sediments are considered negligible. Sample results were corrected for bias by reagent blank subtraction for all analytes with LRBs above the MDL, regardless of sample concentration.

A CRM ("Priority Pollutant T/CLP Soil" from ERA) was obtained and prepared with the soil and sediment samples to demonstrate matrix-specific performance of digestion and analysis procedures. All analytes were recovered within the supplier's specified control limits for all digestions with the exception of Ag and Mn. Due to low recovery, Ag results may be biased low for all soils and sediments. Due to high recovery, Mn results may be biased high for all soils and sediments.

Duplicate digestions were preformed for soil and sediment using a modification of the EPA CLP program for acceptance determination. If the sample results were less than the PQL, a ± PQL control limit was used. If the sample results were greater than the PQL a ± 20% RPD control limit was used. The EPA Inorganic Usability Criteria (1994, *U.S. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review*, EPA 540/R-94013) indicate that a 35% RPD (± 2 times the PQL) control limit may be adopted for soils and sediments due to the relatively high level of inhomogeneity compared with other matrices. For soils and sediments, the average RPD over the duplicate digestions performed was within these broader usability acceptance limits for all analytes, except Na (95% RPD) in soils and Ag (67% RPD) and Sb (38% RPD) in sediments. One batch of soils had unacceptable duplicate results for several analytes (Be, Ce, Co, Cu, Mo, Na, and Ti) even when compared to the broader guidelines. It could not be determined whether a digestion error had occurred or if sample inhomogeneity was the cause. The results for the seven samples in this digestion batch must be considered estimated values according to the usability guidelines.

A LFM also was prepared for each batch of soils and sediments processed. The average recovery was within 70%-130% for all analytes with the exception of Na (145%) in the soils and Be (56%), Se (69%) and Sb (69%) in the sediments. In compliance with the EPA CLP usability guidelines, the sediment results for Be, Se and Sb must be considered estimates that are biased low. The Na results for the soils must also be considered estimates that are biased high.

Conclusions and Future Improvements

In IC analysis, development is in progress to improve the resolution of fluoride and its separation from co-eluting organic species in the sediments.

For metals analysis, the detection limits are dependent upon how clean the blank, reagents and preparation labware can be made. Although CEMRC's detections limits are already low, the MDLs can be improved for some analytes. Reagent grade acid is double distilled in-house, using a quartz distillation apparatus, and this produces ultrapure acid that is initially quite pure. A closed vessel microwave digestion sample preparation system was employed for the 2000 sample preparation and an improvement in our detection limits was observed. At present we are investigating alternative filter materials for use in the soil and sediment preparations as the filters in use were found to be a source of contamination for many analytes. Investigations into preparation method modifications are also underway in an effort to increase reproducibility and reduce contamination introduced by preparation.

Table K1. Comparison of 1999 and 2000 Method Detection Limits for Analyses by AAS

Instrument	Analyte	[a]Units	1999 Method Detection Limit			Accuracy	Precision
			Air Filter	Water	Soil: Acid Extract		
AAS ([b]CV)	Hg	ppt	[e]NA	6	6	± 30%	± 20%
AAS ([c]FIH)	As	ppt	NA	30	150	± 30%	± 20%
	Se	ppt	NA	120	600	± 30%	± 20%
AAS ([d]GF)	As	ppb	1.3	NA	1.4	± 30%	± 20%
	Se	ppb	1.1	NA	1.2	± 30%	± 20%
	Fe	ppb	28	11	NA	± 30%	± 20%

Instrument	Analyte	Units	2000 Method Detection Limit				Accuracy	Precision
			Air Filter	Water		Soil: Acid Extract		
				Drinking	Surface			
AAS (CV)	Hg	ppt	NA	12	0.2	NA	± 30%	± 20%
AAS (FIH)	As	ppt	NA	80	44	NA	± 30%	± 20%
	Se	ppt	NA	90	69	NA	± 30%	± 20%
AAS (GF)	As	ppb	1.4	NA	NA	1.4	± 30%	± 20%
	Se	ppb	1.2	NA	NA	0.92	± 30%	± 20%
	Fe	ppb	29	NA	NA	NA	± 30%	± 20%

[a] Units: ppt = parts per trillion; ppb = parts per billion
[b] CV = cold vapor (Surface waters by cold vapor purge and trap hydride)
[c] FIH = flow injection hydride
[d] GF = graphite furnace
[d] NA = not analyzed

Table K2. Comparison of 1999 and 2000 Method Detection Limits for Analyses by ICP-MS

