1997 Report
Carlsbad Environmental Monitoring & Research Center

Waste-management
Education & Research Consortium (WERC)
College of Engineering
New Mexico State University

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Acronyms and Abbreviations

μBq	microbecquerel
μm	micrometer
A	angstrom
Ac	actinium
Ag	silver
Al	aluminum
Am	americium
AOV	analysis of variance
As	arsenic
ASCII	American Standard Code for Information Interchange
Au	gold
Ba	barium
BOMAB	bottle mannequin absorption phantom
Bq	becquerel
Br	bromine
Ca	calcium
Cd	cadmium
Ce	cerium
CEMRP	Carlsbad Environmental Monitoring and Research Program
Center	Carlsbad Environmental Monitoring & Research Center
CFR	Code of Federal Regulations
Cl	chlorine
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
dpm	disintegrations per minute
EM	Environmental Monitoring
EPA	U.S. Environmental Protection Agency
Eu	europium
eV	electron volts
Fe	iron
g	gram

Ga	gallium
Ge	germanium
H_2O	water
HCl	hydrochloric acid
HF	hydrofluoric acid
Hg	mercury
HNO_3	nitric acid
In	indium
hr	hour
K	potassium
KCl	potassium chloride
keV	kiloelectron volts
km	kilometer
L	liter
La	lanthanum
LIMS	laboratory information management system
m	meter
mΩ	milli-ohm
MBL	Mobile Bioassay Laboratory
mBq	millibecquerel
MDA	minimum detectable amount
MDC	minimum detectable concentration
min	minute
mL	milliliter
mm	millimeter
Mn	manganese
Mo	molybdenum
mR	milliroentgen
NaI	sodium iodide
ng	nanogram
NH_4Cl	ammonium chloride
Ni	nickel
NH_4OH	ammonium hydroxide
NIST	National Institute of Standards and Technology
NMED	New Mexico Environment Department
NMSU	New Mexico State University
Np	neptunium
P	phosphorus
Pa	protactinium
Pb	lead
Pd	palladium
pH	measure of the acidity of an aqueous solution
PM_{10}	suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm

$PM_{2.5}$	suspended particulate matter aerosols with aerodynamic diameter $\leq 2.5\ \mu m$
ppb	parts per billion
PRB	Program Review Board
Pu	plutonium
QA	quality assurance
QC	quality control
Rb	rubidium
RDBMS	relational database management systems
RL	reference level
RIP	Radiochemistry Intercomparison Program
Ru	ruthenium
Rn	radon
S	sulfur
SAB	Science Advisory Board
Sb	antimony
SD	standard deviation
SDWA	Safe Drinking Water Act
SE	standard error
Se	selenium
sec	second
shield	cast iron enclosure
Si	silicon
Sn	tin
Sr	strontium
SWAT	Soil Water and Air Testing Laboratory
Th	thorium
Ti	titanium
Tl	thallium
TSP	total suspended particulate matter aerosols with aerodynamic diameter $<75\ \mu m$
U	uranium
V	vanadium
WERC	Waste-management Education & Research Consortium
WIPP	Waste Isolation Pilot Plant
XRF	X-ray fluorescence
Y	yttrium
Zn	zinc
Zr	zirconium

FORWARD

This report was written, edited and produced collaboratively by the staff of the Carlsbad Environmental Monitoring & Research Center, 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, scientific programmatic structure, resources, and project activities. The second section consists of data summaries containing methods and descriptions of results of studies in the WIPP Environmental Monitoring project.

The issuance of this report and other publications fulfills a major Center mission in making the results of Center research available for public access. Production of this report is supported as part of the Carlsbad Environmental Monitoring & Research Program, a grant from the U.S. Department of Energy to New Mexico State University (DE-FG04-91AL74167). The contents of this report will be available for electronic access by March 1998, at http://www.cemrc.nmsu.edu.

The photographs on the report cover show various activities and facilities associated with the Center Program.

OVERVIEW

Current Program Status

The Carlsbad Environmental Monitoring and Research Program (CEMRP) was established in 1991 with an initial grant of $27 million over a seven year period (1991-1998). Subsequently, the grant was increased to almost $33 million to support operations until 2008. The primary goals of the CEMRP are to:

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

The Carlsbad Environmental Monitoring & Research Center (Center) is a division of the Waste-management Education & Research Consortium (WERC), in the College of Engineering at New Mexico State University (NMSU). A brief history of the Center is presented in Appendix A.

The Center is to function as a nucleus of research excellence supported through grant funding and service contracts. As a part of NMSU, the Center's research programs are conducted under the philosophy of academic freedom and independence from direct external control of research activities and outcomes. The Center'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;
- Establish a health and environmental database accessible to all sectors.

The following are key enabling activities identified as necessary to achieving these objectives:

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

At the end of 1996, staffing reached 18 professional and classified employees. Currently, the Center staff consists of 26 people, including 21 scientific and technical support staff (Table 1) and five student employees. Staffing is projected to continue to grow as new funded projects are added to the Center's activities.

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

In January 1997, the Center was relocated to Light Hall, a new 26,000 ft^2 laboratory and office facility constructed adjacent to the NMSU-Carlsbad campus. The programmatic areas and major instrumentation housed in this facility are described herein (pp. 6-9).

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

With the relocation of the Center to Light Hall in 1997, program needs for external laboratory services declined from previous years. However, a few subcontractual agreements were maintained or initiated to provide specific advanced methodologies for selected analyses (Appendix B). In addition to services provided by external organizations, several NMSU departments and divisions also provided support to the Center for specific projects, including the Physical Science Laboratory (PSL), the Soil Water and Air Testing Laboratory (SWAT), and the Department of Fishery and Wildlife Sciences.

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

A Science Advisory Board (SAB) for the Center was originally established in 1992. During 1997, a new, five-member SAB was selected (Appendix C). The members are scientific experts with national and international reputations in the Center's five scientific areas of specialization. Members of the SAB will visit the Center individually during 1998, to review the individual program areas and provide expert guidance and consultation to the program leaders. SAB members will also provide a public scientific colloquium during their visit to the Center.

A Program Review Board (PRB) was also created in 1997, consisting of two members selected by the NMSU College of Engineering administration (Appendix C). The PRB will visit the Center once during 1998, to review the overall operation of the Center and provide a joint review summary to the administration. Members of the PRB are directors of leading environmental research centers with histories of long-term success in sponsored research.

Establish a program of administration to ensure effective operation of the Center.

Dr. Donald J. Fingleton was Director of the Center during 1991-1996. Dr. Marsha Conley is currently Director of Operations, with responsibility for management of the Center's scientific program, fiscal affairs, and human resources. Expenditures for the CEMRP during fiscal years 1991-1997 totaled approximately $14.4 million (Figure 1). New funding of approximately $3.1 million has been proposed for the 1998 Federal fiscal year. Combined with carryover funds, the projected 1998 budget is approximately $4.4 million.

Formal tracking of project schedules and deadlines is conducted for current studies, as noted in later sections. Regularly scheduled work sessions for systematic 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. Significant accomplishments and events are reported in monthly summaries provided to the DOE, NMSU, SAB and PRB.

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

During 1997, Center staff made 16 presentations at national and regional scientific meetings, and 16 papers were published, are in press, or have been submitted for publication in peer-reviewed scientific journals (Appendix D). Periodic briefings on program activities are provided for representatives of NMSU, DOE, and various local and regional groups. Several database management systems have been developed or acquired and implemented (p. 8). As noted previously, this report and others will be made available *via* the Center web site during 1998.

Establish regional, national and international outreach and collaboration.

The Center was involved in a variety of outreach activities ranging from presentations for special NMSU student programs, to hosting groups of visiting foreign scientists (Appendix E). In addition, Center scientists provided leadership in a variety of scientific organizations and meetings (Appendix F).

Procure additional research grants and service contracts from external sources.

Center scientists generated 14 proposals and pre-proposals during 1997 (Appendix G). Five new projects totaling over $570,000 were funded. Two were not awarded, and the remainder are in various stages of review. These projects represent a wide array of activities, and they have resulted in significant expansion and diversification of the scientific program.

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

The Center staffing now includes five positions for undergraduate students. These students are involved in both laboratory and administrative support activities, including participation in data collection, analyses, and report production. One Center scientist has applied for Graduate Faculty status at NMSU, which will facilitate future involvement of graduate students in Center projects.

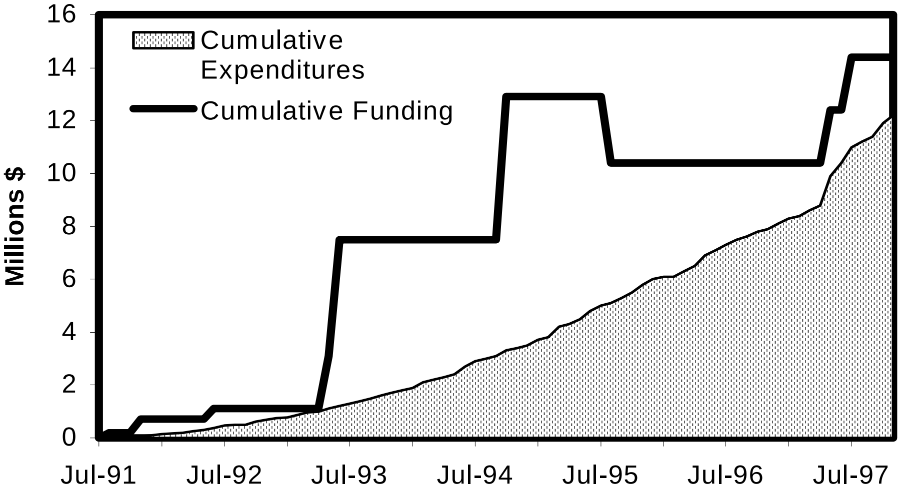

Figure 1. History of CEMRP Funding and Expenditures

Table 1. Listing of Center Staff as of December 31, 1997

Name	Position
Arimoto, Richard	Senior Scientist-Environmental Chemistry
Brown, Brandye	Laboratory Aide (Student)
Brown, Becky	Fiscal Specialist II
Cano, Tony	Laboratory Aide (Student)
Carrillo, Candie	Office Aide (Student)
Chacon, Raquel	Laboratory Aide (Student)
Chatfield, Randy	Technician IV
Conley, Marsha	Director of Operations
Gooden, Deborah	Office Aide (Student)
Kirchner, Thomas	Senior Scientist-Informatics & Modeling
Lee, Shan	Senior Scientist-Radiochemistry
Lynch, Sherry	Technician IV
Madison, Tom	Project Manager
Maung, Okka	Assistant Scientist-Radiochemistry
McNutt, Damon	Technician V
Nesbit, Curtis	Technician II
Nottingham, Amy	Assistant Scientist-Environmental Chemistry
Sage, Sondra	Assistant Scientist-Field Operations
Schloesslin, Carl	Assistant Scientist-Radiochemistry
Schloesslin, Cheryl	Assistant Scientist-Environmental Chemistry
Schoep, David	Science Specialist-Field Operations
Soules, Mary	Administrative Secretary I
Walker, Cheryl	Science Specialist-Internal Dosimetry
Webb, Joel	Physical Scientist IV-Internal Dosimetry
Yahr, Jim	Assistant Scientist-Field Operations
Young, Karen	Administrative Secretary II

Description of Major Scientific Program Areas

Currently, the Center's scientific activities are organized into five major areas of specialization with corresponding assignment of staff roles and responsibilities. Although some of the Center's projects involve only one or two of the program areas, all of the program areas collaborate in carrying out the WIPP Environmental Monitoring (EM) project, and this type of integrative research will characterize many of the Center's future projects.

Internal Dosimetry

The internal dosimetry program conducts analyses and consultation for the study and management of internal radiation exposure. The analyses include collection of information on work and residence history, past and current radiation exposure, bioassays to measure the presence of radionuclides within body tissues (*in vivo*) or body fluids and excretions (*in vitro*), and calculation of dose associated with observed uptakes. Consultation includes interpretation of bioassay results and can extend to collaboration with health care professionals and workplace supervisors. The internal dosimetry program includes a documented quality assurance program for *in vivo* bioassays and a comprehensive technical basis for the assessment of internal exposure. The program meets the requirements and recommendations of the DOE Implementation Guide for Internal Dosimetry Programs (10 CFR 835) and the American National Standards Institute Performance Criteria for Radiobioassay (N13.30). The Center is also involved in the DOE Laboratory Accreditation Program for internal dosimetry and radiobioassay.

The internal dosimetry program is provided as an outreach service to the public to support education about the Center's environmental studies and naturally occurring radiation, and to provide assessment of potential exposure to radioactive contaminants of concern. The program also provides support to the WIPP by conducting bioassays for radiation workers on a routine basis. Full-spectrum dosimetry services are available to evaluate internal radiation exposure to radiation workers and members of the public in the case of an accident at the WIPP. In addition, internal dosimetry services can be provided to other entities that employ the use of radioactive materials.

The Center's fixed *in vivo* bioassay facility occupies approximately 966 ft^2, and provides the primary analytical infrastructure for the internal dosimetry program. The facility includes a large shielded counting chamber, dedicated instrument control workstation, two change rooms with showers and toilets, and a reception area. The counting chamber measuring 2.4 m x 2.4 m x 2.4 m is constructed of 25.40 cm thick cast iron, with a full graded-Z liner consisting of lead, tin and stainless steel. The cast iron composing the chamber was produced for industrial use prior to 1945, and re-cast for the chamber using a specially selected foundry, resulting in very low background radiation from anthropogenic and naturally occurring constituents. The instrument control workstation includes a video display terminal and intercom used to monitor subjects during the examination. Signal processing electronics are located outside the counting shield next to the instrument control workstation. The *in vivo* bioassay facility was commissioned in July 1997.

The counting chamber is equipped with a lung and whole body counting system using technologically advanced, hyperpure germanium detectors. Lung and whole body counts are simultaneously performed with the counting subject lying horizontally on a specially designed counting bed. Two, four-detector germanium arrays designed for lung and whole body counting are positioned over the chest and under the bed, respectively. Under routine operation, photon interactions in the lung counting detectors are integrated using two independent signal processing chains: one chain for low photon energies (5 to 250 keV) and one chain for high photon energies (200 to 2000 keV). The high-energy chain is analyzed independently and then added to the output of the whole body counting detectors to increase sensitivity. This combination of technology allows for sensitive monitoring for internally deposited transuranics, naturally occurring radioactive materials, and mixed fission/activation products. A dedicated computer is used for the acquisition, storage and analysis of gamma-ray spectra collected by the instrument. Resolution of the system is 450, 750, and 2100 eV at photon energies of 5.9, 122, and 1332 keV, respectively. Routine sensitivities for ^{238}Pu, ^{239}Pu and ^{241}Am in lungs are approximately 930, 2400 and 4 Bq, respectively. Routine sensitivities for ^{137}Cs, ^{60}Co and ^{152}Eu in the whole body are approximately 10, 10, and 60 Bq, respectively. Ultrasound techniques may be used to measure the subject's chest wall thickness and composition to account for photon attenuation for positive lung burdens. Chest wall thickness can also be estimated from physiological parameters. Center staff schedule subjects participating in *in vivo* bioassays, with a total of 60 minutes allocated for each appointment. Prior to undergoing the lung and whole body count, subjects view a videotape explaining the procedure, and further explanation is provided by internal dosimetry staff.

In addition to providing services in bioassay, staff of the internal dosimetry program carry out basic research in radiation detection technology and novel applications of *in vivo* bioassay techniques to environmental studies. The staff of the internal dosimetry program are also responsible for the Center's radiation protection program to ensure compliance with the Center's Radioactive Material License, granted under the authority of the New Mexico Environment Department.

Radiochemistry

The primary focus of the radiochemistry program is measurement of radionuclide activities at environmental background levels. Analysis capabilities for environmental media include aerosol samples, soil, surface water and sediment, groundwater, and biota. In addition to environmental media, the laboratory will be developing bioassay analysis capabilities for urine, feces, and tissue. Standard reference materials are used for instrument calibration, and analytical quality control and quality assurance programs are being implemented for the laboratories. The radiochemistry laboratory currently participates in the DOE Environmental Measurements Laboratory, Quality Assessment Program. The Center is also a participant in the National Institute of Standards and Technology (NIST) Radiochemistry Intercomparison Program (RIP) for evaluation of low-level radionuclide measurements.

The radiochemistry laboratory employs procedures for low-level measurement of actinides, fission products, activated corrosion products, and naturally-occurring radionuclides. These analyses employ advanced instrumentation including alpha spectrometry, low background alpha-beta counting, gamma spectrometry, gas proportional counting, and liquid scintillation. Detection levels achievable with the laboratory's current alpha spectrometry instrumentation and techniques are on the order of 370 μBq for actinides.

Approximately 1700 ft^2 of space is allocated to the radiochemistry program, including a primary radiochemistry laboratory, and separate tracer and counting laboratories. The primary laboratory room is equipped with one 6-foot chemical hood, five 8-foot chemical hoods, a separate de-ionized water system, refrigerator, centrifuge and approximately 400 ft^2 of bench surface.

Environmental Chemistry

The environmental chemistry program has capabilities similar to radiochemistry in determining low levels of a variety of inorganic substances in environmental media. Approximately 1400 ft^2 of laboratory space is allocated to environmental chemistry, including a primary laboratory for sample preparation, and an instrumental analysis laboratory. The primary laboratory room is equipped with three 8-foot chemical hoods, a separate ultra-pure water system, dishwasher, refrigerator, electronic balance, and approximately 170 ft^2 of bench surface.

The instrumentation laboratory is equipped for analyses of trace elements, including heavy metals. An atomic absorption spectrometer with flame and graphite furnace was installed in July 1997, and a dual view inductively-coupled plasma optical (atomic) emission spectrometer was installed in November 1997. An ion chromatograph is used for routine analyses of anions (chloride, fluoride, nitrate and sulfate) in water and air samples. The ion chromatograph can also be configured as a high performance liquid chromatograph, for use in the determination of polycyclic aromatic hydrocarbons.

Field Sampling

The Center's field sampling program is focused on design and implementation of protocols for collection and initial processing of samples of environmental media. The field sampling program uses and maintains a wide variety of sampling equipment, including two fully instrumented meteorological stations; low-volume, high-volume, size-selective, dichotomous, and multiple orifice inlet aerosol samplers; soil and sediment collection devices; ground water and surface water collection equipment; *in situ* water quality instrumentation; an *in situ* NaI gamma radiation detection system; a global positioning system; four-wheel drive vehicles; and a small boat with outboard motor.

Approximately 1300 ft^2 of working area is dedicated to staging field sampling activities, and for processing and storing collected samples. This area includes approximately 500 ft^2 of shelving and storage space and 200 ft^2 of bench top workspace. Sample preparation and storage equipment include a muffle furnace, drying ovens, refrigerator, freezers, dishwasher, ultrasonic cleaners, soil sieves, high-volume jar mill soil grinder, mixer soil mills, cross-flow high-volume water filtrator, and electronic balances.

In conjunction with the Center's other programs, staff in the field sampling area carry out experimentation and development related to sampling design, techniques, and instrumentation. As part of the field sampling program development in 1997, a special soil handling program was developed, and a license was obtained from the U.S. Department of Agriculture to allow receipt of soil samples from other states and from foreign countries. In addition to activities related to the WIPP EM, the field sampling program currently conducts weekly analyses of water quality at Brantley Dam Reservoir under a cooperative agreement with the U.S. Department of Interior, Bureau of Reclamation.

Informatics and Modeling

One of the Center's primary objectives is to establish a health and environmental database accessible to all sectors. It is the role of the informatics program to carry out this function for the Center by developing and implementing information management systems. The informatics program includes formal systems for data archival and documentation facilitating analyses and accurate interpretations. Commercial relational data base management systems (RDBMS) are one component of the program. For example, the lung and whole body counting system uses an integrated RDBMS for data collection and storage. An Access® data base (Microsoft, Inc.) is used to archive aerosol and meteorological data collected by the field sampling program. A commercial laboratory information management system (LIMS) is currently under procurement and will be implemented during 1998. The LIMS will provide systematic identification and tracking of samples and reporting of analytical results.

During 1997, the Center added two Sun workstations and a Sun server running Unix. The Sun server provides network services, such as file sharing, electronic mail, and automatic daily backup to all of the Windows and UNIX computers in the Center. The Sun server also supports an Oracle RDBMS that will eventually be the primary data base system for the Center. The Sun workstations currently provide support for general computing, but will eventually function as platforms for numerically intensive applications, such as simulation modeling and statistical analyses. The Center also added a DEC Alpha workstation running OpenVMS, which mirrors the computational support for the lung and whole body counting system. This allows testing of maintenance and upgrades on the secondary system, prior to introduction to the functioning counter, thereby protecting the integrity of the primary counting support system.

The research activities of the informatics program include developing methods for linking data to simulation models. For example, estimates of contaminant doses and risks can be made using models to project potential exposure *via* environmental pathways. The model projections are based on estimates of contaminant movement through the atmosphere, deposition in water and soil, direct uptake by humans or other organisms, and secondary transfer between components of the environment and living organisms.

WIPP Environmental Monitoring Project

The first major project managed by the Center is the WIPP Environmental Monitoring (EM) project. 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 is being implemented during the WIPP pre-disposal phase, and will continue into the operational (disposal) phase. The WIPP EM project is organized and carried out as a scientific research undertaking and has no oversight or regulatory accountabilities. As noted earlier in the overall Center program, the WIPP EM project is conducted under the philosophy of academic freedom and is independent of direct external control of research activities and outcomes.

The activities of the project are based on scientific principles of design, data collection, analysis, and peer review. The principles include reliance on the most advanced knowledge and theory for generation of hypotheses, selection of technologies, design of sample and data collection, and application of inferential statistics, exploratory statistics, and modeling, to interpret results. Studies include not only collection of data, but also research and development to improve technologies specific to the research area for transfer to the DOE and to the scientific community. Pilot studies are routinely used to evaluate existing equipment and techniques and to develop and test new approaches.

The project employs professional information-management principles in organizing, documenting, and archiving data and in providing for public access to information generated by the program. Information generated by the project appears later in this report (pp. 21-104), and will also be presented in scientific publications in peer-reviewed journals, and at industry and scientific conferences (Appendix D). As appropriate, standard quality assurance (QA) and quality control (QC) policies and techniques are applied to the project and are currently being documented. The objectives of the WIPP EM are to:

- Establish baseline data and monitor chemical and radiological constituents in the environment;
- Determine the nature and activity of internally deposited radionuclides in the public;
- Characterize and monitor community health;
- Establish and maintain a health and environmental information database.

In each major research component, the first project level is designed to describe and quantify the processes and patterns characterizing current conditions. This “baseline characterization” focuses on documenting the spatial and temporal patterns of physical processes, existing contaminant sources and levels, and population parameters of interest prior to the acceptance of waste at the WIPP. The second level of the research activities is to design and implement long-term monitoring that will accompany the operation of the WIPP. This “operational monitoring” relies on the results of the baseline characterization to identify key parameters to be monitored and the most effective and efficient technologies, spatial scales, and frequencies for data collection. The organization of the WIPP EM project is shown in Table 2.

For each level and component within the research areas, the following sequence of activities is followed:

1. Review published scientific literature, technical reports, and any available unpublished data and consult with scientific and technical experts and other interested groups. Prepare written documentation of sources of

information, status of knowledge, and any significant knowledge gaps.

2. Develop conceptual study design and objectives, and identify the processes and patterns of interest and information to be generated by the study.
3. Design and conduct pilot studies necessary to evaluate equipment and methods, and collect preliminary data on variability for use in development of sampling plans.
4. Develop and implement detailed plan of sampling and analysis.
5. Periodically analyze data generated by the study to evaluate effectiveness in terms of program objectives and modify study as appropriate.
6. Conduct comparative analyses of different study components to produce integrative interpretations and models of patterns and processes.
7. Prepare periodic written and graphical summaries, analyses, and interpretations of data for inclusion in reports, publications, and presentations.
8. Archive data and documentation in established databases to allow access by the public and scientific community.

The management plan for the WIPP EM incorporates these eight general phases for the major research areas, with specific milestones representing significant products and events in program progress. Key performance indicators for the baseline studies were identified as metrics of the success of this project management plan. Project activities of the WIPP EM baseline studies were originally designed and scheduled for completion by November 1997, under the assumption the WIPP would begin operations at that time. The WIPP did not begin operation during 1997, and some of the project tasks were rescheduled. The WIPP may begin operation by June 1998. For three indicators, successful completion ranged from 50%-80% of individual tasks, while for three other indicators, 100% of the individual tasks were completed (Appendix H). Key performance indicators for 1998 have been identified to serve as the basis for the 1998 WIPP EM project schedule (Table 3).

Table 2. WIPP Environmental Monitoring Organization

Project Levels	**Research Areas**	
	Environmental Components	**Human Population Components**
Baseline Characterization	Soil, Air, Water, Meteorology, Biota	Community Health, Public Perception, Internal Dosimetry
Operational Monitoring	Soil, Air, Water, Meteorology, Biota	Community Health, Public Perception, Internal Dosimetry

Table 3. Key Performance Indicators for 1998

Focus Area	Key Performance Indicator
Aerosols	Continue concurrent high-volume and low-volume sampling at current two locations through 1998
	Initiate operation of high-volume sampler at third location at WIPP site prior to May 1998
	Assume responsibility for one FAS sampling port in WIPP exhaust shaft prior to May 1998
Soils	Complete collection of triplicate samples at current 32 locations by May 1998
Meteorology	Continue concurrent operation of sampling stations at two current sites through 1998
Drinking water	Collect samples at 6 sources in April 1998; repeat sample collection in August 1998
Sediment and surface water	Complete collection of samples at three additional locations in February 1998; repeat sample collection at three locations in July 1998
Biota	Collect animal and vegetation samples during spring and fall 1998
Human studies	Continue *in vivo* bioassays for public to include at least 200 people, including repeated measures on individuals in 1997 studies
Radioanalyses	*Complete by September 1998: analysis of 1997 soil samples, fall 1997 vegetation samples, spring 1998 drinking water samples and May 1997- May 1998 TSP aerosol samples Complete by September 1999: analyses of all remaining samples of soils, drinking water, sediments, surface water, aerosols, vegetation, and fauna collected during 1997 and 1998
Inorganic trace element analyses	Complete analyses of representative subset of low-volume aerosol samples and soil samples by July 1998
Data management and dissemination	Implement electronic Laboratory Information Management System by June 1998
	Issue two reports of community studies by April 1998
	Make Center 1997 report accessible *via* Internet by March 1998
	Present summary of data from analyses completed by September 1998 (* above), in 1998 Center report
	Submit manuscripts for publication by August 1998 on radioanalyses of aerosols and soils

Quality Assurance

General Description

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

The Center's quality assurance policy and implementation recognize 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 part of the work conducted is to develop such procedures, or to evaluate the application of standard procedures to novel media. Likewise, research sampling designs are typically unique to the underlying scientific hypotheses, and therefore may not follow any external format. 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 are spelled out by various compliance guidelines. In the WIPP Environmental Monitoring (EM) project, the Center's strategy is to develop a set of independent data that measure a variety of parameters of interest, frequently using sampling and analyses different from those dictated by regulatory requirements governing the WIPP's certification and operation. In many cases, these efforts 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 Center's projects.

Standard Procedures

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

In projects subject to regulatory or other externally-imposed requirements, formal quality assurance and technical standards documentation is maintained. During 1997, a quality assurance plan, quality assurance implementation plan, technical basis manual, and various standard procedures for *in vivo* radiobioassay were developed to meet requirements as specified in ANSI N13.30, and these are maintained as controlled documents under a formal document control program. In the case of radiochemical analysis of environmental media, a number of standard procedures have been developed, based on HASL-300 Procedures Manual (DOE EML 1992), but these are not currently maintained as controlled documents. Standard procedures for other analytical programs are in development.

Logbooks are maintained by technical staff in field operations to record locations, other specifics of sample collection, and data on instrument identification, performance, calibration and maintenance. Data generated from field sampling equipment instrumentation are error-checked by using routine cross checks, control charts, and graphical summaries. Original logbooks and field data forms are kept in sample files in each 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.

Logbooks are maintained by laboratory workers to record radiological tracer information, calibration of balances and counting equipment, and radioactivity measurements. Data generated from laboratory activities are error-checked manually by the laboratory manager, and original logbooks and data forms are stored in a secure area. A series of standard electronic databases are currently under development for long-term data archival of laboratory data.

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

Personnel

Program managers provide training to laboratory and field workers in methodologies, general laboratory protocol and maintenance routines, and good safety practices. Center 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 and a variety of journal subscriptions.

Regulatory Compliance

To promote good health and safety practices in the laboratories, the Center maintains a Chemical Hygiene Plan and associated training of personnel, in compliance with the requirements of 29 CFR 1910.1450, "Occupational Exposure to Hazardous Chemicals in Laboratories". A Hazard Communication Plan and associated training are maintained for employees who do not meet the definition of laboratory workers, in compliance with requirements of 29 CFR 1910.200. A Chemical Hygiene Officer is responsible for management of the chemical and laboratory safety program, including maintenance of a chemical inventory, periodic laboratory safety audits, and management of any hazardous wastes generated by laboratory activities.

Currently, the Center does not generate any hazardous or toxic wastes as defined and regulated under the Resource Conservation and Recovery Act or the Toxic Substances Control Act. If regulated hazardous waste is generated in the future, it will be disposed of through a licensed treatment, storage and disposal facility. Based on current chemical inventories, the Center is exempt from the reporting requirements in Section 313 of the Emergency Planning and Community Right-to-Know Act. The Center has had no spills of hazardous substances exceeding the reportable quantity limits under the Comprehensive Environmental Response, Compensation and Liability Act. Based upon assessments of laboratory activities and processes conducted prior to construction of the facility, the Center 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 Center'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 Center generates a small amount (<50 kg) of solid, low-level radioactive waste annually, which is disposed of through a licensed commercial disposal facility.

Performance Assessment

During 1996-1997, the Center radiochemistry program participated in the DOE, Office of Environmental Management (EML) Quality Assessment Program (QAP) and the NIST Radiochemistry Intercomparison Program (RIP). The Center received acceptable evaluations on 100% of 20 analyses reported in QAP 45 (1997, DOE-EML-587). For QAP 46 (1997, DOE-EML-591), the Center received acceptable or acceptable with warning evaluations on 95% of 21 analyses reported (Table 4).

In the three rounds of analyses for the NIST RIP, the Center reported 75% (12/15) of ^{238}Pu analyses and 93% (14/15) of ^{239,240}Pu analyses within 10% of NIST values. For ^{241}Am, the Center reported 60% (6/10) of analyses within 10% of NIST values (Table 5).

Analyses of Environmental Samples

Standard quality control measures used in radioanalyses included tracer blanks numbering $\geq$5% of the total number of analyses. Recoveries of radionuclides are monitored by external tracers. Radioanalyses reported herein use standard formulae for calculation of radioactivity concentration, count standard deviation (counting error) and minimum detectable activity concentration (MDC) (Appendix K).

For radioanalytical results reported herein, radioactivity levels greater than MDC were identified for one nuclide in 100% of aerosol samples, for seven nuclides in 86% of vegetation samples, for eight nuclides in 50% of surface water samples and 99% of sediment samples, and for nine nuclides in 96% of soil samples and 38% of drinking water samples (Table 6). Analyses for ^{241}Am failed in all samples of surface water, sediments, vegetation, and air filters; reanalysis of these samples will be conducted in 1998.

External Laboratories

Some analyses presented herein were carried out by other laboratories through subcontract or fee service arrangements. These include analyses of non-radiological constituents in surface water and drinking water samples, analyses of inorganic constituents in aerosol samples by x-ray fluorescence spectrometry, and some analyses of radionuclides in high-volume aerosol samples and soil samples.

The Soil Water and Air Testing Laboratory (SWAT) at NMSU provided analyses of non-radiological constituents. SWAT is accredited by the American Association for Laboratory Accreditation for all analyte/test methods applied to water samples reported in Tables 26a, 26b, 27a, 27b and 32. The SWAT quality assurance/quality control program is documented in a Quality Assurance Program Plan (QA-QAPP-1).

