1998 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
AA	atomic absorption
Am	americium
BOMAB	bottle mannequin absorption phantom
BTEX	ethylbenzene, m,p-xylene, o-xylene, toluene
C	centigrade
Cd	cadmium
Ce	cerium
CEMRP	Carlsbad Environmental Monitoring and Research Program
CEMRC	Carlsbad Environmental Monitoring & Research Center
CFR	Code of Federal Regulations
cm	centimeter
Cm	curium
Co	cobalt
Cs	cesium
Cu	copper
CV	coefficient of variation
DES	Duke Engineering and Services
df	degrees of freedom
DL	detection limit
DOE	U.S. Department of Energy
DOE EML	U.S. Department of Energy Environmental Monitoring Laboratory
DRI	Desert Research Institute
EM	Environmental Monitoring
EML	Environmental Monitoring Laboratory
EPA	U.S. Environmental Protection Agency
Eu	europium
eV	electron volts
Fe	iron
g	gram
Ge	germanium
HCl	hydrochloric acid
HF	hydrofluoric acid
HNO_3	nitric acid
hr	hour
IC	ion chromotography
ICP-ES	inductively coupled plasma emission spectrometry
K	potassium
keV	kiloelectron volts
km	kilometer
L	liter
m	meter
mb	millibar

MBL	mobile bioassay laboratory
mBq	millibecquerel
MCL	maximum contaminant level
MDA	minimum detectable amount
MDC	minimum detectable concentration
min	minute
MJ	mega joules
mL	milliliter
mm	millimeter
NEI	Nuclear Energy Institute (originally the Atomic Industrial Forum)
NIST	National Institute of Standards and Technology
NMAC	New Mexico Administrative Code
NMSU	New Mexico State University
Np	neptunium
Pb	lead
pH	scale indicating acidity or alkalinity of a substance
PM_{10}	particulate matter smaller than 10 micrometers in diameter
$PM_{2.5}$	particulate matter smaller than 2.5 micrometers in diameter
PRB	Program Review Board
Pu	plutonium
QA	quality assurance
QC	quality control
RIP	Radiochemistry Intercomparison Program
ROI	region of interest
Ru	ruthenium
Rn	radon
Sb	antimony
SAB	Science Advisory Board
SD	standard deviation
SE	standard error
sec	second
shield	cast iron enclosure
SDWA	Safe Drinking Water Act
$T_{1/2}$	half-life
Th	thorium
TPH	total petroleum hydrocarbons
TSP	total suspended particulate
U	uranium
W	watt
WERC	Waste-management Education & Research Consortium
WIPP	Waste Isolation Pilot Plant
XRF	X-ray fluorescence

FORWARD

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

Color photographs of various CEMRC activities during 1998 are included as an insert. Production of this report is supported as part of the Carlsbad Environmental Monitoring and Research Program, a grant from the U. S. Department of Energy to New Mexico State University (DE-FG04-91AL74167). The issuance of this report and other publications fulfills a major CEMRC mission in making the results of CEMRC research available for public access.

OVERVIEW

Current Program Status

History and Focus

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

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

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

Key Activities for Success

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

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

At the end of 1997, staffing reached 26 professional and classified employees. Currently, the CEMRC employs 27 personnel, including 23 scientific and technical support staff (Table 1) and four student employees. Four scientific positions are open and in various stages of recruitment. Staffing is projected to continue to grow as new funded projects are added to the CEMRC's activities.

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

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

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

Program needs for external laboratory services have declined, but 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 CEMRC for specific projects, including the Physical Science Laboratory (PSL), the Soil, Water, and Air Testing Laboratory (SWAT), the Fishery and Wildlife Science Department, and the Electron Microscopy Laboratory. Over half of the 1998 publications and presentations by CEMRC staff were co-authored with external colleagues, and one-third of the CEMRC's proposed and existing new projects involve collaboration with other departments or institutions.

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

The Scientific Advisory Board (SAB) for the CEMRC is composed of one scientific expert in each of the CEMRC's five scientific areas of specialization (Appendix C). Each SAB member visited the CEMRC during 1998 to review the individual program areas and provide expert guidance and consultation to the program leaders. Each program leader used the SAB observations and recommendations in structuring specific developmental goals, new experiments, and methods improvements. Program leaders will provide SAB members with follow-up reports prior to each SAB member's visit during 1999.

The Program Review Board (PRB) for the CEMRC consists of three members selected by the NMSU College of Engineering administration (Appendix C). Members of the PRB are directors or former directors of leading environmental research centers with histories of long-term success in sponsored research. Members of the PRB visited the CEMRC as a group during 1998, reviewed the overall operation of the CEMRC, and provided a joint review report to the administration. An action plan responding to the review was prepared by the CEMRC director, and implementation of the plan by the director and NMSU administration is in progress. A follow-up report will be provided to the PRB members prior to their visit during 1999.

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

Current administrative staff includes a director, a fiscal specialist, a project manager, a manager of program development, and two administrative secretaries. Partial support is also provided for the WERC director, two WERC assistant directors, and an administrative assistant on the main campus at NMSU, to assist in coordination with main campus business and with the WERC educational and research programs. Expenditures for the CEMRP during fiscal years 1991-1998 totaled approximately $16.9 million (Fig. 1). New funding under the CEMRP of approximately $3.4 million was received for the 1999 Federal fiscal year. Combined with carryover funds, the projected CEMRP 1999 budget is approximately $4.1 million.

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

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

CEMRC staff authored or co-authored 14 presentations at international, national and regional scientific meetings, and ten papers were published, are in press, or have been submitted for publication in peer-reviewed scientific journals during 1998 (Appendix D). A cumulative list of publications by CEMRC staff since 1996 is presented on the CEMRC web page.

The CEMRC issued two special study reports during 1998, “Cancer incidence in Lea and Eddy Counties, New Mexico, 1970-1994” and “Survey of factors related to radiation exposure and perceptions of environmental risks in Carlsbad, Loving, Malaga, and Hobbs, New Mexico.” The CEMRC also issued a CEMRC 1997 Report that presented extensive data on radionuclides, non-radioactive constituents, and other basic environmental parameters from the WIPP Environmental Monitoring project. These reports and other CEMRC information are available via the CEMRC web site, and data tables referenced in this report are also presented on the web site at http://www.cemrc.org.

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

During 1998, the CEMRC hosted six colloquia presented by visiting scientists (Appendix E). Each colloquium was advertised locally, resulting in participation by representatives from several local scientific, technical, and natural resource management organizations. The CEMRC was involved in a variety of other outreach activities ranging from presentations for special NMSU student programs, to hosting groups of visiting foreign scientists (Appendix F). As described in a later section, over 250 volunteers from the local community have participated in the “Lie Down and Be Counted” project. In addition, CEMRC scientists provided leadership in a variety of professional and scientific organizations and meetings (Appendix G).

Inquiries have been received, and arrangements are in progress, for placement of two visiting scientists at CEMRC during 1999. The candidates are from the National Nuclear Center, Institute for Radiation Safety and Ecology (Kazakhstan), and the State Key Laboratory of Loess & Quaternary Geology, Shaanxi Province (People’s Republic of China).

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

CEMRC scientists generated 17 proposals, pre-proposals and contract modifications during 1998 (Appendix H). New or expanded funding was achieved on ten projects totaling over $400,000, two proposals are pending, and five proposals were not funded. Five previously funded projects were completed in 1998 or remain in progress. These projects represent a wide array of activities, and they have resulted in significant expansion and diversification of the scientific program.

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

During 1998, a total of 16 undergraduate NMSU students worked in laboratory and office aide positions at the CEMRC; these positions provide training and basic skills development relevant to the position assignments. Two CEMRC scientists received Graduate Faculty appointments at NMSU, which will facilitate future involvement of graduate students in CEMRC projects. Seven major presentations and special programs were provided for student groups (Appendix F).

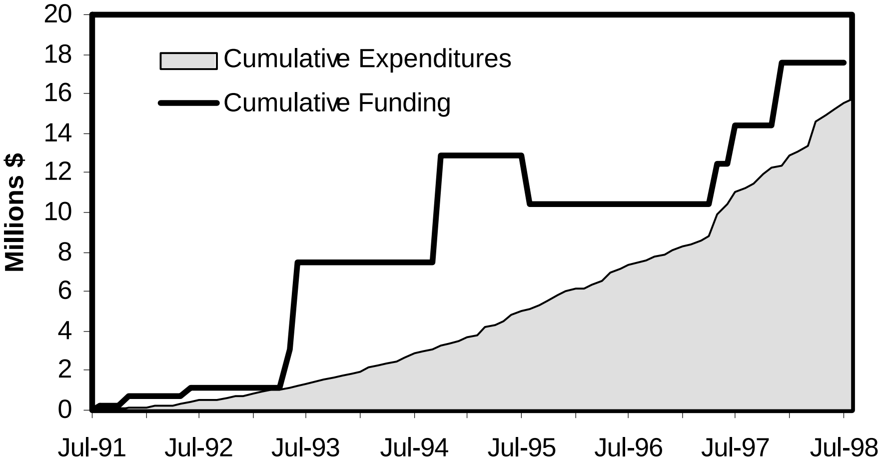


Figure 1. History of CEMRP Funding and Expenditures

Table 1. Listing of CEMRC Staff as of December 31, 1998

Name	Position
Arimoto, Richard	Senior Scientist-Environmental Chemistry
Brannan, Katrina	Laboratory Aide (student)
Brown, Becky	Fiscal Specialist II
Chatfield, Randy	Programmer/Analyst I
Clarkston, Adam	Technician I-Field Operations
Conley, Marsha	Director
Freisinger, Brandye	Laboratory Aide (student)
Khaing, Hnin	Laboratory Aide (student)
Kirchner, Thomas	Senior Scientist-Informatics & Modeling
Lynch, Sherry	Technician IV-Science
Madison, Tom	Project Manager
Marshall, Ida	Office Aide (student)
Maung, Okka	Assistant Scientist-Radiochemistry
Nesbit, Curtis	Associate Health Physicist
Nottingham, Amy	Assistant Scientist-Environmental Chemistry
Patterson, Kris	Technician I-Field Operations
Sage, Sondra	Assistant Scientist-Field Operations
Schloesslin, Carl	Assistant Scientist-Radiochemistry
Schloesslin, Cheryl	Assistant Scientist-Environmental Chemistry
Schoep, David	Science Specialist-Field Operations
Staley, Jeremy	Technician II-Informatics & Modeling
Stewart, Barry	Associate Scientist-Radiochemistry
Stroble, Carolyn	Administrative Secretary I
Webb, Joel	Manager, Program Development
Yahr, Jim	Assistant Scientist-Field Operations
York, Larry	Technician II-Radiochemistry
Young, Karen	Administrative Secretary II

WIPP Environmental Monitoring Project

Project Concept

As defined in the original grant language, 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 independent of direct oversight by DOE, and the project does not provide data to any regulatory body to meet the compliance demonstration requirements applicable to the WIPP.

Study Design for the WIPP EM

A primary objective of the WIPP EM pre-disposal baseline phase is to quantify the existing environmental levels of the radionuclides and inorganic non-radioactive constituents that are known or expected to occur in the wastes to be deposited at the WIPP. These data will serve as a basis for comparison against data collected for the same constituents after the WIPP begins operation, and extending into the post-operational phase. A true quantification requires application of specialized methods, particularly in radiochemistry, to produce data that are free of non-detect values. It is also important to note that the objective requires sampling designs that provide data to characterize the spatial variation in the analytes of interest across the natural landscape in the vicinity of the WIPP, and the temporal variation in the analytes of interest with respect to seasonal and interannual ecosystem fluctuations. For example, the current concentrations of Pu in aerosols in the vicinity of the WIPP span a range of values that may be dependent on such factors as localized soil type and seasonal weather variations that impact resuspension.

The WIPP EM incorporates analyses of a variety of inorganic substances as part of the routine monitoring design. According to information contained in the Waste Isolation Pilot Plant Hazardous Waste Draft Permit, (dated 15 May 1998, Section II.C.3 Permitted TRU Mixed Wastes), the mixed waste to be placed at the WIPP may contain arsenic, barium, beryllium (powder), cadmium, chromium, copper, lead, mercury, nickel, selenium, and silver. These constituents are naturally-occurring elements, and are also produced as contaminants from other anthropogenic sources, so quantification of pre-operational levels in the WIPP region is needed to evaluate potential future releases. Some of these trace elements are of concern due to possible toxicological effects for humans and ecosystems. From a practical standpoint, they are also very important and useful in the WIPP EM project as chemical tracers. The sources for these metals are reasonably well known, even on global scales (Nriagu, J. O. and J. M. Pacyna, 1988, *Nature*, 333:134), and they are readily determined in various types of environmental media.

If contaminant releases from the WIPP were known or suspected, it would become critical to predict the movements of the contaminants within the ecosystem. A second major objective of the WIPP EM baseline studies is to gather information concerning the basic structural/chemical composition of environmental media and ecosystem processes that could be applied in such predictive modeling. Concurrent analyses of naturally occurring radionuclides, non-radioactive elements, and target ions (such as nitrate and sulfate), provide an understanding of the complex and interlocking biogeochemical cycles that characterize the WIPP surface environment. Such characterization provides the basis for modeling of ecosystem processes that determine the fate and transport of contaminants of concern.

The following sections present a brief description of the basic sampling design for each major environmental medium in the WIPP EM, including some primary considerations that serve as the basis of the design. In addition to the core sampling and analyses, information is provided on ancillary studies that are planned or in progress.

Aerosols

Aerosols are considered a prime environmental medium of concern with respect to potential future releases by the WIPP because airborne contaminants can rapidly disperse, can be transported over long distances, and represent a significant mode for uptake by humans and other organisms. CEMRC studies of aerosols focus on both man-made and naturally-occurring radionuclides (including those known or expected to occur in the wastes to be deposited at the WIPP) and selected non-radioactive, inorganic constituents.

Aerosol sampling is conducted at four locations as part of the WIPP EM, with samplers operating continuously at each location. The locations include a port inside the WIPP exhaust shaft, a site approximately 0.1 km northwest (downwind) of the WIPP exhaust shaft (On Site station), a site approximately 1 km northwest (downwind) of the WIPP (Near Field station), and a site approximately 19 km southeast (upwind) of the WIPP (Cactus Flats station) (Fig. 2). The sites were selected on the basis of the prevailing wind directions at the WIPP. In designing aerosol studies, it is widely recognized that there is seldom a satisfactorily defined "control" location that is far enough from a source to ensure isolation from aerosol releases, while adequately replicating key ecological features of aerosol composition, soil, topography, biota and weather conditions. The Cactus Flats location represents a reasonable compromise to approximate a control location for surface parameters, based on average conditions.

Sampling in the WIPP exhaust shaft (Station A) consists of collection of one filter daily (Monday through Friday) from a Fixed Air Sampler (FAS), that is operated with an average air flow of 56 L min^{-1}. The daily FAS samples will be subjected to gross alpha/beta counting individually. The five daily (Monday - Friday) samples from each week will be composited for weekly gamma counting and all weekly composites will be combined each calendar quarter for analyses of Pu and Am by alpha spectrometry. This sampling is a workplace monitor that will provide a gross check of emissions on a short resolution time-scale (for daily and weekly samples), with a higher sensitivity check for cumulative emissions over a three-month time scale. (Collection of FAS samples by the CEMRC began in December 1998, and sample analyses will begin in July 1999).

At the other three stations, aerosol samples for radionuclide analyses are collected using high-volume samplers (approximately 1.13 m^3 min^{-1}). These samplers are operated to maximize particulate loading without impacting air flow, so individual samples are collected for periods ranging from three to six weeks, depending on levels of particulate deposition. By focusing on high particulate loading, this sampling allows collection of sufficient mass for quantitative determination of the manmade alpha-emitting radionuclides (Pu and Am) at background levels via alpha spectrometry, which has been of particular interest in baseline studies. Low-volume samplers (10 L min^{-1}) are operated for collection of samples for analyses of non-radioactive, inorganic constituents (trace metals and selected ionic compounds). Analytical methods for inorganic constituents do not require large sample concentrations, so low-volume sampling includes two 2-day samples, and one 3-day sample weekly.

All three stations support one high-volume sampler collecting total suspended particulate (TSP) matter and one low-volume sampler collecting TSP. The Near Field and Cactus Flats stations also support a second high-volume sampler collecting particulate matter less than 10 μm aerodynamic equivalent diameter (PM_{10}), and two other low-volume samplers, one collecting particulate matter less than 2.5 μm aerodynamic equivalent diameter ($PM_{2.5}$) and one collecting PM_{10}. With respect to human health, PM_{10} and $PM_{2.5}$ are the particulate classes that are generally recognized as the most significant of the respirable aerosol components, and it is important to characterize the natural temporal and spatial variation in these components that would impact potential uptakes of WIPP contaminants by humans.

Additional studies in progress include concurrent operation of a dichotomous sampler at the Near Field station since February 1998 and at the Cactus Flats station since November 1998. The dichotomous sampler is an EPA-equivalent reference method for sequential measurement of both PM_{10} and $PM_{2.5.}$ The mass loading and inorganic constituents will be compared between the dichotomous sampler and the low-volume samplers to evaluate possible future substitution of the dichotomous samplers, and to allow comparisons with data from the low-volume samplers with other results using dichotomous samplers.

Soils

Soils are of high interest to the WIPP EM because aerosol releases of contaminants would eventually be deposited in surface soils, which then can serve as a source for continuing contaminant exposure and uptake via direct contact, food chain pathways, and re-suspension. From this perspective, soil is an integrating medium of primary concern in predictive ecosystem and contaminant transport modeling, that requires good information about the dispersion of analytes of concern across the landscape.

The soil sampling design for the WIPP EM baseline and future monitoring studies is organized to address analyte variability on three spatial scales. First, soil sampling is conducted within a 166 km^2 area centered on the WIPP operations facility, and at a comparable area encompassing the Cactus Flats aerosol sampling station. Within each of these two areas, samples are collected at 16 locations positioned in concentric rectangular grids (Fig 2). At each of the 16 locations in each area, samples are collected at three randomly selected sites within 25-m of the location's reference point. Individual sampling sites are selected on the basis of relatively flat topography and minimum surface erosion or disturbance due to human or livestock activity. The resulting data represent 96 discrete samples that provide for estimation of variability at the small-scale (between samples within a .0025 km^2 area), medium-scale (among locations within each 166 km^2 area), and large-scale (between the two sampling areas located approximately 19 km apart). This type of design has been applied in other experimental studies focusing on analyte dispersion patterns in soils (Gilbert, R.O., 1987, *Statistical Methods for Environmental Pollution Monitoring*, Van Nostrand Reinhold Co., New York*)*.

During baseline studies, samples for pilot projects were collected at various times in 1996 and 1997 using this spatial design. In 1998, the full suite of 96 samples was collected during March-April. In 1999 and subsequent years, the full suite of 96 samples will be collected once annually, during January-February. The limitation of soil sampling to one period annually is based on the assumption that any input of contaminants to surface soils from WIPP releases would occur via aerosol deposition, and since aerosol sampling is conducted continuously, more frequent soil sampling is not warranted unless there was evidence of a contaminant increase in aerosols.

Surface Water and Sediments

The WIPP EM incorporates studies at three reservoirs on the Pecos River, which is the major perennial fresh water system closest to the WIPP that has extensive human usage. The three reservoirs are: Brantley Lake, located approximately 40 miles northwest of the WIPP; Lake Carlsbad, located in Carlsbad and approximately 25 miles northwest of the WIPP; and Red Bluff Lake, located approximately 30 miles southwest of the WIPP. Surface and underground drainage from the area of the WIPP is to the southwest, and Red Bluff Lake is downstream of the area where drainage from the WIPP area enters the Pecos River. Brantley Lake and Lake Carlsbad are both upstream of the WIPP area drainage, and thus would be unlikely to receive contaminants *via* drainage from the vicinity of the WIPP but could be contaminated by atmospheric deposition. In addition to their proximity to the WIPP, these three reservoirs were selected because of the potential exposure of human populations to contaminants through use by the local population for sport fishing and recreation, and through use of Pecos River water for agricultural irrigation in a large region of the river floodplain throughout New Mexico and Texas.

During 1996-97, pilot studies were conducted to identify shallow, mid- and deep-basin areas of each reservoir and to characterize the physical and chemical nature of the sediments at the various depths. The deep basin areas now serve as the focus for sediment sampling because radioactive contaminants (and other inorganic contaminants) are known to concentrate in zones featuring fine-grained sediments, which are highest in the deepest waters. The sediment sampling consists of collection of one sample from each of four randomly selected locations within the deep basins at each reservoir. Each sample analyzed is a composite of two to four grab samples taken from the top 5-10 cm of the sediment surface. Two samples of water (one at the surface and one approximately 0.5 to 1 m above the sediment bed) are also collected at one deep basin site at each reservoir. During 1997-1998, sediment and surface water samples were collected once during the spring, once in winter, and once in the summer. Because of the distance between the WIPP site and these reservoirs, the potential risk of direct contamination of the reservoirs by releases from the WIPP is relatively low compared to other media, and sampling in subsequent years will be conducted once annually in the summer.

Drinking Water

The WIPP EM studies of ground water focus on the major drinking water supplies used by communities in the WIPP region because these are often perceived by the public as a potential route for contaminants to reach humans. However, studies of the hydrogeology of the region suggest (1) that the risk is low for contaminants from the WIPP to reach the various regional underground aquifers that are used as sources of drinking water, and (2) the movement of contaminants into these aquifers, if it occurred, would be extremely slow (DOE, 1997, Waste Isolation Pilot Plant Disposal Phase Final Supplemental Environmental Impact Statement, DOE/EIS-0026-S-2). Five community supplies of drinking water (representing three major regional aquifers) are included in routine sampling, including Carlsbad, Loving/Malaga, Otis, Hobbs, and a secondary source for Carlsbad. One private water well (representing a fourth aquifer) that is located within ten miles of the WIPP is also sampled because it is the only private well in close proximity to the WIPP that is known to have been used for human consumption in recent years, and because it draws from the aquifer considered most likely to be contaminated by releases from the WIPP into ground water, (DOE, 1990, Final Supplemental Environmental Impact Statement, DOE/EIS-0026-FS).

Studies of the drinking water sources utilize samples collected at locations in the drinking water systems that are considered to be representative of the overall supply to the system's user group. Many of the systems draw from several wells simultaneously or on a rotating basis, and routinely sampling all of the dozens of individual wells is not justified. Instead, samples for municipal systems are drawn from the primary reservoir vessels downstream of the well sources, which are more representative of the overall water supply than samples from individual wells. Likewise, for municipal supplies, samples are not taken from individual user taps because of the potential contamination introduced via the residential segments of the system, which would have no demonstrable relationship to contaminants from the WIPP. Recharge of the target aquifers is not known to be strongly linked to seasonal cycles (except in a few cases where an indirect linkage via hydraulic head pressure is suspected). Therefore, there is little basis to expect any significant seasonality in drinking water contaminants of concern, and the WIPP EM sampling design for drinking water does not incorporate a seasonal component.

During initial baseline studies in 1996-1998, the drinking water samples were subjected to a suite of analyses for over 150 analytes, including those that are regulated under the Safe Drinking Water Act, and contaminants known or suspected to be present in the WIPP wastes. In addition to serving as a baseline for future comparisons, these analyses provided information that was considered to be of general interest to the public. Knowledge of the basic chemical composition of the water supplies is also useful in radioanalytical studies, where chemical processes can be strongly affected by non-radioactive components.

In relation to the core objectives of the WIPP EM, radioanalyses of drinking water conducted during 1997-1998 were unable to detect Pu or Am in any of the samples collected. The analyses applied to the samples consisted of traditional alpha spectrometry. Samples of drinking water have also been submitted for thermal ionization mass spectrometry (TIMS) (a potentially more sensitive radioanalytical technique) and results will be reported during the next annual cycle. If the TIMS analyses do not detect any of the manmade actinides of interest, each of the six drinking water supplies will continue to be sampled once annually for selected radiological and inorganic testing, but analyses for man-made actinides will only be repeated with gross detection limits until after WIPP begins operation.

Biota

Studies of biota for the WIPP EM have focused on native vegetation because the vegetation is consumed by beef cattle, and consumption of beef from cattle pastured in the vicinity of the WIPP could serve as an exposure pathway to humans for contaminants released from the WIPP. While it would seem more desirable to monitor the presence of contaminants in the beef directly, the livestock industry in the region routinely uses supplemental feeding for range cattle during some portion of most years. This means that the cattle are potentially exposed to contaminants from distant sources via the supplemental feeding, thereby confounding the interpretation of any direct analyses of range cattle tissues. Secondarily, if the occurrence of radioactive contaminants in major food plants is known, the potential uptake of radioactive contaminants by range cattle can be effectively predicted from existing data on livestock diets, consumption rates, and absorption ratios.

During baseline studies, vegetation samples have been collected from a total of six species of plants that serve as preferred forage species for cattle during at least some portion of the year. These include fall witchgrass (*Leptoloma cognatum*), sand paspalum (*Paspalum setaceum*), spike dropseed (*Sporobolus contractus*), mesa dropseed (*S. flexuosus*), honey mesquite (*Prosopus glandulosa*), and shinnery oak (*Quercus havardii*). The sampling includes collection of discrete samples of each species, because relevant published work indicates that plant species can vary significantly in both uptake of radionuclides into plant tissues and in adherence of radiation-contaminated soil particles to external plant surfaces.

Vegetation is sampled twice annually during the two major periods of new growth for native vegetation (March-May and August-October). Not all of the same species can be sampled at each period because some of the species only produce major new growth during one season, and because the abundance of the species varies among years depending on weather patterns. Six samples of each of three species (contingent on availability) are collected during each sampling period from selected sites on the sampling grid surrounding the WIPP (which encompasses the Near Field aerosol sampling station). The vegetation samples are analyzed for selected radionuclides only. Collecting samples at the same locations used for soils allows for a direct comparison between radionuclide levels measured in soils and vegetation. Vegetation sampling will continue to be conducted twice annually during both baseline and operational monitoring phases.

Additional studies are in progress to evaluate the effectiveness of expanding the biota sampling for radionuclides to include arthropods. In many desert ecosystems, total arthropod biomass has been shown to equal or exceed total biomass for any other consumer component, and arthropod communities encompass primary, secondary and tertiary consumers, as well as detritivores and necrovores. As such, arthropods could be used to study the movement of radionuclides through natural ecosystem food chains.

Human Population

The "Lie Down and Be Counted" project serves as a component of the WIPP EM that directly addresses the general concern about personal exposure to contaminants shared by residents who live near many DOE sites. Although this aspect of the project could be viewed as using local residents as monitors of contaminant release from the WIPP, the design of wide-scale monitoring of other media ensures (as much as reasonably possible) that contaminant releases would be detected in the environment long before significant contact with human residents. It is important to note that an individual who is determined to have internally deposited radioactive materials after the WIPP begins operation, could not use the results of this study to suggest that the uptake occurred as a result of exposure to materials at the WIPP unless that individual had been subject to an *in vivo* bioassay *a priori*, with negative results.

As in other aspects of the WIPP EM, *in vivo* bioassay testing has been used to establish a baseline profile of internally-deposited radionuclides in a sample of local residents. The sampling design included solicitation of volunteers from all segments of the community, with sample sizes sufficient to meet or exceed a 15% range margin of error for comparisons between major population ethnicity and gender categories as identified in the 1990 census. The minimum sample size threshold was achieved for the major categories early in 1998, and is as low as 8% margin of error range for some categories. Baseline sampling will continue to expand the sample size (and thereby increase statistical power) until the WIPP begins operation. After the WIPP begins operation, bioassays of the original volunteer cohort will be repeated on a schedule of once every two years, and additional new volunteers will be incorporated each year to create replacements for attrition from the original cohort.

Meteorological Monitoring

Fully automated meteorological stations are operated by the CEMRC at the Near Field aerosol station and the Cactus Flats aerosol station. Details concerning the sensors and operation of the equipment are presented in the section on meteorology. The data derived from these stations is essential to interpreting results from other parts of the project, particularly the aerosol studies. For example, notable short-term changes in aerosol compositions can be evaluated against wind direction to determine if there were a possible difference in source terms.

Analyses and Release of Data

The scheduling and management of sample analyses collected in the WIPP EM project is based on (1) priorities for providing information to the public in a timely manner, (2) relative risks of human exposure to contaminants among the various media sampled, (3) needs for stringent data validation and verification prior to release, and (4) time constraints resulting from sample preparation and analysis procedures. Based on this, and as noted previously, analyses of daily and weekly composite FAS aerosol samples provide gross data on radiation at a location immediately adjacent to the waste-handling and deposition activities. The analytical results will be made available within a few weeks of sample collection, and these data (along with quarterly composite data) will be posted on the CEMRC web page quarterly. This is a routine, quick turnaround monitoring strategy that focuses on detection of potential short-term, large-scale radioactive contaminant release *via* the medium likely of most risk for worker and public exposure (aerosols).

The project currently has archived high-volume aerosol samples from the On Site, Near Field and Cactus Flats stations that were collected beginning in 1997. Following completion of radioanalyses of these archived samples during 1999, subsequent aerosol analyses will be carried out with quarterly "batches" of filters, with results posted on the web page approximately one month after the end of each quarter.

For samples of soils, sediments, surface water, drinking water and biota, collection is annual or semi-annual (as previously described), and the period of time required for completion of analyses varies with each medium. As for aerosols, archived samples of other media are currently awaiting radioanalyses that will be completed and reported in 1999. Subsequently, analytical results for these media areas will generally be posted to the web site within six months after sample collection.

Cumulative summaries and analyses of the data from the Lie Down and Be Counted project are reported in each year's annual report. Beginning in 1999, summaries will also be provided via a newsletter sent to volunteers. Because these data are considered confidential, individual bioassay results are not presented in any reporting.

The management plan for the WIPP EM incorporates milestones representing significant products and progress, including both routine sampling and analyses and special studies. Key performance indicators that integrate groups of milestones are identified and reviewed annually to serve as metrics of the successful progress of the project. Completion of 1998 key performance indicators is summarized in Appendix I. Nine indicators were completed on time and four indicators were delayed but completed prior to year-end. Three out of 16 indicators were not completed, with 0-10% progress on each. Key performance indicators for 1999 have been identified to serve as the basis for the 1999 WIPP EM project schedule (Table 2).

Table 2. Key Performance Indicators for 1999

Focus Area	Key Performance Indicator
Aerosols	1. Continue concurrent high-volume and low-volume sampling and analysis at current three locations through 1999
	2. Continue collection of daily FAS samples in WIPP exhaust shaft through 1999
Soils	3. Collect samples at current 32 locations during January-February 1999
Meteorology	4. Continue concurrent operation of sampling stations at two current sites through 1999
Drinking water	5. Collect samples from six sources during March-April 1999
Sediment and surface water	6. Collect samples from three reservoirs during June-July 1999
Biota	7. Collect vegetation samples from six locations during spring and fall 1999
	8. Collect composite arthropod sample from one location during April-November 1999
Human studies	9. Continue *in vivo* bioassays for public
Radioanalyses	10. Complete analyses of all 1998 aerosol, soil, sediment, surface water, drinking water, and vegetation samples by October 1999
	11. Complete FAS sample analyses to meet quarterly posting schedule, beginning with July 1999
Non-radiological analyses	12. Complete analyses of representative subset of 1999 low-volume aerosol, soil, sediment, surface water and drinking water samples within three months after each sample collection
Data management and dissemination	13. Implement electronic Laboratory Information Management System by October 1999
	14. Post results of radioanalyses of 1998 samples within two months after completion of analyses of each set of samples
	15. Post results of non-radiological analyses of 1999 samples within two months after completion of each set of samples
	16. Make CEMRC 1998 Report and background data accessible via Internet by March 1999
	17. Submit manuscript for publication by July 1999 on radioanalyses of soils

Quality Assurance

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

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

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

Personnel

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

Regulatory Compliance

To promote good health and safety practices in the laboratories, the CEMRC maintains a Chemical Hygiene Plan and associated training of personnel, in compliance with the requirements of 29 CFR 1910.1450, "Occupational Exposure to Chemical Hazardous Chemicals in Laboratories." A Hazard Communication Plan and associated training are 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.

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

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

Field Sampling Program Quality Assurance

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

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

Calibration and maintenance of equipment and analytical instruments are carried out on 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 CEMRC personnel using certified calibration standards. Records of calibration and maintenance are maintained in instrument-specific files in the program manager's office.

Radiochemistry Program Quality Assurance

During 1998, the CEMRC radiochemistry program participated in one analytical round of the DOE Office of Environmental Management (EML) Quality Assessment Program (QAP), but did not report results for the analyses. The radiochemistry program also participated in one round of testing in the NIST Radiochemistry Intercomparison Program (RIP) on natural-soil matrix (NRIP98-SO).

CEMRC reported ^{239,240}Pu analyses within 8% of NIST values, ^{232}Th within 1% of NIST values, and ^{238}U within 16% of NIST values.

Through past intercomparison program participation (reported in CEMRC 1997 Report), CEMRC has demonstrated basic capabilities to perform standard radioanalytical procedures for various environmental media. However, various aspects of the procedures were found to be unsatisfactory for meeting many of the specific data quality objectives of the WIPP EM, and CEMRC has undertaken an extensive method development and verification project that began in May 1998 and will extend through 1999. Thus, virtually no radioanalytical data were generated by the CEMRC radiochemistry program for this report. The completion of this developmental phase will include adoption of a formal quality assurance plan and implementing procedures for radioanalyses in the WIPP EM project.

Environmental Chemistry Program Quality Assurance

The analytical methods employed in the environmental chemistry program at CEMRC are based, when applicable, on various standard procedures (EPA, 1983, M*ethods for Chemical Analysis of Water and Wastes,* EPA/600/4-79-020; EPA, 1997, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*; EPA/SW-846; American Public Health Association, 1981, *Standard Methods for the Examination of Water and Wastewater, 15th Edition*). For some matrix/analyte combinations, appropriate external standard procedures do not exist, and CEMRC has developed specialized standard procedures to meet the needs of the WIPP EM. The following types of analyses are performed at CEMRC:

- anion and cation analysis by ion chromatography (IC)
- elemental analysis by graphite furnace atomic absorption (AA) spectrometry
- elemental analysis by flow injection hydride AA spectrometry
- mercury analysis by flow injection cold vapor AA spectrometry
- elemental analysis by inductively-coupled plasma atomic emission (ICP-ES) spectrometry

For the WIPP EM, the IC was used to determine the concentrations of a suite of major ions in water samples and aqueous extracts of all media sampled except vegetation (Table 3). The AA and ICP-ES were used to analyze aqueous or acid extracts of samples (excluding vegetation), depending on the particular question or issue being addressed.

A set of standard operating procedures and a formal quality assurance plan have been developed and implemented for the inorganic analyses performed at CEMRC. A summary of the quality assurance/quality control procedures applied by the environmental chemistry program for WIPP EM studies is presented in Appendix K.

In Vivo Radiobioassay Quality Assurance

In vivo radiobioassays are performed in accordance with a formal quality assurance plan and related documentation that were developed to meet the requirements of the Department of Energy Laboratory Accreditation Program (DOELAP) for Radiobioassay. The *in vivo* radiobioassay program is in the final stages of the DOELAP accreditation process and anticipates successful completion during 1999.

During 1998, the CEMRC *in vivo* radiobioassay program participated in the Intercomparison Studies *In Vivo* Program administered by Oak Ridge National Laboratory (ORNL). This program provides quarterly testing for ^{137}Cs, ^{60}Co, ^{57}Co, ^{88}Y and ^{133}Ba deposited in whole body. For the three quarters completed prior to December 1998, CEMRC reported values that were within -0.3 to 3.3% of the ORNL known value for all radionuclides.

External Laboratory Services

Some analyses presented herein were carried out by other laboratories through subcontract or fee service arrangements. These include analyses of radiological and non-radiological constituents in soils, sediments, surface water and drinking water samples, and analyses of inorganic constituents in aerosol samples by X-ray fluorescence (XRF) spectrometry.

Analyses of non-radiological constituents of water samples were provided by the Soil, Water, and Air Testing Laboratory (SWAT) at NMSU. SWAT is accredited by the American Association for Laboratory Accreditation for all of the analyte/test methods applied to drinking water and surface water samples as noted in summaries for these media. 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 and sediments reported herein were conducted by Duke Engineering & Services (DES) in Bolton, Massachusetts. DES maintains a quality assurance program as documented in the DES Environmental Laboratory Quality Assurance Plan (Manual 100). DES has achieved acceptable performance for analyses of environmental samples in the DOE EML QAP, and maintains traceability to NIST through the NEI/NIST Measurement Assurance Program.

A segment of the non-radiological analyses of soils and sediments reported herein were conducted by A&L Plains Laboratory in Lubbock, Texas. A&L soils analyses employ standard methods as defined by EPA, the American Society of Agronomy, and the American Society of Soil Chemists. A&L is approved by the Texas Agricultural Extension Service for analysis of soils, and maintains a quality assurance/quality control program as documented in the A&L Inter-Laboratory QA/QC Program.

XRF analyses of trace elements in aerosol samples were conducted by the Desert Research Institute (DRI), a division of the University and Community College System of Nevada, in Reno, Nevada. Details of the XRF analytical procedure and the quality assurance/quality controls (QA/QC) used for the analyses were presented in the CEMRC 1997 Report.

Table 3. Inorganic Analyses Conducted at CEMRC

Type of Sample	IC (Anions)	IC (Cations)	Hydrides (As, Sb and Se) and Hg, Flow Injection AA	Trace Elements (for ICP-ES & AA)
Air	Filter extraction with DI water and isopropanol	Filter extraction with DI water and isopropanol		Aqueous extract Total dissolution
Drinking and Natural Waters	Syringe filtration with direct injection		Syringe filtration with direct injection	Dissolved Total recoverable
Soils	Aqueous extract		Total recoverable	
Sediments	Aqueous extract		Total recoverable	

WIPP ENVIRONMENTAL MONITORING DATA SUMMARIES

Meteorological Conditions in the Vicinity of the WIPP Site

Methods

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

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

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

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

This report summarizes meteorological data collected over the 12 month period from December 1997 through November 1998. In addition, data collected at the sites from 1 January through 30 November 1997 (11 month period) are compared with data from the same time interval during 1998.

Results

For the 1998 sampling period, data recovery exceeded 97% for all sensors at both the Cactus Flats and Near Field sites. Data recovery was slightly lower during the months of October and November due to a six day period (30 October - 6 November) when new meteorological equipment was installed at the sites. Other short-term (typically less than two hours) data losses occurred throughout the year due to sensor maintenance, repair, performance testing and malfunction.

Averaged over the year, winds were from a southeasterly direction (E, ESE, SE and SSE quadrants, inclusive) 41% and 44% of the time at the Cactus Flats and Near Field sites, respectively (Fig. 3). However, there were some distinctive seasonal variations in wind direction (Figs. 4-5). Wind direction was highly variable during the winter and spring (December through May) when compared with the summer and fall (June through November). During summer and fall, wind from the southwestern quadrant occurred over 50% of the time, but dropped to less than 30% during the winter and spring. The inter-annual and intra-annual variability in wind direction are important parameters in modeling dispersion pathways for potential airborne releases from the WIPP.

Wind velocities were very similar between sites. Wind velocities (10-minute means) were less than 5.4 m s^{-1} over 77% of the time, with speeds frequently from 3.1 to 5.4 m s^{-1}. Calm periods (wind velocities < 0.1 m s^{-1}) occurred less than 1% of the time over the year. Wind velocities > 5.4 m s^{-1} occurred less than 25% of the time, but were more frequent during the spring, and typically came from west and west-northwest. The highest wind velocities recorded at each site were 33.6 m s^{-1} (75 mph) on 21 July, and 23.3 m s^{-1} (52 mph) on 2 April, at the Near Field and Cactus Flats sites, respectively.

