1996 Report

Carlsbad Environmental Monitoring & Research Center

Waste-management Education & Research Consortium (WERC)

New Mexico State University

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Acronyms and Abbreviations

μBq	microbecquerel
μCi	microcurie
μm	micrometers
A	angstroms
aCi	attocurie
Am	americium
BOMAB	bottle mannequin absorption phantom
C	concentration
Cd	cadmium
CEMRP	Carlsbad Environmental Monitoring and Research Program
Center	Carlsbad Environmental Monitoring & Research Center
CFR	Code of Federal Regulations
Ci	Curie
cm	centimeter
c_m	mass concentration
C_{max}	maximum concentrations
Co	cobalt
Cs	cesium
Cu	copper
CV	coefficient of variation
D	discharge factor
d	diameter
DNA	deoxyribonucleic acid
DOE	U.S. Department of Energy
EEG	Environmental Evaluation Group
EIC	electret ionization chamber
EM	Environmental Monitoring
EPA	U.S. Environmental Protection Administration
eV	electron volts
fCi	femtocurie
Fe	iron
FISH	fluorescence in-situ hybridization
g	gram
Ge	germanium
GIS	geographic information system
GPA	glycophorin A
GPS	global positioning system
Hb	hemoglobin
H_3BO_3	boric acid
HCl	hydrogen chloride
HF	hydrogen fluoride
HHI	Harvard Honeycomb Impactor

Acronyms and Abbreviations

HLA	human lymphocyte antigen
HNO_3	nitric acid
HPRT	hypoxanthine-guanine phosphoribosyl transferase
hr	hour
ID	inside diameter
K	potassium
KCl	potassium chloride
keV	kiloelectron volts
km	kilometer
L	liter
m	meter
M	molarity
MBL	mobile bioassay laboratory
mBq	millibecquerel
MDA	minimum detectable amount
MDC	minimum detectable concentration
min	minute
mL	milliliter
mm	millimeter
mR	milliroentgen
NaI	sodium iodide
nCi	nanocurie
NH_4Cl	ammonium chloride
NH_4OH	ammonium hydroxide
NIST	National Institute of Standards and Technology
NMSU	New Mexico State University
NMTR	New Mexico Tumor Registry
Pb	lead
pCi	picocuries
pH	scale showing acidity or alkalinity of a substance
PM_{10}	particulate matter smaller than 10 microns
$PM_{2.5}$	particulate matter smaller than 2.5 microns
Pu	plutonium
Q	acute radioactive release
QA	quality assurance
QC	quality control
$RaCl_2$	radium chloride
RDBMS	relational database management systems
RIP	Radiochemistry Intercomparison Program
Rn	radon
SAB	Science Advisory Board
sec	second
shield	cast iron enclosure

Acronyms and Abbreviations

TcR	T-cell receptor
Th	thorium
TSP	total suspended particulate
U	uranium
V_{avg}	average voltage
WERC	Waste-management Education & Research Consortium
WIPP	Waste Isolation Pilot Plant

FORWARD

This report marks the beginning of a new emphasis on publication of research by the Carlsbad Monitoring & Research Center (Center). The report was written collaboratively by current Center staff and cooperating investigators. The first section is an overview of history, organization, support, programmatic structure, resources, and project activities. The second section consists of nine research summaries. The summaries are brief descriptions of studies conducted by Center staff and research collaborators at other institutions, and include experimentation in instrument design, development of sampling and analytical strategies, and characterization of selected regional population parameters. As noted in text, two of the studies will be issued as separate Center reports, and one of the studies has been submitted for publication in a scientific journal. Two of the studies are slated for publication submittal in 1997. The issuance of such reports and publications fulfills a major Center mission in making the results of Center research available for public access.

OVERVIEW

History and Current Status

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

The primary goals of the CEMRP are to

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

The Center is to function as a nucleus of research excellence supported through grant funding and service contracts. As a part of NMSU, the Center's research programs are conducted under the philosophy of academic freedom and independence from direct external control of research activities and outcomes. The Center's primary objectives are to

- Help ensure that the public, workers, and the environment are adequately protected from exposure to contaminants
- Provide for objective, independent health and environmental monitoring
- Provide advanced training and educational opportunities
- Develop improved measurement methods, procedures, and sensors
- Establish a health and environmental database accessible to all sectors.

The following are enabling activities that have been identified as necessary to achieving these objectives:

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

Dr. Donald J. Fingleton was hired as Director of the Center in 1991. Technical staffing began in 1992 but proceeded slowly in the absence of a permanent physical facility to support operations. By the end of 1994, staffing had reached 18, including 11 scientific and technical support staff. Currently, the Center employs 18 personnel, including 12 scientific and technical support staff (Table 1). Staffing is projected to grow to a total of 25 employees by the end of 1998 with the addition of five scientific and technical support positions.

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

Temporary office accommodations for the Center initially were provided at

Table 1. Listing of Center Staff as of December 31, 1996

Name	Position	Date of Hire
Brown, Becky	Fiscal Specialist I	10/12/94
Clifton, Tammy	Buyer Specialist I	1/3/96
Conley, Marsha	Director of Operations	7/9/96
Fingleton, Donald	Director of Laboratory Development	8/28/91
Kirchner, Thomas	Manager, Data Base Systems	11/26/96
Lee, Shan	Senior Scientist-Radiochemistry	3/15/93
Lynch, Sherry	Administrative Secretary II	3/19/96
Madison, Tom	Senior Research Specialist	6/8/94
Maung, Okka	Assistant Scientist-Radiochemistry	10/24/96
McNutt, Damon	Technician IV	3/18/96
Pates, Derrik	Technician II	5/10/96
Sage, Sondra	Assistant Scientist-Field Operations	7/5/95
Schoep, Dave	Assistant Scientist-Field Operations	8/23/96
Soules, Mary	Administrative Secretary I	8/15/94
Webb, Joel	Physical Scientist IV-Internal Dosimetry	9/11/95
Yahr, Jim	Assistant Scientist-Field Operations	6/7/95
Young, Karen	Administrative Secretary II	7/19/93
Xue, Ying-Hua	Assistant Scientist-Radiochemistry	10/21/96

NMSU-Carlsbad. In 1992, the Center was moved to a leased facility at 800 West Pierce in Carlsbad, which served as a basis for operations through December, 1996. This facility provided approximately 7,000 square feet of space, which allowed expansion of staffing and initial acquisition of laboratory and field equipment. Major equipment acquired for use during occupation of this facility included gamma-ray spectrometers, an atomic absorption spectrophotometer, radiological survey meters, vehicles and sampling equipment for use in the field, global positioning system (GPS) equipment, and computing support for a geographic information system (GIS) and other scientific applications.

Flatow Moore Shaffer McCabe Architects (Albuquerque, New Mexico) and Research Facilities Design (San Diego, California) were selected in 1991 to design the Center's new facilities. Facility development was guided by the need to meet three primary objectives: (1) develop the capability to respond to a variety of environmental and health monitoring needs, (2) conduct analyses using the best available technology, and (3) meet or exceed all applicable regulations regarding worker health and safety.

To meet program objectives, preliminary building designs called for a 53,000-square-foot building with an associated cost of $22 million. This level of funding was projected from language in the Senate version of the Waste Isolation Pilot Plant Land Withdrawal Act (S. 1671 1991). However, the language subsequently was deleted in conference committee, and other funding alternatives for facility construction were initiated.

In December of 1993, DOE Secretary Hazel O'Leary made a commitment to provide approximately $7 million in additional funding to support debt service for construction of the new facility. The design team was reassembled to develop a 73,000-square-foot, multiphased project to meet all objectives within a ten-year period. The first phase of the project was a 25,000-square-foot building to house the Center's environmental and radiochemistry laboratories, fixed *in vivo* facility, mobile bioassay laboratory (MBL), computing operations, and offices for scientific and administrative staff. In 1994, the NMSU Board of Regents approved the sale of New Mexico State University Research Corporation Lease Revenue bonds to secure construction money. Construction of the Phase I facility began in August 1995 and was completed in December 1996. The facility is located adjacent to the NMSU-Carlsbad campus, on 22 acres of land donated to NMSU by New Mexico State Representative Robert S. Light (D-55th District). The NMSU Board of Regents voted on December 14, 1996 to name the Phase I facility the Joanna and Robert Light Hall (to be referred to as Light Hall).

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

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

Beginning in 1992, the Center entered into a number of subcontractual agreements with other research organizations and laboratories (Appendix A). A portion of these agreements allowed for Center staff to visit other laboratories to learn specific advanced methodologies and use of other facilities in conducting analyses. Other agreements provided for studies to be conducted by non-Center scientists in collaboration with Center staff. These subcontracts allowed the Center to begin many studies prior to having a full complement of scientific staff or a physical facility to support the studies. In addition to services provided by external organizations, several NMSU departments and divisions have provided support to the Center for specific projects, including the Physical Science Laboratory and the Soil, Water, and Air Testing Laboratory of WERC.

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

A Science Advisory Board (SAB) was established in 1992. The function of the SAB was to provide expert guidance and consultation to the Center and was composed of scientific experts with international reputations in the Center's scientific areas of specialization. Members of the SAB were identified by Center staff and others and participated by invitation. General meetings of the entire SAB were held periodically during 1992-1995. In addition, several small, discipline-specific, workshops were held to address individual issues.

The membership of the SAB recently has been modified to encompass new areas of research activities and to facilitate a different working structure for the group. The past and current membership of the SAB is presented in Appendix B. Future activities of the SAB will include consultation visits by small "focus groups" and invited technical presentations.

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

Dr. Donald J. Fingleton served as Director of the Center during 1991-1996, and was responsible primarily for program management during that time. In 1996, Dr. Fingleton was named Director of Laboratory Development and assumed management responsibility for completion of the Phase I facility and marketing of the Center's capabilities to develop additional research funding. Management of the Center's scientific program, fiscal affairs, and human resources was transferred to Dr. Marsha Conley, Director of Operations. Actual funding supplied by DOE to the CEMRP during 1991-1996 was below initially proposed levels. Nevertheless, the funding exceeded expenditures throughout the first five years of the program (Figure 1). This accomplished a delay of expenditures until adequate levels of staffing and physical facilities could be acquired to support the scientific program. New funding of approximately $3.9 million has been proposed for the 1997 Federal fiscal year. Combined with carryover funds, the projected 1997 budget is $5.3 million.

Formal tracking of project schedules and deadlines has been instituted for the Center's current studies, as noted in later sections. Regularly scheduled work sessions for systematic scientific program planning and problem solving have been imple-

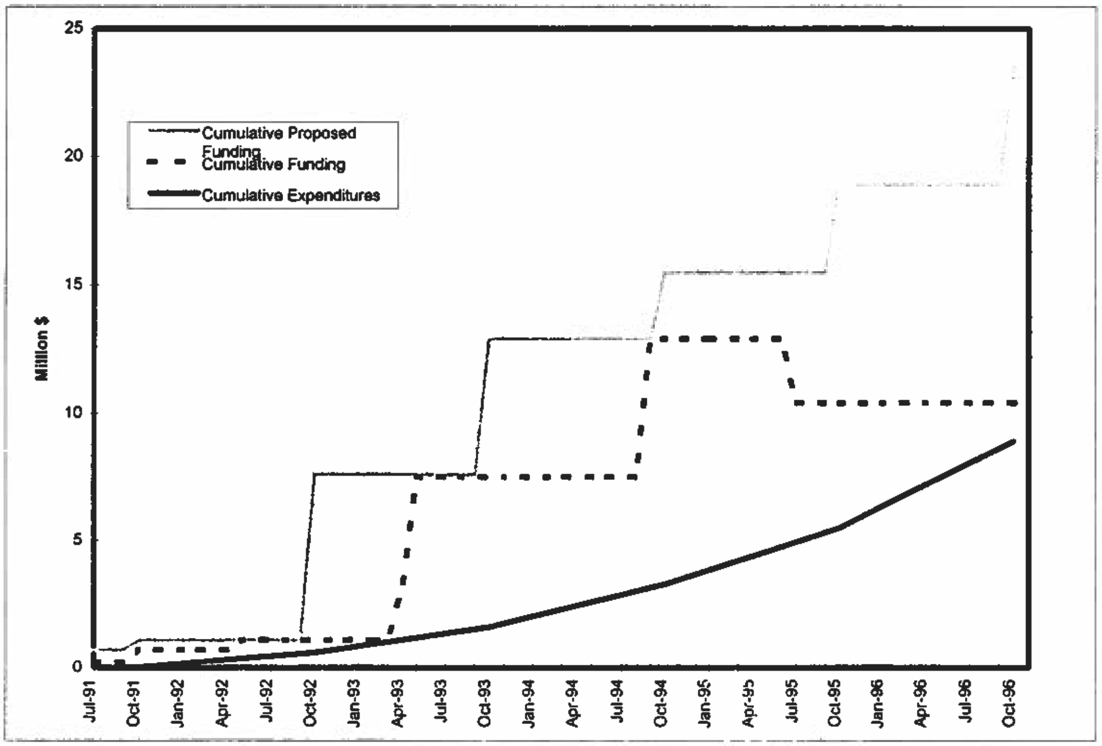

Figure 1. History of Funding and Expenditures

mented to define accountabilities and track progress. Administrative, chemistry, and field operations staffs also have regularly scheduled review and planning sessions. Significant accomplishments and events are reported in monthly summaries provided to DOE, NMSU, and the SAB.

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

Center staff and cooperating investigators have made numerous presentations at national and regional scientific meetings, and four papers have been published, are in press, or have been submitted for publication in peer-reviewed scientific journals (Appendix C). Periodic briefings on program activities are provided for representatives of NMSU, DOE, and various local and regional groups. A database management professional was hired in 1996 to complete development of comprehensive systems for data acquisition, documentation, archival, access, and analysis.

Establish regional, national and international outreach and collaboration.

The Center has been involved in a wide variety of outreach activities ranging from presentations for local public school students to hosting groups of visiting foreign scientists. Examples of these activities are provided in Appendix D.

Procure additional research grants and service contracts from external sources.

The Center is working to establish a record of excellence in environmental research and monitoring. Many of the capabilities being developed are not generally available in the U.S. or elsewhere, which provides great opportunities for expansion of future research scope and activities. Creation of a specialized function for laboratory development is designed to emphasize accomplishing the goal of research expansion and diversification.

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

The Center also has strived to provide educational and training opportunities to school children (K-12), undergraduate, graduate, and post-graduate students, and in-service training to active professionals and others needing advanced knowledge in our areas of excellence. The Center's staff provides a unique blend of scientists, engineers, and health professionals to support these educational activities. Arrangements are in progress to establish faculty status at NMSU for the Center's senior scientific staff. During 1991-1996, the Center provided training and financial support to all of these categories (Appendix E).

WIPP Environmental Monitoring Project

The first major project managed by the Center is the WIPP Environmental Monitoring (EM) project. The purpose of the WIPP EM project is to establish and maintain independent environmental research and monitoring in the vicinity of the WIPP and to make the results easily accessible to all interested parties. This project is being implemented during the WIPP predisposal phase, and will continue into the operational (disposal) phase. The WIPP EM project is organized and carried out as a scientific research undertaking and has no oversight or regulatory accountabilities. As noted earlier in the overall Center program, the WIPP EM project is conducted under the philosophy of academic freedom and is independent of direct external control of research activities and outcomes.

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

The project will employ professional information-management principles in organizing, documenting, and archiving data and in providing for public access to information generated by the program. The information generated by the project also will appear in technical reports, scientific publications in peer-reviewed journals, and presentations for industry and scientific conferences. Recognized quality assurance (QA) and quality control (QC) policies and techniques are applied to the project and are currently being documented. The WIPP EM research agenda also incorporates periodic review by, and input from, external experts in environmental and health monitoring.

The objectives of the WIPP EM are to

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

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

Table 2. WIPP Environmental Monitoring Organization

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

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

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

The management plan for the WIPP EM incorporates these eight general phases for the major research areas, with specific milestones representing significant products and events in program progress. Key performance indicators, identified as metrics of the success of this project management plan, are as follows:

1. Completion of baseline sample collection for each major research component by November 1997, including:
   - Aerosols: at least 18 months of high volume samples and at least ten months of continuous, concurrent high volume and low volume sampling, at one location; at least six months of continuous sampling at one additional location.
   - Soils: sampling of at least 24 sites at varying distances from the WIPP.
   - Meteorology: continuous data collection from two stations for at least 18 months.
   - Drinking water: sampling from at least four municipal and community water sources and at least 50% of

private wells within ten miles of the WIPP.

- Sediment and surface water: sampling from at least four perennial surface water bodies.
- Biota: sampling of selected plants and animals during one spring period and one late summer-fall period.
- Internal dosimetry: make *in vivo* and *in vitro* bioassay services available to the public and WIPP radiation workers (beginning by August 1997).
- Community health: analysis of regional cancer incidence rates (completed in 1996).
- Public perception: regional surveys of environmental value perceptions and various parameters of resource usage and exposure (completed in 1996).