Radioanalyses of alpha-emitting radionuclides in soils reported herein were conducted by Accu-Labs Research, Inc. (ALR) in Golden, Colorado. ALR maintains a Quality Assurance Program to meet standards under 10 CFR 50, Appendix B, and the American Society of Mechanical Engineers (ASME) NQA-1 Standards. The program is documented in the ALR Laboratory Quality Assurance/Quality Control Plan and a series of standard operating procedures.

A portion of the radioanalyses of ^{239,240}Pu in high volume aerosol particulate samples were performed at Argonne National Laboratory (ANL) in Chicago, Illinois. ANL does not maintain a formal quality assurance program applicable to the analyses conducted for these studies.

X-ray fluorescence (XRF) analyses of trace elements in aerosol samples were conducted by the Desert Research Institute, a division of the University and Community

College System of Nevada, in Reno, Nevada. XRF analyses were performed with energy dispersive x-ray fluorescence (EDXRF) analyzer, using a 30 mm^2 silicon detector, with a system resolution ≥165 eV. During XRF analysis, filters were removed from their Petri slides and placed with their sides containing the deposits oriented downward into polycarbonate filter cassettes. A polycarbonate retainer ring kept the filter flat against the bottom of the cassette. These cassettes were loaded into a carousel in the x-ray chamber, which contains 16 openings. The filter identifications were recorded on a data sheet to correspond to numbered positions in the carousel. The sample chamber was evacuated to 10^{-3} torr and a computer program controlled the positioning of the samples and the excitation conditions. Complete analysis of 16 samples under five excitation conditions required approximately 8 hours.

Several blank filters from the same manufacturing lot as the sample filters were provided and analyzed along with the exposed filters. An average blank spectrum was constructed and used for spectral background subtraction of the exposed filters. Net peak intensities were converted to concentrations after subtracting the spectral background and any peak overlap interference which was present. The precision of the concentration measurement was estimated from the counting statistics for each peak. The detection limits achieved depend on analysis time; longer analysis times yield lower detection limits.

Three types of XRF standards were used for calibration, performance testing, and auditing: 1) vacuum-deposited thin-film elements and compounds; 2) polymer films; and 3) NIST thin-glass films. The vacuum deposit standards covered the largest number of elements and were used as calibration standards. The polymer film and NIST standards were used as independent checks of calibration accuracy. NIST standards are the definitive standard reference material, but these are only available for certain elements as follows: Al, Ca, Co, Cu, Mn, and Si (SRM 1832) and Fe, Pb, K, Si, Ti, and Zn (SRM 1833). A separate thin-film standard was used to calibrate the system for each element.

A quality control standard and one or more replicates (to total 10% of all samples analyzed) from a previous run were analyzed with each set of aerosol samples analyzed by XRF spectrometry. When a quality control value differed from specifications by more than ±5% or when a replicate concentration differed from the original value (when values exceeded 10 times the detection limits) by more than ±10%, the samples were re-analyzed. If further tests of standards showed the system calibration had changed by more than ±3%, the instrument was re-calibrated as described above.

Table 4. Summary of Participation in DOE Quality Assessment Program

Report Reference	End Date of Round	Sample Matrix	Radionuclides Analyzed	Evaluation
QAP 46 1997, DOE-EML-591	June 1997	Air filters	^{241}Am, ^{238}Pu, ^{239}Pu, ^{234}U, ^{238}U	Acceptable for ^{241}Am, ^{238}Pu, ^{239}Pu Acceptable with Warning for ^{234}U, ^{238}U
		Soil	^{241}Am, ^{238}Pu, ^{239}Pu, ^{234}U, ^{238}U	Acceptable for ^{241}Am, ^{239}Pu, ^{234}U, ^{238}U Not Acceptable for ^{238}Pu
		Vegetation	^{241}Am, ^{244}Cm, ^{239}Pu	All Acceptable
		Water	^{241}Am, ^{60}Co, ^{137}Cs, ^{54}Mn, ^{238}Pu, ^{239}Pu, ^{234}U, ^{238}U	Acceptable for ^{241}Am, ^{60}Co, ^{137}Cs, ^{54}Mn, ^{234}U, ^{238}U Acceptable with Warning for ^{238}Pu, ^{239}Pu
QAP 45 1997, DOE-EML-591	December 1996	Air filters	^{241}Am, ^{238}Pu, ^{234}U, ^{238}U	All Acceptable
		Soil	^{241}Am, ^{238}Pu, ^{239}Pu, ^{234}U, ^{238}U	All Acceptable
		Vegetation	^{241}Am, ^{244}Cm, ^{239}Pu	All Acceptable
		Water	^{241}Am, ^{60}Co, ^{137}Cs, ^{54}Mn, ^{238}Pu, ^{239}Pu, ^{234}U, ^{238}U	All Acceptable

Table 5. Summary of Participation in NIST Radiochemistry Intercomparison Program

Sample Matrix (units) Report Date	Radionuclides								
	^{238}Pu			$^{239.240}$Pu			^{241}Am		
	Reported Value	% 1 SD	NIST (%)	Reported Value	% 1 [a]SD	NIST (%)	Reported Value	% 1 SD	NIST (%)
Nitric acid (mBq/g) 4/1997	1.98	6	-10.41	1.88	6	-3.59	[b]NR		
	2.15	6	-2.71	1.95	6	0.00	NR		
	2.30	6	4.07	2.05	6	5.13	NR		
	2.15	6	-2.71	2.02	6	3.59	NR		
	2.12	6	-4.07	2.02	6	3.59	NR		
Glass fiber filter (Bq/filter) 7/1997	0.0590	4.5	-4.20	0.0540	4.5	-0.77	0.0680	9	-28.99
	0.0610	4.2	0.02	0.0550	4.2	2.06	0.0990	10	4.40
	0.0590	5.2	7.90	0.0530	5.2	9.70	0.0760	10	-10.60
	0.0540	5.0	-4.92	0.0490	4.0	-2.36	0.0680	15	-22.99
	0.0370	3.5	-35.33	0.0350	3.5	-30.77	0.0100	8.5	12.41
Synthetic urine (Bq/sample) 9/1997	0.0400	3	-6.98	0.0360	2	-5.26	0.0630	5	-4.55
	0.0400	3	-6.98	0.0370	2	-2.63	0.0720	3	7.46
	0.0420	3	-2.33	0.0370	2	-2.63	0.0700	4	4.48
	0.0380	3	-11.63	0.0350	2	-7.89	0.0730	4	8.96
	0.0410	2	-4.65	0.0360	2	-5.26	0.0650	4	-2.99

[a] SD = standard deviation

[b] NR = no results reported by CEMRC

Table 6. Summary of Radioanalytical Results

Radionuclide	Number of Analyses >MDC / Number of Samples Analyzed					
	Drinking Water	Surface Water	[a]Soil	Sediment	Vegetation	[b]Air Filters
^{241}Am	0/5	[c]NR	9/16	NR	NR	NR
^{239,240}Pu	0/5	1/3	16/16	13/15	17/18	48/48
^{228}Th	3/5	2/3	15/16	15/15	[d]NA	NA
^{230}Th	2/5	0/3	16/16	15/15	18/18	NA
^{232}Th	2/5	1/3	15/16	15/15	18/18	NA
^{234}U	5/5	6/6	16/16	15/15	18/18	NA
^{238}U	5/5	6/6	16/16	15/15	18/18	NA
^{137}Cs	0/5	0/6	48/48	15/15	1/18	NA
^{40}K	0/5	2/6	48/48	15/15	18/18	NA

[a] Analyses of soil samples for ^{241}Am, ^{239,240}Pu, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, and ^{238}U were performed by Accu-Labs Research, Inc.

[b] Of the total 48 air filters analyzed for ^{239,240}Pu, 46 were analyzed by Argonne National Laboratory and 2 were analyzed by CEMRC.

[c] NR=Not Reported due to analysis failure

[d] NA=Not Analyzed

WIPP ENVIRONMENTAL MONITORING DATA SUMMARIES

Meteorological Data Summary

Methods

The Center operates two identical meteorological towers in the vicinity of the WIPP site (Figure 2). The Near Field station is located approximately 1 km northwest of the WIPP site at an elevation of 1053 m (latitude 32°22’40.385”N; longitude 103°47’55.425”W). The Cactus Flats station is located approximately 19 km southeast of the WIPP site at an elevation of 1135 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, solar radiation, wind speed and direction, vertical wind speed, and precipitation. Measurements are taken every second and averaged over a ten-minute period for temperature, pressure, relative humidity, wind speed, wind vector, vertical wind speed, and solar radiation. In addition, the maximum wind speed and total precipitation occurring over the 10-minute period are also recorded. The barometric pressure is adjusted for temperature, but is not referenced to mean sea level. The solar radiation sensors (pyranometer) measure the energy flux of both direct and diffuse sky radiation. Wind, temperature and relative humidity are measured at a height of 10 m. Solar radiation, barometric pressure and precipitation are measured at 2, 1 and 0.4 m, respectively.

Data are stored by electronic logging devices, downloaded twice weekly and screened for outliers or other anomalies. Performance checks of the meteorological sensors are conducted quarterly, and sensors are recalibrated annually to ensure data reliability.

Results

The following summarizes meteorological data collected at both sampling stations during January-November, 1997. Data recovery over the sampling period was greater than 95% for the majority of the sensors at both Cactus Flats and Near Field. The barometric pressure and solar radiation sensors at Cactus Flats were rendered nonfunctional during September 2-8, due to a lightning strike. The precipitation gauge at Near Field was inoperable during January 1-February 19, due to a damaged cable. Other short-term data losses were due to sensor maintenance, instrument failure, or other problems.

Cactus Flats and Near Field exhibited very similar wind characteristics. In general, the prevailing winds were from a southeasterly direction throughout the year at both stations (Figure 3). Averaged over the entire sampling period, wind was from a southeasterly direction 45% of the time at Near Field and 42% of the time at Cactus Flats (SSE, SE and ESE sectors, inclusive). At both stations the winter (January-February) and summer (June-August) months exhibited the highest and lowest variability in wind direction, respectively (Figures 4 and 5). From June through August, wind blew from the southeast quadrant (south through east sectors, inclusive) over 70% of the time at both stations. Wind speeds (10 minute average) during January-November ranged from 1.3 to 5.4 m s^{-1} (3-18 mph) over 90% of the time at both Cactus Flats and Near Field. Calm periods or periods of very high winds (>10.7 m s^{-1}) combined, occurred less than 1% of the time. The highest single gusts recorded over the sampling period were 27.9 and 23.6 m s^{-1} (62 and 53 mph) occurring on June 14 at Near Field and Cactus Flats, respectively.

Average air temperatures over the sampling period were similar at Near Field at Cactus Flats (Table 7). Average monthly temperatures peaked at both stations in July and were lowest in January (Tables 8 and 9). The temperatures at Near Field ranged from –11.4 to 40.0 ^{o}C , and from –12.05 to 39.6 ^{o}C at Cactus Flats. At both stations, minimum and maximum readings were recorded on January 13 and June 2, respectively.

As was true for temperature, the annual mean percent relative humidity (%RH) at Cactus Flats (51.2%) and Near Field (48.6%) was very similar. The differences are within sensor accuracy (±5%). At Cactus Flats the %RH ranged from 7.1 to 102.7%, while Near

Field ranged from 6.8 to 101.4% (Table 7). At both stations, the months with the highest and lowest mean %RH were February and March, respectively (Tables 8 and 9). The accuracy of the relative humidity sensors declines for %RH below 12% and above 94%, and readings outside these ranges should be interpreted with caution.

Barometric pressure ranges were 878.4 - 915.1 mb and 872.9 - 909.9 mb at Near Field and Cactus Flats, respectively (Table 7). The annual mean barometric pressure was 897.2 mb at Near Field and 892.1 mb at Cactus Flats, a difference that can be attributed to a combination of sensor accuracy (±0.6 mb) and differences in elevation between the stations.

The daily peak solar radiation is summarized in this report. Peak solar radiation was essentially the same at Cactus Flats and Near Field. Over all months, the mean (±SD) solar radiation peaks were 1053 ± 324 Wm^{-2} and 1075 ± 290 $W\ m^{-2}$ for Cactus Flats and Near Field, respectively. At both stations, the highest monthly mean measurements were recorded in August and the lowest in January.

Over the sampling period, measurable precipitation was recorded on 62 days at Cactus Flats and 39 days at Near Field (Table 10). Overall, the months with highest rainfall were October (7.11 cm) and July (13.23 cm) for Cactus Flats and Near Field, respectively. The months with the greatest number of days with rainfall were February at Cactus Flats and July at Near Field. The largest recorded precipitation event at Near Field occurred on July 3, totaling 5.28 cm. At Cactus Flats, 3.81 cm of precipitation fell on October 7. Cumulative totals were 28.87 cm and 39.30 cm for Cactus Flats and Near Field, respectively.

The distribution of precipitation in desert areas is known to be uneven on a regional scale, with events often occurring as localized, occasionally intense, thunderstorms. However, several other factors may account for the observed differences in precipitation between stations. A damaged sensor cable rendered the precipitation gauge at the Near Field station inoperable from January 1 to February 19 (49 days). During this time, there were 7 days on which precipitation was recorded at Cactus Flats totaling 1.45 cm. In addition, the Cactus Flats station was not operational from September 2-8, and Near Field received precipitation totaling 2.62 cm over that period.

Figure 2. Sampling Locations in the Vicinity of the WIPP

Aerosol Samples are collected at Near Field and Cactus Flats.

Figure 3. Eleven-Month 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) given on scale.

Figure 4. Quarterly Wind Roses, Near Field

[a] See page 25 for explanation.

Figure 5. Quarterly Wind Roses, Cactus Flats

See page 25 for explanation.

Table 7. Summary Statistics for Selected Meteorological Parameters Recorded at Cactus Flats and Near Field stations during January - November, 1997

[a]Location	Statistics	Barometric Pressure (mb)	Air Temperature (°C)	Relative Humidity (%)	[b]Solar Radiation (W m^{-2})
Cactus Flats	[c]Mean	892.1	17.4	51.2	1053
	[d]SD	5.0	10.0	25.9	324
	Minimum	815.3	-12.1	7.1	120
	Maximum	909.9	39.6	102.7	1941
	% Data Recovery	90	98	98	95
Near Field	Mean	897.2	18.0	48.6	1075
	SD	4.88	9.87	25.4	290
	Minimum	878.4	-11.4	6.8	136
	Maximum	915.1	40.0	101.4	1729
	% Data Recovery	98	100	100	90

[a] Location of stations as shown in Figure 2

[b] Statistics were calculated using daily peak solar radiation measurements

[c] Arithmetic mean

[d] SD = Standard Deviation

Table 8. Monthly Summary Statistics for Selected Meteorological Parameters Recorded at Cactus Flats during January - November, 1997

Month	Statistic	Barometric Pressure (mb)	Air Temperature (°C)	Relative Humidity (%)	[a]Solar Radiation (W m^{-2})
January	[b]Mean	894.1	5.2	53.8	596
	Minimum	881.8	-12.1	13.0	120
	Maximum	909.9	24.6	98.2	772
	% Data Recovery	100	100	100	100
February	Mean	893.0	6.4	67.4	717
	Minimum	815.3	-5.0	13.0	225
	Maximum	904.6	24.2	102.7	881
	% Data Recovery	100	100	100	93
March	Mean	893.3	13.9	41.1	927
	Minimum	883.5	-2.2	9.8	439
	Maximum	905.0	32.0	100.4	1065
	% Data Recovery	100	100	100	97
April	Mean	889.2	14.3	54.5	943
	Minimum	872.9	-3.4	10.8	333
	Maximum	899.7	30.6	99.5	1124
	% Data Recovery	100	100	100	97
May	Mean	891.6	21.0	53.8	1025
	Minimum	878.3	8.6	10.5	644
	Maximum	903.9	34.5	98.1	1194
	% Data Recovery	100	100	100	97
June	Mean	889.3	25.0	53.6	1042
	Minimum	882.7	12.7	7.1	766
	Maximum	897.2	39.6	95.7	1311
	% Data Recovery	100	100	100	100

Table continued on next page

Table 8. Monthly Summary Statistics for Selected Meteorological Parameters Recorded at Cactus Flats during January - November, 1997 (Continued)

Month	Statistic	Barometric Pressure (mb)	Air Temperature (°C)	Relative Humidity (%)	[a]Solar Radiation (W m^{-2})
July	Mean	893.0	27.5	46.0	1092
	Minimum	886.3	16.8	9.2	974
	Maximum	900.0	38.5	92.6	1769
	% Data Recovery	97	99	99	97
August	Mean	893.4	26.6	50.0	1596
	Minimum	885.3	14.4	11.5	617
	Maximum	900.0	38.0	93.5	1941
	% Data Recovery	84	100	100	97
September	Mean	893.9	24.2	50.4	1439
	Minimum	890.1	13.00	12.5	1117
	Maximum	900.2	38.0	92.2	1631
	% Data Recovery	10	80	80	73
October	Mean	891.8	17.5	47.0	1255
	Minimum	877.8	-0.1	10.3	381
	Maximum	905.8	34.3	91.8	1695
	% Data Recovery	100	100	100	97
November	Mean	892.6	10.1	47.0	1020
	Minimum	878.0	-4.5	11.4	201
	Maximum	903.3	27.1	93.3	1301
	% Data Recovery	100	100	100	100

[a] Statistics were calculated using daily peak solar radiation measurements

[b] Arithmetic mean

Table 9. Monthly Summary Statistics for Selected Meteorological Parameters Recorded at Near Field during January - November, 1997

Month	Statistics	Barometric Pressure (mb)	Air Temperature (°C)	Relative Humidity (%)	[a]Solar Radiation (W m^{-2})
January	[b] Mean	899.2	5.9	51.9	621
	Minimum	886.8	-11.4	13.3	136
	Maximum	915.1	25.0	98.8	807
	% Data Recovery	100	100	100	97
February	Mean	898.1	7.1	64.2	731
	Minimum	883.0	-3.9	12.4	188
	Maximum	909.8	25.5	101.4	938
	% Data Recovery	99	99	99	89
March	Mean	898.4	14.5	38.4	923
	Minimum	888.3	-1.2	9.8	392
	Maximum	910.5	31.8	96.2	1032
	% Data Recovery	100	100	100	100
April	Mean	894.2	14.7	50.8	490982
	Minimum	878.4	-3.0	10.3	899
	Maximum	904.7	31.0	97.3	1064
	% Data Recovery	100	100	100	17
May	Mean	896.7	21.4	49.7	1154
	Minimum	882.9	8.1	10.1	792
	Maximum	909.1	34.9	94.8	1250
	% Data Recovery	100	100	100	100
June	Mean	894.3	25.6	50.0	1178
	Minimum	887.6	13.3	6.8	980
	Maximum	903.0	40.0	93.2	1405
	% Data Recovery	100	100	100	100

Table continued on next page

Table 9. Monthly Summary Statistics for Selected Meteorological Parameters Recorded at Near Field during January - November, 1997 (Continued)

Month	Statistics	Barometric Pressure (mb)	Air Temperature (°C)	Relative Humidity (%)	[a]Solar Radiation (W m^{-2})
July	Mean	898.0	27.9	43.4	1174
	Minimum	891.1	16.4	7.8	1013
	Maximum	904.0	39.6	92.9	1665
	% Data Recovery	94	100	100	94
August	Mean	898.10	26.9	47.8	1473
	Minimum	889.86	15.2	9.4	895
	Maximum	905.00	38.5	92.3	1662
	% Data Recovery	84	100	100	100
September	Mean	897.99	24.7	50.0	1327
	Minimum	889.93	13.4	8.6	615
	Maximum	906.11	39.0	90.8	1729
	% Data Recovery	100	100	100	100
October	Mean	896.8	17.7	45.1	1160
	Minimum	882.8	-0.1	10.1	348
	Maximum	910.7	34.1	90.0	1594
	% Data Recovery	100	100	100	97
November	Mean	897.5	10.6	44.5	954
	Minimum	882.9	-0.4	11.1	160
	Maximum	908.3	27.8	90.8	1302
	% Data Recovery	100	100	100	100

[a] Statistics were calculated using daily peak solar radiation measurements

[b] Arithmetic mean

Table 10. Summary of Precipitation Data Collected at Cactus Flats and Near Field during January – November, 1997

Location	Month	Monthly Total (cm)	Days with Measurable Precipitation	[a]Average Daily Precipitation (cm)	Maximum Daily Precipitation (cm)	Date of Maximum Precipitation
Cactus Flats	Jan	0.28	3	0.01	0.18	Jan 8
	Feb	1.75	10	0.09	0.94	Feb 12
	Mar	1.37	2	0.04	1.35	March 3
	Apr	5.89	8	0.20	1.88	Apr 24
	May	2.41	6	0.08	1.55	May 7
	Jun	1.75	5	0.58	0.84	June 7
	Jul	3.58	7	0.12	1.35	July 7
	Aug	1.93	7	0.06	1.04	Aug 11
	[b]Sep	1.91	4	0.08	1.24	Sep 21
	Oct	7.11	5	0.23	3.81	Oct 7
	Nov	0.89	5	0.03	0.20	Nov 27
	[c]Totals	28.87	62	0.09		
Near Field	[d]Jan					
	[d]Feb	0.00	0	0.00	0.00	
	Mar	0.00	0	0.00	0.00	
	Apr	0.00	0	0.00	0.00	
	May	3.84	5	0.12	1.35	May 7
	Jun	5.54	5	0.19	2.11	Jun 26
	Jul	13.23	8	0.43	5.28	July 3
	Aug	4.22	4	0.14	2.69	Aug 4
	Sep	7.37	7	0.25	2.77	Sep 21
	Oct	4.34	7	0.01	2.49	Oct 7
	Nov	0.76	3	0.03	0.38	Nov 11
	[c]Totals	39.30	39	0.13		

[a] Averages based only on days when data were collected; some months had missing data as noted below

[b] No data collected from September 2 to September 8, 1997.

[C] Totals based only on days when data collected.

[b] No data collected from January 1 to February 19, 1997.

Particulate Concentrations and Radionuclides in Near-Surface Air

Methods

Aerosol sampling was conducted during 1996-1997, at a site located approximately 1 km northwest of the WIPP (Near Field, Figure 2). For studies of radionuclides at this site, samples were collected for total suspended particulate matter (TSP), and particulate matter $\leq$10 μm aerodynamic diameter (PM_{10}). Samples of TSP and PM_{10} were collected approximately 4 m above ground surface. Samples of PM_{10} were also collected at 2 m above ground surface for a portion of the sample period at this site. Samples for both TSP and PM_{10} were collected concurrently over periods of 8-46 days, using 20 x 25 cm glass fiber filters. High-volume air flows of approximately 1.13 $\pm$ 0.11 m^3 min^{-1} were used for collection of samples, with periodic checks on flow rates determined and recorded from a calibrated Magnehelic® gauge or digital manometer. Beginning in June 1997, the same type of equipment and sampling design were used to collect TSP and PM_{10} samples approximately 5 m above ground surface, at a site located approximately 19 km southeast of the WIPP (Cactus Flats, Figure 2).

Prior to placement in the samplers, all filters were preconditioned in a dessicator, equilibrated and weighed. At the completion of each sampling period, filters were removed from the samplers and placed in glassine envelopes for transport and storage. Loaded filters were reconditioned in a dessicator, re-equilibrated and re-weighed to determine total mass accumulation. The mass accumulation divided by the total air volume drawn through the sampler was used to calculate the aerosol particulate mass concentration. The total air volume for the sampling period was calculated based on an integrated total during each period of sampling time.

Following weighing, filters were ashed in a muffle furnace at 510°C for at least four hours and treated with HNO_3 and HF to dissolve the sample material. Actinide separation was conducted using anion-exchange chromatography (Jiang, F.S., et. al., 1986, *J. Radioanal. Nucl. Chem.* 100(1), 65). Analyses of alpha-emitting radionuclides were carried out with 450 mm^2 silicon surface barrier detectors, or passivated implanted planar silicon detectors, coupled with a multi-channel analyzer. The $^{239,240}Pu$ activity concentration and density were calculated from the total $^{239,240}Pu$ activity divided by the total air volume and the total mass accumulation, respectively. The mean MDC for $^{239,240}Pu$ was determined to be 1 nBq m^{-3}, with 50% average yield. Individual sample-specific MDCs were also calculated. Five blank filters were included for quality control. A part of the air filters were analyzed by Argonne National Laboratory. The MDCs for those samples were calculated from the $^{239,240}Pu$ activities of the blank filters.

Analyses of variance (AOV) and Tukey's means tests were used to examine variability in particulate mass concentrations, $^{239,240}Pu$ activity concentrations, and $^{239,240}Pu$ activity densities in samples collected at the Near Field location.

Results

During June 1996 – September 1997, a total of 44 air filters from Near Field and four air filters from Cactus Flats were collected and analyzed for mass concentrations (Table 11). At Near Field, mean mass concentrations ($\pm$SE) of PM_{10} at the 2-m height, PM_{10} at the 4-m height, and TSP at the 4-m height were 11.9 ($\pm$0.7), 12.2 ($\pm$0.6) and 23.0 ($\pm$1.9) μg m^{-3}, respectively (Table 15). For Cactus Flats, the observed PM_{10} mass concentrations at the 5-m height were 11.2-14.8 μg m^{-3} and TSP mass concentrations at the 5-m height were 15.8-21.9 μg m^{-3} (Table 11).

For Near Field, the AOV results indicated that sampler type (TSP versus PM_{10}) was a significant factor associated with variations in mass concentrations (Table 16). Means comparisons indicated no significant difference between PM_{10} mass concentrations collected at 2 m versus PM_{10} mass concentrations collected at 4 m. However, the mean mass concentration of PM_{10} collected at 4 m was significantly different ($P < 0.05$) from the mean TSP mass concentration at the same height (12.1 versus 23.0 μg m^{-3}). Similar relationships were observed for mass concentrations in samples collected at the same location during February – May 1996 (Lee, S.C., et. al., J. *Radioanal. Nucl. Chem.*, in press).

A total of 42 air filters collected at Near Field during June 1996 – September 1997 were analyzed for ^{239,240}Pu (Table 12), and four air filters collected from Cactus Flats were also analyzed for ^{239,240}Pu (Table 13). For Near Field, mean activity concentrations (±SE) of ^{239,240}Pu were 10.2 (±1.4) nBq m^{-3} for TSP collected at the 4-m height, 6.2 (±1.2) nBq m^{-3} for PM$_{10}$ collected at the 5-m height, and 5.4 (±0.8) nBq m^{-3} for PM$_{10}$ collected at the 2-m height (Table 15). For Cactus Flats, observed activity concentrations in PM$_{10}$ were 4.8–21 nBq m^{-3}, and in TSP were 6.8–14 nBq m^{-3} (Table 13).

The AOV for samples from Near Field indicated that sampler type (TSP versus PM$_{10}$) was a significant factor associated with variations in ^{239,240}Pu activity concentrations (Table 16). Means comparisons indicated no significant difference between activity concentrations in PM$_{10}$ collected at 2 m and activity concentrations in PM$_{10}$ collected at 4 m. However, the mean activity concentration of ^{239,240}Pu in PM$_{10}$ collected at 4 m was significantly different ($P < 0.05$) from the mean activity concentration of ^{239,240}Pu in TSP collected at the same height (6.2 versus 10.2 nBq m^{-3}).

Rodgers and Kenny (1997, *Health Phys.* 72, 300) reported ^{239,240}Pu baseline activity concentrations of -21 ± 180 nBq m^{-3} (mean ± SD) for air samples in the region of the WIPP. All data reported herein are well below the 97.7th quantile (230 nBq m^{-3}) of the baseline distribution reported by these authors. All of the observed values are within the range of activity concentrations observed in TSP samples (4-40 nBq m^{-3}) previously reported by Argonne National Laboratory (Golchert, N.W. and T.L. Duffy, 1994, ANL-94/10). The observed values also are similar to those reported by EPA for TSP samples (7-30 nBq m^{-3}) for three cities within 160-500 miles of the WIPP site, including Santa Fe, New Mexico; Austin, Texas; and El Paso, Texas (U.S. EPA, Office of Radiation and Indoor Air, Report Nos. 76, 78, 80 and 82, 1993-1995).

Activity densities of ^{239,240}Pu were calculated for the four samples from Cactus Flats (Table 13) and the 42 samples from Near Field (Table 14). Mean ^{239,240}Pu activity densities (±SE) in samples from Near Field were 0.44 (±0.05), 0.54 (±0.08), and 0.45 (±0.03) mBq g^{-1} for PM$_{10}$ collected at the 2-m height, PM$_{10}$ collected at the 4-m height, and TSP collected at the 4-m height, respectively (Table 15). Activity densities for ^{239,240}Pu in the Cactus Flats samples were 0.40-2.0 mBq g^{-1} for PM$_{10}$ samples, and 0.42-0.66 mBq g^{-1} for TSP samples (Table 13). For Near Field, the AOV indicated no significant differences in activity density associated with sampler type (TSP, PM$_{10}$ at 4-m height, and PM$_{10}$ at 2-m height) (Table 16).

The overall mean ^{239,240}Pu activity concentration (±SE) observed for February-May 1997 was 8.7 (±2.0) nBq m^{-3}, which was approximately 59% lower than that recorded during the same period in 1996, and the overall mean activity density (±SE) observed for February-May 1997 was 0.44 (±0.03) mBq g^{-1}, which is approximately 32% lower than reported for the same period in 1996
(0.65 ± 0.03 mBq g^{-1}) (Lee, S.C., et. al., *J. Radioanal. Nucl. Chem.*, in press). These differences may result from natural interannual variability in the concentrations and/or resuspension of ^{239,240}Pu, as well as from differences in size-selective sampling efficiency between the two sampling periods.

The activity concentration of ^{239,240}Pu in early 1980 was at ~1 μBq m^{-3} (Golchert, N.W. and T.L. Duffy, 1987, ANL-87-9) and the stratospheric fallout mean residence time has been estimated to be 1.2 years (Lee, S.C., et al., 1986, *Geochemical J.* 19, 283). Holloway and Hayes (1982, *Env. Sci. Tech.*, 16, 127), estimated a mean tropospheric residence time of 71 days for ^{239,240}Pu aerosol fallout. Assuming a ^{239,240}Pu fallout level of 1 μBq m^{-3} in 1980, and using a residence time of 1.2 years (based on first-order kinetics), it can be calculated that 0.01 nBq m^{-3} of ^{239,240}Pu should be the maximum level of ^{239,240}Pu contamination attributable to current atmospheric fallout. Thus, the observed ^{239,240}Pu activity concentrations in aerosols are likely to be the result of soil resuspension processes operating near the earth's surface in the region of the WIPP site. However, ^{239,240}Pu activity densities recorded in this study for particulate matter collected on air filters are much higher than activity densities observed in soil samples during the same period (0.04-0.11 mBq g^{-1}) (p. 51). This may reflect a higher density of Pu in particulates of smaller particles (<75 μm) that are selectively captured in air sampling, as compared to Pu densities in bulk soil, which includes a greater proportion of large particulates.