Air temperatures at Near Field ranged from –10.5 to 43.6 ^{o}C and from –10.1 to 43.6 ^{o}C at Cactus Flats. The maximum temperatures were recorded on 27 June at both sites, and lowest temperatures were recorded on 12 December and 27 December at the Near Field and Cactus Flats sites, respectively. The annual mean temperatures were 18.7 ^{o}C and 18.2 ^{o}C at Near Field and Cactus Flats, respectively. At both locations, December was the coldest month (mean = 5.0 ^{o}C at Near Field; mean = 4.8 ^{o}C at Cactus Flats) and June was the hottest month (mean = 28.9 ^{o}C at Near Field; mean = 29.6 ^{o}C at Cactus Flats) (Fig. 6).

The annual mean relative humidity at Near Field was 41.8% and ranged from 5.3 to 100%. Humidity at the Cactus Flats site was very similar to Near Field, averaging 42.0% and ranging from 5.5 to 101%. Mean relative humidities were lowest when temperatures peaked in late spring and early summer (Fig. 7). It should be noted that the accuracy of the relative humidity sensors declines at relative humidities below 12% and above 94%, and readings outside these ranges should be interpreted with caution.

Barometric pressure did not exhibit an obvious seasonal trend at either site (Fig. 8). The annual mean was 890.9 mb at Cactus Flats and 896.0 mb at the Near Field site. The apparent 5.1 mb difference between the sites can be attributed to a 41 m difference in elevation, and this difference is not significant if corrected using standard barometric conversions that incorporate elevation (U.S. Department of Commerce Weather Bureau, 1963, *Manual of Barometry, Vol. 1*, Washington D.C.).

Solar radiation flux (W m^{-2}) was integrated over daily intervals to calculate total energy received per unit area (MJ m^{-2}). As is typical, solar radiation received at the sites peaked in the summer and was lowest during the winter months (Fig. 9). This pattern is due to a combination of increasing solar radiation intensity, less cloud cover and additional hours of daylight during the summer months. Over the year, the daily total solar radiation ranged from 1 to 33 MJ m^{-2} at Near Field and 1 to 36 MJ m^{-2} at Cactus Flats.

Over the year, a total of 12.88 cm of precipitation was measured on 37 days at Cactus Flats and 17.28 cm of precipitation was measured on 39 days at Near Field (Fig. 10). At both sites, the month of December had the highest number of days (9) on which precipitation was recorded. At Cactus Flats, December was also the month with the highest total precipitation (3.96 cm). In contrast, at the Near Field site, July was the month with the highest total amount of precipitation (5.53 cm).

Overall, 1998 was a much drier year than 1997. In 1997, a total of 38.5 and 27.9 cm of precipitation was recorded at the Near Field and Cactus Flats sites, respectively, between 1 January and 30 November. Over the same time period in 1998 (December, 1997 excluded from the comparison), 12.3 cm of precipitation was recorded at Near Field and 8.9 cm recorded at the Cactus Flats site. In addition to being drier, mean annual temperatures were approximately two degrees higher in 1998 than 1997. Mean temperatures were higher in 1998 than in 1997 for every month except March and August. Given the differences in precipitation and temperature it is not surprising that total solar radiation was also higher in 1998, with Cactus Flats receiving 7984 MJ m^{-2} in 1998 compared with 6294 MJ m^{-2} in 1997 and the Near Field site receiving 7222 MJ m^{-2} in 1998 compared to 6130 MJ m^{-2} in 1997. In contrast, annual mean wind patterns (velocity and direction) were very similar between years, although some differences appeared in seasonal wind patterns.

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

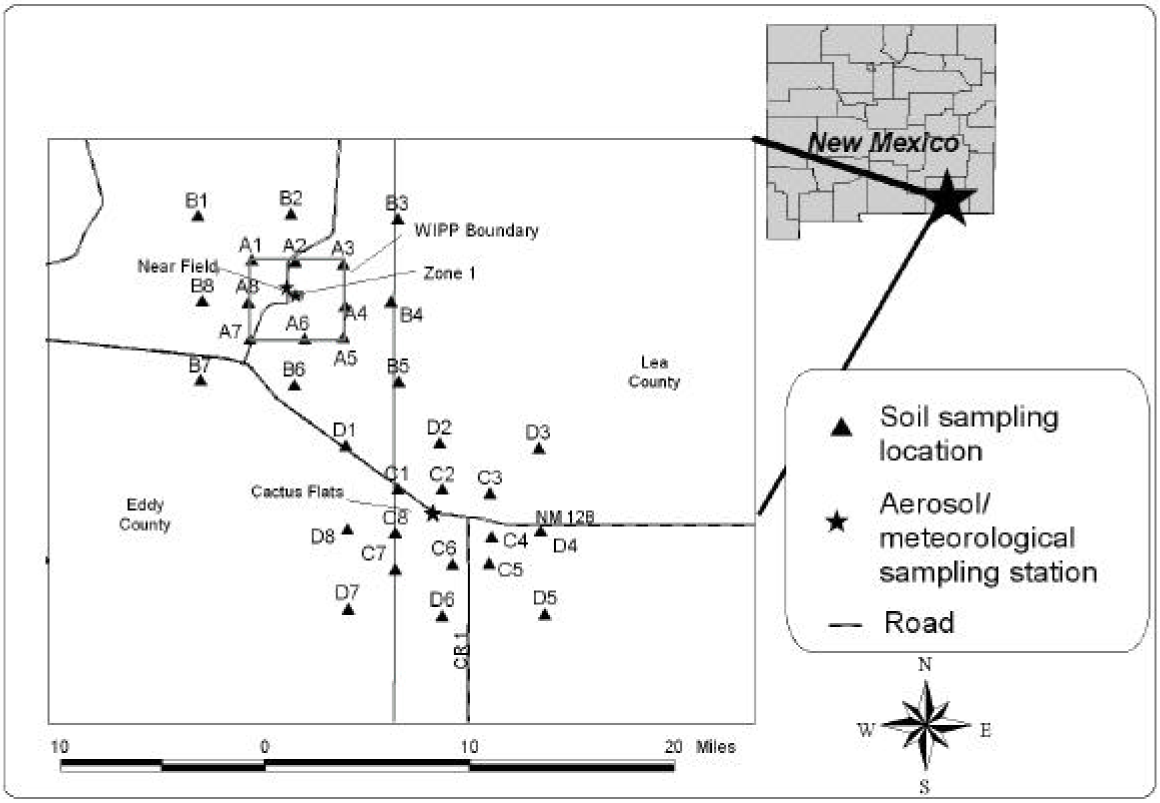
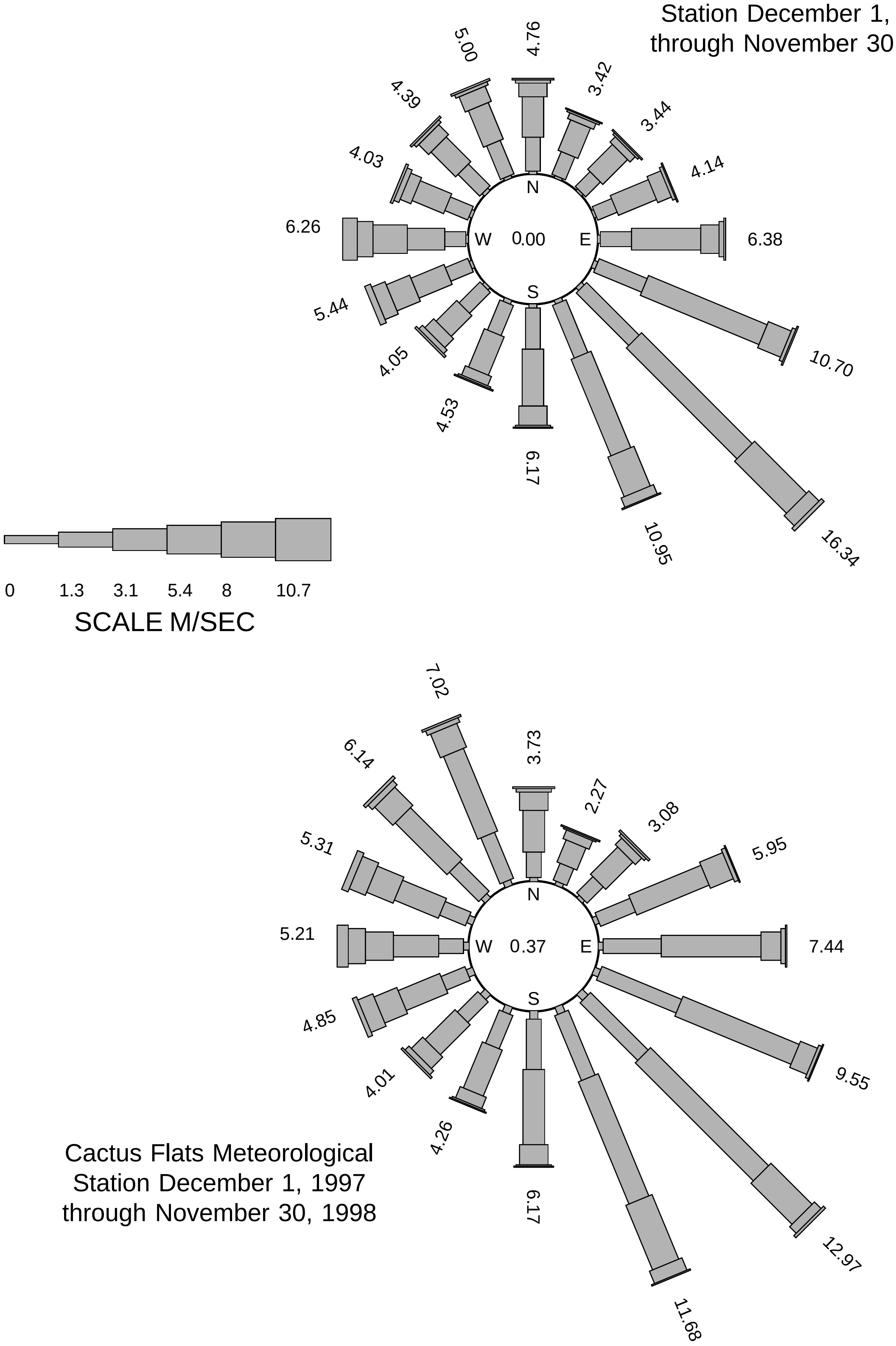


Figure 2. Sampling Locations in the Vicinity of the WIPP
Aerosol and meteorological sampling is conducted at Near Field and Cactus Flats.

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

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

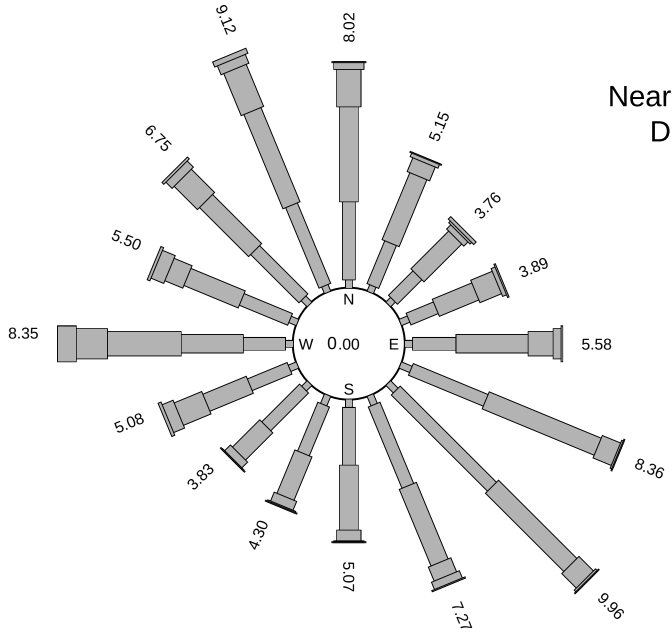


Near Field Meteorological Station December 1, 1997 through November 30, 1998

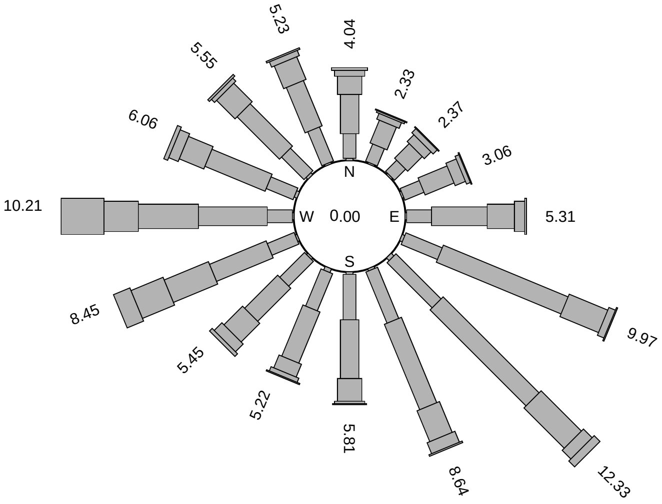
Cactus Flats Meteorological Station December 1, 1997 through November 30, 1998

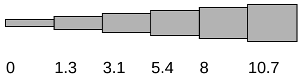
Figure 4. Seasonal Wind Roses, Near Field
[a]See page 25 for explanation.

Near Field Meteorological Station December 1, 1997 through February 28, 1998



Near Field Meteorological Station March 1, 1998 through May 31, 1998





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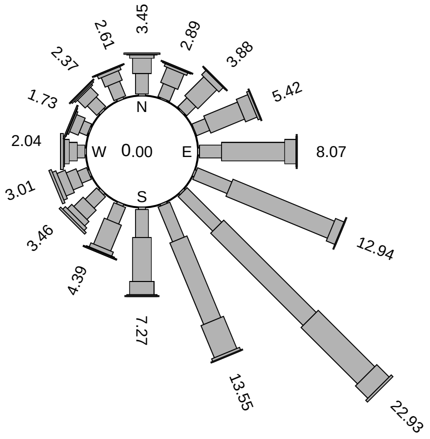
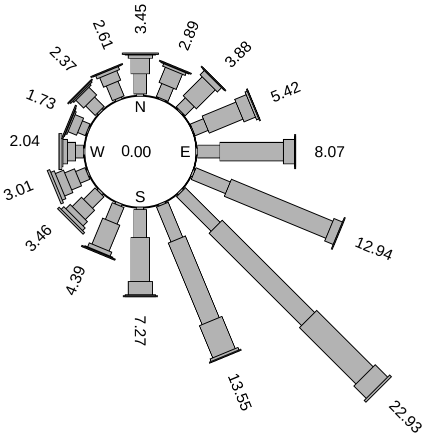




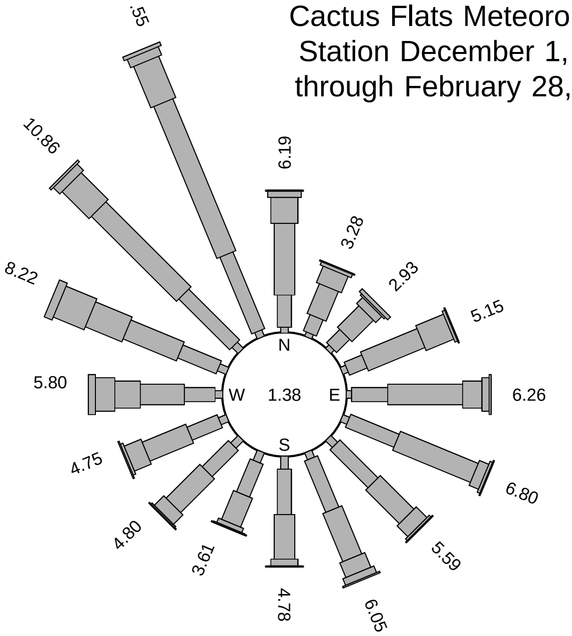
Near Field Meteorological Station June 1, 1998 through August 31, 1998

Near Field Meteorological Station September 1, 1998 through November 30, 1998

Figure 5. Seasonal Wind Roses, Cactus Flats

[a]See page 25 for explanation.

Cactus Flats Meteorological
Station December 1, 1997
through February 28, 1998



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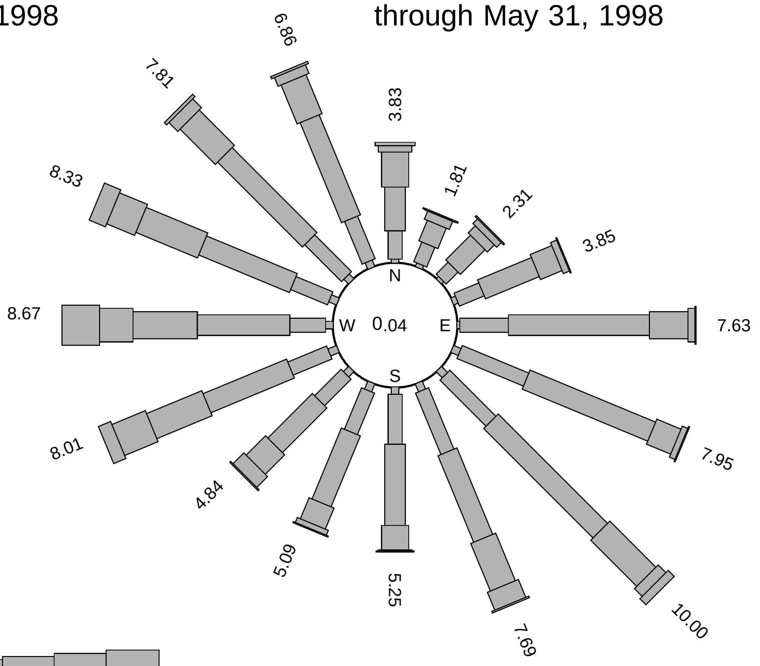
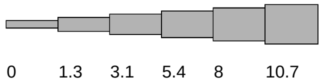
through May 31, 1998





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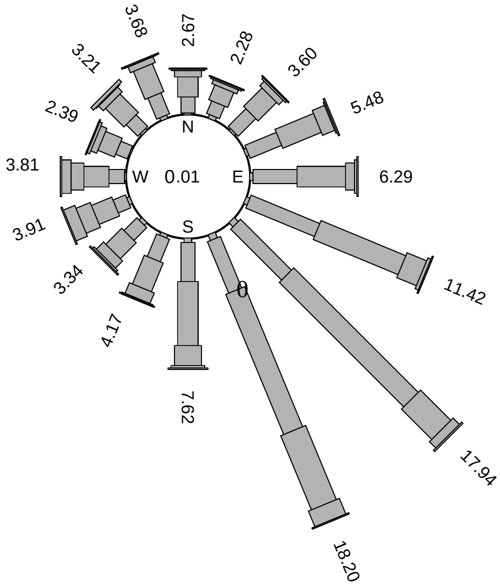
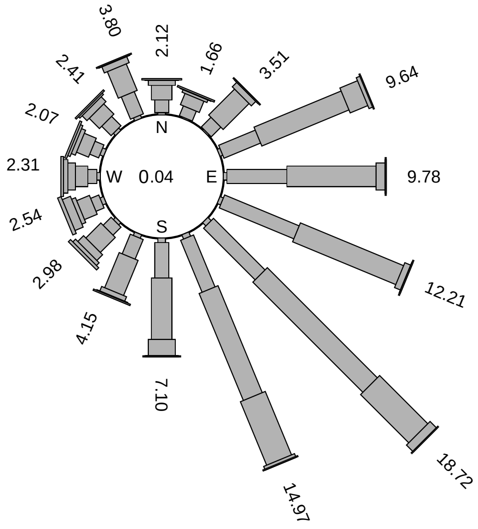


Cactus Flats Meteorological
Station June 1, 1998
through August 31, 1998



Cactus Flats Meteorological
Station September 1, 1998
through November 30, 1998

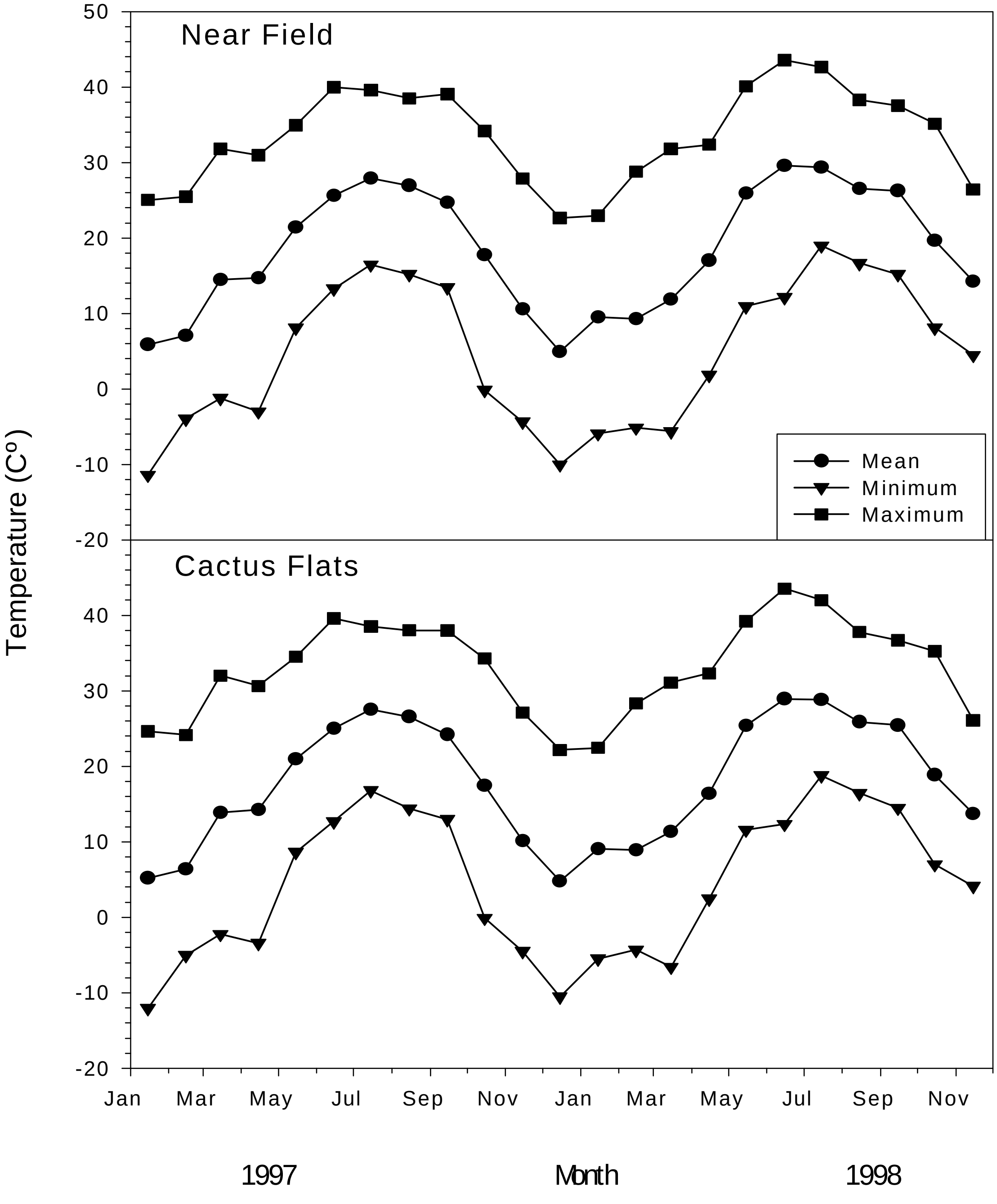


Figure 6. Monthly Mean, Minimum and Maximum Temperatures at Near Field and Cactus Flats from January 1997 through November 1998

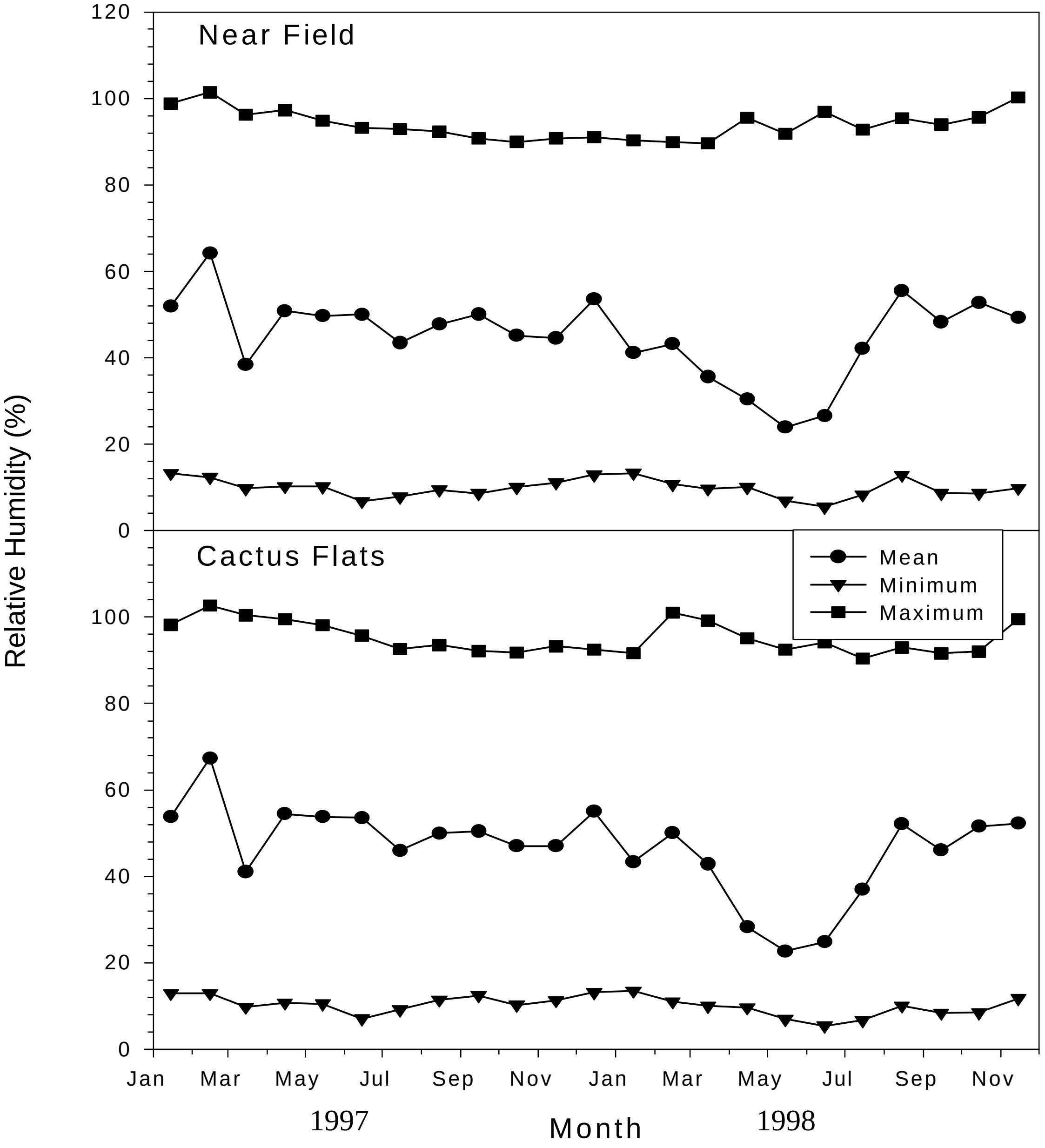


Figure 7. Monthly Mean, Minimum and Maximum Relative Humidity at Near Field and Cactus Flats from January 1997 through November 1998

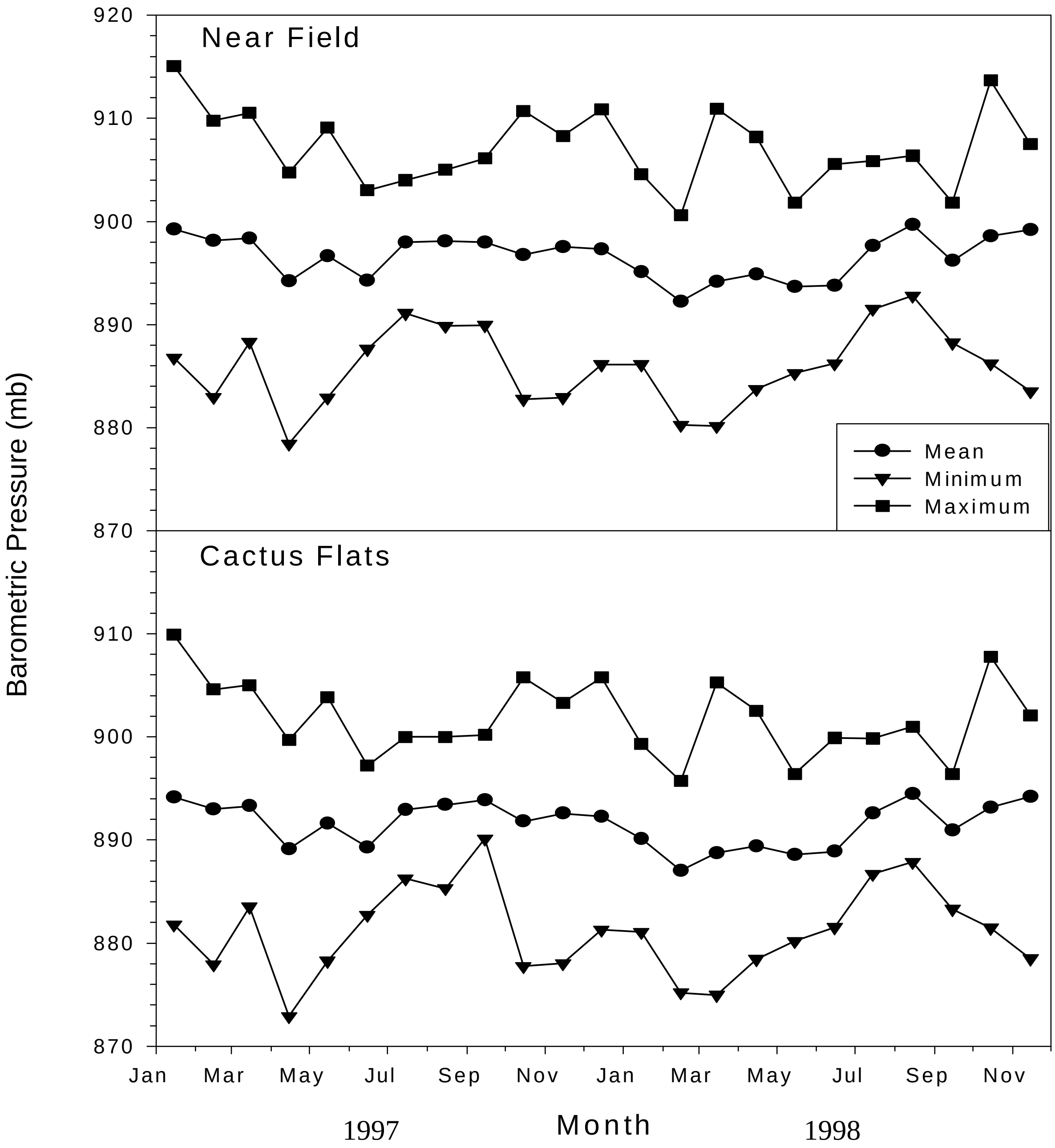


Figure 8. Monthly Mean, Minimum and Maximum Barometric Pressure Measurements at Near Field and Cactus Flats from January 1997 through November 1998

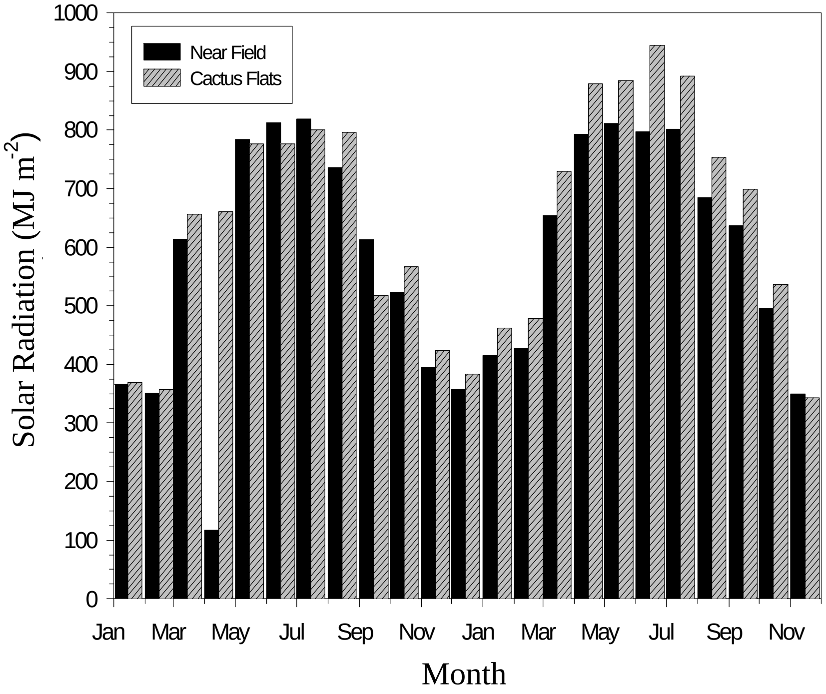


Figure 9. Total Solar Radiation Measured each Month at Cactus Flats and Near Field from January 1997 through November 1998

The low value for April 1997 at the Near Field site resulted when no data were collected from 6 April through 29 April due to a sensor malfunction.

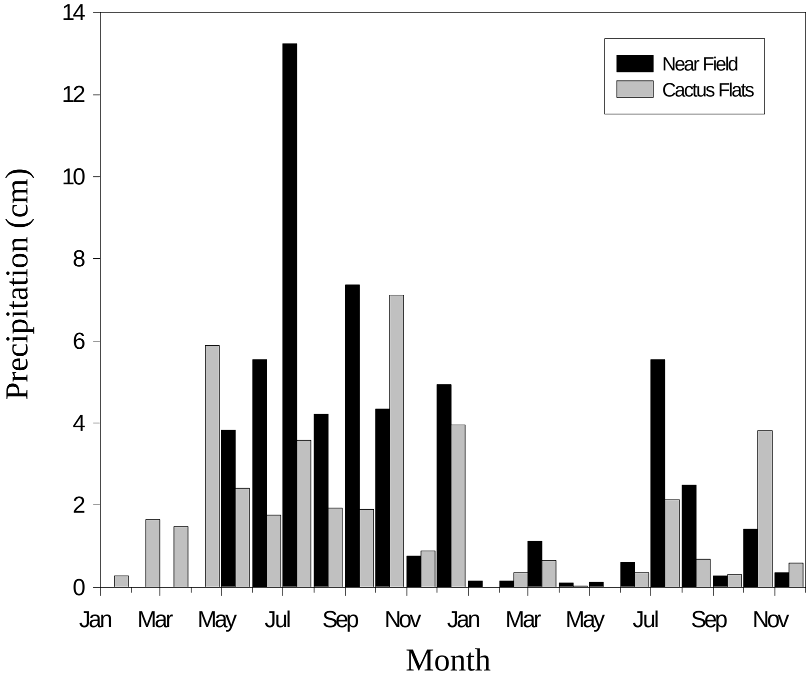


Figure 10. Total Precipitation Measured Each Month at Cactus Flats and Near Field from January 1997 through November 1998

No data were collected at the Near Field site from 1 January to 19 February 1997 due to a sensor malfunction.

Particulate Concentrations and Inorganics in Near-Surface Air

Introduction

The CEMRC aerosol sampling program for the WIPP EM is designed to study the pathway that is unarguably the most likely route by which contaminants from the WIPP site could become rapidly dispersed in the environment. A major objective for these studies of aerosols is to investigate relationships among trace metals, ions, and radionuclides in aerosol samples collected from the vicinity of the WIPP. Detailed documentation of these parameters of pre-operational conditions is necessary to accurately assess any suspected changes occurring after the disposal operations commence. Data for trace metals and aerosol ion concentrations also contribute to an understanding of the natural variability and the sources and sinks for various types of pollutants, which enhances identification of causes for any observed changes in radionuclide activities.

Methods

A summary of the sampling design for the aerosol studies is presented elsewhere in this report (Aerosol section, p. 8). Aerosol samples are currently collected from four sites, but only data from three sampling stations (On Site, Cactus Flats and Near Field) are reported in this summary. Low-volume samplers (10 L min^{-1}) were used to collect aerosol TSP, PM$_{10}$ and PM$_{2.5}$ for non-radiological analyses reported here.

The aerosol samples were analyzed by CEMRC for suites of major and trace elements by atomic absorption (AA) spectrometry and inductively-coupled plasma atomic emission spectrometry (ICP-ES), and the concentrations of selected anions and cations were determined by ion chromatography (IC). A subset of the aerosol samples was also analyzed by an X-ray fluorescence (XRF) technique through a subcontract with the Desert Research Institute (DRI). The XRF studies are a continuation of work begun in December 1996; the first set of XRF data was presented in the CEMRC 1997 Report.

Aerosol filters from low-volume samplers were prepared for the elemental (AA and ICP-ES) analyses using a CEM 2100 Microwave digestion system. A combination of microwave energy and strong acids is needed to destroy the mixed-cellulose ester filter matrix (Gelman Metricel®) and to solubilize the more refractory materials collected on the filter. The aerosol-laden filters were processed in sealed microwave vessels using a combination of HNO_3, HCl, HF, and H_2O_2.

For the IC analyses, individual Gelman Teflo® PTFE Teflon® filters were extracted in clean polyethylene bags after first wetting the filters with isopropyl alcohol. The filters were extracted in three steps with de-ionized water in sealed polyethylene bags, and the extractions were done in an ultrasonic water bath to facilitate the process. The same aqueous extracts of the aerosol samples were used for both anion and cation analyses. In some cases the aqueous extracts not consumed in the IC analyses also were analyzed by ICP-ES to provide intra-laboratory comparisons between instruments. Standard operating procedures have been developed for the CEMRC analyses, and where possible these are based on applicable standard U.S. Environmental Protection Agency (EPA) procedures. A summary of the analytical procedures used for the AA, ICP-ES and IC analyses of WIPP EM samples is presented elsewhere in this report (Appendix K).

Standard operating procedures have been developed for the CEMRC analyses, and where possible these are based on applicable standard U.S. Environmental Protection Agency (EPA) procedures. A summary of the analytical procedures used for the AA, ICP-ES and IC analyses of WIPP EM samples is presented elsewhere in this report (Appendix K).

Gravimetric determinations of aerosol mass were completed at CEMRC. Prior to placement in the aerosol samplers, all filters were preconditioned in a dessicator, equilibrated to ambient conditions, and then weighed using a microbalance (1 μg resolution). At the completion of each sampling period, filters were removed from the samplers and placed in petri dishes for transport and storage. Loaded filters were re-conditioned, re-equilibrated, and re-weighed to determine total mass accumulation. The total air volume for each sampling period was calculated based on an integrated total during each sampling interval. The mass accumulation divided by the total air volume drawn through the sampler was used to calculate the aerosol mass concentrations.

Elemental analyses by XRF were performed by DRI in Reno, Nevada. A Kevex Corporation Model 0700/8000 and a Kevex 0700/IXRF energy dispersive X-ray fluorescence analyzer were used for the analyses. Details of the XRF analytical procedure and the quality assurance/quality controls (QA/QC) used for the analyses were presented in the CEMRC 1997 annual report. Briefly, two protocols were used for the analyses of the aerosol-laden filters: Protocol C for the TSP and PM_{10} samples and Protocol D for the $PM_{2.5}$ samples. These protocols differ in data acquisition times, with longer counting times used for 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}.

