Permit

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Field Office, Albuquerque
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Bonilla

William Honker, Chief
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Dear Mr. Honker:

Enclosed is the Installation Work Plan, Revision 3 (Volumes I and II) for the Environmental Restoration Program at the Los Alamos National Laboratory.

If you have questions, please call me at (505) 665-5027, or ask your staff to call Court Fesmire of my staff at (505) 665-4718.

Sincerely,

Joseph C. Vozella, Chief
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Volume I

Installation Work Plan for Environmental Restoration

Revision 3

November 1993

A Department of Energy
Environmental Cleanup Program

Los Alamos
NATIONAL LABORATORY

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EXECUTIVE SUMMARY

In 1989, the US Department of Energy (DOE) created the Office of Environmental Restoration and Waste Management (EM). The goal of this office is to implement the department's policy of ensuring that its past, present, and future operations do not threaten human health, safety, or the environment. The EM Office implements procedures to meet these goals through three associate directorates: Environmental Restoration (ER), Waste Operations, and Technology Development. The ER Program is responsible for assessing, cleaning up, decontaminating, and decommissioning sites at DOE facilities and at sites formerly used by DOE. This Installation Work Plan (IWP) describes how the DOE and the University of California (UC) will conduct the department's ER Program at Los Alamos National Laboratory (the Laboratory).

The Laboratory and the neighboring residential areas of Los Alamos and White Rock are located predominantly in Los Alamos County, north-central New Mexico, approximately 60 mi north-northeast of Albuquerque and 25 mi northwest of Santa Fe. The 43-mi^2 Laboratory site and the communities adjacent to it are situated on the Pajarito Plateau. The ephemeral and intermittent streams that drain the plateau have created numerous narrow finger-like mesas, whose tops range in elevation from approximately 7,800 ft on the flank of the Jemez Mountains to about 6,200 ft at their eastern termination above the Rio Grande valley. The eastern margin of the plateau stands 300 to 900 ft above the Rio Grande.

Since its inception in 1943, the Laboratory's primary mission has been nuclear weapons research and development. In the fall of 1992, in recognition of the end of the cold war and the ascendancy of non-defense-related problems both at home and abroad, the Laboratory's management announced a reorientation of Laboratory priorities. In September, the director introduced a revised mission statement for the Laboratory that reflects its new, expanded role:

> "Los Alamos National Laboratory is dedicated to developing world-class science and technology and applying them to the nation's security and well-being. The Laboratory will continue its special role in defense, particularly in nuclear weapons technology, and will increasingly use its multidisciplinary capabilities to solve problems in the civilian sector."

To this end, the Laboratory will, over the next 3-5 years, continue its defense programs as directed by Congress and will focus on developing new programs in three nationally significant areas for which it has special capabilities: health and biotechnology, environmental technologies, and industrial partnerships. Other Laboratory programs include applied photochemistry, astrophysics, earth sciences, lasers, computer sciences, energy resources (including solar and geothermal), and nuclear waste management research.

Since the early 1970s, the Laboratory has reported the results of an environmental surveillance program that routinely samples air, water, soil, and foodstuffs throughout the Los Alamos area to determine levels of contamination. The data collected under this program are published annually for distribution to the public and to local, state, and federal agencies. These data indicate that Laboratory operations do not currently threaten human health or the environment. The ER Program at the Laboratory augments the environmental surveillance program by identifying potential future threats to human health and the environment and by mitigating them

through efficient corrective actions that comply with applicable environmental regulations. Corrective actions include such measures as source containment to prevent contaminant migration, controls on future land use, and excavation and treatment of the source to remove hazards to health and the environment.

The ER Program at the Laboratory responds to two primary laws: the Resource Conservation and Recovery Act (RCRA), which is the statutory basis for the ER Program at the Laboratory, and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), which provides a framework for remediating certain hazardous materials at the Laboratory that are not covered by RCRA. The hazardous waste provisions of RCRA govern the day-to-day operations of hazardous waste management, treatment, storage, and disposal (TSD) facilities. The law established a permitting system and set standards for all hazardous-waste-producing operations at a TSD facility. Under this law, the Laboratory qualifies as a treatment and storage facility and must have a permit to operate. In 1984, Congress amended RCRA by passing the Hazardous and Solid Waste Amendments (HWSA). Section 3004(u) of RCRA (as amended by HSWA) mandates that permits for TSD facilities include provisions for corrective action to mitigate releases from facilities currently in operation and to clean up contamination in areas designated as solid waste management units (SWMUs).

Congress conceived and passed CERCLA to clean up the nation's most hazardous abandoned waste sites. Under CERCLA, the Environmental Protection Agency (EPA) ranks abandoned facilities that have hazardous waste sites according to their potential threat to human health and the environment. The high-scoring sites are listed on the National Priorities List and are cleaned up in accordance with CERCLA regulations. The Laboratory has not yet been evaluated to determine whether it should be included on the National Priorities List.

DOE/UC's RCRA permit includes a section called the HSWA Module, which prescribes a specific corrective action program for the Laboratory and provides the primary guidance for the Laboratory's ER Program. This IWP has been prepared in accordance with the HSWA Module and with the corrective action requirements proposed for incorporation in EPA's standards for hazardous waste. EPA proposed Subpart S of 40 CFR 264 in July 1990 to implement the cleanup program mandated in Section 3004(u) of RCRA, and that portion of Subpart S pertaining to corrective action management units has now been promulgated. This IWP describes how each of the following steps in the corrective action process will be implemented at the Laboratory:

- The RCRA facility investigation (RFI)—The goal of this step is to identify the nature and extent of contamination at sources and in environmental pathways that could lead to exposure of human and environmental receptors. This step is being implemented by characterizing the extent of contamination in the detail necessary to determine what corrective measures, if any, need to be taken. The Laboratory is answering only those questions relevant to deciding further actions.

- Corrective measures study (CMS)—If characterization indicates that corrective measures may be needed, this study will evaluate alternatives that might be reasonably implemented. Corrective measures will be evaluated based on their projected efficacy in reducing risks to human and environmental health and safety in a cost-effective manner.

- Corrective measures implementation (CMI)—This step effects the chosen remedy, verifies its efficacy, and establishes ongoing control and monitoring requirements.

Additionally, public involvement is an important component of the Laboratory's ER Program, as mandated by the EPA review process. Accordingly, public hearings will be held, as needed.

This IWP includes

- a program management plan that describes the organization and management of the Laboratory's ER Program, including projected schedules and costs;

- an overview of the ER Program's quality program plan, which integrates DOE Order 5700.6C, Quality Assurance, and QAMS 004180, Interim Guidelines and Specifications for Preparing Quality Assurance Programs, to ensure implementation of basic quality management requirements by the ER Program;

- a health and safety program plan that describes measures to ensure health and safety during implementation of the Laboratory's ER Program;

- a records management program plan that describes the mechanisms to be used to track information and data throughout the ER Program;

- a community relations program plan that describes how the Laboratory will provide information to and receive recommendations from the public throughout the life of the ER Program;

- a proposal to integrate RCRA closure and corrective action requirements; and

- a strategy for conducting interim remedial measures and/or voluntary corrective actions.

The HSWA Module defines the principal requirements with which DOE/UC must comply in implementing the ER Program at the Laboratory. However, RCRA does not address several issues of concern at Los Alamos. For example, source, by-product, and special nuclear materials are exempt from RCRA's definition of solid waste and are therefore not subject to the provisions of the HSWA Module. DOE/UC recognize that these radioactive constituents are of concern and cannot be separated from concerns about hazardous wastes. Thus, DOE/UC's ER Program addresses radioactive as well as other hazardous substances not regulated by RCRA. This approach is intended to implement a technically comprehensive program that covers potential liabilities at sites that may contain hazardous substances not regulated under RCRA and radioactive materials regulated under the Atomic Energy Act; however, it is understood that language in this IWP pertaining to subjects outside the scope of RCRA is not enforceable under the RCRA permit.

The HSWA Module provides a schedule for addressing the SWMUs that the EPA has selected from potential release sites (PRSs) identified by DOE/UC. These units are

being be addressed in RFI work plans. DOE/UC have aggregated into operable units all SWMUs to be taken through the corrective action process. Thus, the permit schedule for completing work plans will be met by submitting one RFI work plan for each of the 23 operable units that contain SWMUs.

DOE/UC propose to extend the RFI process by an amount that will delay completion of the CMS reports beyond the year 2000. This extension is necessary because the SWMUs in the HSWA Module are only a subset of the approximately 1,700 PRSs that the ER Program must address to meet all applicable environmental regulations. In addition, the extended schedule allows the spread of effort over a period compatible with the availability of national resources, including funding.

Current risks from known PRSs are low; hence, at this time, no operable unit or set of PRSs has priority for action over others based on health or environmental concerns. However, DOE/UC are in the process of implementing a site-ranking system, which includes input from stakeholders, to aid in prioritizing PRSs. In addition, in response to requests from local property owners, the ER Program is giving priority to field work at former Laboratory locations in the townsite, which are no longer owned by the DOE.

In accordance with the provisions of the HSWA Module, this IWP is revised annually to reflect the current status of the ER Program at the Laboratory.

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GLOSSARY

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LIST OF ACRONYMS AND ABBREVIATIONS

ADS	Activity data sheet
AEA	Atomic Energy Act
AEC	US Atomic Energy Commission
ANSI	American National Standards Institute
ALARA	As low as reasonably achievable
AOC	Area of concern
AP	Administrative procedure
ASME	American Society of Mechanical Engineers
CEARP	Comprehensive Environmental Assessment and Response Program
CEDE	Committed effective dose equivalent
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CMI	Corrective measures implementation
CMS	Corrective measures study
D&D	Decontamination and decommissioning
DCF	Dose conversion factor
DOE	US Department of Energy
DOE/AL	US Department of Energy/Albuquerque Operations Office
DOE/HQ	US Department of Energy/Headquarters
DP	Director's policy
DQO	Data quality objective
EA	Environmental assessment
EDE	Effective dose equivalent
EETF	Experimental Engineered Test Facility
EIS	Environmental impact statement
EO	Executive order
EPA	US Environmental Protection Agency
ER	Environmental Restoration (Program)
FIMAD	Facility for Information Management, Analysis, and Display
FS	Feasibility study
FWS	Fish and Wildlife Service
FY	Fiscal year
GIS	Geographical Information System
HAZWOP	Hazardous Waste Operations Program
HAZWOPER	Hazardous Waste Operations and Emergency Response
H&S	Health and safety
HSPL	Health and safety project leader
HE	High explosive(s)
HEAST	Health effects assessment summary table(s)
HSWA	Hazardous and Solid Waste Amendments
IRIS	Integrated Risk Information System
IRM	Interim remedial measure
ITP	Integrated test plot
IWP	Installation work plan
LAAO	Los Alamos Area Office (a branch of the Department of Energy)
LANL	Los Alamos National Laboratory
LASL	Los Alamos Scientific Laboratory (the Laboratory before January 1, 1981)
LLW	Low-level waste
MCL	Maximum contaminant level

MDA	Materials disposal area
MIS	Management Information System
MSA	Major systems acquisition
MWDF	Mixed-Waste Disposal Facility
NCP	National (Oil and Hazardous Substances Pollution) Contingency Plan
NEPA	National Environmental Policy Act
NFA	No further action
NMED	New Mexico Environment Department
NRDA	Natural resource damage assessment
NWI	National Wetlands Inventory
OSHA	Occupational Safety and Health Administration
OU	Operable unit
OUPL	Operable unit project leader
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PI	Principal investigator
PL	Project leader
PPL	Programmatic project leader
PRS	Potential release site
QA	Quality assurance
QAPjP	Quality assurance project plan
QC	Quality control
QP	Quality procedure
QPP	Quality program plan
R&D	Research and development
RFA	RCRA facility assessment
RME	Reasonable maximum exposure
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
RPF	Records-Processing Facility
SAFER	Streamlined approach for environmental restoration
SAL	Screening action level
SCS	US Soil Conservation Service
SEN	Secretary of Energy notice
SOP	Standard operating procedure
SWMU	Solid waste management unit
TA	Technical area
TDR	Time domain reflectometry
TRU	Transuranic (waste)
TSD	Treatment, storage, disposal
TTL	Technical team leader
UC	University of California
USGS	US Geological Survey
UST	Underground storage tank
VCA	Voluntary corrective action
VOC	Volatile organic compound
WBS	Work breakdown structure
WL	Working level
WLM	Working-level month

1.0 INTRODUCTION

In 1989, the US Department of Energy (DOE) created the Office of Environmental Restoration and Waste Management (EM). The goal of this office is to implement the department's policy of ensuring that its past, present, and future operations do not threaten human or environmental health and safety (DOE 1991, 0549; DOE 1993, 0992). The EM Office implements procedures to meet these goals through three associate directorates: Environmental Restoration (ER), Waste Operations, and Technology Development. The ER Program is responsible for assessing, cleaning up, decontaminating, and decommissioning sites at DOE facilities and sites formerly used by DOE and its predecessors. As a facility operated by the DOE, Los Alamos National Laboratory (the Laboratory) is a part of this program.

The Laboratory is administered for the DOE by the University of California (UC). Historically, the principal mission of the Laboratory has been the design, development, and testing of nuclear weapons. This effort is supported by research programs in nuclear physics, hydrodynamics, conventional explosives, chemistry, metallurgy, radiochemistry, and biology. In addition to the weapons program, Laboratory personnel are involved in medium-energy physics; space nuclear systems; controlled thermonuclear fusion; laser research; environmental research; geothermal, solar, and fossil energy research; nuclear safeguards; biomedical research; and space physics. Appendix A summarizes activities at the Laboratory's 49 active technical areas (TAs), which are shown in Figure 2-2.

In the fall of 1992, in recognition of the end of the cold war and the ascendancy of non-defense-related problems both at home and abroad, the Laboratory's management announced a reorientation of Laboratory priorities. In September, the director introduced a revised mission statement for the Laboratory that reflects its new, expanded role:

> "Los Alamos National Laboratory is dedicated to developing world-class science and technology and applying them to the nation's security and well-being. The Laboratory will continue its special role in defense, particularly in nuclear weapons technology, and will increasingly use its multidisciplinary capabilities to solve problems in the civilian sector."

To this end, the Laboratory will, over the next 3-5 years, continue its defense programs as directed by Congress and will focus on developing new programs in three nationally significant areas for which it has special capabilities: health and biotechnology, environmental technologies, and industrial partnerships. Other Laboratory programs include applied photochemistry, astrophysics, earth sciences, lasers, computer sciences, energy resources (including solar and geothermal), and nuclear waste management research.

Many of the processes used in carrying out the Laboratory's mission involve the use of hazardous and radioactive materials. During World War II and for a while thereafter, some of these materials were disposed on the Laboratory site or were otherwise released into the environment. Beginning in the 1970s, Congress enacted basic legislation to protect the environment. In that period also, the DOE and the Laboratory began to conduct surveys and to clean up areas where spills and casual disposal had occurred.

The current investigation being conducted at Los Alamos under the ER Program is intended to permit a definitive determination as to the presence or absence of hazardous and radioactive wastes and to restore any sites where such materials are still found to exist. The ER Program at the Laboratory is committed to excellence in carrying out its responsibilities for investigating and remediating hazardous waste disposal sites. To accomplish this quality, the ER Program defines its mission as

> "bringing together multidisciplinary, world-class science, engineering, and state-of-the-art management practices to remedy environmental problems resulting from 50 years of Laboratory activity in Los Alamos by meeting both the letter and spirit of applicable environmental statutes and regulations."