Table 11. Aerosol Particle Mass Concentrations in Aerosol Samples Collected at Near Field and Cactus Flats during June 1996 – September 1997

		[a]Aerosol Particle Mass Concentration (μg m^{-3})		
[b]Location	Sampling Period	[c]PM_{10}-2m	[d]PM_{10}-4/5m	[e]TSP-4/5m
Near Field	6/25/96-7/8/96		18	23
	7/5/96-7/26/96	13		
	7/8/96-7/22/96			19
	7/8/96-7/26/96		13	
	7/22/96-8/9/96			29
	7/26/96-8/16/96	14	14	
	8/9/96-9/6/96			15
	8/16/96-10/1/96	8.6	8.4	
	9/6/96-10/1/96			17
	10/2/96-10/22/96			28
	10/2/96-10/25/96	13		
	10/8/96-10/25/96		13	
	10/22/96-11/18/96			25
	10/25/96-11/27/96	12	12	
	11/18/96-12/5/96			18
	11/27/96-1/2/97	9.2	9.0	
	12/5/96-1/2/97			21
	1/2/97-1/24/97	9.8	9.7	18
	1/24/97-2/19/97	9.9	9.5	18
	2/19/97-3/26/97	17	15	
	3/11/97-3/26/97			48
	3/26/97-4/22/97	14	14	28
	4/22/97-5/26/97	11	10	21
	5/26/97-6/24/97	11	12	21
	6/6/97-7/8/97		12	
	6/24/97-8/6/97		14	
	8/6/97-9/8/97		12	18

Table continued on next page

Table 11. Aerosol Particle Mass Concentrations in Aerosol Samples Collected at Near Field and Cactus Flats during June 1996 – September 1997 (Continued)

		[a]Aerosol Particle Mass Concentration ($\mu g\ m^{-3}$)		
[b]Location	Sampling Period	[c]PM_{10}-2m	[d]PM_{10}-4/5m	[e]TSP-4/5m
Cactus Flats	7/8/97-8/6/97		15	22
	8/6/97-9/8/97		11	
	8/7/97-9/8/97			16

[a] Aerosol particle mass concentrations values do not reflect error associated with total air flow measurements and particulate mass measurements; all measurements are rounded to two significant figures.

[b] Locations as shown in Figure 2

[b] PM_{10}-2 m = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm, collected with high volume sampler at elevation of approximately 2 m above ground surface

[c] PM_{10}-4/5 m = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm, collected with high volume sampler at elevation of approximately 4 m above ground surface at Near Field, and approximately 5 m above ground surface at Cactus Flats

[d] TSP-4/5 m = total suspended particulate matter aerosols with aerodynamic diameter <75 µm, collected with high volume sampler at elevation of approximately 4 m above ground surface at Near Field, and approximately 5 m above ground surface at Cactus Flats

Table 12. $^{239,240}Pu$ Activity Concentrations in Aerosol Samples Collected at Near Field during June 1996 – September 1997

	^{239,240}Pu Activity Concentration (nBq m^{-3})								
	^{a}PM$_{10}$ – 2 m			^{b}PM$_{10}$ – 4 m			^{c}TSP – 4 m		
Sampling Period	^{d}C	^{e}SD	^{f}MDC	C	SD	MDC	C	SD	MDC
6/25/96-7/8/96				1.5E+1	5.02E+0	2.3E-2	1.2E+1	2.3E+0	2.3E-2
7/5/96-7/26/96	1.2E+1	1.7E+0	1.3E-2						
7/8/96-7/22/96							7.5E+0	1.7E+0	2.4E-2
7/8/96-7/26/96				1.8E+1	4.0E+0	1.5E-2			
7/22/96-8/9/96							1.4E+1	4.9E+0	1.7E-2
7/26/96-8/16/96	2.3E+0	7.2E-1	1.3E-2	1.1E+1	2.0E+0	1.4E-2			
8/9/96-9/6/96							4.4E+0	9.4E-1	9.6E-3
8/16/96-10/1/96	3.01E+0	5.3E-1	5.5E-3	2.2E+0	4.2E-1	6.4E-3			
9/6/96-10/1/96							7.8E+0	1.5E+0	1.1E-2
10/2/96-10/25/96	4.6E+0	1.1E+0	1.3E-2						
10/8/96-10/25/96				8.0E+0	2.3E+0	1.7E-2			
10/25/96-11/27/96	5.6E+0	6.1E-1	8.6E-3	3.0E+0	4.9E-1	8.8E-3			
11/18/96-12/5/96							8.5E+0	1.2E+0	1.9E-2
11/27/96-1/2/97	4.6E+0	5.6E-1	8.0E-3	4.5E+0	5.89E-1	8.3E-3			
12/5/96-1/2/97							1.1E+1	1.0E+0	1.1E-2

Table continued on next page

Table 12. ^{239,240}Pu Activity Concentrations in Air Samples Collected at Near Field during June 1996 – September 1997 (Continued)

	^{239,240}Pu Activity Concentration (nBq m^{-3})								
	[a]PM$_{10}$ – 2 m			[b]PM$_{10}$ – 4 m			[c]TSP – 4 m		
Sampling Period	[d]C	[e]SD	[f]MDC	C	SD	MDC	C	SD	MDC
1/2/97-1/24/97	4.3E+0	7.0E-1	1.3E-2	3.4E+0	6.2E-1	1.3E-2	8.8E+0	1.1E+0	1.4E-2
1/24/97-2/19/97	3.0E+0	3.6E-1	1.2E-2	2.4E+0	3.6E-1	1.1E-2	6.9E+0	6.3E-1	1.1E-2
2/19/97-3/26/97	8.6E+0	1.2E+0	8.8E-3	6.9E+0	9.9E-1	8.4E-3			
3/11/97-3/26/97							2.8E+1	2.4E+0	1.9E-2
3/26/97-4/22/97	8.5E+0	8.7E-1	1.1E-2	5.7E+0	5.1E-1	1.1E-2	1.6E+1	9.2E-1	1.1E-2
4/22/97-5/26/97	4.4E+0	4.8E-1	8.8E-3	3.7E+0	4.6E-1	8.3E-3	1.0E+1	1.2E+0	8.6E-3
5/26/97-6/24/97	3.5E+0	5.7E-1	1.0E-2	4.2E+0	4.8E-1	1.0E-2	7.4E+0	6.8E-1	1.1E-2
6/6/97-7/8/97				2.4E+0	3.9E-1	1.3E+0			
7/8/97-8/6/97							7.2E+0	9.6E-1	2.6E+0
8/6/97-9/8/97				2.8E+0	4.3E-1	1.4E+0	3.6E+0	5.2E-1	1.3E-2
8/7/97-9/8/97							3.4E+0	7.5E-1	2.7E+0

[a]PM$_{10}$-2 m = suspended particulate matter aerosols with aerodynamic diameter ≤10 µm, collected with high volume sampler at elevation of approximately 2 m above ground surface

[b]PM$_{10}$-4 m = suspended particulate matter aerosols with aerodynamic diameter ≤10 µm, collected with high volume sampler at elevation of approximately 4 m above ground surface

[c]TSP-4 m = total suspended particulate matter aerosols with aerodynamic diameter <75 µm, collected with high volume sampler at elevation of approximately 4 m above ground surface

[d, e, f] C, SD and MDC as defined in Appendix K; all values are rounded to two significant figures

Table 13. ^{239,240}Pu Activity Concentrations and Activity Densities in Aerosol Samples Collected at Cactus Flats during June - September 1997

	^{239,240}Pu Activity Concentrations (nBq m^{-3})					
	[a]PM$_{10}$ – 5 m			[b]TSP – 5 m		
Sampling Period	**[c]C**	**[d]SD**	**[e]MDC**	**C**	**SD**	**MDC**
6/6/97-7/8/97	4.8E+0	7.8E-1	2.6E+0			
7/8/97-8/6/97				1.4E+1	1.9E+0	5.2E+0
8/6/97-9/8/97	2.1E+1	1.9E+0	3.6E+0			
8/7/97-9/8/97				6.8E+0	1.5E+0	5.4E+0
	^{239,240}Pu Activity Densities (mBq g^{-1})					
	[a]PM$_{10}$ – 5 m			**[b]TSP – 5 m**		
6/6/97-7/8/97	4.0E-1	6.4E-2	2.2E-1			
7/8/97-8/6/97				6.6E-1	8.8E-2	2.4E-1
8/6/97-9/8/97	2.0E+0	1.7E-1	3.2E-1			
8/7/97-9/8/97				4.2E-1	9.4E-2	3.4E-1

[a] PM$_{10}$-5 m = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm, collected with high volume sampler at elevation of approximately 5 m above ground surface

[b] TSP-5 m = total suspended particulate matter aerosols with aerodynamic diameter <75 µm, collected with high volume sampler at elevation of approximately 5 m above ground surface

[c,d,e] C, SD and MDC as defined in Appendix K; all values are rounded to two significant figures

Table 14. ^{239,240}Pu Activity Densities in Aerosol Samples Collected at Near Field during June 1996 – September 1997

	^{239,240}Pu Activity Density (mBq g^{-1})								
	^{a}PM$_{10}$-2m			^{b}PM$_{10}$-4m			^{c}TSP-4 m		
Sampling Period	**^{d}C**	**^{e}SD**	**^{f}MDC**	**C**	**SD**	**MDC**	**C**	**SD**	**MDC**
6/25/96-7/8/96				8.3E-1	2.8E-1	1.3E-3	5.4E-1	1.0E-1	1.0E-3
7/5/96-7/26/96	9.2E-1	1.3E-1	1.0E-3						
7/8/96-7/22/96				1.3E+0	3.0E-1	1.2E-3	3.9E-1	8.7E-2	1.2E-3
7/22/96-8/9/96							4.7E-1	1.7E-1	5.7E-4
7/26/96-8/16/96	1.6E-1	5.1E-2	9.5E-4	7.8E-1	1.5E-1	1.0E-3			
8/9/96-9/6/96							2.9E-1	6.4E-2	6.4E-4
8/16/96-10/1/96	3.5E-1	6.2E-2	6.4E-4	2.6E-1	5.0E-2	7.8E-4			
9/6/96-10/1/96							4.48E-1	8.78E-2	6.6E-4
10/2/96-10/25/96	3.6E-1	8.4E-2	9.9E-4						
10/8/96-10/25/96				6.4E-1	1.8E-1	1.4E-3			
10/25/96-11/27/96	4.6E-1	5.0E-2	7.1E-4	2.5E-1	4.1E-2	7.4E-4			
11/18/96-12/5/96							4.8E-1	6.8E-2	1.0E-3

Table continued on next page

Table 14. ^{239,240}Pu Activity Densities in Aerosol Samples Collected at Near Field during June 1996 – September 1997 (Continued)

	^{239,240}Pu Activity Density (mBq g^{-1})								
	^{a}PM$_{10}$-2m			^{b}PM$_{10}$-4m			^{c}TSP-4m		
Sampling Period	^{d}C	^{e}SD	^{f}MDC	C	SD	MDC	C	SD	MDC
11/27/96-1/2/97	5.0E-1	6.2E-2	8.7E-4	5.0E-1	6.4E-2	9.1E-4			
12/5/96-1/2/97							5.3E-1	4.9E-2	5.1E-4
1/2/97-1/24/97	4.4E-1	7.19E-2	1.3E-3	3.5E-1	6.4E-2	1.4E-3	4.9E-1	6.0E-2	7.5E-4
1/24/97-2/19/97	3.0E-1	3.7E-2	1.2E-3	2.5E-1	3.8E-2	1.2E-3	3.8E-1	3.4E-2	6.1E-4
2/19/97-3/26/97	5.1E-1	7.02E-2	5.2E-4	4.5E-1	6.5E-2	5.5E-4			
3/11/97-3/26/97							5.7E-1	5.0E-2	3.9E-4
3/26/97-4/22/97	6.0E-1	6.1E-2	7.7E-4	4.0E-1	3.6E-2	7.6E-4	5.9E-1	3.4E-2	3.8E-4
4/22/97-5/26/97	4.2E-1	4.6E-2	8.3E-4	3.6E-1	4.5E-2	8.2E-4	4.9E-1	5.9E-2	4.1E-4
5/26/97-6/24/97	3.1E-1	5.0E-2	9.1E-4	3.5E-1	4.0E-2	8.5E-4	3.5E-1	3.2E-2	5.0E-4
8/6/97-9/8/97				2.3E-1	7.0E-2	7.5E-4	2.0E-1	6.0E-2	7.3E-4

[a] PM$_{10}$-2 m = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm, collected with high volume sampler at elevation of approximately 2 m above ground surface

[b] PM$_{10}$-4 m = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm, collected with high volume sampler at elevation of approximately 4 m above ground surface

[c] TSP-4 m = total suspended particulate matter aerosols with aerodynamic diameter <75 µm, collected with high volume sampler at elevation of approximately 4 m above ground surface

[d, e, f] C, SD and MDC as defined in Appendix K; all values are rounded to two significant figures

Table 15. Summary Statistics for Mass Concentrations, ^{239,240}Pu Activity Concentrations and ^{239,240}Pu Activity Densities in Aerosol Samples Collected at Near Field during June 1996 – September 1997

	Aerosol Particle Diameter Class (sampler elevation)	**[a]N**	**[b]Mean**	**[c]SE**	**Minimum**	**Maximum**
Mass Concentration (μg m^{-3})	[d]PM_{10} - 2 m	12	12	0.7	8.6	17
	[e]PM_{10} - 4 m	16	12	0.6	8.3	18
	[f]TSP - 4 m	16	23	2	15	48
^{239,240}Pu [g]Activity Concentration (nBq m^{-3})	PM_{10} - 2 m	12	5.4	0.8	2.3	12
	PM_{10} - 4 m	15	6.2	1.2	2.2	17.7
	TSP - 4 m	15	10.2	1.4	3.6	28
^{239,240}Pu [h]Activity Density (mBq g^{-1})	PM_{10} - 2 m	12	0.44	0.050	0.16	0.92
	PM_{10} - 4 m	15	0.48	0.080	0.23	1.3
	TSP - 4 m	15	0.43	0.030	0.20	0.59

[a] N = number of samples included in calculations

[b] Mean = arithmetic mean

[c] SE = standard error of mean

[d] PM_{10}-2 m = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm, collected with high volume sampler at elevation of approximately 2 m above ground surface

[e] PM_{10}-4 m = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm, collected with high volume sampler at elevation of approximately 4 m above ground surface

[f] TSP-4 m = total suspended particulate matter aerosols with aerodynamic diameter <75 µm, collected with high volume sampler at elevation of approximately 4 m above ground surface

[g] Activity Concentrations as defined in Appendix K; all values are rounded to two significant figures.

[h] Activity Densities calculated as defined for activity concentrations in Appendix K, using accumulated particulate mass concentration (g); all values are rounded to two significant figures.

Table 16. Results of Analyses of Variance for Mass and ^{239,240}Pu Concentrations and ^{239,240}Pu Activity Densities in Air Samples Collected at Near Field during June 1996 – September 1997

Response Variable	Source	[a]df	[b]SS	[c]F	[d]P
Mass Concentration (μg m^{-3})	Samplers	2	1.204E+3	22.56	0.0001
	Error	41	1.094E+3		
	Total	43	2.297E+3		
^{239,240}Pu Activity Concentration (nBq m^{-3})	Sampler	2	1.904E+2	4.17	0.0228
	Error	39	8.902E+2		
	Total	41	1.081E+3		
^{239,240}Pu Activity Density (mBq g^{-1})	Sampler	2	3.136E-2	0.31	0.7318
	Error	39	1.893E+0		
	Total	41	1.925E+0		

[a] df = degrees of freedom

[b] SS = Sum of Squares

[c] F = ratio of mean square of source term to mean square of error term

[d] P = probability of greater value of F due to random chance

X-Ray Fluorescence Analysis of Trace Elements in Aerosol Particles

Methods

Aerosol samples were collected at the Near Field station which is approximately 1 km northwest of the WIPP (Figure 2). All samples were collected from a platform approximately 4 m above the ground, using one of three devices; a total suspended particle (TSP) sampler or samplers (such as the Harvard honeycomb impactor) designed to collect particles of diameters $\leq$2.5 and $\leq$10 µm ($PM_{2.5}$ and PM_{10}, respectively). All are low-volume samplers which operate at a nominal flow rate ~10 L min^{-1}. The volumes of the air sampled are determined from flow controllers with estimated errors of ±10%. The samples analyzed to date were collected on 47 mm diameter Teflon® filters over ~24-hr intervals.

X-ray fluorescence (XRF) analysis was performed by the Desert Research Institute (DRI), on a subset of the aerosol samples collected at the Near Field site. Two sample sets (each set consisting of one TSP, one PM_{10}, and one $PM_{2.5}$ filter collected over a single sampling interval) were randomly selected for analysis for each calendar week between December, 1996 and June, 1997. The XRF analyses performed at DRI can generate data for the following elements (providing their concentrations are sufficiently high): Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, As, Se, Br, Rb, Sr, Y, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, Ba, La, Au, Hg, Tl, Pb, and U. XRF analysis produces a spectrum of peaks or “lines” superimposed on a smoothly varying background. The energy of each line is characteristic of a particular element, and the intensity of each line is proportional to the concentration of the element in the sample. Five separate XRF analyses were conducted on each sample to optimize the detection limits for the specified elements. Two protocols were used for the analyses of the aerosol-laden filters. Protocol C was used for the TSP and PM_{10} samples and Protocol D was used for the $PM_{2.5}$ samples. These protocols differ in data acquisition times, with longer counting times used in Protocol D. The more sensitive analytical scheme was used for the $PM_{2.5}$ samples because the mass of material collected in that size fraction was expected to be lower than in either the TSP or PM_{10} samples.

Particle size corrections to concentration results were made for Al, Si, P, Cl, K, and Ca for coarse particle absorption for the PM_{10} and TSP samples using the theoretical formulation for 2.5_{10} µm particles developed by Dzubay and Nelson (1975, *Adv.X-Ray Analysis* 18, 619). This adjustment is a function of particle-size distribution and composition. Since the actual particle size distribution and composition are unknown, the uncertainty of these adjustments is up to ±25%, and this is reflected in the reported uncertainties. DRI reported approximate concentrations for Na and Mg, but these were not considered quantitative because of uncorrected particle size effects.

Results

Not all elements could be detected by XRF spectrometry in the aerosol samples. In particular, no data were obtained for P, V, Co, Ga, Zr, Mo, Pd, Ag, Cd, In, Sn, Sb, La, Au, Hg, Tl or U, and as noted, the data for Na and Mg are not quantitative. For the other elements, the numbers of samples whose concentrations were above detection limits varied widely; some elements were quantifiable in all samples, while others could be quantified only in one or a few samples (Table 17).

One of the components most evident in the Near Field aerosol is mineral dust, which is produced by the weathering of the Earth’s crust and is generated by grinding, abrasion, sandblasting processes, etc. Moderate to strong winds can deflate mineral particles, and the atmospheric dust particles can travel hundreds, even thousands, of kilometers through the atmosphere before they are finally removed. Therefore, the elemental signature for the dust in the samples as discussed below is probably due to a combination of local dust with some unquantified regional contribution.

Aluminum often is used as an elemental tracer for mineral aerosol, and as a first step in analyzing the aerosol data, we stratified the aerosol data by sampler type and then used regression models to evaluate the relationships between the various elements and Al. Elements strongly correlated with Al include K, Ca, Si, Ti, Mn, Fe, Rb, Sr and Zr (Table 18). Also presented in Table 18 is a column giving the mass ratios to Al for those element-sample combinations significantly correlated with Al. In general the element to Al slopes derived from those regression models were similar to the corresponding mass ratios in average crustal rock. In most cases the observed and crustal values were within a factor of 2, but several preliminary observations and exceptions are noted here. First, the ratios of the elements to Al (X/Al) in the TSP and PM_{10} samples were nearly identical, but for most of the elements (Si, Ti, Mn, Fe, Rb, Sr, and Zr) the X/Al ratios in the TSP and PM_{10} aerosol samples were lower than those representative of average crustal rock. In contrast, two elements (K and especially Ca) apparently are enriched in the regional or local mineral dust, and the correlations between these two elements and Al are lower than those for the more typical crustal elements.

The enrichments of K and Ca are especially prominent in the $PM_{2.5}$ fraction (Table 18), suggesting the existence of a fine particle source for these elements. Iron also is enriched relative to Al in the $PM_{2.5}$ particle fraction. It must be noted, however, that the $PM_{2.5}$ samples were analyzed using a more sensitive analytical protocol. Therefore, it is possible, although unlikely, that some of the apparent differences in the $PM_{2.5}$ fraction as compared to PM_{10} and TSP are due to the different protocols used for analysis. Future studies will focus on verifying the enrichments of these elements in the $PM_{2.5}$ fraction, and on identifying the source or sources for the Ca, K and Fe-rich particles.

All of those elements not correlated with Al were enriched relative to the normalized composition of average crustal material (Table 19). These enrichments are a strong indication of sources for those elements other than those that generate atmospheric mineral dust particles. It is noteworthy that the highest enrichments of these elements occurred in the $PM_{2.5}$ samples. In many cases the X/Al ratios in that size fraction were roughly 10-fold higher than in those for the corresponding TSP or PM_{10} fractions. Submicrometer aerosol particles typically are formed by high temperature processes or gas-to-particle conversion, often in association with pollution emissions. Therefore, it is possible at least some of the observed trace element enrichments, especially in the $PM_{2.5}$ fraction, are caused by anthropogenic emissions.

Interest in the $PM_{2.5}$ size fraction of aerosols is increasing due to recently enacted EPA regulations adopting standards for this component of aerosol pollution. Beyond that, the preliminary results obtained to date have important implications for identifying the sources of particulate matter present in the atmosphere of the Carlsbad area. The elemental data are particularly amenable to source apportionment studies, and this will be another area that will be pursued in the future by environmental chemists. The trace element data also compose a portion of the baseline against which impacts of the WIPP disposal operations can be compared.

Table 17. Summary Statistics for Elemental Concentrations in Aerosol Samples Analyzed by X-Ray Fluorescence Spectrometry

		Aerosol Particle Diameter Classes								
		[a]TSP			**[b]PM$_{10}$**			**[c]PM$_{2.5}$**		
Element	**Units**	**[d]N**	**[e]Mean**	**[f]SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**
Al	μg m^{-3}	22	0.817	0.189	28	0.641	0.139	29	0.052	0.010
Si	μg m^{-3}	22	2.36	0.55	28	1.91	0.40	30	0.167	0.029
S	μg m^{-3}	22	0.499	0.058	28	0.575	0.062	30	0.557	0.062
Cl	μg m^{-3}	14	0.16	0.05	16	0.17	0.04	10	0.11	0.06
K	μg m^{-3}	22	0.355	0.069	28	0.323	0.053	30	0.137	0.030
Ca	μg m^{-3}	22	0.682	0.124	28	0.601	0.087	30	0.088	0.028
Ti	μg m^{-3}	13	0.033	0.008	13	0.029	0.007	2	0.02	0.001
Mn	ng m^{-3}	18	6.1	1.2	24	4.8	0.8	7	1.2	0.4
Fe	μg m^{-3}	22	0.254	0.055	28	0.201	0.039	30	0.040	0.007
Ni	ng m^{-3}	9	1.6	0.4	6	0.8	0.1	4	0.5	0.08
Cu	ng m^{-3}	11	1.4	0.14	12	1.8	0.5	7	1.7	0.6
Zn	ng m^{-3}	20	4.0	0.4	28	3.4	0.33	30	2.8	0.39
As	ng m^{-3}	3	1	0.8	3	5	3	6	3	1
Se	ng m^{-3}	1	0.6		3	0.6	0.03	2	0.6	0.1
Br	ng m^{-3}	20	2.2	0.23	27	2.4	0.23	30	1.9	0.17
Rb	ng m^{-3}	13	1.3	0.3	20	0.94	0.17	1	0.4	
Sr	ng m^{-3}	20	3.0	0.6	23	2.7	0.5	8	0.9	0.3
Y	ng m^{-3}	3	0.9	0.2	2	0.9	0.3	0		
Zr	ng m^{-3}	12	1.7	0.3	11	1.4	0.3	1	0.8	
Ba	μg m^{-3}	1	0.039		2	0.035	0.0001	0		
Pb	ng m^{-3}	3	1.5	0.1	9	2.1	0.2	4	2.0	0.5

[a]TSP = total suspended particulate matter aerosols with aerodynamic diameter <75 μm

[b]PM$_{10}$ = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 μm

[c]PM$_{2.5}$ = suspended particulate matter aerosols with aerodynamic diameter $\leq$2.5 μm

[d]N = number of samples included in calculations

[e]Mean = arithmetic mean

[f]SE = standard error of mean

Table 18. Results of Regression Models Applied to Investigate the Relationship Between Elements and Aluminum in Aerosol Samples

Element (*X*)	Crustal Ratio (*X*/Al)	Aerosol Particle Diameter Classes					
		[a]TSP		[b]PM10		[c]$PM_{2.5}$	
		[d] r^2	[e]Slope	r^2	Slope	r^2	Slope
Si	3.83	0.98	2.93	0.98	2.89	0.90	3.17
S		[f]ns		ns		ns	
Cl		ns		ns		0.79	3.65
K	0.35	0.50	0.53	0.47	0.57	0.31	5.90
Ca	0.37	0.57	0.88	0.57	0.81	0.37	4.95
Ti	0.037	0.96	0.030	0.97	0.025	[g]NA	
Mn	0.0075	0.97	0.0057	0.97	0.0055	ns	
Fe	0.435	0.99	0.296	0.99	0.284	0.94	0.691
Ni		ns		ns		NA	
Cu		ns		ns		ns	
Zn		ns		ns		ns	
As		ns		NA		ns	
Se		NA		NA		NA	
Br		ns		ns		ns	
Rb	0.0014	0.97	0.0010	0.96	0.0010	NA	
Sr	0.0044	0.87	0.0031	0.83	0.0033	ns	
Yt		NA		NA		NA	
Zr	0.0024	0.80	0.0011	0.97	0.0010	NA	
Ba		NA		NA		NA	
Pb		NA		ns		NA	

[a] TSP = total suspended particulate matter aerosols with aerodynamic diameter <75 µm

[b] PM_{10} = suspended particulate matter aerosols with aerodynamic diameter $\leq$10 µm

[c] $PM_{2.5}$ = suspended particulate matter aerosols with aerodynamic diameter $\leq$2.5 µm

[d] r^2 = coefficient of determination, the proportion of variability in a dependent variable accounted for by the independent variable; r is the correlation coefficient, a measure of the strength of the relationship between variables

[e] Slope = regression coefficient, an estimate of the functional relationship between a dependent variable and an independent variable

[f] ns = not significant; probability >0.01 for regression F-statistic

[g] NA = not available; no regression applied due to insufficient number of samples with measurable elemental values

Table 19. Mean Ratios Between Elements and Aluminum, for Elements Not Correlated with Aluminum in Aerosol Samples

		Aerosol Particle Diameter Classes					
		[a]TSP		[b]PM10		[c]$PM_{2.5}$	
Element (*X*)	**Crustal Ratio (*X*/Al)**	**[d]N**	**[e]Mean *X*/Al Ratio**	**N**	**Mean *X*/Al Ratio**	**N**	**Mean *X*/Al Ratio**
S		22	1.58	28	2.18	29	17.7
Cl		14	0.279	16	0.664	10	9.36
[f]Mn	0.0075					7	0.018
Ni	0.00025	9	0.0047	6	0.0038	3	0.0209
Cu	0.00031	11	0.0044	12	0.0047	7	0.0767
Zn	0.00088	20	0.0092	28	0.001	29	0.0897
As	0.000015	3	0.0016	3	0.0088	6	0.154
Se	0.0000006	1	0.0004	3	0.0015	2	0.0092
Br		20	0.0044	27	0.007	29	0.0633
[f]Sr	0.0044					8	0.0085
[g]Y	0.00027	3	0.00054	2	0.00077		
[g]Ba	0.0068	1	0.024	2	0.059		
Pb	0.00025	3	0.0045	9	0.0046	3	0.0769

[a] TSP = total suspended particulate matter aerosols with aerodynamic diameter <75 µm

[b] PM_{10} = suspended particulate matter aerosols with aerodynamic diameter ≤10 µm

[c] $PM_{2.5}$ = suspended particulate matter aerosols with aerodynamic diameter ≤2.5 µm

[d] N = number of samples

[e] Mean = arithmetic mean

[f] No significant correlations were identified between Al and Mn or Sr in TSP and PM_{10} samples

[g] No Y or Ba were quantifiable in $PM_{2.5}$ samples

Surface Soil Radionuclides

Methods

Soil samples were collected during 1996-1997, from 16 locations in the vicinity of the WIPP (Figure 2). At each location, soil was collected at three randomly selected sites within a 50 m radius of a selected reference point. At each location, individual sampling sites were selected on the basis of the following criteria: relatively flat topography, minimum surface erosion and minimum surface disturbance by human or livestock activity. At each sampling site, approximately 12 L of soil were collected from within an 86 cm x 86 cm area, to a depth of approximately 2 cm. Soil samples were excavated using a trowel, sieved to remove all particles >1 mm, and placed in plastic bags for transport and storage. Sampling equipment was cleaned between samples.

In the laboratory, the samples were dried at 105° C, and homogenized using a riffler. The level of homogenization was determined by analyzing 3-L subsamples of the total sample for ^{137}Cs, using a 2-hr counting time. After each gamma analysis, the result was compared to the previous counts for the sample, and the process was continued until a subsample differed from the overall mean count by $\leq$7%. After each count, the subsample was returned to the bulk sample for continuing homogenization if needed.

Following homogenization, a subsample of approximately 3 g of each sample was used for analyses of actinides. Accu-Labs Research, Inc analyzed one sample from each of the 16 locations for 234U, 238U, 230Th, 232Th, 228Th, 239,240Pu, and 241Am. Mean MDCs (approximately 2 to 20 g per sample) for these actinides were 0.04 mBq g^{-1} for ^{239,240}Pu; 0.06 mBq g^{-1} for ^{241}Am; 4 mBq g^{-1} for ^{232}Th, ^{230}Th, and ^{228}Th; and 4.0 mBq g^{-1} for ^{234}U and ^{238}U. Individual, sample-specific MDCs were also calculated.

Analyses of the gamma-emitting radionuclides were conducted using a 3-L Marinelli beaker filled with soil, a high-purity Ge detector coupled with a multi-channel analyzer, and counting times of 72 hr. Average MDCs (approximately 4500 g per sample) for gamma-emitting radionuclides in soil samples were determined to be 1.0 and 0.05 mBq g^{-1} for ^{40}K and ^{137}Cs, respectively.

Variation in activity concentrations for gamma-emitting radionuclides as a function of locations was examined using an analysis of variance with a random effects model to estimate variance components.

Results

Activity greater than MDC was detected in all samples for ^{234}U, ^{238}U, ^{230}Th, ^{239,240}Pu, ^{40}K and ^{137}Cs. For ^{232}Th, ^{228}Th, and ^{241}Am, activity greater than MDC was detected in 15, 15, and 9 (out of 16) samples, respectively. Activity concentrations in individual soil samples ranged from 3.7 - 11 mBq g^{-1} for ^{234}U, 3.7 - 7.4 mBq g^{-1} for ^{238}U, 3.7 - 11 mBq g^{-1} for ^{228}Th, 7.4 - 30 mBq g^{-1} for ^{230}Th, 3.7 - 11 mBq g^{-1} for ^{232}Th, 0.037 - 0.30 mBq g^{-1} for ^{239,240}Pu, 0.037 – 0.11 mBq g^{-1} for ^{241}Am, 163 – 298 mBq g^{-1} for ^{40}K, and 1.39 – 7.48 mBq g^{-1} for ^{137}Cs (Tables 20 and 21).

The coefficient of variation for individual radionuclide activity concentrations ranged from 14% for ^{40}K, to 57% for ^{239,240}Pu (Table 22). Analyses of variance indicated a very weak location effect (P = 0.0121) for ^{137}Cs, a manmade radionuclide, where only 34% of the variability in activity concentration was explained by location. The remaining variability in activity concentration was accounted for by variation between samples within locations (7900 m^2 spatial scale). In contrast, a more distinct location effect ($P < 0.0001$) was observed for a naturally occurring radionuclide ^{40}K, where 63% of the total variability in activity concentration was accounted for by location (Table 23).

These data suggest an inherent difference in the patterns of spatial dispersion of manmade versus naturally occurring radionuclides. It should be noted that these data are only preliminary results of an ongoing study, so extensive interpretation of environmental variability is not warranted at this time. However, understanding the environmental variability in activity concentrations and the spatial scale at which it occurs, are important parameters when attempting to detect small changes in concentrations of environmental contaminants due to technology development.