The XRF analyses 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. However, not all elements were detected in the WIPP EM aerosol samples. The following discussion is based on the XRF analysis of randomly selected sets of samples (two per week), most of which were collected in 1997. Each set consisted of a TSP, PM_{10} and $PM_{2.5}$ low-volume sample collected over a nominal 24-hr period. All of the samples analyzed by XRF were from the Near-Field station. If one or more samples from a set were missing, the others were analyzed anyway.

Results and Discussion

XRF Analyses of Trace Elements

As reported in the CEMRC 1997 Report, the first focus of the studies using the DRI XRF data is to identify the main sources of particulate matter in the Carlsbad area. In general one would expect to see several major components in the aerosol, including (1) mineral dust (Al and Si often are used as an indicators of dust but many other elements are dominated by dust), (2) sulfate and other major ions, (3) a complex and poorly-characterized suite of organics from both natural and anthropogenic sources, and (4) various types of pollution aerosols.

A time-series plot of Al (mineral aerosol) concentrations in the TSP, PM_{10} and $PM_{2.5}$ samples is presented in Fig. 11 (note that the Y-axis for this figure is a logarithmic scale). The mineral aerosol concentrations of Al did not vary strongly with season. However, several moderate dust events were evident, including the two most prominent in early mid-March and July of 1997. The concentrations of Al in the TSP and PM_{10} fractions exhibited a similar pattern of variation, which is not unexpected because most of the dust mass normally is associated with particles less than 10 μm, and therefore the dust concentrations in the PM_{10} samples should be similar to those in the TSP fraction. It is also interesting to note that although the Al concentrations in the $PM_{2.5}$ fraction were only about 10% of those in TSP or PM_{10}, the small particle fraction tracked the PM_{10} and TSP samples rather well, suggesting that the proportion of 2.5 μm dust particles relative to the total mineral dust concentrations stayed relatively constant throughout the year.

Mineral aerosol made up a significant fraction of the TSP mass, but the mass of particulate material in the atmosphere clearly cannot be accounted for by windblown dust alone. If the TSP mass were solely due to mineral dust, all of the points in Fig. 12 would have fallen close to the "crustal ratio" line, which is based on an average Al concentration of ~8% in crustal weathering products (Taylor, S. R., and S. M. McLennan, 1995, *Reviews of Geophysics*, 33, 241). Some points were at or above the crustal line, indicating that under some circumstances the bulk of the TSP could be accounted for by dust concentrations, but this only seemed to occur when the TSP mass concentrations were > 10 $\mu g\ m^{-3}$. To evaluate the dust contribution to the total mass concentrations, one can calculate the percentage of mass accounted for by dust:

$$\text{\% of Mass Concentrations Attributable to Dust} = 100^* ([Al]_{observed} * 12.5)/[Mass]_{observed}$$

For the TSP samples (N = 60), the mean percentage ($\pm$ SD) of mass attributable to dust was 46% ($\pm$ 33%). The corresponding value for PM_{10} (N = 67) was essentially the same (47 $\pm$ 36%). In contrast, the percentage of aerosol mass attributable to mineral dust for the $PM_{2.5}$ fraction (N = 64) was only 9% ($\pm$ 12%), clearly indicating the dominance of non-crustal materials in the small particle fraction.

Compared with Al (see Fig. 11) the atmospheric S mass concentrations followed a similar pattern of variation in all three particle fractions (TSP, PM_{10} and $PM_{2.5}$) (Fig. 13). Presumably, this occurred because most of the S occurred as sulfate aerosol which is mainly formed *via* gas-to-particle conversion (see below). This heterogeneous process favors the formation of submicrometer (often called fine) aerosols, and therefore the bulk of the sulfate mass was carried by the $PM_{2.5}$ fraction. Zn and Pb were also substantially enriched with respect to a crustal source and exhibited patterns more similar to S than to Al, in that their mass tended to be concentrated in the $PM_{2.5}$ fraction.

A comparison of S concentrations as a function of mass (Fig. 14) showed that the calculated sulfate concentrations (derived from the XRF sulfur data) at times accounted for ~40% to 45% of the total mass in the $PM_{2.5}$ fraction. This conclusion is based on the assumption that sulfate was the dominant form of S in the aerosol; evidence supporting this assumption is presented below. Further examination of this relationship for the XRF data indicated that sulfate more commonly accounted for ~20% of the $PM_{2.5}$ mass.

The IC data were used to directly calculate the percentages of mass accounted for by sulfate at Near Field and at Cactus Flats. These calculations showed that the mean percentages of total mass ($\pm$SE) accounted for by sulfate in the $PM_{2.5}$ fraction were comparable to estimates from the XRF data: 18% ($\pm$ 1.9%) at Near Field (N = 19) and 19% ($\pm$ 2.6%) at Cactus Flats (N = 14) (Table 4). The percentage of mass due to sulfate was higher in the $PM_{2.5}$ fraction than in either PM_{10} or TSP, which were similar, at about 10% at both sites. The concentrations of nitrate in the samples were much smaller than sulfate, amounting to only a few percent in any of the size fractions. These results indicate that major ions such as sulfate and nitrate are important, but at least in terms of mass, not dominant components of the background fine aerosol in the area of the WIPP.

Relationship between Aerosol Sulfur and Sulfate

Comprehensive understanding of biogeochemical cycles requires information on the forms in which the elements of interest exist. In the present studies, the analyses provide a means of determining the fraction of S in the atmosphere that exists as sulfate, something not often possible in prior work. To investigate this question, ion chromatography was used to analyze a subset of samples previously analyzed by XRF with low, high and intermediate mass concentrations.

The results of this comparison are shown in a plot of the XRF S data compared to the IC sulfate data (Fig. 15). The diagonal line shown in this figure is the predicted relationship if all of the S were in the form of sulfate (3:1 ratio, MWT(molecular weight) sulfate/MWT of S). For the TSP samples, all of the points fall on the diagonal line or very close to it, supporting the hypothesis that sulfate is the dominant form of S in the aerosol. Clearly some of the PM_{10} and $PM_{2.5}$ points fall to the right of (or below) the line as concentrations increase; this could most easily be explained by the existence of some S species other than sulfate. Another possibility is that one set of measurements is biased. However, even if this were true, the non-sulfate fraction would be small in terms of mass (typically 10% to 15% of the S mass concentration).

Relationship between Aerosol Sulfate and Nitrate

The relationship between aerosol sulfate and nitrate in the WIPP EM data is of interest because these two atmospheric constituents are important for aerosol acidity, and because their concentrations in the atmosphere generally exhibit a degree of co-variability. Nitrate and sulfate in aerosols are mainly formed in the atmosphere *via* the oxidation of gaseous precursors (i.e., nitrogen and sulfur oxides). Sulfate in particular tends to be concentrated in small aerosol particles, and therefore sulfate normally accounts for a larger percentage of the $PM_{2.5}$ mass relative to PM_{10} (or TSP). This characteristic of aerosol sulfate is important in the context of the WIPP-EM because some of the radionuclides of interest also are expected to be enriched in the aerosol $PM_{2.5}$ size fraction.

A comparison of sulfate and nitrate concentrations (Fig. 16) showed little difference between the Near Field and Cactus Flats stations. However, there appeared to be a difference among size fractions, with a higher sulfate to nitrate ratio in the $PM_{2.5}$ samples compared to the TSP and PM_{10} samples. A possible mechanism for this is sorption of gas-phase nitric acid onto pre-existing aerosols (i.e. condensation of nitric acid onto dust and other large particles).

The comparison of sulfate and nitrate concentrations also showed that some of the aerosol samples had unusually high sulfate/nitrate ratios ($\geq$ 50). These anomalous ratios occurred when sulfate loadings were higher than average, and the nitrate concentrations were lower than average. Furthermore, the samples with high sulfate/nitrate were not restricted to one site, nor to a particular size fraction (Fig. 17). It is possible that some artifacts were introduced during sampling or sample preparation, but a more interesting possibility is that the anomalous sulfate/nitrate ratios reflected changing environmental conditions. The most intriguing scenario is that these anomalous chemical signals were related to the very large volumes of smoke transported from Mexico to the southwestern United States in the spring of 1998.

Effects of Fires in Mexico

As part of an investigation of possible effects of the Mexican smoke plumes, aerosol mass concentrations for both Near Field and Cactus Flats were plotted for the spring and early summer of 1998. A strong peak in the $PM_{2.5}$ mass was observed on 23 March 1998 at Near Field and this matched a peak in TSP mass on the same date at Cactus Flats (Fig. 18). While these simultaneous peaks in particle mass may have been caused by a particular smoke event, there was no obvious evidence for a more pervasive influence of the smoke on mass concentrations in any other aerosol size fraction. Another possible source for the simultaneous high mass concentrations is windblown dust event. This is not likely to be the cause because the wind speeds recorded on the days of heavy mass concentrations were not unusually high.

It is interesting to note that some unusually high sulfate/nitrate ratios were observed at or around the same time as the high mass concentrations. At Near Field, the nitrate concentration in the 23 March $PM_{2.5}$ sample was below detection, but if the detection limit for nitrate for a nominal 24-hour sample (0.0088 $\mu g\ m^{-3}$) were substituted, the sulfate to nitrate ratio would be 81, a value much higher than the typical ratios of 5 to 10. Furthermore, the sulfate/nitrate ratios for the prior two $PM_{2.5}$ samples (collected starting 9 and 18 March) were 31 and 84, respectively, indicating that the 23 March sample was not simply an outlier. This is further substantiated by the data from Cactus Flats where a high sulfate/nitrate ratio (66) was observed in the 13 March $PM_{2.5}$ sample. However, the sulfate/nitrate ratios during this period are not uniformly high; the 18 March $PM_{2.5}$ sample from Cactus Flats had a more typical value (6.1).

As mentioned above, the high ratios were more the result of lower nitrate rather than higher sulfate concentrations, suggesting the re-volatilization of nitrate from the aerosol. Tsai and Peng (Tsai, C-J., and S-N. Peng, 1998, *Atmospheric Environment*, 32, 1605) suggest that sampling losses of volatile species, including nitrate, can occur as a result of gas-particle and particle-particle interactions during sampling, and these may apply in this case. Although outside the scope of the WIPP EM, these data raise an interesting question concerning what chemical reactions were responsible for the loss of nitrate during collection of some samples but not others.

Another step in investigating possible effects from the fires was to examine the data for fine-particle K, a commonly used chemical tracer for biomass burning (Andreae, M. O., 1983, *Science*, 220, 1148). One would expect strong peaks in the $PM_{2.5}$ K concentrations during the smoke events, but only one sample, collected on 18 May 1998, appeared to have an unusually high fine particle K concentrations (one collected on 4 May and the other on 18 May 1998). High K concentrations were not observed on 23 March, when the high mass concentrations and the high sulfate/nitrate ratios were observed (Fig. 19). However, the sample with the high concentration of fine particle K was collected when the effects of the smoke from the Mexican fires were readily visible locally, confirming that the long-range transport of smoke aerosol can at times be detected *via* chemical changes in the Carlsbad aerosol.

Although many residents of the Carlsbad area probably were aware of the smoke, the impacts of the fires were more subtle than one might expect. For example, a plot of solar radiation at Carlsbad (Fig. 20) does not show any extended perturbations caused by the smoke. Even though some reductions of the solar flux were evident, these cannot be directly linked to the fires from the data currently available. As noted above, the mass concentrations did not appear to be significantly affected by the fires, but some chemical alterations of the aerosol may have occurred as a result of the fires.

This was the first year in which a relatively complete set of inorganic data were obtained for the WIPP EM, and more information on the effects of Mexican fires on the Carlsbad aerosol will be obtained in future monitoring studies if the situation arises again. In addition, studies by other groups have shown that the smoke aerosols have elevated levels of several carbonyl compounds (R. Dixon, New Mexico Institute of Mining and Technology, personal communication). Methods are being developed by CEMRC for the determination of acetate and formate, two substances that also may be affected by fires.

Analyses of Trace Elements by AA and ICP-ES

Trace element concentrations in a subset of forty low-volume aerosol samples from the three sampling stations were determined at CEMRC using AA spectrometry and ICP-ES. Results of these analyses performed on acid digests of the filters are summarized in Tables 5 and 6. These were the first aerosol samples analyzed by the AA and ICP-ES techniques at CEMRC, and as a first step in evaluating the data, we compared the results from the in-house analyses with XRF data previously obtained. Several caveats regarding this comparison bear mention. First, the analyses were performed on different sets of samples collected at the same station but during different times. Therefore, the samples cannot be considered directly comparable; instead, this comparison gives a first-order indication of whether the data are generally consistent with the earlier results. A series of in-house QC tests were performed to validate the results. A second caveat is that only a small number of samples were available for comparison. For this evaluation, we used data only from the Near Field station because XRF data are only available from that station. Data are available for only 19 samples analyzed by AA and ICP-ES, including six TSP, seven PM_{10}, and six $PM_{2.5}$ samples.

To compare results between the XRF and AA/ICP-ES analyses, we calculated relative percent difference for the mean concentrations of those elements determined by both laboratories. The relative percent difference is calculated as

$$RPD = \frac{(C_1 - C_2)}{(C_1 + C_2) \big/ 2} * 100\,\%$$

where RPD is the relative percent difference, C_1 is the concentration determined by XRF analysis, C_2 is the concentration determined by AA/ICP-ES analysis.

Results of this comparison between analytical techniques are presented in Table 7. In general the results all agreed to within a factor of 3 (this corresponds to a relative percent difference of 100%). This comparison showed the largest differences between techniques for Zn and Ni, but these large differences were driven by a few samples with very high concentrations of these elements. For example, the Zn concentration measured by ICP-ES in the TSP sample collected at Near Field on 6 October 1998 was 0.37 μg m^{-3}. Another sample collected on 22 June 1998 and analyzed by XRF had a Zn concentration of 0.0056 μg m^{-3}. One might speculate that the high Zn concentration resulted from contamination during sampling or sample preparation, but this would only be speculation, and there is no *a priori* reason to discard this sample as problematic. Follow-up examinations of the in-house data with respect to the XRF results will continue as more samples are analyzed. At the same time, both inter- and intra-laboratory comparisons will be conducted to further validate the analytical methods.

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

Table 4. Summary Statistics for Sulfate and Nitrate Concentrations in Aerosols

Sampling Station	Analyte/ Variable	Aerosol Particle Diameter Classes	[a]N	[b]Mean	[c]SE
On Site	% Sulfate	[d]TSP	12	5.4	0.94
	% Nitrate		9	1.8	0.31
	Sulfate/Nitrate Ratio		10	2.9	0.26
	% Sulfate	[e]PM_{10}	0		
	% Nitrate		0		
	Sulfate/Nitrate Ratio		0		
	% Sulfate	[f]$PM_{2.5}$	0		
	% Nitrate		0		
	Sulfate/Nitrate Ratio		0		
Near Field	% Sulfate	TSP	22	10.3	1.3
	% Nitrate		15	3.5	0.57
	Sulfate/Nitrate Ratio		15	4.0	0.74
	% Sulfate	PM_{10}	18	11.7	1.7
	% Nitrate		14	2.3	0.31
	Sulfate/Nitrate Ratio		14	8.1	3.0
	% Sulfate	$PM_{2.5}$	19	17.7	1.9
	% Nitrate		10	2.1	0.48
	Sulfate/Nitrate Ratio		9	19.7	8.6
Cactus Flats	% Sulfate	TSP	31	8.6	0.90
	% Nitrate		19	3.2	0.54
	Sulfate/Nitrate Ratio		19	4.6	1.4
	% Sulfate	PM_{10}	20	9.9	1.5
	% Nitrate		15	2.3	0.38
	Sulfate/Nitrate Ratio		15	7.8	3.3
	% Sulfate	$PM_{2.5}$	14	19.0	2.6
	% Nitrate		8	1.9	0.5
	Sulfate/Nitrate Ratio		8	20.8	7.8

[a] N = number of samples above detection limit that were included in calculation of mean; number in parenthesis is total number of samples analyzed

[b] Mean = arithmetic mean

[c] SE = standard error

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

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

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

Table 5. Summary Statistics for Trace Elements in Aerosol Samples Collected at On Site and Cactus Flats during May - July 1998

		Aerosol Particle Diameter Classes											
		[a]TSP On Site			TSP Cactus Flats			[b]PM_{10} Cactus Flats			[c]$PM_{2.5}$ Cactus Flats		
Element	Units	[d]N	[e]Mean	[f]SE	N	Mean	SE	N	Mean	SE	N	Mean	SE
Al	μg m^{-3}	5	8.3E-1	3.8E-2	6	7.5E-1	1.3E-1	5	4.9E-1	1.2E-1	4	1.2E-1	4.0E-2
As	μg m^{-3}	1	1.9E-3		1	1.8E-3		3	1.5E-3	4.0E-4	2	1.5E-3	5.0E-5
Ba	μg m^{-3}	5	7.8E-3	2.5E-3	6	7.0E-3	2.2E-3	5	6.2E-3	1.1E-3	5	1.3E-3	1.8E-4
Be	μg m^{-3}	0			1	2.4E-1		0			0		
Ca	μg m^{-3}	5	1.9E+0	7.5E-1	6	1.2E+0	6.1E-1	5	7.1E-1	1.7E-1	4	9.0E-2	3.7E-2
Cd	μg m^{-3}	0			0			0			0		
Co	μg m^{-3}	4	6.5E-4	1.2E-4	2	2.4E-3	1.3E-3	1	1.2E-3		1	1.6E-3	
Cr	μg m^{-3}	5	3.1E-3	8.4E-4	4	5.8E-3	1.6E-3	4	4.5E-3	1.4E-3	3	4.0E-3	1.1E-3
Cu	μg m^{-3}	5	1.7E-2	7.1E-3	2	2.0E-2	5.5E-3	4	2.4E-3	7.0E-4	1	1.4E-3	
Fe	μg m^{-3}	5	3.4E-1	8.4E-2	6	3.1E-1	6.9E-2	5	2.7E-1	5.1E-2	5	6.4E-2	1.0E-2
K	μg m^{-3}	5	3.4E-1	5.5E-2	4	3.1E-1	5.3E-2	5	2.7E-1	4.1E-2	4	1.8E-1	2.5E-3
Mg	μg m^{-3}	4	3.6E-1	5.2E-2	6	1.9E-1	7.0E-2	4	1.6E-1	8.5E-3	4	3.8E-2	8.6E-3
Mn	μg m^{-3}	4	9.4E-3	1.9E-3	6	6.3E-3	1.6E-3	5	5.9E-3	1.7E-3	4	1.4E-3	6.2E-4
Mo	μg m^{-3}	0			0			0			0		
Na	μg m^{-3}	4	2.0E-1	5.3E-2	5	4.4E-1	1.7E-1	4	2.4E-1	7.1E-2	2	1.1E-1	2.3E-2
Ni	μg m^{-3}	1	8.4E-4	.	6	1.2E-2	6.9E-3	2	1.0E-2	8.8E-3	2	1.3E-2	1.1E-2
Pb	μg m^{-3}	3	5.3E-3	1.2E-3	5	3.8E-3	1.3E-3	3	3.2E-3	5.3E-4	4	4.3E-3	1.7E-3
Sb	μg m^{-3}	2	1.7E-3	5.0E-5	1	9.0E-4	.	2	8.0E-4	9.5E-5	2	1.5E-3	8.0E-4
Se	μg m^{-3}	0			2	1.9E-3	1.8E-3	0			1	7.2E-5	
Sr	μg m^{-3}	4	5.7E-3	1.0E-3	6	3.9E-3	1.4E-3	5	3.3E-3	8.4E-4	4	1.9E-3	1.1E-3
V	μg m^{-3}	4	1.6E-3	3.5E-4	4	1.3E-3	3.5E-4	5	1.5E-3	1.9E-4	5	6.9E-4	7.9E-5
Zn	μg m^{-3}	1	6.9E-3		2	1.5E-1	1.4E-1	2	2.1E-2	1.5E-2	3	2.2E-2	9.5E-3

[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 above detection limit that were included in calculations
[e] Mean = arithmetic mean
[f] SE = standard error

Table 6. Summary Statistics for Trace Elements in Aerosol Samples Collected at Near Field during May-July 1998

		Aerosol Particle Diameter Classes								
		[a]TSP			**[b,g]PM$_{10}$**			**[c]PM$_{2.5}$**		
Element	**Units**	**[d]N**	**[e]Mean**	**[f]SE**	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**
Al	μg m^{-3}	6	4.8E-1	6.4E-2	7	2.0E+0	1.5E+0	5	1.4E-1	3.3E-2
As	μg m^{-3}	3	9.0E-4	1.3E-4	2	1.4E-3	2.5E-4	3	1.2E-3	2.8E-4
Ba	μg m^{-3}	6	5.7E-3	7.5E-4	7	1.2E-2	7.5E-3	6	2.0E-3	5.4E-4
Be	μg m^{-3}	1	2.8E-1		0			0		
Ca	μg m^{-3}	6	6.4E-1	8.6E-2	7	1.8E+0	1.2E+0	4	1.8E-1	3.6E-2
Cd	μg m^{-3}	0			0			1	2.2E-4	
Co	μg m^{-3}	3	8.2E-4	1.1E-4	3	8.4E-4	6.9E-5	1	3.3E-4	
Cr	μg m^{-3}	6	4.2E-3	1.1E-3	6	9.4E-3	3.1E-3	6	6.6E-3	1.9E-3
Cu	μg m^{-3}	4	2.0E-3	3.6E-4	4	5.4E-3	3.3E-3	2	1.8E-3	4.0E-4
Fe	μg m^{-3}	6	2.7E-1	3.9E-2	7	9.4E-1	6.8E-1	6	8.5E-2	1.5E-2
K	μg m^{-3}	6	2.7E-1	6.5E-2	7	1.1E+0	7.6E-1	4	2.3E-1	3.1E-2
Mg	μg m^{-3}	6	1.4E-1	1.9E-2	7	5.2E-1	3.8E-1	6	4.0E-2	6.1E-3
Mn	μg m^{-3}	6	5.2E-3	9.1E-4	7	5.3E-3	1.1E-3	5	2.1E-3	7.3E-4
Mo	μg m^{-3}	1	1.5E-3		2	2.1E-3	3.0E-4	1	2.4E-3	
Na	μg m^{-3}	5	2.8E-1	6.2E-2	6	1.2E+0	1.0E+0	3	2.5E-1	8.9E-2
Ni	μg m^{-3}	3	9.6E-3	5.9E-3	3	1.7E-2	1.0E-2	2	1.6E-2	1.2E-2
Pb	μg m^{-3}	3	2.0E-3	1.5E-4	5	2.4E-3	3.5E-4	4	2.7E-3	2.9E-4
Sb	μg m^{-3}	1	6.8E-4		2	1.2E-3	1.5E-4	1	1.7E-2	
Se	μg m^{-3}	0			1	9.4E-4		0		
Sr	μg m^{-3}	6	2.8E-3	3.7E-4	7	1.0E-2	7.2E-3	5	7.7E-4	1.7E-4
V	μg m^{-3}	6	1.2E-3	1.6E-4	7	1.4E-3	1.5E-4	5	7.7E-4	1.4E-4
Zn	μg m^{-3}	2	1.9E-1	1.8E-1	5	2.8E-2	1.4E-2	1	5.2E-2	

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

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

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

[d]N = number of samples above detection limit that were included in calculations

[e]Mean = arithmetic mean

[f]SE = standard error

[g]One sample with apparent contamination was excluded for the calculation of summary statistics

Table 7. Summary Statistics Comparing 1997 XRF Data and 1998 ICP-ES and AA Data for Aerosols

	Aerosol Particle Diameter Classes					
	[a]TSP		[b]PM_{10}		[c]$PM_{2.5}$	
Element	[d]N	[e]RPD	N	RPD	N	RPD
Al	6	12	7	-57	5	-46
As	3	54	2	47	3	39
Ba	6	74	7	47	6	
Ca	6	-3	7	-54	4	-42
Cu	4	13	4	-37	2	0
Fe	6	-15	7	-69	6	-36
K	6	13	7	-52	4	-24
Mn	6	-2	7	-9	5	-19
Ni	3	-77	3	-89	2	-90
Pb	3	5	5	2	4	-8
Se	0		1	-14	0	
Sr	6	-8	7	-65	5	-7
Zn	2	-95	5	-73	1	-88

[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 above detection limit that were included in calculations

[e] RPD = relative percent difference where an RPD of 100% corresponds to a difference between values of a factor of 3.

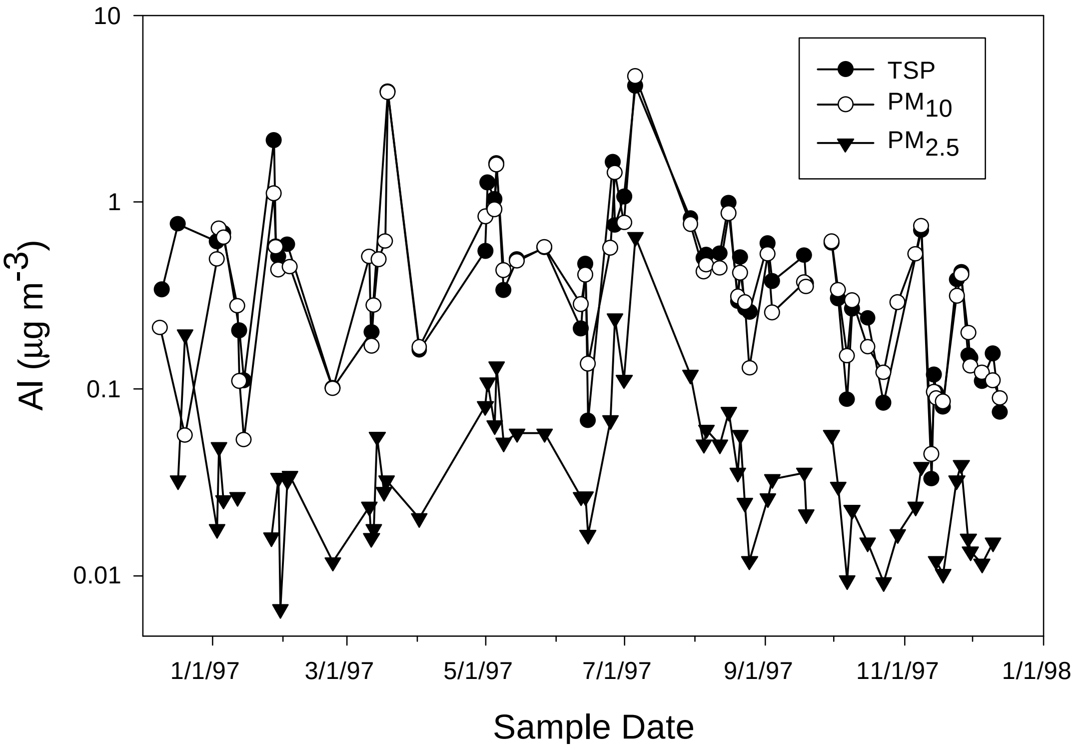


Figure 11. Aerosol Aluminum (Mineral Dust) Concentrations at Near Field

Data obtained by X-ray fluorescence analysis.

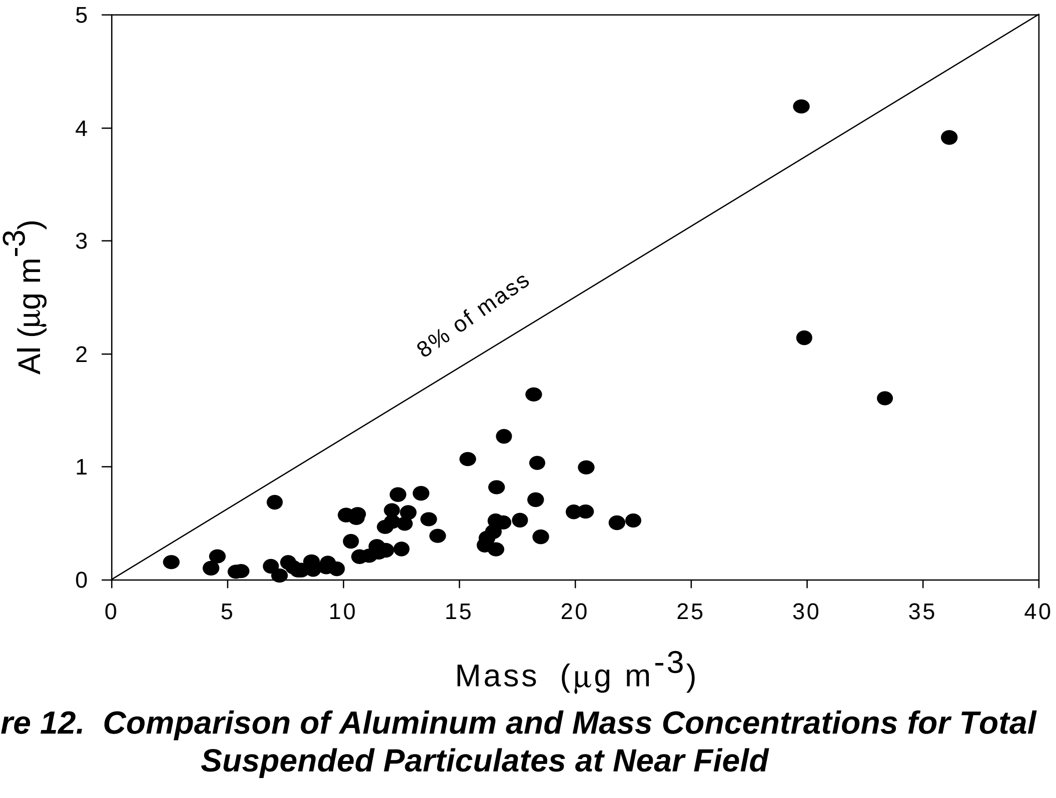


Figure 12. Comparison of Aluminum and Mass Concentrations for Total Suspended Particulates at Near Field

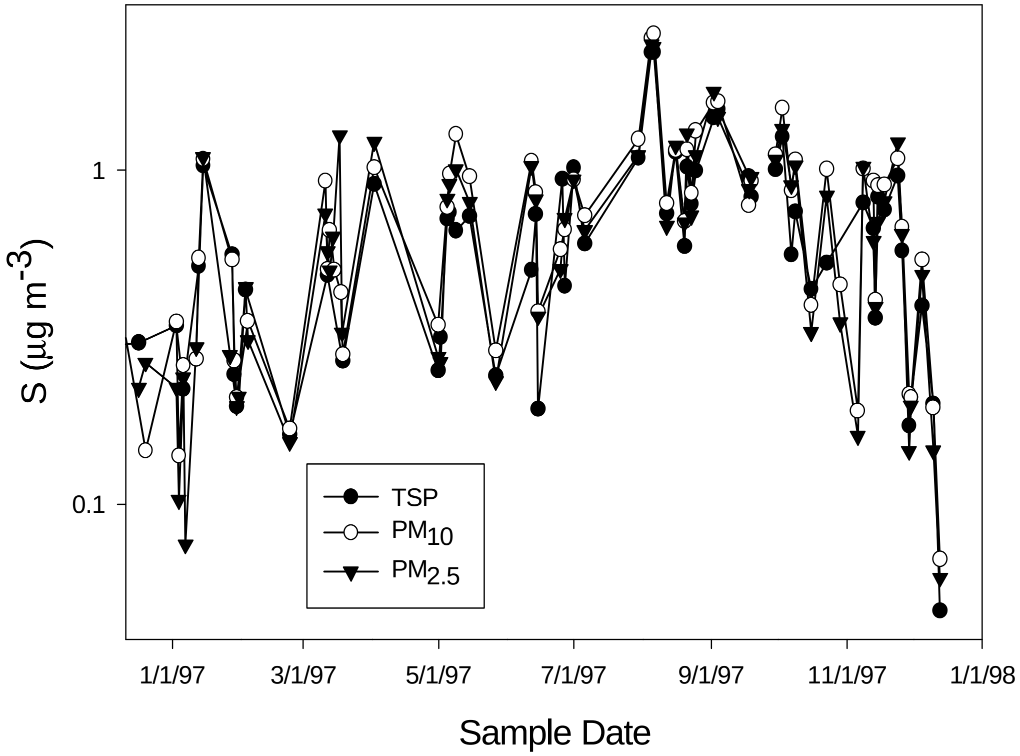


Figure 13. Aerosol Sulfur Concentrations at Near Field

Data obtained by X-ray fluorescence analysis.

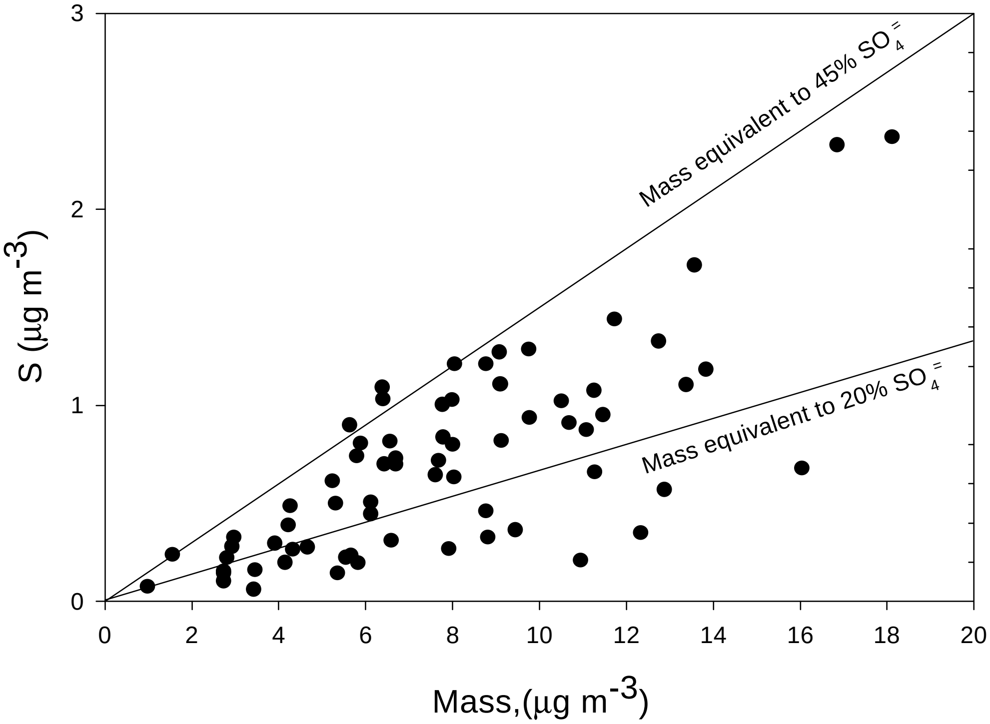


Figure 14. Comparison of Aerosol Sulfur and Mass Concentrations at Near Field

The lines represent the percentages of total mass accounted for by S assuming that all of the S exists as sulfate.