Analyte	Air Filters (μg L^{-1})		Drinking Water (μg L^{-1})		Surface Water (μg L^{-1})		Soil/Sediment (mg L^{-1})	
	1999	2000	1999	2000	1999	2000	1999	2000
Ag	0.01	0.01	0.00	0.01	0.08	0.01	0.05	0.10
Al	38	11	1.8	6.0	17	46	45	34
Ba	0.65	0.34	0.007	0.09	0.45	0.03	2.2	0.21
Be	0.06	0.07	0.04	0.09	0.03	0.05	0.02	0.15
Ca	97	28	6.1	18	150	77	440	154
Cd	0.06	0.04	0.01	0.03	0.46	0.05	0.30	0.10
Ce	0.008	0.007	0.0007	0.01	0.03	0.05	0.03	0.13
Co	0.29	0.07	0.01	0.06	0.03	0.04	0.23	0.16
Cr	7.1	2.6	0.12	0.07	0.38	0.26	3.1	0.47
Cu	0.33	0.45	0.09	0.30	1.6	0.65	5.8	0.15
Dy	0.002	0.005	0.002	0.01	0.004	0.007	0.006	0.10
Er	0.003	0.008	0.002	0.01	0.001	0.005	0.004	0.11
Eu	0.002	0.006	0.001	0.01	0.002	0.009	0.005	0.13
Fe	50	29	1.1	5.4	34	15	120	28
Gd	0.002	0.008	0.002	0.01	0.004	0.007	0.007	0.11
Hg	0.02	0.02	NA	NA	NA	NA	NA	0.05
K	53	21	13	17	59	23	390	36
La	0.006	0.15	0.0004	0.01	0.02	0.07	0.02	0.09
Li	0.43	0.13	0.11	0.06	0.53	0.16	0.31	0.13
Mg	9.7	12	1.7	1.3	19	10	120	15
Mn	0.35	0.38	0.01	0.05	0.57	0.11	0.88	0.37
Mo	0.72	0.11	0.05	0.10	0.02	0.10	0.32	0.12
Na	150	48	3.7	3.7	190	38	580	23
Nd	0.006	0.007	0.002	0.01	0.01	0.05	0.01	0.10
Ni	1.6	0.63	0.02	0.01	1.7	0.65	1.3	0.32
Pb	0.08	0.04	0.04	0.07	1.9	0.17	2.2	0.07
Pr	0.003	0.004	0.0007	0.01	0.005	0.05	0.007	0.09
Sb	0.67	0.04	0.006	0.01	0.24	0.14	0.17	0.09
Sm	0.003	0.007	0.003	0.01	0.002	0.09	0.007	0.07
Sn	35	10	0.12	1.5	20	7.5	74	NA
Sr	0.60	0.07	0.21	0.01	0.53	0.51	1.2	0.51
Th	0.004	0.003	0.00	0.01	0.006	0.006	0.007	0.08
Ti	4.7	4.0	0.12	0.04	0.39	0.24	1.5	3.4
Tl	12	0.004	0.04	0.01	7.9	0.03	1.4	0.14
U	0.003	0.005	0.00	0.01	0.002	0.003	0.008	0.07
V	4.7	0.90	0.37	0.06	0.51	0.13	5.5	1.7
Zn	19	2.6	0.27	0.12	21	1.3	27	1.4

Table K3. Summary of Participation in Environmental Chemistry Performance Evaluation Testing[a]

Analyte	Percent Bias	[b]Method Description	[c]Performance Evaluation
Ag	-2.7	200.8	Acceptable
Al	0.7	200.8	Acceptable
Ammonia as N	12.7	300.0	Acceptable
As	7.0	7060	Acceptable
Ba	-5.2	200.8	Acceptable
Be	-3.8	200.8	Acceptable
Ca	-13.1	200.8	Not Acceptable
Cd	-5.4	200.8	Acceptable
Chloride	-3.6	300.0	Acceptable
Co	1.9	200.8	Acceptable
Cr	-2.6	200.8	Acceptable
Cu	4.7	200.8	Acceptable
Fe	5.6	200.8	Acceptable
Fluoride	-7.0	300.0	Acceptable
K	3.3	200.8	Acceptable
Mg	-10.6	200.8	Check for Error
Mn	-0.5	200.8	Acceptable
Mo	2.9	200.8	Acceptable
Na	-1.8	200.8	Acceptable
Ni	4.0	200.8	Acceptable
Nitrate as N	9.6	300.0	Acceptable
Ortho-phosphate as P	-18.4	300.0	Not Acceptable
Pb	-5.8	200.8	Acceptable
Sb	1.6	200.8	Acceptable
Se	-7.4	7740	Acceptable
Sr	-3.5	200.8	Acceptable
Sulfate	-11.7	300.0	Acceptable
Tl	-3.7	200.8	Acceptable
V	-0.4	200.8	Acceptable
Zn	-3.7	200.8	Acceptable

[a] The testing program used was the Environmental Resource Associates InterLaB WatR™ Pollution WP-58 Proficiency Testing Program.