Table 20. Activity Concentrations for Radionuclides Measured in Soils by Alpha Spectrometry

Radionuclide	[a]Location	[b]Activity Concentration (mBq g^{-1})	[c]SD (mBq g^{-1})	[d]MDC (mBq g^{-1})
^{238}U	A1	3.7E+0	1.9E+0	3.7E+0
	A2	3.7E+0	1.9E+0	3.7E+0
	A3	3.7E+0	1.9E+0	3.7E+0
	A4	3.7E+0	1.9E+0	3.7E+0
	A5	3.7E+0	1.9E+0	3.7E+0
	A6	3.7E+0	1.9E+0	3.7E+0
	A7	3.7E+0	1.9E+0	3.7E+0
	A8	3.7E+0	1.9E+0	3.7E+0
	B1	3.7E+0	1.9E+0	3.7E+0
	B2	7.4E+0	1.9E+0	3.7E+0
	B3	3.7E+0	1.9E+0	3.7E+0
	B4	3.7E+0	1.9E+0	3.7E+0
	B5	3.7E+0	1.9E+0	3.7E+0
	B6	3.7E+0	1.9E+0	3.7E+0
	B7	7.4E+0	1.9E+0	3.7E+0
	B8	3.7E+0	1.9E+0	3.7E+0
^{234}U	A1	7.4E+0	1.9E+0	3.7E+0
	A2	3.7E+0	1.9E+0	3.7E+0
	A3	7.4E+0	1.9E+0	3.7E+0
	A4	7.4E+0	1.9E+0	3.7E+0
	A5	7.4E+0	1.9E+0	3.7E+0
	A6	7.4E+0	1.9E+0	3.7E+0
	A7	3.7E+0	1.9E+0	3.7E+0
	A8	7.4E+0	1.9E+0	3.7E+0
	B1	7.4E+0	1.9E+0	3.7E+0
	B2	3.7E+0	1.9E+0	3.7E+0
	B3	7.4E+0	1.9E+0	3.7E+0
	B4	11.E+0	1.9E+0	3.7E+0
	B5	7.4E+0	1.9E+0	3.7E+0
	B6	7.4E+0	1.9E+0	3.7E+0
	B7	7.4E+0	1.9E+0	3.7E+0
	B8	3.7E+0	1.9E+0	3.7E+0

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Table 20. Activity Concentrations for Radionuclides Measured in Soils by Alpha Spectrometry (Continued)

Radionuclide	[a]Location	[b]Activity Concentration (mBq g^{-1})	[c]SD (mBq g^{-1})	[d]MDC (mBq g^{-1})
^{232}Th	A1	3.7E+0	1.9E+0	3.7E+0
	A2	7.4E+0	1.9E+0	3.7E+0
	A3	[e]<MDC		3.7E+0
	A4	7.4E+0	1.9E+0	3.7E+0
	A5	3.7E+0	1.9E+0	3.7E+0
	A6	7.4E+0	1.9E+0	3.7E+0
	A7	3.7E+0	1.9E+0	3.7E+0
	A8	3.7E+0	1.9E+0	3.7E+0
	B1	7.4E+0	1.9E+0	3.7E+0
	B2	7.4E+0	1.9E+0	3.7E+0
	B3	7.4E+0	1.9E+0	3.7E+0
	B4	7.4E+0	1.9E+0	3.7E+0
	B5	7.4E+0	1.9E+0	3.7E+0
	B6	7.4E+0	1.9E+0	3.7E+0
	B7	1.5E+1	1.9E+0	3.7E+0
	B8	7.4E+0	1.9E+0	3.7E+0
^{230}Th	A1	1.8E+1	1.9E+0	3.7E+0
	A2	1.1E+1	1.9E+0	3.7E+0
	A3	2.2E+1	3.7E+0	3.7E+0
	A4	1.1E+1	1.9E+0	3.7E+0
	A5	7.4E+0	1.9E+0	3.7E+0
	A6	1.1E+1	1.9E+0	3.7E+0
	A7	3.0E+1	3.7E+0	3.7E+0
	A8	1.5E+1	1.9E+0	3.7E+0
	B1	1.5E+1	1.9E+0	3.7E+0
	B2	1.1E+1	1.9E+0	3.7E+0
	B3	1.1E+1	1.9E+0	3.7E+0
	B4	1.1E+1	1.9E+0	3.7E+0
	B5	1.5E+1	1.9E+0	3.7E+0
	B6	1.1E+1	1.9E+0	3.7E+0
	B7	3.3E+1	3.7E+0	3.7E+0
	B8	7.4E+0	1.9E+0	3.7E+0

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Table 20. Activity Concentrations for Radionuclides Measured in Soils by Alpha Spectrometry (Continued)

Radionuclide	[a]Location	[b]Activity Concentration (mBq g^{-1})	[c]SD (mBq g^{-1})	[d]MDC (mBq g^{-1})
^{228}Th	A1	1.1E+1	1.9E+0	3.7E+0
	A2	1.1E+1	1.9E+0	3.7E+0
	A3	<MDC		3.7E+0
	A4	7.4E+0	1.9E+0	3.7E+0
	A5	7.4E+0	1.9E+0	3.7E+0
	A6	3.7E+0	1.9E+0	3.7E+0
	A7	7.4E+0	1.9E+0	3.7E+0
	A8	3.7E+0	1.9E+0	3.7E+0
	B1	1.1E+1	1.9E+0	3.7E+0
	B2	3.7E+0	1.9E+0	3.7E+0
	B3	1.1E+1	1.9E+0	3.7E+0
	B4	1.1E+1	1.9E+0	3.7E+0
	B5	7.4E+0	1.9E+0	3.7E+0
	B6	7.4E+0	1.9E+0	3.7E+0
	B7	1.5E+1	3.7E+0	3.7E+0
	B8	7.4E+0	1.9E+0	3.7E+0
^{239,240}Pu	A1	1.5E-1	1.9E-2	3.7E-2
	A2	2.6E-1	1.9E-2	3.7E-2
	A3	1.1E-1	1.9E-2	3.7E-2
	A4	7.4E-2	1.9E-2	3.7E-2
	A5	2.6E-1	3.7E-2	3.7E-2
	A6	3.0E-1	3.7E-2	3.7E-2
	A7	1.1E-1	1.9E-2	3.7E-2
	A8	1.8E-1	1.9E-2	3.7E-2
	B1	7.4E-2	1.9E-2	3.7E-2
	B2	1.1E-1	1.9E-2	3.7E-2
	B3	1.8E-1	1.9E-2	3.7E-2
	B4	1.5E-1	1.9E-2	3.7E-2
	B5	3.7E-2	1.9E-2	3.7E-2
	B6	7.4E-2	1.9E-2	3.7E-2
	B7	1.5E-1	1.9E-2	7.4E-2
	B8	7.4E-2	1.9E-2	3.7E-2

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Table 20. Activity Concentrations for Radionuclides Measured in Soils by Alpha Spectrometry (Continued)

Radionuclide	**[a]Location**	**[b]Activity Concentration (mBq g^{-1})**	**[c]SD (mBq g^{-1})**	**[d]MDC (mBq g^{-1})**
^{241}Am	A1	7.4E-2	1.9E-2	7.4E-2
	A2	3.7E-2	1.9E-2	3.7E-2
	A3	3.7E-2	1.9E-2	3.7E-2
	A4	3.7E-2	1.9E-2	7.4E-2
	A5	1.1E-1	1.9E-2	7.4E-2
	A6	<MDC		7.4E-2
	A7	7.4E-2	1.9E-2	7.4E-2
	A8	<MDC		1.1E-1
	B1	<MDC		7.4E-2
	B2	<MDC		7.4E-2
	B3	1.1E-1	3.7E-2	1.1E-1
	B4	3.7E-2	1.9E-2	3.7E-2
	B5	<MDC		7.4E-2
	B6	3.7E-2	1.9E-2	3.7E-2
	B7	<MDC		1.1E-1
	B8	<MDC		7.4E-2

[a]Locations of soil sample collection as shown in Figure 2

[b]Activity Concentrations as defined in Appendix K; all values are rounded to two significant figures. Actinide data were reported in units of pCi g^{-1}; conversion to mBq resulted in values that are unit multiples of original data.

[c]SD = Standard Deviation as defined in Appendix K

[d]MDC = Minimum Detectable Activity Concentration; see Appendix K

[e] <MDC = Observed activity concentration was below MDC

Table 21. Activity Concentrations for Radionuclides Measured in Soils by Gamma Spectrometry

Radionuclide	[a]Location	Replicate	[b]Activity Concentration (mBq g-1)	[c]SD (mBq g-1)	[d]MDC (mBq g-1)
^{137}Cs	A1	1	4.62E+0	1.75E-1	5.59E-2
		2	3.26E+0	1.26E-1	5.69E-2
		3	5.02E+0	1.84E-1	4.95E-2
	A2	1	4.69E+0	1.77E-1	5.01E-2
		2	5.19E+0	1.95E-1	5.72E-2
		3	4.58E+0	1.69E-1	4.61E-2
	A3	1	4.02E+0	1.49E-1	4.58E-2
		2	6.38E+0	2.35E-1	5.83E-2
		3	4.28E+0	1.53E-1	4.83E-2
	A4	1	4.13E+0	1.53E-1	4.71E-2
		2	3.12E+0	1.20E-1	5.19E-2
		3	3.96E+0	1.42E-1	4.26E-2
	A5	1	2.14E+0	9.09E-2	4.85E-2
		2	4.93E+0	1.76E-1	5.01E-2
		3	2.79E+0	1.04E-1	4.34E-2
	A6	1	3.14E+0	1.20E-1	5.33E-2
		2	3.53E+0	1.33E-1	5.37E-2
		3	1.39E+0	6.08E-2	4.29E-2
	A7	1	5.86E+0	2.17E-1	5.28E-2
		2	3.34E+0	1.31E-1	5.48E-2
		3	3.00E+0	1.16E-1	4.46E-2
	A8	1	5.27E+0	1.90E-1	5.60E-2
		2	5.28E+0	1.98E-1	6.12E-2
		3	6.20E+0	2.17E-1	4.82E-2
	B1	1	6.23E+0	2.30E-1	6.21E-2
		2	5.67E+0	2.05E-1	5.91E-2
		3	4.14E+0	1.56E-1	5.54E-2
	B2	1	7.22E+0	2.54E-1	6.11E-2
		2	3.52E+0	1.33E-1	5.71E-2
		3	4.55E+0	1.62E-1	4.85E-2
	B3	1	5.16E+0	1.87E-1	5.74E-2
		2	7.06E+0	2.55E-1	5.18E-2
		3	7.48E+0	2.59E-1	4.87E-2
	B4	1	7.02E+0	2.49E-1	6.00E-2
		2	4.85E+0	1.79E-1	6.29E-2
		3	5.35E+0	1.97E-1	5.26E-2

Table continued on next page

Table 21. Activity Concentrations for Radionuclides Measured in Soils by Gamma Spectrometry (Continued)

Radionuclide	[a]Location	Replicate	[b]Activity Concentration (mBq g-1)	[c]SD (mBq g-1)	[d]MDC (mBq g-1)
	B5	1	4.22E+0	1.60E-1	5.14E-2
		2	3.75E+0	1.40E-1	5.10E-2
		3	3.23E+0	1.23E-1	4.39E-2
	B6	1	4.44E+0	1.62E-1	5.35E-2
		2	3.32E+0	1.26E-1	5.00E-2
		3	3.30E+0	1.19E-1	4.05E-2
	B7	1	6.28E+0	2.31E-1	5.64E-2
		2	4.74E+0	1.68E-1	4.25E-2
		3	3.91E+0	1.41E-1	4.24E-2
	B8	1	4.13E+0	1.53E-1	5.65E-2
		2	3.70E+0	1.39E-1	5.65E-2
		3	4.82E+0	1.71E-1	4.53E-2
^{40}K	A1	1	2.59E+2	1.08E+1	6.41E-1
		2	2.29E+2	9.31E+0	5.62E-1
		3	2.37E+2	1.06E+1	2.62E+0
	A2	1	2.10E+2	8.76E+0	5.28E-1
		2	2.33E+2	9.72E+0	5.91E-1
		3	2.04E+2	8.46E+0	2.43E+0
	A3	1	1.84E+2	7.50E+0	5.18E-1
		2	2.11E+2	8.79E+0	5.49E-1
		3	2.17E+2	8.82E+0	4.51E-1
	A4	1	2.04E+2	8.29E+0	5.46E-1
		2	1.90E+2	7.76E+0	5.10E-1
		3	1.93E+2	7.84E+0	4.00E-1
	A5	1	2.36E+2	9.60E+0	6.21E-1
		2	1.97E+2	8.03E+0	5.23E-1
		3	1.98E+2	8.07E+0	4.14E-1
	A6	1	2.32E+2	9.44E+0	5.64E-1
		2	2.29E+2	9.34E+0	5.63E-1
		3	1.89E+2	7.85E+0	2.28E+0
	A7	1	2.24E+2	9.34E+0	6.09E-1
		2	2.01E+2	8.39E+0	5.50E-1
		3	1.88E+2	7.83E+0	4.03E-1
	A8	1	2.73E+2	1.11E+1	6.55E-1
		2	2.49E+2	1.04E+1	6.02E-1
		3	2.76E+2	1.12E+1	4.68E-1

Table continued on next page

Table 21. Activity Concentrations for Radionuclides Measured in Soils by Gamma Spectrometry (Continued)

Radionuclide	[a]Location	Replicate	[b]Activity Concentration (mBq g-1)	[c]SD (mBq g-1)	[d]MDC (mBq g-1)
	B1	1	2.69E+2	1.12E+1	6.52E-1
		2	2.47E+2	1.01E+1	5.67E-1
		3	2.84E+2	1.18E+1	2.95E+0
	B2	1	2.80E+2	1.14E+1	6.27E-1
		2	2.64E+2	1.08E+1	6.14E-1
		3	2.56E+2	1.04E+1	2.68E+0
	B3	1	2.19E+2	8.93E+0	5.70E-1
		2	2.46E+2	1.02E+1	2.72E+0
		3	2.42E+2	9.81E+0	4.77E-1
	B4	1	2.44E+2	9.93E+0	5.97E-1
		2	2.98E+2	1.03E+1	6.16E-1
		3	2.42E+2	1.00E+1	2.68E+0
	B5	1	1.83E+2	7.47E+0	5.24E-1
		2	1.71E+2	6.98E+0	5.04E-1
		3	1.68E+2	7.00E+0	2.20E+0
	B6	1	2.11E+2	8.58E+0	5.63E-1
		2	1.63E+2	6.65E+0	4.74E-1
		3	1.86E+2	7.56E+0	2.20E+0
	B7	1	2.73E+2	1.13E+1	2.92E+0
		2	1.95E+2	7.92E+0	2.27E+0
		3	1.96E+2	7.97E+0	4.24E-1
	B8	1	2.15E+2	8.76E+0	5.43E-1
		2	2.29E+2	9.31E+0	5.51E-1
		3	2.25E+2	9.27E+0	4.34E-1

[a] Locations of soil sample collection as shown in Figure 2.

[b] Activity Concentrations as defined in Appendix K; all values are rounded to three significant figures.

[c] SD = Standard Deviation as defined in Appendix K

[d] MDC = Minimum Detectable Activity Concentration; see Appendix K

Table 22. Summary Statistics for Radionuclide Activity Concentrations in Surface Soil

		[a]Activity Concentration (mBq g^{-1})				
Radionuclide	**[b]N**	**[c]Mean**	**[d]SE**	**Minimum**	**Maximum**	**[e]CV (%)**
^{234}U	16	6.5	0.54	3.7	11	33
^{238}U	16	4.2	0.33	3.7	7.4	31
^{228}Th	15	7.4	0.73	3.7	11	38
^{230}Th	16	14.3	1.4	7.4	30	40
^{232}Th	15	6.4	0.56	3.7	11	34
^{239,240}Pu	16	0.14	0.0020	0.037	0.30	57
^{241}Am	9	0.066	0.010	0.037	0.011	47
^{137}Cs	48	4.50	6.93	1.40	7.50	29
^{40}K	48	224	4.53	163	298	14

[a] Calculated statistics do not include samples with activity concentrations <MDC; mean, SE, minimum and maximum are rounded to two significant figures for radionuclides measured by alpha spectrometry

[b] N = number of samples included in calculations

[c] Mean = arithmetic mean

[d] SE = standard error of mean

[e] CV = coefficient of variation; standard deviation expressed as percentage of the mean; CVs may reflect small rounding error

Table 23. Results of Analyses of Variance for Activity Concentrations of Radionuclides Measured by Gamma Spectrometry

Radionuclide	Source	[a]df	[b]SS	[c]F	[d]P	Variance Component	Percentage of Total Variance
^{137}Cs	Between Locations	15	4.6175E-5	2.58	0.0121	6.27E-7	34.4
	Error	32	3.8280E-5			1.20E-6	65.6
	Total	47	8.4455E-5				
^{40}K	Between Locations	15	3.9110E-2	6.10	< 0.0001	7.26E-4	62.9
	Error	32	1.3694E-2			4.28E-4	37.1
	Total	47	5.2804E-2				

[a] df = degrees of freedom

[b] SS = Sum of Squares

[c] F = ratio of mean square of source term to mean square of error term

[d] P = probability of greater value of F due to random chance

Radionuclides and Other Constituents in Selected Drinking Water Sources

Methods

The water wells in the immediate vicinity of the WIPP site currently provide water primarily for livestock, industrial usage by oil and gas production operations, and monitoring studies conducted by various groups. Aquifers that exist in the region surrounding the WIPP include Dewey Lake, Culebra-Magenta, Ogalalla, Dockum, Pecos River alluvium and Capitan Reef.

Water samples were collected for the Center's radiochemical and related studies during April-October 1997 from six sources of drinking water in the vicinity of the WIPP (Table 24).

The main Carlsbad water supply is the Sheep Draw wellfield, where nine pumping wells are used with a total maximum capacity of 21,000 gallons per minute. The Capitan Reef aquifer is the source for the Sheep Draw wells. Seven reservoirs in the Carlsbad system have a combined storage capacity of nearly 16 million gallons. The Hobbs water supply consists of 28 wells scattered throughout the city, which draw from the Ogalalla aquifer. The number of wells operating at any given time depends on the system load, and the maximum system capacity is 4.6 million gallons per day. Four reservoirs provide storage for just over 11 million gallons of water. The water supply for Loving/Malaga is provided by four wells located near the main 800,000-gallon reservoir. Two other reservoirs have a combined capacity of 300,000 gallons. The Loving/Malaga supply system flow averages 435,000 gallons per day, and the aquifer is hydraulically linked to the flow of the Pecos River. The Otis water system consists of three wells located near the main reservoir, which holds 948,000 gallons. The combined capacity of three other reservoirs is 475,000 gallons. The wells in the Otis system can supply 2,500 gallons of water per minute. The aquifer for Otis also is hydraulically linked to the flow of the Pecos River. The source for water collected at the location identified as Private #1 is the Double Eagle well field, operated by the City of Carlsbad. The Double Eagle well field consists of 28 wells, and draws water from the Capitan Reef aquifer. The water well identified as Private #2 has been used as a source of drinking water in the past, and may be used again in the future. This well draws water from the Culebra aquifer.

At each location, a sample of 110 L was collected for radiochemical analyses. An additional 9 L of water were collected at each source for analyses of various non-radiological constituents and water quality parameters. Samples were collected following source purging of approximately 5 min or at least 50 L. Samples were placed in 50-L plastic containers for transport and storage. Samples for analyses of non-radiological constituents were sent to the Soil Water and Air Testing (SWAT) Laboratory at NMSU. All non-radiological samples were collected according to EPA protocols for the collection, handling and preservation of drinking water samples.

Samples for analyses of alpha-emitting radionuclides were preconcentrated by acidification and coprecipitation. Prior to preconcentration, tracer solutions containing $\leq$1 dpm for each target radionuclide were added to each of the samples. The samples were then passed through ion-exchange chromatograph columns to purify and separate the individual radionuclides (Jiang, F.S., et al., 1986, *J. Radioanal. Nucl. Chem.* 100, 65). Analyses of alpha-emitting radionuclides were carried out with the use of 450 mm^2 silicon surface-barrier detectors, or passivated implanted planar-silicon detectors, coupled with a multi-channel analyzer, with counting times of 10-14 days. Gamma-emitting radionuclide activities were determined using high-purity Ge detectors coupled with multi-channel analyzers, with counting times of three days.

Mean MDCs for actinides were determined to be 5.3 μBq L^{-1} for ^{239,240}Pu, with

30% average yield; 8.8 μBq L^{-1} for ^{241}Am, with 30% average yield; 9.7 μBq L^{-1} for ^{228}Th, 4.5 μBq L^{-1} for ^{230}Th and 7.3 μBq L^{-1} for ^{232}Th with 30% average yield; and 2.9 μBq L^{-1} for ^{234}U and 2.4 μBq L^{-1} for ^{238}U, with 50% average yield. MDCs for gamma-emitting radionuclides were determined to be 0.37 μBq L^{-1} for ^{40}K and .033 Bq L^{-1} for ^{137}Cs. Two blanks were used for quality control in the studies of radioisotopes in drinking water.

Results

Not all radionuclides were quantified in all samples. In particular, neither ^{137}Cs nor ^{40}K, the two gamma emitting radionuclides, were above MDC in any of the drinking water samples. Similarly, no quantifiable activity for two radionuclides of particular interest, ^{239,240}Pu and ^{241}Am, was observed in any of the water samples above MDCs (Table 25). ^{228}Th was measurable above MDCs at three of five sites (Carlsbad, Hobbs, and Private #1), but ^{230}Th and ^{232}Th activities were measurable above MDCs only at Carlsbad and Hobbs.

^{234}U and ^{238}U were quantified at all sites, and the ^{234}U/^{238}U activity ratios were relatively consistent among sites, as follows: Loving = 4.0; Carlsbad = 2.7; Hobbs = 2.4; Private #1 = 3.2, and Otis = 3.0. Although fewer comparisons could be made for Th, the Th isotopes displayed dissimilar relative activities at the two sites where they could be quantified: for example, the ^{228}Th/^{232}Th ratios were 9.4 and 2.5 at Carlsbad and Hobbs, respectively.

^{234}U is a decay product of ^{238}U, and in many environmental media ^{234}U and ^{238}U are in secular equilibrium (the activity ratio of the two isotopes is unity). However, ^{238}U decays through two intermediate transitions, ^{234}Th and ^{234}Pa, before ^{234}U is formed. The three elements involved in this part of the decay chain (U, Th, and Pa) are sufficiently different chemically that they may be separated in nature by various processes. Furthermore, the U isotopes themselves can fractionate in the environment, and owing to the elemental and isotopic effects, naturally occurring U in environmental samples can be enriched or depleted in ^{234}U relative to ^{238}U. In ground water samples, ^{234}U/^{238}U ratios typically range from 0.8 to 10, but ratios from 2 to 5 are expected if total U concentrations are <1 ppb (Goldstein, S. J., et al., 1997, *Health Physics* 72, 10). The observed ^{234}U/^{238}U ratios for all drinking water samples in the present study ranged from 2.4 to 4.0, and thus data obtained to date are generally consistent with previous observations elsewhere.

A similar logic may be applied to explain the enrichment of ^{228}Th to ^{232}Th where ^{232}Th decays to ^{228}Th through the intermediates ^{228}Ra and ^{228}Ac. The observed ^{228}Th/^{232}Th ratio (9.4) in the sample from Carlsbad indicates a rather strong enrichment of ^{228}Th relative to ^{232}Th, possibly suggesting an important role for ^{228}Ra which decays to ^{228}Th. Moreover, the U and Th isotopes in drinking water apparently exhibit different levels of disequilibria. It should be emphasized that these are preliminary analyses and extensive efforts at interpretation of the radionuclide ratios are not warranted at this point. However, evaluating the isotopic ratios in samples from various media in the future will provide a means for understanding processes affecting the radionuclide composition of environmental samples.

Non-radiological analyses were performed for several general categories of substances, including metals, volatile organic compounds, semi-volatile organic compounds, and general secondary water quality parameters. The analytes chosen for study were those regulated under the Safe Drinking Water Act (SDWA), plus selected compounds and elements identified as possible constituents of wastes to be deposited in the WIPP. For constituents regulated under SDWA, primary and secondary maximum contaminant levels (MCLs) are presented as “reference levels” to provide readers with a basis for comparison. However, the results for non-radiological analyses are not appropriate for use as evidence of compliance or non-compliance with any regulatory requirements, and are intended only to provide a general characterization of the chemical composition of the drinking water sources.

The overwhelming majority of non-radiological inorganic analytes were below detectable levels in the drinking water samples (Tables 26a, 26b, 27a, and 27b). An even smaller proportion of the organic analytes were above their detection limits. Bromoform was detected in three of the samples (Hobbs, Otis, and Private #1) and dibromochloromethane was detected in a single sample (Hobbs). Even so, the levels observed for bromoform and dibromochloromethane were below reference levels. Several inorganic non-radiological substances exceeded reference levels (secondary MCLs) in the Otis and Private #2 samples, including chloride (by autoanalyzer), sulfate, and total dissolved solids. The cited reference levels for these analytes are non-enforceable guidelines (secondary MCLs) under the SDWA. The Otis and Private #2 drinking water samples also had relatively high concentrations of Ca, Mg, and Na. In addition, the water samples from Otis and Private #2 were relatively hard, and they exhibited high electrical conductivity compared with the other three sites. All of these factors are consistent with a high mineral content in the Otis and Private #2 drinking water sources.

With respect to heavy metals, Pb and Cu concentrations were highest in the Hobbs sample, but well below reference levels. In contrast, the highest concentrations of Ni, Se, and Tl were found in drinking water from Private #2, but those were also well below reference levels. Again, it is important to emphasize that these results are not appropriate for use in assessments of regulatory compliance.

Table 24. Drinking Water Sources and Sample Collection Locations

Date of Collection	Water Recipient	Chlorination at Collection Point	Location of Sample Collection
4/21/97	Otis	Yes	Pump house on East Derrick Road. (for non-radiological analyses only)
4/29/97	Loving	No	Pump house on Misty Lane
7/16/97	Carlsbad	No	Reservoir at end of Holland St., 1 mile west of Standpipe Rd. (for radioanalyses only)
7/16/97	Hobbs	Yes	Reservoir at Jefferson Street and Bender Boulevard
7/22/97	Private #1	No	Tap 5 miles northwest of WIPP
8/13/97	Otis	Yes	Pump house on East Derrick Road (for radioanalyses only)
10/21/97	Carlsbad	No	Tap 3 miles south of Lea Street and 1 mile west of Standpipe Road. (for non-radiological analyses)
10/22/97	Private #2	No	Well 7 miles southwest of the WIPP (for non-radiological analyses)

Table 25. Radionuclide Activity Concentrations in Drinking Water Sources

[a]Location and Date of Sample Collection	Radionuclide	[b]Activity Concentration (Bq L^{-1})	[c]SD (Bq L^{-1})	[d]MDC (Bq L^{-1})
Loving 4/29/97	^{241}Am	[e]<MDC		1.5E-7
	^{239,240}Pu	<MDC		1.4E-6
	^{228}Th	<MDC		1.3E-6
	^{230}Th	<MDC		2.2E-6
	^{232}Th	<MDC		8.4E-7
	^{234}U	2.3E-3	1.8E-4	2.0E-6
	^{238}U	5.8E-4	4.5E-5	2.5E-7
	^{137}Cs	<MDC		4.3E-2
	^{40}K	<MDC		4.6E-1
Carlsbad 7/16/97	^{241}Am	<MDC		1.4E-6
	^{239,240}Pu	<MDC		3.4E-6
	^{228}Th	7.5E-5	2.6E-6	1.9E-6
	^{230}Th	8.0E-6	1.4E-6	3.0E-6
	^{232}Th	8.0E-6	1.0E-6	1.3E-6
	^{234}U	8.5E-4	6.7E-5	3.4E-6
	^{238}U	3.2E-4	2.6E-5	2.8E-7
	^{137}Cs	<MDC		3.1E-2
	^{40}K	<MDC		3.5E-1
Hobbs 7/16/97	^{241}Am	<MDC		6.4E-6
	^{239,240}Pu	<MDC		4.5E-6
	^{228}Th	2.2E-4	3.8E-6	4.3E-6
	^{230}Th	2.7E-5	1.7E-6	7.8E-6
	^{232}Th	8.7E-5	2.2E-6	3.8E-6
	^{234}U	2.6E-3	2.0E-4	1.6E-6
	^{238}U	1.1E-3	8.2E-5	1.6E-6
	^{137}Cs	<MDC		2.9E-2
	^{40}K	<MDC		3.5E-1
Private #1 7/22/97	^{241}Am	<MDC		1.0E-5
	^{239,240}Pu	<MDC		9.7E-6
	^{228}Th	2.2E-4	3.7E-6	2.2E-6
	^{230}Th	<MDC		3.7E-6
	^{232}Th	<MDC		1.7E-6
	^{234}U	1.4E-3	1.1E-4	2.6E-6
	^{238}U	4.4E-4	3.5E-5	2.2E-7
	^{137}Cs	<MDC		2.9E-2
	^{40}K	<MDC		3.5E-1

Table continued on next page

Table 25. Radionuclide Activity Concentrations in Drinking Water Sources (Continued)

[a]Location and Date of Sample Collection	Radionuclide	[b]Activity Concentration (Bq L^{-1})	[c]SD (Bq L^{-1})	[d]MDC (Bq L^{-1})
Otis 8/13/97	^{241}Am	<MDC		2.6E-5
	^{239,240}Pu	<MDC		7.4E-6
	^{228}Th	<MDC		3.9E-5
	^{230}Th	<MDC		6.0E-6
	^{232}Th	<MDC		2.9E-5
	^{234}U	9.3E-4	1.1E-4	5.0E-6
	^{238}U	3.1E-4	3.7E-5	9.6E-6
	^{137}Cs	<MDC		3.1E-2
	^{40}K	<MDC		3.5E-1

[a] Locations of drinking water collection as described in Table 24

[b] Activity Concentrations as defined in Appendix K

[c] SD = Standard Deviation as defined in Appendix K

[d] MDC = Minimum Detectable Activity Concentration; see Appendix K

[e] <MDC = Observed activity concentration was below MDC

Table 26a. Non-radiological Constituents in Samples from Drinking Water Sources

				Measurements [a]Location and Date of Sample Collection		
Analyte	**Unit**	**[b]DL or MDL**	**[c]RL**	**Carlsbad 10/21/97**	**Hobbs 7/16/97**	**Loving 4/29/97**
[d]Antimony	µg L^{-1}	0.4	6	[q]ND	ND	ND
[d]Arsenic	µg L^{-1}	0.3	50	0.7	7.2	2.0
[d]Barium	µg L^{-1}	0.1	2000	73.3	63.8	32.0
[d]Beryllium	µg L^{-1}	0.2	4	ND	ND	ND
[d]Cadmium	µg L^{-1}	0.1	5	ND	ND	ND
[d]Chromium	µg L^{-1}	1.0	100	ND	ND	5.9
[d]Mercury	µg L^{-1}	0.2	2	ND	ND	ND
[d]Nickel	µg L^{-1}	0.05	100	3.54	3.1	2.8
[d]Selenium	µg L^{-1}	1.0	50	1.4	9.7	2.0
[d]Thallium	µg L^{-1}	0.03	2	0.15	0.06	0.03
[d]Lead	µg L^{-1}	0.1	15.0	0.2	8.7	NR
[d]Copper	µg L^{-1}	0.4	1300	0.9	56.1	NR
[e]Aluminum	mg L^{-1}	0.05	0.05-0.2	ND	[r]NR	NR
[e]Iron	mg L^{-1}	0.05	0.3	ND	ND	NR
[e]Silver	mg L^{-1}	0.02	0.1	ND	ND	NR
[f]Pyridine	µg L^{-1}	0.5		ND	ND	ND
[f]Cresols	µg L^{-1}	0.5		ND	ND	ND
[f]2,4-Dinitrotoluene	µg L^{-1}	0.5		ND	ND	ND
[f]Hexachloroethane	µg L^{-1}	0.5		ND	ND	ND
[f]Nitrobenzene	µg L^{-1}	0.5		ND	ND	ND
[g]Benzene	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]Bromobenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Bromochloromethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Bromodichloromethane	µg L^{-1}	0.5	1000	ND	ND	ND
[g]Bromoform	µg L^{-1}	0.5	100	ND	10.0	ND
[g]n-Butylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]sec-Butylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]tert-Butylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Carbon Tetrachloride	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]Chlorobenzene	µg L^{-1}	0.5	100	ND	ND	ND
[g]Chloroethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Chloroform	µg L^{-1}	0.5	100	ND	ND	ND
[g]Chloromethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]2-Chlorotoluene	µg L^{-1}	0.5	0.5	ND	ND	ND