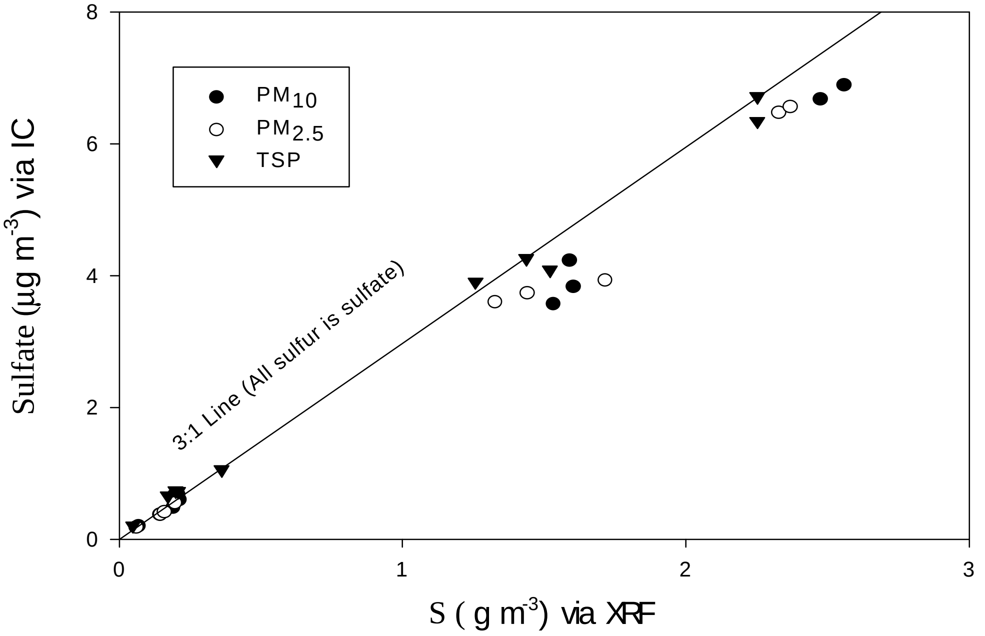


Figure 15. Comparison of Aerosol Sulfate and Sulfur Mass Concentrations at Near Field

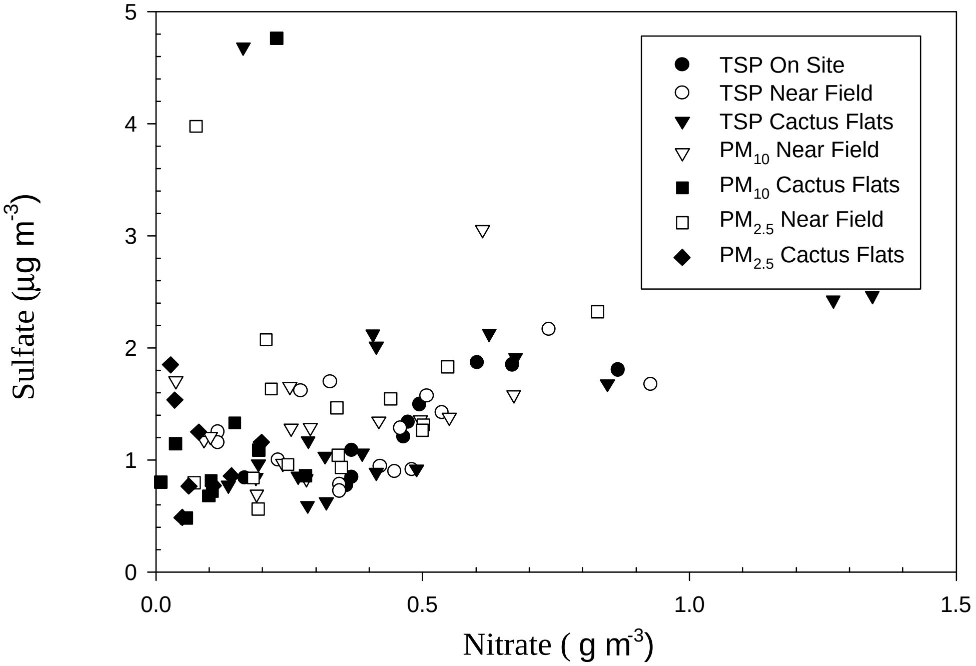


Figure 16. Comparison of Aerosol Sulfate and Nitrate Concentrations at On-Site, Near Field and Cactus Flats

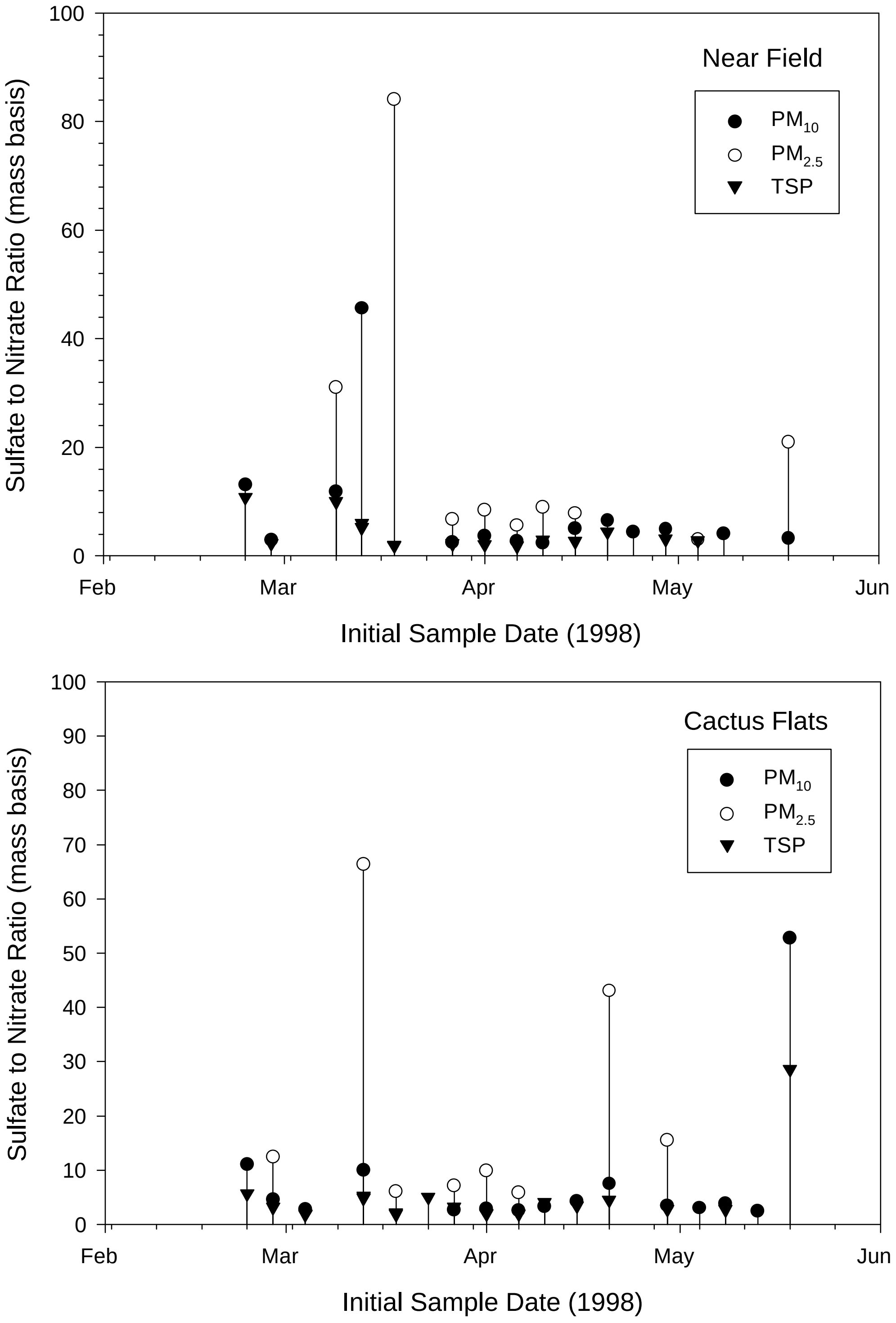


Figure 17. Sulfate: Nitrate Ratios in Aerosols at Near Field and Cactus Flats

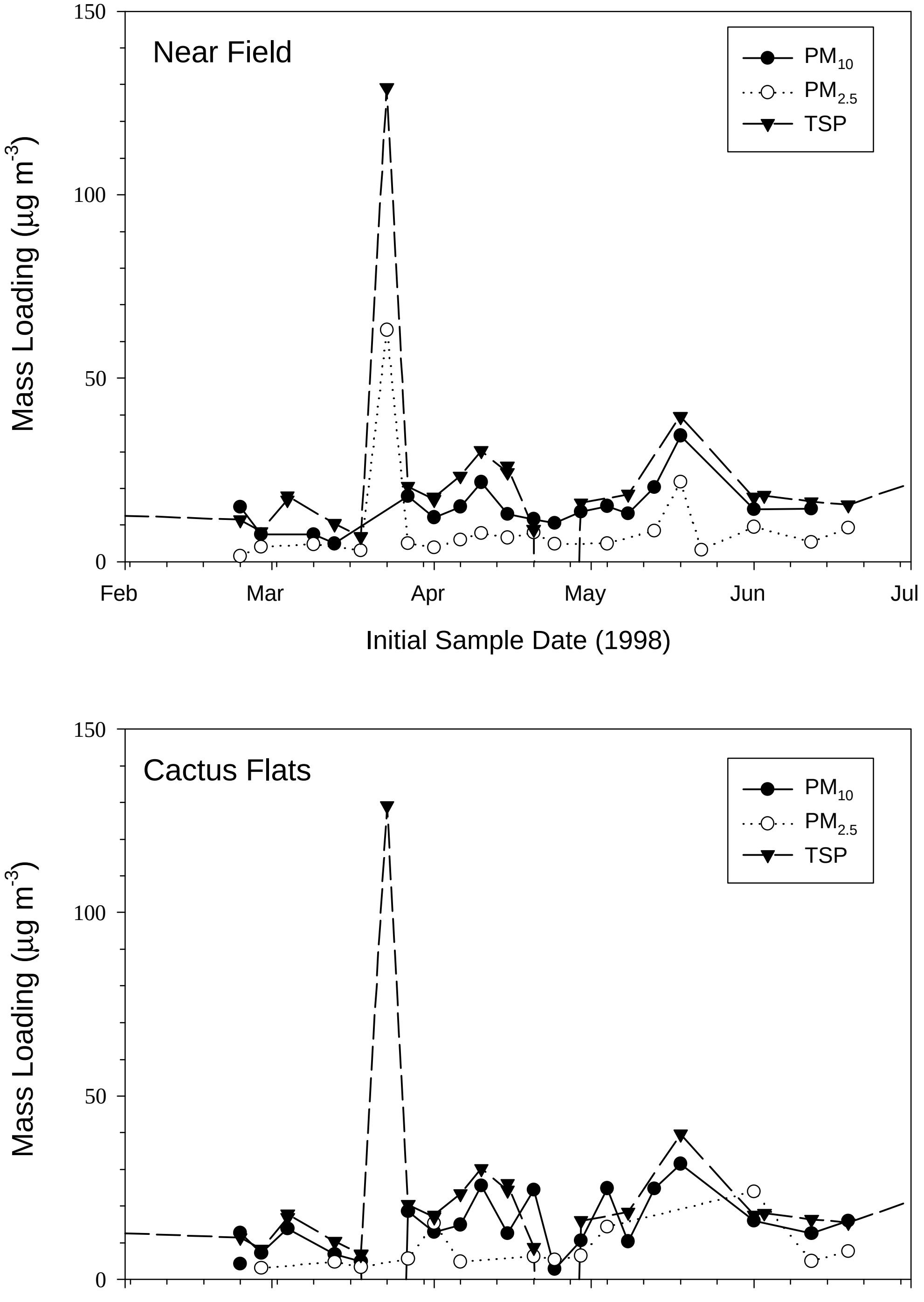


Figure 18. Aerosol Mass Concentrations in Aerosols at Near Field and Cactus Flats

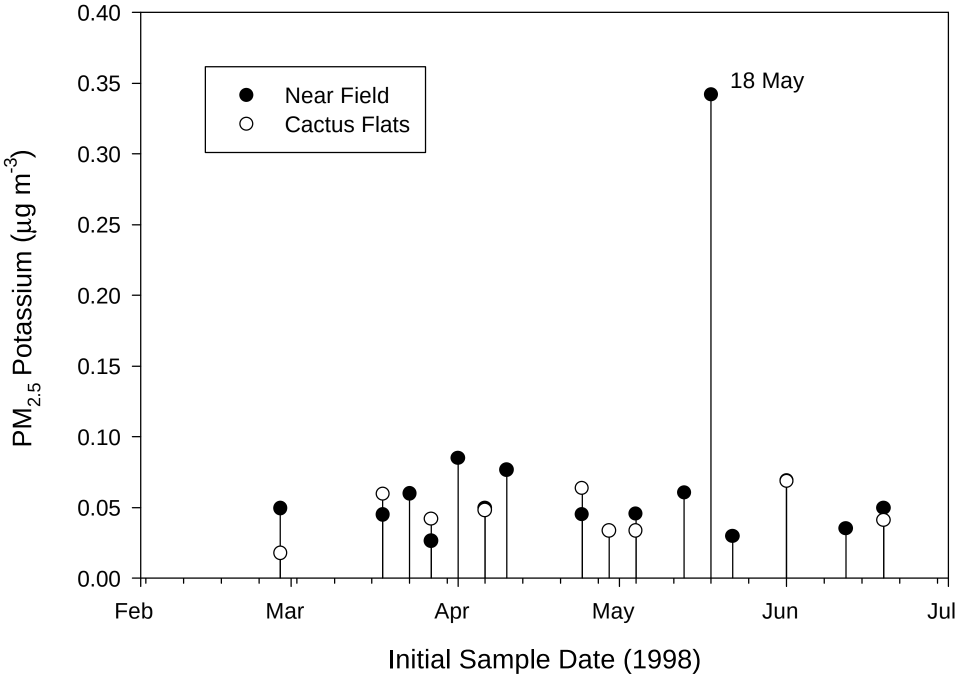


Figure 19. Potassium Concentrations in Aerosols at Near Field and Cactus Flats.

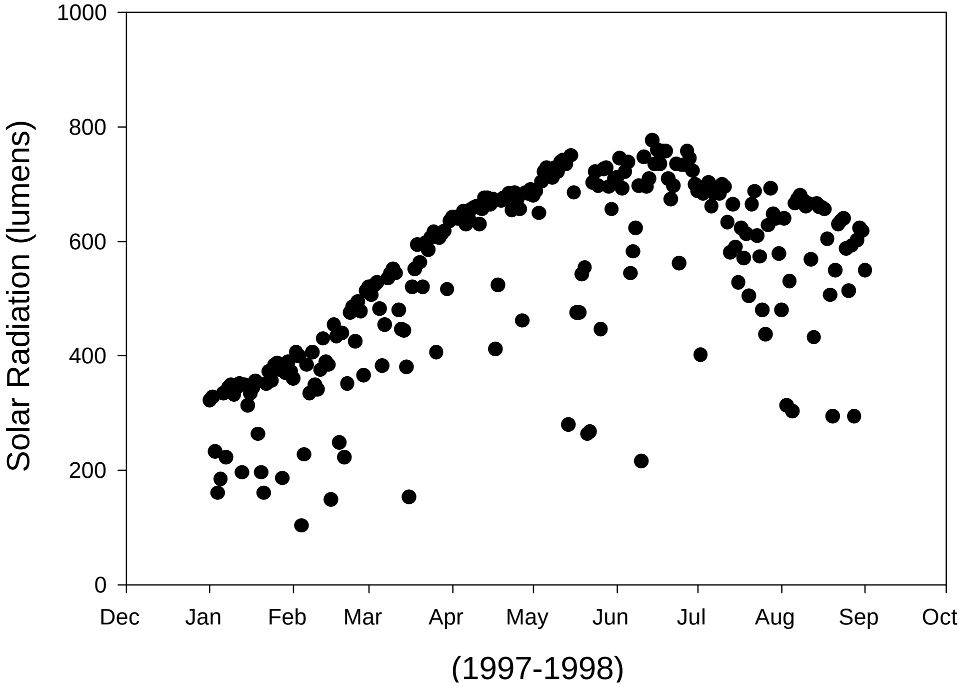


Figure 20. Solar Radiation Measured at Carlsbad, New Mexico

Surface Soil Radionuclides and Inorganic Chemicals

Methods

Results reported herein are for soil samples collected during 1998 from a grid of 16 locations surrounding the WIPP site (the Near Field grid) and a grid of 16 locations approximately 12 miles southeast of the WIPP (the Cactus Flats grid, Fig. 2). The 16 sampling locations composing each grid are distributed over approximately 16,600 hectares. At each of the 32 locations, soil was collected at three randomly selected sites within a 25-m radius of the selected reference point. 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 a 50 cm x 50 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 collections.

The soil samples were homogenized in the laboratory using a riffler. An aliquot of soil was removed for inorganic analyses, and the remainder of the sample was dried at 105° C. The soil aliquot used for inorganic chemical analyses was not oven dried because heating it to 105° C would vaporize any mercury in the sample. The method of homogenization was shown previously to yield subsamples that differed from the overall mean count of a radioactive tracer (^{137}Cs) by no more than 7%. A 250-g aliquot was removed from each homogenized sample and pulverized in a shatter-box prior to analysis for radionuclides.

Soil samples were analyzed at CEMRC for As, Cd, Sb, and Se, using a Perkin Elmer 5100 Graphite Furnace Atomic Absorption Spectrometer (GFAA) system. A FIAS-100 attachment and gold amalgamation system was used with the AA spectrometer for the measurement of Hg. A Perkin-Elmer Optima 3300 DV Inductively Coupled Plasma-Emission Spectrometry (ICP-ES) was used to analyze samples for Al, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, Sr, V, and Zn. Soil samples were analyzed for chloride, floride, nitrate, phosphate, and sulfate using a Dionex DX 500 Ion Chromatograph system equipped with an AS-14 separator column. The reported mean concentrations of these analytes in soil include only those values that were above detection levels. Thus, some estimates of the mean may be biased toward larger values.

Of the 96 samples collected, 37 were submitted for radiochemical analyses. These included one sample from each of the 16 locations of the Near Field grid, and one sample from each of 15 locations in the Cactus Flats grid. The analysis of one sample from Cactus Flats grid was delayed and could not be included in this report. Additionally, a NIST traceable reference soil, replicate samples for five locations, and two split samples were included as quality control checks. Both the replicates and the sample splits were included in the statistical analyses of the results. Forty-eight samples were also submitted for elemental and ionic analyses, including two samples from each of the 16 locations on the Near Field grid, and one sample from each of the 16 Cactus Flats locations.

An aliquot of approximately 10 g of each sample was used for analyses of actinides. Duke Engineering and Services (DES) (Bolton, Massachusetts) analyzed the samples for ^{234}U, ^{235}U, ^{238}U, ^{230}Th, ^{232}Th, ^{228}Th, and ^{239,240}Pu. Samples were recounted if activity measurements were less than the sample specific detection limit and had a sample specific concentration detection limit that exceeded 0.074 mBq g^{-1} for ^{239,240}Pu, 0.15 mBq g^{-1} for ^{235}U, and 3.7 mBq g^{-1} for ^{234}U, ^{238}U, ^{228}Th, ^{230}Th, and ^{232}Th. All radionuclide recoveries were 30-110%. Mean minimal detection concentrations (MDCs) observed for these actinides were 0.02 mBq g^{-1} for ^{239,240}Pu; 0.34 mBq g^{-1} for ^{232} Th, 1.37 mBq g^{-1} for ^{230}Th, 1.20 mBq g^{-1} for ^{228}Th; 3.0 mBq g^{-1} for ^{238}U; and 3.1 mBq g^{-1} for ^{234}U and ^{235}U.

Soil types were identified for each of the 32 sampling locations using soil survey maps (Chugg, J.C., et. al. 1971, *Soil Survey Eddy Area, New Mexico*, U.S. Department of Agriculture, Soil Conservation Service; Turner, M.T., et. al. 1974, *Soil Survey of Lea County, New Mexico*, US Department of Agriculture, Soil Conservation Service) (Table 8). In addition to the above analyses, a 1-L aliquot of soil from each of four soil types found on the Near Field grid was sent to A&L Plains Laboratory (Lubbock, Texas), yielding soil texture information for each of the four soil types identified in the Near Field grid.

Mean concentrations of all analytes were calculated by grid and by soil type, and 95% confidence intervals were computed for the estimated means using Student's *t* distribution. Significant differences between means were identified using a two-sided *t*-test. Multivariate analysis of variance (MANOVA) was used to test the hypothesis of no significant grid effect on analyte concentrations.

Results and Discussion

The soil textures for all of the soils were very similar, having 88-90% sand, 2-4% silt, and 6-10% clay. The Berino Complex soil is classified as a loamy sand, while the Berino Dune Complex, Kermit-Berino Fine Sand and Maljamar Fine Sandy Loam are identified as primarily sands.

The Cactus Flats grid had significantly higher soil concentrations of Al, As, Ba, Be, Ca, Co, Cr, Cu, Fe, K, Mn, Ni, Pb, V and Zn than were found on the Near Field grid ($p < 0.05$) (Fig. 21). Results of the MANOVA confirmed that there were significant differences between the two grids ($p < 0.05$), characterized by generally higher metal concentrations in samples from the Cactus Flats grid than in those from the Near Field grid. However, the ratios of these metals to aluminum (which normalized for the proportion of fine soil particles in the sample) are similar between the two grids (Table 9). This suggests that the observed difference in mean concentration is the result of a larger fraction of fine particles in the soil at the Cactus Flat grid. Soil concentrations of chloride for the Cactus Flats grid were significantly lower than their respective concentrations on the Near Field grid ($p < 0.05$). Furthermore, the ratios of Be, Ca, Co, Cu, Fe, K, Na, Ni, Pb, Se, Sr and Zn to Al were considerably higher in the aerosols than in the soils at both Cactus Flats and Near Field (Table 9). Although soil type did not appear to have an influence on analyte concentrations, a statistical analysis was prohibited because of low and variable numbers of samples collected within each soil type (Fig. 22).

Radionuclide activities greater than MDC were detected in all but one sample. Activity concentrations in individual soil samples were 5.4 - 12 mBq g^{-1} for ^{234}U, 0.20 - 0.65 mBq g^{-1} for ^{235}U, 5.6 - 12 mBq g^{-1} for ^{238}U, 4.2 – 17 mBq g^{-1} for ^{228}Th, 4.5 - 16 mBq g^{-1} for ^{230}Th, 4.7 - 15 mBq g^{-1} for ^{232}Th, and -.0015 - 0.40 mBq g^{-1} for ^{239,240}Pu. Concentrations of the radionuclides were significantly higher on the Cactus Flats grid than on the Near Field grid (Fig. 23) ($p < 0.05$). Results of the MANOVA confirmed that the two grids were significantly different ($p < .05$). However, the mean concentrations of the radionuclides relative to Al were similar between the two grids. Concentrations of the radionuclides at both sites were positively correlated with Al (Fig. 24) suggesting a fine particle effect as previously noted for metals. The overall mean ($\pm$ 95% CI) of 1998 measurements of ^{239,240}Pu concentration in samples from the Near Field grid was 0.090 (± 0.022) mBq g^{-1}, which is significantly lower than the overall mean for measurements made in 1997 on samples from the Near Field grid (0.14 (± 0.041) mBq g^{-1}). Concentrations of ^{239,240}Pu measured in samples from the 16 locations of the Near Field grid in 1998 showed no correlation with the concentrations of ^{239,240}Pu measured in samples from the same locations in 1997 ($r^2 = 0.028$, $n = 16$). These differences are likely the result of differences in analytical methods employed by the laboratories that performed the analyses

(Accu-Labs Research in 1997 and DES in 1998) and natural variability.

The ^{239,240}Pu concentrations reported for 1998 are somewhat higher than those reported as background levels in Ohio (about 0.2 mBq g^{-1}) (Muller, R. N. and D. G. Sprugel, 1977, *Health Physics* 33, 405). The indication that background concentrations of both fallout radionuclides and non-radioactive metals are lower on the Near Field grid than the Cactus Flats grid suggests that there are fundamental differences in the processes which influence the transport and fate of contaminants across the region. Differences in the kinetics of vertical transport of the contaminants in the soils, perhaps due to differences in soil composition at the 32 locations, could also explain the observed pattern. The soil types across the locations were relatively similar, being classified as sandy in all locations. However, the similarity between the two grids in the concentrations of the radionuclides and other metals relative to aluminum suggests that the proportion of clay in the soils could be a correlate of, and perhaps the controlling factor for, mass concentrations of the radionuclides and other metals. Differences in the relative amounts of soil organic materials also could explain the patterns in radionuclide activities and trace metal concentrations; this possibility could be tested by combustion of the soil organics.

Clay minerals are aluminosilicates and hydrated oxides that usually account for the major adsorptive component of soils (Wild, A., 1994, *Soils and the Environment*, Cambridge University Press, Cambridge; Whicker, F. W. and V. Schultz, 1982, *Radioecology: Nuclear Energy and the Environment. Vol. II*, CRC Press, Ann Arbor, Michigan). The failure to see any relationship with soil type may reflect that the criteria used to classify soils may not be adequate for explaining the differences in the kinetics of transport, or that the soil maps have insufficient resolution to show the true soil types associated with the individual samples.

These results demonstrate that significant variability in background levels of contaminants in soil exist in areas having relatively small differences in soil texture, and for contaminants such as Pu, where deposition is thought to be relatively uniform. The differences between the two grids may arise from differences in initial deposition or from a difference in the kinetics of particulates after initial deposition. There are no obvious factors that would suggest that the Cactus Flats grid would tend to have enhanced deposition as compared to the Near Field grid. Although topography and vegetative cover vary somewhat across both grids, they are generally similar on both grids. The presence of dunes at some locations on both grids indicates that some areas are subject to greater levels of soil erosion, deposition and vertical mixing, thus potentially depleting surface concentrations of some constituents.

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

Table 8. Soil Types Occurring on the Cactus Flats and Near Field Soil Sampling Grids[a]

Soil Classification	Description
Berino Complex	The Berino series soils are well-drained soils overlying a light sandy clay loam subsoil. A typical profile is 6 inches of reddish brown, loamy fine sand overlying a red, light, sandy clay loam to about 42 inches thick. The substratum, to a depth of 60 inches or more is a pink light sandy clay loam with a high content of lime.
Berino-Cacique Fine Sandy Loams	The Berino is the same as the Berino unit mapped in Eddy County. The Cacique are well drained sandy clay loams overlain by 8 inches of loamy fine sand and underlain by well indurated caliche at a depth of 20 - 34 inches in the mapped area.
Kimbrough	The Kimbrough series are well-drained gravelly loams, which overlies indurated caliche at a depth of 6 to 20 inches in the mapped area. It is formed on wind and water deposited sediments.
Maljamar/Palomas	The Maljamar was defined after the Eddy County survey was published in 1971. In the mapped area, the Maljamar/Palomas association is equivalent to the Berino Complex mapped in Eddy County.
Pyote	The Pyote series are wind deposited, well-drained soils overlying a fine sandy loam subsoil. Typical profiles include 30 inches of light brown fine sand, 18 inches of yellowish to light brown loamy fine sand, and at a depth of 60 inches, a pink fine sandy loam substratum.
Pyote/Maljamar	The Pyote Maljamar consists of 45 percent Pyote fine sand, 45 percent Maljamar fine sand and 10 percent Palomas and Kermit soils. A typical depth profile is similar to the Pyote Series sands.
Simona	The Simona series are well-drained soils on a fine sandy loam subsoil. A typical profile consists of a surface layer of 8 inches of grayish brown fine sandy loam, and 8 inches of pale brown fine sandy loam. The substratum is platy, white, indurated caliche.
Tonuco	The Tonuco series are excessively drained loamy fine sands, 10 to 20 inches thick, overlying indurated caliche. A typical profile is 12 inches of yellowish-red, loamy fine sand, 8 inches of yellowish-red loamy sand, overlying indurated caliche.
Kermit-Berino Fine Sand	The Kermit – Berino fine sands association have profiles typical of their series. Kermit fine sand makes up 40 - 60 percent of the area, Berino fine sand 30 - 40 percent, and the remainder consists of Active dune and Dune lands. The Kermit is an excessively drained loose sand, with active and stabilized dunes from 3 to 15 feet high. Most of the fines have been winnowed out and blown away. The Berino fine sand is similar but is underlain by caliche.
Berino Dune Complex	The Berino Dune complex consists of deep sandy soils and Dune land. Berino soils make up 30 to 50 percent and Dune lands make up 35 to 50 percent of the area.. Except were the surface layer has been wind eroded, the Berino soils have profiles typical of the Berino series. The Dune lands are typically dunes 3 to 8 feet high, 8 to 30 feet at the base. Most have formed around woody plants and each windstorm adds or takes away sand. Surface soils are typically thicker near the dunes.
Maljamar Fine Sandy Loam	The Maljamar fine sandy loam is a well-drained soil overlying a sandy clay loam subsoil. Indurated caliche is found at depths from 40 to more than 60 inches. A typical profile has 24 inches of yellowish red to red fine sand to fine sandy loam, 12 inches of red loamy clay sand, and 12 inches of red to yellowish red sandy clay loam overlying white fractured, indurated caliche.

[a] Source: Chugg, J.C., et. al. 1971, *Soil Survey Eddy Area, New Mexico*, U.S. Department of Agriculture, Soil Conservation Service; Turner, M.T., et. al. 1974, *Soil Survey of Lea County, New Mexico*, US Department of Agriculture, Soil Conservation Service

Table 9. Analyte/Aluminum Ratios in Soil Samples from the Near Field and Cactus Flats Sampling Grids

[a]Analyte	Cactus Flats Air	Cactus Flats Soil	Near Field Air	Near Field Soil
Al	1.0E+00	1.0E+00	1.0E+00	1.0E+00
As	2.4E-03	4.6E-04	1.9E-03	4.3E-04
Ba	9.3E-03	1.1E-02	1.2E-02	1.1E-02
Be	3.2E-01	8.4E-05	5.8E-01	9.1E-05
Ca	1.6E+00	3.3E-01	1.3E+00	1.3E+00
Cd		3.4E-05		3.2E-05
Chloride		7.5E-04		1.8E-03
Co	3.1E-03	4.2E-04	1.7E-03	4.0E-04
Cr		1.6E-03		1.7E-03
Cu	2.6E-02	4.2E-04	4.2E-03	3.8E-04
Fe	4.0E-01	1.5E+00	5.6E-01	1.4E+00
Hg		3.1E-03		2.5E-03
K	4.1E-01	2.6E-01	5.6E-01	2.6E-01
Mg	2.5E-01	2.0E-01	2.9E-01	2.6E-01
Na	5.9E-01	2.6E-03	5.8E-01	4.2E-03
Ni	1.6E-02	8.8E-04	2.0E-02	9.2E-04
Nitrate		3.9E-03		4.3E-03
Pb	5.1E-03	1.6E-03	4.2E-03	1.4E-03
Phosphate		2.2E-03		2.1E-03
Se	2.6E-03	3.2E-05		5.8E-05
Sr	5.1E-03	2.0E-03	5.9E-03	2.7E-03
Sulfate		3.4E-03		4.7E-03
V	1.8E-03	2.3E-03	2.4E-03	2.4E-03
Zn	2.0E-01	3.4E-03	4.0E-01	3.5E-03
$^{239/240}$Pu		1.0E-04		5.5E-05
^{228}Th		5.5E-03		4.9E-03
^{230}Th		5.3E-03		4.8E-03
^{232}Th		5.4E-03		5.1E-03
^{234}U		4.2E-03		4.3E-03
^{235}U		2.0E-04		2.1E-04
^{238}U		4.3E-03		4.4E-03

[a]Shaded rows are analytes with ratios differing between aerosols and soils.

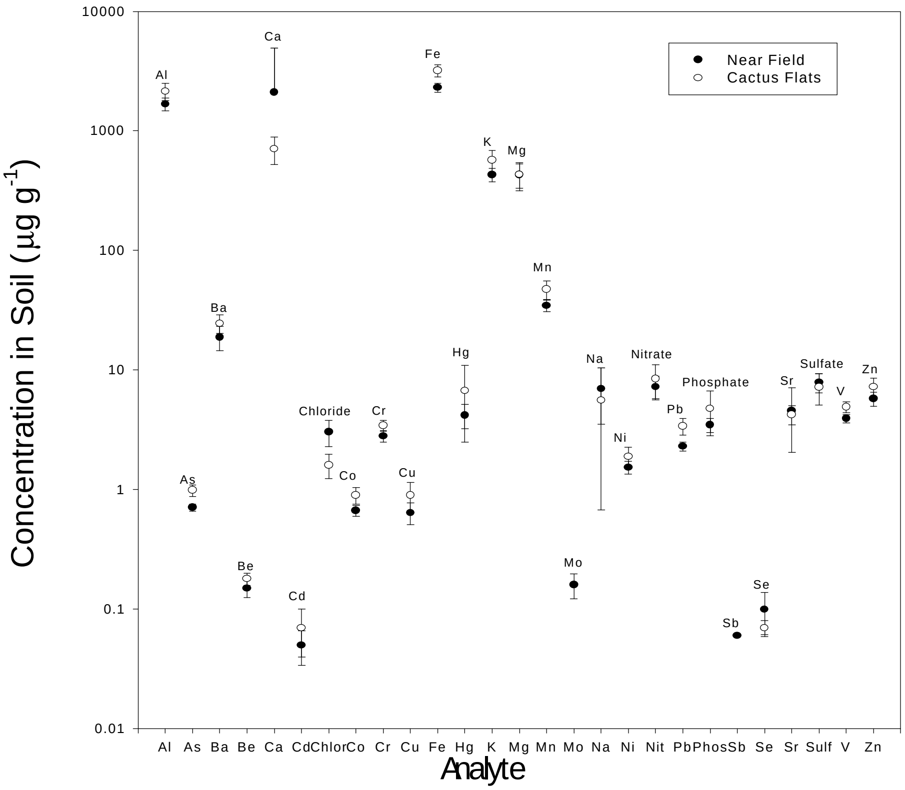


Figure 21. Mean Inorganic Analyte Concentrations in Soil Samples from Near Field and Cactus Flats Grids

Bars are 95% confidence intervals.

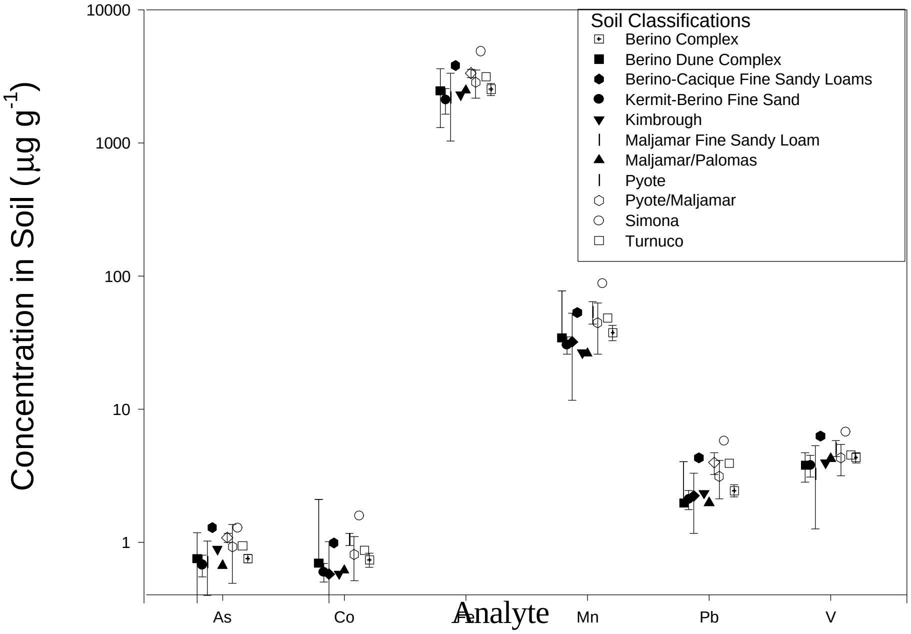


Figure 22. Mean Soil Concentrations of Selected Inorganic Analytes by Soil Type

Bars are 95% confidence intervals.

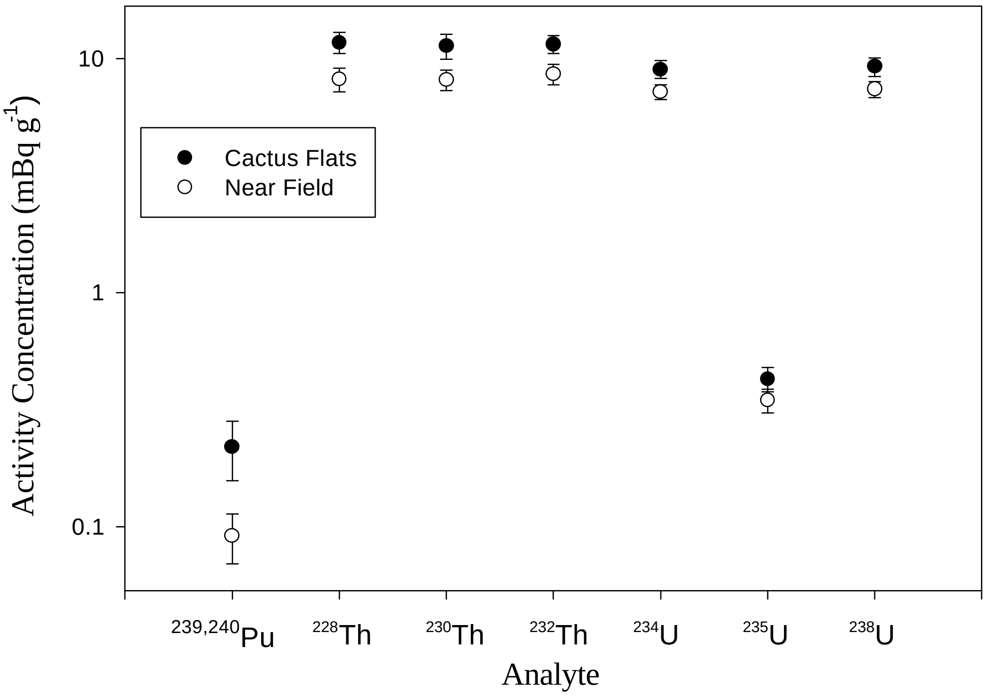


Figure 23. Mean Radionuclide Activity Concentrations in Soil Samples from Near Field and Cactus Flats Grids

Error bars are 95% confidence intervals of the mean.

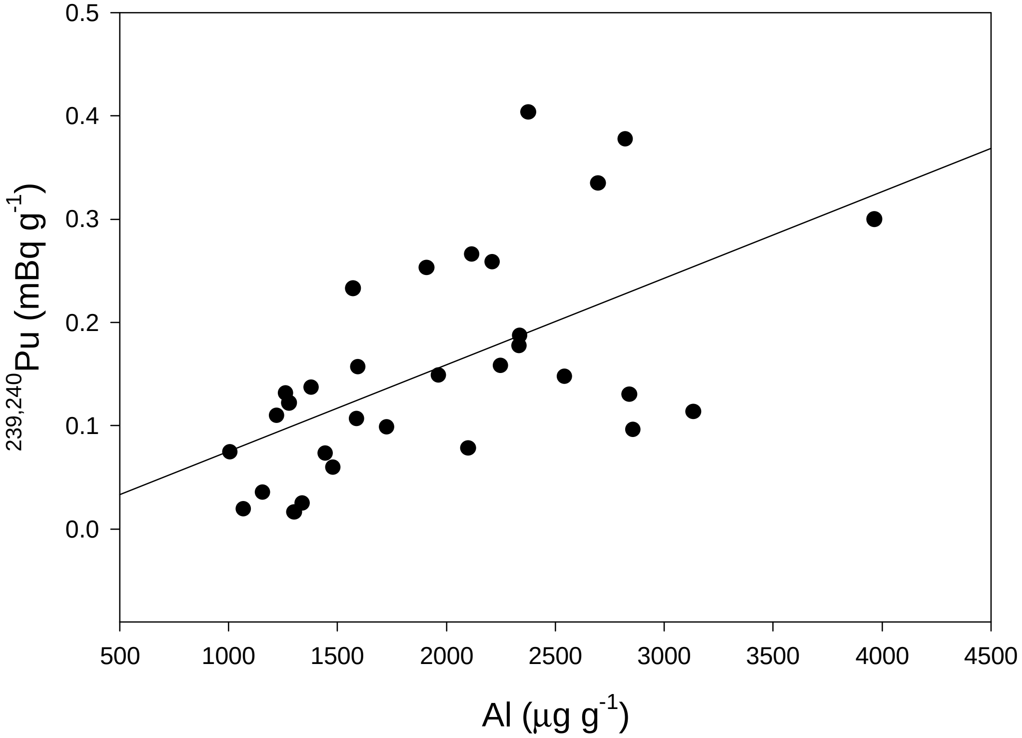


Figure 24. Comparison of Pu Activity Concentrations and Al Concentrations in Soil Samples from Near Field and Cactus Flats Grids.

Radiological and Non-radiological Constituents in Surface Water and Sediments at Selected Reservoirs

Introduction

Surface water and sediment were sampled from three regional reservoirs, Brantley Lake, Lake Carlsbad and Red Bluff Reservoir, from January to March 1998. As described in the WIPP EM project section of this report, Brantley Lake and Red Bluff Reservoir are impoundments located "upstream" and "downstream", respectively, relative to surface and ground water flows from the area immediately surrounding the WIPP site. Both reservoirs support a warm-water fishery and are used for irrigation, livestock watering, wildlife habitat and recreation. Lake Carlsbad is an impounded section of the Pecos River within the city of Carlsbad that is used extensively by the local population for recreational warm-water fishing, boating and swimming. In addition, it can be used for industrial water supply, livestock watering, and wildlife habitat (20 NMAC 6.1, 1995, State of New Mexico Standards for Interstate and Intrastate Streams).

The analyses reported here represent an expansion of studies of sediment and surface water in Brantley Lake that were summarized in the CEMRC 1997 Report. The 1998 samples were analyzed for selected radionuclides, chemical elements and compounds as part of WIPP EM baseline characterization.

Methods

Sediment samples were collected at four randomly selected locations within the deep basins of each reservoir (Fig. 25, 26 and 27). Deep basins were chosen for sampling to minimize the disturbance and particle mixing effects of current and wave action that occur at shallower depths. Also, many of the analytes of interest tend to concentrate in the fine sediments that settle in the deep reservoir basins; thus, measurements from these areas would typically represent the highest levels that might be expected for a given reservoir.

Sediments were collected to depths of 5-10 cm using a grab sampler or Eckman dredge, to obtain $\geq$ 6 L of sediment at each sampling site. In the field, a 1-L aliquot of each sample was sealed in a pre-cleaned plastic jar for inorganic analyses, and $\geq$ 5 L of wet sediment were sealed in a plastic bucket and transported to CEMRC for preparation prior to radiological analyses.

In the laboratory, samples destined for radiochemical analyses were dried at 105°C to a constant weight, pulverized and homogenized prior to analysis. A 250-g aliquot of each sample was sent to Duke Engineering & Services (Bolton, Massachusetts) where it was analyzed for the alpha-emitting radionuclides ^{239,240}Pu, ^{228}Th, ^{230}Th, ^{232}Th, ^{234}U, ^{235}U and ^{238}U. The remainder of the sediment samples was archived for future analyses.

Samples analyzed for inorganic chemical constituents were dried at 60 ^{o}C, and pulverized prior to analysis. Following preparation, the samples were analyzed by CEMRC using ion chromatography (IC), inductively-coupled plasma emission spectrometry (ICP-ES), and atomic absorption spectrometry (AA), as described for soils (p. 48).

In addition to the above analyses, a 1.5-L aliquot of one sediment sample from each reservoir was sent to A&L Plains Laboratory (Lubbock, Texas) (A&L) for several analyses that could not be performed in CEMRC laboratories (i.e. organic analyses) and for inter-laboratory comparison.