This updated Installation Work Plan (IWP) describes how the DOE/UC are conducting the DOE's ER Program at the Laboratory.

In 1980, Congress passed the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) to clean up the nation's most hazardous abandoned waste sites. Under CERCLA, the Environmental Protection Agency (EPA) ranks abandoned facilities that have hazardous waste sites according to their potential threat to human health and the environment. The high-scoring sites are listed on the EPA's National Priorities List and are cleaned up in accordance with CERCLA regulations. The Laboratory has not yet been evaluated to determine whether it should be included on the National Priorities List.

The Laboratory's environmental surveillance program routinely samples air, water, soil, and foodstuffs throughout the Los Alamos area to determine levels of contamination. The data collected under this program are published annually for distribution to the public and to local, state, and federal agencies. These data indicate that Laboratory operations do not currently threaten human health or the environment. The ER Program at the Laboratory augments the environmental surveillance program by identifying potential future threats to human health and the environment and by mitigating them through efficient corrective actions that comply with applicable environmental regulations. Corrective actions include such measures as source containment to prevent contaminant migration, controls on future land use, and excavation and treatment of the source to permanently eliminate hazards to health and the environment. The formal ER Program at the Laboratory took effect in 1990 through provisions of a permit issued by the EPA to the DOE/UC. The EPA retains oversight and approval authority for the program at Los Alamos.

The ER Program is regulated by the Resource Conservation and Recovery Act (RCRA). The hazardous waste management provisions of RCRA as enacted in 1976 govern the day-to-day operations of hazardous waste treatment, storage, and disposal (TSD) facilities. Sections 3004(u) and (v) of RCRA established a permitting system and set standards for all hazardous-waste-producing operations at a TSD facility. Under this law, the Laboratory qualifies as a treatment and storage facility and must have a permit to operate.

In 1984, Congress amended RCRA by passing the Hazardous and Solid Waste Amendments (HSWA). Sections 201, 202, 203, 206, 207, 212, 215, and 224 of HSWA modified the permitting sections of RCRA (Sections 3004 and 3005). In accordance with these provisions of HSWA, the Laboratory's permit to operate includes a section that prescribes a specific corrective action program for the Laboratory, which includes provisions for mitigating releases from facilities currently

in operation and for cleaning up inactive sites. This portion of the permit is known as the HSWA Module.

The HSWA Module specifies a three-step corrective action process (Figure 1-1):

- The RCRA facility investigation (RFI)—The goal of this step is to identify the extent of contamination at the source and the environmental pathways along which contaminants could travel to human and environmental receptors. This step is being implemented by characterizing the extent of contamination in the detail necessary to determine what corrective measures, if any, need to be taken. This approach focuses on answering those questions relevant to deciding further actions in a cost-effective manner.

- Corrective measures study (CMS)—If characterization indicates that corrective measures are needed, this study will evaluate alternatives that might reasonably be implemented. These measures will be evaluated based on their projected efficacy in reducing risks to human and environmental health and safety in a cost-effective manner.

- Corrective measures implementation (CMI)—This step will implement the remedy chosen by the regulatory authority, verify its effectiveness, and establish ongoing control and monitoring requirements.

This IWP has been prepared to comply with the HSWA Module of the Laboratory's RCRA permit (EPA 1990, 0306). The major components of this IWP that address the requirements of the HSWA Module are shown in Table 1-1. The fundamental unit to which these requirements apply is the solid waste management unit (SWMU), defined by EPA in the HSWA Module as

> "...any discernible unit at which solid wastes have been placed at any time, irrespective of whether it was intended for the management of solid or hazardous waste. Such units include any area at or around a facility at which solid wastes have been routinely and systematically released."

The HSWA Module defines the principal requirements with which DOE/UC must comply in implementing the ER Program at the Laboratory. However, RCRA does not address several issues of concern at Los Alamos. For example, source, by-product, and special nuclear materials (defined in the Atomic Energy Act) are exempt from RCRA's definition of solid waste and are therefore not subject to the provisions of the HSWA Module. DOE/UC recognize that these radioactive constituents are of concern and cannot be separated from concerns about hazardous wastes. Thus, DOE/UC's ER Program addresses radioactive as well as other hazardous substances not regulated by RCRA. The sites that potentially contain hazardous substances, such as radionuclides, but no hazardous constituents defined by RCRA are called areas of concern (AOCs). In this document, SWMUs and AOCs are collectively referred to as "potential release sites" (PRSs). This approach is intended to implement a technically comprehensive program that covers potential liabilities at sites that may contain hazardous substances not regulated under RCRA and

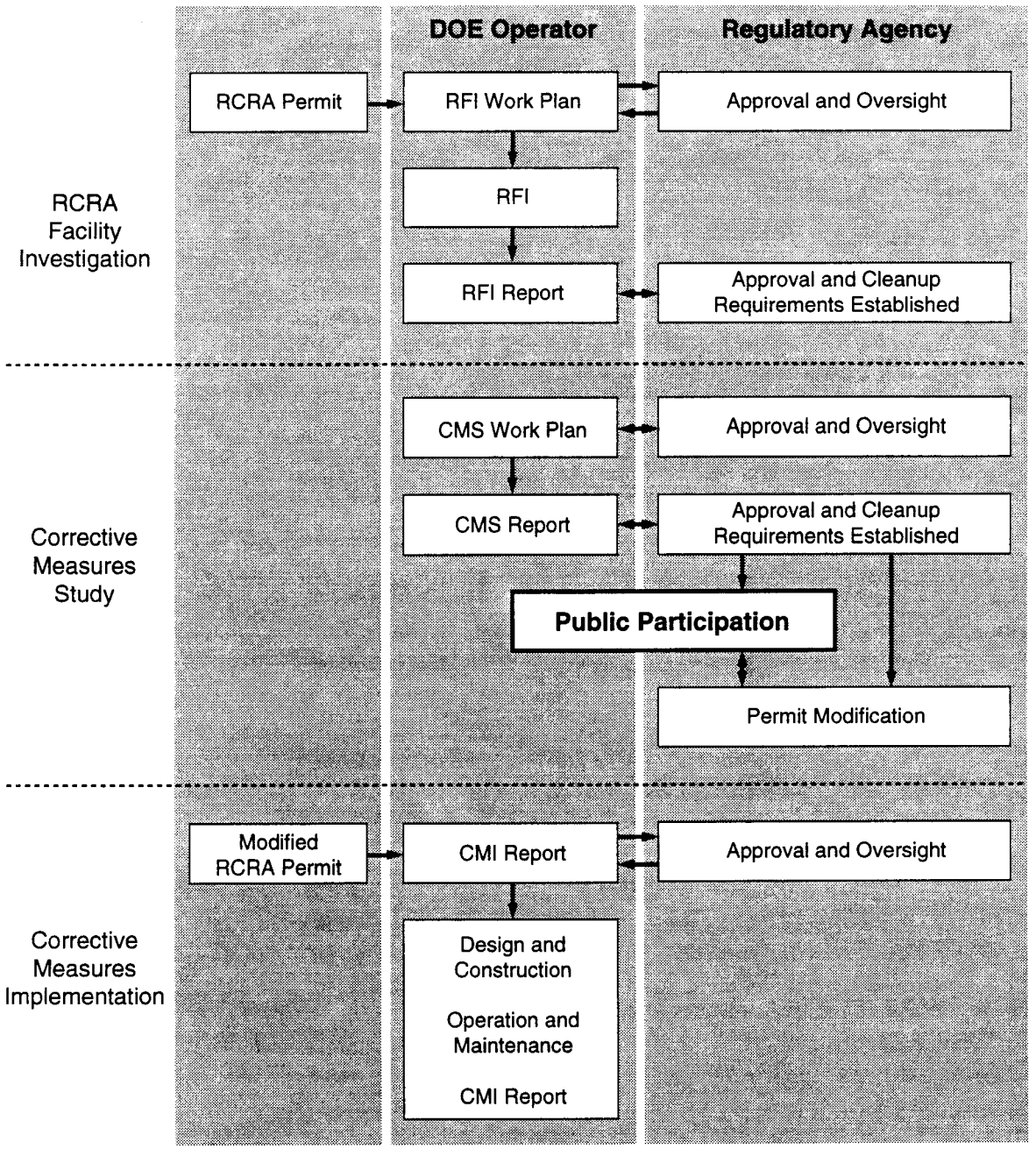

Figure 1-1. RCRA corrective action process at the Laboratory.

TABLE 1-1

REQUIREMENTS OF THE HSWA MODULE DESCRIBED IN THIS IWP

Requirement	Location in IWP
Programmatic elements of the RCRA facility investigation (RFI) work plan	Chapter 3 and Annex I
Installationwide description of the current conditions of the Laboratory	Chapter 2
Tabular summaries of the Laboratory's potential release sites	Appendix F
RFI investigation work schedule	Annex I and Appendix N
Outlines for the task-specific RI/FS documents	Chapter 3
Installationwide overview of the hydrogeological environment of the Laboratory	Chapter 2
Project Management Plan	Annex I
Data Collection Quality Assurance Plan	Annex II
Data Management Plan	Annex IV
Health and Safety Plan	Annex III
Community Relations Plan	Annex V

radioactive materials regulated under the Atomic Energy Act; however, it is understood that language in this IWP pertaining to subjects outside the scope of RCRA is not enforceable under the RCRA permit.

DOE/UC are using the operable unit (OU) approach defined in CERCLA for organizing and managing the various PRSs. OUs are aggregates of PRSs that will be addressed together. The details for each step required under the corrective action process will be presented individually for each OU.

The HSWA Module provides a schedule for addressing the SWMUs that the EPA has selected from PRSs identified by DOE/UC. The permit schedule for completing work plans will be met by submitting one RFI work plan for each of the 23 operable units that contains SWMUs. These units are being addressed in RFI work plans. Any necessary CMS reports must be completed by May 23, 2000.

DOE/UC propose to extend the RFI process by an amount that will delay completion of the last CMS reports beyond the year 2000. This extension is necessary because the SWMUs in the HSWA Module are only a subset of the approximately 1,700 PRSs that the ER Program must address to meet all applicable environmental regulations. In addition, the extended schedule allows the spread of effort over a period compatible with the availability of national resources, including funding.

Current risks from known PRSs are low; hence, at this time, no OU or set of PRSs has priority for action over others based on health or environmental concerns. However, DOE/UC are in the process of implementing a site-ranking system, which includes input from stakeholders, to aid in prioritizing PRSs. In addition, in response to requests from local property owners, the ER Program is giving priority to field work at former Laboratory locations in the townsite, which are no longer owned by the DOE.

This program is conducted to meet the requirements of applicable DOE environmental orders, including 5400.1, General Environmental Protection Program; 5400.2A, Environmental Compliance Issue Coordination; 5400.3, Hazardous and Radioactive Mixed Waste Program; 5400.4, Comprehensive Environmental Response, Compensation, and Liability Act Requirements; and 5400.5, Radiation Protection of the Public and the Environment. Additional DOE orders incorporated in this program are listed in Annex I.

This IWP provides generic information about the ER Program at the Laboratory; thus, each RFI work plan need discuss only information specific to individual OUs. Chapter 2 of this document contains a description of the environmental setting and a brief history of the Laboratory. Chapter 3 describes the regulatory framework and structure of the ER Program, including the addition in 1992 of the Laboratory's Decontamination and Decommissioning Program to the ER Program. Chapter 4 describes the technical approach used throughout the ER Program at the Laboratory.

This document contains five annexes consisting of plans required by the HSWA Module: the Program Management Plan, an overview of the ER Program's Quality Assurance Program, the Health and Safety Program Plan, the Records Management Program Plan, and the Community Relations Program Plan. In addition, it contains several appendices that supplement, as needed, information provided in Chapters 1-4 and the annexes. The appendices are followed by a list of contributors, a glossary, and a table showing conversion of metric to English units of measure.

In accordance with the provisions of the HSWA Module, this plan is revised annually to reflect the current status of the ER Program at the Laboratory, future plans, and near- and long-term schedules. This document is the third revision.

References for Chapter 1

DOE (US Department of Energy), August 1991. "Five-Year Plan: Fiscal Years 1993-1997," National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161. (DOE 1991, 0549)

DOE (US Department of Energy), January 1993. "Environmental Restoration and Waste Management Five-Year Plan, Fiscal Years 1994-1998," Volumes I and II, DOE/S-00097P, Washington, DC. (DOE 1993, 0992)

EPA (US Environmental Protection Agency), April 10, 1990. Module VIII of RCRA Permit No. NM0890010515, EPA Region VI, issued to Los Alamos National Laboratory, Los Alamos, New Mexico, effective May 23, 1990, EPA Region VI, Hazardous Waste Management Division, Dallas, Texas. (EPA 1990, 0306)

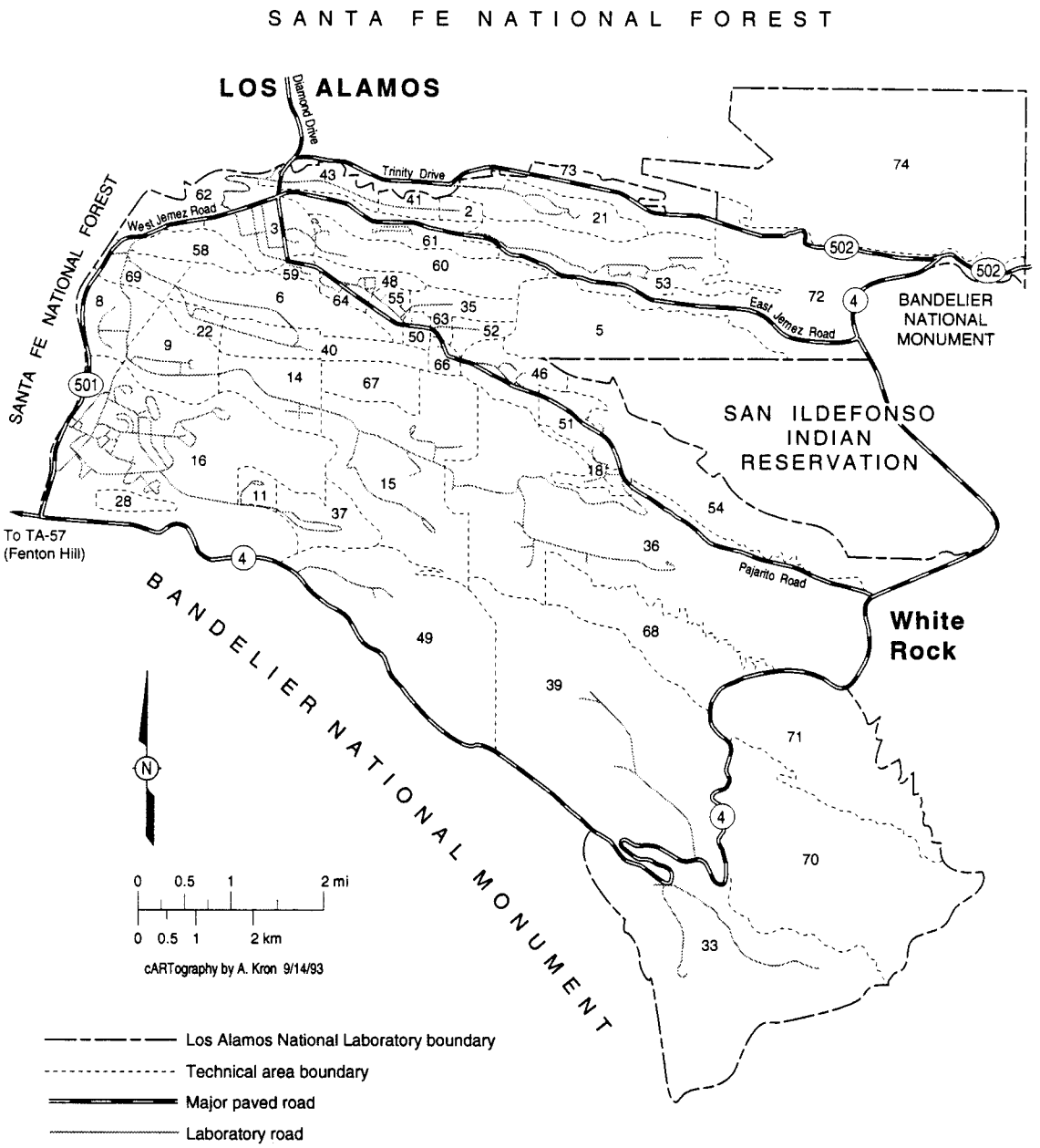

Figure 2-2. Technical areas at Los Alamos National Laboratory.