Table continued on next page

Table 26a. Non-radiological Constituents in Samples from Drinking Water Sources (Continued)

			Measurements			
			[a]Location and Date of Sample Collection			
Analyte	**Unit**	**[b]DL or MDL**	**[c]RL**	**Carlsbad 10/21/97**	**Hobbs 7/16/97**	**Loving 4/29/97**
[g]4-Chlorotoluene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Dibromochloromethane	µg L^{-1}	0.5	100	ND	1.1	ND
[g]1,2-Dibromo-3-chloropropane	µg L^{-1}	0.5	0.20	ND	ND	ND
[g]1,2-Dibromoethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Dibromomethane	µg L^{-1}	0.5	100	ND	ND	ND
[g]1,2-Dichlorobenzene	µg L^{-1}	0.5	600	ND	ND	ND
[g]1,3-Dichlorobenzene	µg L^{-1}	0.5	75	ND	ND	ND
[g]1,4-Dichlorobenzene	µg L^{-1}	0.5		ND	ND	ND
[g]Dichlorodifluoromethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,1-Dichloroethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,2-Dichloroethane	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]1,1-Dichloroethene	µg L^{-1}	0.5	7.0	ND	ND	ND
[g]cis^{-1},2-Dichloroethene	µg L^{-1}	0.5	70	ND	ND	ND
[g]trans^{-1},2-Dichloroethene	µg L^{-1}	0.5	100	ND	ND	ND
[g]1,2-Dichloropropane	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]1,3-Dichloropropane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]2,2-Dichloropropane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,1-Dichloropropene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]cis^{-1},3-Dichloropropene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]trans^{-1},3-Dichloropropene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Ethylbenzene	µg L^{-1}	0.5	70	ND	ND	ND
[g]Hexachlorobutadiene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Isoproylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]4-Isopropyltoluene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Methylene chloride	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]Naphthalene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Propylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Styrene	µg L^{-1}	0.5	100	ND	ND	ND
[g]1,1,1,2-Tetrachloroethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,1,2,2-Tetrachloroethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Tetrachloroethene	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]Toluene	µg L^{-1}	0.5	1000	ND	ND	ND
[g]1,2,3-Trichlorobenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,2,4-Trichlorobenzene	µg L^{-1}	0.5	70	ND	ND	ND

Table continued on next page

Table 26a. Non-radiological Constituents in Samples from Drinking Water Sources (Continued)

				Measurements		
				[a]Location and Date of Sample Collection		
Analyte	**Unit**	**[b]DL or MDL**	**[c]RL**	**Carlsbad 10/21/97**	**Hobbs 7/16/97**	**Loving 4/29/97**
[g]1,1,1-Trichloroethane	µg L^{-1}	0.5	200	ND	ND	ND
[g]1,1,2-Trichloroethane	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]Trichloroethene	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]Trichlorofluoromethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,2,3-Trichloropropane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,2,4-Trimethylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,3,5-Trimethylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Vinyl chloride	µg L^{-1}	0.5	2.0	ND	ND	ND
[g]Xylenes	µg L^{-1}	0.5	10000	ND	ND	ND
[h]1,2-Dibromoethane	µg L^{-1}	0.01	0.01	ND	ND	ND
[h]1,2-Dibromo-3-Chloropropane	µg L^{-1}	0.01	0.01	ND	ND	ND
[i]Alachlor	µg L^{-1}	0.225	2.0	ND	ND	ND
[i]Aldrin	µg L^{-1}	0.09	0.09	ND	ND	ND
[i]Chlordane	µg L^{-1}	0.6	2.0	ND	ND	ND
[i]Dieldrin	µg L^{-1}	0.04	0.04	ND	ND	ND
[i]Endrin	µg L^{-1}	0.063	2.0	ND	ND	ND
[i]Heptachlor	µg L^{-1}	0.094	0.4	ND	ND	ND
[i]Heptachlor Epoxide	µg L^{-1}	0.067	0.2	ND	ND	ND
[i]Hexachlorobenzene	µg L^{-1}	0.02	1.0	ND	ND	ND
[i]Lindane	µg L^{-1}	0.03	0.2	ND	ND	ND
[i]Methoxychlor	µg L^{-1}	0.96	40.0	ND	ND	ND
[i]Toxaphene	µg L^{-1}	1.0	3.0	ND	ND	ND
[i]Aroclor 1016	µg L^{-1}	0.08	0.5	ND	ND	ND
[i]Aroclor 1221	µg L^{-1}	3.0	0.5	ND	ND	ND
[i]Arochlor 1232	µg L^{-1}	0.10	0.5	ND	ND	ND
[i]Arochlor 1242	µg L^{-1}	0.10	0.5	ND	ND	ND
[i]Arochlor 1248	µg L^{-1}	0.13	0.5	ND	ND	ND
[i]Arochlor 1254	µg L^{-1}	0.10	0.5	ND	ND	ND
[i]Arochlor 1260	µg L^{-1}	0.14	0.5	ND	ND	ND
[i]Hexachlorocyclopentadiene	µg L^{-1}	0.05	50.0	ND	ND	ND
[j]2,4-D	µg L^{-1}	10.0	70.0	ND	ND	ND
[j]2,4,5-TP(Silvex)	µg L^{-1}	1.0	50.0	ND	ND	ND
[j]Dicamba	µg L^{-1}	2.0	2.0	ND	ND	ND
[j]Dinoseb	µg L^{-1}	2.0	7.0	ND	ND	ND
[j]Pentachlorophenol	µg L^{-1}	1.0	1.0	ND	ND	ND
[j]Picloram	µg L^{-1}	20.0	500.0	ND	ND	ND

Table continued on next page

Table 26a. Non-radiological Constituents in Samples from Drinking Water Sources (Continued)

				Measurements		
				[a]Location and Date of Sample Collection		
Analyte	Unit	[b]DL or MDL	[c]RL	Carlsbad 10/21/97	Hobbs 7/16/97	Loving 4/29/97
[k]Dalapon	µg L^{-1}	10.0	200	ND	ND	ND
[l]3-Hydroxycarbofuran	µg L^{-1}	5.0	5.0	ND	ND	ND
[l]Aldicarb	µg L^{-1}	0.5	0.5	ND	ND	ND
[l]Aldicarb Sulfone	µg L^{-1}	1.0	1.0	ND	ND	ND
[l]Aldicarb Sulfoxide	µg L^{-1}	0.5	0.5	ND	ND	ND
[l]Baygon	µg L^{-1}	1.0	1.0	ND	ND	ND
[l]Carbaryl	µg L^{-1}	5.0	5.0	ND	ND	ND
[l]Carbofuran	µg L^{-1}	1.0	40.0	ND	ND	ND
[l]Methiocarb	µg L^{-1}	0.5	0.5	ND	ND	ND
[l]Methomyl	µg L^{-1}	5.0	5.0	ND	ND	ND
[l]Oxamyl	µg L^{-1}	5.0	200.0	ND	ND	ND
[m]Glyphosate	µg L^{-1}	5.0	700	ND	ND	ND
[n]Endothall	µg L^{-1}	25.0	100.0	ND	ND	ND
[o]Diquat	µg L^{-1}	1.0	20.0	ND	ND	ND
[o]Atrizine	µg L^{-1}	9.2	3.0	ND	ND	ND
[p]Butachlor	µg L^{-1}	0.2	0.2	ND	ND	ND
[p]Di(2-ethylhexyl)adipate	µg L^{-1}	2.0	400.0	ND	ND	ND
[p]Di(2-ethylhexyl)phthalate	µg L^{-1}	2.0	6.0	ND	ND	ND
[p]Hexachlorocyclopentadiene	µg L^{-1}	0.2	0.2	ND	ND	ND
[p]Metribuzin	µg L^{-1}	0.2	0.2	ND	ND	ND
[p]Metolachlor	µg L^{-1}	0.2	0.2	ND	ND	ND
[p]Propachlor	µg L^{-1}	0.3	0.3	ND	ND	ND
[p]Simazine	µg L^{-1}	0.2	4.0	ND	ND	ND
[p]Benzo(a)pyrene	µg L^{-1}	0.2	0.2	ND	ND	ND

[a] Locations of drinking water collection as described in Table 24

[b] DL or MDL=Detection Limit or Method Detection Limit; Detection Limit is the smallest concentration or amount of some component of interest that can be measured by a single measurement with a stated level of confidence; Method Detection Limit is based on a method's ability to determine an analyte in a sample matrix, despite its source of origin. Values in this column are DLs for pyridine, cresols, 2,4-dinitrotoluene, hexachloroethane and nitrobenzene. All other values in this column are MDLs.

[c] RL = Reference Level; levels adopted as limits or guidelines under the Safe Drinking Water Act (SDWA); some sources may not be subject to regulation under SDWA. No RL values are presented for constituents not covered by SDWA.

[d] Measured by EPA Method 200.8

[e] by ICP, Measured by EPA Method 200.7

[f] SW846-8270

[g] Measured by EPA Method 502.2

[h] Measured by EPA Method 504

[i] Measured by EPA Method 505

[j] Measured by EPA Method 515.2

[k] Measured by EPA Method 552.1

[l] Measured by EPA Method 531.1
[m] Measured by EPA Method 547
[n] Measured by EPA Method 548.1
[o] Measured by EPA Method 549.1
[p] Measured by EPA Method 525.2
[q] ND = Not Detected
[r] NR = Not Reported by Laboratory
[s] EL = Sample storage time was exceeded at laboratory; no result reported

Table 26b. Non-radiological Constituents in Samples from Drinking Water Sources

				Measurements		
				[a]Location and Date of Sample Collection		
Analyte	**Unit**	**[b]DL or MDL**	**[c]RL**	**Otis 4/21/97**	**Private #1 7/22/97**	**Private #2 10/22/97**
[d]Antimony	μg L^{-1}	0.4	6	ND	ND	ND
[d]Arsenic	μg L^{-1}	0.3	50	1.9	7.6	3.3
[d]Barium	μg L^{-1}	0.1	2000	18.4	95.3	8.4
[d]Beryllium	μg L^{-1}	0.2	4	ND	ND	ND
[d]Cadmium	μg L^{-1}	0.1	5	0.1	ND	0.1
[d]Chromium	μg L^{-1}	1.0	100	4.3	ND	ND
[d]Mercury	μg L^{-1}	0.2	2	ND	ND	ND
[d]Nickel	μg L^{-1}	0.05	100	10.71	2.3	24.4
[d]Selenium	μg L^{-1}	1.0	50	4.7	4.8	14.6
[d]Thallium	μg L^{-1}	0.03	2	ND	ND	0.37
[d]Lead	μg L^{-1}	0.1	15.0	0.9	2.1	0.1
[d]Copper	μg L^{-1}	0.4	1300	2.4	3.4	3.2
[e]Aluminum	mg L^{-1}	0.05	0.05-0.2	ND	ND	ND
[e]Iron	mg L^{-1}	0.05	0.3	ND	ND	0.40
[e]Silver	mg L^{-1}	0.02	0.1	ND	ND	ND
[f]Pyridine	μg L^{-1}	0.5		ND	ND	ND
[f]Cresols	μg L^{-1}	0.5		ND	ND	ND
[f]2,4-Dinitrotoluene	μg L^{-1}	0.5		ND	ND	ND
[f]Hexachloroethane	μg L^{-1}	0.5		ND	ND	ND
[f]Nitrobenzene	μg L^{-1}	0.5		ND	ND	ND
[g]Benzene	μg L^{-1}	0.5	5.0	ND	ND	ND
[g]Bromobenzene	μg L^{-1}	0.5	0.5	ND	ND	ND
[g]Bromochloromethane	μg L^{-1}	0.5	0.5	ND	ND	ND
[g]Bromodichloromethane	μg L^{-1}	0.5	1000	ND	ND	ND
[g]Bromoform	μg L^{-1}	0.5	100	3.5	3.5	ND
[g]n-Butylbenzene	μg L^{-1}	0.5	0.5	ND	ND	ND
[g]sec-Butylbenzene	μg L^{-1}	0.5	0.5	ND	ND	ND
[g]tert-Butylbenzene	μg L^{-1}	0.5	0.5	ND	ND	ND
[g]Carbon Tetrachloride	μg L^{-1}	0.5	5.0	ND	ND	ND
[g]Chlorobenzene	μg L^{-1}	0.5	100	ND	ND	ND
[g]Chloroethane	μg L^{-1}	0.5	0.5	ND	ND	ND
[g]Chloroform	μg L^{-1}	0.5	100	ND	ND	ND

Table continued on next page

Table 26b. Non-radiological Constituents in Samples from Drinking Water Sources (Continued)

				Measurements		
				[a]Location and Date of Sample Collection		
Analyte	**Unit**	**[b]DL or MDL**	**[c]RL**	**Otis 4/21/97**	**Private #1 7/22/97**	**Private #2 10/22/97**
[g]Chloromethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]2-Chlorotoluene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]4-Chlorotoluene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Dibromochloromethane	µg L^{-1}	0.5	100	ND	ND	ND
[g]1,2-Dibromo-3-chloropropane	µg L^{-1}	0.5	0.20	ND	ND	ND
[g]1,2-Dibromoethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Dibromomethane	µg L^{-1}	0.5	100	ND	ND	ND
[g]1,2-Dichlorobenzene	µg L^{-1}	0.5	600	ND	ND	ND
[g]1,3-Dichlorobenzene	µg L^{-1}	0.5	75	ND	ND	ND
[g]1,4-Dichlorobenzene	µg L^{-1}	0.5		ND	ND	ND
[g]Dichlorodifluoromethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,1-Dichloroethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,2-Dichloroethane	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]1,1-Dichloroethene	µg L^{-1}	0.5	7.0	ND	ND	ND
[g]cis^{-1},2-Dichloroethene	µg L^{-1}	0.5	70	ND	ND	ND
[g]trans^{-1},2-Dichloroethene	µg L^{-1}	0.5	100	ND	ND	ND
[g]1,2-Dichloropropane	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]1,3-Dichloropropane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]2,2-Dichloropropane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,1-Dichloropropene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]cis^{-1},3-Dichloropropene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]trans^{-1},3-Dichloropropene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Ethylbenzene	µg L^{-1}	0.5	70	ND	ND	ND
[g]Hexachlorobutadiene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Isoproylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]4-Isopropyltoluene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Methylene chloride	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]Naphthalene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Propylbenzene	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Styrene	µg L^{-1}	0.5	100	ND	ND	ND
[g]1,1,1,2-Tetrachloroethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]1,1,2,2-Tetrachloroethane	µg L^{-1}	0.5	0.5	ND	ND	ND
[g]Tetrachloroethene	µg L^{-1}	0.5	5.0	ND	ND	ND
[g]Toluene	µg L^{-1}	0.5	1000	ND	ND	ND

Table continued on next page

Table 26b. Non-radiological Constituents in Samples from Drinking Water Sources (Continued)

			Measurements [a]**Location and Date of Sample Collection**			
Analyte	**Unit**	[b]**DL or MDL**	[c]**RL**	**Otis 4/21/97**	**Private #1 7/22/97**	**Private #2 10/22/97**
[g]1,2,3-Trichlorobenzene	$\mu g\ L^{-1}$	0.5	0.5	ND	ND	ND
[g]1,2,4-Trichlorobenzene	$\mu g\ L^{-1}$	0.5	70	ND	ND	ND
[g]1,1,1-Trichloroethane	$\mu g\ L^{-1}$	0.5	200	ND	ND	ND
[g]1,1,2-Trichloroethane	$\mu g\ L^{-1}$	0.5	5.0	ND	ND	ND
[g]Trichloroethene	$\mu g\ L^{-1}$	0.5	5.0	ND	ND	ND
[g]Trichlorofluoromethane	$\mu g\ L^{-1}$	0.5	0.5	ND	ND	ND
[g]1,2,3-Trichloropropane	$\mu g\ L^{-1}$	0.5	0.5	ND	ND	ND
[g]1,2,4-Trimethylbenzene	$\mu g\ L^{-1}$	0.5	0.5	ND	ND	ND
[g]1,3,5-Trimethylbenzene	$\mu g\ L^{-1}$	0.5	0.5	ND	ND	ND
[g]Vinyl chloride	$\mu g\ L^{-1}$	0.5	2.0	ND	ND	ND
[g]Xylenes	$\mu g\ L^{-1}$	0.5	10000	ND	ND	ND
[h]1,2-Dibromoethane	$\mu g\ L^{-1}$	0.01	0.01	ND	ND	ND
[h]1,2-Dibromo-3-Chloropropane	$\mu g\ L^{-1}$	0.01	0.01	ND	ND	ND
[i]Alachlor	$\mu g\ L^{-1}$	0.225	2.0	ND	ND	ND
[i]Aldrin	$\mu g\ L^{-1}$	0.09	0.09	ND	ND	ND
[i]Chlordane	$\mu g\ L^{-1}$	0.6	2.0	ND	ND	ND
[i]Dieldrin	$\mu g\ L^{-1}$	0.04	0.04	ND	ND	ND
[i]Endrin	$\mu g\ L^{-1}$	0.063	2.0	ND	ND	ND
[i]Heptachlor	$\mu g\ L^{-1}$	0.094	0.4	ND	ND	ND
[i]Heptachlor Epoxide	$\mu g\ L^{-1}$	0.067	0.2	ND	ND	ND
[i]Hexachlorobenzene	$\mu g\ L^{-1}$	0.02	1.0	ND	ND	ND
[i]Lindane	$\mu g\ L^{-1}$	0.03	0.2	ND	ND	ND
[i]Methoxychlor	$\mu g\ L^{-1}$	0.96	40.0	ND	ND	ND
[i]Toxaphene	$\mu g\ L^{-1}$	1.0	3.0	ND	ND	ND
[i]Aroclor 1016	$\mu g\ L^{-1}$	0.08	0.5	ND	ND	ND
[i]Aroclor 1221	$\mu g\ L^{-1}$	3.0	0.5	ND	ND	ND
[i]Arochlor 1232	$\mu g\ L^{-1}$	0.10	0.5	ND	ND	ND
[i]Arochlor 1242	$\mu g\ L^{-1}$	0.10	0.5	ND	ND	ND
[i]Arochlor 1248	$\mu g\ L^{-1}$	0.13	0.5	ND	ND	ND
[i]Arochlor 1254	$\mu g\ L^{-1}$	0.10	0.5	ND	ND	ND
[i]Arochlor 1260	$\mu g\ L^{-1}$	0.14	0.5	ND	ND	ND
[i]Hexachlorocyclopentadiene	$\mu g\ L^{-1}$	0.05	50.0	ND	ND	ND
[j]2,4-D	$\mu g\ L^{-1}$	10.0	70.0	ND	ND	ND
[j]2,4,5-TP(Silvex)	$\mu g\ L^{-1}$	1.0	50.0	ND	ND	ND

Table continued on next page

Table 26b. Non-radiological Constituents in Samples from Drinking Water Sources (Continued)

				Measurements		
				[a]Location and Date of Sample Collection		
Analyte	Unit	[b]DL or MDL	[c]RL	Otis 4/21/97	Private #1 7/22/97	Private #2 10/22/97
[j]Dicamba	µg L^{-1}	2.0	2.0	ND	ND	ND
[j]Dinoseb	µg L^{-1}	2.0	7.0	ND	ND	ND
[j]Pentachlorophenol	µg L^{-1}	1.0	1.0	ND	ND	ND
[j]Picloram	µg L^{-1}	20.0	500.0	ND	ND	ND
[k]Dalapon	µg L^{-1}	10.0	200	ND	ND	ND
[l]3-Hydroxycarbofuran	µg L^{-1}	5.0	5.0	ND	ND	ND
[l]Aldicarb	µg L^{-1}	0.5	0.5	ND	ND	ND
[l]Aldicarb Sulfone	µg L^{-1}	1.0	1.0	ND	ND	ND
[l]Aldicarb Sulfoxide	µg L^{-1}	0.5	0.5	ND	ND	ND
[l]Baygon	µg L^{-1}	1.0	1.0	ND	ND	ND
[l]Carbaryl	µg L^{-1}	5.0	5.0	ND	ND	ND
[l]Carbofuran	µg L^{-1}	1.0	40.0	ND	ND	ND
[l]Methiocarb	µg L^{-1}	0.5	0.5	ND	ND	ND
[l]Methomyl	µg L^{-1}	5.0	5.0	ND	ND	ND
[l]Oxamyl	µg L^{-1}	5.0	200.0	ND	ND	ND
[m]Glyphosate	µg L^{-1}	5.0	700	ND	ND	ND
[n]Endothall	µg L^{-1}	25.0	100.0	ND	[s]EL	ND
[o]Diquat	µg L^{-1}	1.0	20.0	ND	ND	ND
[o]Atrizine	µg L^{-1}	9.2	3.0	ND	ND	ND
[p]Butachlor	µg L^{-1}	0.2	0.2	ND	ND	ND
[p]Di(2-ethylhexyl)adipate	µg L^{-1}	2.0	400.0	ND	ND	ND
[p]Di(2-ethylhexyl)phthalate	µg L^{-1}	2.0	6.0	ND	ND	ND
[p]Hexachlorocyclopentadiene	µg L^{-1}	0.2	0.2	ND	ND	ND
[p]Metribuzin	µg L^{-1}	0.2	0.2	ND	ND	ND
[p]Metolachlor	µg L^{-1}	0.2	0.2	ND	ND	ND
[p]Propachlor	µg L^{-1}	0.3	0.3	ND	ND	ND
[p]Simazine	µg L^{-1}	0.2	4.0	ND	ND	ND
[p]Benzo(a)pyrene	µg L^{-1}	0.2	0.2	ND	ND	ND

[a] Locations of drinking water collection as described in Table 24

[b] DL or MDL=Detection Limit or Method Detection Limit; Detection Limit is the smallest concentration or amount of some component of interest that can be measured by a single measurement with a stated level of confidence; Method Detection Limit is based on a method's ability to determine an analyte in a sample matrix, despite its source of origin. Values in this column are DLs for pyridine, cresols, 2,4-dinitrotoluene, hexachloroethane and nitrobenzene. All other values in this column are MDLs.

[c] RL = Reference Level; levels adopted as limits or guidelines under the Safe Drinking Water Act (SDWA); some sources may not be subject to regulation under SDWA. No RL values are presented for constituents not covered by SDWA.

[d] Measured by EPA Method 200.8

[e] by ICP, Measured by EPA Method 200.7

[f] SW846-8270

[g] Measured by EPA Method 502.2

[h] Measured by EPA Method 504

[i] Measured by EPA Method 505

[j] Measured by EPA Method 515.2

[k] Measured by EPA Method 552.1

[l] Measured by EPA Method 531.1

[m] Measured by EPA Method 547

[n] Measured by EPA Method 548.1

[o] Measured by EPA Method 549.1

[p] Measured by EPA Method 525.2

[q] ND = Not Detected

[r] NR = Not Reported by Laboratory

[s] EL = Sample storage time was exceeded at laboratory; no result reported

Table 27a. Additional Non-radiological Constituents in Samples from Drinking Water Sources

			[a]Location and Date of Sample Collection		
Analyte	**Unit**	**[b]RL**	**Carlsbad 10/21/97 ([c]DL)**	**Hobbs 7/16/97 (DL)**	**Loving 4/29/97 (DL)**
[d]Calcium	$mg\ L^{-1}$		64.4 (0.4)	49.3 (0.1)	79.4 (0.1)
[d]Magnesium	$mg\ L^{-1}$		33.6 (0.4)	19.6 (0.1)	34.5 (0.1)
[d]Potassium	$mg\ L^{-1}$	1000	2.0 (0.4)	2.9 (0.1)	1.7 (0.1)
[d]Sodium	$mg\ L^{-1}$		27.6 (0.4)	71.2 (0.1)	13.8 (0.1)
[d]Silica	$mg\ L^{-1}$		6.15 (0.05)	53.65 (0.05)	8.70 (0.05)
[e]Nitrate/nitrite as N	$mg\ L^{-1}$	10/1.0	0.87 (0.05)	4.5 (0.5)	4.5 (0.5)
[f]Ammonium as nitrogen	$mg\ L^{-1}$		0.06 (0.01)	0.02 (0.01)	0.02 (0.01)
[g]Water Kjeldahl Nitrogen	$mg\ L^{-1}$		0.4 (0.1)	0.2 (0.1)	0.1 (0.1)
[h]Total phosphorus	$mg\ L^{-1}$		ND (2.05)	0.10 (0.05)	0.06 (0.05)
[i]Calcium (for SAR)	$meqL^{-1}$		3.21 (0.04)	2.46 (0.01)	3.96 (0.01)
[i]Magnesium (for SAR)	$meqL^{-1}$	125	2.77 (0.04)	1.61 (0.01)	2.84 (0.01)
[j]Alkalinity (as $CaCO_3$)	$mg\ L^{-1}$		229.5 (0.01)	170.0 (0.1)	183.5 (0.1)
[j]Carbonate	$meq\ L^{-1}$	350	0.00 (0.01)	00.0 (0.01)	0.00 (0.01)
[j]Carbonate alkalinity	$mg\ L^{-1}$		0.0 (1.0)	0.0 (1.0)	0.0 (1.0)
[j]Bicarbonate	$meq\ L^{-1}$	700	4.59 (0.01)	3.40 (0.01)	3.67 (0.01)
[j]Bicarbonate alkalinity	$mg\ L^{-1}$		280.1 (1.0)	207.4 (1.0)	223.9 (1.0)
[k]Hardness as $CaCO_3$	$mg\ L^{-1}$		299 (1)	204 (1)	340 (1)
[l]Chloride by autoanalyzer	$mg\ L^{-1}$	250	32.1 (0.5)	75.4 (0.5)	27.2 (0.5)
[m]Fluoride by electrode	$mg\ L^{-1}$	2.0	0.41 (0.05)	1.29 (0.05)	0.65 (0.05)
[n]Sulfate	$mg\ L^{-1}$	250	85 (2)	120 (20)	128 (10)
[o]Platinum-Cobalt color		15	ND (5)	ND (5)	ND (5)
[p]Electrical Conductivity	$m\Omega\ cm^{-1}$		709 (1)	825 (1)	719 (1)
[q]pH of water		6.5-8.5	7.18	7.22	7.13
Total Dissolved Solids	$mg\ L^{-1}$	500	391 (1)	515 (1)	366 (1)
Total Suspended Solids	$mg\ L^{-1}$		<1 (1)	<1 (1)	<1 (1)

[a] Locations of drinking water collection as described in Table 24

[b] RL = Reference Level; levels adopted as limits or guidelines under the Safe Drinking Water Act (SDWA); some sources may not be subject to regulation under SDWA. No RL values are presented for constituents not covered by SDWA.

[c] DL=Detection Limit; the smallest concentration or amount of some component of interest that can be measured by a single measurement with a stated level of confidence.

[d] by ICP, Measured by EPA Method 200.7

[e] Measured by EPA Method 353.2

[f] Measured by EPA Method 350.1

[g] Measured by EPA Method 351.2

[h] Measured by EPA Method 365.2

[i] Measured by EPA Method 200

[j] Measured by EPA Method 310.1

[k] Measured by EPA Method 130.2

[l] Measured by EPA Method 325.2

[m] Measured by EPA Method 340.2

[n] Measured by EPA Method 375.2

[o] Measured by EPA Method 110.2

[p] Measured by EPA Method 120.1

[q] Measured by EPA Method 150.1

[r] ND = Not Detected

Table 27b. Additional Non-radiological Constituents in Samples from Drinking Water Sources

Analyte	Unit	[b]RL	[a]Location and Date of Sample Collection		
			Otis 4/21/97 ([c]DL)	**Private #1 7/22/97 (DL)**	**Private #2 10/22/97 (DL)**
[d]Calcium	mg L^{-1}		271.5 (0.1)	30.8 (0.1)	643.2 (0.4)
[d]Magnesium	mg L^{-1}		113.0 (0.1)	11.4 (0.1)	171.2 (0.4)
[d]Potassium	mg L^{-1}	1000	4.5 (0.1)	3.1 (0.1)	8.5 (0.1)
[d]Sodium	mg L^{-1}		115.0 (0.1)	59.0 (0.1)	233.2 (0.4)
[d]Silica	mg L^{-1}		9.10 (0.05)	33.70 (0.05)	18.0 (0.50)
[e]Nitrate/nitrite as N	mg L^{-1}	10/1.0	4.95 (0.5)	1.86 (0.05)	0.27 (0.05)
[f]Ammonium as nitrogen	mg L^{-1}		0.08 (0.01)	0.02 (0.01)	0.20 (0.01)
[g]Water Kjeldahl Nitrogen	mg L^{-1}		[r]ND (0.1)	0.1 (0.1)	1.0 (0.1)
[h]Total phosphorus	mg L^{-1}		ND (0.05)	0.08 (0.05)	ND (2.05)
[i]Calcium (for SAR)	meqL^{-1}		13.55 (0.01)	1.54 (0.01)	32.08 (0.04)
[i]Magnesium (for SAR)	meqL^{-1}	125	9.30 (0.01)	.93 (0.01)	14.08 (0.04)
[j]Alkalinity (as CaCO$_3$)	mg L^{-1}		163.0 (0.1)	149.0 (0.1)	164.5 (0.1)
[j]Carbonate	meq L^{-1}	350	0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
[j]Carbonate alkalinity	mg L^{-1}		0.0 (1.0)	0.0 (1.0)	0.0 (1.0)
[j]Bicarbonate	meq L^{-1}	700	3.26 (0.01)	2.98 (0.01)	3.29 (0.01)
[j]Bicarbonate alkalinity	mg L^{-1}		198.9 (1.0)	181.8 (1.0)	200.7 (1.0)
[k]Hardness as CaCO$_3$	mg L^{-1}		1142 (1)	124 (1)	2308 (1)
[l]Chloride by autoanalyzer	mg L^{-1}	250	378.1 (12.5)	48.7 (2.5)	450 (5)
[m]Fluoride by electrode	mg L^{-1}	2.0	0.80 (0.05)	0.80 (0.05)	2.29 (0.05)
[n]Sulfate	mg L^{-1}	250	622 (20)	45 (2)	2117 (50)
[o]Platinum-Cobalt color		15	ND (5)	ND (5)	1.0 (5)
[p]Electrical Conductivity	mΩ cm^{-1}		2560 (1)	598 (1)	4020 (1)
[q]pH of water		6.5-8.5	7.38	7.90	6.81
Total Dissolved Solids	mg L^{-1}	500	1750 (1)	306 (1)	3816 (1)
Total Suspended Solids	mg L^{-1}		6 (1)	<1 (1)	4.5 (1)

[a] Locations of drinking water collection as described in Table 24

[b] RL = Reference Level; levels adopted as limits or guidelines under the Safe Drinking Water Act (SDWA); some sources may not be subject to regulation under SDWA. No RL values are presented for constituents not covered by SDWA

[c] DL=Detection Limit; the smallest concentration or amount of some component of interest that can be measured by a single measurement with a stated level of confidence

[d] by ICP, Measured by EPA Method 200.7

[e] Measured by EPA Method 353.2

[f] Measured by EPA Method 350.1

[g] Measured by EPA Method 351.2

[h] Measured by EPA Method 365.2

[i] Measured by EPA Method 200

[j] Measured by EPA Method 310.1

[k] Measured by EPA Method 130.2

[l] Measured by EPA Method 325.2

[m] Measured by EPA Method 340.2

[n] Measured by EPA Method 375.2
[o] Measured by EPA Method 110.2
[p] Measured by EPA Method 120.1
[q] Measured by EPA Method 150.1
[r] ND = Not Detected

Radionuclides and Other Constituents in Sediments and Surface Water

Methods

Sediment samples were collected during March-April, 1997, from Brantley Lake, a reservoir located on the Pecos River, approximately 12 miles north of Carlsbad, in Eddy County, New Mexico (Figure 6). Areas of the lake falling into three depth categories (0-5 m, 5-10 m, >10 m) were identified using preliminary bathymetric surveys. Using a small boat, sediment samples were collected at five randomly selected locations within each of the three depth categories (total of 15 samples). Samples were collected to depths of 5-10 cm using a grab sampler or Eckman dredge, to obtain $\geq$5 L of sediment at each location. Sediment samples were placed in plastic containers for storage and transported to the laboratory. In the laboratory, sediment samples were dried at 105°C to a constant weight, pulverized and homogenized prior to analyses.