Surface water was sampled at two locations in the both Brantley Lake and Red Bluff Reservoir, and at one location in Lake Carlsbad. Within each reservoir, surface water samples were taken in the same general area as the sediment samples. At each sampling location, one sample was collected from the surface (~ 0.5 - 1 m depth) and a second sample was collected from approximately 0.5 - 1 m above the sediment bed. The sample volume collected for radiological analyses was approximately 105 L. In addition, two 1-L samples were collected for inorganic analyses by CEMRC. At Red Bluff Reservoir and Lake Carlsbad, additional 3-L surface samples were collected for analysis of substances regulated under the Safe Drinking Water Act (SDWA), plus selected compounds and elements identified as possible constituents of waste to be deposited in WIPP. These analyses were performed by the NMSU SWAT Laboratory. Samples collected in 1997 from Brantley Lake were analyzed for these substances and reported in the CEMRC 1997 Report. All water samples for analysis by the SWAT Laboratory were collected and handled in accordance with EPA guidelines.

In the laboratory, the water collected for radiological analyses was filtered to 0.2 µm using a high-volume filtration unit, acidified with HNO_3 to a pH < 2, and a 3-L aliquot was removed for analysis of gamma-emitting radionuclides (^{40}K, ^{60}Co and ^{137}Cs). Surface water samples collected for inorganic analyses by CEMRC were analyzed following applicable EPA standard methods.

Results

Radiological Analyses of Reservoir Sediments

^{239,240}Pu concentrations measured in sediment samples ranged from 0.07 to 0.41 mBq g^{-1}. Mean concentrations (± SE) of ^{239,240}Pu were 0.13 (± 0.03), 0.26 (± 0.02), and 0.36 (± 0.07) mBq g^{-1} for Lake Carlsbad, Brantley Lake, and Red Bluff Reservoir, respectively (Table 10 and Fig. 28). The sediment concentrations of ^{234}U, ^{235}U, and ^{238}U, ranged from 32.7 to 96.6 mBq g^{-1}, 1.2 to 3.2 mBq g^{-1}, and 24.9 to 58.2 mBq g^{-1}, respectively. Mean concentrations for all three U isotopes were lowest in Lake Carlsbad, and highest in Red Bluff Reservoir (Fig. 29). The pattern of concentration of Th (^{228}Th, ^{230}Th, ^{232}Th) measured in sediment samples was different from U, with the highest mean concentration in Brantley Lake samples, and the lowest mean concentration in Lake Carlsbad samples (Fig. 30).

Although the sediment concentrations of the U and Th isotopes were variable within and between reservoirs, the isotopic ratios were very similar across all three reservoirs. The reservoirs appeared to be slightly enriched in ^{234}U compared to ^{238}U, with mean ^{234}U/^{238}U activity ratios ranging form 1.4 to 1.6. Mean ^{228}Th/^{232}Th ratios were close to unity, ranging from 1.2 to 1.0, indicating that the isotopes are in secular equilibrium within the sediments. In a review of U and Th sediment chemistry, Onishi, Y., et. al. (1981, *Critical Review: Radionuclide Transport, Sediment Transport, and Water Quality Mathematical Modeling; and Radionuclide Adsorption/Desorption Mechanisms*, NUREG/CR-1322, Pacific Northwest Laboratory, Richland, Washington), reported that U has been found to be much more soluble than Th in the water column of oxidizing and alkaline environments. Th is relatively insoluble under alkaline conditions and adsorption to suspended particulate is rapid. In addition, ^{238}U decays to ^{234}U via the relatively short-lived ^{234}Th ($T_{1/2}$ = 24.1 days). These chemical and physical properties result in an enrichment of ^{234}U in sediments relative to ^{238}U because the intermediate Th isotope is scavenged from the water column and deposited on the sediments before the decay to ^{234}U occurs.

These concentration data of the individual radionuclides in sediments suggest that there may be differences between lakes. In particular, sediment concentrations in Lake Carlsbad appear to be lower than in the other two reservoirs. A multiple analysis of variance (MANOVA) was used to test the null hypothesis that there are no significant differences in radionuclide concentrations between reservoirs. The MANOVA results (Wilks' Lambda = 0.061, F = 1.304, numerator df = 14, denominator df = 6, P > 0.392) suggest that there were no significant differences between the lakes. The relatively high variance in concentrations between samples within each reservoir combined with the small number of samples in each reservoir (N = 4 per reservoir) undoubtedly constrains the power of the MANOVA to detect differences.

Comparing measurements made on sediment samples collected from Brantley Lake during January 1998 to measurements from samples collected in the same general area of the lake during March/April 1997, the mean value for ^{239,240}Pu was approximately 30% higher (0.39 ± 0.089 mBq g^{-1}) in 1997 analyses (Fig. 31). In contrast, the mean Th and U measurements were 30-120% higher in the 1998 analyses. The reasons for these differences are not clear. However the number of samples collected was relatively small and the analyses were performed by different laboratories using different analytical methods. Additional future sampling will help clarify whether differences are real or an analytical artifact.

The sediment and soil concentrations were compared by calculating the mean activity concentration of all samples of a given type (pooled across all reservoirs and soil sampling sites in the vicinity of the WIPP site) and then taking the ratio of the means. Sediments had higher activity concentrations than soil for all radionuclides measured with concentration ratios ranging from 1.7 for ^{239,240}Pu to 7.2 for ^{234}U (Fig. 32). The observed difference in concentrations is not surprising because reservoir sediments are often a sink or integrator for many contaminants as the soil in the surrounding watershed is leached and eroded. One of the primary factors that may influence contaminant concentrations in both sediment and soil is the particle size distribution. Particle size analyses on representative samples of sediment and soil revealed a substantial difference in the proportion of fine and coarse-grained particles in each media. Sediments in the three reservoirs studied contained between 38-52% silt and clay-sized (< 63 µm) particles, with clay-size particles dominating the size distribution. In contrast, soils collected in the vicinity of the WIPP contained 88-90% sand-size particles and only 10-12% small particle sizes. As noted in the methods, the sediment sampling focused on the profundal zones (deep, undisturbed basins) of the reservoirs, that are characterized as zones of accumulation for fine-grained sediments. It is well documented that many contaminants (including many radionuclides) are found in higher concentrations in the fine-grained particles (Mudroch, A. and J.M. Azcue, 1995, *Manual of Aquatic Sediment Sampling*, Lewis Publishers, Ann Arbor, Michigan; Hakanson, L. and M. Jansson, 1983, *Principles of Lake Sedimentology*, Springer-Verlag, New York.; Onishi, et. al. 1981). One method that is commonly used to correct the concentrations for differences in the amount of the fine-grained silts and clays, is to normalize the concentration data to the amount of Al present in the samples. In sediments and soils, Al occurs primarily as alumino-silicates which are primarily associated with the silt and clay fractions in both media (Mudroch and Azcue, 1995) and can be used to represent the amount of fine-grained material in these media. Using this technique to correct for particle size, the radionuclide activity: Al concentration ratios ranged from 0.2 (^{239,240}Pu) to 0.9 (^{234}U) which suggests that Al-normalized soil concentrations are very similar, or in the case of ^{239,240}Pu even slightly higher, than in the sediments.

Radiological Analyses of Surface Waters

Filtered water samples (0.2 µm filter) were analyzed by gamma spectroscopy for ^{137}Cs, ^{60}Co and ^{40}K. All results were below detection limits, suggesting that most of the radioactivity in the water column contributed by these radionuclides, if present, was associated with the seston (suspended particulate or colloids larger than 0.2 µm) that was filtered out. The filters were not analyzed, thus no direct radioanalytical data are available on the seston fraction. However, the total activity of ^{40}K in the water samples (seston + water) was estimated using the total recoverable K measured in three of the surface water samples analyzed by CEMRC using atomic emission spectrometry. Natural K contains approximately 0.0117% ^{40}K by mass (Turner, J.E., 1986, *Atoms, Radiation and Radiation*

Protection, Pergamon Press, New York). By estimating the total number of atoms of ^{40}K in a water sample, the activity concentration of ^{40}K in surface water samples was estimated to be 166, 657 and 163 and 164 mBq L^{-1} for Brantley Lake, Red Bluff Reservoir and the two samples collected from Lake Carlsbad, respectively. These estimates are lower than the ^{40}K activity concentrations (1050 and 1160 mBq L^{-1}) measured in two unfiltered Brantley Lake water samples collected in March 1997. Additional study is necessary to determine the basis for these differences. It is possible that they are an artifact of the different analysis methodologies (gamma spectroscopy versus atomic emission spectroscopy) or that fractionation of the radionuclide occurred.

Non-Radiological Analyses of Surface Water and Sediment

Surface water and sediment samples from all three reservoirs were analyzed by CEMRC for a suite of elements and inorganic compounds. Of the three reservoirs sampled, the surface water collected in Red Bluff Reservoir exhibited the highest concentrations of the major analytes (analytes with a concentration >100 mg L^{-1}) and Lake Carlsbad had the lowest concentrations (Fig. 33). The water concentrations of the minor analytes (Cr, Fl, K, Mo, Ni and Se) were also highest in Red Bluff reservoir (Fig. 34), but similar in Brantley Lake and Lake Carlsbad.

Brantley Lake sediments were relatively high in Al, Co, Cr, and Fe while Red Bluff Reservoir sediments were high in Na and chloride (Fig. 35 and 36). Lake Carlsbad typically had the lowest sediment concentrations for many of the analytes, including Al, Ba, Be, Co, Fe, K, Mo, Mn, Na, Ni, V, chloride, and sulfate. The high Na and chloride concentrations observed in Red Bluff water and sediments was not unexpected given that the reservoir is located down-gradient from a number of highly saline lakes or playas and saline aquifer inputs. The ratio of the mean concentrations (all reservoirs combined) observed in sediment versus surface water samples (sediment/water) ranged between 1×10^2 and 1×10^4. Al, Fe and Mn occurred in the highest ratios, with lower ratios for more soluble analytes (Na, chloride and sulfate) (Fig. 37).

As was the case for radionuclides, inorganic analyte concentrations in sediments were typically 10 to 100 times higher than in soils. As previously noted, these differences may be due in large part to differences in the particle size distributions of the sediment and soil samples. When corrected for particle size by normalizing to Al, sediment and soil concentrations appear more similar, with the normalized sediment/soil ratios ranging from 0.5 to 3 for most of the analytes (Fig. 38). For all but four of the analytes, the normalized sediment and soil concentrations were within a factor of 10, with the concentration ratio for selenium at 12. Three of the analytes, Na (ratio = 71), sulfate (ratio = 98) and chloride (ratio = 240), appeared to be enriched in sediments relative to soil.

In addition to the CEMRC analyses, the NMSU SWAT laboratory and A&L Plains laboratory performed several analyses on surface water and sediment samples. The SWAT laboratory analyzed one surface water sample from Red Bluff reservoir and Lake Carlsbad for a large number of volatile organics, semi-volatile organics, metals and secondary analytes that are either regulated under the Safe Drinking Water Act (SDWA) or that will be constituents of the waste going into WIPP. It should be noted that none of the reservoirs serve as primary drinking water sources and therefore are not subject to regulation under the SDWA.

In Lake Carlsbad and Red Bluff Reservoir, all of the analyses of organic compounds in surface water samples were below method detection limits. In addition, all metals and secondary analytes were either below detection limits or below the regulatory reference levels. In 1997, surface water from Brantley Lake was analyzed for the same chemical constituents with similar results (presented in the CEMRC 1997 Report).

One sediment sample from each of the three reservoirs was analyzed by A&L for

BTEX (ethylbenzene, m,p-xylene, o-xylene, toluene) and TPH (total petroleum hydocarbons), compounds typically associated with contamination from oil and gas operations. BTEX concentrations in all of the sediment samples were below the method detection limits. The sediment concentrations of TPH were 10, 52 and 118 mg kg^{-1} in Brantley Lake, Red Bluff Reservoir and Lake Carlsbad samples, respectively. For comparative purposes, in New Mexico, remediation of TPH contaminated soils is considered adequate when TPH concentrations drop below 1000 mg kg^{-1} (20 NMAC 9.1, section 708).

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

Table 10. Summary Statistics for Radionuclide Activity Concentrations in Sediment Samples from Three Regional Reservoirs

	Activity Concentration (mBq g^{-1})											
	Brantley Lake				Red Bluff Reservoir				Lake Carlsbad			
Radionuclide	**[a]N**	**[b]Mean**	**[c]SE**	**[d]CV (%)**	**N**	**Mean**	**SE**	**CV (%)**	**N**	**Mean**	**SE**	**CV (%)**
^{239,240}Pu	4	0.26	0.02	12	4	0.36	0.07	39	4	0.13	0.03	49
^{228}Th	4	37.25	3.08	17	4	34.80	0.81	5	4	22.10	2.32	21
^{230}Th	4	44.23	7.36	33	4	32.80	1.17	7	4	23.78	2.27	19
^{232}Th	4	37.48	4.40	23	4	30.03	1.43	10	4	22.38	2.13	19
^{234}U	4	53.48	5.06	19	4	79.23	11.62	29	4	38.63	2.78	14
^{235}U	4	1.96	0.20	21	4	2.57	0.35	27	4	1.39	0.07	11
^{238}U	4	38.83	1.82	9	4	49.10	6.11	25	4	27.50	1.40	10

[a] N = number of samples included in calculations
[b] Mean = arithmetic mean
[c] SE = standard error of mean
[d] CV = coefficient of variation; standard deviation expressed as percentage of the mean; CVs may reflect small rounding error

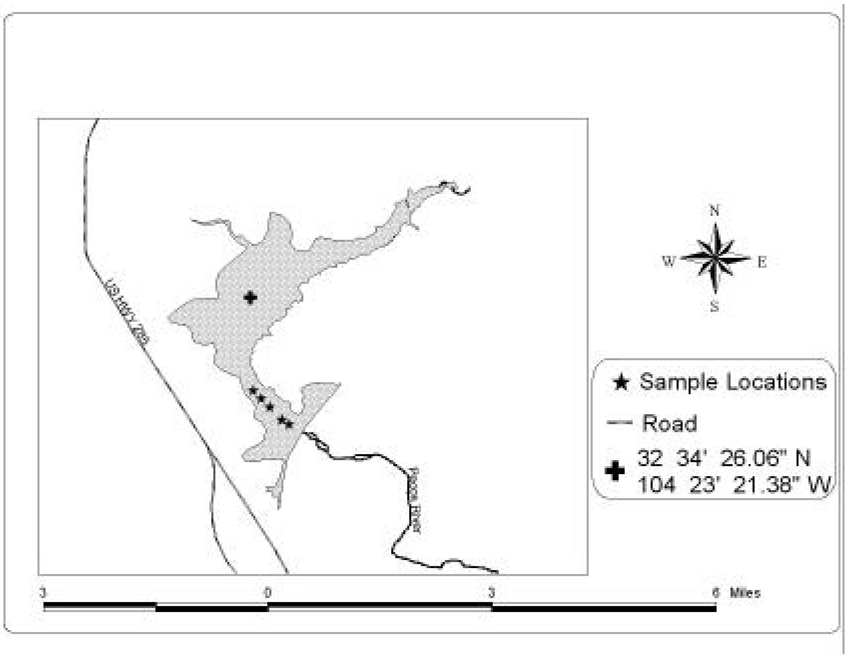


Figure 25. Surface Water and Sediment Sampling Locations at Brantley Lake

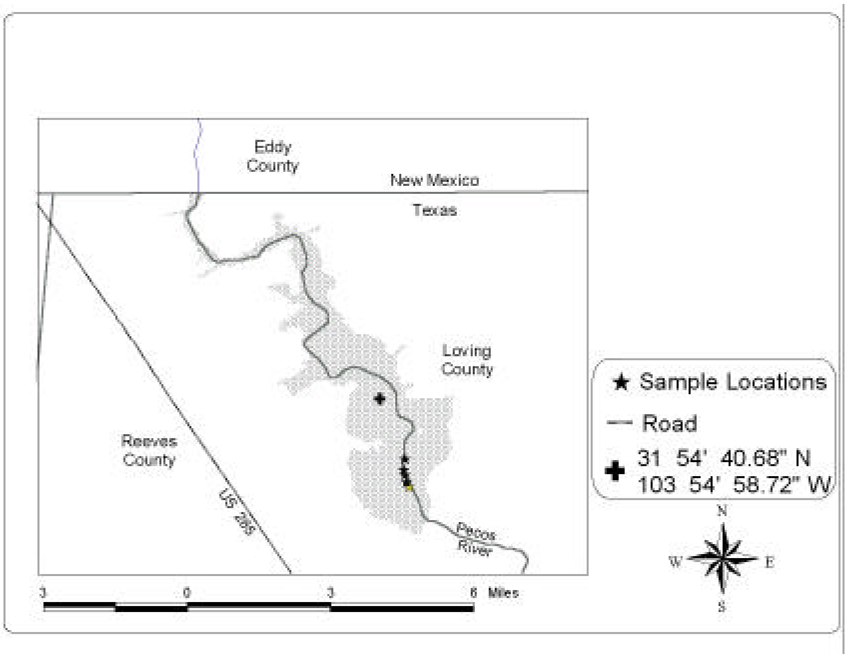


Figure 26. Surface Water and Sediment Sampling Locations at Red Bluff Reservoir

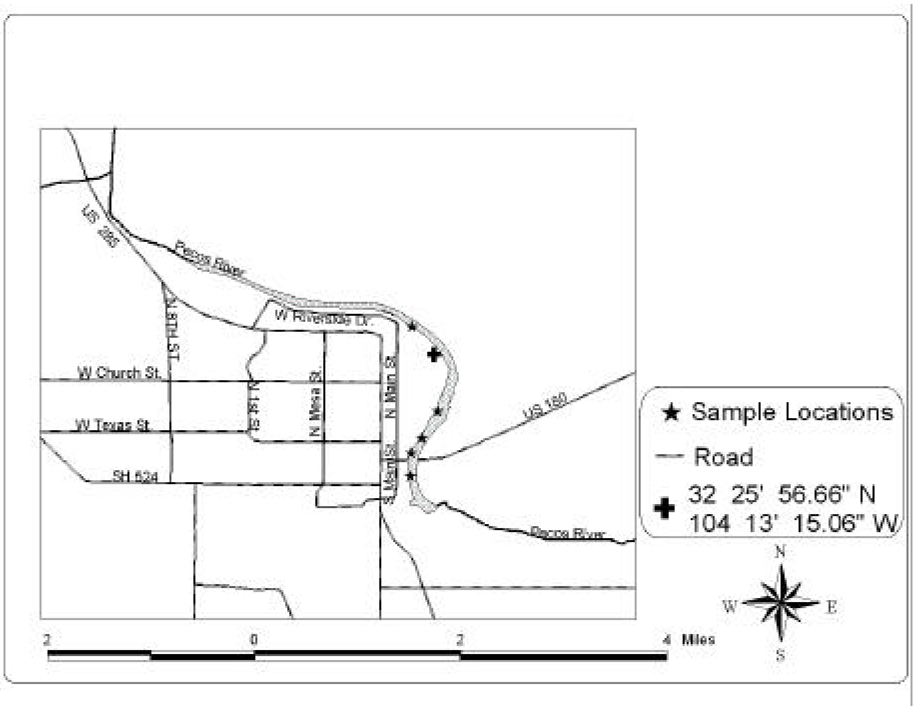


Figure 27. Surface Water and Sediment Sampling Locations at Lake Carlsbad

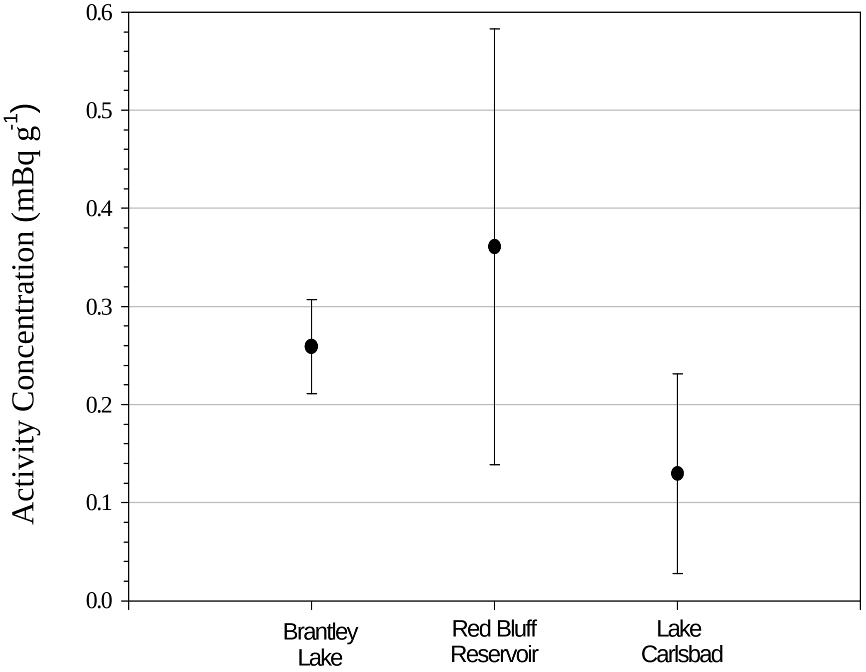


Figure 28. Mean ^{239,240}Pu Activity Concentrations in Sediment Samples from Three Regional Reservoirs.

Error bars represent the 95% confidence interval for the mean.

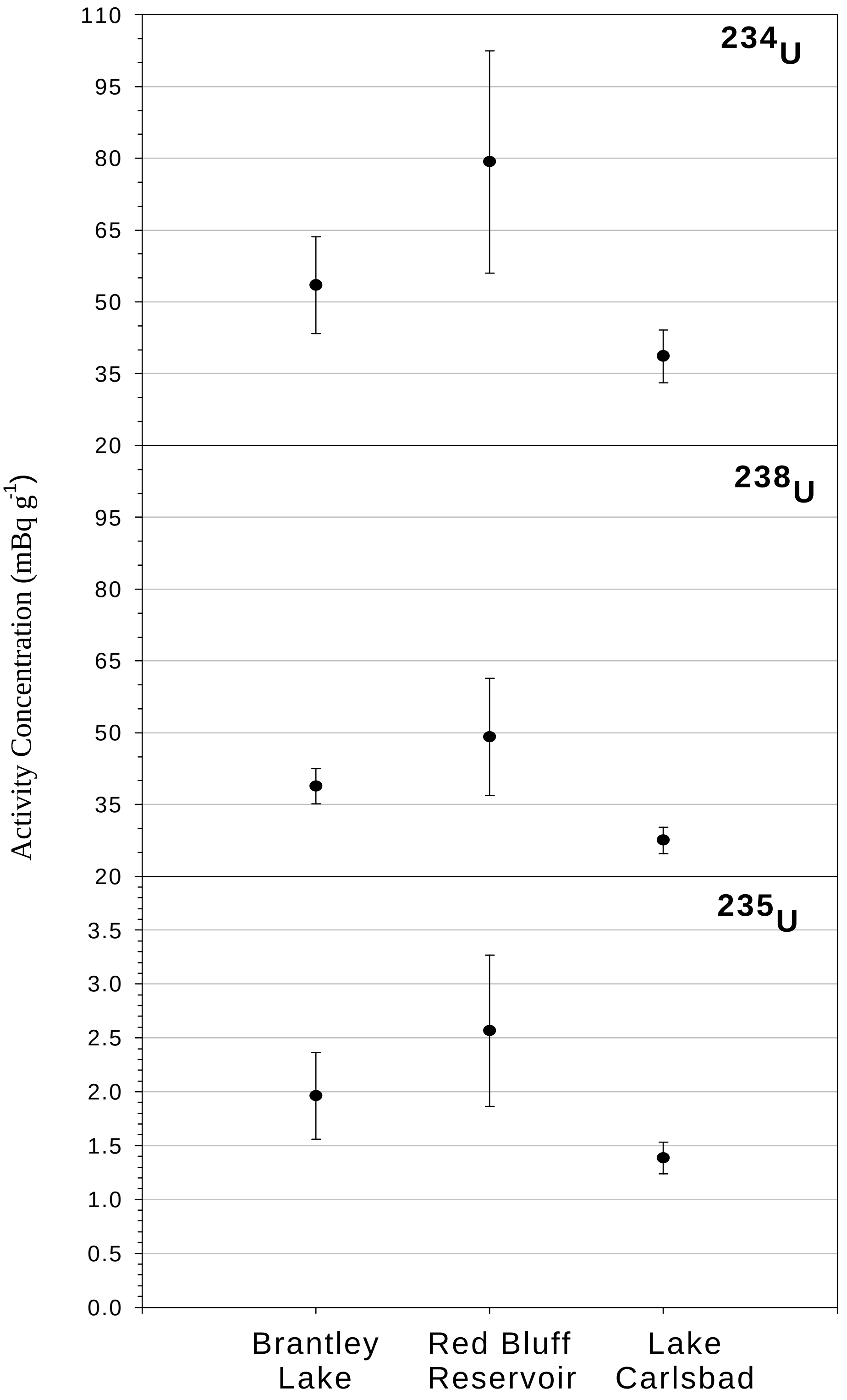


Figure 29. Mean Activity Concentrations of Three U Isotopes in Sediment Samples from Three Regional Reservoirs

Error bars represent the 95% confidence interval for the mean.

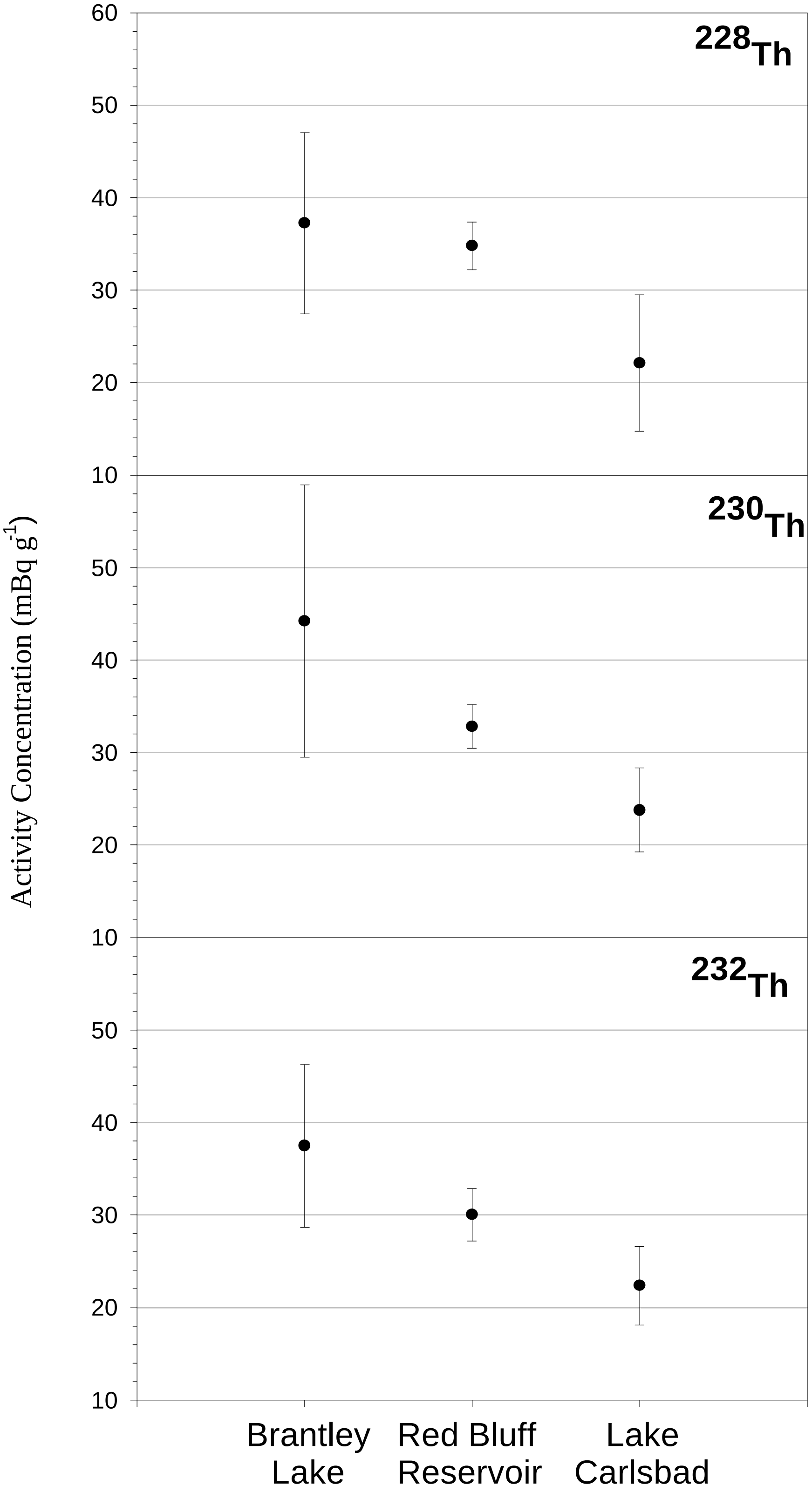


Figure 30. Mean Activity Concentrations of Three Th Isotopes in Sediment Samples from Three Regional Reservoirs

Error bars represent the 95% confidence interval for the mean.

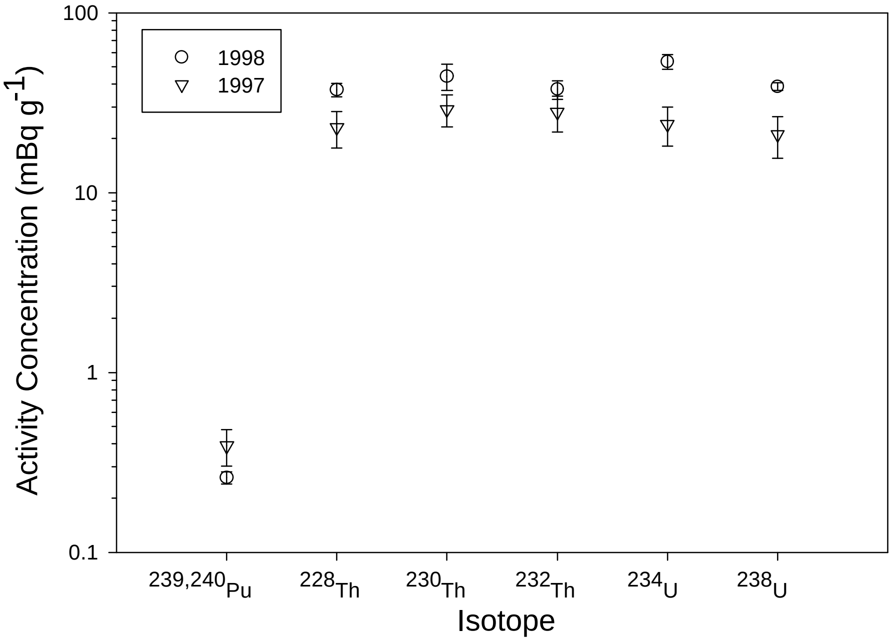


Figure 31. Comparison of Mean Activity Concentrations of ^{239,240}Pu, U and Th Isotopes from Sediments Collected in 1997 and 1998 from Brantley Lake

Error bars are 1 standard error of the mean value.

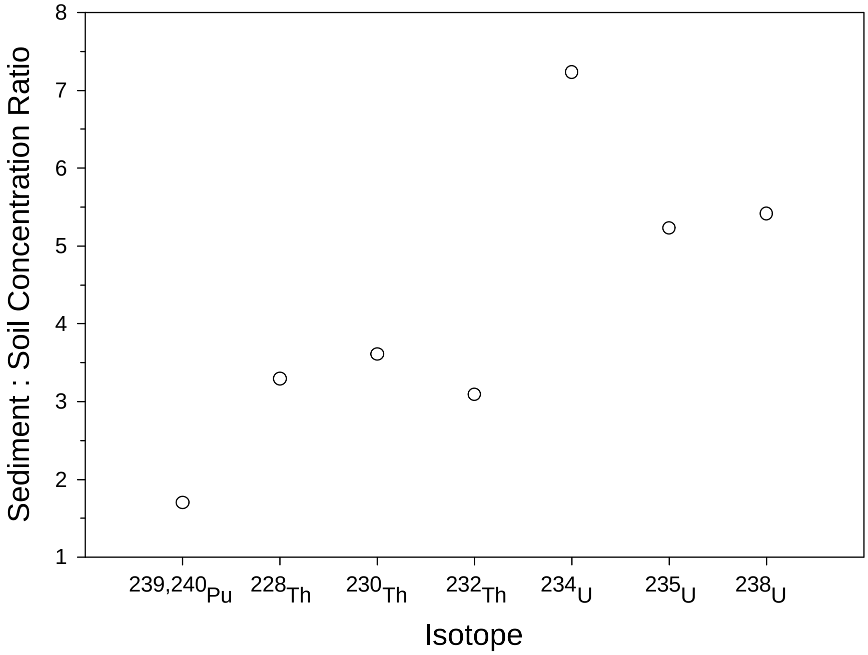


Figure 32. Comparison of Sediment:Soil Activity Concentration Ratios for Select Radionuclides

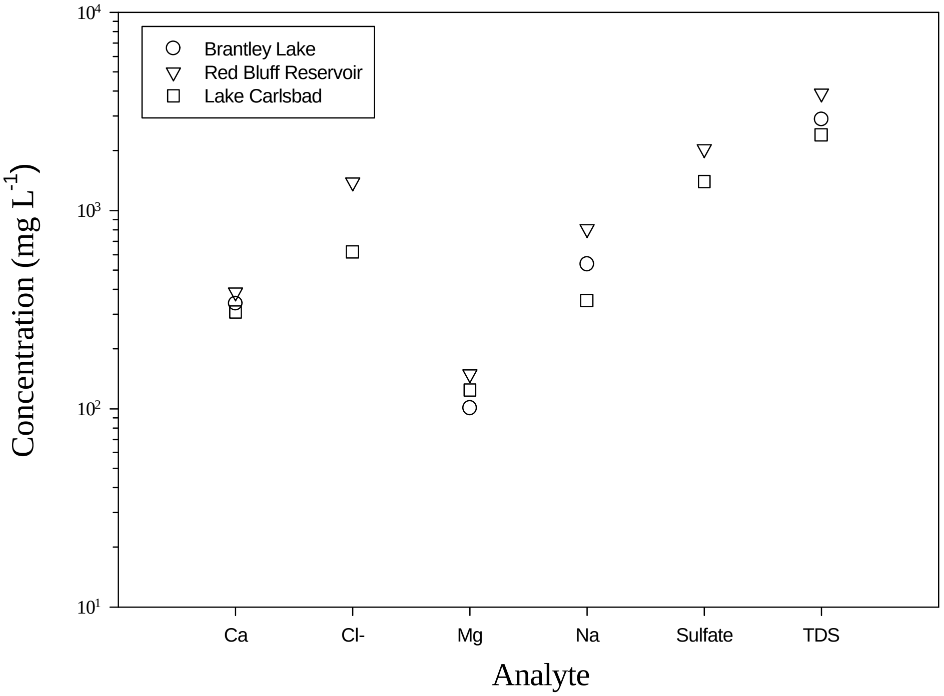


Figure 33. Concentrations of Major Inorganic Analytes (>100 mg L^{-1}) in Surface Water Samples from Three Regional Reservoirs.
The Lake Carlsbad sample shown was collected at a depth of 0.5 m.

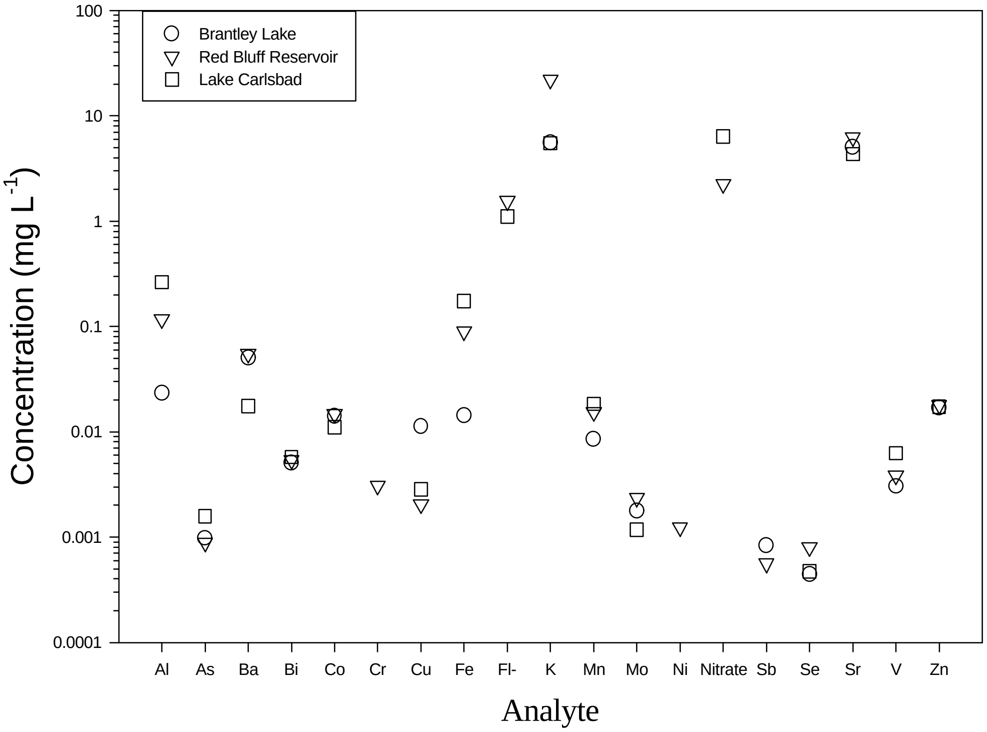


Figure 34. Concentrations of Minor Inorganic Analytes (<100 mg L^{-1}) in Surface Water Samples from Three Regional Reservoirs
The Lake Carlsbad sample shown was collected at a depth of 0.5 m.

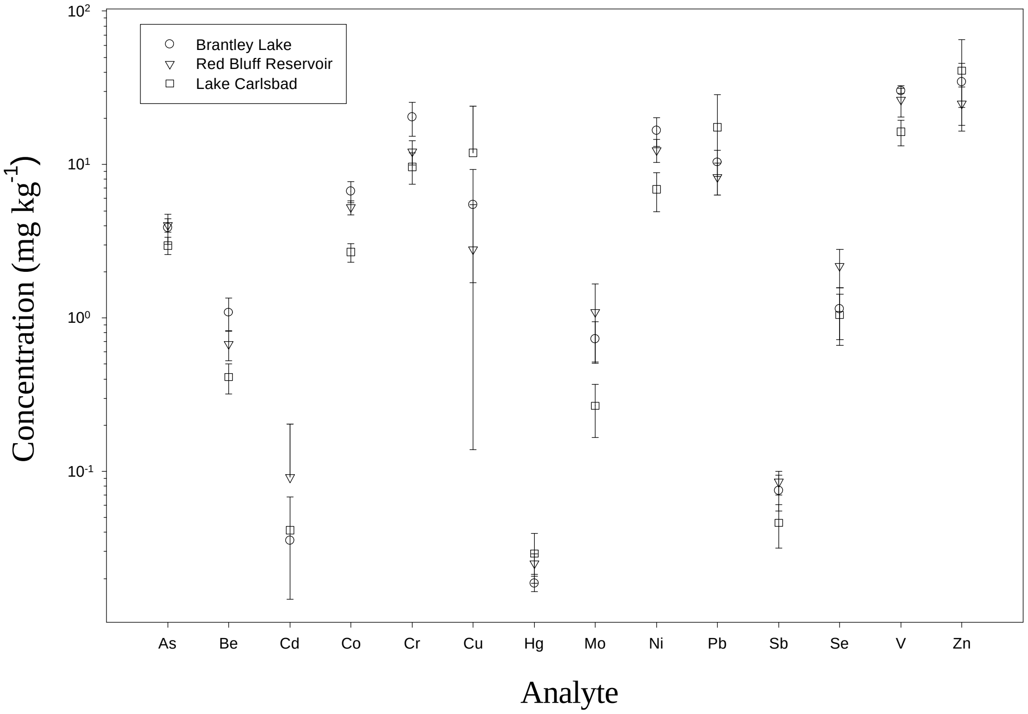


Figure 35. Mean Concentrations of Minor Inorganic Analytes (<100 mg kg^{-1}) in Sediment Samples from Three Regional Reservoirs

Error bars represent the 95% confidence interval of the mean.