2. Completion of all laboratory analyses of samples noted above by December 1997.
3. Presentation of all studies conducted during 1991–1995 in the form of publications, reports, or public databases by July 1997.
4. Presentation of all data generated from sampling and analyses during 1996–1997 in the form of publications, reports, or public databases by July 1998.
5. Completion of design and schedule for operational monitoring studies by July 1997.
6. Initiation of operational monitoring studies by November 1997 or when the WIPP begins receipt of waste.

Description Of Major Scientific Program Areas

At the current time, the Center's scientific activities are organized into five major areas of specialization with corresponding assignment of staff roles and responsibilities. All areas of specialization collaborate in carrying out the WIPP Environmental Monitoring project, and this type of integrative research is anticipated to characterize many of the Center's future projects.

Internal Dosimetry

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

The internal dosimetry program will be provided as an outreach service to the public to support education about naturally occurring radiation and the Center's environmental studies, and to provide assessment of potential exposure to radioactive contaminants of concern. The program also will be available to provide support to the WIPP by conducting bioassays for radiation workers. Full-spectrum dosimetry services will be available to evaluate internal radiation exposure to radiation workers and members of the public in the case of an accident at the WIPP.

The Center's fixed *in vivo* bioassay facility occupies approximately 966 square feet in the Phase I building and provides the primary analytical infrastructure for the internal dosimetry program. The facility includes a counting chamber measuring 8 feet × 8 feet × 8 feet, constructed of 10-inch-thick cast iron with a full graded-Z shield. The cast iron composing the chamber was produced for industrial use prior to 1945, and recast for the chamber using a specially selected foundry, resulting in very low background radiation from anthropogenic and naturally occurring constituents in the iron.

The counting chamber is equipped with a lung and whole-body counting system composed of two hyperpure Ge crystal detector arrays. The lung detector array is suspended above the subject, and includes four Ge crystals. The whole-body detector array is located below the counting bed and includes four Ge crystals each performing at 80% relative efficiency. Lung and whole-body counts are conducted simultaneously with the subject positioned on a large bed inside the counting chamber. A dedicated computer serves the integrated electronic system for acquisition and storage of radiation spectra generated by the detectors. Resolution of the system is in the order of 450, 750, and 2,100 eV at photon energies of 5.9, 122, and 1,332 keV, respectively. Sensitivities for Pu and Am in lungs are expected to be 20 and 0.1 nCi, respectively. Sensitivities for Cs and Co in the whole body are expected to be 1 and 2 nCi, respectively. Ultrasound techniques will be used to measure subjects' chest wall thickness to account for photon attenuation. The Center's staff will schedule *in vivo* bioassay subjects for 45 min for each appointment. Prior to undergoing the radiation count, subjects will view a videotape that explains the procedure, and further explanation will be provided by internal dosimetry staff. Showers, changing rooms, staff offices, and a consultation room are located adjacent to the counting chamber. Commissioning of the fixed *in vivo* bioassay facility is scheduled for June 1997.

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

Radiochemistry and Environmental Chemistry

The purpose of the environmental chemistry and radiochemistry programs is to conduct measurements of radionuclides and trace elements at background levels. Analysis capabilities for environmental media include air, soil, surface water and sediment, groundwater, and biota. In addition to environmental media, the laboratories provide bioassay analysis capabilities for urine, feces, blood, and tissue. Standard reference materials for instrument calibration and analytical quality control and quality assurance programs are being implemented for the laboratories. The radiochemistry laboratory currently participates in the DOE Environmental Measurements Laboratory Quality Assessment Program. Out of over 100 laboratories participating in the program in 1996, the Center was one of only two laboratories that performed more than ten analyses and received the highest evaluation for all analyses (Sanderson and Greenlaw, *Semi-Annual Report of the Department of Energy, Office of Environmental Management, Quality Assessment Program*, EML-581, 1996). The Center is also a pilot participant in the National Institute of Standards and Technology (NIST) Radiochemistry Intercomparison Program (RIP) for evaluation of low-level radionuclide measurements.

The radiochemistry laboratory employs procedures for low-level measurement of actinides, fission products, activated corrosion products, and naturally occurring radionuclides. These analyses employ advanced instrumentation including alpha spectrometry, low background alpha-beta counting, gamma spectrometry and liquid scintillation. Detection levels achievable with the laboratory's current alpha spectrometry instrumentation and techniques are 75 µBq (2 fCi) for actinides.

Approximately 1,700 square feet of space in the Phase I facility is allocated to the radiochemistry program, including a primary radiochemistry laboratory and separate tracer and counting laboratories. The primary laboratory room is equipped with one 6-foot chemical hood, five 8-foot chemical hoods, a separate deionized water system, and approximately 400 square feet of bench surface.

The environmental chemistry laboratory will have capabilities similar to that of the radiochemistry laboratory in conducting low-level measurements of inorganic contents in environmental media. Full-spectrum trace element analyses will be accomplished using atomic absorption spectrometry and X-ray fluorescence spectrometry. Instrumentation and commissioning for the environmental chemistry laboratory will occur during 1997.

The environmental chemistry and radiochemistry laboratories provide analytical support for the Center's programs and also serve as research facilities for method development. Areas of development include improvements in radioanalytical processes for separation, purification, and measurement, particularly for unusual media. Improving non-destructive techniques for trace element determination will be investigated. Development of inductively-coupled plasma mass spectrometry also may be included in future studies.

Field Sampling

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

Approximately 1,300 square feet of the Phase I facility provides working area for staging field sampling activities and for processing and storing collected samples. This area includes approximately 500 square feet of shelving and storage space and 200 square feet of bench-top work space. Sample preparation and storage equipment includes a muffle furnace, drying oven, freezer, and soil sieves and grinders.

As with the Center's other programs, staff in the field sampling area carry out experimentation and development related to sampling design, techniques, and instrumentation.

Informatics

One of the Center's primary objectives is to establish a health and environmental database accessible to all sectors. It is the role of the informatics program to carry out this function by developing and implementing information management systems. The informatics program includes formal systems for data archival and documentation that facilitate analyses and accurate interpretations. Commercial relational database management systems (RDBMS) will be one component of the program. For example, the lung and whole-body counting system will use an integrated RDBMS for data collection and storage, and other systems may be used for meteorological data collected by the field sampling program. The Center has adopted the use of flat ASCII files as the primary format for long-term archiving of basic scientific data, which is a protocol standard used for over ten years by participants in the National Science Foundation's Long Term Ecological Research program. This format provides maximum flexibility for data transfer and integration with diverse applications software. The informatics program also includes creation and maintenance of metadata, which include information about sampling methods, sampling location, units, experimental design, investigators, and other details that create context for interpretation of data. Metadata are recognized as key components of effective informatics programs in environmental monitoring and research (Michener, et al., *Non-geospatial metadata for the ecological sciences*, Ecological Applications, in press).

The research activities of the informatics program include data linkage to simulation modeling in systems ecology. For example, estimates of contaminant doses and risks can be made, using models to project potential exposure via environmental pathways. The model projections are based on estimates of contaminant movement through the atmosphere, deposition in water and soil, direct uptake by humans or other organisms, and secondary transfer between components of the environment and living organisms. Data from the WIPP Environmental Monitoring project will provide a basis for benchmark parameter estimates that can be applied to models of transport processes in desert ecosystems.

RESEARCH SUMMARIES

Survey of Factors Related to Contaminant Exposure and Perceptions of Environmental Risks in Carlsbad, Loving, Malaga, and Hobbs, New Mexico

Problem Statement and Background

In addition to people working at the WIPP, people who live and work close to the facility in Eddy and Lea counties are at risk of potential exposure from any releases of contaminants that could occur at the WIPP. There are two population centers in Eddy County within a 30-mile radius of the WIPP. Carlsbad, 26 miles west of the facility, is a primarily non-Hispanic white, comparatively affluent, urban community. Loving-Malaga, 18 miles southwest of the facility, is a primarily Hispanic white, rural community. The city of Hobbs is located 40 miles northeast of the WIPP site in Lea County. Carlsbad and Hobbs are similar in size and many characteristics. Based on distance from the WIPP, Hobbs is less likely to be affected by any release of contaminants at the WIPP and, therefore, represents a possible reference population for purposes of future comparisons with populations nearer to the WIPP.

Investigators with the Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center, were engaged under Contract No. Q00082 with New Mexico State University to conduct a survey of residents within selected communities in the region of the WIPP. The survey was designed to characterize a variety of parameters that are related to exposure to naturally occurring and anthropogenic contaminants, and public interests and perceptions of environmental and health issues.

Methods

A standard questionnaire was administered by telephone to 778 households, including 944 individuals in Carlsbad and Loving-Malaga. The questionnaire was administered to 314 households, including 598 individuals in Hobbs. The survey participants were part of a random sample of published residential telephone numbers. To ensure study accuracy and adequate and unbiased representation of residents, interviews were conducted on weekdays and weekends at a variety of times, using computer software designed for survey research. Quality control was maintained in each aspect of the survey, and a verification study was performed to assess study accuracy and acceptability to survey participants.

Results

In Carlsbad and Loving-Malaga, 66% of the households contacted agreed to participate and completed an interview. In Hobbs, 69.8% of the households contacted agreed to participate and completed an interview. The average size of households surveyed was 2.5 people in Carlsbad, 2.9 people in Loving-Malaga, and 2.8 people in Hobbs. The proportion of households with children was 33% in Carlsbad, 50% in Loving-Malaga, and 43% in Hobbs. The proportion of Hispanic households was 10.5% in Carlsbad, 36.1% in Loving-Malaga, and 17.7% in Hobbs.

Most respondents in all communities lived in single-family detached dwellings, with a majority of the remainder residing in mobile homes. Non-mobile homes in Carlsbad and Loving-Malaga were usually of wood-frame construction and cement slab foundations, whereas brick or cement-block construction was more common in homes in Hobbs. Indoor Rn has not been identified as a problem in southeast New Mexico, and less than 15% of all households reported that they had tested their homes. Few people could recall the Rn test results.

1990 U.S. Census information indicated that most homes in Carlsbad, Loving-Malaga, and Hobbs were connected to municipal water systems. However, approximately 5% of surveyed households in Carlsbad and Loving-Malaga used water from private wells, and 26% of the surveyed households in Hobbs used water from private wells. In addition, approximately 7% of the surveyed households in Carlsbad and Loving-Malaga, and 9.4% of surveyed households in Hobbs, used bottled water for drinking and cooking.

Over 75% of the surveyed households in all three communities reported that they never ate home-raised dairy foods (eggs and milk) or meats (beef and poultry), although slightly more households in Loving-Malaga reported consumption of these foods. Home- and locally-grown fruits and vegetables were eaten by almost half the households in all three communities when these foods are in season. In Carlsbad and Loving-Malaga, 39% of households reported eating deer, and 32% reported eating self-caught fish at least once per year. Rates were slightly lower in Hobbs, with 28% for deer and 24% for fish.

Some adults in all communities reported current or past employment in occupations in which they may have been exposed to radioactive or chemically hazardous materials. In Carlsbad and Loving-Malaga, such occupations included work in underground uranium mines (where they may have been exposed to high levels of Rn), nuclear fuel production, nuclear weapons production, radioactive waste handling, and hazardous waste handling. In Hobbs, respondents reported work in oil and gas exploration and production, medical and dental occupations, nuclear fuel production, radioactive waste handling, and hazardous waste handling.

Most adults in all communities regarded the environment in their communities to be unpolluted, with air quality generally regarded to be better than that of soil and water. In general, a larger proportion of adults in Carlsbad than in Hobbs judged the environmental quality of their community favorably. The air was judged to be “very clean” by 44.4% in Carlsbad vs. 25.4% in Hobbs, the water was judged to be “very clean” by 38.4% in Carlsbad vs. 23.6% in Hobbs, and the soil was judged to be “very clean” by 28.8% of those in Carlsbad vs. 19.3% of those in Hobbs.

Adults surveyed in all communities expressed a high level of concern for protection of the environment and of human health. Seventy percent of adults were “concerned” or “very concerned” about pollution in the environment. High levels of concern were expressed about pesticides, radioactive and toxic wastes, water contamination, chemical contaminants in food, and adverse health effects, including birth defects and cancer.

Over half of the adults interviewed in all communities (61.9% in Carlsbad and 56.2% in Hobbs) indicated that they would be willing to give samples of blood or urine to support monitoring of pollution in the environment.

Conclusions

This study provided data on population characteristics and lifestyles that will be useful for estimating the health risks associated with potential releases of wastes from the WIPP. For example, the levels of usage of private water supplies and consumption of locally-grown vegetables and fruits illustrate potential pathways for contaminant transport to humans. The survey also documents extant contaminant exposure sources in the population that are not associated with the WIPP. In general, response patterns for Carlsbad and Hobbs were similar for the parameters surveyed, indicating that using future data from Hobbs as a reference population is feasible. The survey results demonstrate that members of the public in this region have a high level of concern about preserving the environment and protecting health. The expressed willingness of adults to give samples of blood and urine suggests that good public participation can be expected for bioassay programs to monitor for the appearance of contaminants potentially arising from releases at the WIPP.

Acknowledgments

The complete report of this study will be released by the Center during 1997. Co-investigators for the study were F. D. Gilliland, W.E. Lambert, and R. Mahler, Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center.

Cancer Incidence Rates In Eddy And Lea Counties, New Mexico, 1970-1994

Problem Statement and Background

Investigators with the Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center, were engaged under Contract No. Q00082 with New Mexico State University to conduct an analysis of current and historic cancer incidence rates in populations living near the WIPP.

Methods

Cancer incidence rates were calculated using New Mexico Tumor Registry (NMTR) data for tissues known to be sensitive to radiation and chemical agents. The NMTR serves as a repository and data-collection agent for confidential medical abstracts of cancer cases, and reports data on incidence, treatment, mortality, and survival to the National Cancer Institute. The data include information collected at the Guadalupe Medical Center in Carlsbad, New Mexico, as well as at health care facilities and pathology laboratories statewide and in adjacent Texas counties. Population estimates for New Mexico used to calculate incidence rates were derived from the censuses of 1960, 1970, 1980, and 1990. The age distribution of the 1970 U.S. population was used for age adjustment of incidence rates. Spatial variation was assessed by comparing cancer incidence rates among residents of Eddy and Lea counties with rates for all other New Mexican counties and U.S. average rates for the period from 1970 to 1992. Temporal variation was assessed by comparing three-year moving average cancer incidence rates among residents of Eddy and Lea counties with statewide and U.S. trends for the period between 1970 and 1994. Cancer incidence rates were stratified by ethnicity and sex to control for variation among these groups. To provide an indication of variability, upper and lower 95% confidence intervals were calculated using standard errors. Because the study was designed to be descriptive, no statistical tests were applied to means comparisons to assess significance of differences.

Results

In general, the cancer incidence rates in Eddy and Lea counties were less than, or comparable to, statewide and national rates. Cancer incidence rates were higher among males than females and higher among non-Hispanic whites than Hispanic whites (Table 3). However, the cancer incidence rates showed marked variation among cancer sites, especially when they were stratified by ethnicity and sex. Comparisons at the county level were frequently based on very low levels of incidence, particularly for less common cancers. This resulted in large confidence intervals for the spatial analysis and widely varying rates for the temporal analysis.

For the period between 1970 and 1992 in Eddy County, cancer incidence rates among males and females were below or equal to statewide averages for bladder, bone, breast, and prostate cancer. In Eddy County, at least one ethnic-gender group had incidence rates higher than the corresponding statewide average for brain and other nervous system, colon, laryngeal, liver, lung, ovarian, stomach, thyroid, and uterine cancers and for leukemia and non-Hodgkin's lymphoma. Incidence rates that were notably high compared to statewide and/or U.S. rates include rates of colon and liver cancer among Hispanic white males, leukemia among Hispanic white females, lung cancer among all non-Hispanic whites,

Table 3. The Rank of Average Cancer Incidence Out of 32 Counties, Among Residents of Eddy and Lea Counties, for the Period Between 1970 and 1992

Eddy County				
Cancer Site	Non-Hispanic White		Hispanic	
	Males	Females	Males	Females
All Sites	11	14	16	7
Bone	17	15	11	14
Bladder	17	24	25	19
Brain and CNS*	27	18	24	11
Breast	N/A	15	N/A	12
Colon	21	13	4	17
Larynx	6	12	18	29
Leukemia	24	10	17	7
Liver	12	17	4	22
Lung	5	5	16	8
NHL**	19	13	1	4
Ovary	N/A	19	N/A	10
Prostate	20	N/A	24	N/A
Stomach	7	19	18	10
Thyroid	15	6	21	18
Uterus - Corpus	N/A	15	N/A	4
Childhood - All Sites	25	13	28	12
Childhood - Leukemia	12	6	21	7

Lea County				
Site	Non-Hispanic White		Hispanic	
	Males	Females	Males	Females
All Sites	31	30	28	31
Bone	11	16	27	26
Bladder	23	29	14	3
Brain and CNS*	25	26	22	22
Breast	N/A	29	N/A	30
Colon	27	25	18	28
Larynx	21	8	1	2
Leukemia	27	29	14	19
Liver	15	8	15	1
Lung	11	22	21	22
NHL**	24	26	27	29
Ovary	N/A	23	N/A	23
Prostate	30	N/A	31	N/A
Stomach	27	18	6	11
Thyroid	25	29	28	24
Uterus - Corpus	N/A	29	N/A	32
Childhood - All Sites	21	23	7	9
Childhood - Leukemia	18	14	10	8

*Central Nervous System; **Non-Hodgkin's Lymphoma
Valencia and Cibola counties are combined

and non-Hodgkin's lymphoma among all Hispanic whites.