Since its inception, UC has operated the Laboratory for the federal government. Research activities were established in wooden buildings south of the original Ranch School buildings in what is now downtown Los Alamos. Additional Laboratory buildings were constructed; army-style barracks, temporary and prefabricated, provided housing.

With the end of World War II and the growth of international competition, a national policy of maintaining superiority in the field of atomic energy was established. Congress chose to sustain the Los Alamos site; the Atomic Energy Commission (AEC) received control of the Laboratory from the Army and renewed the operating contract with UC. Thereafter, a major construction program was started south of Los Alamos Canyon. During subsequent years, the Laboratory continued to expand at a steady rate, first under the AEC and later under the Energy Research and Development Administration. Since 1978, the Laboratory has operated under the control of the DOE and is currently officially known as Los Alamos National Laboratory.

2.4 Waste Management Practices

To accommodate wastes generated during the course of the corrective action process, the ER Program proposes to construct a Mixed-Waste Disposal Facility. This facility will operate under the appropriate federal and state permits and will meet all relevant federal and state pollution control requirements.

2.5 Overview of the Environmental Setting

2.5.1 Land Use Patterns

Most Laboratory and community developments are confined to mesa tops. Large tracts of land north, west, and south of the Laboratory site are managed by the Santa Fe National Forest, Bureau of Land Management, Bandelier National Monument, General Services Administration, and Los Alamos County (Figure 2-3). The San Ildefonso Pueblo borders Los Alamos County and the Laboratory to the east.

Laboratory land is used for building sites, experimental areas, waste disposal locations, roads, and utility rights-of-way. However, these uses account for only a small part of the land. Most of the land controlled by the Laboratory serves as a buffer zone for Laboratory facilities, providing security and safety, and as a reserve for future construction. The Laboratory's long-range site development plan (Pava 1990, 0368) ensures adequate planning for the best possible future uses of available Laboratory lands.

The public is allowed limited access to certain areas of the Laboratory site. An area north of Ancho Canyon between the Rio Grande and State Road 4 is open to hikers, boaters, and hunters, but woodcutting and vehicles are prohibited. Portions of Mortandad and Pueblo canyons are also open to the public. An archaeological site (the Otowi tract), northwest of State Road 502 near the White Rock Y, is open to the public, subject to restrictions imposed by regulations to protect cultural resources.

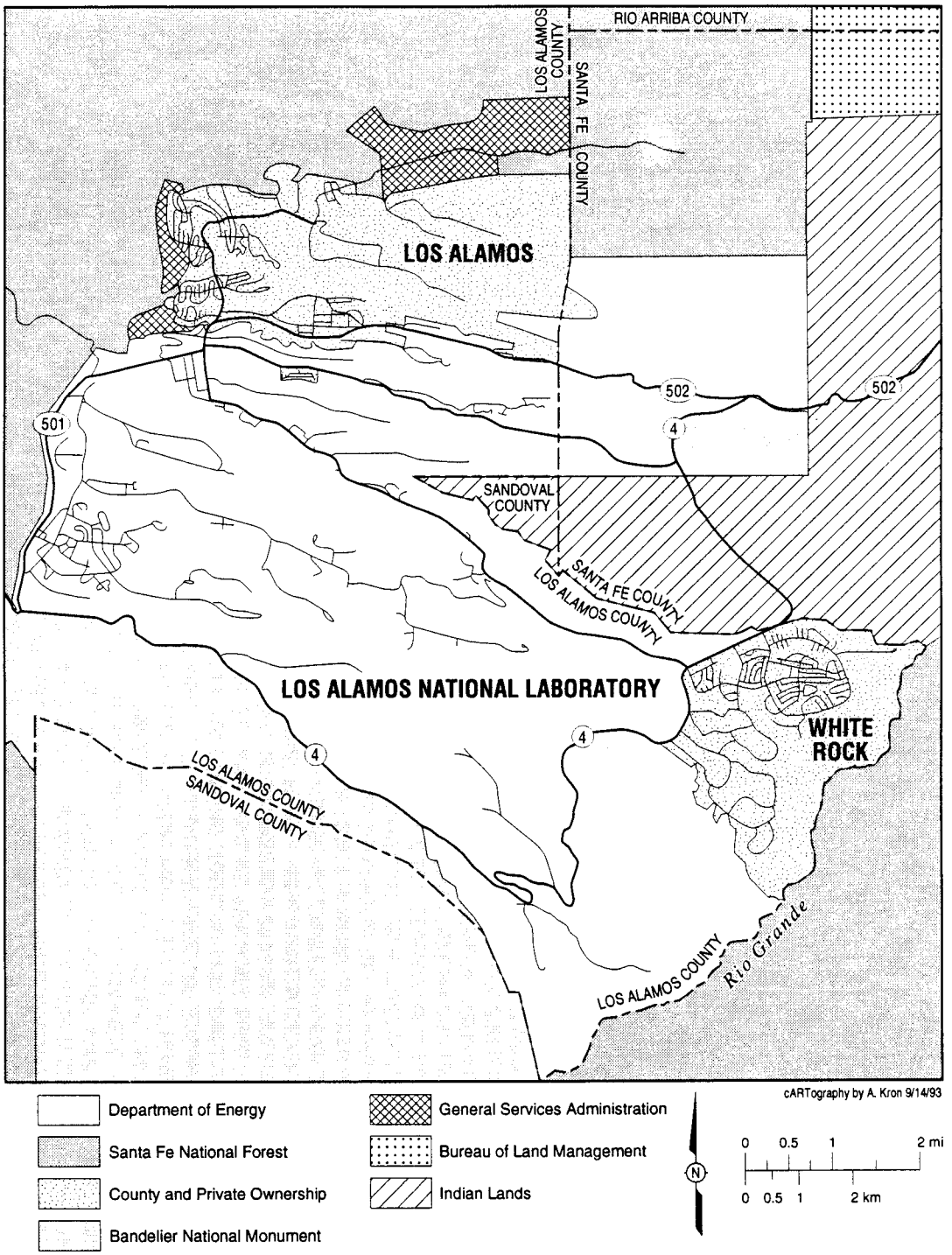

Figure 2-3. Land use map for the Laboratory and adjacent lands.

2.5.2 Ecology

Understanding of the structural and functional relationships among Los Alamos area ecosystems is limited, partly because of the wide diversity of ecosystems. This diversity has been created by the pronounced 4,920-ft elevation gradient that extends from the Rio Grande on the east to the Jemez Mountains 12 mi to the west. Many canyons, with abrupt changes in surface slope, parallel this gradient. The pronounced east-west canyon and mesa orientations, with concomitant differences in soils, moisture, and solar radiation, produce an interlocking finger effect among ecological life zones, resulting in many transitional overlaps of plant and animal communities within small areas. Maps of the topography, wetlands, and flood plains at Los Alamos are contained in Appendix B. Section 2.6 provides a detailed overview of the hydrogeological environment at Los Alamos.

2.5.2.1 Flora

Six major vegetative complexes (community types) are found in Los Alamos County. A piñon-juniper forest surrounds most of the Laboratory. Within the confines of the Laboratory's border, the predominant community types are ponderosa pine woodland (6,900 to 7,500 ft in the western third of the reservation), piñon-juniper (6,200 to 6,900 ft in the central third), and juniper-grassland (5,600 to 6,200 ft in the eastern third).

Less is known about ecosystems other than the piñon-juniper woodland. Hakonson et al. (1973, 0118) provide a general description of the Laboratory and environs. Almost 350 plant species have been identified, and species lists have been prepared (DOE 1979, 0051). Special studies have described the past and current status of the flora of the complex (Foxx and Tierney 1980, 0101; 1984, 0102; 1985, 0103). Past and present uses of the Laboratory and adjacent lands have resulted in structural changes in plant communities. Laboratory uses have had, and will continue to have, important consequences for local ecosystems. Few construction and waste disposal activities have occurred in the flood plains of canyons in and near the Laboratory. Natural wetland areas occur in some canyons, and more extensive wetlands have developed as a result of effluent outfalls.

The grama grass cactus, which is proposed for inclusion in the federal endangered species list, has been found on the dry mesa tops of Los Alamos County at elevations of about 6,000 to 6,400 ft. However, it has not been found on Laboratory property. Penalties exist for transporting plants protected under the 1985 New Mexico Rule No. NRD:85-3. Among the species protected under this rule, nine have been documented in the vicinity of Los Alamos County. To date, none has been found on Laboratory property.

2.5.2.2 Fauna

Before the Laboratory was established, Native Americans and European settlers farmed the mesas, disturbing areas that are now in various stages of succession. These areas afford suitable feeding locations for herbivores, especially deer and elk, and adjacent timbered canyon slopes provide cover for these species. Sheer canyon walls at lower elevations serve as important nesting habitats for birds of prey. Generally, larger mammals, reptiles, and invertebrates are most sensitive to variations in elevations and are confined to smaller ranges.

Information on the fauna within the Laboratory complex is largely qualitative. Species lists have been compiled from observational data and published data (DOE 1979, 0051), but the occurrence of some species has not been verified. Only one limited fauna survey has been conducted on Laboratory grounds (Miera et al. 1977, 0148). Special studies are currently under way to provide a more comprehensive survey of vertebrate fauna.

Based on published reports and ongoing surveys, one federally listed endangered animal species, the peregrine falcon, is known to inhabit Los Alamos County. A peregrine aerie exists in Pueblo Canyon. The nesting peregrines from this aerie, as well as other raptors, hunt on Laboratory lands; however, no critical habitats have been defined. The Jemez Mountain salamander has been found in the moist upper reaches (above 8,000 ft) of the canyons that dissect the plateau, usually at an elevation higher than that of the Laboratory. In 1985, one specimen was collected and recorded as having been found on Laboratory property. This species is listed as endangered by the state and federal governments.

2.5.3 Climate

Bowen (1990, 0033) has compiled and interpreted climatological data for the Los Alamos area, and this information is summarized below.

Los Alamos has a semiarid, temperate mountain climate. Forty percent of the 18-in. annual precipitation normally occurs from thundershowers during July and August. Winter precipitation falls primarily as snow, with accumulations of about 51 in. annually.

Summers are generally sunny, with moderate, warm days and cool nights. Maximum daily temperatures are usually below 90°F. Brief afternoon and evening thundershowers are common, especially in July and August. High altitude, light winds, clear skies, and dry atmosphere allow night temperatures to drop to the 50s (°F) after even the warmest day. Winter temperatures typically range from about 15°F to 25°F during the night and from 30°F to 50°F during the day. Occasionally, temperatures drop to 0°F or below. Many winter days are clear with light winds, allowing strong sunshine to make conditions comfortable even when air temperatures are cold. Snowstorms with accumulations exceeding 4 in. are common in Los Alamos, and some of these storms are associated with strong winds, frigid air, and dangerous wind chills, especially in the mountains.

The climate from 1961 through 1988 had slightly cooler temperatures and higher precipitation than those recorded from 1911 through 1988 (entire record). The only significant difference between the period between 1961 and 1988 and the entire record period is the large amount of snowfall.

Because of complex terrain, surface winds in Los Alamos often vary greatly with time of day and location. With light winds and clear skies, a distinct daily wind cycle often exists: a light southeasterly to southerly upslope wind during the day and a light westerly to northwesterly drainage wind during the night (Figure 2-4, from Environmental Protection Group 1990, 0497). However, several miles to the east toward the edge of Pajarito Plateau near the Rio Grande valley, a different daily wind cycle is common: a moderate southwesterly up-valley wind during the day and either a light northwesterly to northerly drainage wind or moderate southwesterly wind at night. The predominant winds are southerly to northwesterly over western Los Alamos County and southwesterly and northeasterly toward the Rio Grande valley.

Historically, no tornadoes have been reported to have touched down in Los Alamos County. Strong dust devils can produce winds up to 75 mph at isolated spots in the county, especially at lower elevations. Strong winds with gusts exceeding 60 mph are common during the spring.

Lightning is common over the Pajarito Plateau. Fifty-eight thunderstorm days occur during an average year, mostly during the summer. Lightning protection is an important design factor for most facilities at the Laboratory. Hail damage can also occur. Hailstones with diameters up to 0.25 in. are common; 0.5-in.-diameter hailstones are infrequent.

The irregular terrain at Los Alamos affects atmospheric turbulence and dispersion, sometimes favorably and sometimes unfavorably. Enhanced dispersion promotes greater dilution of contaminants released into the atmosphere. The complex terrain and forests create an aerodynamically rough surface, forcing increased horizontal and vertical dispersion. Dispersion generally decreases at lower elevations, where the terrain becomes smoother and less vegetated. The frequent clear skies and light, large-scale winds cause good vertical daytime dispersion, especially during the warm season. Strong daytime heating during the summer can force vertical mixing up to 3,000 to 6,000 ft above ground level, but the effectiveness of the generally light winds in diluting contaminants horizontally is limited.

Clear skies and light winds have a negative effect on nighttime dispersion, causing strong, shallow surface inversions to form. These inversions can severely restrict near-surface vertical and horizontal dispersion. Inversions are especially strong during the winter. Drainage winds can fill lower areas with cold air, thereby creating deeper inversions, which are common toward the Rio Grande valley on clear nights with light winds. Canyons can also limit dispersion by channeling air flow. Strong, large-scale inversions during the winter can limit vertical mixing to under 3,000 ft above ground level.

Dispersion is generally greatest during the spring, when winds are strongest. However, deep vertical mixing is greatest during the summer. Dispersion is generally low during summer and autumn, when winds are light. Even though low-level winter dispersion is generally greater, intense surface inversions can cause least-dispersive conditions during the night and early morning.

During the winter, the frequencies of atmospheric dispersive capability (sampled at TA-59) are 52% unstable (Stability Classes A through C), 21% neutral (Class D), and 27% stable (Classes E and F). The frequencies are 44%, 22%, and 34%, respectively, during the summer. These stability category frequencies are based on measured vertical wind variations. Stability generally increases (the winds become less dispersive) toward the valley.