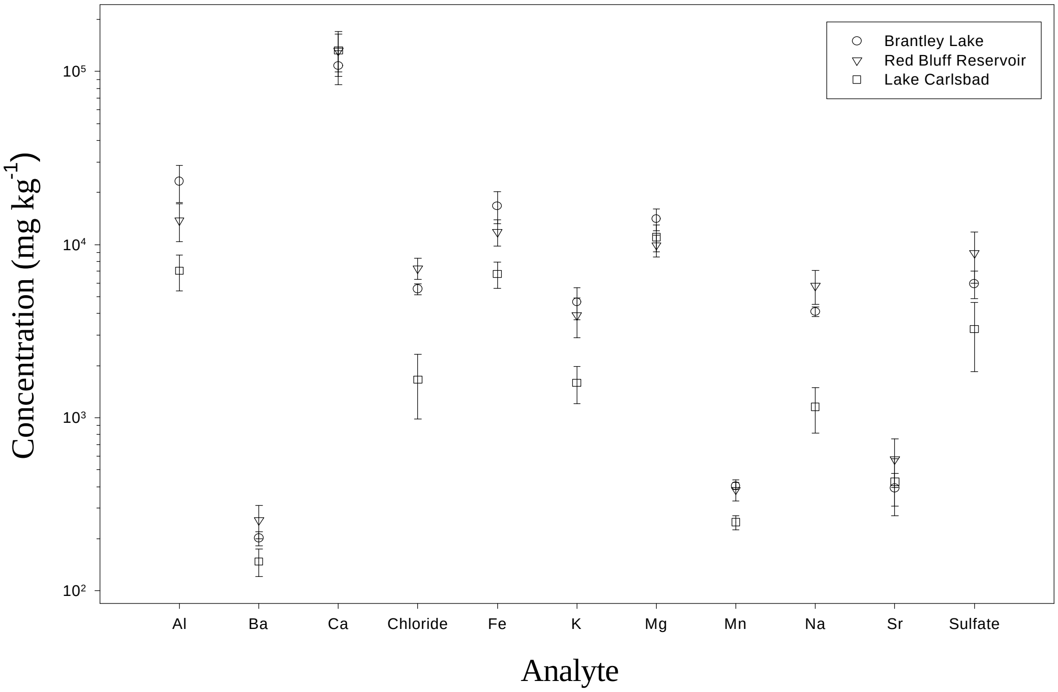


Figure 36. Mean Concentrations of Major Inorganic Analytes (>100 mg kg^{-1}) in Sediment Samples from Three Regional Reservoirs

Error bars represent the 5% confidence interval of the mean.

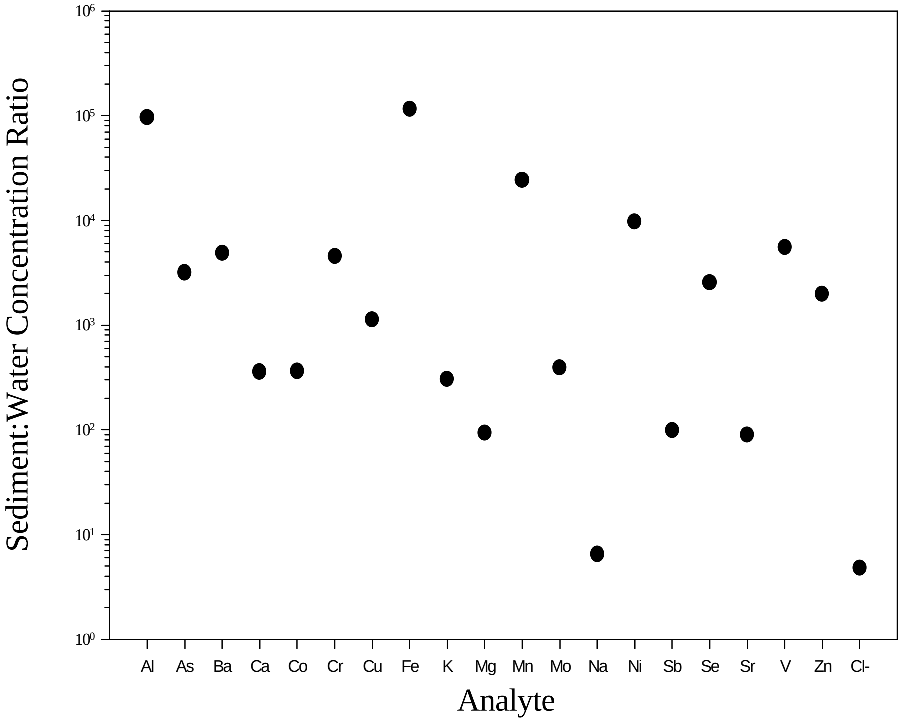


Figure 37. Sediment:Surface Water Concentration Ratios of Inorganic Analytes from Three Regional Reservoirs

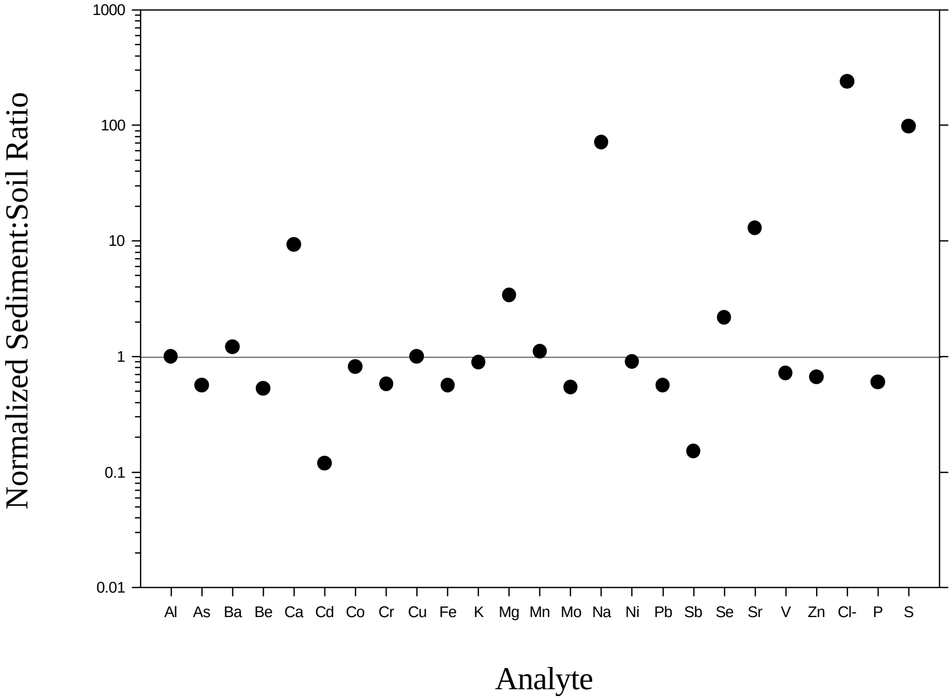


Figure 38. Sediment: Soil Concentration Ratios of Inorganic Analytes from Three Regional Reservoirs

Ratio values are normalized to Al concentrations.

Non-radiological Constituents in Selected Drinking Water Sources

Introduction

The water wells in the immediate vicinity of the WIPP site provide water primarily for livestock, industrial usage by oil and gas production operations, and monitoring studies conducted by various groups. From April to August 1998, water samples were collected for the CEMRC's environmental chemistry studies from six sources in the vicinity of the WIPP: Loving, Otis, Carlsbad, Private Well #2, WIPP-Double Eagle, and Hobbs (Table 11).

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

The analyses of water samples reported herein continues the baseline evaluation that began in 1997, for which preliminary results were reported in the CEMRC 1997 Report. As in all of the other WIPP-EM studies, the first priority of this work is to establish baseline concentrations for substances of environmental concern as a result of operations at the WIPP facility. A secondary objective for the non-radiological studies reported here was to validate the analytical methods through an inter-laboratory calibration.

Methods

Nine L of water were collected at each source for analyses of various non-radiological constituents and water quality parameters. All samples were collected following purging of the sources for approximately 5 min or at least 50 L.

Samples for analyses of SDWA constituents were sent to the Soil Water and Air Testing (SWAT) laboratory at NMSU. All samples for the SWAT laboratory were collected according to EPA protocols for the collection, handling and preservation of drinking water samples.

For the inter-laboratory comparison, separate aliquots of all drinking water samples collected in 1998 were analyzed by CEMRC and the SWAT laboratory. The analyses performed by CEMRC were done by using ion chromatography, inductively-coupled emission spectrometry, and atomic absorption spectrometry as summarized in Appendix K. A de-ionized water blank also was analyzed by both groups as part of this comparative study. This inter-laboratory comparison provides a means of evaluating the developmental efforts at CEMRC over the past year.

Results and Discussion

Analyses were performed by the SWAT laboratory 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 referred to as "reference levels" to provide readers with a basis for comparison. However, the results presented are not appropriate for use as evidence of compliance or non-compliance with any regulatory requirements. Instead, these results are intended to provide only a general indication of the chemical composition of the drinking water sources prior to the opening of the WIPP.

The overwhelming majority of inorganic analytes were below detectable levels in the drinking water samples, and only a few of the organic analytes were above their detection limits. Analyses of the 1997 samples indicated the presence of bromoform in samples from Hobbs, Otis, and a private tap five miles northwest of the WIPP (designated Private #1). Bromoform was not detected in the 1998 Otis sample. Private #1 was not sampled in 1998, but the water system for Private #1 is the same as for the 1998 WIPP-Double Eagle sample, which showed no bromoform present. Interestingly, bromoform was present in the 1998 Hobbs sample at about the same concentration as in the 1997 sample (9 $\mu g\ L^{-1}$ in 1998 vs. 10 $\mu g\ L^{-1}$ in 1997). In 1997, dibromochloromethane was detected in a single sample from Hobbs (collected 16 July 1997), where the concentration was 1.1 $\mu g\ L^{-1}$. This finding was confirmed by the analysis of the 1998 Hobbs sample, which had exactly the same concentration. Despite their presence, the levels observed for bromoform and dibromochloromethane were below reference levels.

To evaluate trends in concentrations over time, the data for three pairs of drinking water samples collected in 1997 and 1998 (i.e., Loving, Otis, and Hobbs) were compared and contrasted. Those pairs of samples were collected at about the same time of year, thus eliminating the possible effects of seasonal trends. The concentrations of almost all analytes in the sample pairs were in close agreement. Of the 80 pairs of values compared, there were only a few cases in which the differences between years were a factor of 5 or greater. For the Hobbs samples, the Pb concentration was a factor of 10 lower in the August 1998 sample compared with the July 1997 sample (0.8 vs. 8.7 $\mu g\ L^{-1}$). In contrast, the Tl concentration was more than four-fold higher in the 1998 sample compared to the 1997 sample (0.26 vs. 0.06 $\mu g\ L^{-1}$). Ammonium (as nitrogen) concentrations also differed substantially in the 1997 and 1998 Hobbs samples, with concentrations of 0.02 and 0.2 $\mu g\ L^{-1}$, respectively.

At Otis, the K concentration in 1997 was 4.5 mg L^{-1}, but in the 1998 sample, K was less than the detection limit of 0.4 L^{-1}, representing more than a factor of 10 change. It is also noteworthy that Tl was detected in the 1998 Otis drinking water sample but not in the 1997 sample. Less remarkable was the detection of Kjeldahl nitrogen and total P in the 1998 Otis sample. There were no particularly noteworthy differences in the Loving sample for 1997 compared with 1998.

As in 1997, several inorganic non-radiological substances exceeded reference levels (secondary maximum contaminant levels) in the 1998 samples from the Otis and Private #2 sources. Specifically, these were 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 fact that the 1998 and 1997 data showed essentially identical patterns for these analytes indicates that the high concentrations were not spurious results but rather a true indication of elevated levels. Compared with the other sites, the Otis and Private #2 drinking water samples also (1) had relatively high concentrations of Ca, Mg, Na, and Cl^-; (2) were relatively hard, and (3) exhibited high electrical conductivity. All of these factors are consistent with a high mineral content in the Otis and Private #2 drinking water sources.

Some differences between the CEMRC and SWAT laboratory Ca and K concentrations were observed in the inter-laboratory comparison. The average relative percent difference (RPD) for the Ca concentrations was 24%, with the CEMRC concentrations higher than the SWAT values in five of six cases. The RPD for K was 70%, with the CEMRC concentrations lower than SWAT for all six samples. It is interesting and noteworthy that in all cases, the CEMRC data were closer to the 1997 SWAT lab data than the 1998 SWAT lab data. Why this should be the case is unclear, but as demonstrated in the QA section, the CEMRC instrumental methods for the analysis of Ca and K (as well as Na and Mg) have been at least partially verified through an intra-laboratory calibration exercise in which the ICP-ES and IC data were compared. As discussed elsewhere in Appendix K, the results of this intra-laboratory comparison showed that the instrumental analyses by the CEMRC are likely to be quite accurate for Ca, K, and other alkali and alkaline earths.

With respect to heavy metals, the Cu concentration in the 1998 Hobbs sample appeared to be higher than at the other sites, and this same pattern was also noted in 1997. In contrast to the 1997 results, however, the Pb concentration at Hobbs was not higher than at the other sites but instead roughly comparable; there was a ten-fold drop in the Pb concentration for the 1998 Hobbs sample relative to 1997. While the Cu and Pb concentrations were well below reference levels in all samples, some differences did exist between the CEMRC and SWAT data for these and several other heavy metals and metalloids as discussed below. As was the case in 1997, the highest concentrations of Ni, Se, and Tl were found in drinking water from Private Well #2, but as before, those concentrations were well below reference levels. Again, it is important to emphasize that these results are not appropriate for use in assessments of regulatory compliance.

The inter-laboratory comparison showed consistent results, if not close agreement, for 14 of 20 analytes (relative percent differences of less than 30%). For Cu, the between-laboratory differences are skewed by the Hobbs 1998 sample, where CEMRC reported a concentration of 2.0 compared with 15 $\mu g\,L^{-1}$ reported by SWAT. As noted above, the SWAT data indicated that Cu was substantially higher at Hobbs than at the other sites. On the other hand, if the lower CEMRC value for Hobbs is compared with the other data, the Cu concentrations would be similar at all sites, ranging from 1.8 to 4.1 $\mu g\,L^{-1}$. Patterns in the between-laboratory differences in the Cu data are not clear cut. Although the CEMRC data for Hobbs are more in line with the other sites, the Cu concentrations determined by SWAT for Hobbs were high in both years, even though the reported concentration was substantially lower in 1998 than in 1997 (15 versus 56.1 $\mu g\,L^{-1}$).

For both Ni and Pb, the CEMRC reported "less than" values that were lower than the concentrations reported by SWAT for the Hobbs water sample and the blank. The first point to keep in mind with respect to these results is that the concentrations of both elements in the drinking water samples were orders-of-magnitude below the respective MCLs. The second point that bears mention is that a preservative was placed in the SWAT sample containers before sampling while none was used for the CEMRC samples. Therefore, one possible explanation for the observed differences is that small but detectable amounts of these metals were introduced into the SWAT samples with the preservative. However, an equally valid explanation is that these metals were lost to the walls of collection containers because CEMRC did not acidify samples immediately after collection. Follow-up studies on preservatives will be conducted in the upcoming year.

For Hg and Sb, CEMRC reported concentrations lower than the "less than" values reported by SWAT. These results are not inconsistent, and they are the result of the very low detection limits made possible by the flow injection system used for the analysis of these elements at CEMRC.

Differences in the Se data are less easily explained, although contamination from the preservative used by SWAT or sorption to the walls of the CEMRC sample containers are still possible explanations. For Se, the CEMRC concentration for the Hobbs sample was $< 0.2\ \mu g\,L^{-1}$ compared with 10 $\mu g\,L^{-1}$ for SWAT. In all other samples, the CEMRC reported below detection limits ($< 0.2\ \mu g\,L^{-1}$) while SWAT reported concentrations ranging from 1.2 to 10.2 $\mu g\,L^{-1}$. Results for arsenic in one of the six samples, (the WIPP-Double Eagle sample) are similarly discrepant. The flow injection analysis accessory system used for the As and Se analysis at CEMRC eliminates most matrix interferences, and therefore the sensitivity and precision for these elements should be quite good. In comparison, the ICP-mass spectrometric methods used by the SWAT laboratory are more subject to matrix interferences for these elements. Follow-up studies of the As and Se analytical methods will be undertaken in the coming year.

The data for fluoride, chloride, nitrate (as N) and sulfate agreed well between laboratories, with RPDs generally below 25%. Of these anions, the fluoride concentrations showed the greatest discrepancies. The configuration of the ion chromatograph at CEMRC is such that the quantitation of F^- is difficult. As F^- is usually not of great concern, this difference between laboratories is not considered a major problem.

In summary, the analysis of drinking water samples in 1998 showed remarkable consistency with the results of the previous year's analyses based on SWAT data. Few organic contaminants were detected and those inorganic substances that were quantified were, with a few exceptions, below reference levels. Finally, with the exception of the Se analyses and some questions regarding sample preservation, the CEMRC data appear to be well validated based on the inter-laboratory comparisons with SWAT.

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

Table 11. Drinking Water Sources and Sample Collection Locations

Date of Collection	Water Recipient	Chlorination at Collection Point	Location of Sample Collection
4/14/98	Loving	No	Chlorination house on Misty Lane
4/22/98	Private #2	No	Private well 7 miles southwest of the WIPP
4/22/98	Otis	No	Water tower
5/12/98	Carlsbad	No	Sheep Draw, main supply line
5/12/98	WIPP-Double Eagle	No	Klines Corral, main supply line
8/4/98	Hobbs	Yes	Jefferson St. pump station

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

Introduction

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

Methods

Following the commissioning of the Center's *in vivo* monitoring facility, 272 citizen volunteers were assayed during July 1997 to September 1998. These volunteers were recruited through presentations to local community groups and businesses. When a citizen volunteer arrived at the Center for a bioassay, he or she viewed a short video explaining the measurement protocol, and completed a lifestyle questionnaire which included questions regarding age, sex, ethnicity, occupation, foreign travel, wild game consumption, smoking habit and any nuclear medicine procedures (Table 12). In addition, the subject's height and weight were recorded.

Measurement System

Lung and whole body counts were simultaneously performed with the subject positioned horizontally using two arrays of hyper-pure Ge detectors. Each array consisted of four detectors and represented a specific detector design, low energy (LEGe) and coaxial (COAX). The primary function of the LEGe detector array was lung counting (7 to 250 keV). Each LEGe detector was fitted with a 0.6 mm thick carbon composite entrance window. The active diameter, area, and thickness of each LEGe detectors as 70 mm, 3800 mm^2, and 20 mm, respectively. The function of the second detector array (COAX detectors) was to measure higher energy photons (100 to 2000 keV) emitted from radionuclides deposited in the whole body. The active diameter, length, and relative efficiency of the COAX detectors were 75 mm, 76 mm, and 80%, respectively. The high energy (1333 keV) resolution performance of the LEGe detectors was matched to that of the COAX and was added, using additional signal processing electronics, to the signal from the COAX detectors to increase the sensitivity of the whole body count.

The counting shield consists of a large shielded room measuring 2.7 m wide, 3.0 m long, and 2.7 m high. It is constructed from 25 cm-thick cast iron obtained from pre-World War II iron. A graded-Z liner (Z represents the charge of the liner element) consisting of 64 mm of lead, 32 mm of tin, and 32 mm of stainless steel was added to the inside of the iron walls of the shield to attenuate photons produced within the shield walls.

Radionuclides analyzed for in lungs included ^{232}Th, ^{144}Ce, natural U, ^{235}U, ^{226}Ra, ^{233}U, ^{155}Eu, ^{210}Pb, ^{237}Np, Pu isotopes, ^{241}Am, ^{244}Cm, and ^{252}Cf. Radionuclides analyzed for in the whole body included ^{40}K, ^{51}Cr, ^{54}Mn, ^{58}Co, ^{59}Fe, ^{60}Co, ^{65}Zn, ^{88}Y, ^{95}Zr, ^{103}Ru, ^{106}Ru, ^{125}Sb, ^{131}I, ^{133}Ba, ^{133}I, ^{134}Cs, ^{137}Cs, ^{140}Ba, ^{141}Ce, ^{152}Eu, ^{154}Eu and ^{192}Ir (Table 13). A 30-min count time was used for each subject.

Data Analysis

The proprietary software package ABACOS Plus from Canberra Industries was used for routine calibration, operation, data analysis, and data archival. This software was specially developed for *in vivo* applications and is currently employed at *in vivo* facilities located at General Electric Nuclear, Wilmington, North Carolina; Savannah River Plant, Aiken, South Carolina; Rocky Flats Environmental Technology Site, Golden, Colorado; Oak Ridge National Laboratory, Oak Ridge, Tennessee; Mound Site, Mound, Ohio; Fernald Site, Fernald, Ohio; and Lawrence Livermore National Laboratory, Livermore, California.

The identification of radionuclides of interest was accomplished using a library-driven peak search and a library-driven region of interest (ROI) analysis. The concept of 'library driven' means that only the portions of the spectrum that would contain the photons of interest (usually listed in a library) are examined.

Peak Search Analysis

A peak search was the first analysis performed on the spectral data. In simplified terms, a peak was identified by approximating, through a correlation function, the second derivative of each channel in the spectrum (Canberra, 1991, *Nuclide Identification Algorithms and Software Verification and Validation Manual*, 07-0464). When the algorithm is sampling a portion of the spectrum that contains no peaks, the second derivative should approach zero. When a peak is encountered, the second derivative will become positive and remain so until an inflection point is reached. At the inflection point, the second derivative will become negative and increase to a very large negative value just past the apex or centroid of the peak. When these conditions occurred within the spectrum, a peak was considered identified. The peak ROI, background and net counts were determined for identified peaks as described below.

Region of Interest Analysis

A region of interest, centered at a given photon energy, was established for all radionuclides regardless of whether or not a peak was identified as described above. For radionclides that were not identified by the peak search, the width of the ROI was determined by multiplying a constant by the calibrated resolution of the spectrometer at the photon energies of interest. Constants of 2 and 3 were empirically determined and verified for radionuclides deposited in lungs and whole body, respectively. Typical ROI widths for radionuclides in lungs were 25 channels and for radionuclides in whole body were 13. For radionuclides identified by the peak search, the ROI width was determined as the channels on both sides of the centroid, where the second derivative returned to zero.

Background and net counts for each ROI were calculated using a step-background computation. This computation calculates the background counts for each channel (i) in the ROI of interest (B_i) using the following equation:

$$B_i = L_{avg} + \frac{\sum_{j=L}^{i} Y_j}{\sum_{j=L}^{R} Y_j} \times \left(R_{avg} - L_{avg}\right)$$

Equation 1

where Y_j is the total counts in channel j, L is the left starting channel of the ROI, R is the right ending channel of the ROI, L_{avg} is the average value of the Compton continuum on the left side of the ROI determined from the sum of four channels to the left of L, and R_{avg} is the average value of the Compton continuum on the right side of the ROI determined from the sum of four channels to the right of R. Next, the total background counts for the region of interest (B_T) were calculated by summing B_i from channels R to L. Finally, the net count rate in the ROI was calculated by subtracting B_T from the observed gross counts and dividing by the count time.

Decision Level (L_c) and Minimum Detectable Amount (MDA)

To determine whether or not activity has been detected in a particular person, the parameter, Decision Level (L_C) was used. The L_C represents the 95th percentile of a null distribution that results from the differences of repeated, pair-wise background measurements. An individual result (net count rate) was assumed to be statistically greater than background if it was greater than L_C. It is important to recognize that the use of this criterion (L_C) will result in a statistically inherent 5% false positive error rate per pair-wise comparison (5% of all measurements will be determined to be positive when there is actually no activity in the person). Decision levels were calculated using the following equation based on the recommendations of HPS N13.30 (Performance Criteria for Radiobioassay, May 1996):

$$L_C\,(c\,s^{-1}) = \frac{2.33\sqrt{C_{gross}}}{t}$$

Equation 2

where C_{gross} is the total gross counts in the region of interest and t is the count time in seconds.

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, but it should not be used to decide if a specific radiobioassay has or has not detected activity within a person. MDA was calculated using the following equation (HPS N13.30, Performance Criteria for Radiobioassay, May 1996):

$$MDA(Bq) = \frac{3.29\sqrt{S_{B1}^2 + S_{B0}^2} + 3}{K_{0.05} \cdot t \cdot U}$$

Equation 3

where $K_{0.05}$ is the calibration factor, taking into consideration counting efficiency and self absorption, that represents the 5th percentile in distribution of individual specific calibration factors; U is a conversion factor taking into account photon yield, radioactive decay during the counting interval and unit conversion; t is the count time in seconds; S_{B1} is the standard deviation, including Poisson and other random error components in the count of a subject, determined by the routine measurement procedure, where the subject contains no actual analyte activity above that of the appropriate blank; and S_{B0} is the standard deviation, including Poisson and other random error components, in the unadjusted count of an appropriate blank. The term S_{B1} was determined from the measurement of 272 and 271 individuals for radionuclides deposited in lungs and whole body, respectively (a single whole body count was invalidated due to instrument malfunction). The term S_{B0} was determined from 20 measurements of a bottle manikin absorption (BOMAB) phantom filled with de-ionized water.

It is important to note that the use of $K_{0.05}$ applies to lung counting where individual-specific calibration factors vary with subject chest wall thickness. For example, in this study individual-specific calibration factors for ^{238}Pu ranged from 4E-5 to 4E-7. For radionclides deposited in the whole body, a single calibration factor per photon energy is applied to all individuals regardless of anthropomorphic characteristics. Historically, the variability associated with K in lung counting has been ignored, resulting in unrealistically low estimates of MDA for radionuclides deposited in lungs.

Calibration factors for lung counting were determined as a function of photon energy and muscle equivalent chest wall thickness (*MCWT*) using the humanoid torso phantom developed by Lawrence Livermore National Laboratory, 100% muscle equivalent chest plates, and ^{238}Pu and ^{241}Am/^{152}Eu lung sets. Calibration factors for whole body counting were determined using a BOMAB phantom filled with a muscle equivalent epoxy containing ^{152}Eu and ^{40}K.

For plutonium isotopes, ^{244}Cm and ^{252}Cf, the *MCWT* was determined from the subject's height, weight and age using Equation 4 (Sumerlin, T. J. and S. P. Quant, 1982, *Radiation Protection Dosimetry*, 3, 203):

$$MCWT\,(cm) = \left(1.02\,\frac{W_a}{H_a^2} - 0.03A + 0.8\right) \times 0.1$$

Equation 4

where W_a is the subject's weight (kg), H_a is the subject's height (m) and A is the subject's age.

The total thickness of tissue composing the chest wall (CWT) was determined for the remaining radionuclides in lungs using Equation 5, which represents a composite of the work performed by Fry (Fry, F. A., 1980, *Health Physics*, 39, 89), Garg (Garg, S. P., 1977, *Health Physics* 32, 54) and Dean (Dean, P. N., 1973, *Health Physics*, 24, 439):

$$CWT(cm) = -2.0038 + 1.973\frac{W_b}{H_b}$$

Equation 5

where W_b is the subject's weight (lb) and H_b is the subject's height (inch). It is important to note that this predictive equation is not normalized to muscle equivalent thickness and will result in a conservative estimate of calibration factors (Vickers, L. R., 1996, *Health Physics*, 70, 346). The calibration factors selected for the MDA calculation for plutonium isotopes, ^{244}Cm and ^{252}Cf (photon energies less than 20 keV) corresponded to the 95th percentile of the *MCWT* (*K* is inversely proportional to *MCWT*) determined from Equation 4. The calibration factors selected in the calculation of MDA for the remaining radionuclides in lungs (photon energies greater than 20 keV) corresponded to the 95th percentile of CWT determined from Equation 5. This value of CWT was then converted into muscle equivalent chestwall thicknesses for each photon energy greater than 20 keV ($MCWT_{>20\ keV}$) using Equation 6 (Krammer, G. H., et. al. 1998, *Health Physics*, 74, 594):

$$MCWT_{>20\ keV}(cm) = \frac{CWT}{m_{msc,i}}\left[m_{adp,i}AMF + m_{msc,i}(1 - AMF)\right]$$

Equation 6

where $m_{msc,i}$ is the linear attenuation coefficient at photon energy *i* for muscle (cm^{-1}), $m_{adp,i}$ is the linear attenuation coefficient at photon energy *i* for adipose (cm^{-1}) and *AMF* is the adipose mass fraction. The *AMF* for male and females were assumed to be 0.34 and 0.64, respectively (Vickers, L. R., 1996, *Health Physics*, 70, 346). A single value of *AMF*, weighted by the proportion of males and females in the cohort, was used for the calculation of $MCWT_{>20\ keV}$.

Results and Discussion

Cohort Demographics

Demographic characteristics (Table 12) of the LDBC cohort are generally consistent with the survey published by CERMC in 1998 entitled "Survey of Factors Related to Radiation Exposure and Perception of Environmental Risks in Carlsbad, Loving, Malaga, and Hobbs" and the 1990 Census for citizens living in Carlsbad. With respect to gender, ethnicity, and lifestyle, the current LDBC cohort is reasonably representative of the citizens living in the vicinity of the WIPP. The largest deviations of the LDBC demographics from those of the 1990 census were the over-sampling of males and under-sampling of Hispanics by 12.7 and 19.4 %, respectively. Interestingly, the 1998 CEMRC survey study (cited above) also under-sampled Hispanics, to an even greater degree, relative to the 1990 Census. The LDBC project is ongoing, and future recruitment efforts will focus on enrolling additional females and Hispanics. However, the 1998 CEMRC survey and current study results suggest that the recruitment of Hispanics, in proportion to the 1990 Census, will be difficult. In addition, it is important to note that if the presence of a radionuclide is dependent on a subclass of interest (gender, ethnicity, etc.), valid population estimates can still be made by correcting for the proportion of under- or over-sampling for the particular subclass.

Background Rates and Variability

The variance in background count rates generally decreased with photon energy for each count type (e.g. lung or whole body count) and source of background (e.g. human subjects or BOMAB phantom, Fig. 39 and 40). This is expected, since the counting efficiency of the instrument decreases with photon energy. Background rates of a whole body count were generally greater than that of a lung count. This also would be expected, since whole body counts were performed with eight detectors compared with four for lung counts, and the primary whole body counting detectors (COAX) are massive relative to the lung counting detectors, resulting in greater background due to increased intrinsic efficiency and photon/cosmic ray interaction cross sections.

The difference in background rates between the human subjects and the BOMAB phantom were greater for lung counts than whole body counts, where the BOMAB phantom provided a reasonable estimate of human subject background at energies less than 700 keV. The energy response or shape of the background spectrum was well approximated by the BOMAB phantom, especially for a lung count (Fig. 39). For both lung and whole body counts, repeated measures of the BOMAB phantom underestimated the variance in human subject background (Fig 40).

The variance to mean ratio (Fig. 41) in human subject background for a lung and whole body count was consistently greater than one. This has important implications to whole body and nuclear counting, since it is often assumed that background is characterized by a Poisson distribution. With a Poisson distribution, the variance to mean ratio is one, and the best estimate of the mean response is that observed (Knoll, G. F., 1989, *Radiation Detection and Measurement*, John Wiley & Sons Inc., New York). If there are no other sources of variability, then the mean, variance and standard deviation of a count result (e.g. background) can be estimated from a single measurement. For these data, if the Poisson assumption is applied and the human background was estimated from the measurement of single subject or phantom (often the case), the variability in background would have been underestimated by as much as a factor of 10, but in all cases at least a factor of 2. Underestimating the variability of background will result in an unrealistically low estimate of measurement sensitivity.

Minimum Detectable Amount

The range, mean and 95th percentile of *MCWT* (Equation 4) for plutonium isotopes, ^{244}Cm and ^{252}Cf were 1.7 to 4.9, 2.7 and 3.6 cm, respectively. The range, mean and 95th percentile of *CWT* (Equation 5) were 1.0 to 6.8, 3.1 and 5.0 cm, respectively. The 95th percentile of *CWT* when converted to $MCWT_{>20\ keV}$ (Equation 6) ranged from 3.6 cm at 47 keV to 4.7 cm at 440 keV (Table 13).

MDAs calculated as described herein for radionuclides in lungs ranged from 6.2E+00 Bq for ^{235}U to 3.1E+04 Bq for ^{239}Pu (Table 13). MDAs for radionuclides in the whole body ranged from 1.4E+01 Bq for ^{88}Y to 1.9E+02 for ^{40}K. Values of MDA reported herein are a factor of 2 to 12 greater than those reported in the CEMRC 1997 Report. The reasons for the increases are threefold. First, values of MDA reported in 1997 were based on repeated measures of a BOMAB phantom filled with 140 g of K (reference man level). Although this is standard practice in bioassay programs throughout the U.S., the data reported herein demonstrated that such methodology underestimates the variability in human background (Fig. 40 and 41). Based on *a priori* assumptions, a CWT value of 2.4 was used for calculations in the CEMRC 1997 Report to determine $K_{0.05}$ for MDA calculation of radionuclides in lungs. Finally, the previous calibration for radionuclides in lungs was based on phantom overlays consisting of 50% muscle and 50% adipose equivalent materials. A calibration based on 50% muscle/50% fat overlays has less photon attenuation because of the adipose content than that used for the current data (100% muscle overlays).

Values of MDA reported herein are more realistic than the MDAs as typically calculated, because the variability and magnitude of human subject background and population based calibration factors ($K_{0.05}$) have been considered. It is important to note that most facilities, especially those for lung counting, do not calculate MDA in this manner. Typically, an average or more ideal value of *CWT* (corresponding to *K)* is selected for the MDA calculation. However, such methodology can be quite misleading when applied to a population of individuals whose body shapes and sizes are unknown *a priori*. For example, the reported MDA applies only to those individuals with a *CWT* less than or equal to that assumed in the MDA calculation. If the assumed value of *CWT* was the average of a population, then 50% of the individuals in the population would have a *CWT* greater than the assumed value, resulting in a non-detect lung count for a lung burden equal to the reported MDA. In contrast, for this study only 5% of the population would be expected to have a *CWT* thickness greater than that assumed for the MDA calculation (in this case *MCWT*). Thus, the MDA reported herein would result in only 5% of the population having a non-detect lung count for a lung burden equal to the reported MDA at the 95% confidence level.

Results Greater Than L_C

As previously discussed, the criterion, L_C, was used to evaluate whether a result was in excess of background, and the use of this criterion will result in statistically inherent 5% false positive error rate per pair-wise comparison (5% of all measurements will be determined to be positive when there is no activity present in the person). For a particular radionuclide, to evaluate whether the frequency of results greater than L_C was consistent with a false positive error rate, a binomial statistical approach was applied. For example, if a radionuclide was not present in the sample population, the frequency of results greater than L_C should fall within the distribution-free confidence interval for a proportion equal to the error rate. The width of the confidence interval is dependent on the sample size (in this case, 272 and 271 for lung and whole body counts, respectively), the proportion of interest (5%) and level of confidence (95%). A frequency of results greater than the distribution-free confidence interval, for a radionuclide not present in the shielded room background (defined as a 24-hour count of the BOMAB phantom), would suggest a low frequency baseline of occurrence in the local population. The term ‘distribution-free’ refers to the idea that the derived statistical interval does not require any distributional assumptions with regards to the data being evaluated (Hahn, J. and W.Q. Meeker, 1991, *Statistical Intervals A Guide for Practitioners*, John Wiley & Sons, Inc. New York).

Using the ROI methodology, the percentage of results greater than L_C were consistent with a 5% random false positive error rate, at the 95% confidence level, for all radionuclides except ^{232}Th via ^{212}Pb, ^{235}U / ^{226}Ra, ^{60}Co, ^{137}Cs, ^{40}K, ^{54}Mn, ^{103}Ru, ^{232}Th via ^{228}Ac and ^{65}Zn (Table 14). Five of these (^{232}Th via ^{212}Pb, ^{60}Co, ^{40}K, ^{54}Mn (^{228}Ac interference), and ^{232}Th via ^{228}Ac) are part of the shield-room background and positive detection would be expected at low frequency. The percentage of results greater than L_C for ^{103}Ru and ^{65}Zn were below the 95% confidence interval for the random false positive error rate and may be statistical anomalies (38 comparisons to the confidence interval were made). ^{40}K is a naturally occurring isotope of an essential biological element, so detection in all individuals is expected. ^{137}Cs and ^{235}U / ^{226}Ra are not components of the shielded room background and were observed at frequency greater than the 95% confidence interval for the false positive error rate (discussed in more detail later). In addition to false positive rates, the ROI methodology appeared to be effective with respect to false negative error rates (Table 15). For example, 24-hour measurements of the BOMAB phantom were used to determine an equivalent human body burden for shield contamination from the Th series and ^{60}Co. Theoretically, if a subject had a body burden equal to L_C, the detection of that radionuclide at L_C would be missed, when actually present (false negative), 50% of the time. The false negative error rate would then increase as the body burden becomes smaller relative to L_C until eventually no activity would be detected. In all cases, shield contamination was equivalent to body burdens at levels below L_C and false negative error rates consistent with theory were observed.

In contrast, the peak search methodology did not perform as well as the ROI methodology with respect to false positive and false negative error rates and low activity radionuclide detection (Table 14). While valuable to the practice of bioassay, this observation has little impact on this study because the ROI methodology was used for the detection and quantification of radionuclide activity.

^{40}K results were positive for all individuals, ranging from 2308 to 6513 Bq with an overall mean (± SE) of 3293 (± 784) Bq. 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 4730 (± 46) Bq, which was significantly greater ($P < 0.0001$) than that of females, which were 3507 ± 39 Bq (mean ± SE). This result was also expected since, in general, males tend to have larger body sizes and greater muscle content than females.

In 27.8% of individual measurements, the value for ^{137}Cs was greater than L_C, ranging from 6 to 25 Bq. This percentage was significantly higher than the distribution-free confident interval for a 5% random false positive error rate (2.2 to 7.4%), suggesting a low frequency baseline occurrence of ^{137}Cs in the local population. From these data, detectable ^{137}Cs is present in 22% to 33% (95% confidence level) of citizens living in the Carlsbad area. These results are consistent with preliminary conclusions that were reported in the CEMRC 1997 Report and 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 and 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).

Individual ^{137}Cs results were then compared to two sources of demographic data to determine whether the presence of ^{137}Cs was dependent on a particular demographic or lifestyle parameter using a Chi-square test of independence (L. Ott, 1988, *An Introduction to Statistical Methods and Data Analysis*, PWS-Kent Publishing Company, Boston, MA; Table 16). The presence of ^{137}Cs was independent of gender, ethnicity, age, radiation work history, consumption of wild game, nuclear medical treatments and European travel. Occurrence of detectable ^{137}Cs was slightly associated ($p = 0.032$) with smoking habit, where smokers had a higher prevalence of ^{137}Cs relative to non-smokers (21.3 to 11.2%, respectively). These data are interesting because ^{137}Cs is often assumed to be correlated to the consumption of wild game, but this pattern did not appear in these data. The association of ^{137}Cs with smoking habit is also interesting, and could be related to the presence of fallout ^{137}Cs in tobacco. However, the statistical significance of this dependence was weak, and further study is warranted.