[b] The method description number corresponds to the EPA standard testing method used.

[c] Definitions:

Acceptable: reported value falls within the acceptance limits.
Not Acceptable: reported value falls outside acceptance limits.
Check for Error: reported value falls within acceptance limits and outside of warning limits.

Table K4. Method Detection Limits for Analyses by Ion Chromatography

Sample Matrix	Units	Unit Type	Fluoride	Chloride	Nitrite	Nitrate	Phosphate	Sulfate
Low volume aerosol filter	μg L^{-1}	General	25.5	29.9	21.4	82.9	20.8	30.1
Drinking water and surface water	μg L^{-1}	General	68	80	[a]NR	45	36	35
Soil	μg L^{-1}	General	68.1	79.2	39.0	44.9	34.6	36.1
Sediment	μg L^{-1}	General	16	22	NA	59	250	140
[b]Low volume aerosol filter	μg m^{-3}	Matrix specific	0.7286	0.8571	0.0229	0.0482	0.0375	0.0386
[c]Drinking water and surface water	μg L^{-1}	Matrix specific	68	80	NR	45	36	35
[d]Soil	mg kg^{-1}	Matrix specific	0.68	0.80	0.39	0.45	0.35	0.36
[d]Sediment	mg kg^{-1}	Matrix specific	0.016	0.022	NR	0.059	0.250	0.140

[a] NR = not reported
[b] Teflo® 0.2 micron 45 mm diameter filter extracted into 30 mL ultrapure water; nominal flow volume of 28 L^3 of air per filter
[c] Water samples are analyzed by direct injection
[d] 1 g of solid material extracted into 10 mL ultrapure water

Table K5. Mean Laboratory Reagent Blank Results for Ion Chromatography

Sample Matrix	Fluoride	Chloride	Nitrite	Nitrate	Phosphate	Sulfate
Low volume aerosol filter (μg L^{-1})	5.47	15.5	4.9	51.7	1.7	16.4
Drinking water and surface water (mg L^{-1})	0.6744	-0.0838	NR	0.1566	0.0002	0.0060
Soil (mg kg^{-1})	-0.0563	-0.0324	-0.1241	1.1341	0.1817	0.1481
Sediment (mg kg^{-1})	0	0	[a]NR	0.0009	0	0

[a] NR = not reported

Table K6. Mean Laboratory Fortified Matrix Recovery Results for Ion Chromatography

Sample Matrix	Fluoride	Chloride	Nitrate	Phosphate	Sulfate	% Recovery Limit
Low volume aerosol filter	97%	91%	100%	98%	107%	70-130%
Drinking water & surface water	77%	93%	79%	72%	102%	70-130%
Soil	73%	[a]NA	84%	72%	NA	70-130%
Sediment	Not Reported	NA	95%	74%	NA	70-130%

[a]NA = not applicable; concentration of analyte in sample is more than 4 times spike concentration

Table K7. Mean Relative Percent Difference Results for Duplicate Analyses using Ion Chromatography

Sample Matrix	Fluoride	Chloride	Nitrite	Nitrate	Phosphate	Sulfate	% Recovery Limit
Low volume aerosol filter	[a]NA	NA	NA	4	NA	0.8%	± 20
Drinking water/ surface water	1%	3%	[b]NR	1%	3%	9%	± 20
Soil	NA	14%	NR	-7%	5%	4%	± 20
Sediment	-2.6%	2%	NR	4.9%	NA	-1%	± 20

[a]NA = not applicable; concentration present in samples was < 5 times MDL therefore ± MDL control limit used

[b]NR = not reported

Table K8. Mean Laboratory Fortified Blank (LFB) or Certified Reference Material (CRM) Recovery Results for Ion Chromatography

Sample Matrix	**Fluoride (%)**	**Chloride (%)**	**Nitrate (%)**	**Phosphate (%)**	**Sulfate (%)**	**Recovery Limit (%)**
Low volume aerosol filter (LFB)	99	98	102	99	100	85-115
Drinking water and surface water (LFB)	95	102	91	93	102	85-115
Soil (CRM)	73	92	81	67	80	80-120
Sediment (CRM)	67	79	90	101	117	80-120

Table K9. QC Results for Cations in Aerosol Filters Analyzed by Ion Chromatography

Parameter	**Sodium**	**Ammonium**	**Potassium**	**Magnesium**	**Calcium**
MDL (µg L^{-1})	10	13	20	7	8
MDL (µg m^{-3})	0.0107	0.0139	0.0214	0.0075	0.0086
Average LRB (µg L^{-1})	53	14	12	15	48
Average LFM recovery (%)	114	112	106	105	108
Average RPD (%)	1.7	0.6	0.8	[a]NA	1.8
Average LFB recovery (%)	107	103	98	95	99

[a] NA = not applicable; concentration present in samples was < 5 times MDL therefore ± MDL control limit used

Appendix L. Quality Assurance/Quality Control for Radioanalyses

The CEMRC radioanalytical program continued method development throughout 2000, resulting in standard methodologies for determining background levels of alpha- and gamma-emitting radionuclides in sediment, and for Am and Pu in high volume air filters. QA activities in 2000 were essentially the same as they were for 1999, but included an increase in the number of analytes for performance evaluation samples and in the use of matrix spiked samples.