For the period between 1970 and 1992 in Lea County, cancer incidence rates among males and females were below statewide averages for bone, brain and other nervous system, breast, colon, ovarian, prostate, thyroid, and uterine cancers and non-Hodgkin's lymphomas. At least one ethnic-gender group had incidence rates higher than the corresponding statewide average for bladder, laryngeal, liver, lung, and stomach cancers and leukemia. Cancer incidence rates that were notably high compared to statewide and/or U.S. rates include rates of laryngeal cancer among Hispanic whites and liver cancer among Hispanic white females.

Three-year moving average cancer incidence rates in Eddy and Lea counties are generally less than or comparable in magnitude to statewide rates from 1970 to 1994, but often do not appear to follow statewide or U.S. trends. In general, incidence rates among Eddy County residents for cancers of all sites combined were slightly higher than statewide rates and lower than U.S. rates from 1970 to 1994. Cancer incidence rates followed the statewide pattern, increasing steadily through 1991 and then dropping. This pattern is strongly influenced by the underlying patterns of change in incidences of prostate and female breast cancer, which are suspected to be associated with changes in diagnosis for these two cancer types. Incidence rates among Lea County residents for cancers of all sites combined were lower than statewide and U.S. rates from 1970 to 1994. Lea County rates did not follow the same pattern of increase as statewide rates, remaining fairly steady during this period.

Conclusions

This report presents a descriptive summary of cancer incidence rates for the populations of Eddy and Lea counties during the last twenty years. The results include several instances of large variations and clustering of cancer incidence rates that are likely sampling artifacts associated with small population sizes and relatively rare cancer types. Temporal changes in incidence of some cancer types (such as prostate cancer and female breast cancer) are thought to be strongly influenced by changes in detection methods. This history of past variability is important in assessing and interpreting future cancer incidence data, relative to potential effects of exposure to materials to be disposed of at the WIPP. Given the relatively small population sizes in the immediate region of the WIPP (30 residents in a 10 mile radius, and 2,000 within 20 miles), the historical variability in cancer incidence rates (as revealed in this study), and the potential of confounding effects from changes in medical technology, health habits and other population attributes, it would be very difficult to demonstrate that an increase in cancer incidence is the result of exposure to contaminants at the WIPP.

Acknowledgments

The complete report of this study will be released by the Center during 1997. Co-investigators for the study were F.D. Gilliland and W.E. Lambert, Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center.

Statistical Issues in the Design of a Bioassay Surveillance System For Populations Near the Waste Isolation Pilot Plant

Problem Statement and Background

Investigators with the Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center, were engaged under Contract No. Q00082 with New Mexico State University to evaluate alternative strategies for surveillance of the population body burdens of radionuclides in persons living near the WIPP. Although specific analytical methods for bioassay surveillance currently are under development, a variety of *in vitro* and *in vivo* methods may be used. In *in vitro* bioassay methods, radioactivity is measured in samples of urine, feces, blood, or other tissues. *In vivo* methods employ external detectors to make measurements of radiation emanating from within the body. The ability of these methods to detect increases in radioactivity in potentially exposed groups is dependent both on selecting accurate scientific measurement methods and on obtaining measurements from adequate numbers of persons. This study identifies epidemiological and statistical issues relevant to design of a surveillance program to establish baseline levels of radioactivity in the population before the WIPP begins to receive waste and to detect increases in population mean body burdens of radionuclides after the facility begins operations.

Methods

The analytical methodology consisted of iterative calculations of sample size across ranges of parameters of concern. The sizes of samples were calculated for various baseline levels of radioisotopes in the population, using both continuous data and binary data, with baseline levels expressed as either the mean level of radioactivity in the population or the frequency of "positives" in the population before exposure. The goal of the sample size analyses was to estimate the minimum sample sizes required to detect small but statistically significant increases in the population average body burden. The analyses for continuous data included both independent samples and sequential, correlated samples. The effect of random measurement error on the ability of the analytic system to detect increases in the mean population body burden also was evaluated.

The minimum detectable amount (MDA) is the amount of radioactivity that can be detected with a false negative (Type II) rate of <5% from samples of body fluid or from external measurement of body burden. If the proportion of measurements below the MDA from a population sample does not exceed 30%, conventional statistical methods (e.g., t-test) can be used to estimate the sample sizes required to detect significant differences between groups. Some of the more recently developed bioassay methods may be sensitive enough to meet this performance criterion and thus would support the use of conventional methods to estimate sample sizes. Published literature and consultation with bioassay experts suggest that, using standard detection technologies, the detection of background radioactivity from Pu above MDAs will be extremely rare in the general population without occupational exposure. The detection of radiation from other radionuclides, such as ^{137}Cs is expected to be much higher. Depending on the technology used, the observation of an MDA for some radionuclides in the general population living in the vicinity of the WIPP may be less than 1 in 10,000 persons. One statistical approach applicable to this type of data is the use of a binary outcome variable, such that an individual's measurement is considered to be "negative" if below the MDA or "positive" if above the MDA.

Results

Required sample sizes first were calculated for comparisons of group means, using continuous data obtained from independent samples of the groups. An example of independent samples for two groups would be samples from individuals from the same community selected at random at two different times, such as before and after waste is deposited in the WIPP. The calculated minimum sample sizes were based on the difference in mean levels between the two groups and the variability in body burdens in these samples. As these parameters were varied in the analysis, several patterns were evident. Minimum sample sizes on the order of hundreds of people would be required to detect increases in population mean body burdens of 25% to 100%. Larger sample sizes were needed to detect smaller differences between samples, and sample size requirements increased as the variance in the distribution increased. Smaller differences in population mean levels could be detected using a larger baseline (or reference) sample as compared to smaller subsequent samples of equal size. This result indicates that measurements made on a large number of people could be used to estimate a baseline population mean and variance with a high degree of confidence, and subsequent smaller samples of the population could be used to allow detection of a small increase.

Sample size requirements also were calculated for sequential measurements for comparisons of group means, using continuous data obtained from the same sample or "cohort" of people at different times. Assuming a high correlation (correlation coefficient, r = 0.90) between consecutive measurements on the same individuals, minimum sample sizes of less than 100 were estimated to be needed to detect increases in population mean body burdens on the order of 25% to 100% of the baseline level (Figure 2). As the measurement-to-measurement correlation decreased from 0.90 to 0.25, estimated minimum sample sizes approached 200.

Using binary data (with either negative or positive score for each individual) and assuming a binomial distribution, minimum sample sizes were calculated to detect a doubling, and five- and ten-fold increases in the background rate. At a background prevalence of one positive in 10,000 persons, to demonstrate a 20-fold increase in the prevalence of positives, bioassays would have to be conducted on 3,000 people and at least two positives would have to be detected to achieve statistical significance. At the same prevalence rate, to determine if there was a doubling of the background rate virtually all of the 105,000 persons living in the 50-mile radius around the WIPP would have to be measured (Figure 3). Simulations could be conducted for binary data with more robust distributional assumptions, such as Poisson, but this was not included within the scope of these studies.

Two components of test accuracy were evaluated in the analyses—(1) "sensitivity", the proportion of all those persons who have been exposed whose bioassay is positive and (2) "specificity", the proportion of all those who were not exposed whose bioassay is negative. Sample sizes were estimated for various baseline prevalence rates of one positive in 10,000 persons to 25 per 1,000 persons for perfect sensitivity of 100% down to 80%, and for perfect specificity of 100% down to 90%. The results indicated that decreases in sensitivity slightly increased estimates of minimum sample size, and at low background prevalence rates, small decreases in specificity greatly increased estimates of minimum sample size.

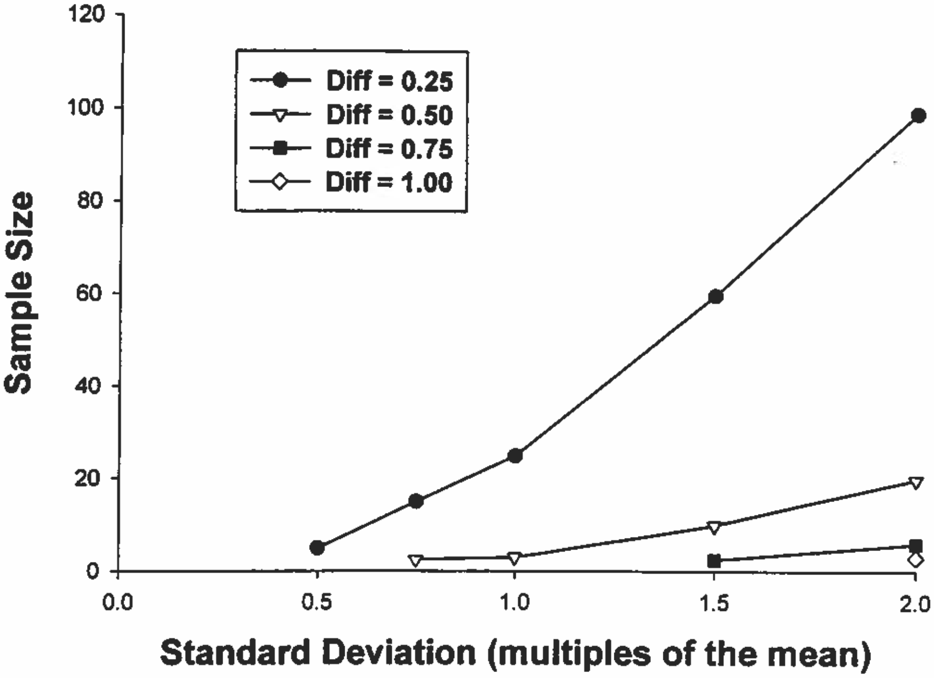

Figure 2. Minimum Sample Sizes for Cohorts in Which the Correlation Between Successive Measurements Is High (r = 0.90)

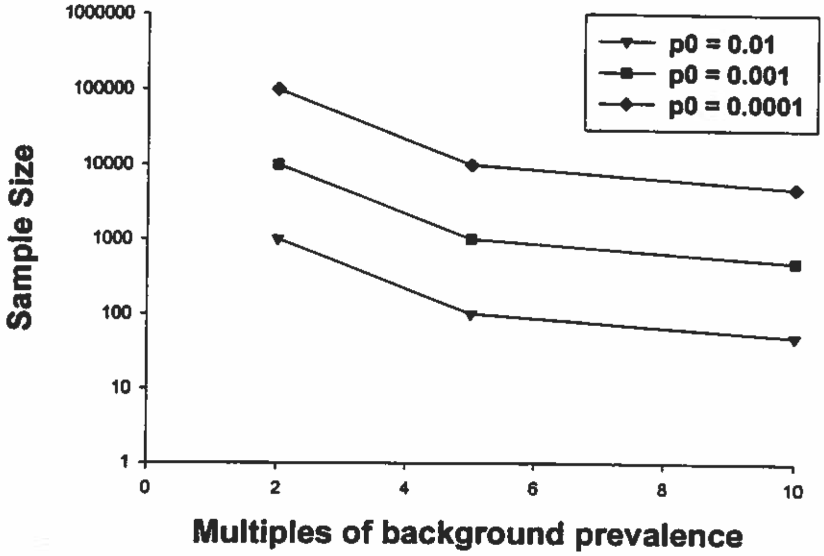

Figure 3. Estimated Minimum Sample Sizes by Binary Outcome Approach

Conclusions

This study identifies several constraints posing substantial difficulties in the use of conventional statistics to accurately estimate population mean body burden of radioactivity. The area where the WIPP is sited is sparsely populated, and the numbers of potentially exposed persons available for bioassay are smaller than the sample sizes needed to detect small increases in the population mean, under some detection scenarios. For example, the analyses indicate that the number of people living closest to the WIPP facility (30 residents in a 10-mile radius, and 2,000 within 20 miles) is too small to use an independent sampling design for surveillance, even if very low detection limits are possible. The use of cohort designs in sampling may be more effective, although this would still require a detection level low enough to produce continuous data. In addition, small decrements in the specificity of the analytic methods will introduce large amounts of error into the surveillance system, greatly increasing minimum sample size requirements and compromising the system's ability to detect increases in population mean body burdens.

For analytical methods where the minimum detectable levels for a given radionuclide are generally higher than the levels occurring in the nonoccupationally exposed persons living near the WIPP, conventional statistics may not be applicable, and alternative statistical approaches will be necessary. However, the statistical and analytical limitations associated with a public bioassay program are offset by the Center's environmental monitoring program. This monitoring program will be capable of detecting contaminant releases at the source, before they reach the general population. Integration of bioassay surveillance provides a measure of final assurance in interpreting the results of any contaminant releases identified by the environmental monitoring program.

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Co-investigators for the study were F.D. Gilliland, W.E. Lambert, C.A. Stidley, and K. Trinkaus, Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center.

Atmospheric Monitoring Network Design For Detecting Acute Radiation Releases

Problem Statement and Background

Pilot studies using high-volume atmospheric aerosol sampling have been conducted near the WIPP since 1993. The purpose of the studies has been to characterize, by size, the temporal variability in aerosol mass and actinide composition. The studies include routine measurements of total suspended particulate matter (TSP) aerosols with an aerodynamic diameter (d_a) less than about 75 µm, and aerosols with d_a less than 10 µm (PM_{10}). Atmospheric aerosol sampling has been identified as an essential element of long-term environmental monitoring to be conducted in association with operation of the WIPP.

Factors that are important in designing an operational monitoring network include (1) distance from the source to the monitors, (2) area over which the network is sensitive to a specified level of pollutant impact, (3) number of monitors needed to provide a specified likelihood of detecting releases of varying magnitude, (4) sampling frequency and duration, (5) meteorological conditions, (6) location of individual samplers, (7) predicted release mechanisms and characteristics, and (8) cost-effectiveness of various monitor placement strategies.

Investigators with the Harvard School of Public Health were engaged under Contract No. Q00083 with New Mexico State University to collaborate in studies to support design of an atmospheric aerosol monitoring network in the vicinity of the WIPP. Design objectives for the monitoring network that were addressed in this study focused on detection of acute actinide radioactivity impacts in the event of an accidental release from the WIPP.

Methods

Releases of contaminants to the environment can be examined by comparing a background set of samples to a potentially impacted set of samples (e.g., downwind). The number of samples needed to detect a prespecified difference in the associated contaminant measurements can be estimated for a given Type I and Type II error rate using standard statistical methods, if the variance of the two populations is known.

The number of surveillance stations required to attain a specified level of network sensitivity was examined by identifying locations where maximum pollutant concentrations (C_{max}) can be expected to occur (Noll and Miller, *Air Monitoring Survey Design*, 1978, Ann Arbor Science). The Gaussian puff dispersion equation was used to estimate downwind pollutant concentrations resulting from an instantaneous or quasi-instantaneous release.

The puff equation forms the basis of the U.S. Environmental Protection Agency's INPUFF 2.0 dispersion model (EPA/600/8-86/024, 1986) and can be expressed as shown in Eq 1 where,

C = concentration at the receptor located at point x, y, z at time t (Ci m^{-3})

x = downwind distance of the receptor from the source (m)

y = crosswind distance of the receptor from the plume center-line (m)

z = height above ground level (m)

Q = source term or acute emission (Ci)

σ_x = the standard deviation in the downwind direction of a puff concentration distribution (m)

$$C(x,y,z,t)=\frac{Q}{\sqrt{(2\pi)^3}\sigma_x\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{x-\mu t}{\sigma_x}\right)^2\right]\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]+\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]\right\} \quad (1)$$

σ_y = the standard deviation in the crosswind direction of the plume concentration distribution (m)

σ_z = the standard deviation in the vertical of the plume concentration distribution (m)

μ = wind speed (m sec^{-1})

t = time elapsed from the pollutant release (sec)

H = effective height of emission (m)

A probability distribution of the C_{max} downwind distance was generated by performing a Monte Carlo simulation of Eq. 1 under varying atmospheric conditions (e.g., stability, wind speed) and release scenarios. Frequency distributions were generated for the standard Pasquill-Gifford atmospheric stability classes (Table 4). The frequency distribution for the effective height of emission was assumed to be triangular with a range of 5-50 m and a mode of 20 m. These two parameters were selected to represent uncertainty about the timing (e.g., meteorological conditions) and nature (release conditions) of an accidental release from the WIPP. Simulations were conducted using @Risk (Palisade Corporation, 1988). Vertical and horizontal coefficients of dispersion were estimated deterministically by the method of Briggs (Hanna et al., *Handbook on Atmospheric Diffusion*, DOE/TIC-11223, 1982).