Surface water samples were initially collected in March 1997, at three locations in the deepest part of the reservoir (>13 m). Three additional samples were collected in September 1997. At each location, water was collected at 2-m increments from the surface to just above the sediment, using a high-volume sampling pump. For radiological analyses, the total volume collected for each sample was $\geq$110 L. The water samples were placed in 50-L plastic containers for transport and storage. In the laboratory, the samples collected in March were acidified to a pH of <2 using HCl and gravity filtered by allowing the samples to settle for >24 hr prior to radiochemical analysis. The water was siphoned off to just above the sediment in the bottom of the container. The samples collected in September were passed through a 0.2μm filter, and acidified to a pH of <2 using HCl prior to analysis. A surface water sample collected in April 1997 was sent to the Soil Water and Air Testing Laboratory at NMSU for non-radiological analyses. The sample was handled and preserved according to EPA protocols for drinking water samples.

To separate alpha-emitting radionuclides in sediments, 3-5 gm of material were first treated with HF, HCl and HNO_3 to dissolve the sample material, followed by separation and purification of actinides using ion chromatography. Analyses of alpha-emitting and gamma-emitting radionuclides in water samples were conducted as described for drinking water samples (p. 61), with counting times of 2-14 days.

Mean MDCs for actinides in surface water samples were determined to be 0.00012 mBq L^{-1} for ^{239,240}Pu, with 30% average yield, 0.020 mBq L^{-1} for ^{228}Th, with 30% average yield, 0.014 mBq L^{-1} for ^{230}Th, with 30% average yield, 0.010 mBq L^{-1} for ^{232}Th, with 30% average yield, 0.74 mBq L^{-1} for ^{234}U, with 70% average yield, and 0.70 mBq L^{-1} for ^{238}U, with 70% average yield. MDCs for gamma-emitters were determined to be 280 mBq L^{-1} for ^{40}K, and 25.7 mBq L^{-1} for ^{137}Cs. Mean MDCs for actinides measured by alpha spectrometry in sediment samples were determined to be 0.16 mBq g^{-1} for ^{239,240}Pu, with 25% average yield, 0.55 mBq g^{-1} for ^{228}Th, with 60% average yield, 0.36 mBq g^{-1} for ^{230}Th, with 60% average yield, 0.28 mBq g^{-1} for ^{232}Th, with 60% average yield, 0.21 mBq g^{-1} for ^{234}U with 50% average yield, and 0.19 mBq g^{-1} for ^{238}U, with 50% average yield. Mean MDCs for radionuclides measured by gamma spectrometry in sediment samples were determined to be 1.21 mBq g^{-1} for ^{40}K, and .109 mBq g^{-1} for ^{137}Cs. A total of three tracer blanks were used for quality control for sediment analyses, and one tracer blank was used for surface water analyses.

Results

Two out of 15 sediment samples analyzed for ^{239,240}Pu were below MDC. The lake-wide mean (±SE) activity concentration for ^{239,240}Pu, for samples above MDC, was 0.35 ± 0.062 mBq g^{-1} (dry), and ranged from 0.13 to 0.94 mBq g^{-1} (Tables 28 and 29). There did not appear to be a significant change in ^{239,240}Pu concentrations in sediments at different depths of water. The mean concentration (±SE) within each water depth class was 0.38 ± 0.19, 0.29 ± 0.054, and 0.39 ± 0.089 mBq g^{-1} for the 0-5, 5-10 and >10 m depths, respectively (Table 30).

^{137}Cs was detected in all sediment samples. Activity concentrations ranged from 0.675 to 29.0 mBq g^{-1} with a mean (±SE) of 9.90 ± 1.71 mBq g^{-1}. Mean activity concentrations (± SE) at different water depths were 6.49 ± 3.02, 13.2 ± 3.98, and 9.97 ± 0.214 mBq g^{-1} for the 0-5, 5-10 and >10 water depths respectively. Naturally occurring radionuclide activity concentrations in sediment exhibited a wide range of variability across the reservoir. ^{40}K activity concentrations ranged from 302 to 2130 mBq g^{-1}. Activity concentrations of select Th isotopes ranged from 11-44, 12-48, and 11-48 mBq g^{-1} for ^{228}Th, ^{230}Th, and ^{232}Th, respectively. ^{234}U concentrations ranged from 3.4 to 54 mBq g^{-1} and ^{238}U concentrations ranged from 3.0 to 40 mBq g^{-1}.

The variability in ^{239,240}Pu and ^{137}Cs activity concentrations in sediments generally was highest in shallow water depths (Table 30). This may reflect the fact that the sediments in the deeper basins generally are more homogenous with respect to particle size than sediments in shallower waters. Shallow water sediments can be affected significantly by the sorting effects of current and wave action, with the result being a relatively heterogeneous particle size distribution in shallow water sediments (H◇kanson, L. and M. Jansson, 1983, *Principles of Lake Sedimentology*, Springer-Verlag). The deep sediments were anoxic, fine-grained, organic sediments while the shallow water sediments ranged from fine-grained sediments to sandy, coarse-grained sediments. The trend with water depth was not so apparent in the naturally occurring radionuclides.

In surface water, both ^{234}U and ^{238}U activity were measured in all six water samples (Table 31). No detectable ^{137}Cs or ^{230}Th activity was measured in any of the samples. For other radionuclides, the number of samples with measurable activity varied. The low occurrence of measurable activities in the surface water may be the result of the way in which the samples were handled, especially filtering. As noted in the methods section, the samples collected in March were allowed to settle (gravity filtered) for more than 24 hours prior to siphoning off the top-water, and the samples collected in September were passed through a 0.2 μm filter prior to analysis. Both treatments likely removed a significant portion of the seston in the water column with varying efficiencies. Seston includes nonliving particulate matter, phytoplankton and other microorganisms suspended in the water column. It has been demonstrated that in aquatic systems, a large proportion of the radioactivity in the water column for various radionuclides, particularly the anthropogenic radionuclides ^{239,240}Pu and ^{137}Cs, is associated with the seston (Whicker, F.W., et. al., 1990, *Ecol. Monog*. 60, 471; Paine, D., 1980, In *Transuranic Elements in the Environment*, DOE/TIC-22800, 644). For these samples, no analyses of the seston component were conducted.

Non-radiological analyses of surface water included metals, volatile organic compounds, semi-volatile organic compounds and general secondary water quality parameters (Table 32). The analytes included those substances regulated under the Safe Drinking Water Act (SDWA), plus selected compounds and elements identified as possible constituents of waste to be deposited in the WIPP. For comparative purposes only, the table includes the primary and secondary maximum contaminant levels (MCLs) for constituents regulated under the SDWA, indicated as “reference limits”. It should be noted Brantley Lake water is not used as a drinking water source and is therefore not subject to regulation under the SDWA. These samples were collected for research purposes only, and the test results are not appropriate for use as evidence of compliance or non-compliance with any regulatory requirement.

The Brantley Lake water sample was above reference levels for chloride, sulfate, and total dissolved solids. The cited reference levels for these analytes are non-enforceable guidelines (secondary MCLs) under the SDWA. All other analytes regulated under the SDWA were either below detection limits or below reference levels.

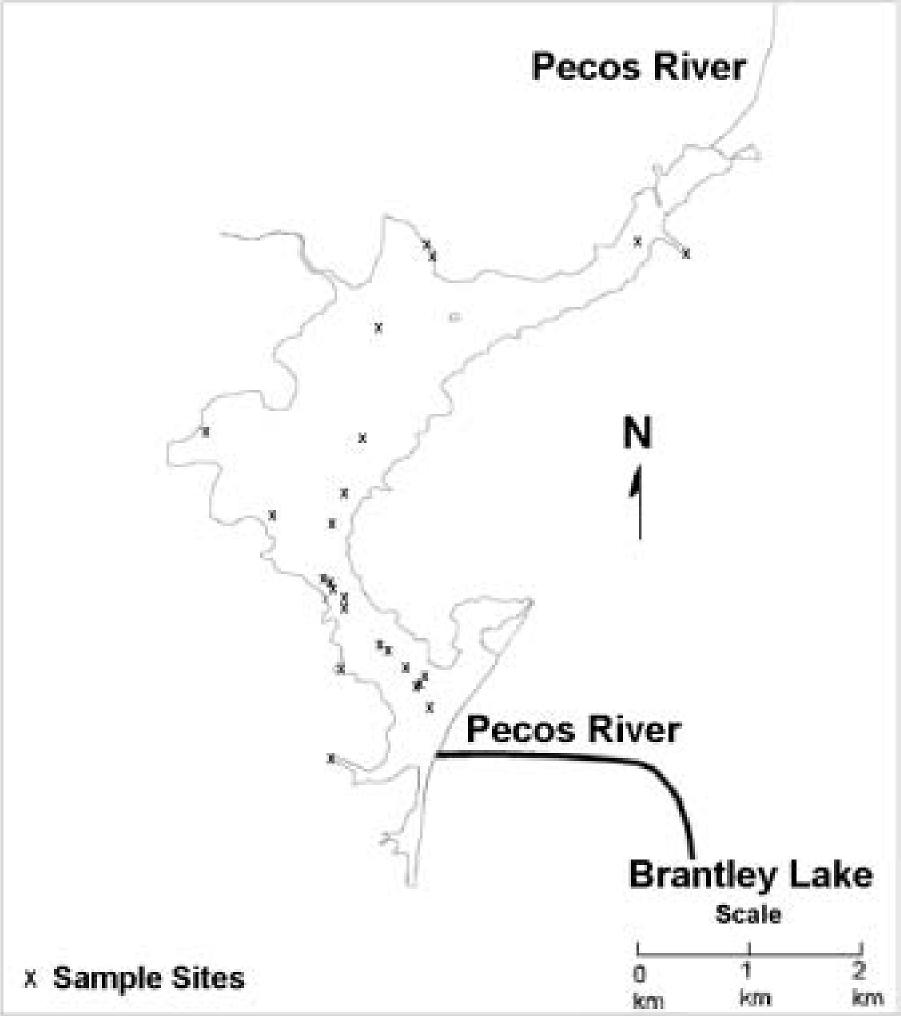

Figure 6. Sampling Locations at Brantley Lake

Table 28. Radionuclide Activity Concentrations in Brantley Lake Sediment Samples

Radionuclide	[a]Location	Overlying Water Depth (m)	[b]Activity Concentration (mBq g^{-1})	[c]SD (mBq g^{-1})	[d]MDC (mBq g^{-1})
^{239,240}Pu	BLS11	0-5	1.3E-1	1.6E-03	1.6E-2
	BLS12	0-5	2.6E-1	5.5E-2	6.9E-2
	BLS13	0-5	2.2E-1	6.0E-2	7.4E-2
	BLS14	0-5	9.4E-1	8.6E-2	1.4E-1
	BLS15	0-5	[e]<MDC		3.0E-1
	BLS1	5-10	4.6E-1	9.1E-2	1.1E-1
	BLS7	5-10	3.1E-1	3.7E-2	1.0E-1
	BLS8	5-10	2.2E-1	3.1E-2	1.0E-1
	BLS9	5-10	3.4E-1	3.7E-2	2.6E-2
	BLS10	5-10	1.4E-1	1.2E-2	7.5E-3
	BLS2	>10	3.0E-1	6.6E-2	9.4E-2
	BLS3	>10	6.5E-1	1.3E-1	1.9E-1
	BLS4	>10	3.4E-1	4.4E-2	5.9E-2
	BLS5	>10	<MDC		9.7E-1
	BLS6	>10	2.7E-1	3.2E-2	8.3E-2
^{228}Th	BLS11	0-5	4.4E+1	6.8E+0	9.7E-1
	BLS12	0-5	1.2E+1	1.8E+0	7.2E-1
	BLS13	0-5	1.2E+1	8.9E-1	1.2E-1
	BLS14	0-5	1.7E+1	1.2E+0	2.2E-1
	BLS15	0-5	1.8E+1	1.9E+0	4.6E-1
	BLS1	5-10	3.1E+1	4.6E+0	6.9E-2
	BLS7	5-10	2.5E+1	3.4E+0	7.0E-1
	BLS8	5-10	2.0E+1	1.9E+0	3.7E-1
	BLS9	5-10	1.6E+1	1.8E+0	1.6E-2
	BLS10	5-10	1.8E+1	2.6E+0	4.2E-1
	BLS2	>10	1.4E+1	3.5E+0	3.5E+0
	BLS3	>10	2.3E+1	2.6E+0	3.1E-2
	BLS4	>10	1.1E+1	8.3E-1	2.1E-3
	BLS5	>10	2.6E+1	2.8E+0	2.2E-2
	BLS6	>10	4.1E+1	5.3E+0	6.9E-1
^{230}Th	BLS11	0-5	4.2E+1	6.5E+0	9.6E-1
	BLS12	0-5	1.2E+1	1.8E+0	6.9E-1
	BLS13	0-5	1.4E+1	1.1E+0	9.6E-2
	BLS14	0-5	1.7E+1	1.2E+0	2.2E-1
	BLS15	0-5	1.7E+1	1.8E+0	4.5E-1
	BLS1	5-10	3.3E+1	5.0E+0	6.9E-2
	BLS7	5-10	2.4E+1	3.3E+0	6.9E-1

Table continued on next page

Table 28. Radionuclide Activity Concentrations in Brantley Lake Sediment Samples (Continued)

Radionuclide	[a]Location	Overlying Water Depth (m)	[b]Activity Concentration (mBq g^{-1})	[c]SD (mBq g^{-1})	[d]MDC (mBq g^{-1})
	BLS8	5-10	1.9E+1	1.9E+0	3.6E-1
	BLS9	5-10	1.6E+1	1.8E+0	1.6E-2
	BLS10	5-10	2.0E+1	2.8E+0	4.2E-1
	BLS2	>10	2.1E+1	4.9E+0	7.2E-1
	BLS3	>10	2.7E+1	3.0E+0	3.1E-2
	BLS4	>10	1.4E+1	1.1E+0	2.1E-3
	BLS5	>10	3.3E+1	3.6E+0	2.2E-2
	BLS6	>10	4.8E+1	6.3E+0	6.8E-1
^{232}Th	BLS11	0-5	4.2E+1	6.5E+0	6.4E-1
	BLS12	0-5	1.5E+1	2.1E+0	5.5E-1
	BLS13	0-5	1.1E+1	8.4E-1	9.6E-2
	BLS14	0-5	1.7E+1	1.2E+0	1.5E-1
	BLS15	0-5	1.9E+1	1.9E+0	3.0E-1
	BLS1	5-10	2.7E+1	4.2E+0	6.9E-2
	BLS7	5-10	2.3E+1	3.0E+0	4.6E-1
	BLS8	5-10	1.9E+1	1.8E+0	2.4E-1
	BLS9	5-10	1.5E+1	1.7E+0	1.6E-2
	BLS10	5-10	1.8E+1	2.6E+0	3.9E-1
	BLS2	>10	4.8E+1	1.1E+1	8.4E-1
	BLS3	>10	2.1E+1	2.4E+0	3.1E-2
	BLS4	>10	1.2E+1	8.9E-1	2.1E-3
	BLS5	>10	2.4E+1	2.6E+0	2.2E-2
	BLS6	>10	3.7E+1	4.9E+0	4.6E-1
^{234}U	BLS11	0-5	3.3E+1	8.8E+0	5.3E-1
	BLS12	0-5	1.3E+1	3.6E+0	3.6E-1
	BLS13	0-5	5.9E+0	1.5E+0	8.4E-2
	BLS14	0-5	3.4E+0	9.1E-1	9.4E-2
	BLS15	0-5	5.2E+0	1.4E+0	2.1E-2
	BLS1	5-10	9.5E+0	8.2E-1	9.5E-2
	BLS7	5-10	5.4E+1	4.2E+0	8.6E-2
	BLS8	5-10	5.4E+1	4.0E+0	4.7E-2
	BLS9	5-10	3.1E+1	2.6E+0	2.4E-1
	BLS10	5-10	3.4E+1	9.4E+0	4.7E-1
	BLS2	>10	3.8E+1	3.0E+0	1.7E-1

Table continued on next page

Table 28. Radionuclide Activity Concentrations in Brantley Lake Sediment Samples (Continued)

Radionuclide	[a]Location	Overlying Water Depth (m)	[b]Activity Concentration (mBq g^{-1})	[c]SD (mBq g^{-1})	[d]MDC (mBq g^{-1})
	BLS3	>10	9.7E+0	8.3E-1	3.9E-1
	BLS4	>10	1.0E+1	8.1E-1	2.9E-1
	BLS5	>10	3.4E+1	3.0E+0	1.7E-1
	BLS6	>10	2.6E+1	2.2E+0	9.7E-2
^{238}U	BLS11	0-5	4.0E+1	1.0E+1	4.9E-1
	BLS12	0-5	1.3E+1	3.6E+0	2.4E-1
	BLS13	0-5	5.2E+0	1.4E+0	8.4E-2
	BLS14	0-5	3.0E+0	8.0E-1	1.9E-2
	BLS15	0-5	4.9E+0	1.3E+0	5.6E-2
	BLS1	5-10	7.2E+0	6.2E-1	9.5E-2
	BLS7	5-10	3.7E+1	2.8E+0	6.1E-2
	BLS8	5-10	3.8E+1	2.9E+0	6.8E-2
	BLS9	5-10	3.0E+1	2.6E+0	2.6E-1
	BLS10	5-10	2.7E+1	7.5E+0	4.7E-1
	BLS2	>10	3.5E+1	2.8E+0	1.8E-1
	BLS3	>10	7.3E+0	6.7E-1	3.3E-1
	BLS4	>10	8.1E+0	8.5E-1	3.5E-1
	BLS5	>10	2.9E+1	2.6E+0	1.2E-1
	BLS6	>10	2.3E+1	2.0E+0	3.6E-2
^{137}Cs	BLS11	0-5	1.59E+1	5.89E-1	2.8E-1
	BLS12	0-5	2.40E+0	9.40E-2	6.4E-2
	BLS13	0-5	2.10E+0	8.42E-2	5.4E-2
	BLS14	0-5	1.14E+1	3.93E-1	7.2E-2
	BLS15	0-5	6.75E-1	4.52E-2	6.4E-2
	BLS1	5-10	8.10E+0	2.87E-1	8.3E-2
	BLS7	5-10	1.11E+1	3.89E-1	8.9E-2
	BLS8	5-10	7.80E+0	2.74E-1	7.1E-2
	BLS9	5-10	1.02E+1	3.56E-1	8.4E-2
	BLS10	5-10	2.90E+1	1.02E+0	2.6E-1
	BLS2	>10	1.01E+1	3.55E-1	1.0E-1
	BLS3	>10	9.70E+0	3.41E-1	9.4E-2
	BLS4	>10	9.30E+0	3.72E-1	1.1E-1
	BLS5	>10	1.05E+1	3.69E-1	9.8E-2
	BLS6	>10	1.02E+1	3.60E-1	1.2E-1

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Table 28. Radionuclide Activity Concentrations in Brantley Lake Sediment Samples (Continued)

Radionuclide	[a]Location	Overlying Water Depth (m)	[b]Activity Concentration (mBq g^{-1})	[c]SD (mBq g^{-1})	[d]MDC (mBq g^{-1})
^{40}K	BLS11	0-5	2.13E+3	8.61E+1	2.8E+0
	BLS12	0-5	4.67E+2	1.89E+1	6.3E-1
	BLS13	0-5	3.02E+2	1.22E+1	5.4E-1
	BLS14	0-5	4.99E+2	2.02E+1	7.2E-1
	BLS15	0-5	5.16E+2	2.09E+1	6.8E-1
	BLS1	5-10	4.86E+2	1.97E+1	8.5E-1
	BLS7	5-10	5.35E+2	2.17E+1	8.8E-1
	BLS8	5-10	4.71E+2	1.82E+1	7.5E-1
	BLS9	5-10	5.74E+2	2.32E+1	8.5E-1
	BLS10	5-10	1.75E+3	7.07E+1	2.7E+0
	BLS2	>10	7.24E+2	2.93E+1	1.1E+0
	BLS3	>10	6.60E+2	2.67E+1	9.7E-1
	BLS4	>10	6.78E+2	2.81E+1	2.8E+0
	BLS5	>10	6.88E+2	2.78E+1	9.6E-1
	BLS6	>10	6.65E+2	2.69E+1	9.8E-1

[a] Locations of sediment sample collection as shown in Figure 2; results reported are from samples collected during March-April,1997

[b] Activity Concentrations as defined in Appendix K; values for radionuclides measured by alpha spectrometry are rounded to two significant figures; values for radionuclides measured by gamma spectrometry are rounded to three significant figures

[c] SD = Count Standard Deviation as defined in Appendix K

[d] MDC = Minimum Detectable Activity Concentration; see Appendix K

[e] <MDC = Observed activity concentration was below MDC

Table 29. Summary Statistics for Radionuclide Activity Concentrations from Brantley Lake Sediment Samples

		Activity Concentration (mBq g^{-1})				
Radionuclide	**[b]N**	**[c]Mean**	**[d]SE**	**Minimum**	**Maximum**	**[e] CV (%)**
^{239,240}Pu	13	0.35	0.062	0.13	0.94	64
^{228}Th	15	22	2.6	11	44	46
^{230}Th	15	24	2.8	12	48	45
^{232}Th	15	23	2.9	11	48	48
^{234}U	15	24	4.4	3.4	54	72
^{238}U	15	20	3.6	3.0	40	68
^{137}Cs	15	9.90	1.71	0.675	29.0	67
^{40}K	15	743	130	302	2130	68

[a] Calculated statistics do no include samples with activity concentrations <MDC; mean, SE, minimum and maximum are rounded to two significant figures for radionuclides measured by alpha spectrometry; mean, SE, minimum and maximum are rounded to three significant figures for radionuclides measured by gamma spectroscopy

[b] N = number of samples included in calculations

[c] Mean = arithmetic mean

[d] SE = standard error of mean

[e] CV = coefficient of variation; standard deviation expressed as percentage of the mean; CVs may reflect small rounding error

Table 30. Summary Statistics for Radionuclide Activity Concentrations as a Function of Water Depth in Brantley Lake Sediment Samples

	[a]Activity Concentration (mBq g^{-1})											
	0-5 m Water Depth				5-10 m Water Depth				>10 m Water Depth			
Radionuclide	[b]N	[c]Mean	[d]SE	[e]CV (%)	N	Mean	SE	CV (%)	N	Mean	SE	CV (%)
^{239,240}Pu	4	0.38	0.19	97	5	0.29	0.054	41	4	0.39	0.089	46
^{228}Th	5	21	6.0	65	5	22	2.7	28	5	23	5.3	51
^{230}Th	5	21	5.5	59	5	22	2.9	29	5	29	5.8	45
^{232}Th	5	21	5.5	59	5	20	2.1	23	5	28	6.3	50
^{234}U	5	12	5.5	101	5	36	8.3	51	5	24	5.8	55
^{238}U	5	13	6.8	116	5	28	5.6	45	5	21	5.5	60
^{137}Cs	5	6.49	3.02	104	5	13.2	3.98	67	5	9.97	0.214	5
^{40}K	5	783	339	97	5	763	247	72	5	683	11.4	4

[a] Calculated statistics do no include samples with activity concentrations <MDC; mean, SE, minimum and maximum are rounded to two significant figures for radionuclides measured by alpha spectrometry; mean, SE, minimum and maximum are rounded to three significant figures for radionuclides measured by gamma spectroscopy

[b] N = number of samples included in calculations

[c] Mean = arithmetic mean

[d] SE = standard error of mean

[e] CV = coefficient of variation; standard deviation expressed as percentage of the mean; CVs may reflect small rounding error

Table 31. Radionuclide Activity Concentrations in Water Samples from Brantley Lake

Radionuclide	[a]Location	[b]Activity Concentration (mBq L^{-1})	[c]SD (mBq L^{-1})	[d]MDC (mBq L^{-1})
$^{239/240}$Pu	BLW4	[e] <MDC		2.7E-3
	BLW5	<MDC		5.2E-4
	BLW6	1.5E-3	5.8E-4	4.6E-4
^{228}Th	BLW4	5.0E-2	8.5E-3	1.5E-2
	BLW5	5.5E-2	9.2E-3	1.6E-2
	BLW6	<MDC		5.8E-2
^{230}Th	BLW4	<MDC		1.9E-2
	BLW5	<MDC		2.0E-2
	BLW6	<MDC		3.5E-3
^{232}Th	BLW4	<MDC		8.0E-3
	BLW5	1.9E-2	4.7E-3	8.4E-3
	BLW6	<MDC		1.4E-2
^{234}U	BLW1	7.3E+1	6.8E+0	7.9E-1
	BLW2	1.5E+2	2.3E+1	2.1E+0
	BLW3	5.0E+1	4.5E+0	3.2E-1
	BLW4	2.1E+1	1.1E+0	3.0E-1
	BLW5	3.3E+0	2.0E-1	8.0E-2
	BLW6	1.9E+1	1.0E+0	1.0E-1
^{238}U	BLW1	3.3E+1	3.1E+0	7.4E-1
	BLW2	6.4E+1	1.0E+1	2.7E+0
	BLW3	2.3E+1	2.1E+0	3.2E-1
	BLW4	1.2E+1	6.0E-1	3.0E-1
	BLW5	1.9E+0	1.0E-1	8.0E-2
	BLW6	1.0E+1	5.0E-1	1.0E-1
^{137}Cs	BLW1	<MDC		2.1E+1
	BLW2	<MDC		3.3E+1
	BLW3	<MDC		2.0E+1
	BLW4	<MDC		2.0E+1
	BLW5	<MDC		3.0E+1
	BLW6	<MDC		3.1E+1

Table continued on next page

Table 31. Radionuclide Activity Concentrations in Water Samples from Brantley Lake (Continued)

Radionuclide	[a]Location	[b]Activity Concentration (mBq L^{-1})	[c]SD (mBq L^{-1})	[d]MDC (mBq L^{-1})
^{40}K	BLW1	1.05E+3	8.44E+1	3.0E+2
	BLW2	ND		3.1E+1
	BLW3	1.16E+3	8.84E+1	3.1E+2
	BLW4	<MDC		3.7E+2
	BLW5	<MDC		3.1E+2
	BLW6	<MDC		3.6E+2

[a] Locations of surface water collection as shown in Figure 2; samples BLW1, BLW2, and BLW3 were collected in March 1997 and BLW4, BLW5 and BLW6 were collected in September 1997; September samples were passed through a 0.2 μm filter prior to analysis

[b] Activity Concentrations as defined in Appendix K

[c] SD = Count Standard Deviation as defined in Appendix K

[d] MDC = Minimum Detectable Activity Concentration as defined in Appendix K

[e] <MDC = Observed activity concentration was below MDC

Table 32. Non-radiological Constituents in Water Sample from Brantley Lake

[a]Analyte	Unit	[b]DL	[c]RL	[d]Measurement
[e]Antimony	µg/L	0.4	6	ND
[e]Arsenic	µg/L	0.3	50	1.6
[e]Barium	µg/L	0.1	2000	68.6
[e]Beryllium	µg/L	0.2	4	ND
[e]Cadmium	µg/L	0.1	5	0.1
[e]Chromium	µg/L	1.0	100	3.0
[e]Mercury	µg/L	0.2	2	ND
[e]Nickel	µg/L	0.05	100	13.11
[e]Selenium	µg/L	1.0	50	4.5
[e]Thallium	µg/L	0.03	2	0.04
[e]Lead	µg/L	0.1	15.0	0.7
[e]Copper	µg/L	0.4	1300	7.6
[f]Aluminum	mg/L	0.05	0.05-0.2	ND
[f]Iron	mg/L	0.05	0.3	ND
[f]Silver	mg/L	0.02	0.1	ND
[f]Calcium	mg/L	0.1		426.1
[f]Magnesium	mg/L	0.1		133.0
[f]Potassium	mg/L	0.1	1000	11.7
[f]Sodium	mg/L	0.1		661.0
[f]Silica	mg/L	0.05		3.05
[g]Pyridine	µg/L	0.5		ND
[g]cresols	µg/L	0.5		ND
[g]2,4-Dinitrotoluene	µg/L	0.5		ND
[g]Hexachloroethane	µg/L	0.5		ND
[g]Nitrobenzene	µg/L	0.5		ND
[h]Benzene	µg/L	0.5	5.0	ND
[h]Bromobenzene	µg/L	0.5	0.5	ND
[h]Bromochloromethane	µg/L	0.5	0.5	ND
[h]Bromodichloromethane	µg/L	0.5	1000	ND
[h]Bromoform	µg/L	0.5	100	ND

Table continued on next page

Table 32. Non-radiological Constituents in Water Sample from Brantley Lake (Continued)

[a]Analyte	Unit	[b]DL	[c]RL	[d]Measurement
[h]n-Butylbenzene	µg/L	0.5	0.5	ND
[h]sec-Butylbenzene	µg/L	0.5	0.5	ND
[h]tert-Butylbenzene	µg/L	0.5	0.5	ND
[h]Carbon Tetrachloride	µg/L	0.5	5.0	ND
[h]Chlorobenzene	µg/L	0.5	100	ND
[h]Chloroethane	µg/L	0.5	0.5	ND
[h]Chloroform	µg/L	0.5	100	ND
[h]Chloromethane	µg/L	0.5	0.5	ND
[h]2-Chlorotoluene	µg/L	0.5	0.5	ND
[h]4-Chlorotoluene	µg/L	0.5	0.5	ND
[h]Dibromochloromethane	µg/L	0.5	100	ND
[h]1,2-Dibromo-3-chloropropane	µg/L	0.5	0.20	ND
[h]1,2-Dibromoethane	µg/L	0.5	0.5	ND
[h]Dibromomethane	µg/L	0.5	100	ND
[h]1,2-Dichlorobenzene	µg/L	0.5	600	ND
[h]1,3-Dichlorobenzene	µg/L	0.5	75	ND
[h]Dichlorodifluoromethane	µg/L	0.5	0.5	ND
[h]1,1-Dichloroethane	µg/L	0.5	0.5	ND
[h]1,2-Dichloroethane	µg/L	0.5	5.0	ND
[h]1,1-Dichloroethene	µg/L	0.5	7.0	ND
[h]cis-1,2-Dichloroethene	µg/L	0.5	70	ND
[h]trans-1,2-Dichloroethene	µg/L	0.5	100	ND
[h]1,2-Dichloropropane	µg/L	0.5	5.0	ND
[h]1,3-Dichloropropane	µg/L	0.5	0.5	ND
[h]2,2-Dichloropropane	µg/L	0.5	0.5	ND
[h]1,1-Dichloropropene	µg/L	0.5	0.5	ND
[h]cis-1,3-Dichloropropene	µg/L	0.5	0.5	ND
[h]trans-1,3-Dichloropropene	µg/L	0.5	0.5	ND
[h]Ethylbenzene	µg/L	0.5	70	ND
[h]Hexachlorobutadiene	µg/L	0.5	0.5	ND
[h]Isoproylbenzene	µg/L	0.5	0.5	ND
[h]4-Isopropyltoluene	µg/L	0.5	0.5	ND
[h]Methylene chloride	µg/L	0.5	5.0	ND
[h]Naphthalene	µg/L	0.5	0.5	ND
[h]Propylbenzene	µg/L	0.5	0.5	ND
[h]Styrene	µg/L	0.5	100	ND
[h]1,1,1,2-Tetrachloroethane	µg/L	0.5	0.5	ND
[h]1,1,2,2-Tetrachloroethane	µg/L	0.5	0.5	ND

Table continued on next page

Table 32. Non-radiological Constituents in Water Sample from Brantley Lake (Continued)