2.5.4 Population Distribution

Los Alamos County had an estimated 1991 population of approximately 18,200 (based on the 1990 census adjusted to 1991). Two residential areas (Los Alamos and White Rock) and their related commercial areas exist in the county (Figure 2-1). The Los Alamos townsite (the original area of development that now includes residential areas known as Eastern Area, Western Area, North Community, Barranca Mesa, and North Mesa) has an estimated population of 11,400. The White Rock area (including the residential areas of White Rock, La Senda, and Pajarito Acres) has about 6,800 residents. About one-third of the people employed in Los

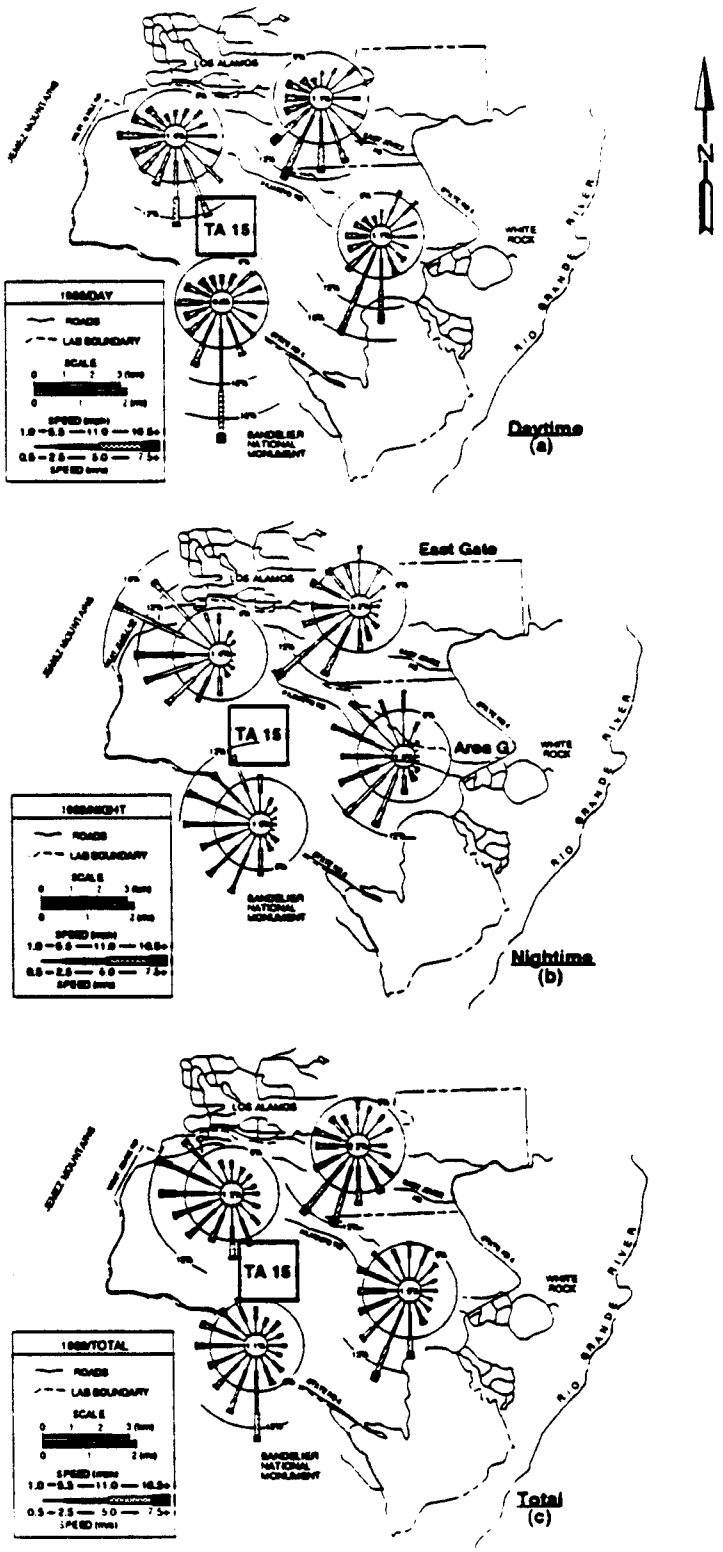

Figure 2-4. Wind roses at Laboratory stations during 1989.

Alamos commute from other counties. Population estimates for 1990 place about 213,000 persons within a 50-mi radius of Los Alamos (Table 2-1).

2.6 Geologic and Hydrologic Setting

This summary of the hydrogeologic environment at the Laboratory and in the northern New Mexico region is intended to describe the major geologic, hydrologic, and hydrogeologic features and their conceptual interrelationships. It addresses the regional and installation-wide geologic setting and the hydrologic characteristics that affect surface water and groundwater occurrence and movement and their interactions as they relate to the potential for contaminant transport. The sources cited here and additional literature on the hydrology and geology of the Los Alamos region may be found in an annotated bibliography of geologic, hydrogeologic, and environmental studies related to solid waste management units at the Laboratory LANL (1990, 0143). This bibliography was submitted to EPA in September 1990, and it and the literature it describes are available for review in the ER Program's public reading room located at 1450 Central Avenue, Suite 101, in Los Alamos.

TABLE 2-1

1990 POPULATION WITHIN 80 KM OF LOS ALAMOS

	Distance from TA-53 (km)								
Direction	1–2	2–4	4–8	8-15	15–20	20–30	30–40	40–60	60–80
N	1	0	0	0	0	0	1,136	0	368
NNE	0	0	0	565	0	542	1,730	1,797	221
NE	1	0	0	0	317	15,352	1,009	1,135	3,846
ENE	0	0	0	1,940	1,563	2,716	2,729	1,187	2,214
E	0	0	83	25	556	1,145	696	0	1,402
ESE	0	0	0	0	0	293	23,151	1,067	1,476
SE	0	0	6,757	0	0	0	53,520	2,443	8
SSE	0	0	0	0	0	0	426	4,347	95
S	0	0	0	50	0	318	614	6,775	0
SSW	0	0	0	20	0	817	201	8,238	33,485
SW	0	0	0	0	0	0	315	4,157	0
WSW	0	0	0	0	0	315	313	2,545	207
W	0	0	0	0	0	0	0	164	132
WNW	0	1,435	6,535	0	0	0	0	0	3,081
NW	0	523	1,721	0	0	0	0	1,438	0
NNW	0	578	579	0	0	0	0	64	62
1990 Population Distribution	2	2,536	15,675	2,600	2,436	21,497	85,838	35,357	46,597

Total population within 80 km of Los Alamos is 213,000.

2.6.1 Geology

2.6.1.1 Regional Setting

The Laboratory is situated on the Pajarito Plateau on the east flank of the Jemez Mountains and on the west side of the Rio Grande valley (Figure 2-5). The Jemez Mountains are part of the Jemez volcanic field, which consists of some 432 mi^3 of volcanic rocks erupted from numerous vents, including a giant, multistage caldera (Gardner et al. 1986, 0310). The Jemez volcanic field occurs at the intersection of the Jemez lineament, a northeast-trending alignment of volcanic fields, and the Rio Grande rift, a major north-trending zone of extensional tectonics (Aldrich 1986, 0554).

Two major volcanic eruptions in the Jemez Mountains that occurred about 1.5 and 1.13 million years ago produced widespread and voluminous ash flow sheets: the Otowi and Tshirege members of the Bandelier Tuff (Smith and Bailey 1966, 0377; Spell et al. 1990, 0607). The morphology of the Pajarito Plateau is dominated by a gently eastward-sloping surface, formed on top of the Bandelier Tuff, which is dissected by numerous steep-sided canyons. The Otowi and Tshirege Members of the Bandelier Tuff were erupted concomitantly with the collapse of the Toledo and Valles calderas, respectively. Following formation of the calderas, volcanism continued with the extrusion of domes along ring fractures. The latest eruption in the Jemez Mountains occurred about 130,000 years ago, producing the El Cajete pumice and Banco Bonito rhyolite flow (Gardner et al. 1986, 0310; Self et al. 1988, 0500). Vestiges of volcanic activity continue today, as evidenced by solfataric and hot spring activity both within and outside of the Valles caldera (Goff et al. 1989, 0774). Studies of P-wave arrival time delays suggest the presence of partially molten rock beneath the Valles caldera, possibly the remnants of the cooling Bandelier magma chamber (Roberts et al. 1991, 0775).

The Pajarito Plateau is in the western part of the Española basin of the Rio Grande rift, a major tectonic feature of the western United States. The Española basin lacks distinct major faults on its eastern margin, but faults of major vertical offset may exist within the Precambrian rocks of the Sangre de Cristo uplift (Vernon and Riecker 1989, 0558; Biehler et al. 1991, 0528). The western margin is characterized by a prominent zone of major faults, which cuts Miocene to Quaternary rocks of the Jemez volcanic field (Smith et al. 1980, 0776; Gardner and Goff 1984, 0719; Goff et al. 1990, 0557). These border faults exerted strong control on the location and development of the volcanic field (Gardner and Goff 1984, 0719; Gardner et al. 1986, 0310).

Rocks formed before the rift developed are exposed around the margins of and underlie the Española basin. These rocks consist of Mississippian to Permian marine limestones, sandstones, and shales; Mesozoic marine to terrestrial sandstones and shales; and Eocene sandstones, shales, and freshwater limestones. Precambrian rocks—predominantly quartzite, granitic gneiss and schist, and greenstone—are exposed in the cores of the flanking Sangre de Cristo, Nacimiento, and Brazos uplifts (Kelley 1978, 0641). The earliest sediments deposited in the Tertiary Española basin are those of the Abiquiu, Picurís, and Los Piños formations, which consist of tuffaceous sandstones and volcaniclastic conglomerates derived largely from volcanic highlands to the north and northeast. These units range in age from about 28 to 17 million years old (Baldridge et al. 1980, 0527; May 1984, 0536; Ingersoll et al. 1990, 0533).

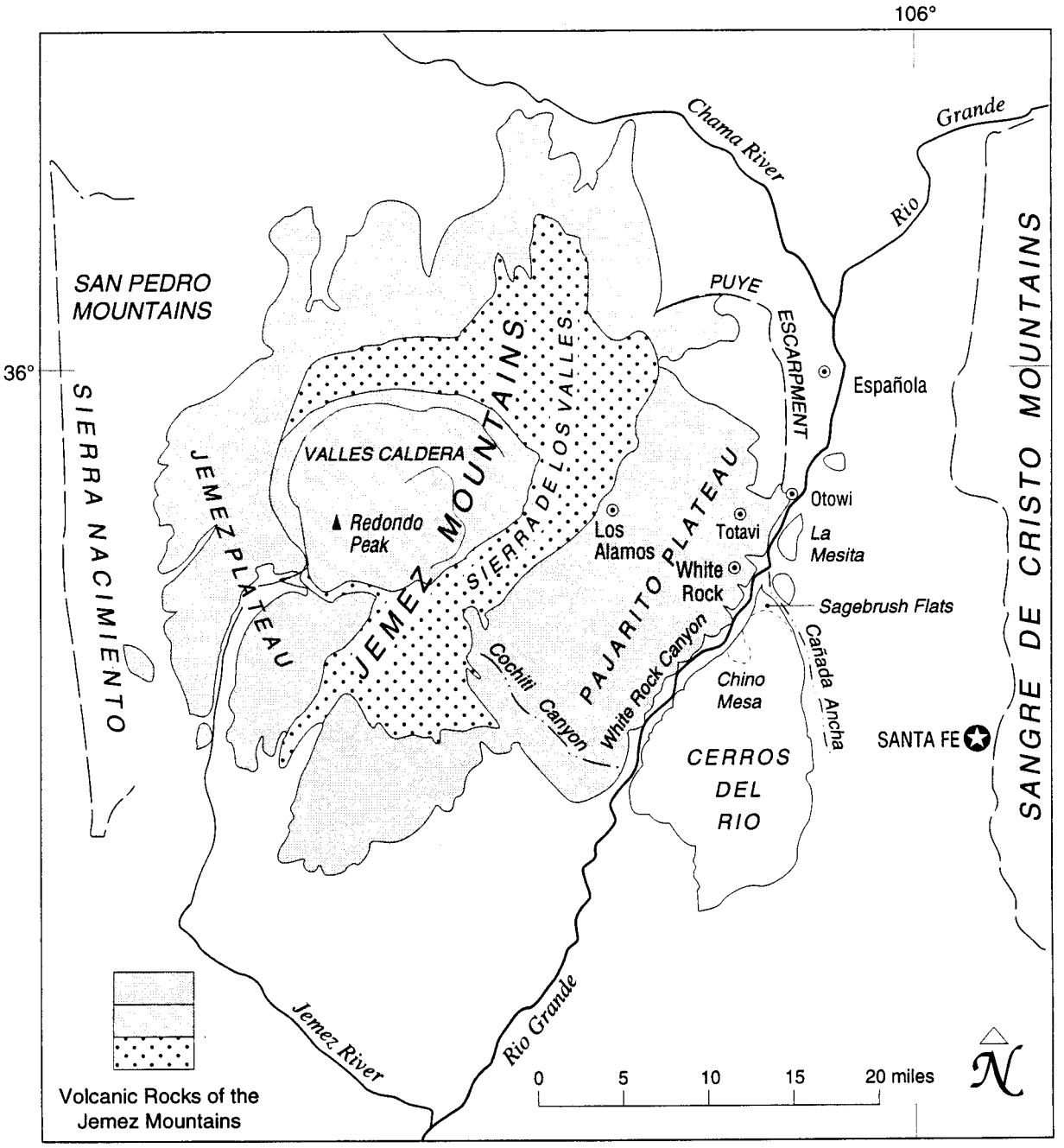

Figure 2-5. General geographic location map showing topographical features in the vicinity of Los Alamos.

2.6.1.2 Stratigraphic Units

Beneath a veneer of soils and alluvial deposits, the mesas of the Pajarito Plateau are immediately underlain by the Bandelier Tuff of Pleistocene age, which is exposed in the canyon walls and is penetrated by numerous drill holes. Beneath the Bandelier Tuff, a sequence of interstratified sedimentary and volcanic rocks of Miocene to Pleistocene age occur, which have been penetrated by water supply wells and which have been studied where they outcrop in canyons on the margins of the Pajarito Plateau. These rock units include volcanic rocks of the Paliza Canyon Formation, Tschicoma Formation, and the Cerros del Rio volcanic field, and sedimentary deposits of the Puye Formation, the Totavi Formation, the Cochiti Formation, and the Santa Fe Group. These units are briefly discussed below. Figure 2-6 is a generalized geologic cross section from west to east of the Laboratory's geologic setting.

2.6.1.2.1 Santa Fe Group

The Santa Fe Group of Miocene and early Pliocene age (formed 18 to 4.5 million years ago) is a thick series of terrestrial conglomerates, sandstones, and mudstones, with minor limestones, evaporites, volcanic tuffs, and intercalated basalts. These rocks are the most extensive units filling the Rio Grande rift, and most production from water wells at Los Alamos is from the Santa Fe Group (Griggs and Hem 1964, 0313; Purtymun 1984, 0196). Sedimentary rocks usually dominate the Santa Fe Group, although basalts constitute up to 45% of the section penetrated by water supply wells at the Laboratory (Purtymun et al. 1984, 0713). In the Española basin and underlying the northern part of Los Alamos County, the Santa Fe Group is subdivided into two formations (Tesuque and Chamita formations) and several members, which reflects the diversity of the coalesced alluvial fans deposited in the Española basin (Galusha and Blick 1971, 0108; Ingersoll et al. 1990, 0533). Early investigators inferred that all Santa Fe Group rocks exposed around the flanks of the Pajarito Plateau and intersected by water wells beneath the plateau belonged to the Tesuque Formation (Griggs and Hem 1964, 0313; Cooper et al. 1965, 0495), although more recent investigations suggest that some of the upper Santa Fe Group in the vicinity of Los Alamos is instead Chamita Formation (Turbeville et al. 1989, 0221).