When considering the case of an acute radioactive release (Q_0) that would yield a maximum concentration equal to some specified baseline level (C_0) at ground level located at some distance downwind (i.e., x=μt, y=0, z=0,t), Eq. 1 reduces to:

$$C_0=\frac{2Q_0}{\sqrt{(2\pi)^3}\sigma_x\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\left(\frac{H}{\sigma_z}\right)^2\right] \quad (2)$$

The possibility for detection of acute radioactivity releases by an atmospheric monitoring network was examined by adapting the method developed by Pelletier (In *Environmental Surveillance in the Vicinity of Nuclear Facilities*, 1967, Pergamon Press) to Eq. 1. The puff dispersion equation can be used to show that the ratio of an acute release (Q_0) that is required to yield a maximum ground-level concentration at a specified distance (x) along the plume centerline, to the release (Q) that is required to yield the same concentration at a ground-level point (x') equidistant from the source but off the plume centerline is:

$$\frac{Q_0}{Q}=\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \quad (3)$$

The distance y can be calculated as:

$$y = x\sin\Theta \quad (4)$$

Table 4. Frequency Distribution of Pasquill-Gifford Atmospheric Stability Classes

Stability Class	Relative Frequency
A	0.03
B	0.13
C	0.31
D	0.39
E	0.09
F	0.02

Substituting Eq. 4 into Eq. 3 and solving for Θ gives:

$$\Theta = \sin^{-1}\left[\frac{\sigma_y\sqrt{2\left(\ln(Q) - \ln(Q_0)\right)}}{x}\right] \qquad (5)$$

where *D* is the angle between the two receptor locations as measured from the source and represents the maximum possible spacing between an adjacent pair of monitors such that theoretically no plume caused by release *Q* would pass between them undetected. By setting Q_0 equal to the emission that gives *t* time-weighted average ground-level concentrations equal to baseline environmental levels, Θ was calculated for varying levels of sensitivity by adjusting *Q*. Because of the symmetry inherent to the Gaussian dispersion model, a monitor placed at a given location would actually cover an angle equal to 2Θ. Using equal probability for all wind directions, the total number of monitors, *N*, needed to ensure the detection of a release of magnitude *Q* was calculated by:

$$N = \frac{360}{2\Theta} \qquad (6)$$

The value of Q_0 that gives a time-weighted concentration equal to baseline environmental levels was calculated by integrating the Gaussian puff equation (Eq. 1) over the time during which the air sample is collected, then dividing the result by the sample duration.

Meteorological information can be used to distribute a reduced number of monitors (in a nonuniform manner) and still maintain a specified level of network sensitivity. A weighting factor (f_i) was developed that represents the frequency with which the wind blows from the source toward each directional region. The area around the site was divided into four regions (A_1=0-89°, A_2=90-179°, A_3=180-269°, A_4=270-360°). The f_i values were determined from an analysis of 15-min average wind direction data collected by the WIPP meteorological tower during calendar year 1992 (f_1=0.15, f_2=0.50, f_3=0.22, f_4=0.13).

A probabilistic approach was used to determine the most efficient distribution of a specified number of monitors based upon the nonuniform weighting of the local regions. In this way, the total number of monitors in the network can be reduced without compromising network sensitivity. An iterative method was used to determine the minimum number of samplers needed to yield a given probability of detecting a specified release at a given distance downwind. The method is based on the following equation:

$$\Pr(Detection) = \sum_{i}^{n} f_i \frac{2\Theta N_i}{A_i} \qquad (7)$$

where A_i is the size of the arc relative to the source in which monitors may be placed (degrees) and N_i is the number of samplers in A_i. Eq. 7 was used to calculate the probability of detecting a release from different numbers and locations of monitors.

Results

In the absence of atmospheric actinide data, sample size calculations were applied to gross alpha measurements made near the WIPP (Kenney and Ballard, *Preoperational Radiation Surveillance of the WIPP Project by EEG during 1989*, EEG-47, 1990). Initial sample size calculations indicated that a 25% increase in the mean atmospheric alpha activity could be detected by two sets of particulate measurements each comprised of 250 samples—one set from a potentially impacted zone (i.e., downwind) and the other from an unimpacted zone.

The relatively large number of samples required is a direct function of the variability in the environmental data. The variability is likely to be related to climatic and meteorological conditions. This theory is supported by statistical analyses of gross alpha data collected from 1987–1989 that show statistically significant temporal variability within each year (Kenney and Ballard, 1990; Kenney et al., *Preoperational Radiation Surveillance of the WIPP Project by EEG during 1985-1988*, EEG-43, 1990). The timing of the variability is not constant from year to year, suggesting the importance of microscale meteorological conditions such as wind speed, precipitation, and insolation. Therefore, understanding the potential relationship between meteorological conditions and ambient particulate radioactivity is important for achieving greater efficiency in attainment of environmental monitoring objectives.

Using simulation results, the cumulative distribution function indicates that C_{max} can be expected to lie between 100 and 1,000 m from the source with greater than 90% confidence (mean=250 m) (Figure 4). Thus, the number of monitors required to achieve a specified level of network sensitivity to acute releases can be minimized by placing the monitors within 1 km of the source. Using this assumption, a monitoring network design was evaluated to achieve detection of short-term releases of at least 0.5 Ci ^{239,240}Pu, which is the release amount predicted from spontaneous ignition of a transuranic waste drum located in the underground repository (DOE, *Waste Isolation Pilot Plant Final Safety Analysis Report*, vol. 1, 1990). For this projection, samplers would be located 1 km from the source, and would operate at a flow rate of 1.1 m^3 min^{-1} for consecutive sampling periods of seven days. The local ambient activity concentration of ^{239,240}Pu resulting from fallout was assumed to be 37 μBq m^{-3}. The effective release height was assumed to be 20 m, with slightly unstable atmospheric conditions prevailing in the area. Using Eq. 2 to calculate Q_0 and the Brigg's equations for rural areas to compute the coefficients of dispersion (in this projection, σ_x=σ_y=105 m, and σ_z=73 m), Θ was computed to be 24° from Eq. 5. With these parameters, and using Eq. 6 without weighting for wind direction or other meteorological factors, a minimum number of 8 monitors uniformly located 1 km from the source were projected to be

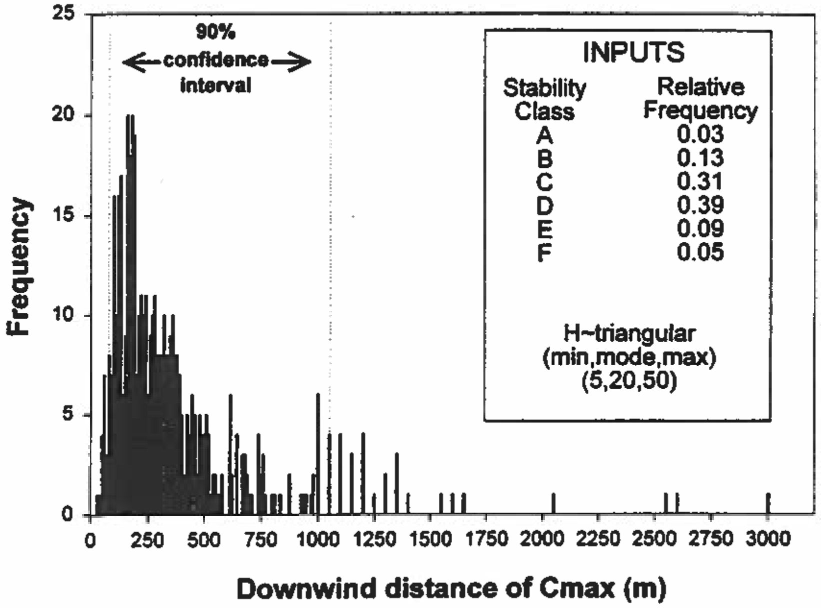

Figure 4. Histogram of Downwind Distance of Cmax Obtained from a Monte Carlo Simulation of 500 Trials

required to ensure detection of a ^{239,240}Pu release of 0.5 Ci.

Simulations were repeated using a weighting factor (f_i) for wind direction patterns to calculate the probability of detecting a release for a specific configuration (Figure 5) of monitors among four directional regions (plot restricted to detection probabilities > 70%). The vertical spread for each *N* represents the range of probabilities achieved from the most to the least judicious distribution of the monitors. For example, a total of six monitors can yield a detection probability from 74% to 89% depending on their distribution among the four sectors.

Conclusions

The methods described provide a tool to generate numerical data that can be used for comparative purposes during the network design process. An important aspect of the model is its ability to optimize network design to provide the most cost-effective monitoring strategy. This method provides qualitative estimates of the expected performance of alternative monitoring strategies.

Although some meteorological uncertainty is accounted for in the model, the methods described here provide point estimates of expected activity concentrations and monitor needs. As with any deterministic model, these point estimates are subject to uncertainty regarding the true value or distribution of certain input parameters (e.g., wind direction at time of release) and stochastic variability inherent in other parameters (e.g., variation in wind direction during transport). In addition, the physical characteristics of the plume, effective release height, particle size distribution, and the state of the atmosphere also contribute to the model prediction uncertainty. For example, the model does not include parameters to account for the atypical "plume" that would result from chronic low-level releases.

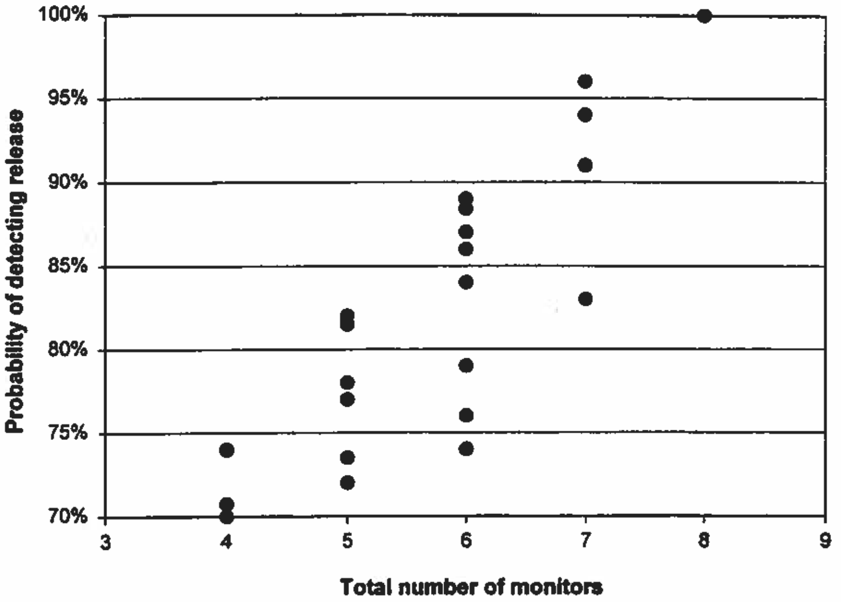

Figure 5. Probability of Detecting a 0.5 Ci Release of ^{239,240} Pu for Different Numbers and Positions of Atmospheric Monitors

Note: Monitors located 1 km from source, operating at 1.1 m^3 min^{-1} for seven consecutive days and ambient ^{239,240}Pu = 37 µBq m^{-3} (1 aCi m^{-3}).

Acknowledgments

Co-investigators for this study were D. MacIntosh, H. Ozkaynak, and J. D. Spengler, Harvard School of Public Health.

Biomarkers for Public Health Surveillance of Genotoxic Damage

Problem Statement and Background

In the past decade, new methods have been developed to assess genetic alterations related to exposure to radiation and chemical agents. Investigators with the Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center were engaged under Contract No. Q00082 with New Mexico State University to conduct a literature review of these methods. This review evaluated the utility of the currently available biomarkers for somatic mutations and chromosomal aberrations related to ionizing radiation. Specifically, the review evaluated the potential applicability of various methods for monitoring for the occurrence of genetic damage in the human population living near the WIPP.

Methods

Literature reviewed for this study included reports published in peer-reviewed scientific books and journals and internal reports of various agencies and laboratories.

Results

Genetic damage from ionizing radiation is detectable in many tissues of the human body, but it is most easily observed in erythrocytes (red blood cells) and T-lymphocytes (white blood cells) obtained by venous blood draw. Genetic alterations occur at two levels. At the "macro" level, structural abnormalities may occur in the chromosomes, and at the "micro" level, deoxyribonucleic acid (DNA) may be damaged, resulting in changes to genes (mutations) and the aberrant expression of genes. This damage may increase the risk for cancer if the alterations occur to genes involved in carcinogenesis.

Chromosomal rearrangements include translocations, ring formations, terminal deletions, and the formation of cytoplasmic micronuclei. These structural changes can be detected in cultured lymphocytes whose karyotypes are quantified by microscopy and computerized image analyzers. A relatively new method, fluorescence in-situ hybridization (FISH), also can detect rearrangements of bands on chromosomes. Chromosome fragments that become detached from the nucleus during cell division may form cytoplasmic micronuclei that can be quantified by microscopic analysis and, recently, flow cytometry. Chromosomal aberrations have been analyzed in occupationally-exposed groups (nuclear workers and uranium miners) and environmentally-exposed groups (samples from populations in Hiroshima, Nagasaki, and Chernobyl). High variability within and between individuals has been observed in these studies. Although semi- and fully-automated assay systems have been developed and have greatly reduced analysis time and cost, high intra- and inter-variability limits the sensitivity of any proposed surveillance program and increases the sample sizes required to detect increases above baseline prevalence rates.

Ionizing radiation has been demonstrated to damage several mammalian genes, including the hemoglobin (Hb) and glycophorin A (GPA) genes in erythrocytes, and the hypoxanthine-guanine phosphoribosyl transferase (HPRT) gene, the T-cell receptor (TcR) gene, and the human lymphocyte antigen (HLA) genes in T-lymphocytes. Assay methods for these gene mutations include polymerase chain reaction (PCR) with reverse transcriptase identification of point mutations and flow cytometry with fluorescent-labeled antibodies. Background variant and mutant frequencies are known in some populations, and ways to reduce analytic error have been developed. However, as is the case for the monitoring of chromosomal aberrations, substantial intra- and inter-individual variability exist with these gene systems. Sources of intra-individual variability include the timing of the sample relative to the exposure of interest and variations in physiologic state. Sources of inter-individual variability include lifestyle factors such as smoking and diet and host characteristics such as age and DNA repair capacities.

Conclusions

At the present time, assays are not sufficiently developed to justify their use to monitor populations living close to the WIPP. Variability needs to be reduced by improving blood sample collection, handling, and analytic methods, and better characterization of the host factors influencing intra- and inter-individual variability. Both chromosomal aberrations and mutations in erythrocytes (GPA variants) and T-cells (TcR mutants) hold promise for future use in population monitoring.

Acknowledgments

Co-investigators for this study were F. D. Gilliland, and W. E. Lambert, Epidemiology & Cancer Control Program, University of New Mexico Health Sciences Center.

Determination of Atmospheric ^{239,240}Plutonium in the Vicinity of the Waste Isolation Pilot Plant

Problem Statement and Background

The source of atmospheric Pu and other actinides within and adjacent to the WIPP site prior to receipt of wastes can be considered to be the result of global fallout from nuclear weapons testing, destruction of satellites carrying nuclear power sources, and accidental releases from nuclear industry installations.

For purposes of environmental regulatory compliance, Argonne National Laboratory, near Chicago, Illinois, has been monitoring ^{239,240}Pu concentrations in air since 1973. During the period of 1973 to 1982, ^{239,240}Pu aerosol concentrations were in the range of 1.5–2.5 μBq m^{-3} (40–70 aCi m^{-3}). Since 1983, the ^{239,240}Pu concentrations in air have decreased significantly to approximately 0.2 μBq m^{-3} (5 aCi m^{-3}) or less (Golchert and Duffy, *1986 Annual Site Environmental Report for Argonne National Laboratory,* ANL-87-9, 1987).