During 2000, the CEMRC radioanalytical program participated in two rounds of the DOE Environmental Measurement Laboratory Quality Assurance Program (EML QAP), resulting in "acceptable" ratings for 56 individual determinations of eighteen analytes in glass fiber filters, soil, vegetation and water samples (Table L1). One "warning" rating was received for ^{239,240}Pu in soil in the September 1999 distribution. An "acceptable" rating for ^{239,240}Pu in soil was received in the March 2000 distribution. Two "warning" ratings were received for U in soil samples from the March 2000 distribution. The radioanalytical program also participated in five rounds of the National Institute of Standards and Technology (NIST) Radiochemistry Intercomparison Program (NRIP). Reports of traceability were received for measurements of four analytes in glass fiber filters, three analytes in two separate sets of soil samples, four analytes in water and four analytes in synthetic urine (Table L2). CEMRC reported Am results for one set of soil samples that were within 5% of the NIST values, but not within the traceability limits. However, traceability was achieved for Am on the following set of soil performance tests. Methods to calculate the reported uncertainty for NRIP samples were revised during 2000 to better reflect potential systematic biases.

Routine activities conducted for radioanalyses included (1) tracking and verification of analytical instrument performance, (2) use of American Chemical Society certified reagents, (3) use of American Society for Testing and Materials (ASTM) Type II water for reagent preparations, (4) use of NIST traceable radionuclide solutions and (5) verification testing of radionuclide concentrations for tracers not purchased directly from NIST. In addition to analyte-surrogate isotopic tracers used in samples, ^{148}Gd was added to samples where no alpha emitters were expected (e.g. thorium blanks) to provide a monitor that spectral shifting had not taken place. For high volume air filters, ^{209}Po was added to the Am portion of the sample after chemical separation of Am, but before purification of Am. The ^{209}Po was used as a monitor that ^{210}Po, a naturally occurring radionuclide that can interfere with the ^{243}Am tracer, was chemically removed from the sample.

Daily (or each time the system was used) performance checks were done on the gas-flow, α/β proportional counter used for the FAS program. These checks included counting ^{239}Pu and ^{90}Sr standards for efficiency control charting and ensuring that α/β cross-talk were within limits. Sixty-minute background counts were also recorded daily. Standards made with ^{152}Eu were counted daily or before system use on the high purity Ge (HPGe) coaxial and well detector systems used for drinking water, surface water, soil, and FAS samples. Efficiency, centroid, and resolution measurements were made and tracked using the detector system software. Routine background determinations were made on the HPGe detector systems by counting blank samples, and the data were used to blank correct the sample concentrations. Pulser checks were performed on the alpha spectrometer before each sample was counted to ensure acceptable detector resolution and centroid. Also, control charting of alpha detector response, resolution, and centroid was implemented using ^{148}Gd sources.

Standard procedures included use of blanks to identify contamination or interference carried through the analytical process, but blank measurements were not used to correct measurements made by alpha spectroscopy. Blanks constituted approximately 10% of the sample load for WIPP EM analyses, and consisted of laboratory reagent blanks and matrix blanks. Matrix blanks employed a medium as close as possible to that of the sample matrix that had been verified free of the radioanalytes of interest. A laboratory reagent blank was used when no suitable matrix blank was available, and consisted of major inorganic constituents known to compose the sample matrix. Results for blank measurements (Table L3) indicated that Pu and Am contamination (considered to result from sample cross contamination, especially with analysis of higher activity performance samples) was detected infrequently, but the practice of analyzing blanks at least 10% of the time will be continued to monitor for contamination. ^{241}Am contamination appeared in blanks for one batch of performance assessment water samples but the blank activity was a small fraction of the actual sample activity. Detectable activity of ^{228}Th in blanks can be attributed to the addition of ^{232}U tracer to the sample. Due to the amount of time required for U to be chemically separated from Th during sample preparation, ^{228}Th ingrowth produces a small amount of ^{228}Th impurity in the sample. In addition, some small amount of ^{228}Th impurity may be present in the ^{232}U tracer due to incomplete tracer purification. Mathematical corrections for ^{228}Th ingrowth have been implemented for future analyses. The most common source of detectable ^{234}U in blanks is spectral tailing of ^{232}U tracer into the ^{234}U region of interest, but another possible source is incomplete removal of ^{234}U by water purification systems. The magnitude of contributions to activity measurements for ^{234}U from these sources will be investigated further in the coming year.