The percentage of results greater than L_C for ^{235}U/^{226}Ra (9.9%) was significantly (although slightly) higher than the distribution-free confidence interval for a 5% random false positive error rate (2.2 to 7.4%). These data are not nearly as suggestive, when compared to ^{137}Cs, of low frequency baseline occurrence of ^{235}U/^{226}Ra. It is important to note that ^{235}U and ^{226}Ra are naturally occurring and these two radionuclides cannot be distinguished via gamma spectroscopy. Therefore, any positive signal could be the result of either or both radionuclides. This effect was not apparent in the initial data reported in the CEMRC 1997 Report and requires a larger sample size to support or reject the apparent pattern.

No data tables for the LDBC are presented on the CEMRC web site due to the confidential nature of the results.

Table 12. Demographic Characteristics of the "Lie Down and Be Counted" (LDBC) Population Sample to Date

Characteristic		LDBC ([a]margin of error)	[b]CEMRC, 1998	[c]Census, 1990
Gender	Male	60.7% (54.8 to 66.5%)	34.9%	48.0%
	Female	39.3% (33.5 to 45.2%)	64.7%	52.0%
Ethnicity	Hispanic	14.0% (9.9 to 18.0%)	9.7%	33.4%
	Non-Hispanic	82.7% (78.3 to 87.1%)	83.2%	63.0%
	Other	3.3% (1.5 to 6.6%)	7.1%	3.6%
Age 60 or older		25.7% (20.6 to 30.9%)	44.3%	33.7%
Currently or previously classified as a radiation worker		4.0% (1.5 to 6.3%)	6.9%	[d]NA
Consumption of wild game within last 3 months		16.9% (12.5 to 21.3%)	21.6%	NA
Medical treatment, other than x-rays, using radionuclides		8.5% (5.1 to 11.8%)	4.0%	NA
European travel within the last 2 years		4.4% (1.8 to 6.6%)	NA	NA
Current smoker		14.0% (9.9 to 18.0%)	25.0%	NA

[a] The margin of error represents the 95% confidence interval of the observed proportion. Under complete replication of this experiment, one would expect the confidence interval to include the true population proportion 95% of the time if the sample was representative of the true population.

[b] Respondent demographics and lifestyle characteristics identified in the community study reported in “Survey of Factors Related to Radiation Exposure and Perceptions of Environmental Risks in Carlsbad, Loving, Malaga and Hobbs, New Mexico.”

[c] United States Department of Commerce, Economics and Statistics Administration, Bureau of the Census. *1990 Census of Population*. Washington, DC: US Government Printing Office.

[d] NA = not available

Table 13. MDA Parameters for Radionuclides Deposited in Lungs and Whole Body

Radionuclide	In Vivo Count Type	Photon Energy (keV)	95th Percentile of [a]MCWT (cm)	[b]K$_{0.05}$ (%)	[c]S_{B1} (counts)	[d]S_{B0} (counts)	[e]MDA (Bq)
^{239}Pu	Lung	1.7E+01	3.6E+00	5.8E-03	1.8E+01	6.6E+00	3.1E+04
^{238}Pu	Lung	1.7E+01	3.6E+00	5.8E-03	1.8E+01	6.6E+00	1.2E+04
^{244}Cm	Lung	1.8E+01	3.6E+00	1.1E-02	1.2E+01	6.8E+00	6.4E+03
^{252}Cf	Lung	1.9E+01	3.6E+00	1.9E-02	9.6E+00	7.5E+00	4.5E+03
^{210}Pb	Lung	4.7E+01	4.6E+00	4.5E-01	1.3E+01	6.5E+00	1.6E+02
^{232}Th	Lung	5.9E+01	4.6E+00	5.5E-01	1.3E+01	6.8E+00	2.8E+03
^{241}AM	Lung	6.0E+01	4.6E+00	5.6E-01	1.3E+01	8.2E+00	1.5E+01
Natural U via ^{234Th}	Lung	6.3E+01	4.6E+00	5.8E-01	1.3E+01	7.3E+00	1.3E+02
^{232}Th via ^{228}Th	Lung	8.4E+01	4.7E+00	6.4E-01	1.4E+01	9.1E+00	4.1E+02
^{237}Np	Lung	8.7E+01	4.7E+00	6.5E-01	1.3E+01	1.1E+01	4.0E+01
^{155}Eu	Lung	1.1E+02	4.7E+00	7.1E-01	1.4E+01	9.1E+00	2.2E+01
^{144}Ce	Lung	1.3E+02	4.7E+00	7.7E-01	1.2E+01	7.7E+00	3.2E+01
^{235}U	Lung	1.9E+02	4.7E+00	7.5E-01	1.1E+01	6.8E+00	6.2E+00
^{226}Ra	Lung	1.9E+02	4.7E+00	7.5E-01	1.1E+01	6.8E+00	1.0E+02
^{232}Th via ^{212}Pb	Lung	2.4E+02	4.7E+00	5.4E-01	8.3E+00	5.6E+00	8.4E+00
^{233}U	Lung	4.4E+02	4.7E+00	3.2E-01	8.2E+00	5.4E+00	3.7E+01
^{155}Eu	Whole Body	1.1E+02	[f]NA	3.9E-01	5.5E+01	3.6E+01	1.5E+02
^{141}Ce	Whole Body	1.5E+02	NA	4.1E-01	5.0E+01	3.5E+01	5.6E+01
^{192}Ir	Whole Body	3.2E+02	NA	3.3E-01	2.5E+01	1.5E+01	2.0E+01
^{51}Cr	Whole Body	3.2E+02	NA	3.3E-01	2.5E+01	1.3E+01	1.6E+02
^{152}Eu	Whole Body	3.4E+02	NA	3.2E-01	2.5E+01	1.4E+01	6.5E+01
^{133}Ba	Whole Body	3.6E+02	NA	3.2E-01	3.5E+01	2.2E+01	3.9E+01
^{131}I	Whole Body	3.6E+02	NA	3.1E-01	2.2E+01	1.2E+01	1.9E+01
^{125}Sb	Whole Body	4.3E+02	NA	2.9E-01	1.8E+01	1.3E+01	5.0E+01
^{1013}Ru	Whole Body	5.0E+02	NA	2.7E-01	1.6E+01	9.8E+00	1.5E+01
^{133}I	Whole Body	5.3E+02	NA	2.6E-01	1.5E+01	1.2E+01	1.6E+01
^{140}Ba	Whole Body	5.4E+02	NA	2.6E-01	1.5E+01	1.3E+01	5.9E+01
^{134}Cs	Whole Body	6.0E+02	NA	2.5E-01	3.6E+01	8.1E+00	2.8E+01
^{106}Ru	Whole Body	6.2E+02	NA	2.5E-01	1.3E+01	9.1E+00	1.3E+02
^{137}Cs	Whole Body	6.6E+02	NA	2.4E-01	1.7E+01	8.5E+00	1.8E+01
^{95}Zr	Whole Body	7.6E+02	NA	2.3E-01	1.2E+01	8.4E+00	2.3E+01
^{58}Co	Whole Body	8.1E+02	NA	2.2E-01	1.3E+01	1.0E+01	1.4E+01
^{54}Mn	Whole Body	8.3E+02	NA	2.2E-01	1.2E+01	1.6E+01	1.7E+01
^{88}Y	Whole Body	9.0E+02	NA	2.1E-01	1.2E+01	8.7E+00	1.4E+01
^{232}Th via ^{228}Ac	Whole Body	9.1E+02	NA	2.1E-01	1.3E+01	9.1E+00	5.0E+01
^{59}Fe	Whole Body	1.1E+03	NA	2.0E-01	1.3E+01	6.0E+00	2.5E+01
^{65}Zn	Whole Body	1.1E+03	NA	2.0E-01	1.5E+01	1.7E+01	4.3E+01
^{154}Eu	Whole Body	1.3E+03	NA	1.8E-01	1.1E+01	5.3E+00	3.6E+01
^{60}Co	Whole Body	1.3E+03	NA	1.8E-01	1.1E+01	8.8E+00	1.5E+01
^{40}K	Whole Body	1.5E+03	NA	1.7E-01	1.4E+01	1.2E+01	1.9E+02

[a]MCWT = muscle equivalent chest wall thickness

[b]K$_{0.05}$ = the calibration factor, taking into consideration counting efficiency and self absorption, that represents the 5th percentile in distribution of individual specific calibration factors

[c]S_{B1} = determined from the measurement of 272 and 271 individuals for radionuclides deposited in lungs and whole body, respectively (a single whole body count was invalidated due to instrument malfunction.)

[d] S_{B0} = determined from 20 measurements of a bottle manikin absorption (BOMAB) phantom filled with de-ionized water.

[e] MDA = minimum detectable amount

[f]NA = not applicable

Table 14. Results Greater Than L_C for Radionuclides Deposited in Lungs and Whole Body

Radionuclide	In Vivo Count Type	% Results ≥ ^aL_C via ROI Method	% Results ≥ ^aL_C via Peak Search Method	Present in Shielded Room Background (24 hour)
^{241}Am	Lung	4.4	0.4	No
^{144}Ce	Lung	5.1	0.0	No
^{252}Cf	Lung	4.4	0.0	No
^{244}Cm	Lung	5.5	0.0	No
^{155}Eu	Lung	6.3	0.0	No
^{237}Np	Lung	4.4	0.4	No
^{210}Pb	Lung	4.8	0.4	No
Plutonium Isotope	Lung	5.5	0.4	No
^{232}Th via ^{212}Pb	Lung	31.3	0.4	Yes
^{232}Th	Lung	4.8	0.7	No
^{232}Th via ^{228}Th	Lung	4.0	0.0	No
^{233}U	Lung	4.1	0.4	No
^{235}U / ^{226}Ra	Lung	9.9	0.0	No
Natural Uranium via ^{234}Th	Lung	5.1	0.4	No
^{133}Ba	Whole Body	3.7	0.4	No
^{140}Ba	Whole Body	5.2	1.1	No
^{141}Ce	Whole Body	4.1	0.4	No
^{58}Co	Whole Body	4.4	1.8	No
^{60}Co	Whole Body	56.8	17.0	Yes
^{51}Cr	Whole Body	5.9	0.4	No
^{134}Cs	Whole Body	2.2	0.0	No
^{137}Cs	Whole Body	27.7	14.4	No
^{152}Eu	Whole Body	7.0	1.1	No
^{154}Eu	Whole Body	3.3	0.7	No
^{155}Eu	Whole Body	3.0	1.1	No
^{59}Fe	Whole Body	3.3	0.4	No
^{131}I	Whole Body	5.2	0.4	No
^{133}I	Whole Body	4.4	1.5	No
^{192}Ir	Whole Body	4.4	0.0	No
^{40}K	Whole Body	100.0	100.0	Yes
^{54}Mn	Whole Body	12.9	2.2	Yes, ^{228}Ac interference
^{103}Ru	Whole Body	1.5	0.0	No
^{106}Ru	Whole Body	4.8	0.4	No

Table continued on next page

Table 14. Results Greater Than L_C for Radionuclides Deposited in Lungs and Whole Body (Continued)

Radionuclide	In Vivo Count Type	% Results ≥ $^{a}L_C$ via ROI Method	% Results ≥ $^{a}L_C$ via Peak Search Method	Present in Shielded Room Background (24 hour)
^{125}Sb	Whole Body	4.4	0.7	No
^{232}Th via ^{228}Ac	Whole Body	37.3	9.2	Yes
^{88}Y	Whole Body	5.9	0.7	No
^{65}Zn	Whole Body	0.4	0.0	No
^{95}Zr	Whole Body	6.6	0.7	No

[a] The 95% confidence interval for a random, 5% error rate is 2.2 to 7.4%. An observed percentage outside this interval would be consider statistically inconsistent with a random 5 % false positive error rate

Table 15. Evaluation of False Negative Error Rate of the ROI Algorithm

Radionuclide	Photon Energy (keV)	Equivalent Human Body Burden (c s^{-1})	Typical Human ^{a} L_C (c s^{-1})	Body Burden relative to L_C	Observed False Negative Rate (%)
^{212}Pb	2.4E+02	6.4E-03	8.7E-03	0.73	68.3
^{228}Ac	8.4E+02	4.4E-03	1.1E-02	0.39	87.0
^{228}Ac	9.1E+02	5.8E-03	1.1E-02	0.53	63.2
^{60}Co	1.3E+03	9.5E-03	9.6E-03	1.00	43.0

[a] Theoretically, if a subject had a body burden equal to L_C, the detection of that radionuclide at L_C would be missed when actually present (false negative) 50% of the time. The false negative error rate would then increase as the body burden becomes smaller relative to L_C until eventually no activity would be detected.

Table 16. Demographic Characteristics Associated with Occurrence of ^{137}Cs in Local Residents

Characteristic		Percent of Population (n=196) where Cs-137 was Not Detected (H_0), ([a]margin of error)	Percent of Population (n=75) where Cs-137 was Detected (H_A), (margin of error)	[b]p-value (H_A Ì H_0)
Gender	Male	57.1 (51.3 to 63.5)	69.3 (63.5 to 74.5)	0.066
	Female	42.9 (36.5 to 48.7)	30.7 (25.5 to 36.5)	
Ethnicity	Hispanic	14.3 (10.3 to 18.8)	13.3 (9.2 to 17.3)	0.516
	Non-Hispanic	83.2 (78.6 to 87.5)	81.3 (76.4 to 85.6)	
	Other	2.6 (0.7 to 4.4)	5.3 (2.2 to 7.7)	
Age	≥ 60 years	23.0 (17.7 to 27.7)	24.0 (18.8 to 29.2)	0.860
	< 60 years	77.0 (72.0 to 82.0)	76.0 (70.8 to 81.2)	
Currently or previously classified as a radiation worker	Yes	4.5 (1.8 to 6.6)	2.7 (0.7 to 4.8)	0.472
	No	95.4 (93.0 to 98.2)	97.3 (95.2 to 98.9)	
Consumption of wild game within last 3 months	Yes	84.7 (80.4 to 89.3)	78.7 (73.8 to 83.4)	
	No	15.3 (10.7 to 19.6)	21.3 (16.6 to 26.2)	0.237
Medical treatment, other than x-rays, using radionuclides	Yes	4.6 (1.8 to 6.6)	2.8 (0.7 to 4.8)	0.516
	No	95.4 (93.0 to 98.2)	97.3 (95.2 to 98.9)	
European travel within the last 2 years	No	4.1 (1.8 to 6.6)	5.3 (2.6 to 7.7)	0.654
	Yes	95.9 (93.4 to 98.2)	94.7 (91.9 to 97.4)	
Current smoker	Yes	11.2 (7.4 to 14.8)	21.3 (16.6 to 26.2)	0.032
	No	88.8 (85.6 to 93.4)	78.7 (74.2 to 83.8)	

[a] The margin of error represents the 95% confidence interval of the observed proportion. Under complete replication of this experiment, one would expect the confidence interval to include the true population proportion 95% of the time if the sample was representative of the true population.

[b] The probability of observing a percentage greater than H_A assuming that the percentage (H_O) is the true value.

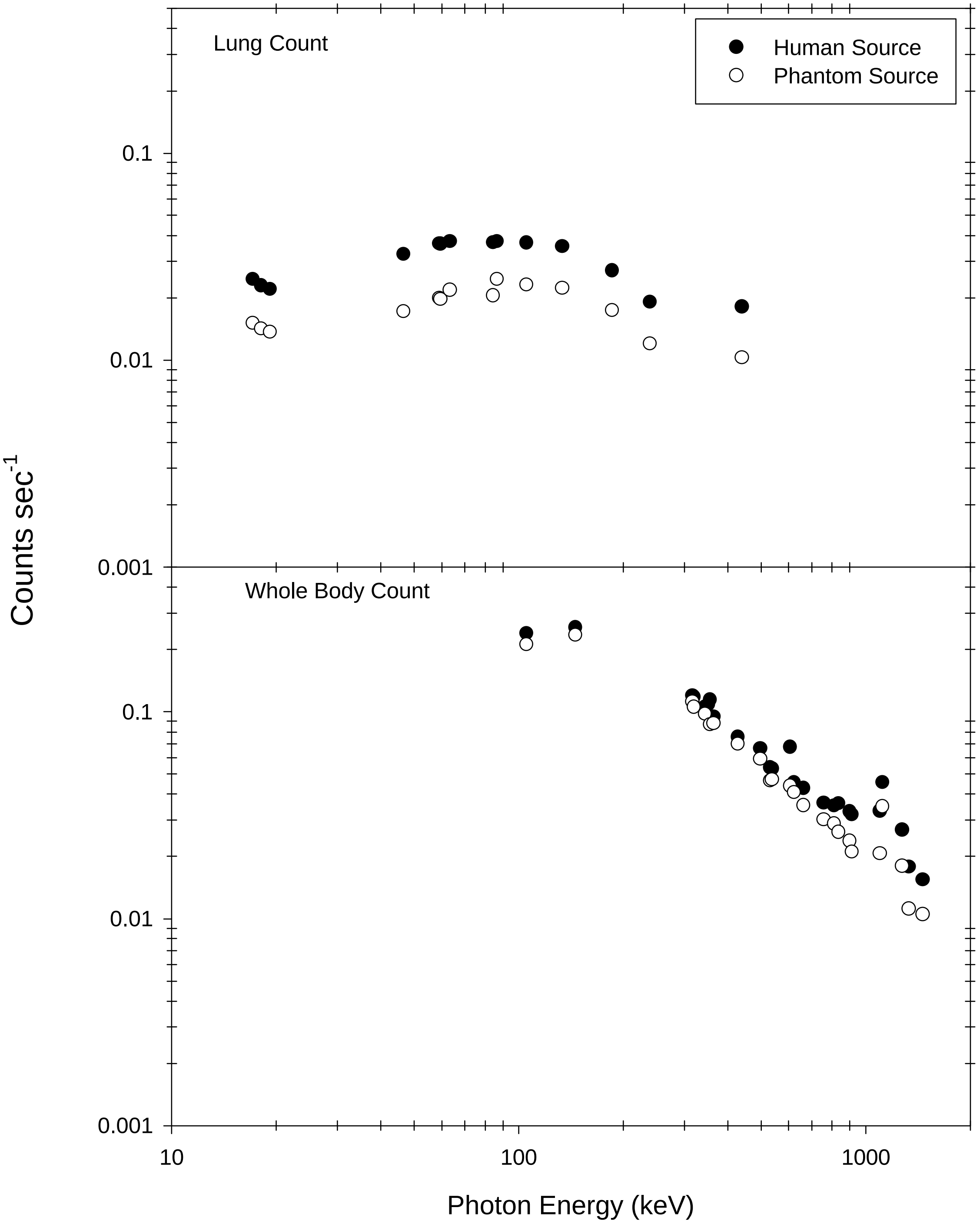


Figure 39. Mean Background Count Rate as a Function of In Vivo Count Type, Source of Background and Photon Energy

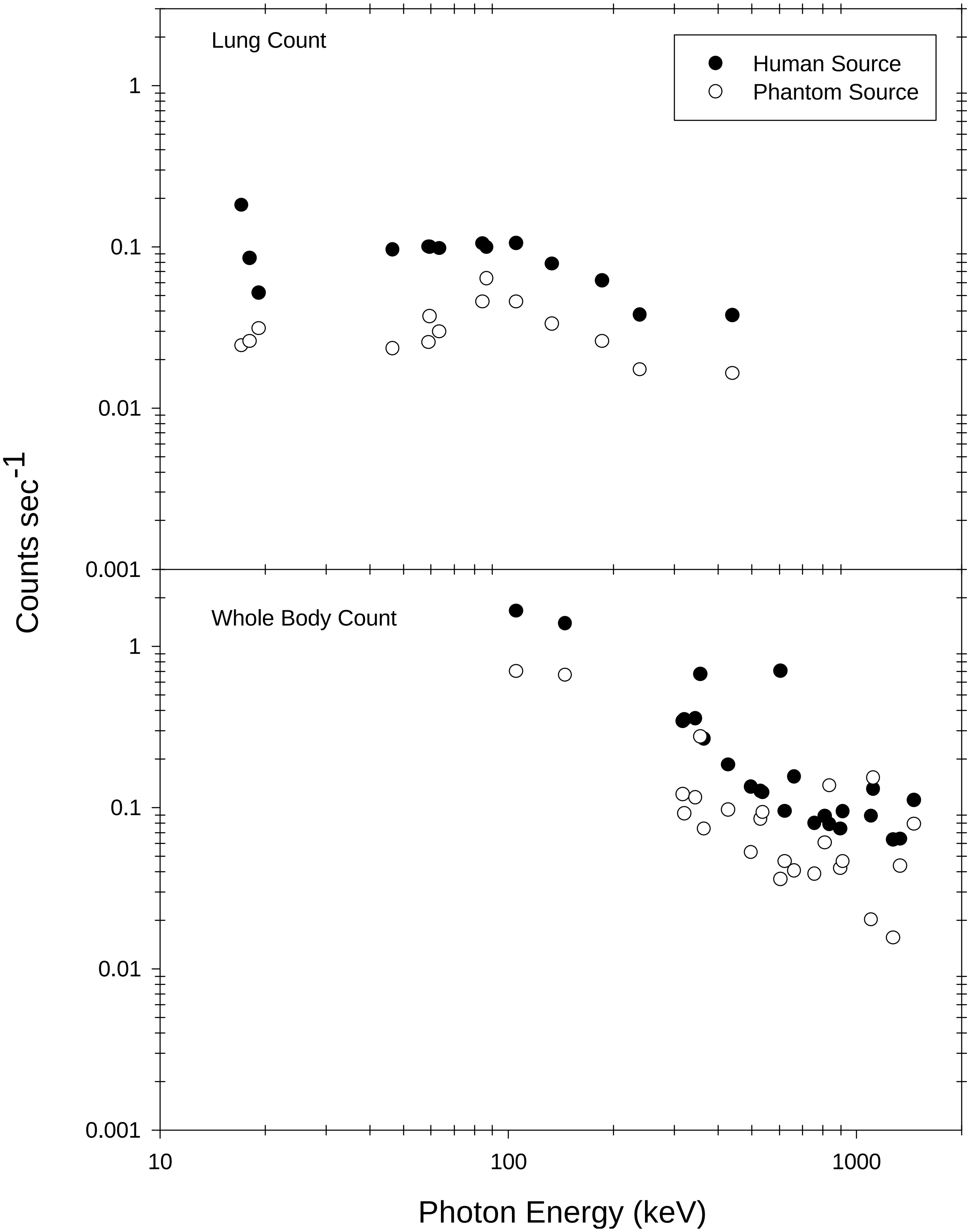


Figure 40. Variance in the Background Count Rate as a Function of In Vivo Count Type, Source of Background and Photon Energy

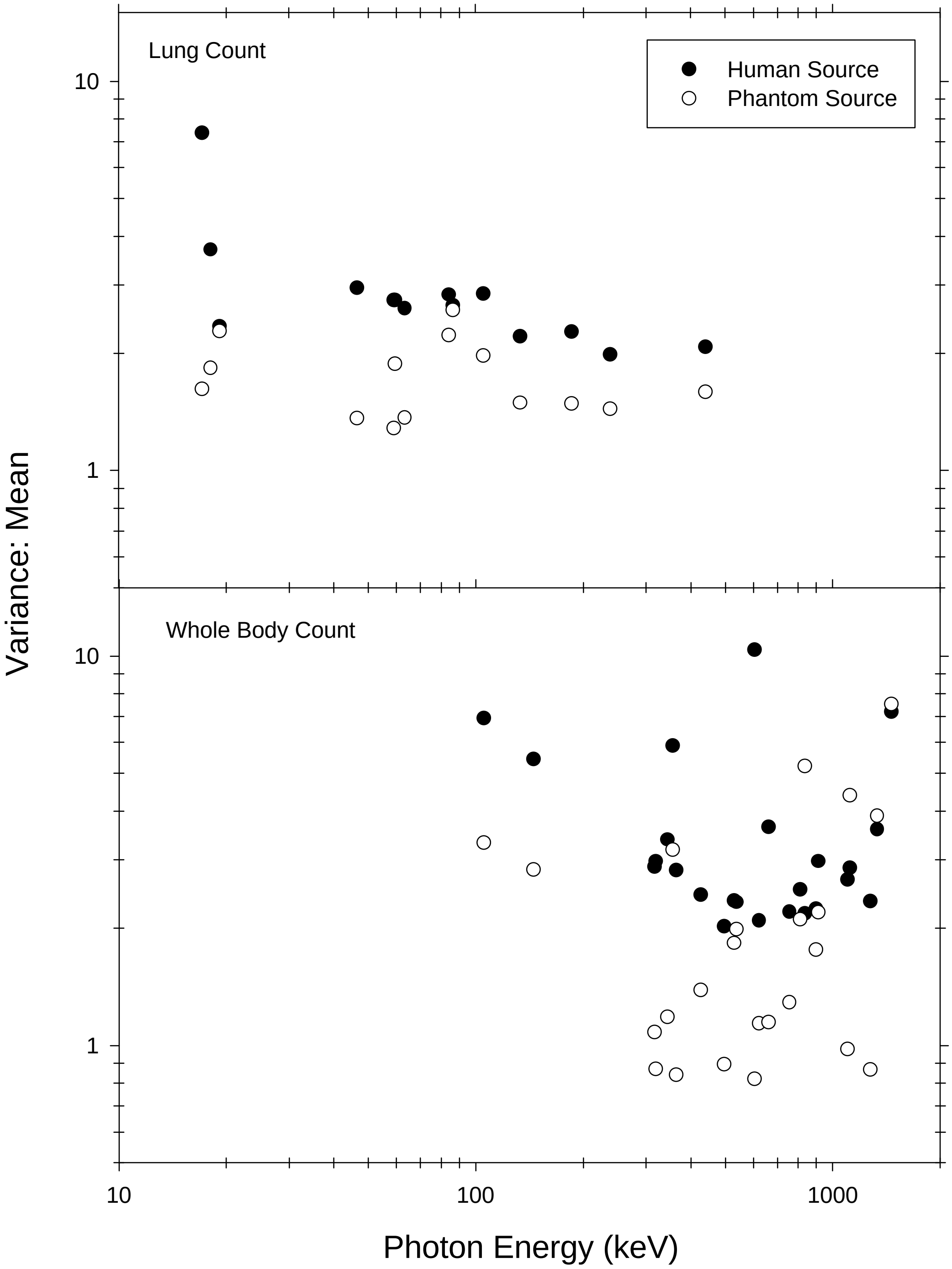


Figure 41. Variance to Mean Ratio of Background Counts as a Function of In Vivo Count Type, Source of Background and Photon Energy.

A variance to mean ratio of 1 would be expected for Poisson data.

APPENDICES

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

The Carlsbad Environmental Monitoring & Research Center (CEMRC) was created in 1991, as a division of the Waste-management Education & Research Consortium (WERC), in the College of Engineering at New Mexico State University (NMSU). The CEMRC was conceived as a result of inquiries to WERC by concerned citizens of the Carlsbad region, acting as a grassroots coalition who recognized the need for high quality, independent health and environmental assessment. Many individuals and organizations supported the CEMRC's formation including the residents of Carlsbad, New Mexico, and the surrounding region; NMSU; the Carlsbad Department of Development; the New Mexico Congressional Delegation; the New Mexico Radioactive and Hazardous Materials Committee; Westinghouse Electric Corporation; and the U.S. Department of Energy (DOE). The CEMRC was established with a grant entitled "Carlsbad Environmental Monitoring and Research Program" (CEMRP) from DOE to NMSU. The CEMRP initially was funded for $27 million over a seven year period (1991–1998). Subsequently, the grant was increased to almost $33 million to support operations of the program until 2008.

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

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

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

Appendix B. Subcontractors for Scientific Work during 1998

Subcontractor	Scope of Work
A&L Plains Laboratory	Analyses of soil and sediment samples
Argonne National Laboratory	Radiochemical analyses of environmental samples
Battelle Memorial Institute, Pacific Northwest Division	Fabrication of lung sets for *in vivo* bioassay
Desert Research Institute	Preparation of QA documentation for environmental chemistry
Duke Engineering and Services	Preparation of QA documentation for radiochemistry, radioanalyses of soil and sediment samples
Los Alamos National Laboratory	Analyses of water samples by thermal ionization mass spectrometry
NMSU Electron Microscopy Laboratory	Analyses of vegetation surfaces
NMSU Physical Sciences Laboratory	Meteorological station usage and technical assistance
NMSU Soil, Water, Air Testing Laboratory	Analyses of water samples
University of Rhode Island	Neutron activation analysis, gamma-ray spectroscopy

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

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

Appendix D. Presentations and Publications during 1998

Author	Title	Publisher/Conference
Arimoto, R.	Trace elements and radionuclides in the atmosphere	NMSU Department of Chemistry and Biochemistry, invited seminar
Arimoto, R.	Sources and composition of aerosol particles	Handbook of Atmospheric Chemistry, submitted
Arimoto, R.	The biogeochemistry of aerosols	New Mexico Institute of Mining and Technology, invited seminar
Arimoto, R.	The use of naturally occurring radionuclides (Be-7 and Pb-210) as atmospheric tracers	44th Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Albuquerque, New Mexico
Arimoto, R., J. A. Snow, W. C. Graustein, J. L. Moody, B. J. Ray, R. A. Duce, K. K. Turekian and H. B. Maring	Factors controlling the activities of ^{7}Be and ^{210}Pb in aerosols from Bermuda: examination of the data for a day-of-the-week effect.	American Geophysical Union, Fall Meeting, San Francisco, California
Arimoto, R.	Asian Dust	Korea Institute of Science and Technology, Seoul, Korea
Arimoto, R.	Ground Station Studies	Meeting for Asia Pacific Regional Experiment (APARE)/Transport and Atmospheric Chemical Evolution over the Pacific (TRACE-P), Hong Kong
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, 28:551-528, 574
Ezat, U. F. Dulac, W. Guelle, C. Moulin, J.M. Prospero, K.D. Perry, and R. Arimoto	Mineral dust from Africa over the Caribbean	Deauville Conference 98, 6th International Symposium in Analytical Sciences, Valencia, Spain
Huang, S., U. Tomza, R. Arimoto, K. A. Rahn, and J. M. Prospero	Determining the composition of Saharan aerosol at Barbados, Bermuda and Izaña	American Geophysical Union, Spring Meeting, Boston, Massachusetts
Huang, S., K. A. Rahn, and R. Arimoto	Origins of ozone at Bermuda: Evidence from Trace-element Data	American Geophysical Union, Fall Meeting, San Francisco, California
Huang, S., K. A. Rahn, and R. Arimoto	Testing and optimizing two factor-analysis techniques on aerosol at Narragansett, Rhode Island	Atmospheric Environment, in press
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 12:311-320

Appendix D. Presentations and Publications during 1998 (Continued)

Author	Title	Publisher/Conference
Khodzher, T.V., K.A. Rahn, U. Tomza, and R. Arimoto	On the origin of the Siberian aerosol	Joint International Symposium on Global Atmospheric Chemistry, Seattle, Washington
Kirchner, T.B.	Misjudging tolerance: errors involving randomization tests	Ecological Society of America, 83rd Annual Meeting, Baltimore, Maryland
Kirchner, T.B.	Variability and uncertainty in ecological systems	NMSU Department of Biology, invited seminar
Kirchner, T.B.	Variability, confidence, and uncertainty: sorting out the confusion	44th Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Albuquerque, 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	Journal of Radioanalytical and Nuclear Chemistry 234:267-272
Peterson, S.R. and T.B. Kirchner	Data quality and validation of radiological assessment models	Health Physics 74:148-157
Tomza, U., L. Granina, R. Arimoto, and A. Grachev	Studying the chemical budget of Lake Baikal by means of neutron activation and synchrotron radiation	Ecological Session, XII National Synchrotron Radiation Conference, Novosibirsk, Russia
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, in press
Webb, J.	In vivo measurement sensitivity/occurrence of radionuclides in residents of the Carlsbad, New Mexico area	44th Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Albuquerque, New Mexico
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, 28:41-28, 47
Zhang, X.Y., R. Arimoto, G.H. Zhu, T. Chen, and G.Y. Zhang	Concentration, size-distribution and deposition of mineral aerosol over Chinese desert regions	Tellus, in press
Zhang, X.Y., R. Arimoto, and Z.S. An	Glacial and interglacial patterns for Asian dust transport	Quaternary Science Reviews, in press

Appendix E. Guest Colloquia

Topic	Group/Event
Ecosystem dynamics, contaminant transport, and risk in semiarid systems	David Breshears, Environmental Science Group, Los Alamos National Laboratory
Beyond lung counting: application of liver and bone	Milan Gadd, Senior Health Physicist, Rocky Flats Environmental Technology Site
Sources, emission, regional- and global-scale transport of Asian dust	Xiaoye Zhang, Director, Dust & Geochemistry Laboratory, State Key Laboratory of Loess & Quaternary Geology, Chinese Academy of Sciences, China
New observations on the long-term behavior of cesium-137 and the actinides in surface soils	Ward Whicker, Professor, Department of Radiological Health Sciences, Colorado State University
NIST low-level radiochemistry measurement quality assurance program	Kenneth Inn, Group Leader, Office of Radiation Measurements, National Institute of Standards and Technology
A hierarchical view of disturbance in the longleaf pine ecosystem	William Michener, Associate Scientist, J.W. Jones Ecological Research CEMRC
Environmental effects of underground nuclear testing for peacetime applications	Boris Golubov, Science Secretary, Scientific Council on Biosphere Problems, Russian Academy of Sciences, Moscow, Russia
Natural and anthropogenic aerosols at Big Bend National Park, Texas	Thomas Cahill, Professor Emeritus, Department of Atmospheric Sciences, University of California, Davis

Appendix F. Major Tours, Presentations and Exhibits

Group/Event
Webster University, Environmental Issues class – CEMRC tour and presentation
Scientific delegation from Xi'an, Shaanxi Province, Peoples' Republic of China – CEMRC tour, presentation and dinner
Representatives of Center for Environmental Resource Management, University of Texas at El Paso – CEMRC tour
Senator Jeff Bingaman (D-NM) – CEMRC tour
Delegations from Texas State Energy Conservation Office, Texas General Services Commission, Texas Natural Resource Conservation Commission, Texas Low-Level Radioactive Waste Disposal Authority, Texas A&M University, Texas Tech University, University of Texas at Austin, Amarillo National Resource Center for Plutonium, Texas Department of Public Safety, Texas Attorney General office, and Texas Department of Health – CEMRC tour and presentation
NMSU/National Science Foundation Research Experience for Undergraduates – CEMRC tour and presentation
International Workshop on Technologies in Nuclear Waste Repositories – CEMRC tour and presentation
Earth Day, Living Desert State Park – exhibit "How Nature Recycles"
25th Memorial Guadalupe Mountains National Symposium – CEMRC exhibit
NMSU Mini-symposium on Environmental Chemistry – poster and exhibit
Chemistry Club, New Mexico Institute of Mining and Technology – CEMRC tour and presentation
New Mexico Endowment for the Humanities, Annual Meeting – CEMRC tour
Carlsbad Public Schools Science Showcase – exhibit "Picture Yourself in Science"
WorldNet TV – filmed interview for international broadcast, program on nuclear energy
44th Annual Conference on Bioassay, Analytical and Environmental Radiochemistry – CEMRC exhibit
Carlsbad Municipal Schools, Fourth-grade Teachers – CEMRC tour and presentation
Carlsbad Municipal Schools, P.R. Leyva Middle School, Gifted Classes – CEMRC tour and program

Appendix G. Leadership Participation by CEMRC Staff in Professional Functions

Function	CEMRC Staff/Role
American Geophysical Union Spring Meeting, Boston, Massachusetts	R. Arimoto, Atmospheric Sciences Program Committee Chair, Co-Chair for technical session "Biogeochemical cycles and air-sea exchange"; recipient of Editor's Award for Excellence in Reviewing for the Journal of Geophysical Research-Atmospheres
Pacific Exploratory Mission – Tropics Experiment, Moffet Field, California	R. Arimoto, Member, NASA Review Panel
International Global Atmospheric Chemistry/Asia Pacific Regional Experiment, Seoul, Korea	R. Arimoto, Member, Executive Committee
American Geophysical Union, Spring Program Committee Meeting, Washington, D.C.	R. Arimoto and C. Schloesslin, Program Organization group
American Geophysical Union, Journal of Geophysical Research-Atmospheres	R. Arimoto, Associate Editor
American National Standards Institute, HPS N13.25, Internal Dosimetry Programs for Plutonium Exposure – Minimum Requirements	J. Webb, Member, Standards Committee Working Group
44th Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Albuquerque, New Mexico	M. Conley, Member, Program Committee
University of Texas at El Paso, National Science Foundation Model Institutions for Excellence Project	M. Conley, Member, Advisory Committee

Appendix H. 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, 1998-2002	Funded, in progress
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, in progress
Characterization of ambient particulate matter in the Paso del Norte region	R. Arimoto (with five NMSU investigators)	U.S. Environmental Protection Agency, via Southwest Center for Environmental Research and Policy	$30,000, 1999-2000	Funded
Proposal to establish the U.S. Department of Energy Waste Isolation Pilot Plant Environmental Research Park	M. Conley	DOE/Carlsbad Area Office	No request for funding	Submitted
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, in progress
Tools and methodologies for reducing uncertainties in assessment models	T. Kirchner (with W. Whicker, Colorado State University)	U.S. Environmental Protection Agency, National Exposure Research Laboratory	$1,339,578 1999-2003	Submitted, not funded
Colorado Health Advisory Panel	T. Kirchner	Colorado Department of Public Health & Environment	$25,000 1997-1998	Terminated
Non-invasive transuranic waste migration monitoring system at the WIPP site using neutron detectors	S. Lee (with E. Fenves, University of Texas at Dallas, and D. Cline, UCLA)	DOE, Federal Energy Technology Center	$1,125,983 1998-2001	Submitted, not funded
Determination of americium and thorium in brines	S. Lee	Sandia National Laboratory	$8,000 1998-2000	Funded, schedule delayed

Table continued on next page

Appendix H. New Project Development (Continued)

Proposal/Bid Title	PI(s)	Sponsor	Funding Proposed/ Term	Status
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, not funded
Soil and aerosol sampling and analyses	D. Schoep	Los Alamos National Laboratory	$5,977, 1998	Funded, completed
Limnological monitoring: Brantley Dam Reservoir	D. Schoep	U.S. Department of Interior, Bureau of Reclamation	$56,379, 1997-2000	Funded, in progress
Baseline *in vivo* radiobioassay measurements	J. Webb	Waste Control Specialists, Inc.	$47,916, 1997-1999	Funded, in progress
In vivo Radiobioassay Measurements for WIPP Personnel	J. Webb	Westinghouse Electric Company	$190,213, 1998-1999	Funded, in progress
Radiobioassays for Ir-192	J. Webb	Radiographic Specialists, Inc.	$3,742	Funded, completed
The role of natural ionizing radiation in modulating cellular function	J. Webb	Lovelace Respiratory Research Institute	$198,342, 1999-2001	Submitted, not funded
^{210}Pb - A biomarker for exposure of people to radon in indoor environments	J. Webb	Lovelace Respiratory Research Institute	$43,000 1998-2000	Submitted, not funded
In Vivo measurements of radiation workers at Pantex Plant	J. Webb	Mason Hanger Corporation	$5,356, 1998-1999	Funded, completed
In vivo measurements of affected workers at Hanford Site	J. Webb	Fluor Daniel Hanford	$8790, 1998-1999	Funded, in progress
Measurement of ^{210}Pb and ^{7}Be in environmental media using contrasting geometries	J. Webb	International Atomic Energy Agency	No funding requested	Submitted
The cow counter: technology for the measure of radio-contaminants and fat-free lean content in livestock	J. Webb (with G. Duff, NMSU)	DOE, via Waste-management Education and Research Consortium	$169,860, 1999-2000	Funded, in progress

Appendix I. Status of Completion of 1998 Key Performance Indicators

1. Concurrent high-volume and low-volume aerosol sampling at two locations through 1998. [Completed]
2. Initiate operation of high volume aerosol sampler at third location at WIPP site prior to May 1998. [Completed]
3. Assume responsibility for one FAS sampling port in WIPP exhaust shaft prior to May 1998. [Delayed, completed December 1998]
4. Complete collection of triplicate soil samples at current 32 locations by May 1998. [Delayed, completed June 1998]
5. Concurrent operation of meteorological sampling stations at two sites through 1998. [Completed]
6. Collect drinking water samples at 6 sources in April 1998; repeat sample collection in August 1998. [April collection completed; August collection delayed, completed December 1998]
7. Collect sediment and surface water samples at three locations in February 1998 and July 1998. [February collection delayed, completed March 1998; July collection delayed, completed October 1998]
8. Collect animal and vegetation samples during spring and fall 1998. [Vegetation and animal (arthropod) collection completed]
9. Continue *in vivo* bioassays for public to include at least 200 people including repeated measures on individuals in 1997 studies. [Bioassays for over 250 people completed, repeat measurements postponed to begin in 1998.]
10. Radioanalyses of segment of 1997 soil, vegetation and aerosol samples, and spring 1998 drinking water samples. [Not completed; radioanalyses completed for subset of 1998 soil, sediment and surface water samples only]
11. Inorganic trace element analyses of representative subset of low-volume aerosol samples and soil samples by July 1998. [Completed]
12. Implement electronic Laboratory Information Management System by June 1998. [Not completed; system procured, implementation delayed]
13. Issue two reports of community studies by April 1998. [Completed]
14. Make CEMRC reports accessible *via* Internet by March 1998. [Completed]
15. Present summary of data from analyses in 1998 CEMRC report. [Completed]
16. Submit manuscripts for publication on radioanalyses of aerosols and soils. [Not completed, due to delay in completion of radioanalyses]

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. Quality Assurance/Quality Control for Inorganic Analyses

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

Instrumentation

A DIONEX 500 ion chromatography (IC) system was used to determine the concentrations of a suite of anions, including nitrate, sulfate, chloride, fluoride, bromide, and phosphate in aqueous extracts. Configured differently, the same instrument was used to determine the concentrations of several cations (calcium, magnesium and potassium). The anion analyses were performed with the use of an AS14 anion exchange column and chemical suppression while the cations were determined using a CG12A guard column and a CS12A analytical column.