The U.S. Environmental Protection Agency (EPA), Environmental Monitoring Systems Laboratory in Las Vegas, Nevada, also has conducted off-site radiation monitoring at the Nevada Test Site. Most ^{239,240}Pu concentrations of composite air samples have been reported to be less than minimum detectable concentrations (MDCs) of 0.4–4 μBq m^{-3} (10–100 aCi m^{-3}) (U.S. EPA/EMSL, EPA 600/4-90/030, 1991; U.S. EPA/EMSL, EPA600/R-93/141, 1992).

In Carlsbad, New Mexico, the Environmental Evaluation Group (EEG) has been monitoring atmospheric ^{239,240}Pu within and adjacent to the WIPP site since 1985. No composite samples have been reported to exceed ^{239,240}Pu MDCs of 0.5-22 μBq m^{-3} (14–590 aCi m^{-3}) (Kenney, *Preoperational Radiation Surveillance of the WIPP Project by EEG during 1992,* EEG-54, 1994).

Because fallout actinides have been deposited fairly evenly throughout the northern hemisphere, the resulting activity concentration in samples of environmental media is extremely low. Nevertheless, if sufficiently large samples are processed, and a highly sensitive radioanalytical method is used, background concentrations of ^{239,240}Pu and other actinides resulting from fallout can be determined. Data produced from such analyses can be used to establish the present background level of ^{239,240}Pu in environmental samples. This may serve to identify possible emissions from the WIPP site or other nuclear industry sources before concentrations reach levels that could pose health hazards. Such analyses also are valuable in testing the design of sampling equipment, the filter media, and sample collection times.

Methods

A high-volume air sampler for total suspended particulate (TSP) matter aerosols was installed approximately 1 km northwest of the WIPP exhaust shaft. The sampler has a flow rate of approximately 1.1 m^3 min^{-1}, and captures TSP consisting of those aerosols with an aerodynamic equivalent diameter of less than approximately 75μm. The sampler intake is located approximately 5 m above the ground. The sampler uses filters measuring 20-cm × 25-cm. The effectiveness in collection of aerosol particulate matter was evaluated for various filter media. The media types evaluated included glass fiber, Teflon, cellulose, and quartz. Sampling periods of 7–21 days were conducted to determine the optimal sampling period for ^{239,240}Pu determination.

Prior to weighing, each filter was preconditioned in a desiccator with a relative least 12 hours. An electronic analytical balance was used for filter weighing. The balance was calibrated and checked with a set of NIST-traceable weights. The mass concentration was calculated from the mass difference and the total air volume.

To quantify the background Pu activity of glass-fiber filters, ^{239,240}Pu activity was analyzed in seven glass-fiber filter blanks. Each filter weighed approximately 3.6 ±0.1 g. Radioanalytical work was performed at the Environmental Research Division, Argonne National Laboratory. Alpha-particle spectrometry was performed using a 450 mm^2 silicon surface barrier detector and a multichannel analyzer. The instrumental background counts in the range of interest of ^{239,240}Pu were 2±1 counts per 10,000 min. An aliquot of ^{242}Pu solution with approximately 1.7–3.4 mBq (0.045–0.09 pCi) was added to the sample as a tracer. The ^{242}Pu activity concentration was calibrated by a 2π–geometry gas proportional counter that had been calibrated with a NIST-traceable standard. The impurity check was performed with alpha-particle spectrometry.

Prior to total dissolution, each glass-fiber sample was muffled at 520 ±10°C for at least six hours to destroy all organic materials. The sample was then digested and dissolved in a mixture of 50% HF and 8M HNO_3. The solution was centrifuged and the residue was dissolved into a mixture of HNO_3 and HCl. After addition of approximately 3 mL concentrated H_3BO_3, the solutions was combined and converted to 8M HNO_3.

An anion-exchange column was used to separated Pu from other actinides by eluting U with 8M HNO_3, eluting Th with concentrated HCl, and eluting Pu with a mixture of 0.1M HCl and 0.001M HF. The Pu fraction was evaporated and dissolved into a 8M HNO_3. The same procedure was employed to purify Pu. The purified Pu solution was evaporated to near dryness and 15 mL of the plating solution, a mixture of 1M NH_4Cl and 0.001 M HCl with pH 3, was added. Electrodeposition on a stainless steel disc was performed at 1.0 A for 80 min. Before interrupting the current, approximately 2 mL concentrated NH_4OH was added. After the cell was removed, it was rinsed with deionized water and dried.

Results

Comparisons were made of the physical performance of Teflon, quartz, cellulose, and glass-fiber filters. Teflon and cellulose filters were found to cause significant pressure drop in the sampler due to their low porosity. Quartz filters did not produce pressure drops, but they were found to be fragile, resulting in loss of filter particles during the sampler loading, unloading, and weighing processes. Pressure drops and fragility were not observed for glass-fiber filters, although the glass-fiber medium was found to contain trace amounts of Pu and naturally-occurring actinides.

Table 5 shows the total counts, net counts, and activity with one standard deviation for ^{239,240}Pu in seven glass-fiber filter blanks. The net counts were calculated from total counts and instrument backgrounds.

One blank filter showed extremely low activity, with no counts in the region of interest of ^{239,240}Pu after a counting period of time of 3,399 min. The average activity was 12±20 μBq (0.3±0.5 fCi), using the instrumental background value and a 100% uncertainty for the zero-count sample. These results indicate large variations in ^{239,240}Pu activity in blank filters, and analyses of larger numbers of blank filters are needed to accurately characterize the activity in order to establish a detection limit for loaded filters.

to establish a detection limit for loaded filters.

Table 6 shows total amounts of air, mass, and ^{239,240}Pu concentrations from six samples from a high-volume TSP sampler. The samples were collected from 14-day continuous sampling periods during June–September 1994. The range of aerosol particulate concentrations was 21–44 µg m^{-3}. The larger mass concentrations were typically associated with windy weather.

The six TSP samples were analyzed to determine ^{239,240}Pu, following the radioanalytical procedure described previously. Recoveries of ≥70% were obtained for the analyses. The atmospheric ^{239,240}Pu concentrations from these samples varied from 0.005–0.016 µBq m^{-3} (0.14–0.44 aCi m^{-3}).

Conclusions

The radioanalytical method applied in this study was effective in quantifying extremely low amounts of ambient ^{239,240}Pu in the atmosphere. During the period of these observations, the amount of particulate matter collected by a high-volume TSP sampler with 20-cm × 25-cm glass-fiber filters during a 14-day period was typically 0.5–1 g.

The mass concentration, ^{239,240}Pu concentration in air, and activity density on airborne solids at the WIPP site were in the ranges of 21–44 µg m^{-3}, 0.005–0.02 µBq m^{-3} (0.1 – 0.4 aCi m^{-3}), and 240–460 µBq g^{-1} (6–12 fCi g^{-1}), respectively, for the sampling periods in this study. The range of atmospheric ^{239,240}Pu concentrations observed in this study is similar to that reported by Argonne National Laboratory. The results also generally agree with data collected by EPA and EEG, although no direct comparison is possible, due to the lower sensitivity of the radioanalyses conducted by these groups. Analyses of blank filters suggest that <10% of the observed variability in measurements of atmospheric ^{239,240}Pu activity is the result of ^{239,240}Pu in the blank filters.

Table 5. Radioactivities of ^{239,240}Pu in 20-cm × 25-cm Glass-Fiber Blanks

Count Time (min.)	Recovery (%)	Total Counts	Net Counts	Activity (μBq)	Activity (fCi)
3402	73± 6	2	1.3	26 ±18	0.7 ±0.5
3400	89± 6	3	2.2	37± 26	1.0 ±0.7
3425	87 ±6	0	0	<11	<0.3
3399	100 ±6	2	1.2	18 ±11	0.5 ±0.3
4021	88 ±6	1	0.4	7 ±7	0.2± 0.2
5775	90 ±5	1	0.4	4 ±4	0.1± 0.1
7963	97± 5	2	1.2	7 ±4	0.2 ±0.1

Table 6. Mass and ^{239,240}Pu Concentrations of TSP Samples

Sample	Total Air Volume (m^3)	Mass Conc. ($\mu g\ m^{-3}$)	^{239,240}Pu Conc. ($\mu Bq\ m^{-3}$)	^{239,240}Pu Conc. ($\mu Bq\ g^{-1}$)
336	23976	30	0.011±0.004	350±110
383	21721	44	0.016±0.003	370±30
448	23645	21	0.010±0.001	430±80
477	24334	27	0.012±0.002	460±100
481	23171	22	0.007±0.002	360±70
484	23481	23	0.005±0.002	240±40

Response of Electret Radon Detectors to Interference from Ambient Gamma Radiation

Problem Statement and Background

A large number of instruments and devices are available for measuring the natural background concentration of Rn. The electret ionization chamber (EIC) is a commonly used detector for outdoor Rn measurements where long exposure times are required to measure low ambient Rn concentrations. The measurement of Rn in air based upon the discharge of an electret can be confounded by background gamma radiation, and background gamma corrections previously have used the known background gamma exposure rate with a constant conversion factor. Gamma background corrections become significant when monitoring low concentrations of Rn for long durations since the discharge of the electret due to the cumulative gamma background may be of the same magnitude as the discharge due to Rn. This difficulty was identified as a concern to any future Rn monitoring studies at the WIPP. Investigators with the Department of Mechanical, Industrial & Nuclear Engineering, University of Cincinnati, were engaged under Contract No. Q00095 with New Mexico State University to study the response of the EIC when exposed to gamma radiation and to develop an improved method for correcting the discharge of the electret caused by ionizing radiation from terrestrial and cosmic sources.

Methods

Responses of the EIC to known, constant concentrations of Rn were evaluated to determine a discharge factor for Rn. An array of eight EICs was installed in a calibration chamber having a known Rn concentration generated using a $RaCl_2$ source. The duration of exposures ranged from one to six days, with Rn concentrations of 12-18 pCi L^{-1}.

A series of experimental irradiations were conducted to expose groups of EICs to known uniform fields of gamma radiation. A calibrated, high-pressure ionization chamber was utilized to determine the exposure rate at different distances from a ^{137}Cs source and a ^{60}Co source, respectively. An array of eight EICs was mounted in a support allowing essentially the same exposure rate for each detector. The EICs were exposed in a uniform field at a given distance from the source, for a predetermined period of time. In order to investigate the directional dependency of the EICs to irradiation from an external source of photons, some of the EICs in each array were positioned to irradiate the EIC from the bottom, side, and top. The duration of exposures ranged from one hour to 45 hours, with exposure rates ranging from approximately 2.5 mR hr^{-1} to 6 mR hr^{-1}.

A multivariate analysis of variance was performed using orientation, gamma energy, gamma exposure rate, electret type, and average electret voltage as factors. F-statistics were generated to test the significance of these factors. Linear regression was used to estimate the factor parameters and variances.

Results

A nonlinear relationship was observed for the response of the EIC to known concentrations of Rn, as described by the equation:

$$D_{Rn} = 0.44 \times \ln(1.93 \times V_{avg}) \qquad (1)$$

where D_{Rn} is the discharge factor for Rn (volts $pCi^{-1}L$) and V_{avg} is the average electret voltage discharge. The regression coefficients for this relationship were significant, suggesting a strong predictive relationship between average voltage and the Rn discharge factor (Table 7). The existence of an average voltage dependent calibration factor for alpha particles from Rn and its short-lived progeny suggests that the discharge due to photon irradiation is related to the average potential during exposure, which is different from a constant Rn calibration factor.

Table 7. Regression Coefficients for Gamma and Radon Discharge Factors Using the Equation $D_\gamma = a \times \ln(b \times V_{avg})$

Regression Equation Coefficients

Exposure Source	a	b
^{60}Co	0.642 ± 0.057	79.86 ± 69.76
^{137}Cs	0.792 ± 0.163	11.97 ± 21.07
Combined γ	0.666 ± 0.051	57.16 ± 41.97
^{222}Rn	0.440 ± 0.013	1.934 ± 0.3404

The relationship between the gamma discharge factor (D_γ) (volts mR^{-1}) and average electret voltage (V_{avg}) also is strongly nonlinear, as described by the equation:

$$D_\gamma = 0.666 \times \ln(57.2 \times V_{avg}) \qquad (2)$$

where the constants were determined experimentally for EIC Rn detectors discharged by exposure to ^{137}Cs and ^{60}Co. However, the parameter estimate for the exponential term had low predictive power, due to large variability in the measured discharge of the electrets.

Using analysis of variance, the gamma discharge factor, D_γ was demonstrated to be independent of the orientation of the electrets and dependent upon the gamma exposure rate and gamma exposure energy delivered to the electret. These results indicate that the gamma energy and dose rate did not behave as independent factors, which could be related to the difference in the activities of the ^{137}Cs and ^{60}Co used for the experiments. Further investigation is required to fully resolve the nature of the dependency.

Conclusions

External gamma radiation must be monitored whenever the EIC is used to monitor Rn since it has been shown that the EIC is susceptible to discharge from cosmic and terrestrial gamma radiation exposure. Use of a constant gamma background correction factor for gamma radiation, rather than a voltage dependent correction factor suggested by this research, will introduce a systematic bias and result in values for the measured Rn concentration that consistently are lower than the true value. The most accurate estimate of gamma irradiation would be obtained by integrating the background exposure during Rn measurements using a calibrated ionization chamber to determine the total gamma exposure delivered to the EIC Rn detector. The EIC is a sensitive device for measuring the cumulative Rn concentration in the air. However, a voltage dependent correction factor must be applied to account for the discharge of the EIC produced by the natural and technologically-enhanced gamma radiation background, particularly when used near areas where gamma-emitting radioactive materials are present.

Acknowledgments

The complete report for this study has been submitted to Health Physics. Co-investigators for the study were S. Usman, H. Spitz, and L. Shoaib, University of Cincinnati, Department of Mechanical, Industrial & Nuclear Engineering.

Sources of Uncertainty in Aerosol Particle Mass Measurements Using Low-Volume Atmospheric Sampling

Problem Statement and Background

Pilot studies of low-volume atmospheric aerosol sampling have been conducted near the WIPP since 1993. The studies provided basic information on equipment performance, sampling techniques, and sensitivity of various analytical methods, and provided preliminary data on size-specific aerosol mass and trace element distributions. The data collected included measurements of particulate matter with an aerodynamic diameter less than 10 μm (PM_{10}) and those less than 2.5 μm ($PM_{2.5}$).

Particle mass concentration (c_m) is calculated by the equation:

$$c_m = \Delta m_p \left(\frac{1}{\Delta T Q} \right) \quad (1)$$

where, c_m = aerosol particle mass concentration, Δm_p = mass of the collected particles, ΔT = calendar time during a sample interval, and Q = air flow rate.

Error in estimation of c_m is a function of the accuracy of measurements of Δm_p, ΔT, and Q. Analyses of pilot study aerosol data showed large variations in particle mass concentration (c_m) in duplicate samples of both PM_{10} and $PM_{2.5}$. Occasional observations of intermittent pump operation on hot days (≥35°C) indicated that actual pump run time (Δt) was sometimes less than ΔT. This study was designed to evaluate the effect of two error sources, Δt and intersampler variation, on estimation of c_m in the environmental setting at the WIPP site.

Methods

A programmable power outlet box was designed and built with mechanical timers to directly measure Δt during each sample interval. Pumps were placed in two pump shelters with vent holes and cooling fans (pumps 1, 2, and 3 in shelter A; pumps 4, 5, 6, and 7 in shelter B). Samplers were mounted 1 m above ground level on aluminum crossbars and placed to minimize turbulence and interference. The distance between adjacent samplers was approximately 50 cm. Pumps were connected to samplers with equal lengths of 0.64-cm ID polypropylene tubing and quick connectors. Flow was controlled by placing a needle valve between the sampler and pump. Initial and final flow rates were measured using a calibrated rotometer.

Samples were collected using a Harvard Honeycomb Impactor (HHI) containing a 47-mm diameter Teflon membrane filter with hydrophobic glass backing pad, and commercially available pumps operated at 10 L min^{-1}. Each part of a sample system (pump, HHI sampler, and sampler crossbar) was numbered. HHI parts (inlet, body, and filter holder) were used as a unit to eliminate errors associated with variations between system parts. To increase filter mass loading and improve the accuracy and precision of the gravimetric analysis, sampling intervals of approximately 72 hours were used.

Three sets of concurrent samples were collected during June and August in 1996. Each sample set consisted of three or four PM_{10} samples and three or four $PM_{2.5}$ samples to produce a total of seven samples in each set. The HHI sampler configuration (either PM_{10} or $PM_{2.5}$) for a specific pump and crossbar location was varied randomly to offset the potential effect of the HHI inlet size on pump reliability. Filters were desiccated for a minimum of 24 hours prior to weighing, both before and after sample collection.

A second experiment was conducted to evaluate the variation resulting from differences between the HHI samplers, without the influence of pump run time. Five sets of triplicate samples for both PM_{10} and $PM_{2.5}$ were collected using pumps with run times $\geq$ 99% of ΔT. The coefficient of variation (CV) was calculated for each set of triplicate samples.