Isotopic tracers were used to determine the analytical system's effectiveness in extracting, purifying, and quantifying the isotopes of interest. Although some samples had tracer recoveries < 20% for Am, U and Th (Table L4), they were still adequate to meet minimum detectable concentration requirements for reporting under the study plan. In general, Am yields for analyses during 2000 were improved over those recorded in 1999, and Am yields were greater for filter samples than other environmental media. In high volume air filters, a few Am yields were greater than 100% which is attributed to ^{210}Po spectral interferences with the ^{243}Am tracer in samples that were analyzed before initiation of the use of ^{209}Po as a purity monitor. However, these samples had ^{241}Am activity well below MDC, so reported results were not affected. Compared to 1999, Pu yields were somewhat lower for analyses conducted during 2000 for water and soil samples. Relative variance in tracer yields (as indicated by coefficients of variation) was highest for Pu in water samples (45%), Am in soil samples (44%) and U in soil samples (43%). Overall, relative variance in yields decreased in 2000, indicating better control of the analytical process.

Analyses of laboratory duplicates (aliquots of the same sample analyzed separately) were used to estimate precision, which is analyte- and matrix-specific (Table L5). Approximately 10% of the sample load during WIPP EM soil analyses was laboratory duplicate samples. The mean relative percent difference (RPD) between isotope activity concentrations in laboratory duplicate WIPP EM soil samples was greatest for ^{239,240}Pu, ^{241}Am and ^{235}U. High RPD values can be associated with both variations introduced in the analytical process and background heterogeneity in the distribution of the analytes within the original sample. However, RPDs should be interpreted in comparison to relative error ratios (RER). For example, for ^{241}Am, although the RPD is high (34.2%), the RER is low (1.01), reflecting the relatively high counting uncertainty resulting from the extremely low activity concentrations of ^{241}Am in the samples. By comparison, the mean RPD for ^{228}Th was relatively low, while the mean RER was the highest of the nine analytes, reflecting the smaller counting uncertainties resulting from relatively higher ^{228}Th activity concentrations in the samples. The relative contributions of analytical error and background heterogeneity can thus not be determined from these results. For five of eight analytes, the RPDs for WIPP EM soil analyses in 2000 were lower than those reported for analyses during 1999.

Analyses of matrix spike samples were used to test the effectiveness of the analytical procedure to accurately quantify the analyte of interest (Table L6). Approximately 10% of the non-FAS sample load during WIPP EM analyses were matrix spikes. For water analyses, NIST traceable ^{239}Pu, ^{241}Am, ^{238}U and ^{230}Th standards were spiked into 3 L of ASTM Type II water. For air filter analyses, NIST traceable ^{239}Pu and ^{241}Am were spiked onto blank air filters. For soil analyses, EML QAP-50 soil was used as the matrix spike. A surface water matrix spike was prepared and used with sample batches of both surface water and drinking water. One surface water matrix spike yielded a positive 22% bias for ^{239,240}Pu, which may be attributed to a low chemical yield that produced overestimation of the Pu activity concentration. Despite this, all values for ^{239,240}Pu measured in the surface water and drinking water samples were < MDC, eliminating any effect of the bias. ANSI N42.22 criteria were met for all other matrix spikes during WIPP EM analyses.

Table L1. Summary of Participation in Environmental Monitoring Laboratory Quality Assurance Program