2.6.1.2.2 Keres Group

Two formations of the Keres Group (Bailey et al. 1969, 0019; Gardner et al. 1986, 0310), may be important in the pre-Bandelier Tuff subsurface in the southern parts of the Laboratory. These are the Paliza Canyon and Cochiti formations, each about 13 million to about 6 or 7 million years old. The St. Peter's Dome area lies about 3 mi from the southern boundary of the Laboratory and was a major center of Keres Group volcanism (Goff et al. 1990, 0557). Large volumes of Paliza Canyon andesite were erupted from the St. Peter's dome center and spread to the east and north. It appears that some of the volcanic units encountered in wells at TA-49 (Weir and Purtymun 1962, 0228) may be Paliza Canyon lavas that have been misidentified as Tschicoma and Cerros del Rio units, as discussed below.

Beneath the southern Pajarito Plateau, sedimentary deposits of the Cochiti Formation compose the Miocene basin fill and are therefore laterally equivalent to the sedimentary rocks of part of the Santa Fe Group and possibly also to those of the Puye Formation (Section 2.6.1.2.4) to the north (Gardner et al. 1986, 0310). The

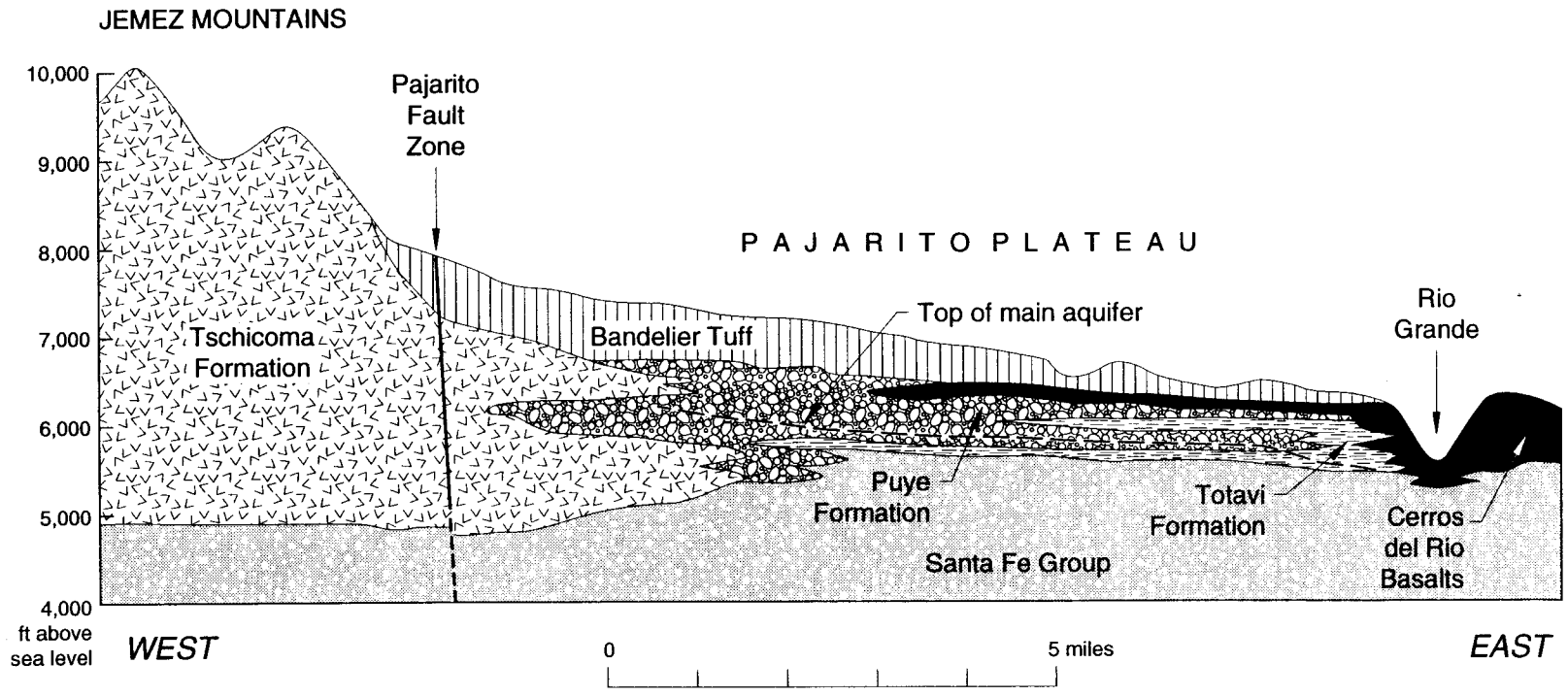

Figure 2-6. Generalized geologic section showing stratigraphy and structure from the Sierra de Los Valles across the Pajarito Plateau to the Rio Grande.

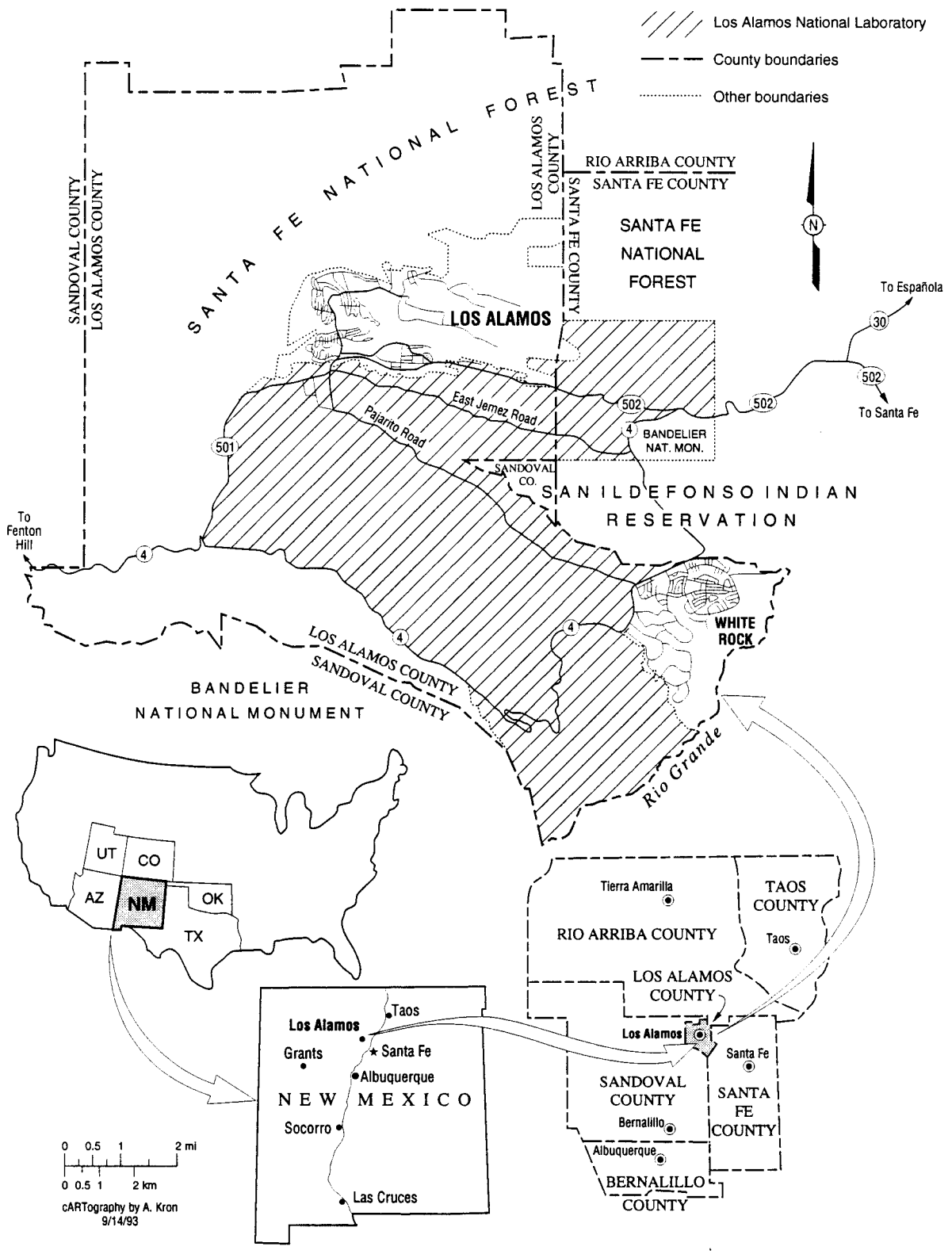

Figure 2-1. Location map of Los Alamos National Laboratory.

2.0 INSTALLATION DESCRIPTION

2.1 Geographic Setting

Los Alamos National Laboratory (the Laboratory) and the neighboring residential areas of Los Alamos and White Rock are located predominantly in Los Alamos County, north-central New Mexico, approximately 60 mi north-northeast of Albuquerque and 25 mi northwest of Santa Fe (Figure 2-1). The 43-mi^2 Laboratory site and the communities adjacent to it are situated on the Pajarito Plateau, which consists of a series of fingerlike mesas separated by deep canyons containing ephemeral and intermittent streams that run from west to east. Mesa tops range in elevation from approximately 7,800 ft on the flank of the Jemez Mountains to about 6,200 ft at their eastern termination above the Rio Grande valley. The eastern margin of the plateau stands 300 to 900 ft above the Rio Grande (DOE 1979, 0051). The Department of Energy (DOE) controls the area within the Laboratory's boundaries and has the option of completely restricting access.

2.2 Mission of Los Alamos National Laboratory

The Laboratory is administered for the DOE by the University of California (UC). Since its inception in 1943, the principal mission of the Laboratory has been the design, development, and testing of weapons for the nation's nuclear arsenal. This effort is supported by research programs in nuclear physics, hydrodynamics, conventional explosives, chemistry, metallurgy, radiochemistry, and biology. In addition to the weapons program, Laboratory personnel are involved in medium-energy physics; space nuclear systems; controlled thermonuclear fusion; laser research; environmental research; geothermal, solar, and fossil energy research; nuclear safeguards; biomedical research; and space physics. Appendix A summarizes activities at the Laboratory's 49 active technical areas (TAs), which are shown in Figure 2-2.

In August 1977, the Laboratory site was dedicated as a National Environmental Research Park. The ultimate goal of programs associated with this research facility is to encourage environmental research that will contribute understanding of how people can best live in balance with nature while enjoying the benefits of technology. Park resources are available to individuals and organizations outside the Laboratory to facilitate self-supported research on these subjects.

In 1992, the Laboratory expanded its mission to include development of new programs in three nationally significant areas for which it has special capabilities: health and biotechnology, environmental technologies, and industrial partnerships.

2.3 History of Los Alamos National Laboratory

In 1942, the US Army Manhattan Engineer District was established to develop the atomic bomb. The research quickly progressed to a point that necessitated a remote site for experimental work, and the Army selected the Los Alamos Ranch School for Boys as an appropriate location. The Undersecretary of War directed acquisition of the school site, which consisted of a group of some 50 log buildings on a 790-acre site northwest of Santa Fe. The project ultimately acquired an additional 3,120 privately owned acres and 45,666 acres of public land managed by the US Forest Service. In 1943, this land became known as the Los Alamos Site, later Los Alamos Scientific Laboratory.

Cochiti Formation consists dominantly of basin fill gravels derived from the volcanic centers of the southern and central Jemez Mountains volcanic field. The transition between the Cochiti, Santa Fe, and Puye formations probably occurs somewhere beneath Los Alamos County, but it is very poorly defined.

2.6.1.2.3 Tschicoma Formation

The Tschicoma Formation consists of a sequence of dacitic domes and lavas that were erupted from vents in the central to northeastern Jemez Mountains between about 7 and 3 million years ago (Gardner et al. 1986, 0310). These volcanic rocks outcrop extensively in the mountains immediately west of the Laboratory and are reported in the subsurface beneath the western and southern part of the Laboratory (Weir and Purtymun 1962, 0228; Griggs and Hem 1964, 0313; Dransfield and Gardner 1985, 0082).

2.6.1.2.4 Puye Formation

The Puye Formation consists of a Pliocene-to-Pleistocene fanglomerate that was shed eastward from Tschicoma volcanic centers in the northeastern Jemez volcanic field between about 4 and 1.7 million years ago. Earlier workers (e.g., Griggs and Hem 1964, 0313) included the Totavi Lentil, now considered a separate formation (Section 2.6.1.2.5), as part of the Puye Formation. Most of the Puye conglomerates contain cobbles of dacitic to andesitic composition in a volcanic sand matrix. The beds include stream flow deposits, debris flow deposits, volcanic ash and block flow deposits, and ash fall and pumice fall deposits (Waresback and Turbeville 1990, 0543). The Puye Formation is best exposed north of the Laboratory, but lithologically similar rocks have been penetrated in drill holes as far south as Frijoles Mesa (Weir and Purtymun 1962, 0228; Dransfield and Gardner 1985, 0082). Under parts of the Laboratory, the Puye Formation is interstratified with basalts of the Cerros del Rio volcanic field. In Los Alamos water supply wells, the top of the main aquifer is usually within the Puye Formation.

2.6.1.2.5 Totavi Formation

Immediately beneath the fanglomerates of the Puye Formation, unconformably overlying the Santa Fe Group, is a section of poorly consolidated fluvial gravels, which Griggs originally named the Totavi Lentil of the Puye Formation (Griggs and Hem 1964, 0313). The gravels contain clasts that differ lithologically from those in the Puye, including abundant well-rounded cobbles and boulders of quartzite, granite, and pegmatite that record a source area distant from the Jemez Mountains; this unit probably represents axial channel gravels of an ancestral Rio Grande. Recently, Waresback and Turbeville (1990, 0543) redefined these fluvial gravels as a separate formation, the Totavi Formation, which also includes lacustrine sediments that are complexly interstratified with the upper Puye Formation ("old alluvium" of Griggs and Hem 1964, 0313). In some water supply wells beneath the Laboratory, the Totavi was reported between the Santa Fe and the Puye, occurring at lower elevations in the eastern wells (Cooper et al. 1965, 0495; Purtymun et al. 1983, 0712; Purtymun et al. 1984, 0713). The presence of the Totavi at these levels suggests that Rio Grande river gravels were deposited on erosional surfaces, a setting analogous to Quaternary terraces of the Rio Grande in the Española basin described by Dethier et al. (1988, 0773), before deposition of the Puye fans, which unconformably overlie older formations.

2.6.1.2.6 Cerros del Rio Basalts

Basaltic flows, breccias, and scoria of the Cerros del Rio occur in the subsurface beneath much of the Pajarito Plateau (Dransfield and Gardner 1985, 0082) and outcrop in the east and southeast parts of Los Alamos County (Griggs and Hem, 1964, 0313). These volcanic rocks are associated with the Pliocene-to-Pleistocene Cerros del Rio basalt field, east of the Rio Grande, and rocks from this field have been dated at 4.6 to 2.0 million years old (Gardner et al. 1986, 0310). The youngest lava flows in this area occurred between the two Bandelier Tuff eruptions, 1.5 and 1.13 million years ago ("basaltic andesite of Tank Nineteen" described by Smith et al. 1970, 0776). Part of this volcanic field is also known as basaltic rocks of Chino Mesa (Griggs and Hem 1964, 0313). The top of the main aquifer beneath the Laboratory is locally within this section of basaltic rocks.

2.6.1.2.7 Otowi Member, Bandelier Tuff

The Otowi Member of the Bandelier Tuff underlies the Tshirege Member in the subsurface beneath much of the Pajarito Plateau and outcrops in many of the canyons (Griggs and Hem 1964, 0313). The Otowi Member is mostly a nonwelded ash flow tuff (ignimbrite) that was erupted from the Jemez Mountains 1.5 million years ago (Spell et al. 1990, 0607). It is highly porous and poorly indurated and is composed of multiple flow units. Where it outcrops, cooling joints are typically absent because of relatively low emplacement temperatures and the lack of induration. The Guaje Pumice Bed generally occurs at the base of the Otowi Member and consists of sorted pumice fragments that average 0.8 to 1.6 in. in size (Crowe et al. 1978, 0041).