[a]Analyte	Unit	[b]DL	[c]RL	[d]Measurement
[h]Tetrachloroethene	µg/L	0.5	5.0	ND
[h]Toluene	µg/L	0.5	1000	1.1
[h]1,2,3-Trichlorobenzene	µg/L	0.5	0.5	ND
[h]1,2,4-Trichlorobenzene	µg/L	0.5	70	ND
[h]1,1,1-Trichloroethane	µg/L	0.5	200	ND
[h]1,1,2-Trichloroethane	µg/L	0.5	5.0	ND
[h]Trichloroethene	µg/L	0.5	5.0	ND
[h]Trichlorofluoromethane	µg/L	0.5	0.5	ND
[h]1,2,3-Trichloropropane	µg/L	0.5	0.5	ND
[h]1,2,4-Trimethylbenzene	µg/L	0.5	0.5	ND
[h]1,3,5-Trimethylbenzene	µg/L	0.5	0.5	ND
[h]Vinyl chloride	µg/L	0.5	2.0	ND
[h]Xylenes	µg/L	0.5	10000	ND
[i]1,2-Dibromoethane	µg/L	0.01	0.01	ND
[i]1,2-Dibromo-3-Chloropropane	µg/L	0.01	0.01	ND
[j]Alachlor	µg/L	0.225	2.0	ND
[j]Aldrin	µg/L	0.09	0.09	ND
[j]Chlordane	µg/L	0.6	2.0	ND
[j]Dieldrin	µg/L	0.04	0.04	ND
[j]Endrin	µg/L	0.063	2.0	ND
[j]Heptachlor	µg/L	0.094	0.4	ND
[j]Heptachlor Epoxide	µg/L	0.067	0.2	ND
[j]Hexachlorobenzene	µg/L	0.02	1.0	ND
[j]Lindane	µg/L	0.03	0.2	0.07
[j]Methoxychlor	µg/L	0.96	40.0	ND
[j]Toxaphene	µg/L	1.0	3.0	ND
[j]Aroclor 1016	µg/L	0.08	0.5	ND
[j]Aroclor 1221	µg/L	3.0	0.5	ND
[j]Arochlor 1232	µg/L	0.10	0.5	ND
[j]Arochlor 1242	µg/L	0.10	0.5	ND
[j]Arochlor 1248	µg/L	0.13	0.5	ND
[j]Arochlor 1254	µg/L	0.10	0.5	ND
[j]Arochlor 1260	µg/L	0.14	0.5	ND
[j]Hexachlorocyclopentadiene	µg/L	0.05	50.0	ND
[k]2,4-D	µg/L	10.0	70.0	ND
[k]2,4,5-TP(Silvex)	µg/L	1.0	50.0	ND
[k]Dicamba	µg/L	2.0	2.0	ND

Table continued on next page

Table 32. Non-radiological Constituents in Water Sample from Brantley Lake (Continued)

[a]Analyte	Unit	[b]DL	[c]RL	[d]Measurement
[k]Dinoseb	µg/L	2.0	7.0	ND
[k]Pentachlorophenol	µg/L	1.0	1.0	ND
[k]Picloram	µg/L	20.0	500.0	ND
[l]Dalapon	µg/L	10.0	200	ND
[m]3-Hydroxycarbofuran	µg/L	5.0	5.0	ND
[m]Aldicarb	µg/L	0.5	0.5	ND
[m]Aldicarb Sulfone	µg/L	1.0	1.0	ND
[m]Aldicarb Sulfoxide	µg/L	0.5	0.5	ND
[m]Baygon	µg/L	1.0	1.0	ND
[m]Carbaryl	µg/L	5.0	5.0	ND
[m]Carbofuran	µg/L	1.0	40.0	ND
[m]Methiocarb	µg/L	0.5	0.5	ND
[m]Methomyl	µg/L	5.0	5.0	ND
[m]Oxamyl	µg/L	5.0	200.0	ND
[n]Glyphosate	µg/L	5.0	700	ND
[o]Endothall	µg/L	25.0	100.0	ND
[p]Diquat	µg/L	1.0	20.0	ND
[q]Atrizine	µg/L	9.2	3.0	ND
[q]Butachlor	µg/L	0.2	0.2	ND
[q]Di(2-ethylhexyl)adipate	µg/L	2.0	400.0	ND
[q]Di(2-ethylhexyl)phthalate	µg/L	2.0	6.0	ND
[q]Hexachlorocyclopentadiene	µg/L	0.2	0.2	ND
[q]Metribuzin	µg/L	0.2	0.2	ND
[q]Metolachlor	µg/L	0.2	0.2	ND
[q]Propachlor	µg/L	0.3	0.3	ND
[q]Simazine	µg/L	0.2	4.0	ND
[q]Benzo(a)pyrene	µg/L	0.2	0.2	ND
[r]Nitrate/nitrite as N	mg/L	0.5	10/1.0	0.33
[s]Ammonium as nitrogen	mg/L	0.01		0.23
[t]Water Kjeldahl Nitrogen	mg/L	0.1		0.78
[u]Total phosphorus	mg/L	0.05		ND
[v]Calcium (for SAR)	meq/L	0.01		21.26
[v]Magnesium (for SAR)	meq/L	0.01	125	10.95
[w]Alkalinity (as $CaCO_3$)	mg/L	1		115.0
[w]Carbonate	meq/L	0.01	350	0.00
[w]Carbonate alkalinity	mg/L	1		0.0
[w]Bicarbonate	meq/L	0.01	700	2.30
[w]Bicarbonate alkalinity	mg/L	1		140.3

Table continued on next page

Table 32. Non-radiological Constituents in Water Sample from Brantley Lake (Continued)

[a]Analyte	Unit	[b]DL	[c]RL	[d]Measurement
[x]Hardness as $CaCO_3$	mg/L	0.1		1610
[y]Chloride by autoanalyzer	mg/L	12.5	250	1162.0
[z]Fluoride by electrode	mg/L	0.05	2.0	0.77
[aa]Sulfate	mg/L	20	250	1137
[bb]Platinum-Cobalt color		5	15	1.0
[cc]Electrical Conductivity	mohm/cm	1		4480
[dd]pH of water			6.5-8.5	7.83
Total Dissolved Solids	mg/L	1	500	4012
Total Suspended Solids	mg/L	1		15

[a] Analyses reported were conducted on a sample of Brantley Lake surface water collected on April 1, 1997

[b] DL=Detection Limit; the smallest concentration or amount of some component of interest that can be measured by a single measurement with a stated level of confidence

[c] RL = Reference Level; levels adopted as limits or guidelines under various state and federal regulatory programs; water from Brantley Lake is not used as a source of community drinking water, and is not subject to regulation under the Safe Drinking Water Act

[d] Sample collected at a single location near Brantley Lake Dam; consisting of subsamples from surface to near lake bottom at depth of >10m.

[e] Measured by EPA Method 200.8

[f] by ICP, Measured by EPA Method 200.7

[g] SW846-8270

[h] Measured by EPA Method 502.2

[i] Measured by EPA Method 504

[j] Measured by EPA Method 505

[k] Measured by EPA Method 515.2

[l] Measured by EPA Method 552.1

[m] Measured by EPA Method 531.1

[n] Measured by EPA Method 547

[o] Measured by EPA Method 548.1

[p] Measured by EPA Method 549.1

[q] Measured by EPA Method 525.2

[r] Measured by EPA Method 353.2

[s] Measured by EPA Method 350.1

[t] Measured by EPA Method 351.2

[u] Measured by EPA Method 365.2

[v] Measured by EPA Method 200

[w] Measured by EPA Method 310.1

[x] Measured by EPA Method 130.2

[y] Measured by EPA Method 325.2

[z] Measured by EPA Method 340.2

[aa] Measured by EPA Method 375.2

[bb] Measured by EPA Method 110.2

[cc] Measured by EPA Method 120.1

[dd] Measured by EPA Method 150.1

Radionuclides in Selected Plant Species

Methods

Vegetation samples were collected during May, 1997 from six locations in the vicinity of the WIPP (Figure 2). Samples of three grass species were collected for analyses of radionuclide activity concentrations, including *Sporobolus flexuosus* (mesa dropseed), *Paspalum stramineum* (sand paspalum), and *Leptoloma cognatum* (fall witch grass). These species are known to be preferred by livestock for consumption on the open range (Personal communication, S. Daly, Soil Conservationist, U.S. Bureau of Land Management, Carlsbad Area Office). Approximately 100-500 g (dry weight) of each species were collected at each of the six locations. The samples were collected by enclosing the upper plant parts inside a plastic bag, then cutting the plants near the soil surface using metal clippers. This method was used to retain as much as possible of the dust adhering to the leaf and stem surfaces as part of the sample. The samples were dried at 105° C for 24 to 48 hours, weighed, and then the vegetative material was cut with metal scissors into smaller pieces to facilitate placing in the vegetation containers for further processing. The samples were ashed in a muffle furnace, first at 500° C for at least four hours to reduce the volume, and then at 800° C for at least 12 hours.

Prior to analyses of gamma-emitting radionuclides, the ashed vegetation samples were digested with HF, HCl and HNO_3. Gamma-emission counts were conducted with a 3-L Marinelli beaker of vegetation, using a high-purity Ge detector coupled with a multi-channel analyzer, with counting times of 72 hr. To isolate alpha-emitting radionuclides, the ashed samples were treated as described for soil samples (p. 51). Mean MDCs for actinides in vegetation samples were determined to be 1.21 μBq g^{-1} for ^{239,240}Pu, 1.9 μBq g^{-1} for ^{230}Th, 1.4 μBq g^{-1} for ^{232}Th, 2.2 μBq g^{-1} ^{234}U, and 2.6 μBq g^{-1} ^{238}U. Average yields were 30% for ^{239,240}Pu, ^{230}Th, and ^{232}Th, and 60% for ^{234,238}U. One chemical blank was used to establish background levels for the analyses of the vegetation samples.

Activity concentrations for two radionuclides, ^{239,240}Pu and ^{40}K, were compared between species across the six locations using an analysis of variance (AOV), with logarithmic data transformation due to unequal variances among sample groups.

Results

Activity concentrations were highly variable among and within the three plant species (Tables 33 and 34). Unwashed plants were used for this analysis because their activity concentrations represent the levels of radionuclides important to the uptake of the contaminants by livestock or other grazing animals. High variability in the data is expected because the degree of surface contamination can vary greatly due to local conditions and recent weather conditions.

The actinides (U, Th, and Pu) are generally insoluble and have low rates of root uptake, although U is taken up by some plant species to a greater extent than Th or Pu exposure (Whicker, F. W. and V. Schultz, 1982, *Radioecology: Nuclear Energy and the Environment* 1, CRC Press, Inc., Florida). Hence, much of the variability in the actinide concentrations in the plants is expected to be due to variability in the surface concentrations of soil on the plants. U had the greatest coefficient of variation in *P. stramineum* and *S. flexuosus,* but was similar to the variability of Th and Pu in *L. cognatum.* The AOV revealed no significant differences among the species in their concentrations of ^{239,240}Pu (Table 35).

^{40}K was detected in all samples. Furthermore, the ratio of ^{40}K to ^{239,240}Pu in plants was approximately 1.8 times greater than the ratio in soil (Table 22), which is probably due to the uptake and incorporation of ^{40}K into tissues. ^{40}K had the lowest coefficient of variation in all 3 species, which is probably due to the fact that K is an essential nutrient for plants. ^{40}K typically constitutes about 0.0119% of the mass of K in the environment and is responsible for a large fraction of the total background radiation exposure (Whicker, F. W. and V. Schultz, 1982, *Radioecology: Nuclear Energy and the Environment* 1, CRC Press, Inc., Florida). There is very little biological discrimination between ^{40}K and stable K. Hence, biota will tend to regulate the levels of ^{40}K in their tissues to the same degree they regulate stable K. The AOV revealed no significant differences among the species in their concentrations of ^{40}K (Table 35).

^{137}Cs was detected in only 1 sample. The ratio of ^{137}Cs activity concentration in plants to ^{137}Cs activity concentration in soils has been shown in other studies to be about 0.010 (Whicker, F. W. and T. B. Kirchner, 1987, *Health Physics* 52, 717). Using the mean activity concentrations of ^{137}Cs in soil (Table 22), the ^{137}Cs associated with plants would be expected to be about 0.045 mBq g^{-1}, which is below the MDC for ^{137}Cs in this study. Assuming the ratio of ^{137}Cs to ^{239,240}Pu in the plant surface contamination would be equal to the ratio of ^{137}Cs to ^{239,240}Pu in the soil, then the expected activity concentration would range from 0.05 - 0.1 mBq g^{-1}, which is also just below the MDC for ^{137}Cs. Thus, it may be possible to detect ^{137}Cs in plants, if the methodology for extracting and counting ^{137}Cs could be slightly improved.

^{137}Cs is of interest because it is a chemical analog of K and can often be used as a tracer for K in biological transport processes. On one hand, ^{137}Cs is often retained in tissues longer than is K, and hence is subject to biological concentration, i.e. an increase in the ratio of ^{137}Cs to ^{40}K. On the other hand, ^{137}Cs tends to bind to clay in soil, so that soil can reduce the bio-availability of ^{137}Cs as compared to ^{40}K, and thus can act as a sink for ^{137}Cs exposure (Whicker, F. W. and V. Schultz, 1982, *Radioecology: Nuclear Energy and the Environment* 1, CRC Press, Inc., Florida). The presence in the study areas of sandy soils with a low clay content would normally suggest that ^{137}Cs would remain available for biological uptake, as has been observed in other areas having sandy soils. If ^{137}Cs were tightly bound to the soils, then one would expect the ratio of ^{137}Cs to ^{230,232}Th or ^{239,240}Pu in the plants would match those found in the soil, since the activity of ^{230,232}Th and ^{239,240}Pu in the plant samples is expected to be associated with leaf surface contamination.

Table 33. Radionuclide Activity Concentrations in Spring Vegetation Samples

		Vegetation Species								
		Paspalum stramineum			***Leptoloma cognatum***			***Sporobolus flexuosus***		
Radionuclide	**[a]Location**	**[b]Activity Concentration (Bq g^{-1})**	**[c]SD (Bq g^{-1})**	**[d]MDC (Bq g^{-1})**	**Activity Concentration (Bq g^{-1})**	**SD (Bq g^{-1})**	**MDC (Bq g^{-1})**	**Activity Concentration (Bq g^{-1})**	**SD (Bq g^{-1})**	**MDC (Bq g^{-1})**
^{137}Cs	A1	[e]<MDC		5.08E-4	<MDC		4.08E-4	<MDC		1.40E-4
	A5	<MDC		9.73E-4	<MDC		2.63E-4	<MDC		3.11E-4
	A8	<MDC		3.88E-4	<MDC		4.57E-4	<MDC		3.32E-4
	B1	<MDC		7.68E-4	<MDC		3.04E-4	<MDC		2.60E-4
	B2	<MDC		2.20E-4	3.63E-4	8.57E-5	1.63E-4	<MDC		1.09E-4
	B6	<MDC		3.91E-4	<MDC		2.78E-4	<MDC		1.16E-4
^{40}K	A1	3.51E-1	1.54E-2	5.63E-3	2.14E-1	7.88E-3	4.51E-3	1.12E-1	4.28E-3	2.28E-3
	A5	1.72E-1	9.07E-3	1.06E-2	5.44E-2	2.65E-3	2.82E-3	9.87E-2	4.04E-3	3.08E-3
	A8	2.44E-1	8.68E-3	4.11E-3	3.10E-1	1.15E-2	4.97E-3	1.47E-1	5.57E-3	3.55E-3
	B1	2.14E-1	9.37E-3	8.78E-3	1.85E-1	6.97E-3	3.32E-3	1.49E-1	5.37E-3	2.74E-3
	B2	4.42E-2	2.73E-3	3.52E-3	1.32E-1	4.87E-3	1.97E-3	5.16E-2	2.22E-3	1.71E-3
	B6	9.97E-2	5.22E-3	4.11E-3	1.02E-1	4.75E-3	4.37E-3	4.59E-2	2.09E-3	1.84E-3
^{239,240}Pu	A1	7.5E-6	1.1E-6	1.2E-6	9.0E-6	1.2E-6	8.3E-7	1.1E-6	2.7E-7	1.9E-7
	A5	1.2E-5	2.6E-6	3.8E-6	<MDC		2.7E-6	2.2E-6	5.5E-7	3.7E-7
	A8	3.0E-6	1.3E-6	1.3E-6	2.3E-6	7.5E-7	5.9E-7	8.3E-7	3.1E-7	6.7E-7
	B1	8.6E-6	1.8E-6	2.0E-6	1.0E-5	1.4E-6	8.6E-7	3.1E-6	7.4E-7	1.0E-6
	B2	1.9E-6	7.8E-7	1.6E-6	1.3E-5	1.4E-6	7.6E-7	8.6E-6	1.1E-6	7.7E-7
	B6	1.3E-6	4.0E-7	6.7E-7	2.4E-6	7.2E-7	1.3E-6	4.9E-6	1.0E-6	1.1E-6
^{230}Th	A1	1.3E-4	3.3E-6	2.7E-7	3.3E-4	2.1E-5	4.1E-6	1.2E-4	6.0E-6	1.3E-6
	A5	4.4E-4	2.7E-5	7.7E-6	5.4E-5	4.0E-6	1.8E-6	4.2E-4	2.4E-5	2.2E-6
	A8	1.3E-4	3.9E-6	7.7E-7	6.6E-4	3.6E-5	3.8E-6	2.7E-5	5.2E-7	1.5E-7
	B1	5.8E-4	3.5E-5	3.7E-6	2.3E-4	9.4E-6	2.1E-6	2.9E-4	1.8E-5	1.3E-6
	B2	8.0E-5	5.3E-6	1.4E-6	6.3E-4	4.0E-5	1.2E-6	5.0E-5	1.2E-6	8.6E-8
	B6	1.8E-4	9.6E-6	1.5E-6	7.6E-5	8.2E-6	9.9E-7	1.6E-4	1.5E-5	6.3E-7
^{232}Th	A1	1.8E-4	4.3E-6	5.1E-8	3.8E-4	2.5E-5	2.0E-6	1.2E-4	6.1E-6	5.8E-6
	A5	4.5E-4	2.8E-5	2.5E-6	5.0E-5	3.7E-6	1.5E-6	4.2E-4	2.4E-5	1.0E-6
	A8	1.5E-4	4.2E-6	4.0E-7	6.9E-4	3.8E-5	1.9E-6	2.7E-5	5.2E-7	9.2E-8
	B1	6.3E-4	3.7E-5	3.1E-6	5.8E-5	4.3E-6	1.7E-6	3.0E-4	1.8E-5	1.1E-6
	B2	8.0E-5	5.2E-6	1.4E-6	7.0E-4	4.3E-5	5.5E-7	6.8E-5	1.0E-6	7.8E-8
	B6	1.9E-4	9.8E-6	1.3E-6	7.8E-5	3.6E-6	8.9E-7	1.6E-4	1.5E-5	8.4E-7
^{234}U	A1	4.6E-5	2.7E-6	1.1E-7	2.3E-5	2.3E-6	8.6E-7	5.0E-5	6.2E-6	2.2E-6
	A5	5.3E-5	3.3E-6	3.4E-7	2.9E-4	2.7E-5	1.3E-6	1.0E-5	6.2E-7	6.7E-8
	A8	4.3E-4	3.6E-5	8.8E-7	6.3E-5	6.4E-6	1.1E-6	1.4E-5	9.3E-7	1.3E-7
	B1	4.7E-4	4.1E-5	2.9E-6	1.4E-4	4.4E-5	1.1E-5	2.7E-4	2.9E-5	2.8E-6
	B2	1.1E-4	1.1E-5	2.2E-6	3.4E-5	7.0E-6	2.8E-6	2.8E-4	2.1E-5	3.2E-7
	B6	2.9E-5	2.5E-6	3.4E-7	1.1E-4	2.0E-5	8.2E-6	2.8E-5	4.2E-6	2.5E-6

Table continued on next page

Table 33. Radionuclide Activity Concentrations in Spring Vegetation Samples (Continued)

		Vegetation Species								
		Paspalum stramineum			*Leptoloma cognatum*			*Sporobolus flexuosus*		
Radionuclide	[a]Location	[b]Activity Concentration (Bq g^{-1})	[c]SD (Bq g^{-1})	[d]MDC (Bq g^{-1})	Activity Concentration (Bq g^{-1})	SD (Bq g^{-1})	MDC (Bq g^{-1})	Activity Concentration (Bq g^{-1})	SD (Bq g^{-1})	MDC (Bq g^{-1})
^{238}U	A1	5.1E-5	2.8E-6	4.2E-8	2.4E-5	2.5E-6	8.6E-7	4.3E-5	5.4E-6	2.8E-6
	A5	4.8E-5	3.0E-6	1.2E-7	2.8E-4	2.7E-5	8.8E-7	9.5E-6	1.0E-6	7.3E-8
	A8	4.5E-4	3.7E-5	2.3E-6	6.3E-5	6.5E-6	1.2E-6	1.4E-5	9.2E-7	1.3E-7
	B1	4.6E-4	4.1E-5	2.5E-6	1.3E-4	4.4E-5	1.6E-5	2.5E-4	2.9E-5	2.7E-6
	B2	1.2E-4	1.3E-5	5.5E-7	2.6E-5	5.9E-6	4.1E-6	2.6E-4	2.1E-5	7.5E-7
	B6	2.6E-5	2.3E-6	4.5E-7	9.8E-5	1.8E-5	9.2E-6	2.6E-5	3.9E-6	1.7E-6

[a] Locations of vegetation collection as shown in Figure 2

[b] Activity Concentrations as defined in Appendix K, per unit dry vegetation mass; values are rounded to two significant figures for radionuclides measured by alpha spectrometry; values are rounded to three significant figures for radionuclides measured by gamma spectroscopy

[c] SD = Count Standard Deviation as defined in Appendix K, per unit dry vegetation mass

[d] MDC = Minimum Detectable Activity Concentration; see Appendix K, per unit dry vegetation mass

[e] <MDC = Observed activity concentration was below MDC

Table 34. Summary Statistics for Radionuclide Activity Concentrations in Spring Vegetation Samples

			Activity Concentration (Bq g^{-1})				
Species	**Radionuclide**	**[b]N**	**[c]Mean**	**[d]SE**	**Minimum**	**Maximum**	**[e]CV (%)**
Paspalum stramineum	^{137}Cs	0	[f]ND				
	^{40}K	6	1.88E-1	4.44E-2	4.42E-2	3.51E-1	58
	^{239,240}Pu	6	5.7E-6	1.7E-6	1.3E-6	1.2E-5	74
	^{230}Th	6	2.6E-4	8.3E-5	8.0E-5	5.8E-4	79
	^{232}Th	6	2.8E-4	8.7E-5	8.0E-5	6.3E-4	76
	^{234}U	6	1.9E-4	8.4E-5	2.9E-5	4.7E-4	108
	^{238}U	6	1.9E-4	8.5E-5	2.6E-5	4.6E-4	107
Leptoloma cognatum	^{137}Cs	1	3.63E-4		3.63E-4	3.63E-4	
	^{40}K	6	1.66E-1	3.7E-2	5.44E-2	3.10E-1	55
	^{239,240}Pu	5	7.4E-6	2.2E-6	2.3E-6	1.3E-5	65
	^{230}Th	6	3.3E-4	1.1E-4	5.4E-5	6.6E-4	80
	^{232}Th	6	3.3E-4	1.3E-4	5.0E-5	7.0E-4	96
	^{234}U	6	1.1E-4	4.0E-5	2.3E-5	2.9E-4	90
	^{238}U	6	1.0E-4	4.0E-5	2.4E-5	2.8E-4	93
Sporobolus flexuosus	^{137}Cs	0	ND				
	^{40}K	6	1.01E-1	1.82E-2	4.59E-2	1.49E-1	44
	^{239,240}Pu	6	3.4E-6	1.2E-6	8.3E-7	8.6E-6	85
	^{230}Th	6	1.8E-4	6.3E-5	2.7E-5	4.2E-4	86
	^{232}Th	6	1.8E-4	6.2E-5	2.7E-5	4.2E-4	82
	^{234}U	6	1.1E-4	5.2E-5	1.0E-5	2.8E-4	119
	^{238}U	6	1.0E-5	4.9E-5	9.5E-6	2.6E-4	120

[a] Calculated statistics do no include samples with activity concentrations <MDC; mean, SE, minimum and maximum are rounded to two significant figures for radionuclides measured by alpha spectrometry; mean, SE, minimum and maximum are rounded to three significant figures for radionuclides measured by gamma spectroscopy

[b] N = number of samples included in calculations

[c] Mean = arithmetic mean

[d] SE = standard error of mean

[e] CV = coefficient of variation; standard deviation expressed as percentage of the mean; CVs may reflect small rounding error

[f] ND = Not Detected; all measurements of specific radionuclide in this species were <MDC

Table 35. Results of Analyses of Variance for Activity Concentrations of Radionuclides in Spring Vegetation Samples

Radionuclide	Source	[a]df	[b]SS	[c]F	[d]P
^{239}Pu	Species	2	2.02	1.32	0.2987
	Error	14	10.70		
	Corrected total	16	12.72		
^{40}K	Species	2	1.00	1.26	0.3116
	Error	15	5.95		
	Corrected total	17	6.95		

[a] df = degrees of freedom

[b] SS = Sum of Squares

[c] F = ratio of mean square of source term to mean square of error term

[d] P = probability of greater value of F due to random chance

In Vivo Measurement Sensitivity and Occurrence of Radionuclides in Residents of the Carlsbad, New Mexico Area

Methods

Citizen volunteers from the Carlsbad, New Mexico area were monitored for internally deposited radionuclides through a project entitled 'Lie Down and be Counted' (Appendix I). This project is provided as an outreach service to the public to support education about naturally occurring and man-made radioactivity present in the environment prior to the opening of the Waste Isolation Pilot Plant (WIPP). In addition, information obtained from these measurements will be used to evaluate and improve upon the uncertainties associated with bioassay methodologies. It is important to note that these data represent an interim summary of an ongoing study.

Following the commissioning of the Center's *in vivo* monitoring facility, 81 citizen volunteers were measured during July to September 1997. The measurements were conducted to identify internally deposited radionuclides in lungs and the whole body. Each examination lasted 1800 s and employed the measurement geometry described in the Internal Dosimetry program description (p. 6). Chestwall thickness, used to correct for photon attenuation by tissue overlying the lungs, was estimated from physical parameters as described in the Internal Dosimetry Technical Basis Manual for the Center's Internal Dosimetry program. Spectral analyses were performed using the software package ABACOS® Plus from Canberra Industries. Radionuclides of interest (Table 36) were identified from review of the WIPP Safety Analysis Report (DOE/WIPP-95-2065, 1995) and the Internal Dosimetry Technical Basis Document for the WIPP (DOE/WIPP-96-2196, 1996). In addition, the naturally occurring radionuclide ^{40}K was also monitored.

Two important parameters when interpreting bioassay data are Minimum Detectable Amount (MDA) and Decision Level (L_C). The value of MDA indicates the ability of a facility to detect a radionuclide in a person. The MDA represents the amount of a radionuclide that, if present, would be detected 95% of the time under routine operation of a facility. The MDA is used to measure the efficacy of a facility and should not be used to decide if a specific radiobioassay has or has not detected activity within a person (HPS N13.30, Performance Criteria for Radiobioassay, May 1996).

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 resulting 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. It is important to note that use of this criterion will result in a statistically inherent 5% false positive error rate (5% of all measurements will be determined to be positive when there is no true activity in the person).

MDA and L_C were calculated using the following equations, respectively (HPS N13.30, Performance Criteria for Radiobioassay, May 1996):

$$MDA = \frac{\left(1+\Delta_K\right)\left(2\Delta_B B + 3.29 s_0 + 3\right)}{KT} \qquad \text{(equation 1)}$$

where:

Δ_K = maximum fractional systematic error bound in the calibration factor K
Δ_B = maximum expected fractional systematic error bound in the appropriate blank
B = total count for the appropriate blank
S_0 = standard deviation in the net count of a subject with no internal deposition
K = calibration factor including self absorption and gamma yield
T = standard subject counting time

and

$$L_C = 1.65\sqrt{2S_B^2} \qquad \text{(equation 2)}$$

where:

S_B^2 = variance in the background count of a subject with no internal deposition

The parameter B was estimated from 10 replicated counts of a BOMAB phantom filled with H_20 and reference man levels of KCl (265 g). For the MDA calculation, S_0 was multiplied by $\sqrt{2}$ because it was assumed that the variance in the BOMAB counts would underestimate the true variance in an unexposed population by a factor of two. The parameters Δ_K and Δ_B where assumed to be 0.10 and 0.05, respectively (HPS N1330, Performance Criteria for Radiobioassay, May 1996). For lung counts, the value of K was selected for a chestwall thickness of 2.4 cm and a composition of 50% muscle and 50% adipose. The parameter S_B^2 was estimated from the Compton continuum before and after the peak region of interest using a step algorithm provided with the Genie VMS spectroscopy system (Genie VMS V4.0, 1995, Canberra Industries).

Results

MDA's for the radionuclides of interest ranged from 3.7 to 2410 Bq (Table 37) and are consistent with values typically reported in the literature. Results for ^{60}Co have been excluded because of slight ^{60}Co contamination in the shield's internal liner. This liner is scheduled for replacement during 1998. For all radionuclides except ^{137}Cs and ^{40}K, no values greater than MDA were observed (Table 37). One observation for ^{137}Cs and all observations for ^{40}K were greater than MDA.

The number of results greater than L_C for each individual radionuclide (excluding ^{40}K where all results were greater than L_C) ranged from 1 to 20 of the 81 persons counted (Table 38). For all radionuclides, excluding ^{137}Cs and ^{40}K, the number of results greater than L_C were consistent with a random false positive error rate of 5%, suggesting no detectable occurrence of these radionuclides in citizens living in the Carlsbad area. For example, with a sample size of 81 and a false positive error rate of 5%, between 1 and 8 false positive results would be expected at a 95% confidence level, with no detectable activity present in the person.

^{40}K values ranged from 2070 to 4770 Bq with an overall mean (±SD) of 3070 ± 70 Bq (N = 81). Such results are expected since K is an essential biological element contained primarily in muscle, and a constant fraction of all naturally occurring K is the radioactive isotope ^{40}K. The mean ^{40}K value for males (±SE), was 3520 ± 74 Bq (N = 47), which was significantly greater ($P < 0.01$) than that of females, 2410 ± 37 Bq (mean ± SE, N = 35).

In 20 individual measurements, the value for ^{137}Cs was greater than L_C, ranging from 6 to 18 Bq. The frequency of this occurrence is much greater than that expected from random error ($P < 0.0001$) suggesting an occurrence of detectable ^{137}Cs in 15% to 35% (95% confidence level) of citizens living in the Carlsbad area (Hahn, J. and W.Q. Meeker, 1991, *Statistical Intervals A Guide for Practitioners*, John Wiley & Sons, Inc. New York). These results are not unexpected since ^{137}Cs is an abundant, long-lived fission product. Because of its abundance, mobility, and physiological properties, ^{137}Cs is widely distributed throughout the biosphere. ^{137}Cs has been detected previously in many organisms including humans (Whicker, F.W. and V. Schultz, 1982, *Radioecology: Nuclear Energy and the Environment* 1, CRC Press, Inc., Florida).

Table 36. Radionuclides of Interest for "Lie Down and Be Counted" Project

In Vivo Measurement Type	Radionuclides of Interest
Lung	^{252}Cf, ^{244}Cm, ^{241}Am, $^{238, 239, 240, 242}$Pu, ^{237}Np, $^{233, 234, 235, 238}$U, $^{228, 232}$Th
Whole Body	$^{152, 154, 155}$Eu, ^{144}Ce, ^{125}Sb, ^{137}Cs, ^{106}Ru, ^{60}Co, ^{40}K

Table 37. MDAs for In Vivo Monitoring Facility for a Routine Lung and Whole Body Count.