Media	Radionuclide	[a]Percent Bias QAP-51	[b] Results QAP-51	Percent Bias QAP-52	Results QAP-52
Air Filters	^{241}Am	-7.1	Acceptable	-2.3	Acceptable
	^{57}Co	-3.2	Acceptable	-0.2	Acceptable
	^{60}Co	-0.5	Acceptable	2.6	Acceptable
	^{137}Cs	-5.6	Acceptable	6.6	Acceptable
	^{238}Pu	-4.2	Acceptable	12.5	Acceptable
	^{239,240}Pu	-1.5	Acceptable	9.0	Acceptable
	^{54}Mn	4.0	Acceptable	5.5	Acceptable
	^{234}U	-0.8	Acceptable	4.8	Acceptable
	^{238}U	5.7	Acceptable	4.8	Acceptable
Soil	^{228}Ac	NA	NA	2.5	Acceptable
	^{212}Bi	NA	NA	5.7	Acceptable
	^{214}Bi	NA	NA	7.3	Acceptable
	^{137}Cs	NA	NA	0.3	Acceptable
	^{40}K	NA	NA	-1.9	Acceptable
	^{212}Pb	NA	NA	1.8	Acceptable
	^{214}Pb	NA	NA	7.5	Acceptable
	^{239,240}Pu	-10.9	Warning	22.9	Acceptable
	^{234}U	7.4	Acceptable	18.9	Warning
	^{238}U	4.5	Acceptable	18.4	Warning
Vegetation	^{241}Am	1.0	Acceptable	-6.7	Acceptable
	^{244}Cm	15.5	Acceptable	10.0	Acceptable
	^{60}Co	10.8	Acceptable	10.4	Acceptable
	^{137}Cs	9.1	Acceptable	10.1	Acceptable
	^{40}K	12.7	Acceptable	3.8	Acceptable
	^{239,240}Pu	3.7	Acceptable	-3.2	Acceptable
Water	^{241}Am	11.3	Acceptable	3.6	Acceptable
	^{60}Co	1.4	Acceptable	6.3	Acceptable
	^{137}Cs	0.5	Acceptable	2.9	Acceptable
	Gross Alpha	NA	NA	1.8	Acceptable
	Gross Beta	NA	NA	-2.9	Acceptable
	^{238}Pu	3.8	Acceptable	10.2	Acceptable
	^{239,240}Pu	2.9	Acceptable	13.3	Acceptable
	^{234}U	6.8	Acceptable	7.9	Acceptable
	^{238}U	12.2	Acceptable	1.6	Acceptable

[a] Percent bias is calculated as the mean of measurements by CEMRC minus the sponsor's known value, expressed as a percentage relative to the known value.

[b] Results for EML QAP "acceptable" are defined in Report EML-605, December 1999 for QAP-51 and in Report EML-608, June 2000 for QAP-52; NA = not applicable, nuclide was not analyzed

Table L2. Summary of Participation in NIST Radiochemistry Intercomparison Program

Media	Radionuclide	[a]Percent Bias	[b]Results
Air Filter	^{241}Am	3.7	NIST Traceable, 6.4%
	^{238}Pu	1.2	NIST Traceable, 7.1%
	^{240}Pu	3.5	NIST Traceable, 8.6%
	^{238}U	3.4	NIST Traceable, 9.7%
Soil (SO-3)	^{241}Am	-4.5	Not Traceable
	^{238}Pu	-0.7	NIST Traceable, 2.5%
	^{238}U	-1.2	NIST Traceable, 5.9%
Soil (SO-11)	^{241}Am	-2.3	NIST Traceable, 4.2%
	^{238}Pu	1.5	NIST Traceable, 4.1%
	^{238}U	2.7	NIST Traceable, 4.0%
Water	^{241}Am	2.5	NIST Traceable, 12%
	^{238}Pu	1.0	NIST Traceable, 10%
	^{240}Pu	2.0	NIST Traceable, 9%
	^{238}U	-2.2	NIST Traceable, 8%
Synthetic Urine	^{241}Am	-0.6	NIST Traceable, 13%
	^{238}Pu	-4.0	NIST Traceable, 13%
	^{239}Pu	-3.1	NIST Traceable, 8.5%
	^{238}U	4.3	NIST Traceable, 7.4%

[a] Percent bias is the difference between sponsor's known value for a sample, and the mean of measurements by CEMRC for the sample, expressed as a percent relative to the sponsor's value
[b] Results for NIST Traceablity are defined under ANSI 42.22 standards at the stated limit

Table L3. Results for Radioanalyses of Actinides in Blank Samples

Parameter	**Analyte and Matrix Group**								
	^{238}Pu	**^{239,240}Pu**	**^{241}Am**	**^{234}U**	**^{235}U**	**^{238}U**	**^{228}Th**	**^{230}Th**	**^{232}Th**
	Soil (WIPP EM 2000, NRIP, EML QAP 51 & QAP 52)								
[a]N	7	7	6	4	2	5	5	5	5
[b]N > MDC	0	0	1	2	0	2	3	2	1
[c]Minimum (mBq kg^{-1})	[d]NA	NA	21	148	NA	183	216	76	112
[e]Maximum (mBq kg^{-1})	NA	NA	NA	185	NA	203	682	427	NA
	Water (WIPP EM 2000 Drinking Water & Surface Water, NRIP, EML QAP 51 & QAP 52)								
N	7	7	5	7	7	7	2	2	2
N > MDC	0	0	2	7	2	3	1	0	0
Minimum (µBq L^{-1})	NA	NA	4290	200	112	157	490	NA	NA
Maximum (µBq L^{-1})	NA	NA	12770	5258	2732	2796	NA	NA	NA
	FAS Quarterly Composite Filters (April 1999 - June 2000)								
N	8	8	8	8	8	8	8	8	8
N > MDC	0	0	0	4	1	1	4	0	0
Minimum (µBq)	NA	NA	NA	344	33	573	484	NA	NA
Maximum (µBq)	NA	NA	NA	789	NA	NA	814	NA	NA
	Low Volume Air Filters (2000 FAS Incident Filters, NRIP, EML QAP 51 & QAP 52)								
N	20	20	20	17	17	17	14	14	14
N > MDC	0	2	2	9	2	4	10	0	0
Minimum (µBq)	NA	176	425	283	229	500	700	NA	NA
Maximum (µBq)	NA	257	912	833	264	733	1350	NA	NA
	High Volume Air Filters (WIPP EM February 1998 - June 2000)								
N	18	18	18	0	0	0	0	0	0
N > MDC	0	1	1	NA	NA	NA	NA	NA	NA
Minimum (µBq)	NA	78	186	NA	NA	NA	NA	NA	NA
Maximum (µBq)	NA	NA	NA	NA	NA	NA	NA	NA	NA
Vegetation (EML QAP 51 & QAP 52)									
N	2	2	2	0	0	0	0	0	0
N > MDC	0	0	0	NA	NA	NA	NA	NA	NA