Results

In the experiment to evaluate the effect of actual pump run time (Δt) three pumps (2, 4, and 5) were reliable, running nearly 100% of each 72-hr sample interval (Figure 6). Four pumps (1, 3, 6, and 7) consistently ran significantly less than the sample interval (ΔT). This appeared to be indicative of a mechanical problem, possibly related to the pump thermal overload switches.

Aerosol particle mass concentrations calculated using Eq. 1 (without correction for Δt) for each experimental sample set, exhibited large variation between the collocated, concurrent samples for both PM_{10} and $PM_{2.5}$ (Figure 7). Particle mass concentrations calculated substituting Δt for ΔT provided little improvement in agreement between the duplicate samples (Figure 7). In this experiment, pump failures occurred randomly throughout a sample period and pumps were out of service for various lengths of time (0.1-38.6 hr). Thus, each sample within a 72-hr sample interval was representative of only a portion of a sample period. These data indicate that, at least during the season when this experiment was conducted, samples derived from small portions of a sampling interval ($\Delta t \ll \Delta T$) could not be used to estimate c_m during the entire sample interval, even when a pump time correction is used.

In the second experiment with five sets of triplicate samples in each particulate class, the CV represents an estimate of the level of variability resulting from differences between samplers. The CV values in these measurements averaged 7% for both PM_{10} and $PM_{2.5}$. Individual CV values derived from triplicate samples ranged from 4.2% to 10.5% for PM_{10} and from 1.4% to 11.5% for $PM_{2.5}$ (Figure 8).

Conclusions

Pump unreliability was determined to be a potentially large source of error in calculation of c_m. Using a pump run time correction was not satisfactory, because samples collected for periods much less than the sampling interval were not representative of the aerosol mass for the sample interval. This suggests that, at least for the season represented in this experiment, in this environment there can be significant changes in aerosol mass loading within a period as short as 72 hr. Pump run time records are useful to identify data that should be eliminated from analyses because they are not sufficiently representative of the sampling interval. For the most effective sampling, it is essential that pumps be capable of running continuously over the sample interval, which can be enhanced through improved pump shelters for protection and temperature control.

Although low pump reliability can explain the lack of agreement between duplicate samples using the same samplers, variations between sampler units are another potential source of error in estimating c_m. From the data collected in this study, it appears that the maximum error associated with variations between individual samplers typically would be below 12%.

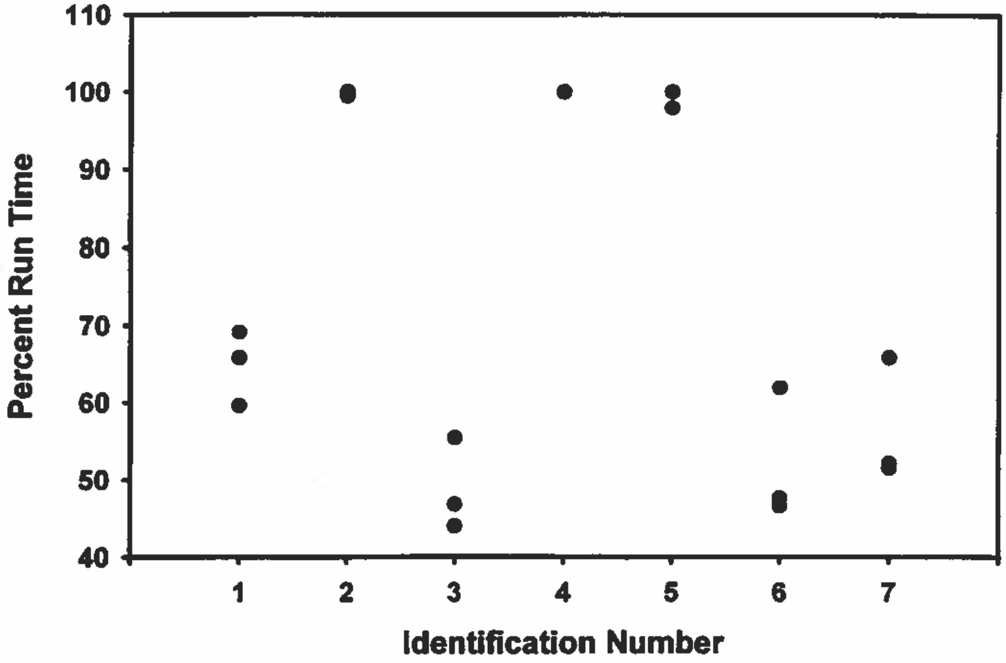

Figure 6. Percent Run Time for Seven Pumps Used in Sample Collection

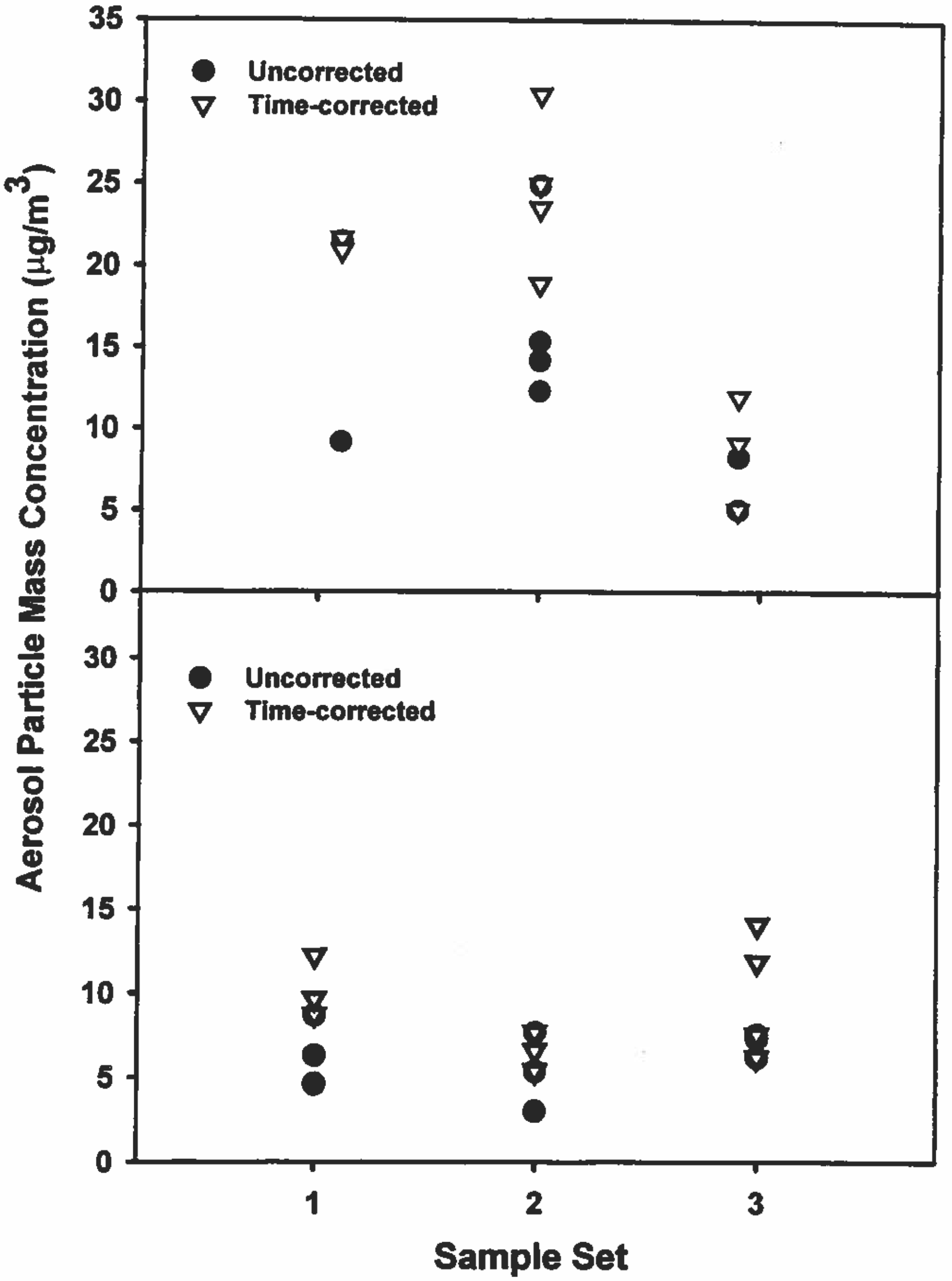

Figure 7. Estimated Aerosol Particle Mass Concentrations for Seven Samplers Operating Concurrently at Three Sampling Periods

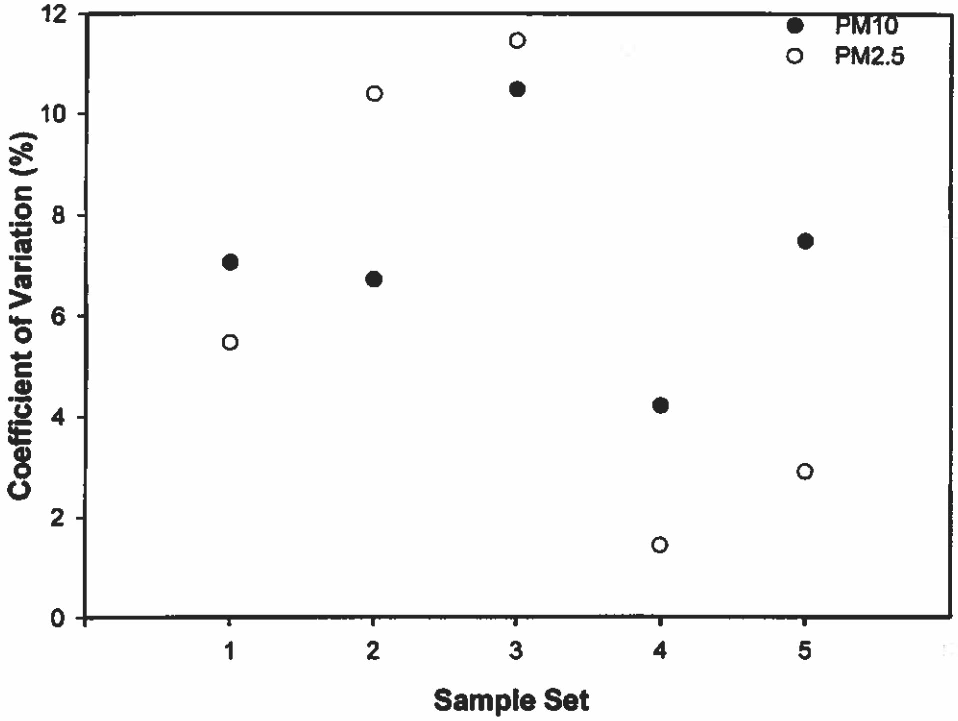

Figure 8. Coefficients of Variation for Estimates of Aerosol Particle Mass Concentrations from Triplicate Samples at Five Sampling Periods

The Effects Of Graded-Z Lining On Low-Energy Background In A Shielded Room Used For Lung Examinations

Problem Statement and Background

A cast iron (Fe) enclosure (shield) is commonly used in whole-body counting to reduce cosmic and terrestrial background radiation so that small amounts of internally deposited photon, X-ray, or bremsstrahlung emitting radionuclides can be detected. As cosmic radiation, mainly muons, interact with the thick Fe walls of the shield, a distribution of low-energy secondary and tertiary photons are produced. These photons can then interact with the whole-body detectors resulting in an increase in the Compton continuum (background) thus reducing the sensitivity of a whole-body measurement. To address this problem, health physicists historically have added a graded-Z liner (Z represents the charge of an element) to the inside of the counting shields.

A graded-Z liner usually consists of three layers of material of decreasing Z. The first layer is constructed from lead (Pb, Z equals 82). This very dense material attenuates the secondary photons produced by the cosmic radiation, reducing the Compton continuum, through photoelectric interactions. However, the ionization within the Pb created by the photoelectric interactions produces Pb X-rays at approximately 75 kiloelectron volts (keV). The Pb X-rays create a significant interference to low-energy photon (Am) and X-ray (Pu) counting. For scintillation detectors, this interference overwhelms the benefits of the absorber. A second layer, consisting of cadmium (Cd, Z equals 48), then is added to absorb the X-rays from the Pb. Through a similar mechanism as with Pb, Cd X-rays are produced at approximately 23 keV. These X-rays create a significant interference to X-ray counting for both solid-state and scintillation detectors. A third and final layer, consisting of copper (Cu, Z equals 29), then is added. The Cu absorbs the Cd X-rays and emits its characteristic X-ray at approximately 8 keV. In contrast to the previous two materials, the Cu X-rays do not interfere in most low-energy counting applications.

The technical basis for application of a graded-Z liner was developed without a radioactive source in the counting geometry. This is important because the liner was developed to attenuate radiation emitted from the shield, not radiation originating from within. With whole-body counting, the counting subject is naturally radioactive and serves as a significant source of radiation. Therefore, liners were not designed to absorb scattered photons emitted from the counting subject. The objective of this research was to observe the effects of a graded-Z liner on low energy background in the presence of a human counting subject.

Methods

Measurements were performed in a 1.2-m × 1.2-m × 2.4-m shield room constructed of 15-cm-thick Fe. The shield room is located in the Center's mobile bioassay laboratory. Background measurements were taken using an array of two, 13-cm × 15-cm dual scintillation crystal, phoswich detectors. Background measurements from 10 to 110 keV were taken for the Fe and each layer of the graded-Z liner. In addition, data for the Pu and Am regions of interest (11 to 31 keV and 40 to 82 keV, respectively) were recorded. The graded-Z liner consisted of 64 mm Pb, 32 mm Cd, and 32 mm Cu, respectively. For each of the Fe/liner-layer combinations, background measurements were observed for an empty shield, a bottle mannequin absorption phantom (BOMAB), and a human subject.

The BOMAB was used to simulate photon scattering resulting from radiopotassium (^{40}K) in a human subject. The potassium content in reference man is approximately 140 g, of which 0.012% is ^{40}K (Snyder, et. al, *Report of the Task Group on Reference Man,* ICRP 23, Pergamon Press, 1975). This amount of ^{40}K translates to 0.12 µCi and was uniformly distributed in the BOMAB phantom using KCl. Count times for the empty shield and BOMAB were 417 min each and 30 min for the human subject. All measurements were taken in a lung counting geometry. The empty shield and BOMAB measurements were replicated twice each.

Results

Background spectra were produced for the empty shield, BOMAB, and human subject for each of the shield/liner-layer combinations (Figures 9-11). Background spectra were similar in both spectral shapes and count rates for the BOMAB as compared to the human subject, and these patterns varied markedly from the background spectra for the empty room (Figure 12). For the empty shield and BOMAB measurements, the background count rates were calculated from the sum of the replicate measurements, with the exception of the Fe/Pb shield/liner-layer combination, in which one of the measurements was eliminated due to detector malfunction. The total background for the human subject was 20% greater than that of the BOMAB. This would be expected since the counting subject was larger than reference man. These data confirm that the BOMAB, containing the appropriate amount of ^{40}K, can be used to simulate low-energy background from a human subject.

For purposes of comparisons, background measurements were summed for each 10 keV interval from 10 to 110 keV (Table 8), and for the Pu and Am regions of interest (Table 9). For the empty shield, the increase in the Compton continuum resulting from cosmic radiation interactions within the Fe was reduced by 34% through the application of a graded-Z liner. However, this effect was not uniform from 10 to 110 keV. From 10 to 80 keV, background was reduced by 17%, whereas a 56% reduction was observed from 80 keV to 110 keV. For the Pu and Am regions of interest, background was reduced by 15% and 19%, respectively. These data suggest that the energy of secondary and tertiary photons produced in the Fe from cosmic interactions, to a large extent, are at energies greater than 80 keV.

For the BOMAB, background radiation from 10 to 110 keV was reduced by 5% by the application of a graded-Z liner. The ^{40}K content of the BOMAB increased the background over this energy range by 694% relative to the empty shield. The reduction in background was not uniform over the entire energy range, which was a pattern similar to that observed for the empty room. From 10 to 80 keV, there was only 1% decrease in background, whereas a 13% decrease was observed from 80 to 110 keV. These data suggest that cosmic radiation interactions in the Fe were still a significant component in background radiation, even with a radioactive counting subject. The full graded-Z liner had no effect on background for the Pu region of interest and reduced background for the Am region of interest by 4%.