2.6.1.2.8 Cerro Toledo Rhyolite and Interbedded Sediments

An interbedded sequence of rhyolitic tuffs and sediments commonly occurs between the Otowi and Tshirege members of the Bandelier Tuff. The rhyolitic tuffs were erupted between 1.5 and 1.2 million years ago, predominantly from the Cerro Toledo domes in the northeastern Jemez Mountains (Heiken et al. 1986, 0316). Beneath the Pajarito Plateau, the sediments are epiclastic sands and sandy gravels that lithologically resemble Puye Formation fanglomerates. At the Laboratory, deposits in this interval have sometimes been referred to as "Tsankawi pumice" or "Tsankawi member." These units may play an important role in the migration of water in the subsurface beneath the Laboratory (Stoker et al. 1991, 0715).

2.6.1.2.9 Tshirege Member, Bandelier Tuff

The most widespread rock unit on the Pajarito Plateau is the Tshirege Member of the Bandelier Tuff (Griggs and Hem 1964, 0313), which was erupted from the Valles caldera in the Jemez Mountains about 1.13 million years ago (Spell et al. 1990, 0607). The Tshirege Member is composed of multiple flow units of crystal-rich ash-flow tuff (ignimbrite) and displays significant variations in welding and alteration, both in a single stratigraphic section and with varying distance from the caldera. Individual units tend to be more welded and thicker to the west. Flow units are locally separated by volcanic surge deposits of well-sorted, fine-grained, cross-bedded crystal and pumice fragments. Vapor phase alteration, caused by postemplacement cooling and migration of entrained magmatic gases, occurs in much of this unit. The base

of the Tshirege Member is often marked by 1.5 to 10 ft of bedded, unconsolidated, pumice-rich ash fall tuff of the Tsankawi Pumice Bed (Bailey et al. 1969, 0019; Crowe et al. 1978, 0041). The Tsankawi Pumice Bed is generally poorly recognized in drill bit cuttings because rotary drills commonly grind the soft materials into dust.

The Tshirege Member has been subdivided into a sequence of mappable units based either on erosional characteristics (Weir and Purtymun 1962, 0228; Baltz et al. 1963, 0024; Purtymun and Kennedy 1971, 0200) or on primary cooling units (Crowe et al. 1978, 0041). These units have been correlated over large distances on the Pajarito Plateau. However, the boundaries between the units are not always distinct in the field and can be difficult to recognize in drill holes, causing investigators to place the contacts between units at different locations. Furthermore, in the absence of geologic mapping in the intervening areas, the validity of the correlations is uncertain.

Stratigraphic features in the tuff, such as volcanic surge deposits, may locally provide a preferential migration pathway for moisture and contaminants in the subsurface (Purtymun 1973, 0710; Crowe et al. 1978, 0041). Purtymun (1973, 0710) noted increased rates of vapor phase migration of tritium away from storage shafts at TA-54 along a stratigraphic boundary that includes surge layers. Individual flow units in the Tshirege Member contain vertical cooling joints that may or may not cross flow unit boundaries. In ash flow tuffs, cooling joint spacing varies primarily with the thickness of the unit, emplacement temperature, substrate temperature, and topography. Joint density tends to be greatest in welded tuff and least in nonwelded tuff. Hydraulic conductivities are generally greatest in the fractured, welded parts of ash flow tuffs and least in the nonwelded parts (Crowe et al. 1978, 0041).

2.6.1.2.10 Post-Bandelier Units

Stratigraphically overlying the Bandelier Tuff are discontinuous Quaternary alluvial units that occur as thin deposits (typically less than 15 ft thick) on mesa tops and as deposits in canyons. Alluvial fans consisting mostly of dacite debris are being shed over the Bandelier Tuff at the western boundary of the Laboratory. Well-sorted to poorly sorted sandy and gravelly alluvium occurs in the major drainages of the Pajarito Plateau, ranging up to at least 70 ft thick in some drill holes (Baltz et al. 1963, 0024). Additional, older alluvium occurs on stream terraces on the sides of the canyons, which can be buried by colluvial deposits from the canyon walls. The distribution of alluvial deposits on the mesas has not been mapped, but these deposits are most widespread on the western part of the Pajarito Plateau. Post-Bandelier alluvial units represent a range of ages from 1.1 million years ago to the present. Generally, alluvial units on the surface of the mesas are probably oldest, becoming inactive as drainages were incised into the plateau. Those units lowest in the drainages grade into the active alluvium along canyon bottoms.

The alluvial sediments in the canyon bottoms probably record a complex history of erosion and deposition, in part related to regional climatic changes. In Cabra Canyon, immediately north of Los Alamos, several cycles of erosion and deposition of sediment have occurred over the last 6,000 years, during which most of the previously stored sediment was eroded (Gardner et al. 1990, 0639). Similar cycles of erosion and deposition have been documented in many parts of the southwestern United States, and the older alluvial units in the vicinity of Los Alamos may also record the effects of regional climatic changes (Dethier et al. 1988, 0773).

The mesas of the Pajarito Plateau are also covered in part by deposits of the El Cajete pumice, erupted from El Cajete crater in the Jemez Mountains. Deposits of pumice on the mesas have not been mapped, but at the Laboratory they are generally most common to the south, and the axis of the volcanic dispersal plume is south of Los Alamos County. Available data suggest that the El Cajete pumice is 130,000 to 170,000 years old (Self et al. 1988, 0500).

2.6.1.3 Soils

A large variety of soils have developed on the Pajarito Plateau as the result of interactions of the underlying bedrock, slope, and climate (Nyhan et al. 1978, 0161). The mineral components of the soils are in large part derived from the Bandelier Tuff, but dacitic lavas of the Tschicoma Formation, basalts of the Cerros del Rio volcanic field, and sedimentary rocks of the Puye Formation are locally important. Alluvium derived from the Pajarito Plateau and from the east side of the Jemez Mountains contributes to soils in the canyons and also to those on some of the mesa tops. Layers of pumice derived from El Cajete in the Jemez Mountains and windblown sediment derived from other parts of New Mexico are also significant components of many soils on the Pajarito Plateau.

Soils formed on the tops of mesas on the Pajarito Plateau include the Carjo, Frijoles, Hackroy, Nyjack, Pogna, Prieta, Seaby, and Tocal series. These soils typically have loam or sandy loam surface horizons and clay or clay loam subsurface horizons. Some, including the Frijoles, Hackroy, and Seaby soils, contain abundant pumice. Others, including the Prieta soils, contain abundant wind-deposited sediment. Soils on the mesas can vary widely in thickness and are typically thinnest near the edges of the mesas, where bedrock is often exposed. Soils formed from alluvial and colluvial deposits include the Potrillo, Puye, and Totavi series and are generally loose and sandy. The slopes between the mesa tops and canyon bottoms often consist of steep rock outcrops and patches of shallow, undeveloped colluvial soils. South-facing canyon walls are steep and usually have little or no soil material or vegetation; in contrast, the north-facing walls generally have areas of very shallow, dark-colored soils and are more heavily vegetated (Nyhan et al. 1978, 0161).

Soil-forming processes extend along fractures in bedrock, and coatings of clay and calcium carbonate on fractures record the transport of water to significant depths in the tuff. For example, at TA-54, Area G, calcium carbonate has been observed as deep as 39 ft and clay coatings as deep as 46 ft below the ground surface (Purtymun et al. 1978, 0207). Roots have also been observed at similar depths along fractures in core holes and pits, suggesting that these soil-forming processes continue at depth today.

2.6.1.4 Geologic Structure

As mentioned earlier, the Laboratory is on the Pajarito Plateau, which lies at the western margin of the Española basin of the Rio Grande rift, a major tectonic feature of the North American continent. The Pajarito fault system forms the western margin of the Española basin and exhibits Holocene movement and historic seismicity (Gardner and House 1987, 0110; Gardner et al. 1990, 0639; Gardner and House, in preparation, 0720). The fault system is made up of over 65 mi of mapped fault traces and connects with regional structures that extend at least as far as Cochiti to the south and Taos to the northeast (Gardner and House 1987, 0110).

Within Los Alamos County, the Pajarito fault system consists of three active, or potentially active, fault segments: the Frijoles Canyon, Rendija Canyon, and Guaje Mountain segments. The Frijoles Canyon fault segment is a zone of faulting over 0.25 mi in width, whose major scarp forms the western boundary of the Laboratory. Near the southwestern corner of the Laboratory, the major scarp of the Frijoles Canyon segment is over 410 ft high in rocks about 1 million years old. Movement on this fault segment is normal-oblique, and the fault's eastern side is relatively downdropped. Where exposed north of Los Alamos Canyon, the Rendija Canyon and Guaje Mountain faults are characterized by zones of gouge and breccia generally 100 to 150 ft wide. Both fault segments produce visible offsets of stratigraphic horizons and are dominantly normal-oblique faults whose west sides are downdropped. There are some indications of strike-slip movements on the Guaje Mountain fault segment (Wachs et al. 1988, 0502; Aldrich and Dethier 1990, 0017; Gardner et al. 1990, 0639). The youngest movements on the Guaje Mountain segment have been constrained to between roughly 4,000 and 6,000 years ago (Gardner et al. 1990, 0639). Displacement on the Guaje Mountain and Rendija Canyon faults apparently decreases south of Los Alamos Canyon, and narrow zones of faulting are replaced by wide (over 300 ft) zones of intense brecciation and fracturing superimposed on the network of cooling joints in the Bandelier Tuff (Vaniman and Wohletz 1990, 0541). In contrast to cooling joints, these tectonic fractures cross flow unit and lithologic unit boundaries; thus, tectonic fractures may provide more continuous and more deeply penetrating flow paths for groundwater migration than do cooling joints.

Dransfield and Gardner (1985, 0082) integrated a variety of data to produce structure contour and paleogeologic maps of the pre-Bandelier Tuff surface beneath the Pajarito Plateau. Their maps reveal that subsurface rock units are cut by a series of down-to-the-west normal faults; the overlying Bandelier Tuff is not obviously displaced by these buried faults. However, where detailed fracture studies have been done on the plateau, they have shown that fracture abundances and apertures increase in the Bandelier Tuff over fault projections, which indicates the tectonic fracturing mentioned above (Vaniman and Wohletz 1990, 0541). In addition, small-scale offsets along fractures have been observed in various parts of the Laboratory, including Area G at TA-54 (Rogers 1977, 0216), that suggest additional unmapped fault zones. Unfortunately, detailed fracture studies on the Pajarito Plateau are few.

2.6.1.5 Seismicity and Volcanism

The Laboratory lies within a region that possesses a long and rich history of volcanic and tectonic activity that dates from the distant past into the Late Pleistocene and present, respectively. Volcanism began in the Jemez Mountains volcanic field more than 13 million years ago and continued without significant hiatus up through about 130,000 years ago (Gardner et al. 1986, 0310). Reports of questionable reliability describe what were apparently phreatic explosions and possible associated earthquakes within the volcanic field around 100 years ago (Santa Fe *Daily New Mexican* 1882, 0780). Regardless, given the long history of spatially focused, geologically continuous volcanic activity, future volcanism can be expected. Although volcanic activity directly affecting the Laboratory may prove unlikely, sufficient data to quantify the probabilities and nature of future volcanism are lacking.

Direct effects of future seismicity at the Laboratory are likely, although quantification of probabilities is not possible at present. Numerous small earthquakes are recorded in the Los Alamos area and northern New Mexico each year (Sanford 1979, 0540; Cash and Wolff 1984, 0530; Gardner and House 1987, 0110). Since establishment

of the Laboratory, several earthquakes of Richter magnitude 3 to 4 have shaken Los Alamos (Gardner and House 1987, 0110). Recent work has shown that three fault segments in Los Alamos County are seismically active and that they are capable of generating large earthquakes of about 7 or more on the Richter scale (Gardner and House 1987, 0110; House and Cash 1988, 0132; Gardner et al. 1990, 0639; Gardner and House, in preparation, 0720). Unknown at this time are how frequently these large earthquakes occur and what their potential is for generating surface rupture and mass wasting (occurrences such as rockfalls and landslides, which are not caused primarily by the movement of water) within the confines of the Laboratory.

2.6.1.6 Geomorphic Processes

Significant geomorphic processes active on the Pajarito Plateau include (1) erosion of mesa top soils by run-off, (2) retreat of canyon walls by rockfall and landsliding, (3) colluvial transport on sloping portions of canyon walls, and (4) erosion and deposition of sediments by streams in the canyon bottoms. Few data exist on the rates of erosion and landscape change caused by these different processes on the Pajarito Plateau. Estimates of long-term vertical erosion rates on mesa tops have been made based on stripping of overlying units (Purtymun and Kennedy 1971, 0200), but these estimates may be of limited value because the resistant, cliff-forming units may be eroded primarily by lateral cliff retreat rather than by vertical erosion. Erosion rates vary considerably on the mesa tops; the highest rates occur in and near drainage channels and in areas of locally steeper slope gradient, and the lowest rates occur on relatively gently sloping portions of the mesa tops removed from channels. Areas where run-off is concentrated by roads and other development are especially prone to accelerated erosion.

The rates and processes of erosion may differ significantly between the north and south slopes of canyons. Given current vegetation and climate, the more extensive exposures of bedrock on south-facing sides and greater soil cover on north-facing sides suggest that erosion rates of fine-grained material that can be transported by run-off are higher on the drier, less-vegetated, south-facing sides of canyons, although this material is largely retained on the north-facing slopes. However, no studies have been conducted to quantify the rates and processes of erosion on canyon sides.

Cliff faces retreat primarily by dislodgement of blocks bounded by joints and, to a lesser extent, by large-scale landsliding, including the formation of huge toreva blocks in White Rock Canyon. At present, the rates of cliff retreat have not been documented. Neither is it known to what extent cliff retreat rates may vary with climatic changes, with evolution of the canyons, or with proximity to side drainages.

Thicknesses, detailed stratigraphy, and ages of alluvium in canyon bottoms are, in general, poorly known, and therefore the rates of deposition, erosion, and transport of sediments through canyons are largely unknown. Available studies that have examined alluvial stratigraphy on the Pajarito Plateau reveal multiple cycles of extensive erosion of sediment, followed by renewed deposition, in the past 6,000 years (Gardner et al. 1990, 0639). At Cabra Canyon, north of Los Alamos, the last few hundred years has been marked by the net accumulation of sediment in the canyon bottom (Gardner et al. 1990, 0639), but it is not known how long this sediment will stay in storage before being mobilized by floods and transported downcanyon. It is possible that these erosional cycles are climatically driven and regional in extent, but more extensive data from additional canyons are needed before this determination can be made. On a longer time scale, evidence from the adjacent Española

basin does suggest a strong climatic control on periods of alluviation and canyon incision over the last million years (Dethier et al. 1988, 0773).

2.6.2 Hydrology

2.6.2.1 General Surface Water Conditions

The Rio Grande is the master stream in north-central New Mexico. All surface water drainage and groundwater discharge from the plateau ultimately arrives at the Rio Grande. The Rio Grande at Otowi, just east of Los Alamos, has a drainage area of 14,300 mi2 in southern Colorado and northern New Mexico. The discharge for the period of record has ranged from a minimum of 60 cubic feet per second (cfs) in 1902 to 24,400 cfs in 1920. The river transports about 1 million tons of suspended sediments past Otowi annually.