[a] Number of blanks analyzed
[b] Number of blank samples with values greater than MDC (minimum detectable concentration)
[c] Not applicable for isotopes measured above MDC in < 2 blanks
[d] Minimum activity/activity concentration observed in blanks > MDC
[e] Maximum activity/activity concentration observed in blanks > MDC

Table L4. Laboratory Tracer Recovery Results for Radioanalyses of Actinides

[a]Matrix Group	Parameter	[b]Tracer Recovery by Analyte			
		Pu	**Am**	**U**	**Th**
Soil WIPP EM 2000 NRIP EML QAP 51 EML QAP 52	[c]N	73	64	50	46
	[d]Mean (%)	64	66	58	69
	[e]CV (%)	28	44	43	39
	[f]Minimum (%)	15	6	17	12
	[g]Maximum (%)	94	97	94	97
	[h]N < 20%	1	9	2	4
Water WIPP EM 2000 NRIP EML QAP 51 EML QAP 52	N	33	29	33	20
	Mean (%)	47	81	72	88
	CV (%)	45	23	18	15
	Minimum (%)	13	34	50	45
	Maximum (%)	80	97	96	98
	N < 20%	3	0	0	0
FAS Quarterly Composite Filters April 1999 – June 2000	N	12	12	15	12
	Mean (%)	76	82	59	76
	CV (%)	21	18	39	30
	Minimum (%)	37	52	5	11
	Maximum (%)	92	94	93	99
	N < 20%	0	0	2	1
Low Volume Air Filters FAS Incident NRIP EML QAP 51 EML QAP 52	N	35	36	32	18
	Mean (%)	79	83	66	78
	CV (%)	27	25	35	27
	Minimum (%)	1	2	24	8
	Maximum (%)	98	105	101	93
	N < 20%	1	2	0	1
High Volume Air Filters WIPP EM February 1998 - June 2000	N	165	165	[i]NA	NA
	Mean (%)	75	92	NA	NA
	CV (%)	17	11	NA	NA
	Minimum (%)	11	62	NA	NA
	Maximum (%)	95	155	NA	NA
	N < 20%	1	0	NA	NA
Vegetation EML QAP 51 EML QAP 52	N	7	7	NA	NA
	Mean (%)	75	76	NA	NA
	CV (%)	35	24	NA	NA
	Minimum (%)	26	46	NA	NA
	Maximum (%)	95	92	NA	NA
	N < 20%	0	0	NA	NA

[a] Each group includes samples, blanks, and quality assurance samples of the various types of environmental media; types within each group are described in text

[b] Tracer = an isotope of the radionuclide of interest, that is distinguishable from the analyte of interest, but assumed to behave the same in radiochemical processes

[c] N = number of samples included in each analysis; EML and NRIP analyses did not require the determination of Th

[d] Mean tracer percent yield

[e] CV = coefficient of variation for tracer percent yield; standard deviation expressed as percentage of mean

[f] Minimum observed tracer percent yield from all analyses

[g] Maximum observed tracer percent yield from all analyses

[h] Number of samples with tracer percent yields less than 20%; samples having Pu yields < 20% were reanalyzed (except high volume air filters)

[i] NA = not applicable; not included in analyses

Table L5. Results of Radioanalyses Of Actinides in Replicate Soil Samples

Parameter	Results by Analyte								
	^{238}Pu	^{239,240}Pu	^{241}Am	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th
[a]N > MDC	0	5	5	2	2	2	5	5	5
[b]Mean RPD (%)	[f]NA	13.6	34.2	6.9	12.9	1.1	8.2	5.4	7.6
[c]Maximum RPD (%)	NA	47.3	126	7.7	14.5	1.3	19.8	10.2	13.2
[d]Mean RER	NA	0.81	1.01	1.19	0.64	0.20	2.39	1.55	2.11
[e]Maximum RER	NA	2.74	2.95	1.29	0.65	0.23	5.16	2.71	3.40