The greatest reduction in background with the BOMAB occurred with the Fe/Pb+Cd shield/liner-layer combination. For this combination, the total background radiation, the background radiation from 10 to 80 keV, and the background radiation from 80 to 110 keV were reduced by 18%, 14%, and 26%, respectively. The Fe/Pb+Cd shield/liner-layer combination also produced the greatest reduction in background

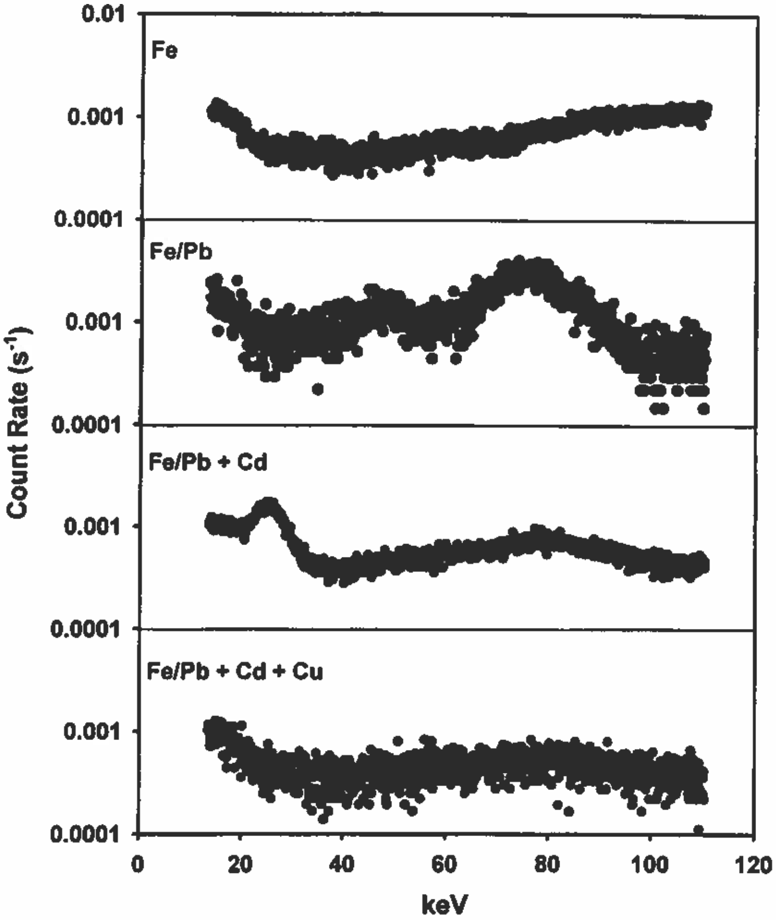

Figure 9. Background Radiation Measurements for Empty Shield

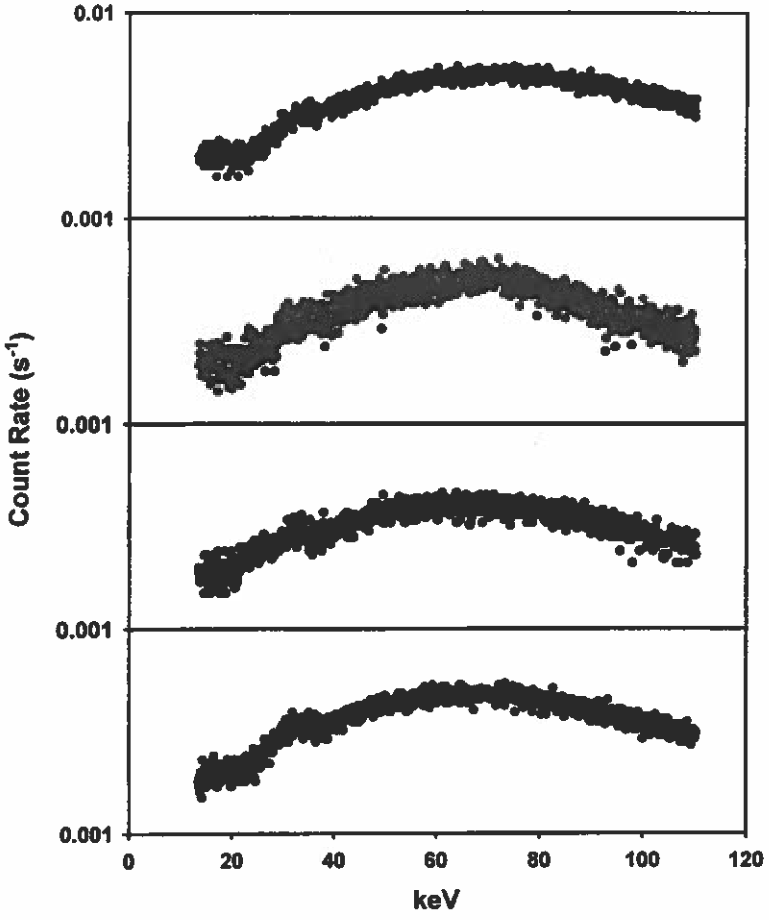

Figure 10. Background Radiation Measurements for BOMAB

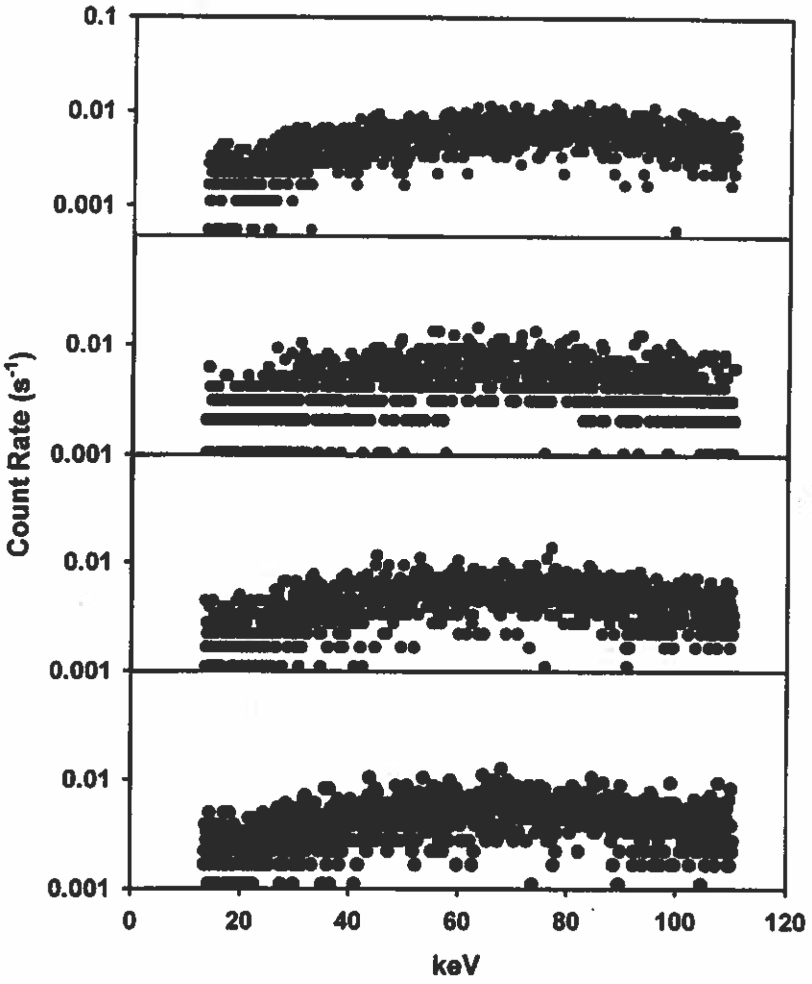

Figure 11. Background Radiation Measurements for Human Subject

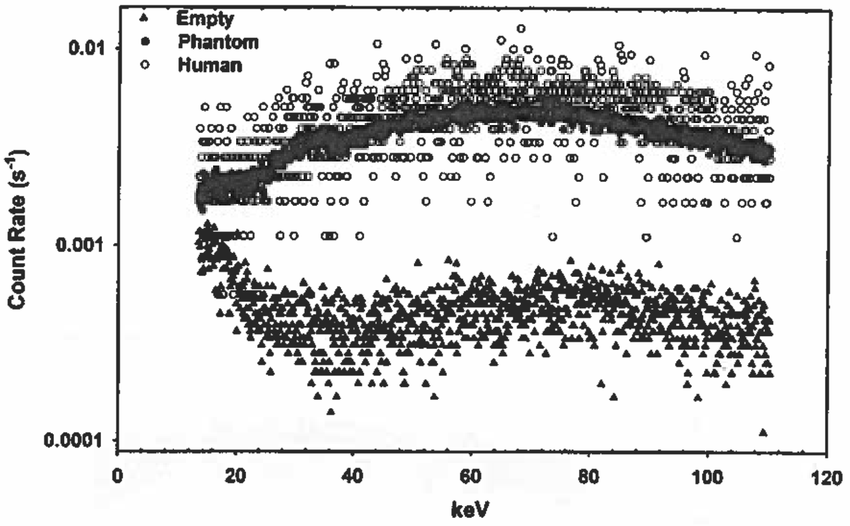

Figure 12. Ratio of Photoelectric: Compton Scatter Interaction Coefficients for Cu and Cd

Table 8. Cumulative Background Radiation Measurements in Counts (s^{-1}) Within 10 keV Intervals from 10 to 100 keV

Shield/Liner-Layer Combination	10 to 20 (keV)	21 to 30 (keV)	31 to 40 (keV)	41 to 50 (keV)	51 to 60 (keV)	61 to 70 (keV)	71 to 80 (keV)	81 to 90 (keV)	91 to 100 (keV)	101 to 111 (keV)
Empty Shield										
Fe	0.07	0.13	0.17	0.22	0.27	0.33	0.41	0.50	0.61	0.73
Fe/Pb	0.11	0.19	0.27	0.41	0.51	0.69	0.99	1.16	1.23	1.29
Fe/Pb + Cd	0.07	0.21	0.25	0.30	0.35	0.41	0.48	0.55	0.61	0.65
Fe/Pb + Cd + Cu	0.06	0.11	0.15	0.19	0.24	0.29	0.34	0.40	0.44	0.48
BOMAB										
Fe	0.15	0.39	0.74	1.15	1.63	2.15	2.68	3.18	3.62	4.02
Fe/Pb	0.15	0.40	0.75	1.17	1.65	2.18	2.70	3.13	3.48	3.78
Fe/Pb + Cd	0.14	0.40	0.71	1.07	1.48	1.89	2.31	2.69	3.01	3.30
Fe/Pb + Cd + Cu	0.14	0.40	0.76	1.18	1.65	2.15	2.64	3.08	3.47	3.81
Human Subject										
Fe	0.17	0.45	0.90	1.42	2.08	2.78	3.49	4.17	4.77	5.27
Fe/Pb	0.16	0.45	0.87	1.41	2.04	2.71	3.36	3.89	4.39	4.77
Fe/Pb + Cd	0.16	0.47	0.89	1.40	1.98	2.58	3.19	3.73	4.19	4.60
Fe/Pb + Cd + Cu	0.16	0.44	0.85	1.36	1.93	2.55	3.14	3.71	4.18	4.57

Table 9. Cumulative Background Radiation Measurements in Total Counts (s^{-1}) for the Pu and Am Regions of Interest

Shield/Liner-Layer Combination	Pu	Am
Empty Shield		
Fe	0.13	0.26
Fe/Pb	0.19	0.78
Fe/Pb + Cd	0.21	0.25
Fe/Pb + Cd + Cu	0.11	0.21
BOMAB		
Fe	0.42	2.09
Fe/ Pb	0.43	2.08
Fe/ Pb + Cd	0.43	1.71
Fe/ Pb + Cd + Cu	0.44	2.01
Human Subject		
Fe	0.49	2.78
Fe/ Pb	0.49	2.66
Fe/ Pb + Cd	0.50	2.47
Fe/ Pb + Cd + Cu	0.48	2.46

radiation for the Am region of interest (18%), but no reduction for the Pu region of interest.

For all energy levels, the use of a full graded-Z liner with the BOMAB produced higher background radiation than the use of Fe/Pb+Cd shield/liner-layer combination. The increase in background radiation observed with BOMAB by the addition of Cu layer may be explained by the greater ratio of the photoelectric interaction coefficient to the Compton interaction coefficient between Cd and Cu (Figure 13). The greater the ratio of the photoelectric interaction coefficient to the Compton interaction coefficient, the greater the likelihood that a scattered photon will be absorbed rather than scattered. Cd, having the higher ratio, will produce fewer backscattered photons from the phantom relative to Cu, thus reducing background. This effect was not confirmed by the human subject measurements. It is possible that the observed increase with the BOMAB was caused by an uncontrolled bias such as positioning.

For the human subject, virtually no reduction in background radiation was achieved by use of the full graded-Z liner in comparison to the Fe/Pb+Cd shield/liner-layer combination. This pattern is similar to that observed for the comparison of the full graded-Z liner and the Fe/Pb+Cd shield/liner-layer combination for the BOMAB. For the human subject with a full graded-Z lining, 13%, 10%, and 20% reductions were observed in total background radiation, background radiation from 10 to 80 keV, and background radiation from 80 to 110 keV, respectively. For the human subject with a Fe/Pb+Cd shield/liner-layer combination, 13%, 9%

and 21% reductions were observed in total background radiation, background radiation from 10 to 80 keV, and background radiation from 80 to 110 keV, respectively. As noted in the measurements for the empty chamber and the BOMAB, reductions in background radiation were higher for the 80 to 110 keV range than for the 10 to 80 keV range.

For the human subject, use of the Pb+Cd liner resulted in no reduction in background radiation in the Pu region of interest, and use of the full graded-Z liner resulted in only 2% reduction in background radiation for the Pu region of interest. For the Am region of interest, the Pb+Cd liner produced 11% reduction in background radiation, and the full graded-Z liner produced 12% reduction in background radiation.

Conclusions

For the empty shield, BOMAB, and human subject, low-energy background from 10 to 110 keV was reduced by the application of a graded-Z liner when scintillation detectors were used. However, the decrease in background was not constant for all energies. For each treatment there was a greater reduction in background from 80 to 110 keV than from 10 to 80 keV. These data suggest that the energy of secondary and tertiary photons produced in the Fe from cosmic interactions were greater than 80 keV. The BOMAB containing reference man levels of ^{40}K was effective to simulate low-energy background from a human subject. For both the BOMAB and human subject, the greatest reduction in total background radiation was observed with the Fe/Pb+Cd shield/liner-layer combination. There was no additional reduction in total background radiation by application of the Cu layer for either the BOMAB or human subject. For both the BOMAB and the human subject, there was little or no reduction in background radiation achieved by the application of any shield/liner-layer combination for the Pu region of interest. For the BOMAB and human subject, similar reductions in background radiation were observed for the full graded-Z liner and the Fe/Pb+Cd shield/liner-layer combination for the Am region of interest.