Essentially all Rio Grande flow downstream of the Laboratory passes through Cochiti Reservoir, which began filling in 1976. It is designed to provide flood control, sediment retention, recreation, and fishery development. Flood flows are temporarily stored and released at safe rates. The dam is expected to trap at least 90% of the sediments carried by the Rio Grande.

Los Alamos surface water occurs primarily as ephemeral streams in canyons cut into the Pajarito Plateau. Only four of the canyons contain perennial reaches inside Laboratory boundaries: Pajarito, Water, Ancho, and Chaquehui canyons. Of these four reaches, only Pajarito Canyon occurs upstream (to the west) of any Laboratory facilities or effluent discharge points. Other perennial reaches occur outside Laboratory lands in the drainage areas of Guaje, Los Alamos, Sandia, Pajarito, Water (and its tributary Cañon del Valle), Ancho, and Chaquehui canyons.

Within Laboratory boundaries, perennial reaches in the lower portions of Ancho and Chaquehui canyon are close enough to the Rio Grande that they extend to the Rio Grande without being depleted. In lower Water Canyon, the perennial reach is very short, extends into an intermittent reach that is also short, and does not extend to the Rio Grande. In Pajarito Canyon, about 1 mi east of State Road 501, a spring sometimes called Homestead Spring feeds a perennial reach a few hundred yards long, followed by an intermittent reach that flows varying distances, depending on climate conditions.

Essentially all other reaches of canyons within the Laboratory boundary are ephemeral; that is, they flow naturally only briefly in response to precipitation or snowmelt in the immediate locality. Some other reaches are intermittent, especially those that flow during part of the year as the result of snowmelt. This snowmelt recharges the alluvial perched groundwater, and discharge from the perched systems supports intermittent stream flow for a somewhat longer period.

Springs between elevations 7,900 and 8,900 ft mean sea level on the flanks of the Jemez Mountains supply base flow throughout the year to the upper reaches of Cañon de Valle and in Guaje, Los Alamos, Pajarito, and Water canyons (Purtymun 1975, 0194). These springs discharge water perched in the Bandelier Tuff and Tschicoma Formation at rates from 2 to 135 gal./min (Abeele et al. 1981, 0009). The volume of flow from the springs is insufficient to maintain surface flow within more than the western third of the canyons before it is depleted by evaporation, transpiration, and infiltration into the underlying alluvium.

Eleven drainage areas, with a total area of 82 mi2, pass through the Laboratory's eastern boundary. Run-off from heavy thunderstorms and heavy snowmelt reaches the Rio Grande several times a year in some drainages. Los Alamos, Pajarito, and Water canyons have drainage areas at the east boundary of greater than 10 mi^2. Pueblo Canyon has 8 mi^2, and all the rest have less than 5 mi^2. Theoretical maximum flood peaks range from 24 cfs for a 2-year frequency to 686 cfs for a 50-year frequency (McLin 1992, 0825). The overall flooding risk to community and Laboratory buildings is low because nearly all the structures are located on the mesa tops, from which run-off drains rapidly into the deep canyons.

Contaminants enter the surface water drainages by surface run-off, by liquid discharges, and occasionally by air deposition (Becker 1985, 0029; 1986, 0027). Run-off-derived contaminants are largely bound to sediments; their rate of downstream travel is governed by the scouring and carrying power of subsequent run-off events (Lane et al. 1985, 0140). Given sufficient time, these sediments eventually will be moved across the Laboratory boundary.

Nearly every drainage has received liquid industrial or sanitary effluents discharged from the Laboratory. The effluent discharges determine the flow and water quality characteristics in drainages that contain little natural water. With travel downstream, most of the effluent-derived metals and radionuclides become sediment bound and remain near the surface of the stream channel; other contaminants, such as nitrate, are lost by evaporation or move downward into the alluvium. Detailed field investigations in Mortandad Canyon, for example, demonstrate that generally more than 99% of the total inventory of transuranic radioactivity discharged (Gallaher, in preparation, 1019) from the treatment plant effluents are associated with sediments in or immediately adjacent to the stream channel (Stoker et al. 1991, 0715).

In canyons that have received treated, low-level radioactive effluents (Acid-Pueblo, DP-Los Alamos, and Mortandad canyons) concentrations of radioactivity in the alluvium are generally highest near the treated effluent outfall and decrease downstream in the canyon as the sediments and radionuclides are transported and dispersed by other treated industrial effluents, sanitary effluents, and surface run-off.

A study of transport of plutonium by snowmelt run-off was published in 1990 (Purtymun et al. 1990, 0215). The conclusions include the finding that most plutonium moved by run-off in Los Alamos and Pueblo canyons that reached the Rio Grande is transported with sediments—about 57% with suspended sediments and 40% with bed sediments. A total of about 600 mCi of plutonium was carried to the Rio Grande by five snowmelt run-off events studied during the years 1975 to 1986.

Environmental monitoring for chemical and radiochemical quality in surface water began with US Geological Survey investigations (Purtymun 1964, 0183; 1975, 0194; Purtymun and Kunkler 1967, 0202; Purtymun 1967, 0188) and have been continued by the Laboratory (ESG 1970-1990; Environmental Protection Group 1993, 0829).

2.6.2.2 Natural Surface Flow Characteristics by Drainage

Figure 2-7 shows the location of the major surface water drainages in the Los Alamos area. The highlights of surface flow characteristics are presented below.

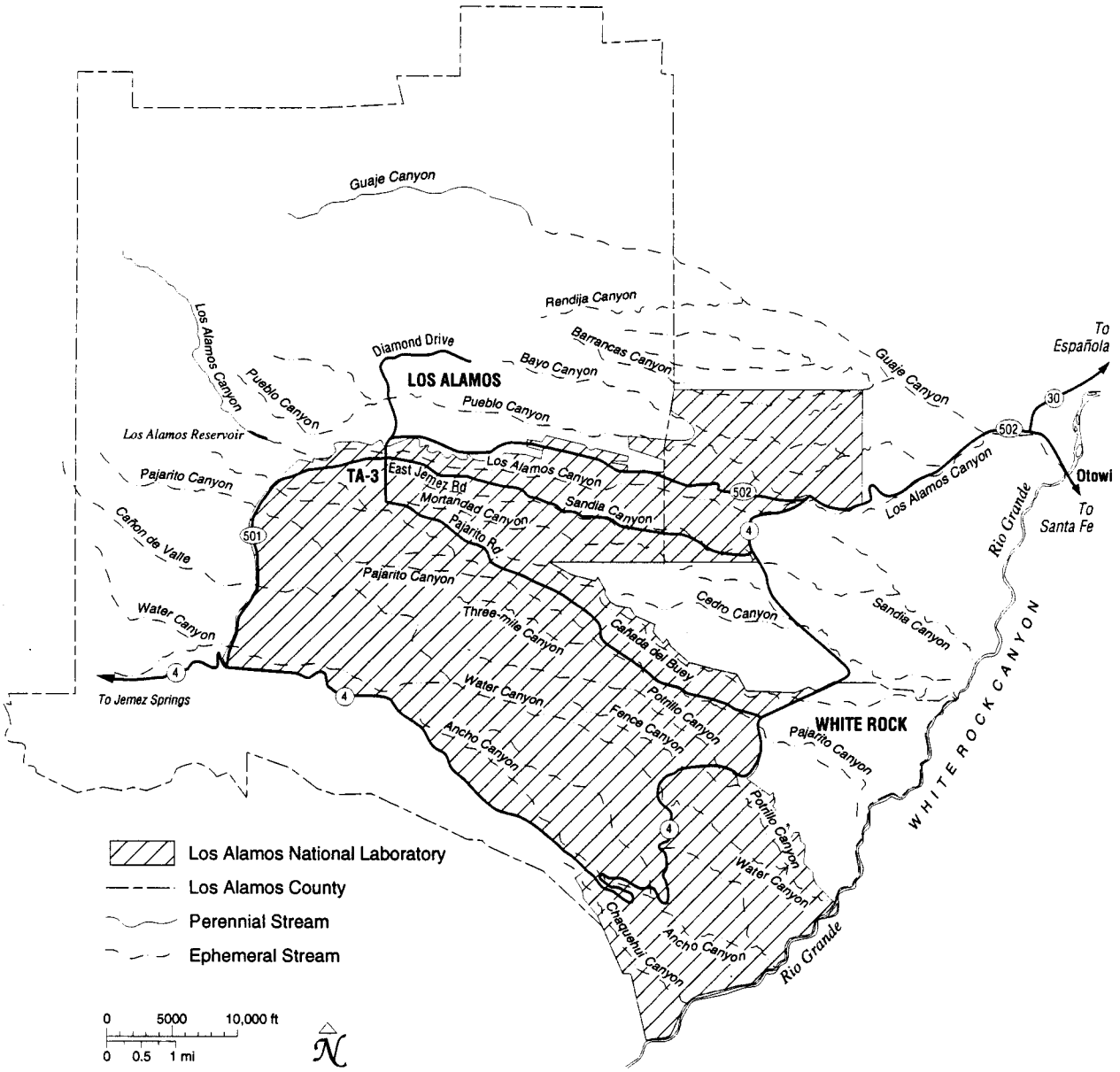

Figure 2-7. Location of the major surface water drainages in the Los Alamos area.

2.6.2.2.1 Guaje Canyon

Guaje Canyon is the largest single drainage, with a total area of about 26 mi2. It heads in the Sierra de Los Valles on US Forest Service lands. None of Guaje Canyon proper is within the Laboratory boundary; however, the facilities of the Guaje Water Supply Well Field are located in Guaje Canyon. Its tributary, Barrancas Canyon, drains part of the northeast portion of the Laboratory. Guaje Canyon then crosses San Ildefonso Pueblo lands to its confluence with Los Alamos Canyon, which is within about a mile of the confluence of Los Alamos Canyon and the Rio Grande.

On a regional scale, Guaje is an interrupted stream. It has a perennial reach extending from springs upstream of the reservoir to some distance downstream from the Guaje reservoir and an intermittent reach for an additional distance. Most of it, however, is ephemeral, and is dry most of the year in its lower reach before joining Los Alamos Canyon. Snowmelt does not reach the Rio Grande from Guaje.

Thunderstorm run-off from Guaje Canyon occasionally reaches the Rio Grande through Los Alamos Canyon. The estimated 24-hr run-off for a 2-yr-recurrence, 6-hr event at the confluence with Los Alamos Canyon is about 8 acre-ft (McLin 1992, 0825). This run-off would be expected to flow on through a short reach of lower Los Alamos Canyon to the Rio Grande.

2.6.2.2.2 Bayo Canyon

Bayo Canyon heads on the plateau on land owned by Los Alamos County. It has a total drainage area of about 4 mi2. Bayo Canyon extends across the northeast part of the Laboratory before it crosses San Ildefonso Pueblo lands to the point of its confluence with Los Alamos Canyon. In the past, the Laboratory conducted some of its activities in part of Bayo Canyon. No discharges regulated under the National Pollutant Discharge Elimination System are currently made into Bayo Canyon. Bayo is entirely ephemeral and has neither springs nor perennial reaches. No significant snowmelt occurs in Bayo.

The estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm is calculated to be less than 1 acre-ft near the eastern Laboratory boundary near the confluence of Bayo Canyon with Los Alamos Canyon (McLin 1992, 0825), and that flow would not be expected to extend through Los Alamos Canyon to reach the Rio Grande.

2.6.2.2.3 Pueblo Canyon

Pueblo Canyon heads on the flanks of the Sierra de Los Valles. It has a total drainage area of about 8.4 mi2. It originates on US Forest Service lands, extends across land owned by Los Alamos County, and then crosses the northeast part of the Laboratory to the point of its confluence with Los Alamos Canyon, which is slightly west of the boundary between the Laboratory and San Ildefonso Pueblo. Pueblo Canyon is entirely ephemeral and has neither springs nor perennial reaches. Snowmelt from the upper reaches occasionally extends downstream as far as the townsite but does not normally reach Laboratory lands.

Continuous, effluent-supported flow occurs in the lower reach of Pueblo Canyon because it receives discharge from the sanitary wastewater treatment plant oper-

ated by Los Alamos County. This flow continues on into the lower reach of Los Alamos Canyon and is discussed in the next section on Los Alamos Canyon.

The estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm at the confluence of Pueblo Canyon with Los Alamos Canyon (within the Laboratory boundary) is about 4 acre-ft (McLin 1992, 0825). Assuming continued saturation of the alluvium by discharge from the sanitary wastewater treatment plant in Pueblo Canyon, this flow would probably extend through Los Alamos Canyon to reach the Rio Grande.

2.6.2.2.4 Los Alamos Canyon

Los Alamos Canyon heads on the flanks of the Sierra de Los Valles. It drains a total area of about 59 mi2 (including its major tributaries). It originates on US Forest Service lands and extends across the north central part of the Laboratory before entering San Ildefonso Pueblo lands a short distance downstream of its confluence with Pueblo Canyon.

On a regional scale, Los Alamos Canyon is an interrupted stream. Several perennial springs occur in the upper reaches of Los Alamos Canyon and in its tributary, Quemazon Canyon. These upper reaches are perennial from the springs down to within a few hundred yards of the Los Alamos reservoir.

In most years, snowmelt adds enough water to the reservoir to overflow and support flow onto the Laboratory lands. Snowmelt extends downstream to the confluence with the Rio Grande about half the time; for example, between 1975 and 1986, snowmelt reached the Rio Grande during five of the years on a total of 205 days, averaging about 41 days a year during those five years or about 4.7 % of the total number of days in the 12-yr period. The estimated 24-hour runoff for a 2-yr-recurrence, 6-hr storm is 22 acre-ft at the confluence with the Rio Grande (McLin 1992, 0825).

Discharge from the sanitary wastewater treatment plant results in effluent-supported flow that regularly continues on into the lower reach of Los Alamos Canyon. The effluent-supported flow combines with perennial flow from Basalt Spring on San Ildefonso Pueblo lands just east of the Laboratory boundary. In 1992, the combined flow generally extended in Los Alamos Canyon to about the confluence with Bayo or Guaje canyon. The alluvium has apparently become sufficiently saturated that the surface flow extended to the Rio Grande most of the time during the first three months of 1993.

2.6.2.2.5 Sandia Canyon

Sandia Canyon heads on the plateau within the Laboratory boundary. It has a total drainage area of about 5.7 mi2. The small drainage extends across the central part of the Laboratory. No perennial springs or perennial reaches in Sandia Canyon occur within Laboratory lands. Sandia Canyon is ephemeral within the Laboratory boundaries. No significant snowmelt occurs in Sandia Canyon.

The estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm at the location where Sandia Canyon crosses State Road 4 is less than 1 acre-ft (McLin 1992, 0825); this run-off is not expected to extend to the confluence with the Rio Grande, about 4 mi farther downstream.

A significant effluent-supported flow arising from the major discharge of treated sanitary sewage effluent occurs in Sandia Canyon and typically extends about 2.5 to 3 mi downstream.

About 3 miles east of the Laboratory boundary, on San Ildefonso Pueblo lands, a perennial spring, known as Sandia Spring, supports a perennial flow for a few hundred yards. This flow does not normally reach the Rio Grande. The spring is fed by water from the main aquifer.