Radionuclide	Minimum Detectable Amount (Bq)	Organ
^{252}Cf	560	Lung
^{244}Cm	930	Lung
^{241}Am	4	Lung
^{238}Pu	930	Lung
^{239}Pu	2410	Lung
^{240}Pu	930	Lung
^{242}Pu	1100	Lung
^{233}U	110	Lung
^{234}U	890	Lung
^{235}U	4	Lung
^{238}U	1370	Lung
^{237}Np	10	Lung
^{228}Th	7	Lung
^{232}Th	1150	Lung
^{144}Ce	10	Whole Body
^{152}Eu	60	Whole Body
^{154}Eu	40	Whole Body
^{155}Eu	110	Whole Body
^{125}Sb	60	Whole Body
^{106}Ru	1330	Whole Body
^{40}K	70	Whole Body
^{137}Cs	10	Whole Body

Table 38. Number of Individual Count Results Greater than L_C

Radionuclide	[a]Results > L_C	% Results > L_C
^{241}Am	7	8.6
^{252}Cf	3	3.7
^{244}Cm	4	4.9
$^{(b)\ 238,\ 239,\ 240,\ 242}$Pu	3	3.7
^{233}U	4	4.9
$^{(b)\ 238,\ 234}$U	9	11.1
^{235}U	5	6.2
^{237}Np	5	6.2
$^{(b)\ 228,\ 232}$Th	1	1.2
^{144}Ce	4	4.9
^{152}Eu	4	4.9
^{154}Eu	4	4.9
^{155}Eu	1	1.2
^{137}Cs	20	24.7
^{125}Sb	3	3.7
^{106}Ru	6	7.4
^{40}K	81	100

[a] Between 1 and 8 results greater than L_C are expected even when no measurable internal deposition is present.

[b] Analytical method cannot distinguish between isotopes.

APPENDICES

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

The Carlsbad Environmental Monitoring & Research Center (Center) 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 Center was conceived by a grassroots coalition recognizing the need for high quality, independent health and environmental assessment. Many individuals and organizations supported the Center'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 Center 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. Donald J. Fingleton served as Director of the Center during 1991-1996, and was responsible primarily for program management during that time. In 1996, Dr. Fingleton was named Director of Laboratory Development and assumed management responsibility for marketing of the Center's capabilities to develop additional research funding. Management of the Center's scientific program, fiscal affairs, and human resources was transferred to Dr. Marsha Conley, Director of Operations. Dr. Fingleton was transferred to a position with WERC in 1997.

Temporary office accommodations for the Center initially were provided at NMSU-Carlsbad. In 1992, the Center moved to a leased facility at 800 West Pierce in Carlsbad, which served as a basis for operations through December 1996. This facility provided approximately 7,000 ft^2 of space, which allowed expansion of staffing and initial acquisition of laboratory and field equipment.

Flatow Moore Shaffer McCabe Architects (Albuquerque, New Mexico) and Research Facilities Design (San Diego, California) were selected in 1991 to design the Center's new facilities. To meet program objectives, preliminary building designs called for a 53,000 ft^2 building with an associated cost of $22 million. This level of funding was projected from language in the Senate version of the Waste Isolation Pilot Plant Land Withdrawal Act (S. 1671 1991). However, the language subsequently was deleted in conference committee, and other funding alternatives for facility construction were initiated.

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. The design team reassembled to develop a 73,000-square-foot, multi-phased project to meet all objectives within a ten-year period. The first phase of the project was a 25,000 ft^2 building to house the Center's environmental and radiochemistry laboratories, fixed *in vivo* facility, mobile bioassay laboratory (MBL), computing operations, and offices for scientific and administrative staff. 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 Center, a variety of other developmental projects were undertaken to support the Center's scientific activities. In 1993, design began for the MBL that would complement the facilities planned for the new Center 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.

Appendix B. Subcontractors for Scientific Work during 1997

Subcontractor	Scope of Work
Acculabs Research, Inc.	Analyses of soil samples
Argonne National Laboratory	Radiochemical analyses of environmental samples
Desert Research Institute	Trace element analysis with X-ray fluorescence spectrometry
Harvard University	Technical support for development of aerosol sampling equipment
NMSU Physical Sciences Laboratory	Meteorological station usage and technical assistance; development of video and brochure for “Lie Down and Be Counted” project
NMSU Soil Water and Air Testing Laboratory	Analyses of water samples
Kopecky, Kenneth, Ph.D.	Technical review of community health reports
Skrabble, Kenneth, Ph.D.	Technical basis manual for *in vivo* bioassay program
Thein, Myint, Ph.D.	Quality assurance documentation for radiobioassay program

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

Member	Affiliation	Board
O. Doyle Markham, Ph.D.	Director, Environmental Science & Research Foundation, Inc., Idaho Falls, Idaho	PRB
Michael H. Smith, Ph.D.	Director, Savannah River Ecology Laboratory, Aiken, South Carolina	PRB
Thomas Cahill, Ph.D.	Professor (Emeritus), Atmospheric Sciences/Physics, University of California, Davis, Davis, California	SAB
Milan S. Gadd, Ph.D.	Senior Health Physicist, Rocky Flats Environmental Technology Site, Golden, Colorado	SAB
Kenneth G.W. Inn, Ph.D.	Group Leader, Office of Radiation Measurements, Ionizing Radiation Division, Physics Laboratory, National Institute of Standards and Technology, Gaithersburg, MD	SAB
William K. Michener, Ph.D.	Associate Scientist, J.W. Jones Ecological Research Center, Newton, Georgia	SAB
F. Ward Whicker, Ph.D.	Professor, Department of Radiological Health Sciences, Colorado State University, Ft. Collins, Colorado	SAB

Appendix D. Presentations and Publications during 1997

Author	Title	Publisher/Conference
Arimoto, R.	Aerosol measurements	Georgia Institute of Technology, Atlanta, Georgia
Arimoto, R.	Air quality issues	State Key Laboratory of Loess and Quaternary Geology, Xi'an, Peoples Republic of China
Arimoto, R., Y. Gao, M Zhou, D.S. Lee, L. Chen, D. Gu, Z. Wang	Atmospheric deposition of trace elements to the Western Pacific Basin	In Baker, J.E. (Ed.), Atmospheric Deposition of Contaminants to the Great Lakes and Coastal Waters, SETAC Press, Pensacola, Florida, pp. 209-225, 1997
Arimoto, R., R.A. Duce, J.M. Prospero, D.L. Savoie, R.W. Walbot, J.E. Dibb, B.G. Heikes, N.F. Lewis and U. Tomza	Comparisons of trace constituents from ground stations and the DC-8 aircraft during PEM-West B.	Journal of Geophysical Research, 102, 28,539-28,550, 1997
Arimoto, R.	Comparisons of trace constituents from ground stations and the DC-8 aircraft during PEM-West B.	Asia-Pacific Regional Experiment/International Global Atmospheric Chemistry Workshop, Hong Kong
Arimoto, R.	Influences of atmospheric transport pathways on radionuclide activities in aerosol particles from the North Atlantic	International Symposium on Atmospheric Chermistry and Future Global Environment, Nagoya, Japan
Arimoto, R.	Influences of atmospheric transport pathways on radionuclide activities in aerosol particles from the North Atlantic	American Geophysical Union Fall Meeting, San Francisco, California
Arimoto, R., B.J. Ray, N.F. Lewis, U. Tomzw, and R.A. Duce	Mass-particle size distributions of atmospheric dust and the dry deposition of dust to the remote ocean	Journal of Geophysical Research, 102(15), 867-874, 1997
Arimoto, R., J.A. Snow, B.J. Ray, R.A. Duce, W.C. Graustein, and K.K. Turekian	Naturally occurring radionuclides and atmospheric transport over the North Atlantic	American Geophysical Union Fall Meeting, San Francisco, California
Chen, L., G.R. Carmichael, M. Hong, H. Ueda, S. Shim, C.H. Song, Y.P. Kin, R. Arimoto, J. Prospero, D. Savoie, K. Murano, J.K. Park, H. Lee, and C. Kang	Analysis of ground-based measurements at Cheju Island, South Korea	Journal of Geophysical Research 102, 28,551-28,574, 1997
Fingleton, D.J. and S.C. Lee	Environmental monitoring near the WIPP: Building public confidence through independent research	New Mexico Journal of Science 37: 176-190

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Appendix D. Presentations and Publications during 1997 (Continued)

Author	Title	Publisher/Conference
Gao, Y.R., R. Arimoto, R.A. Duce, X.Y. Zhang, G.Y. Zhang, S. An, L.Q. Chen, M.Y. Zhou, and D.Y. Gu	Temporal and spatial distributions of mineral aerosol and its total deposition over continental China and the China Sea	Tellus 49B, 172-189, 1997
Huang, S., K. Rahn, and R. Arimoto	A graphical method for determining the dry-depositional component of aerosol samples and their field blanks	Atmospheric Environment 31, 3383-3394, 1997
Huang, S.R., R. Arimoto, K.A. Rahn, W.C. Graustein, and K.K. Turekian	Seasonal variations of pollution elements and radionuclides in aerosol at Bermuda	American Geophysical Union Fall Meeting, San Francisco, California
Jickells, T.D., S. Dorling, W.G. Deuser, T.M. Church, R. Arimoto, and J. Prospero	Air-borne dust fluxes to a deep water sediment trap in the Sargasso Sea	Global Biogeochemical Cycles, in press
Kirchner, T.B.	Distributed processing and simulation modeling	Simulation Practice and Theory 5, 35-47, 1997
Kirchner, T.B.	Time, space, variability and uncertainty	Risk Assessment: Logic and Measurement Symposium, Savannah River Ecology Laboratory, Aiken, South Carolina
Kirchner, T.B.	Uncertainty analysis	Workshop on Calculating and Understanding Risks from Radionuclides Released to the Environment, Radiological Assessments Corporation, Santa Fe, New Mexico
Lee, S.C., K.A. Orlandini, J. Webb, D. Schoep, T. Kirchner, and D.J. Fingleton	Measurement of baseline atmospheric plutonium-239,240 and americium-241 in the vicinity of the Waste Isolation Pilot Plant	4th International Conference on Methods and Applications of Radioanalytical Chemistry, Kona, Hawaii
Lee, S.C., K.A. Orlandini, J. Webb, D. Schoep, T. Kirchner, and D.J. Fingleton	Measurement of baseline atmospheric plutonium-239,240 and americium-241 in the vicinity of the Waste Isolation Pilot Plant	Journal of Radioanalytical and Nuclear Chemistry, accepted pending revisions

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Appendix D. Presentations and Publications during 1997 (Continued)

Author	Title	Publisher/Conference
Maung, O. and S.C. Lee	Radioanalytical measurements of Pu and Am by CEMRC	1st Users Group Meeting, Radiochemistry Intercomparison Program, Carlsbad, New Mexico.
Michener, W.K., J.W. Brunt, J. Helly, T.B. Kirchner and S.G. Stafford	Non-geospatial metadata for the ecological sciences	Ecological Applications 7, 330-342, 1997
Peterson, S.R. and T.B. Kirchner	Data quality and validation of radiological assessment models	Health Physics, in press
Prospero, J.M. and R. Arimoto	Temporal and spatial variations in mineral aerosol concentrations in the AEROCE network	American Geophysical Union Fall Meeting San Francisco, California
Sioutas, C., S.T. Ferguson, J.M. Wolfson, H. Ozkaynak, and P. Koutrakis	Inertial collection of fine particles using a high-volume rectangular geometry conventional impactor.	Journal of Aerosol Science 28(6), 1015-1028 (work conducted under CEMRC support)
Snow, J.A., J.T. Merrill, R. Arimoto, and J.L. Moody	Cluster analysis of transport of aerosol Al and Sb to Bermuda	American Geophysical Union Fall Meeting, San Francisco, California
Tomza, U., R. Arimoto, S. Huang, and B.J. Ray	What can we learn from the color of an air filter?	American Geophysical Union Fall Meeting, San Francisco, California
Usman, S., H. Spitz, L. Shoaib, and S.C. Lee	Analysis of electret ion chamber radon detector response to interference from ambient gamma radiation	Health Physics, submitted
Webb, J.	The effects of detector thickness on low-energy background for large area HpGe detectors	DOE Intercalibration Committee Lung Counting Workshop, Aiken, South Carolina
Webb, J.	The effects of graded-Z lining on low-energy background in a shielded room used for lung examinations	DOE Intercalibration Committee Lung Counting Workshop, Aiken, South Carolina
Zhang, X.Y., R. Arimoto, Z.S. An	Dust emission from Chinese desert sources linked to variations in atmospheric circulation	Journal of Geophysical Research 102, 28,041-28,047, 1997
Zhang, X.Y., R. Arimoto, and Z.S. An	Glacial and interglacial patterns for Asian dust transport	Quaternary Science Reviews, accepted

Appendix E. Major Tours, Presentations and Exhibits

Group/Event
Joint International Review Committee of the Waste Isolation Pilot Plant (Nuclear Energy Agency/International Atomic Energy Agency) - Center tour
Natural Resources staff and administrators, Guadalupe Mountains National Park – Center tour & presentation
New Mexico Legislature Radioactive and Hazardous Materials Committee – Center tour & presentation
NMSU/Alliance for Minority Participation-Center tour & presentation
NMSU/National Institutes of Health Biomedical Research Initiative for Native Americans – Center tour & presentation
NMSU/National Science Foundation Research Experience for Undergraduates – Center tour & presentation
Energy Communities Alliance, Carlsbad, New Mexico-exhibit
Leadership Training Conference, American Association of Retired Persons, Carlsbad, New Mexico – exhibit
New Mexico Spaceport Summit, Las Cruces, New Mexico - exhibit
Technology Development Conference, Albuquerque, New Mexico – exhibit
Waste Management 97, Tucson, Arizona-exhibit

Appendix F. Leadership Participation by Center Staff in Professional Functions

Function	Center Staff/Role
American Geophysical Union Spring Meeting, Baltimore, Maryland	R. Arimoto, Atmospheric Sciences Program Committee Chair
American Geophysical Union Fall Meeting, San Francisco, California	R. Arimoto, Session Chair, AEROCE: Atmosphere Ocean Chemistry Experiment
International Global Atmospheric Chemistry/Asia Pacific Regional Experiment, Hong Kong	R. Arimoto, Member, Coordinating Committee
International Symposium on Atmospheric Chemistry and Future Global Environment, Nagoya, Japan	R. Arimoto, Session Chair, Aerosols and Climate
MODSIM 1997 Workshop, Albuquerque, New Mexico	T. Kirchner, Co-chair, Health and Ecological Modeling group
4th International Conference on Methods and Applications of Radioanalytical Chemistry, Kona, Hawaii	S. Lee, Technical Session Chair, Non-radiometric methods for determination of long-lived radionuclides
American National Standards Institute, HPS N13.25, Internal Dosimetry Programs for Plutonium Exposure – Minimum Requirements	J. Webb, Member, Standards Committee Working Group
DOE Intercalibration Committee Lung Counting Workshop, Aiken, South Carolina	J. Webb, Session Chair

Appendix G. New Project Development

Proposal/Bid Title	PI(s)	Sponsor	Funding Proposed/ Term	Status
An investigation of sulfur chemistry in the Antarctic troposphere	R. Arimoto (with D. Davis, Georgia Institute of Technology, and others)	National Science Foundation	$160,000, 1997-2001	Submitted, pending
Assessing exposure and risks from toxic chemicals in Artesia, New Mexico	R. Arimoto	New Mexico Environment Department	$47,000	Pre-proposal submitted
Groundwater sampling and analysis activities: Lea Land, Inc. Landfill, Lea County, New Mexico	R. Arimoto	Lea Land, Inc.	$82,000, 1997-1998	Submitted, not awarded
Mineral dust and radionuclides over the North Atlantic	R. Arimoto (with R.A. Duce, Texas A&M University)	National Science Foundation	$260,600, 1997-1999	Funded
Colorado Health Advisory Panel	T. Kirchner	Colorado Department of Public Health & Environment	$25,000, 1997-1998	Funded
Long-term risk from actinides in the environment: modes of mobility	T. Kirchner (with D. Breshears, Los Alamos National Laboratory, and S.A. Ibrahim, Colorado State University)	DOE Office of Environmental Management	$89,900, 1997-2000	Funded
Analytical services	S. Lee	Connecticut Department of Environmental Protection	$57,000	Pre-proposal submitted
Plutonium analysis of South American air filters	S.C. Lee	DOE Environmental Measurements Laboratory	$2,500, 1997	Funded, completed
Radiological assessment of aerosol particulate matter in the U.S./Mexico border region – survey of selected naturally-occurring radioactive materials	S. Lee	Southwest Center for Environmental Research and Policy	$59,000, 1998-2000	Submitted, pending
Limnological monitoring: Brantley Dam Reservoir	D. Schoep	U.S. Department of Interior, Bureau of Reclamation	$56,379, 1997-2000	Funded

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Appendix G. New Project Development (Continued)

Proposal/Bid Title	PI(s)	Sponsor	Funding Proposed/ Term	Status
Baseline *in vivo* radiobioassay measurements	J. Webb	Waste Control Specialists, Inc.	$18,473, 1997-1998	Funded
In vivo Radiobioassay Measurements for WIPP Personnel	J. Webb	Westinghouse Electric Company	$176,000 1997-1998	Funded
^{210}Pb - A biomarker for exposure of people to radon in indoor environments	J. Webb	Lovelace Respiratory Research Institute	$43,000 1998-2000	Pre-proposal submitted
Use of chemical extraction and surface spectroscopy to assess changes in bioavailability of metals and radionuclides during transport in soil columns	J. Webb (with M. Siegel, Sandia National Laboratory, and others)	Sandia National Laboratory	$350,000, 1998-2000	Pre-proposal submitted, not awarded

Appendix H. Status of Completion of 1997 Key Performance Indicators

Indicator #1 **-** Completion of baseline sample collection for each major research component by November 1997, including:

- Aerosols: at least 18 months of high-volume samples and at least ten months of continuous, concurrent high volume and low volume sampling, at one location; at least six months of continuous sampling at one additional location.
- Soils: sampling of at least 24 sites at varying distances from the WIPP.
- Meteorology: continuous data collection from two stations for at least 18 months.
- Drinking water: sampling from at least four municipal and community water sources and at least 50% of private wells within ten miles of the WIPP.
- Sediment and surface water: sampling from at least four perennial surface water bodies.
- Biota: sampling of selected plants and animals during one spring period and one late summer-fall period.
- Internal dosimetry: make *in vivo* and *in vitro* bioassay services available to the public and WIPP radiation workers (beginning August 1997).
- Community health: analysis of regional cancer incidence .
- Public perception: regional surveys of environmental value perceptions and various parameters of resource usage and exposure .

Status – All sampling targets were completed for aerosols, soils, meteorology, drinking water, internal dosimetry, community health, and public perception. Soil sampling included samples from 16 locations collected during 1996-May 1997, samples from the same 16 locations collected during October-November, 1997, and samples from an additional 16 new locations collected during October-November, 1997. Meteorological data collection during and previous to 1996, was found to have used a non-standard measurement frequency. Therefore, the earlier data are not directly comparable with current meteorological monitoring, and are not included in this report. Meteorological data collected during 1997 from two locations were verified and are presented herein. For drinking water, it was determined that none of the private wells within 10 miles of the WIPP site are currently used for drinking water. However, one private well was identified that had been used as a source of drinking water within the last ten years, and a sample was collected from this source. For sediment and surface water, samples were collected from only one perennial surface water body (Brantley Lake), and additional sampling of other surface water locations was re-scheduled for January-February 1998. For biota, sampling of vegetation was completed during spring and fall 1997, but no sampling of animal biota was conducted. Animal biota sampling is scheduled for April-May, 1998. Studies of regional cancer incidence rates and regional surveys of environmental value perceptions were completed in 1996.

Indicator #2 **-** Completion of all laboratory analyses of samples noted above by December 1997.

Status **-** Analyses of Am were unsuccessful for samples of sediments, vegetation, and some soil samples; these analyses will be repeated in 1998. Analyses of Am were also unsuccessful for a portion of high-volume aerosol samples; these cannot be repeated due to complete usage of the sample filters. Otherwise, radioanalyses of high-volume aerosol samples collected through August, 1997 from two locations were completed and are reported herein, or in a separate publication (Appendix D). A small number of pilot analyses of trace elements were conducted on low-volume aerosol samples collected during 1996-1997 and are reported herein. Radioanalyses of soil samples collected during 1996-May 1997 from 16 locations were completed and are reported herein. Radioanalyses of additional soil samples collected during October-November, 1997 have not yet been completed. Radioanalyses of all drinking water, surface water, and sediment samples were completed and are reported herein. Non-radiological analyses of drinking water and surface water samples were also completed. Radiological analyses of vegetation samples collected during spring 1997 were completed and are reported herein. Radiological analyses of vegetation samples collected during fall 1997 have not been completed. *In vivo* bioassay services were successfully developed and implemented for the public, and results are reported herein. The i*n vivo* bioassay services were also available for WIPP radiation workers, although they were not used, due to postponement of operations at the WIPP. *In vitro* bioassay services were not developed.

Indicator #3 – Presentation of all studies conducted during 1991–1995 in the form of publications, reports, or public databases by July 1997.

Status – Summaries of a number of studies were included in the Center's 1996 report or appear in individual publications (Appendix D). Reports of the community health and public perception studies will be published as Center reports in March 1998. No other valid data from earlier studies have been identified.

Indicator #4 **-** Presentation of all data generated from sampling and analyses during 1996–1997 in the form of publications, reports, or public databases by July 1998.

Status – As noted previously, some portions of meteorological data collected prior to 1997 have not been published because of questionable validity due to measurement frequency. Most data generated from sampling conducted during 1996-1997 are reported herein, with the exception of some sample analyses not yet completed, as noted above.

Indicator #5 **-** Completion of design and schedule for operational monitoring studies by July 1997.

Status – A project schedule for sampling and analyses for the WIPP EM was developed by July 1997, and is summarized in the key performance indicators for 1998 (Table 3).

Indicator #6 **-** Initiation of operational monitoring studies by November 1997 or when the WIPP begins receipt of waste.

Status – The 1998 project schedule incorporates sampling and analyses constituting monitoring that will occur after the expected initiation of WIPP operation in May 1998.

Appendix I. “Lie Down and Be Counted” Project

The Carlsbad Environmental Monitoring & Research Center (Center), as part of its internal dosimetry program, is conducting an *in vivo* bioassay services research project entitled "Lie Down and Be Counted”. This outreach effort involves citizen research volunteers from southeastern New Mexico and supports education for the public about naturally occurring radioactivity and the Center’s environmental studies. The objective of the research is to characterize and monitor the internal deposition of radionuclides in the general population surrounding the WIPP. The data collected prior to the opening of the WIPP facility will provide information for future studies and serve as a baseline for operational monitoring. The goal of the project is to have at least 200 participating volunteers, who are monitored annually, for the duration of the project.

The Center initiated a public outreach program explaining the *in vivo* bioassay services project at the Center and soliciting research volunteers. The public outreach program involved creating a brochure and producing an instructional video, explaining the procedures of the whole body count, as well as the value of the data collected. NMSU assisted in the development of the brochure and video, both of which were completed in June 1997. Shortly thereafter, the *in vivo* monitoring facility was commissioned. Starting in July 1997, scientists from the Center began meeting with local organizations and citizens’ groups to show the video and to answer questions regarding the “Lie Down and be Counted” project. During 1997, presentations were given at two local Rotary Clubs, a Kiwanis Club, a Lions Club, a Women’s Club, a chapter of the American Association of Retired Persons, the Cavern City Bass Anglers, a Democratic Women’s group and a Republican Women’s group. As of December 1997, 150 citizens had registered to participate in the “Lie Down and Be Counted” project and 81 of these were counted between July and September 1997. The next objective of the public outreach program is to mail out brochures to solicit volunteers from wider age ranges and more diverse ethnic, occupational and economic backgrounds.

Participants in the *in vivo* bioassay services project were recruited solely on a voluntary basis and included male and female adults over the age of 18. Participation in the “Lie Down and Be Counted” project involves a six step process:

- Filling out a background questionnaire;
- Signing a research consent form;
- Changing into hospital scrubs provided by the Center (removing street clothes reduces the level of radiation detected from naturally occurring sources such as soil and radon);
- Measuring the height and weight of the participant;
- Lying down in the counting room for 30 minutes while measurements are performed;
- Reviewing the *in vivo* results with a research scientist. Following the initial measurement, citizen volunteers will be asked to return annually for continued monitoring.

As part of the "Lie Down and Be Counted” project, the Center will mail an annual summary of the data collected to all the participants. All count results are confidential, so the summary will not present any individual results identified by name of volunteer.

Appendix J. CEMRC Quality Assurance Policy

The Carlsbad Environmental Monitoring & Research Center (Center) is a division of the Waste-management Education & Research Consortium in 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. In addition to the general goals, mission and standards of NMSU, the Center adheres to the following principles:

- 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.

- 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. Equations for Radioanalytical Results

For radionuclides measured by gamma spectrometry, activity concentration is calculated as:

$$C = \frac{S}{V \cdot E \cdot Y \cdot T_1 \cdot U_f \cdot K_c \cdot K_w} \qquad \text{(equation K1)}$$

where:

C = activity concentration per unit volume or mass
S = net peak area
V = volume or mass
E = attenuation corrected efficiency
Y = branching ratio of the peak energy
U_f = conversion factor
T_1 = time interval of count
K_c = correction factor for nuclide decay during counting
K_w = correction factor for nuclide decay from the time the sample was obtained to the start of the count.

Count standard deviation (SD) (often referred to as counting error) for radionuclides measured by gamma spectrometry is calculated as:

$$SD = C\sqrt{\left(\sigma_S/S\right)^2 + \left(\sigma_V/V\right)^2 + \left(\sigma_E/E\right)^2 + \left(\sigma_Y/Y\right)^2 + \left(\sigma_K/K\right)^2} \qquad \text{(equation K2)}$$

where:

C = activity concentration per unit volume or mass
SD = standard deviation of activity concentration
σ_S = standard deviation of net peak area, S
σ_V = standard deviation of sample quantity, V
σ_E = standard deviation of efficiency, E
σ_Y = standard deviation of branching ratio, Y
σ_K = standard deviation of composite decay correction factor, K

MDC for radionuclides measured by gamma spectrometry is calculated as:

$$MDC = \frac{3.29\sigma}{T_1 \cdot E \cdot Y \cdot V \cdot U_f \cdot K_c \cdot K_w \cdot C_f} \qquad \text{(equation K3)}$$

where:
MDC = minimum detectable activity concentration
σ = standard deviation of net signal
C_f = mass or volume conversion factor
and T_1, E, Y, V, U_f, K_c K_w, and U_f are as defined in equation K1.

For radionuclides measure by alpha spectrometry, activity concentration is calculated as:

$$C = \frac{(Net\ CPM)_{sample}}{(Net\ CPM)_{standard}} \times \frac{(Activity)_{standard}}{Sample\ size} \qquad \text{(equation K4)}$$

where:
C = activity concentration
$NetCPM_{sample}$ = net counts per minute of the sample
$NetCPM_{standard}$ = net counts per minute of standard
$Activity_{standard}$ = activity added to the sample prior to analysis
Sample size = mass or volume of sample

Count standard deviation (SD) (often referred to as counting error) for radionuclides measured by alpha spectrometry is calculated as:

$$SD = \frac{\left[(S/D_s)^2 + (B/D_b)^2\right]^{1/2}}{E \cdot V \cdot R \cdot D} \qquad \text{(equation K5)}$$

where:
SD = standard deviation of activity concentration
S = sample gross counts
B = blank counts
D = decay correction factor
R = recovery efficiency
D_s = sample counting time
D_b = blank counting time
and E and V are as defined in equation K1.

MDC for radionuclides measured by alpha spectrometry is calculated as:

$$\text{MDC} = \frac{4.66\sigma_b}{E \cdot V \cdot R \cdot D \cdot C_f} \qquad \text{(equation K6)}$$

where:
MDC = minimum detectable activity concentration
S_b = standard deviation of background counting rate
C_f is as defined in equation 4
and E,V, R and D are as defined in equation K1 and R and D are as defined in equation K5.

GLOSSARY

aerosol - solid and liquid particles dispersed in a gas.

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.

aerodynamic diameter – diameter of a sphere of unit density with the same settling velocity as the particle size of concern.

attenuation - the reduction in level of a quantity, such as the intensity of a wave, over an interval of a variable, such as the distance from a source.

bathymetric – pertaining to depth measurements in a body of water.

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.

Compton continuum - energy levels in the response of a photon spectroscopy instrument corresponding to scattered electrons.

coprecipitation – process of removal of a target material from a solution by use of a chemical carrier that binds to the target material creating a solid that is separated from the solution.

desiccation - thorough removal of water from a substance, often with the use of a drying agent.

dosimetry - the measurement of radiation doses.

electrodeposition - electrolytic process in which a metal is deposited at the cathode from a solution of its ions; includes electroplating and electroforming.

elute - to remove by dissolving, as an adsorbed material from an adsorbent.

F-statistics - use of a mathematical formula to compare an experimental observation with a theoretical distribution, the F-distribution.

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

graded-Z liner - lining inside shielded room consisting of three layers of material of decreasing Z used to decrease background of room.

gravimetric analysis - measurement of mass based on force of gravity on material or object of interest quantified as weight.

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

ion-exchange chromatography – procedure in which a stationary phase material combines with or exchanges ions with a material in a solution phase.

in situ - in the original location.

in vitro - taking place outside a living cell or organism..

in vivo - taking place in a living cell or organism.

informatics - information management systems.

kiloelectronvolts - a unit of energy, equal to 1,000 electronvolts.

linear regression - the straight line running among the points of a scatter diagram about which the amount of scatter is smallest, as defined, for example, by the least squares method.

logarithm - which presents the exponent of the power to which a base number is raised to equal the original value

logarithmic data transformation - the process of representing data using the logarithms of the values rather than the original values. Logarithmic data transformation is often performed in statistical analysis when the variability in data is proportional to the magnitude of the data.

Marinelli beaker – a plastic container shaped to fit inside gamma-ray detection instrumentation.

multi-channel analyzer – a device that converts successive electronic signals into parallel amplitude channels.

nonlinear - pertaining to a response that is other than directly or inversely proportional to a given variable.

null distribution - the distribution used for hypotheses testing in which the research hypotheses attempts to contradict

passivated implanted planar silicon detector – radiation detection instrument that uses a detector constructed of silicon with ion implantation.

phoswich - combination of two dissimilar scintillator detectors (phosphor sandwich), optically coupled to a single photo-multiplier tube.

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

preconcentration – process of concentrating a material by removal of non-target matrix material.

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

scintillation crystal - a substance that emits a flash of light when contacted by a high-energy particle.

scintillation detector - a device in which the scintillations produced in a fluorescent material by an ionizing radiation are detected and counted by a multiplier phototube and associated circuits.

seston - includes nonliving particulate matter, phytoplankton and other microorganisms suspended in the water column.

silicon surface barrier detector – radiation detection instrument which uses a detector constructed from thin, high-purity silicon and a thin layer of gold.

spectrometer - a spectroscope that is provided with a calibrated scale either for measurement of wavelength or for measurements of refractive indices of transparent prism materials; a spectroscope equipped with a photoelectric photometer to measure radiant intensities at various wavelengths.

spectrophotometer - an instrument that measures transmission or apparent reflectance of visible light as a function of wavelength, permitting accurate analysis of color or accurate comparison of luminous intensities of two sources or specific wavelengths.

spectroscope - an optical instrument consisting of a slit, collimator lens, prism or grating, and a telescope or objective lens that produces a spectrum for visual observation.

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.

stochastic - pertaining to random variables.

temporal - pertaining to or limited by time.

tertiary - third level.

Torr – a unit of pressure = 1/760 atmosphere.

tracer blank – A known amount of an isotope of an element of interest, that is different from the isotope targeted for analysis; the tracer is added to a sample, and the amount detectable in the final analysis is used to estimate loss of the isotope of interest that may occur during various chemical preparation processes.

Tukey's Test - Tukey’s Honest Significant Difference (Tukey Test) – When comparing more than two means in an ANOVA procedure, mean separation tests (multiple comparison methods) are needed to determine which means differ from which other means. Tukey’s Honest Significant Difference is a mean separation test that will control false positive error rates at alpha under any partial null hypothesis.