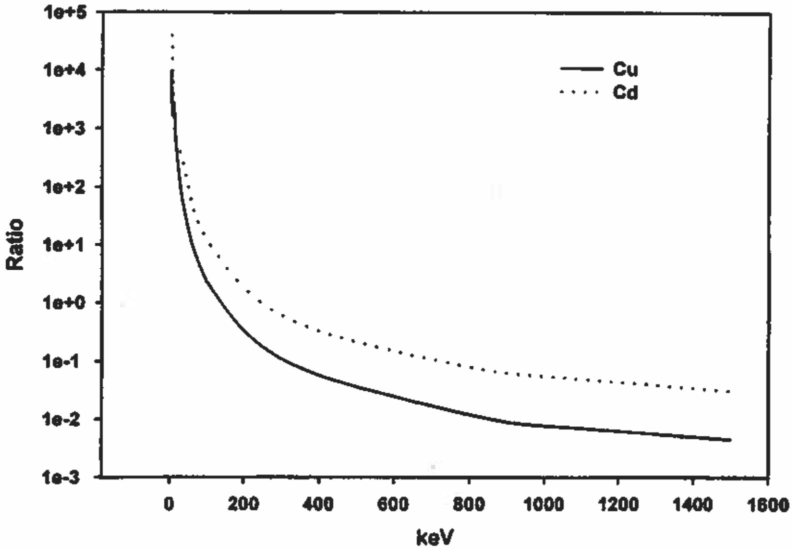

Figure 13. Ratio of Photoelectric: Compton Scatter Interaction Coefficients for Cu and Cd

APPENDICES

Appendix A. Current and Past Subcontractors for Scientific Work

Subcontractor	Period	Scope of Work
Argonne National Laboratory	1996–1998	Radiochemical analyses of environmental samples
Desert Research Institute	1996–1997	Trace element analysis with X-ray fluorescence spectrometry
Gram, Inc.	1996–1997	General technical support for aerosol, soil, and hydrologic studies
Grassberger, Robert E.	1993–1994	Feasibility assessment and proposal for generation of grant funding
Harvard University	1993–1997	Technical support for development of aerosol sampling and data management
Johnson, Ruth	1994	Software installation and development
Lewis, Susan	1994–1995	Research and development in aerosol sampling
Lyons, Berry	1993	Consultation on hydrogeology and geochemistry
Radiation Safety Associates, Inc.	1995–1996	Development of radiation protection program documents
S. M. Stoller	1993–1994	Development of budget and cost-tracking database
Thein, Myint	1996–1997	Quality assurance for radiobioassay program
The Center for Excellence in Nuclear Technology, Engineering, and Research	1995	Neutron activation fission track analyses of urine samples
University of Cincinnati	1993–1996	Technical assistance in development of *in vivo* bioassay facility
University of New Mexico	1994–1996	Surveys and analyses of selected human population characteristics in the region of the WIPP

Appendix B. Past and Current SAB Membership

Member	Position	Location
Boecker, Bruce, Ph.D.	Physical Biologist, Toxicologist	Inhalation Toxicology Research Institute, Albuquerque, New Mexico
Cadena, Fernando, Ph.D.	Professor	Department of Civil Engineering, New Mexico State University
Eiceman, Gary A., Ph.D.	Professor	Chemistry Department, New Mexico State University
Gilliland, Frank D., M.D., Ph.D.	Assistant Professor of Medicine	Epidemiology & Cancer Control Program, University of New Mexico Medical Center
Guilmette, Raymond, Ph.D.	Physical Biologist	Inhalation Toxicology Research Institute, Albuquerque, New Mexico
Hadley, William, Ph.D.	Dean	College of Pharmacy, University of New Mexico
Hickman, David, Ph.D.	Physicist, Principal Investigator	Special Projects Division, Lawrence Livermore National Laboratories
Johnson, Jim, Ph.D.	Professor	Department of Radiological Health Science, Colorado State University
Keane, Al,	Biophysicist	Internal Dosimetry, Argonne National Laboratory
Knab, Daryl,	Radiochemistry Section Leader (retired)	Health and Environmental Chemistry Group, Los Alamos National Laboratory
Lambert, William E., Ph.D.	Project Epidemiologist	Epidemiology & Cancer Control Program, University of New Mexico Medical Center
Laurer, Gerard, Ph.D.	Research Professor	AJ Lanza Laboratories, New York University Medical Center
Nelson, Donald M.	Group Leader, Environmental Radiochemistry	Environment, Safety and Health Division, Argonne National Laboratory
Ozkaynak, Haluk, Ph.D.	Lecturer	Environmental Science & Physiology Dept., Harvard School of Public Health
Robbins, John A., Ph.D.	Senior Research Scientist	Great Lakes Environmental Research Laboratory, National Oceanic and Atmospheric Administration

Appendix B. Past and Current SAB Membership (Continued)

Member	Position	Location
Samet, Jonathan M., M.D.	Chairman	Department of Epidemiology, School of Hygiene & Public Health, Johns Hopkins University
Snipes, M. Burt, Ph.D.	Physical Biologist, Toxicologist	Inhalation Toxicology Research Institute, Albuquerque, New Mexico
Spengler, John D., Ph.D.	Director	Exposure Assessment & Engineering Program, Department of Environmental Health, Harvard School of Public Health
Spitz, Henry B., Ph.D.	Associate Professor	Department of Mechanical, Industrial, and Nuclear Engineering, University of Cincinnati
Tisue, Thomas, Ph.D.	Professor	Department of Chemistry, Clemson University
Thomé, Daryl,	Scientific Specialist	Remote Sensing Laboratory, Bechtal Nevada
Tombes, Averett S., Ph.D.	Vice President for Research and Economic Development	New Mexico State University
Toohey, Richard E., Ph.D.	Director, Radiation Internal Dose Information Center	Oak Ridge Institute for Science and Education
Ward, Timothy, Ph.D.	Assistant Director	Waste-management Education & Research Consortium, College of Engineering, New Mexico State University

Current members in bold

Appendix C. Presentations and Publications during 1994–1996

Author	Year	Title	Publisher/Conference
Fingleton, D.J.	1991	Biomedical Waste Management	Vocational Needs and Current Environmental Issues Seminar, Carlsbad, NM
Fingleton, D.J., R.K. Bhada, and C.F. Wu	1991	An Environmental and Bioassay Monitoring Facility for Research, Education, and Application	37th Annual Conference on Bioassay and Analytical and Environmental Radiochemistry, Ottawa, Ontario, Canada
Fingleton, D.J., and M.M. MacDonnel	1991	Assessing Exposures and Risks in Heterogeneously Contaminated Areas: A Simulation Approach	Environmental Remediation '91 Meeting, Pasco, WA
MacDonnel, M.M., L.A. Haroun, J.M. Peterson, D.A. Blunt, D.J. Fingleton, and M.H. Picel	1991	Strategy for Integrated CERCLA/NEPA Risk Assessments	Environmental Remediation '91 Meeting, Pasco, WA
Fingleton, D.J., L. Habegger, H. Hootman, L. Nieves, B.A. Carnes	1991	Environmental Remediation: Decision Making in Light of Uncertainty	Environmental Remediation '91 Meeting, Pasco, WA
Fingleton, D.J.	1991	Carlsbad Environmental Monitoring & Research Center	National Society Of Professional Engineers Meeting, Carlsbad, NM
Fingleton, D.J. R.K. Bhada, J.D. Morgan, and H. Julien	1992	The Carlsbad Environmental Monitoring & Research Center: An Independent Program for Community Information	Waste Management '92 Symposium, Tucson, AZ
Fingleton, D.J., R.K. Bhada, and J.D. Morgan	1992	Assessing the Risks of Hazardous Waste Management Strategies: An Innovative Approach to Credibility	5th Annual Hazardous Waste Management Conference & Exhibition, Albuquerque, NM
Fingleton, D.J., R.K. Bhada, and J.D. Morgan	1992	Waste Management and Environmental Remediation: An Innovative Approach to Credibility	Second Waste Management and Environmental Sciences Conference, San Juan, Puerto Rico
Fingleton, D.J.	1992	Siting Hazardous Waste Management Facilities: A Risk Based Approach Using Geographical Information Systems	Second Waste Management and Environmental Sciences Conference, San Juan, Puerto Rico
MacIntosh, D., H. Ozkaynak, J. Spengler, and D.J. Fingleton	1993	Designing an Atmospheric Radioactivity Monitoring Network Near the Waste Isolation Pilot Plant	American Nuclear Society Topical Meeting on Environmental Transport and Dosimetry, Charleston, SC
MacIntosh, D., H. Ozkaynak, and D.J. Fingleton	1993	Atmospheric Monitoring in the Vicinity of Radioactive Waste Repositories	39th Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Colorado Springs, CO
Lee, S.C., and D.J. Fingleton	1994	Determination of Pu-239,240 in Air Around the WIPP Site	40th Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Cincinnati, OH

Appendix C. Presentations and Publications during 1994–1996 (Continued)

Author	Year	Title	Publisher/Conference
Lambert, W., C. Stidely, F. Gilliland, J. Samet, and D.J. Fingleton	1994	Statistical Issues in the Design of a Population Surveillance Program	40th Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Cincinnati, OH
Tisue, T,. X.H. Pan, S.T. Hu, J.P. King, and S.C. Lee	1994	Establishing Baseline Concentrations of Radionuclides in Soils of Southeastern New Mexico: Strategies for Hitting a Moving Target	40th Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, Cincinnati, OH
Lee, S.C., J.M.R. Hutchinson, K.G.W. Inn, and M. Thein	1994	An Intercomparison Study of Np-237 Determination in Artificial Urine Samples	3rd International Conference on Methods and Applications of Radioanalytical Chemistry, Kailua-Kona, HI
Fingleton, D.J., and A.K. Goodbar	1994	Independent Environmental Characterization Studies in the Vicinity of the Waste Isolation Pilot Plant	Wm'94 Nuclear and Hazardous Waste Symposium, Tucson, AZ
Lee, S.C., J.G. Choi, and V. Hodge	1994	Electrodeposition of Selected Alpha-emitting Nuclides from Ammonium Acetate Electrolyte	Journal of Alloys and Compounds, 213/214, pp 466-466
Lee, S.C., J.M.R. Hutchinson, K.G.W. Inn, and M. Thein	1995	An Intercomparison Study of Np-237 Determination in Artificial Urine Samples	4th Annual Meeting of the Council on Ionizing Radiation Measurements and Standards, Gaithersburg, MD
Lee, S.C., J.M.R. Hutchinson, K.G.W. Inn, and M. Thein	1995	An Intercomparison Study of Np-237 Determination in Artificial Urine Samples	Health Physics, Vol. 68, No. 3
Spitz, H., and D.J. Fingleton	1995	Complete *In Vivo* Capabilities in a Mobile Facility	1995 U.S. Department of Energy Lung Intercalibration Meeting, Richland, WA
Webb, J.L., D.J. Fingleton, S.C. Lee, and S.B. Spitz	1996	The Effects of Graded-Z Lining and Human Subjects on Low-Energy Background in a Counting Shield Used for Lung Examinations	Canberra User's Group Meeting, Las Vegas, NV
Usman, S., H. Spitz, L. Shoaib, J. O'Hare, C. Becker, and S.C. Lee	1996	Response of Electret Radon Detectors to Interference from Ambient Gamma Radiation	Mid-year Health Physics Society Meeting, Scottsdale, AZ
Fingleton, D.J.	1996	Fate and Transport of Radionuclides in the Terrestrial Ecosystem	Fifth Annual Meeting of the Council on Ionizing Radiation Measurements and Standards, Gaithersburg, MD
Lee, S.C., J. Webb, and D.J. Fingleton	1996	Determination of Baseline Atmospheric Pu-239,240 in the Vicinity of the Waste Isolation Pilot Plant	42nd Annual Conference on Bioassay, Analytical, and Environmental Radiochemistry, San Francisco, CA

Appendix C. Presentations and Publications during 1994–1996 (Continued)

Author	Year	Title	Publisher/Conference
Webb, J.L., D.J. Fingleton, and S.C. Lee	1996	The Effect of Graded-Z Lining on Low-Energy Background in a Counting Shield for Lung Examinations	Central Rocky Mountain Chapter of the Health Physics Society, Annual Spring Technical Meeting, Ft. Collins, CO
Webb, J.L., D.J. Fingleton, S.C. Lee, and H.B. Spitz	1996	The Effects of Graded-Z Lining and Human Subjects on Low-Energy Background in a Counting Shield Used for Lung Examinations	41st Annual Meeting of the Health Physics Society, Seattle, WA
Usman, S., H. Spitz, L. Shoaib S.C. Lee		Analysis of Electret Ion Chamber Radon Detector Response to Interference from Ambient Gamma Radiation	Health Physics, submitted
Sioutas, C., S.T. Ferguson, J.M. Wolfson, H. Ozkaynak, and P. Koutrakis		Inertial Collection of Fine Particles using a High-Volume Rectangular Geometry Conventional Impactor	Journal of Aerosol Science, in press

Appendix D. Examples of Outreach Activities during 1994–1996

Group	Activity	Date
Southeast New Mexico Economic Diversification Project Committee	Meeting attendance	Weekly meetings
American Nuclear Society—Carlsbad Section	Meeting attendance and chairmanship	Monthly meetings
Local Emergency Planning Committee (LEPC)	Membership and meeting attendance	Monthly meetings
National Cave & Karst Research Institute (NCKRI)	Meeting attendance	Periodic meetings
New Mexico State University Alumni Association	Presentation	November 1, 1994
Minority Assistance League	Presentation	November 29, 1994
All Russian Congress (World Environmental Conference, Moscow, Russia)	Meeting attendance	June 3-5, 1995
WERC Executive Board meeting	Presentation	November 30, 1995
New Mexico Environment Department	Presentation	January 9, 1996
DOE Environmental Program Meeting	Meeting attendance	January 17-18, 1996
Southwest Technology Development Institute (NMSU)	Meeting attendance	January 19, 1996
Kiwanis	Presentation	February 16, 1996
Public Meeting	Presentation	February 20, 1996
New Mexico State University Department of Civil Engineering	Presentation	February 29, 1996
Public Meeting	Presentation	March 7, 1996
Lions Club-Carlsbad and Artesia, NM	Presentation	March 8, 1996
Los Alamos National Laboratory	Meeting attendance	April 11, 1996
Conference of National Laboratory Directors	Meeting attendance	April 23, 1996
Laboratory Quality Assurance Steering Committee	Meeting attendance	June 13, 1996
American Association of Retired People	Presentation	June 17, 1996
Systems Ecology Research Project	Presentation, tour, and field trip	June 25, 1996
Bridges Program (Biomedical Initiative for Native Americans)	Presentation, tour and field trip	July 20-21, 1996

Appendix D. Examples of Outreach Activities during 1994–1996 (Continued)

Group	Activity	Date
Thomas Grumbly, U.S. Department of Energy	Tour of building site	July 23, 1996
DOE Carlsbad Area Office and Sandia National Laboratories	Presentation	August 27, 1996
Radioactive Hazardous Materials Committee	Meeting attendance	September 6, 1996
New Mexico State University-Carlsbad Technology Development Project at WIPP	Meeting attendance	October 2, 1996
Interim Science & Technology Legislative Committee	Presentation	October 28, 1996
Group visit from Carlsbad, Czechoslovakia Republic	Presentation	November 3, 1996
Radioactive & Hazardous Materials Committee	Tour of building site	December 3, 1996

Appendix E. Educational and Training Activities Sponsored

Activity	Participant	Date
Atmospheric science	Harvard University faculty and graduate students	1991-1994
In vivo bioassay	University of New Mexico graduate student	1993-94
Soil science	NMSU faculty and graduate student	1993-95
Health physics	University of Cincinnati faculty and graduate students	1993-96
Limnological and soil science studies	Texas A&M University undergraduate student	Summer 1993
Environmental science	NMSU graduate student	1994
Soil science studies	Boloit College undergraduate student	Summer 1994
Environmental science and gamma-spectroscopy	NMSU-Carlsbad undergraduate students	1995-96
Environmental and radiochemistry	NMSU-Carlsbad undergraduate student	1996

GLOSSARY

aberrant - an atypical group, individual, or structure.

acute radioactive release - having a sudden onset, sharp increase and brief duration.

aerosol - particles dispersed in a gas.

aliquot - a part of a sample that has been divided into exactly equal parts with no remainder (chem); a representative sample of a larger quantity (med).

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.

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.

biomarker - indicator of exposures or damage to the human body.

bremsstrahlung - radiation that is emitted by an electron accelerated in its collision with the nucleus of an atom.

carcinogenesis - initiation of cancer formation.

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

cytoplasmic micronuclei - minute disjunctnuclear bodies distributed within cytoplasm.

deionization - an ion-exchange process in which all charged species or ionizable organic and inorganic salts are removed from solution.

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

dosimetry - the measurement of radiation doses.

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

electronvolts - a unit of energy that is equal to the energy acquired by an electron when it passes through a potential difference of 1 volt in a vacuum.

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

erythrocytes - red blood cells

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

flow cytometry - a technique for optical analysis and separation of cells and metaphase chromosomes based on light scattering and fluorescence.

fluorescence in-situ hybridization - technique using a fluorescent microscope to identify chromosome aberrations that are differentially stained due to selective DNA bonding.

glycophorin A - a red blood cell transmembrane glycoprotein.

gravimetric analysis - that branch of quantitative analytical chemistry in which a desired constituent is converted, usually be precipitation or combustion, to a pure compound or element, of definite known composition, and is weighed; in a few cases a compound or element is formed that does not contain the constituent but bears a definite mathematical relationship to it.

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

hemoglobin - the iron-containing, oxygen-carrying molecule of the red blood cells of vertebrates comprising four polypeptide subunits in a heme group.

human lymphocyte antigen - antigens located surface of cell membranes, important in normal immune response.

hydrophobic - lacking an affinity for, repelling, or failing to adsorb or absorb water.

hypoxanthine-guanine phosphoribosyl transferase - a mammalian protein functional in purine metabolism.

in situ - in the original location.

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

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

informatics - information management systems.

karyotype - the morphological characteristics of chromosomes within a cell.

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

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

macro - a prefix meaning large.

micro - a prefix indicating smallness; a prefix indicating extreme sensitivity.

molarity - measure of the number of gram-molecular weights of a compound dissolved in 1 liter of solution.

muon - collective name for two semistable elementary particles with positive and negative charge.

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

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

photoelectric interaction coefficient

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

polymerase - an enzyme that links nucleotides together to form polynucleotide chains.

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

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

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

somatic mutation - genetic change within nonreproductive cells.

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

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

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

standard deviation - the positive square root of the expected value of the square of the difference between a random variable and its mean.

stochastic - pertaining to random variables.

T-cell receptor - protein on the surface of T lymphocytes that specifically recognizes molecules of the major histocompatibility complex, either alone or in association with foreign antigens.

T-lymphocyte - a type of white blood cell.

temporal - pertaining to or limited by time.

tertiary - third level.

transcriptase - enzyme functional in replication of DNA.