[a] Number of replicate sample pairs > MDC for subject analyte

[b] Mean relative percent difference (RPD); RPD defined as the absolute value of the difference between the analyte concentration in the first sample (a) and the concentration in the second sample (b), divided by the average of the two concentrations ($\overline{x}$) and expressed as a percent: $RPD = \frac{|a-b|}{\overline{x}} \times 100\ \%$

[c] Maximum relative percent difference (RPD)

[d] Relative error ratio (RER); RER defined as the absolute value of the difference between the analyte concentration in the first sample (c_1) and the concentration in the second sample (c_2), divided by the quadratic sum of the count standard deviation (uncertainty) of the first sample (s_1) and the second sample (s_2): $RER = \frac{|c_1 - c_2|}{\sqrt{s_1^2 + s_2^2}}$

[e] Maximum relative error ratio (RER)

[f] NA = not applicable; no measurements were > MDC

Table L6. Ranges of Bias as Measured by Matrix Spikes in Radioanalyses of Actinides

Matrix Group	**Parameter**	**[a]Percent Bias between Measured and Known Values by Analyte**								
		^{238}Pu	**^{239,240}Pu**	**^{241}Am**	**^{234}U**	**^{235}U**	**^{238}U**	**^{228}Th**	**^{230}Th**	**^{232}Th**
Soil WIPP EM 2000	[b]N	4	4	2	1	[c]NA	1	NA	NA	NA
	[d]Minimum	-5.9	3.6	0.4	-3.0	NA	-3.5	NA	NA	NA
	[e]Maximum	16.8	14.2	7.9	-3.0	NA	-3.5	NA	NA	NA
	[f] % Meeting ANSI N42.22 Criteria	100	100	100	100	NA	100	NA	NA	NA
Surface Water WIPP EM 2000	N	NA	1	1	NA	NA	1	NA	1	NA
	Minimum	NA	22.3	0.0	NA	NA	0.0	NA	2.5	NA
	Maximum	NA	22.3	0.0	NA	NA	0.0	NA	2.5	NA
	% Meeting ANSI N42.22 Criteria	NA	0	100	NA	NA	100	NA	100	NA
High Volume Air Filters WIPP EM February 1998-June 2000	N	NA	8	8	NA	NA	NA	NA	NA	NA
	Minimum	NA	0	0	NA	NA	NA	NA	NA	NA
	Maximum	NA	-5.9	-5.4	NA	NA	NA	NA	NA	NA
	% Meeting ANSI N42.22 Criteria	NA	100	100	NA	NA	NA	NA	NA	NA

[a] Percent bias is the difference between the measured value and the known value for a matrix spike, expressed as a percent relative to the known value

[b] N = number of matrix spikes for each analytical group

[c] NA = not applicable; no matrix spike used for the subject nuclide

[d] Minimum observed bias

[e] Maximum observed bias

[f] ANSI N42.22 criteria for the acceptance of testing results where the absolute value of the bias between the reported value, Vr, and the or known value, Vn, shall be less than or equal to three times the total propagated reported uncertainty, σ_r, and the uncertainty of the known value, σ_n: $|Vr - Vn| \le 3 \times \sqrt{\sigma_r^2 + \sigma_n^2}$

GLOSSARY

aerosol - particles dispersed in a gas

aliquot - a subsample drawn from a larger sample

alpha-emitting - producing ionizing radiation in the form of alpha particles

anthropogenic - referring to environmental alterations resulting from the presence or activities of humans

actinides - the series of radioactive elements that starts with actinium and ends with lawrencium

coefficient of variation - a statistical parameter that expresses standard deviation as a percentage of the mean, calculated as standard deviation divided by the mean, multiplied by 100

dosimetry - the measurement of radiation doses

gamma-emitting - producing ionizing radiation in the form of gamma rays

gross alpha - measurement of total number of alpha decays without specification of individual energies

in vivo - taking place within a living cell or organism

informatics - information management systems

photon - a massless particle, the quantum of the electromagnetic field, carrying energy, momentum and angular momentum

radionuclide - a type of atom that loses particles and energy through decay or transformation into other elements

shield - cast iron or steel enclosure often used in conjunction with gamma detectors to reduce the influence of background radiation on measurements

spallation - a nuclear reaction in which several nucleons are released from the nucleus of an atom

standard deviation - a statistical parameter, calculated as the positive square root of the expected value of the square of the difference between a random variable and its mean

standard error - the standard deviation of the probability function or probability density function of a random variable and of a statistic; typically the standard deviation of the mean

temporal - pertaining to or limited by time