Elemental analyses employed an atomic absorption spectrometer (AAS) with a computer-controlled Perkin-Elmer 5100PC atomic absorption unit with Zeeman background correction. Samples are introduced into the AAS by aspiration through an air/acetylene flame, by vaporization in a heated graphite furnace, by flow-injection via a heated quartz cell, or via an unheated quartz cell (for Hg). The third instrument used for inorganic analyses was a Perkin-Elmer 3300 dual-view, inductively-coupled plasma atomic (or optical) emission spectrometer (ICP-ES). The AAS and ICP-ES are complementary; AAS is more sensitive than the ICP-ES, especially for the hydride elements (As, Sb, and Se), but compared with the ICP-ES, the AAS has a narrower linear range, requires more operator effort for calibration and operation, and has a much lower sample throughput.

General Quality Control

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

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

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

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

Quality Control for Analyses by IC

For the IC analyses, QC samples are analyzed with each sample batch as an indicator of the reliability of the data produced. The types, frequencies of analysis, and limits for these QC samples have been established in a set of standard operating procedures.

Method Detection Limits (MDL) were established for each analyte in each sample matrix according to EPA Method 300.0 (Determination of Inorganic Anions by Ion Chromatography) (Table K1). QC samples included Laboratory Reagent Blanks (LRB), with one LRB prepared for each sample batch (normally a set of ten samples). LRB results below MDL are considered acceptable (Table K2). For aerosol filter analyses, some LRB results indicated reagent blank contamination, which was subsequently identified and eliminated. Results for samples analyzed prior to elimination of the contamination were corrected by subtraction of the blank value for each analyte. Laboratory Fortified Matrix (LFM) samples were also used for QC, with one LFM analysis per sample group. Results from analyses of LFMs are used to calculate matrix spike recoveries, with recoveries of 70-130% considered acceptable. As prescribed by EPA Method 300.0, chloride and sulfate values in water samples and chloride, phosphate and sulfate values in sediments were not reported because the concentration of the fortification was less than 25% of the background concentration (Table K3).

One duplicate analysis was performed for each sample group. When feasible, duplicate aliquots of some field samples were analyzed. In cases where duplicate aliquots from the original sample were not feasible (such as aerosol filters), separate aliquots of the sample extract were analyzed. The relative percent difference (RPD) between the sample and the duplicate was calculated, with a difference of < 20% (or an absolute difference of ± MDL for samples less than five times the MDL) considered acceptable. For aerosol filters, differences between the chloride duplicates were not within limits when the observed values were less than or near the MDL (Table K4).

A Laboratory Fortified Blank (LFB) was prepared and analyzed with each sample batch, using a spiked ultrapure water sample for aerosol filters and water samples, and certified reference materials (CRM) for soils and sediments. Recoveries of 85-115% were considered acceptable for aerosol filters, sediments, and water samples. The CRM was “Anions in Soils” from Environmental Research Associates (ERA) in Arvada, Colorado. The preparation procedure used to certify the standard was found to be slightly different from the procedure employed at CEMRC. ERA provided corrected means for calculations of recoveries based on the CEMRC procedure (Table K5). Because there is no existing standard reference method for extracting solid material for anion analysis by ion chromatography, the results may not be directly comparable.

Low-volume aerosol filters were also analyzed by IC for five cations with overall acceptable results (Table K6). Acceptance limits for each QC parameter were the same as previously described. In sample batches where the laboratory reagent blanks were above the MDL, blank subtraction was performed for those affected analytes.

Quality Control for Elemental Analyses by ICP-ES and AAS

For elemental analyses, sets of quality control samples comparable to those previously described for IC analyses were included with each sample batch. Detailed performance results for all QC measures are not presented here due to the number of elements that can be determined by ICP-ES and AAS. For all media (aerosol filters, water, soils, and sediments), ICP-ES and AAS values were reported to the method detection limit as determined by EPA protocols (Table K7). Digestion QC samples were analyzed at a frequency of 10% relative to samples. The digestion QC control parameters used for the evaluation of metals in aerosol filters included LRB filters and vendor-supplied certified reference filters. Due to sample volume limitations, duplicate and post digestion spike analyses could not be performed for ICP-ES analyses of the aerosol samples.

For water, soils, and sediments, a practical quantitation limit (PQL) was also calculated to evaluate precision based on the analysis of duplicate samples. The PQL is obtained by multiplying the method detection limit (MDL) by five. The digestion quality control parameters used for the evaluation of metals in water, soils, and sediments were based on EPA Contract Laboratory Program (1994, U.S. EPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review, EPA 540/R-94013) and SW846 methods (EPA, 1997, *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, EPA/SW-846. No comparable control parameters presently exist for aerosol samples.

For aerosol samples, unused cellulose ester filters were used as LRB samples. LRB results above the MDL were subtracted from each associated batch of sample results, because the LRB results were greater than the MDL for many of the analytes studied. The sources of this filter contamination have not yet been identified. A cellulose ester CRM (“Trace Metals on Filter Media” from High Purity Standards in Charleston, South Carolina) and a LFB were also used with analyses of aerosol samples. Mean recoveries for all analytes were within 85-115% of control limits, with the exception of Se. The CRM results for Se were 40%, 62%, 43% and 118%, while the LFB recovery for Se was 131%. The source of the inconsistent Se recoveries is not known at this time, and therefore, Se values for aerosol samples should be considered semi-quantitative at best.

Four standard QC measures were used in association with analyses of water samples. Ultrapure water was used for LRB samples and results were less than the MDLs for all analytes except Al, Ba, Ca, Cd, Fe, Mg and K. For Al and Fe, all sample results were less than the reagent blank, resulting in concentrations reported as <MDL. Cd results in the samples were corrected for the LRB values in each associated batch. For Ba, Ca, K, Mg, and K, all sample measurements were at least 10 times higher than the LRB values, and therefore the contaminant effects for these analytes are considered negligible. A LFB was prepared by adding a known quantity of each analyte of interest to ultrapure water. All analytes were recovered within the 85-115% limits as specified by EPA methods. LFM samples were also used for QC in analyses of water samples, with all recoveries within the 85%-115% acceptance window specified in the EPA methods, with the exception of Pb. Although Pb was recovered at 81%, this level is considered usable according to EPA inorganic usability protocols. A duplicate digestion analysis of water samples was also performed to demonstrate reproducibility, but a slight modification of the EPA CLP program was used for acceptance determination. If the sample result was less than the PQL, a ± PQL control limit was used. If the sample result was greater than the PQL, a ±20% RPD control limit was used. All duplicate results were within these modified acceptance limits.

For soils and sediments, LRB samples of ultrapure water were compared to MDLs to determine if contamination was introduced during sample preparation. The LRB results were above the MDLs for Ca, Mg, and Fe. However, the sample measurements were several orders of magnitude higher than the LRB results for these analytes, and therefore the contaminant effects on the measurements were considered negligible. If the LRB result were greater than the MDL, a correction to the sample results was made. Several of the LRB results for Cu, Cd, Ni and Na were at approximately the same level as those measured in the soil samples (within a factor of five), and therefore, results for these analytes may be biased high. These results would be considered “estimated” but would be considered usable according to EPA inorganic data usability protocols (1994, U.S. EPA Contract Laboratory Program

National Functional Guidelines for Inorganic Data Review, EPA 540/R-94013.) All other LRB results were within acceptance limits for soils. The elemental concentrations of all analytes in sediment samples were at least ten times higher than LRB results, and therefore the contaminant effects on measurements in sediments are considered negligible.

A CRM ("Priority Pollutant T/CLP Soil" from ERA) was obtained and prepared with the soil and sediment samples to demonstrate matrix-specific performance of digestion and analysis procedures. All analytes were recovered within the supplier's specified control limits for all digestions. The average CRM recoveries were within 85%-115% for all analytes, with the exception of Zn at 73% and Sb at 56%. A low bias for Sb was expected, due to use of a standard hotplate digestion procedure that allows loss of Sb as a SbCl precipitate. Additional studies are underway to resolve the low bias for Zn. Duplicate digestions were preformed for soil and sediment using a modification of the EPA CLP program for acceptance determination. If the sample result was less than the PQL, a ± PQL control limit was used. If the sample result was greater than the PQL a ±20% RPD control limit was used. For soils, the average RPD over the nine digestions performed was within acceptance limits for all analytes. Al, As, Ba, Ca, Cr, Fe, Mg, Ni, K, V, and Zn each had one of the nine digestions outside the acceptance limits. None of the RPDs were outside the limits established in the EPA usability protocols. For sediments, the duplicate precision for Mo in the first digestion was 22%, which is outside the acceptance limit. However, the Mo data are considered usable according to the EPA inorganic usability protocols. All other duplicate results for the sediments were within acceptance limits. A LFM also was prepared for soil, with an average recovery for the nine digestions within 85%-115% windows for all analytes with the exception of Sb at 37%. All individual recoveries were within the 70%-130% acceptance window specified in the EPA methods with the exception of Sb and Se in one sediment digestion. As previously noted a low bias for Sb was expected due to the digestion procedure used. Experiments to resolve the bias for Se are in progress.

Table K1. Method Detection Limits for Analyses by IC

Sample Matrix	Units	Unit Type	Fluoride	Chloride	Nitrate	Phosphate	Sulfate
Low volume aerosol filter	mg L^{-1}	General	0.0033	0.0078	0.0042	0.0111	0.0082
Drinking water, surface water	mg L^{-1}	General	0.0406	0.330	0.0555	0.102	0.108
Soil, sediment	mg L^{-1}	General	0.0487	0.0210	0.0588	0.235	0.111
[a]Low volume aerosol filter	ug m^{-3}	Matrix specific	0.0035	0.0084	0.0045	0.0119	0.0088
[b]Drinking water, surface water	mg L^{-1}	Matrix specific	0.0406	0.3296	0.0555	0.1018	0.1080
[c]Soil, sediment	mg kg^{-1}	Matrix specific	0.4868	0.2096	0.5875	2.3531	1.1070

[a] Teflo® 0.2 micron 45 mm diameter filter extracted into 30 mL ultrapure water; nominal flow volume of 28 L^3 of air per filter

[b] Water samples are analyzed by direct injection

[c] 5 g of solid material extracted into 50 mL ultrapure water

Table K2. Mean Laboratory Reagent Blank Results

Sample Matrix	Units	Fluoride	Chloride	Nitrate	Phosphate	Sulfate
Low volume aerosol filter	mg L^{-1}	0.0179	-0.0105	0.0531	0.0000	0.0093
Drinking water, surface water	mg L^{-1}	0.0000	0.2693	0.0000	0.0000	0.0000
Soil	mg L^{-1}	0.0000	0.0000	0.0000	0.0000	0.0000
Sediment	mg L^{-1}	0.0000	0.0000	0.0000	0.0000	0.0000

Table K3. Mean Laboratory Fortified Matrix Recovery Results

Sample Matrix	Fluoride	Chloride	Nitrate	Phosphate	Sulfate
Low volume aerosol filter	92%	96%	106%	98%	100%
Drinking water, surface water	88%	Not reported	73%	91%	Not reported
Soil	83%	108%	82%	85%	93%
Sediment	100%	Not reported	107%	Not reported	Not reported

Table K4. Mean Relative Percent Difference Results

Sample Matrix	Fluoride	Chloride	Nitrate	Phosphate	Sulfate
Low volume aerosol filters	0.00%	23.5%	2.50%	16.6%	0.93%
Drinking water, surface water	0.00%	1.92%	5.21%	0.00%	2.07%
Soil	0.72%	4.26%	1.92%	14.9%	7.03%
Sediment	0.05%	0.02%	0.06%	0.24%	0.11%

Table K5. Mean Laboratory Fortified Blank Recovery Results

Sample Matrix	Fluoride	Chloride	Nitrate	Phosphate	Sulfate	% Recovery Limit
Low volume aerosol filter	95%	100%	99%	97%	99%	85-115%
Drinking water, surface water	97%	103%	98%	96%	92%	85-115%
[a]Soil	84% (67.7%)	80% (74.0%)	[b]99% ([b]97.0%)	[c]129% ([c]83.3%)	92% (74.4%)	80-120%
[d]Sediment	187% (208%)	68% (79.9%)	[b]36% ([b]101%)	[c]89% ([c]57.6%)	139% (60.0%)	80-120% (85-115%)

[a] Values in parentheses are uncorrected for different preparation method

[b] Nitrate as N

[c] Phosphate as P

[d] Values in parentheses are uncorrected for different preparation method

Table K6. QC Results for Cations in Aerosol Filters Analyzed by IC

	Sodium	Ammonium	Potassium	Magnesium	Calcium
MDL (mg L^{-1})	0.0216	0.0193	0.0297	0.0074	0.0533
MDL (μg m^{-3})	0.0231	0.0207	0.0318	0.0079	0.0571
Average LRB (mg L^{-1})	0.0263	0.0153	-0.0112	0.0042	-0.0456
Average LFM	103%	102%	97.8%	94.9%	98.8%
Average RPD	10.2%	12.5%	8.49%	16.7%	8.91%
Average LFB	99.5%	93.7%	95.2%	94.7%	99.3%

Table K7. Method Detection Limits for Analyses by ICP-ES and AAS

Instrument	Analyte	Units	Method Detection Limit			Accuracy	Precision
			^{a}Air Filter	Water	Soil: Acid Extract		
ICP-ES	Al	ppm	0.0114	0.0227	0.242	± 30%	± 10%
	Sb	ppm	0.0026	0.0046	0.9172	± 30%	± 10%
	Ba	ppm	0.0002	0.0001	0.13	± 30%	± 10%
	Be	ppm	0.0002	0.0001	0.0156	± 30%	± 10%
	Bi	ppm	NA	0.0031	0.6288	± 30%	± 10%
	Cd	ppm	0.0006	0.0003	0.0002	± 30%	± 10%
	Ca	ppm	0.0044	0.1189	2.08	± 30%	± 10%
	Cr	ppm	0.0006	0.0008	0.1658	± 30%	± 10%
	Co	ppm	0.0007	0.0002	0.0440	± 30%	± 10%
	Cu	ppm	0.0003	0.0010	0.1922	± 30%	± 10%
	Fe	ppm	0.0024	0.0164	1.42	± 30%	± 10%
	Pb	ppm	0.0026	0.0007	0.1473	± 30%	± 10%
	Mg	ppm	0.0020	0.0109	0.87	± 30%	± 10%
	Mn	ppm	0.0002	0.0001	0.0249	± 30%	± 10%
	Mo	ppm	0.0006	0.0002	0.031	± 30%	± 10%
	Ni	ppm	NA	0.0002	0.0347	± 30%	± 10%
	K	ppm	0.0153	0.0175	NA	± 30%	± 10%
	Na	ppm	TBD	0.1332	0.145	± 30%	± 10%
	Sr	ppm	0.0006	0.0004	0.14	± 30%	± 10%
	V	ppm	0.0038	0.0007	0.1492	± 30%	± 10%
	Zn	ppm	0.0002	0.0025	0.24974	± 30%	± 10%

Table continued on next page

Table K7. Method Detection Limits for Analyses by ICP-ES and AAS (Continued)

Instrument	Analyte	Units	Method Detection Limit			Accuracy	Precision
			[a]Air Filter	Water	Soil: Acid Extract		
AAS ([b]CV)	Hg	ppt	NA	10	10	± 30%	± 20%
AAS ([c]FIH)	Sb	ppt	NA	55	280	± 30%	± 20%
	As	ppt	NA	27	140	± 30%	± 20%
	Se	ppt	NA	42	210	± 30%	± 20%
AAS ([d]GF)	Sb	ppb	2.0	1.5	2.0	± 30%	± 20%
	As	ppb	1.0	0.38	1.0	± 30%	± 20%
	Cd	ppb	0.2	0.02	0.2	± 30%	± 20%
	Cr	ppb	0.5	0.5	0.5	± 30%	± 20%
	Co	ppb	0.8	0.69	0.8	± 30%	± 20%
	Cu	ppb	0.5	0.28	0.5	± 30%	± 20%
	Pb	ppb	1.0	0.98	1.0	± 30%	± 20%
	Ni	ppb	0.5	0.44	0.5	± 30%	± 20%
	Se	ppb	1.0	NA	1.0	± 30%	± 20%
	Zn	ppb	5.0	NA	5.0	± 30%	± 20%

[a] µg per filter
[b] Cold vapor
[c] Flow injection hydride
[b] Graphite furnace

Appendix L. Corrected Version of 1997 Aerosol Summary

The following is a corrected version of the section of the CEMRC 1997 Report dealing with radionuclides in aerosols. Original values are shown as strikeouts, with corrected values in bold. Equations used for calculation of values are given at the end of the section. The changes of primary significance are values for MDCs. The errors generally resulted from application of incorrect formulae in calculations and transcription errors.

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, Fig. 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 ± 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, Fig. 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~~ **2.1** 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. **Samples with ^{239,240}Pu measurements below the sample-specific MDC were excluded from statistical analyses.**

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 L1). At Near Field, mean mass concentrations (±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 (±0.7), 12.2 (±0.6) and 23.0 (±1.9) µg m^{-3}, respectively (Table L5). 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 L1).

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 L6). 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~~ **12.2** 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~~ **40** air filters collected at Near Field during June 1996 – September 1997 were analyzed for ^{239,240}Pu (Table L2), and four air filters collected from Cactus Flats were also analyzed for ^{239,240}Pu (Table L3). **Three results from Near Field samples were below MDC, and one analysis of a Cactus Flats sample failed.** For Near Field, mean activity concentrations (±SE) of ^{239,240}Pu were ~~10.2 (±1.4)~~ **10.3 (± 1.6)** nBq m^{-3} for TSP collected at the 4-m height, ~~6.2 (±1.2)~~ **5.9 (±1.2)** nBq m^{-3} for PM_{10} collected at the 4-m height, and ~~5.4 (±0.8)~~ **5.6 (± 0.9)** nBq m^{-3} for PM_{10} collected at the 2-m height (Table L5). For Cactus Flats, observed activity concentrations in PM_{10} were ~~4.8–21~~ **5.0-17** nBq m^{-3}, and in TSP was ~~6.8–14~~ **11** nBq m^{-3} (Table L3).

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 L6). 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~~ **5.9** versus ~~10.2~~ **10.3** 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~~ **three** samples from Cactus Flats (Table L3) and the 37 samples from Near Field (Table L4). Mean ^{239,240}Pu activity densities (±SE) in samples from Near Field were ~~0.44 (±0.05)~~ **0.46 (±0.33)** , ~~0.54 (±0.08)~~ **0.48 (±0.08)** , and ~~0.45 (±0.03)~~ **0.45 (±0.026)** 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 L5). Activity densities for ^{239,240}Pu in the Cactus Flats samples were ~~0.40-2.0~~ **0.33-1.7** mBq g^{-1} for PM_{10} samples, and ~~0.42-0.66~~ **0.51** mBq g^{-1} for the TSP sample (Table L3). 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 L6).

The overall mean ^{239,240}Pu activity concentration (±SE) observed for February-May 1997 ~~was 8.7 (±2.0)~~ **10.0 (±2.5)** nBq m^{-3}, which was approximately ~~59%~~ **53%** 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)~~ **0.48 (±0.03)** mBq g^{-1}, which is approximately ~~32%~~ **26%** 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}) 48). 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.

The following equations were used in calculations of values for this section.

$$C = \frac{N_S \cdot S_{Tr}}{N_{Tr} \cdot U}$$

where C is the activity concentration, N_S is the net count rate of the analyte of interest, N_{Tr} is the net count rate of the tracer, S_{Tr} is the initial activity of tracer added to the sample and U is a conversion factor taking into account branching ratio, radioactive decay during the counting interval, radioactive decay since sample collection, unit conversion and sample volume or mass.

$$SD = \frac{\sqrt{\frac{C_S}{t_S^2} + \frac{C_{BK}}{t_{BK}^2} \cdot S_{Tr}}}{N_{Tr} \cdot U}$$

where SD is the standard deviation in activity concentration, C_S are the total sample counts for the analyte of interest, C_{BK} are the total background counts for the analyte of interest, t_S is the sample count time, and t_{BK} is the background count time.

$$MDC = \frac{\left(3.29 \cdot \sqrt{\frac{C_{BK}}{t_{BK}^2} + \frac{C_{BL}}{t_{BL}^2}} + \frac{2.71}{t_S}\right) \cdot S_{Tr}}{N_{Tr} \cdot U}$$

where MDC is the minimum detectable concentration, C_{BL} are the total background counts for the batch blank, t_{BL} is batch blank count time.

Table L1. Aerosol Particle Mass Concentrations in Aerosol Samples Collected at Near Field and Cactus Flats during June 1996 – September 1997

		[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**
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	**24**
	8/6/97-9/8/97		12	18

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Table L1. 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 (μg 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 Fig. 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 L2. ^{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~~ **<MDC**	~~5.02E+0~~	~~2.3E-2~~ **2.2E+1**	1.2E+1	~~2.3E+0~~ **2.7E+0**	~~2.3E-2~~ **3.7E+0**
7/5/96-7/26/96	1.2E+1	~~1.7E+0~~ **1.9E+0**	~~1.3E-2~~ **2.1E+0**						
7/8/96-7/22/96							~~7.5E+0~~ **7.2E+0**	~~1.7E+0~~ **2.2E+0**	~~2.4E-2~~ **3.6E+0**
7/8/96-7/26/96				~~1.8E+1~~ **1.7E+1**	~~4.0E+0~~ **5.1E+0**	~~1.5E-2~~ **8.4E+0**			
7/22/96-8/9/96							~~1.4E+1~~ **<MDC**	~~4.9E+0~~	~~1.7E-2~~ **2.5E+1**
7/26/96-8/16/96	~~2.3E+0~~ **<MDC**	~~7.2E-1~~	~~1.3E-2~~ **2.7E+0**	1.1E+1	~~2.0E+0~~ **2.4E+0**	~~1.4E-2~~ **3.1E+0**			
8/9/96-9/6/96							~~4.4E+0~~ **4.3E+0**	~~9.4E-1~~ **1.2E+0**	~~9.6E-3~~ **1.8E+0**
8/16/96-10/1/96	~~3.01E+0~~ **3.0E+0**	~~5.3E-1~~ **6.2E-1**	~~5.5E-3~~ **7.6E-1**	~~2.2E+0~~ **2.1E+0**	~~4.2E-1~~ **5.0E-1**	~~6.4E-3~~ **6.8E-1**			
9/6/96-10/1/96							7.8E+0	~~1.5E+0~~ **1.8E+0**	~~1.1E-2~~ **2.5E+0**
10/2/96-10/25/96	~~4.6E+0~~ **4.5E+0**	~~1.1E+0~~ **1.4E+0**	~~1.3E-2~~ **2.4E+0**						
10/8/96-10/25/96				~~8.0E+0~~ **7.9E+0**	~~2.3E+0~~ **3.6E+0**	~~1.7E-2~~ **7.3E+0**			
10/25/96-11/27/96	~~5.6E+0~~ **5.5E+0**	~~6.1E-1~~ **6.7E-1**	~~8.6E-3~~ **6.7E-1**	3.0E+0	~~4.9E-1~~ **4.1E-1**	~~8.8E-3~~ **4.7E-1**			
11/18/96-12/5/96							~~8.5E+0~~ **8.4E+0**	1.2E+0	~~1.9E-2~~ **9.7E-1**
11/27/96-1/2/97	4.6E+0	~~5.6E-1~~ **5.7E-1**	~~8.0E-3~~ **4.1E-1**	4.5E+0	~~5.89E-1~~ **6.0E-1**	~~8.3E-3~~ **4.6E-1**			
12/5/96-1/2/97							1.1E+1	1.0E+0	~~1.1E-2~~ **5.7E-1**

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Table L2. ^{239,240}Pu Activity Concentrations in Aerosol 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~~ **7.9E-1**	~~1.3E-2~~ **8.0E-1**	3.4E+0	~~6.2E-1~~ **6.5E-1**	~~1.3E-2~~ **6.7E-1**	8.8E+0	~~1.1E+0~~ **1.2E+0**	~~1.4E-2~~ **8.7E-1**
1/24/97-2/19/97	~~3.0E+0~~ **2.8E+0**	~~3.6E-1~~ **4.1E-1**	~~1.2E-2~~ **5.4E-1**	~~2.4E+0~~ **2.2E+0**	~~3.6E-1~~ **3.7E-1**	~~1.1E-2~~ **5.4E-1**	~~6.9E+0~~ **6.8E+0**	~~6.3E-1~~ **6.8E-1**	~~1.1E-2~~ **6.8E-1**
2/19/97-3/26/97	~~8.6E+0~~ **8.4E+0**	1.2E+0	~~8.8E-3~~ **8.3E-1**	~~6.9E+0~~ **6.8E+0**	~~9.9E-1~~ **1.1E+0**	~~8.4E-3~~ **7.9E-1**			
3/11/97-3/26/97							~~2.8E+1~~ **2.7E+1**	2.4E+0	~~1.9E-2~~ **1.1E+0**
3/26/97-4/22/97	~~8.5E+0~~ **8.4E+0**	~~8.7E-1~~ **8.6E-1**	~~1.1E-2~~ **7.0E-1**	~~5.7E+0~~ **5.6E+0**	~~5.1E-1~~ **5.9E-1**	~~1.1E-2~~ **6.0E-1**	1.6E+1	~~9.2E-1~~ **9.6E-1**	~~1.1E-2~~ **4.7E-1**
4/22/97-5/26/97	~~4.4E+0~~ **4.3E+0**	~~4.8E-1~~ **4.9E-1**	~~8.8E-3~~ **4.4E-1**	~~3.7E+0~~ **3.6E+0**	4.6E-1	~~8.3E-3~~ **4.5E-1**	1.0E+1	1.2E+0	~~8.6E-3~~ **7.7E-1**
5/26/97-6/24/97	~~3.5E+0~~ **3.4E+0**	~~5.7E-1~~ **5.5E-1**	~~1.0E-2~~ **6.5E-1**	~~4.2+0~~ **4.1E+0**	~~4.8E-1~~ **5.6E-1**	~~1.0E-2~~ **6.1E-1**	~~7.4E+0~~ **7.2E+0**	~~6.8E-1~~ **6.9E-1**	~~1.1E-2~~ **5.4E-1**
~~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~~ **4.9E+0**	~~4.3E-1~~ **1.2E+0**	~~1.4E+0~~ **1.2E+0**	~~3.6E+0~~ **7.2E+0**	~~5.2E-1~~ **1.8E+0**	~~1.3E-2~~ **3.2E+0**
~~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 this section ~~in Appendix K~~; all values are rounded to two significant figures

Table L3. ^{239,240}Pu Activity Concentrations and Activity Densities in Aerosol Samples Collected at Cactus Flats during June - September 1997

Sampling Period	**^{239,240}Pu Activity Concentrations (nBq m^{-3})**					
	[a]PM$_{10}$ – 5 m			**[b]TSP – 5 m**		
	[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~~ **1.1E+1**	~~1.9E+0~~ **2.8E+0**	~~5.2E+0~~ **2.7E+0**
8/6/97-9/8/97	~~2.1E+1~~ **1.7E+1**	~~1.9E+0~~ **2.8E+0**	~~3.6E+0~~ **1.8E+0**			
8/7/97-9/8/97				~~6.8E+0~~ **5.0E+0**	~~1.5E+0~~ **2.1E+0**	~~5.4E+0~~ **4.7E+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~~ **5.1E-1**	~~8.8E-2~~ **1.3E-1**	~~2.4E-1~~ **1.3E-1**
8/6/97-9/8/97	~~2.0E+0~~ **1.7E+0**	~~1.7E-1~~ **2.7E-1**	~~3.2E-1~~ **1.8E-1**			
8/7/97-9/8/97				~~4.2E-1~~ **3.3E-1**	~~9.4E-2~~ **1.4E-1**	~~3.4E-1~~ **3.1E-1**

[a] PM$_{10}$-5 m = suspended particulate matter aerosols with aerodynamic diameter ≤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 this section ~~Appendix K~~ ; all values are rounded to two significant figures

Table L4. ^{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~~ **<MDC**	~~2.8E-1~~	~~1.3E-3~~ **1.2E+0**	~~5.4E-1~~ **5.3E-1**	~~1.0E-1~~ **1.2E-1**	~~1.0E-3~~ **1.6E-1**
7/5/96-7/26/96	~~9.2E-1~~ **9.0E-1**	~~1.3E-1~~ **1.5E-1**	~~1.0E-3~~ **1.6E-1**						
7/8/96-7/22/96				1.3E+0	~~3.0E-1~~ **3.9E-1**	~~1.2E-3~~ **6.4E-1**	~~3.9E-1~~ **3.7-1**	~~8.7E-2~~ **1.1E-1**	~~1.2E-3~~ **1.9E-1**
7/22/96-8/9/96							~~4.7E-1~~ **<MDC**	~~1.7E-1~~	~~5.7E-4~~ **8.5E-1**
7/26/96-8/16/96	~~1.6E-1~~ **<MDC**	~~5.1E-2~~	~~9.5E-4~~ **1.9E-1**	~~7.8E-1~~ **7.5E-1**	~~1.5E-1~~ **1.7E-1**	~~1.0E-3~~ **2.3E-1**			
8/9/96-9/6/96							2.9E-1	~~6.4E-2~~ **7.8E-2**	~~6.4E-4~~ **1.2E-1**
8/16/96-10/1/96	3.5E-1	~~6.2E-2~~ **7.2E-2**	~~6.4E-4~~ **8.9E-2**	~~2.6E-1~~ **2.5E-1**	~~5.0E-2~~ **6.0E-2**	~~7.8E-4~~ **8.2E-2**			
9/6/96-10/1/96							~~4.48E-1~~ **4.5E-1**	~~8.78E-2~~ **1.1E-1**	~~6.6E-4~~ **1.4E-1**
10/2/96-10/25/96	~~3.6E-1~~ **3.5E-1**	~~8.4E-2~~ **1.1E-1**	~~9.9E-4~~ **1.8E-1**						
10/8/96-10/25/96				~~6.4E-1~~ **6.2E-1**	~~1.8E-1~~ **2.9E-1**	~~1.4E-3~~ **5.8E-1**			
10/25/96-11/27/96	~~4.6E-1~~ **4.5E-1**	~~5.0E-2~~ **5.5E-2**	~~7.1E-4~~ **3.8E-2**	2.5E-1	~~4.1E-2~~ **3.4E-2**	~~7.4E-4~~ **4.0E-2**			
11/18/96-12/5/96							4.8E-1	6.8E-2	~~1.0E-3~~ **5.5E-2**

Table continued on next page

Table L4. ^{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~~ **5.1E-1**	~~6.2E-2~~ **6.3E-2**	~~8.7E-4~~ **4.5E-2**	5.0E-1	~~6.4E-2~~ **6.7E-2**	~~9.1E-4~~ **5.1E-2**			
12/5/96- 1/2/97							5.3E-1	4.9E-2	~~5.1E-4~~ **2.8E-2**
1/2/97- 1/24/97	~~4.4E-1~~ **4.3E-1**	~~7.19E-2~~ **8.1E-2**	~~1.3E-3~~ **8.2E-2**	3.5E-1	~~6.4E-2~~ **6.7E-2**	~~1.4E-3~~ **6.9E-2**	4.9E-1	~~6.0E-2~~ **6.4E-2**	~~7.5E-4~~ **4.8E-2**
1/24/97- 2/19/97	~~3.0E-1~~ **2.8E-1**	~~3.7E-2~~ **4.1E-2**	~~1.2E-3~~ **5.5E-2**	~~2.5E-1~~ **2.3E-1**	~~3.8E-2~~ **3.9E-2**	~~1.2E-3~~ **5.7E-2**	~~3.8E-1~~ **3.7E-1**	~~3.4E-2~~ **3.7E-2**	~~6.1E-4~~ **3.7E-2**
2/19/97- 3/26/97	5.1E-1	~~7.02E-2~~ **7.1E-2**	~~5.2E-4~~ **5.0E-2**	4.5E-1	~~6.5E-2~~ **6.9E-2**	~~5.5E-4~~ **5.2E-2**			
3/11/97- 3/26/97							5.7E-1	~~5.0E-2~~ **4.9E-2**	~~3.9E-4~~ **2.2E-2**
3/26/97- 4/22/97	~~6.0E-1~~ **5.9E-1**	~~6.1E-2~~ **6.0E-2**	~~7.7E-4~~ **4.9E-2**	4.0E-1	~~3.6E-2~~ **4.1E-2**	~~7.6E-4~~ **4.3E-2**	~~5.9E-1~~ **5.8E-1**	~~3.4E-2~~ **3.5E-2**	~~3.8E-4~~ **1.7E-2**
4/22/97- 5/26/97	~~4.2E-1~~ **4.1E-1**	~~4.6E-2~~ **4.7E-2**	~~8.3E-4~~ **4.1E-2**	~~3.6E-1~~ **3.5E-1**	~~4.5E-2~~ **4.6E-2**	~~8.2E-4~~ **4.5E-2**	~~4.9E-1~~ **4.8E-1**	~~5.9E-2~~ **6.0E-2**	~~4.1E-4~~ **3.7E-2**
5/26/97- 6/24/97	~~3.1E-1~~ **3.0E-1**	~~5.0E-2~~ **4.9E-2**	~~9.1E-4~~ **5.7E-2**	~~3.5E-1~~ **3.4E-1**	~~4.0E-2~~ **4.6E-2**	~~8.5E-4~~ **5.0E-2**	~~3.5E-1~~ **3.4E-1**	~~3.2E-2~~ **3.3E-2**	~~5.0E-4~~ **2.6E-2**
8/6/97- 9/8/97				~~2.3E-1~~ **4.0E-1**	~~7.0E-2~~ **1.0E-1**	~~7.5E-4~~ **10.0E-2**	~~2.0E-1~~ **3.9E-1**	~~6.0E-2~~ **9.8E-2**	~~7.3E-4~~ **1.7E-1**

[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 this section ~~Appendix K~~; all values are rounded to two significant figures

Table L5. 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 ($\mu g\ m^{-3}$)	[d]PM_{10} - 2 m	12	12	0.7	8.6	17
	[e]PM_{10} - 4 m	~~16~~ **15**	12	0.6	8.3	18
	[f]TSP - 4 m	~~16~~ **17**	23	2	15	48
$^{239,240}Pu$ [g]Activity Concentration ($nBq\ m^{-3}$)	PM_{10} - 2 m	~~12~~ **11**	~~5.4~~ **5.6**	~~0.8~~ **0.9**	~~2.3~~ **2.8**	12
	PM_{10} - 4 m	~~15~~ **13**	~~6.2~~ **5.9**	~~1.2~~ **1.2**	~~2.2~~ **2.1**	~~17.7~~ **17**
	TSP - 4 m	~~15~~ **13**	~~10.2~~ **10.3**	~~1.4~~ **1.6**	~~3.6~~ **4.3**	~~28~~ **27**
$^{239,240}Pu$ [h]Activity Density ($mBq\ g^{-1}$)	PM_{10} - 2 m	~~12~~ **11**	~~0.44~~ **0.46**	~~0.050~~ **0.33**	~~0.16~~ **0.28**	~~0.92~~ **0.90**
	PM_{10} - 4 m	~~15~~ **13**	0.48	0.080	0.23	1.3
	TSP - 4 m	~~15~~ **13**	~~0.43~~ **0.45**	~~0.030~~ **0.26**	~~0.20~~ **0.033**	~~0.59~~ **0.12**

[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 this section ~~Appendix K~~, using accumulated particulate mass concentration (g); all values are rounded to two significant figures.

Table L6. Results of Analyses of Variance for Mass and ^{239,240}Pu Concentrations and ^{239,240}Pu Activity Densities in Aerosol Samples Collected at Near Field during June 1996 – September 1997

Response Variable	Source	^{a}df	^{b}SS	^{c}F	^{d}P
Mass Concentration ($\mu g\ m^{-3}$)	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~~ **1.761E+2**	~~4.17~~ **4.31**	~~0.0228~~ **0.0214**
	Error	~~39~~ **34**	~~8.902E+2~~ **6.94E+2**		
	Total	~~41~~ **36**	~~1.081E+3~~ **8.702E+2**		
^{239,240}Pu Activity Density ($mBq\ g^{-1}$)	Sampler	2	~~3.136E-2~~ **3.970E-3**	~~0.31~~ **0.05**	~~0.7318~~ **0.9531**
	Error	~~39~~ **34**	~~1.893E+0~~ **1.403E+0**		
	Total	~~41~~ **36**	~~1.925E+0~~ **1.407E+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

GLOSSARY

aerosol - particles dispersed in a gas.

aliquot - a subsample drawn from a larger sample.

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

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

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

aerodynamic diameter – distance around 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.

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.

dosimetry - the measurement of radiation doses.

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

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

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

informatics - information management systems.

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

lumen – a unit of luminous flux equal to the light emitted in a unit solid angle by a uniform point source of one candle intensity.

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

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

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

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

standard error – the standard deviation of the probability function or probability density function of a random variable and of a statistic.

temporal - pertaining to or limited by time.

tertiary - third level.