2.6.2.2.6 Mortandad Canyon

Mortandad Canyon, which heads on the plateau, has a total drainage area of about 5.9 mi2, or a total of 10.4 mi^2 including Cañada del Buey. The small drainage originates within the Laboratory, crosses the central part of the Laboratory, and extends across San Ildefonso lands down to the Rio Grande. Mortandad Canyon is entirely ephemeral; neither perennial springs nor perennial reaches occur in Mortandad Canyon. No significant snowmelt occurs in Mortandad Canyon.

The theoretically estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm at the boundary of Laboratory and San Ildefonso lands is less than 1 acre-ft; this run-off would not be expected to extend to the confluence with the Rio Grande. The conservative nature of the calculated estimates is supported by environmental sampling data and physical observation that there has not been any continuous flow from the upper or middle reaches of Mortandad Canyon to or across the eastern Laboratory boundary with San Ildefonso Pueblo for the last 33 yr (Environmental Protection Group 1993, 0829).

Cañada del Buey joins Mortandad Canyon about 1/2 mi upstream from the confluence with the Rio Grande. Cañada del Buey is entirely ephemeral in character. The county-operated sewage treatment plant in White Rock discharges into Cañada del Buey about 2 mi upstream of its confluence with Mortandad Canyon. This discharge results in effluent-supported surface flow that regularly extends to the Rio Grande.

The theoretically estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm in the subdrainage of Cañada del Buey within the eastern boundary of the Laboratory is less than 1 acre-ft (McLin 1992, 0825). The theoretically estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm in all of Cañada del Buey at the Rio Grande is about 6 acre-ft.

2.6.2.2.7 Pajarito Canyon

Pajarito Canyon heads on the flanks of the Sierra de Los Valles. It has a total drainage area of about 13.6 mi2, including its major subdrainages known as Two-Mile Canyon and Three-Mile Canyon. It originates on US Forest Service lands and extends across the south-central part of the Laboratory before entering Los Alamos County lands in White Rock.

On a regional scale, Pajarito Canyon is an interrupted stream attributable to several perennial springs in the upper reaches of Pajarito Canyon that support flow in a perennial reach followed by an intermittent reach to within about a half mile west of the Laboratory boundary. Pajarito Canyon then has an ephemeral reach extending downstream to a point about 1 mi east of the Laboratory boundary. At this point,

Homestead Spring supports another perennial reach for at least several hundred yards, followed by an intermittent and/or ephemeral reach that may extend down to near its confluence with Three-Mile Canyon. Homestead Spring is probably groundwater run-off of alluvial perched water recharged from west of the Laboratory boundary; this inference is supported by a tritium measurement that indicates the water is not likely more than a couple decades old (Adams and Goff 1991, 0959). Both Two-Mile and Three-Mile canyons are ephemeral and/or intermittent because of groundwater run-off of alluvial water recharged by snowmelt.

East of the confluence with Three-Mile Canyon, Pajarito Canyon is ephemeral across Laboratory land, on east across Los Alamos County lands through White Rock, down to a point about 0.4 mi upstream from its confluence with the Rio Grande. At this point, a large perennial spring fed from the main aquifer, identified as Spring 4A and commonly called Pajarito Spring, supports perennial flow the remainder of the distance to the confluence with the Rio Grande.

In most years, snowmelt extends onto Laboratory lands for periods ranging from a few days to a few weeks and may extend down to or below the confluence with Three-Mile Canyon. Snowmelt occasionally extends downstream as far as the confluence with the Rio Grande.

The estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm at the Laboratory boundary with White Rock is 2 acre-ft and, at the confluence with the Rio Grande, about 6 acre-ft (McLin 1992, 0825).

2.6.2.2.8 Water Canyon

Water Canyon, which heads on the flanks of the Sierra de Los Valles, drains a total area of about 19.5 mi2. It originates on US Forest Service lands and extends across the southern portion of the Laboratory all the way to its confluence with the Rio Grande in White Rock Canyon.

On a regional scale, Water Canyon is an interrupted stream attributable to several perennial springs in the upper reaches of Water Canyon, including Armistead, American, and other springs in the upper reaches of Cañon de Valle (the major subdrainage to Water Canyon). These springs support perennial reaches followed by intermittent reaches limited to the area west of the boundary of the Laboratory and State Road 501.

Water Canyon, and its major tributary, Cañon del Valle, are ephemeral from the western Laboratory boundary all the way across all the active technical areas and on east past State Road 4 down to a point below the confluence with its tributary, Potrillo Canyon. At this point, there is a small perennial spring, known as Spring 5AA, fed by the main aquifer that supports a very short perennial reach. This flow does not extend to the Rio Grande.

Frequently, some regular anthropogenic flow occurs in part of Water Canyon in a reach that extends from near the southwest corner of the Laboratory boundary to a point slightly downstream of the confluence with its tributary, Cañon del Valle. This flow occurs because all of the flow from the Water Canyon Gallery is contained and diverted through a pipeline to a microstrainer facility near State Road 501. When the water from the gallery is not used for industrial supply, it is released and flows through stormwater drainages back into the Water Canyon drainage.

Snowmelt in Water Canyon seldom extends downstream as far as the Laboratory boundary. However, on one occasion in the early 1970s, it extended all the way to the Rio Grande (Gallaher 1993, 1057).

The estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm at the confluence with the Rio Grande is about 2 acre-ft (McLin 1992, 0825).

The tributary Potrillo Canyon, and its tributary Fence Canyon, are entirely ephemeral in character. Based on simulations, run-off flows in these tributaries are not expected to reach the Rio Grande.

2.6.2.2.9 Ancho Canyon

Ancho Canyon, which heads on the plateau within the Laboratory near the middle of the southern Laboratory boundary, has a total drainage area of about 7 mi2. It extends across Laboratory lands all the way to its confluence with the Rio Grande.

Ancho Canyon is ephemeral within the active Laboratory technical areas and on to the east past State Road 4 to a point about 0.8 mi upstream from its confluence with the Rio Grande. At that point, a perennial spring, fed by the main aquifer and known as Ancho Spring, supports a perennial flow all the way to the confluence with the Rio Grande. No significant snowmelt occurs in Ancho Canyon.

The estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm at the confluence with the Rio Grande is about 1 acre-ft.

2.6.2.2.10 Chaquehui Canyon

Chaquehui Canyon, which heads on the plateau in the southeastern corner of the Laboratory, has a drainage area of about 1.5 mi2. It extends across Laboratory lands all the way to its confluence with the Rio Grande.

Chaquehui Canyon is ephemeral all the way down to a point about 1/2 mi upstream from its confluence with the Rio Grande. At this point, a perennial spring, fed by the main aquifer and known as Doe Spring, supports perennial flow for a short distance, followed by a short intermittent reach. About 1/4 mi upstream from the confluence with the Rio Grande, perennial flow from Springs 9 and 9A supports perennial flow that extends to the Rio Grande. No significant snowmelt occurs in Chaquehui Canyon.

The estimated 24-hr run-off for a 2-yr-recurrence, 6-hr storm at the Rio Grande is less than 1 acre-ft, which is not expected to extend to the confluence with the Rio Grande.

2.6.2.3 General Groundwater Conditions

Groundwater occurs in three modes in the Los Alamos Area: (1) water in shallow alluvium in some of the larger canyons, (2) perched groundwater (groundwater body above a less permeable layer that separates it from the underlying main aquifer by an unsaturated zone), and (3) the main aquifer of the Los Alamos area.

2.6.2.3.1 Perched Groundwater in Alluvium

Intermittent and ephemeral streamflows in the canyons of the Pajarito Plateau have deposited alluvium that ranges in thickness to as much as 100 ft. The alluvium in canyons that head on the Jemez Mountains is generally composed of sands, gravels, pebbles, cobbles, and boulders derived from the Tschicoma Formation and Bandelier Tuff on the flank of the mountains. The alluvium in canyons that head on the plateau is comparatively more finely grained, consisting of clays, silts, sands, and gravels derived from the Bandelier Tuff. Saturated hydraulic conductivity of the alluvium typically ranges from 10^{-2} cm/s for a sand to 10^{-4} cm/s for a silty sand (Abeele et al. 1981, 0009).

In contrast to the underlying volcanic tuff and sediments, the alluvium is quite permeable. Ephemeral run-off in some canyons infiltrates the alluvium until downward movement is impeded by the less permeable tuff and sediments, which results in a buildup of a shallow alluvial groundwater body. Depletion by evapotranspiration and movement into the underlying rocks limits the horizontal and vertical extent of the alluvial water (Purtymun et al. 1977, 0206). The limited saturated thickness and extent of the alluvial groundwater preclude its use as a viable source of municipal and industrial supply to the community and the Laboratory. Lateral flow of the alluvial perched groundwaters is in an easterly, down-canyon direction. Tracer studies in Mortandad Canyon have shown that the velocity of water ranges from about 60 ft/day in the upper reach to about 7 ft/day in the lower reach of the canyon (Purtymun 1974, 0192).

The water quality in the alluvial perched groundwaters is variable, depending on the location and history of effluent discharges. In Mortandad Canyon, for example, plutonium concentrations fluctuate up and down in response to variations in treatment plant effluent and storm run-off water, which cause some dilution of the shallow alluvial perched groundwater. Tritium concentrations have fluctuated almost in direct response to the average annual concentration of tritium in the TA-50 effluent, with a lag time of about 1 yr (Environmental Protection Group 1992, 0740).

Purtymun (1975, 0194; 1973, 0191) has written reviews of alluvial perched groundwaters by drainage area. The results of an extensive monitoring study of the alluvial perched groundwater in Mortandad Canyon are presented by Abrahams et al. (1962, 0231), Baltz et al. (1963, 0024), Purtymun (1973, 0191), Purtymun (1974, 0192), Purtymun et al. (1977, 0206), Purtymun et al. (1983, 0209), and Stoker et al. (1991, 0715).

2.6.2.3.2 Perched Water in Volcanic Sediments and Basalts

Perched water bodies occur in the conglomerates and basalts beneath the alluvium in the mid and lower reaches of Pueblo and Los Alamos canyons and in the lower reach of Sandia Canyon. Depth to perched water ranges from about 90 ft in the midreach of Pueblo Canyon to about 450 ft in lower Sandia. The vertical and lateral extent of the perched groundwaters, the nature and extent of perching units, and the potential for migration of perched water to the main aquifer is not fully understood by investigators to date. Only the body in lower Pueblo and Los Alamos canyons has been studied in some detail.

Patterns of chemical quality and water level measurements indicate that the lower perched groundwater in Pueblo Canyon is hydrologically connected to the stream in Pueblo Canyon (Abrahams and Purtymun 1966, 0014). Water from this perched groundwater discharges at the base of the basalt at Basalt Spring, which is off the Laboratory site in lower Los Alamos Canyon on the San Ildefonso Pueblo. The rate of movement of the perched groundwater in this vicinity has been estimated at about 60 ft/day or about 6 mo from recharge to discharge (Abrahams and Purtymun 1966, 0014).

It is unknown whether the perched water systems are hydraulically interconnected. Available data, however, suggest that most of the systems are of limited extent: testing of the perched system in mid-Pueblo Canyon resulted in depletion of the perched groundwater after about an hour's pumping at 2 to 3 gal./min (Weir et al. 1963, 0395). Perched water was encountered in mid-Los Alamos Canyon during the drilling of the Otowi-4 supply well (Stoker et al. 1992, 0826), but it was not reported in an adjacent well (Test Well 3) located 300 ft to the east. (However, Test Well 3 was drilled with a cable tool rig in 1947 and the driller may not have noticed the perched groundwater if it was present.)

Some perched water occurs in volcanics on the flanks of the Jemez Mountains offsite to the west of the Laboratory. This water discharges in several springs (including American and Armistead springs) and provides flow for the gallery in Water Canyon. The gallery contributed to the Los Alamos water supply for 41 years, producing 23 to 96 million gallons annually.

2.6.2.3.3 Main Aquifer

The main aquifer of the Los Alamos area is the only aquifer capable of large-scale municipal water supply (Purtymun 1984, 0196). In 1989, water for the Laboratory, the communities of Los Alamos and White Rock, and Bandelier National Monument was supplied from 11 deep wells in three well fields. The wells are located on the Pajarito Plateau and in Los Alamos and Guaje canyons east of the plateau. Municipal and industrial water supply during 1992 was 1.43 billion gallons, with individual well yields ranging from about 175 to 1,400 gpm (Stoker et al. 1992, 0826). Purtymun (1984, 0196) summarizes aquifer hydraulic characteristics as determined during aquifer tests or during periods of production of supply wells and test holes.

The surface of the main aquifer rises westward from the Rio Grande within the Santa Fe Group into the lower part of the Puye Conglomerate beneath the central and western part of the plateau. The depths to water below the mesa tops range from about 1,200 ft along the western margin of the plateau to about 600 ft at the eastern margin. The main aquifer is separated from the water in the alluvium and perched water in the volcanics by 350 to 620 ft of tuff and volcanic sediments (Environmental Protection Group 1993, 0829). The main aquifer exhibits artesian conditions in the eastern part along the Rio Grande (Purtymun 1984, 0196). Continuously recorded water level data collected in test wells since the fall of 1992 indicate that, throughout the plateau, the main aquifer responds to barometric and earth tide effects in the manner typical of confined aquifers.

The exact source of recharge to the main aquifer is unknown. Cushman (1965, 0042) suggested three sources of recharge: infiltration of run-off in canyons, underflow from the Valles Caldera through the Tschicoma Formation, and infiltration on mesas. However, a large quantity of hydrologic, structural, and geochemical data indicate

that the caldera may not serve as an appreciable source of recharge to the main aquifer (Conover et al. 1963, 0246; Griggs and Hem 1964, 0313; Goff 1991, 1020). Furthermore, natural recharge through undisturbed Bandelier Tuff on the mesa tops is believed to be insignificant (Purtymun and Kennedy 1971, 0200; Kearl et al.1986, 0135), and few or no data exist to support an evaluation of canyon run-off as a recharge source. It is inferred that major recharge of the main aquifer occurs from the west because the piezometric surface slopes downward to the east. Water level elevations suggest that groundwater flows from the Jemez Mountains east and east-southeast toward the Rio Grande, where a part is discharged into the river through seeps and springs (Purtymun et al. 1980, 0208). Springs fed by the main aquifer discharge an estimated 4,300 to 5,000 acre-ft of water annually into White Rock Canyon along an 11-mi reach between Otowi Bridge at State Road 502 and the mouth of Rito de Frijoles (Cushman 1965, 0042).

The hydraulic gradient of the aquifer averages about 60 to 80 ft/mi within the Puye Conglomerate but increases to 80 to 100 ft/mi along the eastern edge of the plateau as the water in the aquifer enters the less permeable sediments of the Santa Fe Group. The rate of movement of water in the upper section of the aquifer varies, depending on the materials in the aquifer. Aquifer tests indicate that the movement ranges from 20 ft/yr in the Tesuque Formation to 345 ft/yr in the more permeable Puye Conglomerate (Purtymun 1984, 0196).

In an effort to better understand the nature of recharge to the main aquifer in the Los Alamos area, a series of isotope and age-dating measurements on selected water samples has been initiated by Laboratory and other DOE researchers. To date, low-detection-limit tritium analyses have been completed on 12 samples from springs in White Rock Canyon and on 5 samples from wells into the main aquifer (Environmental Protection Group 1993, 0829).

The values for tritium in the groundwater range from less than detectable to about 7 pCi/L. The values are all less than values for tritium in contemporary precipitation (about 30 to 60 pCi/L) and much less than the roughly 700 pCi/L that would be present now in water precipitated in northern New Mexico during 1962 and 1963, when tritium from atmospheric nuclear weapons testing was at its maximum (Environmental Protection Group 1993, 0829). The conclusion is that the water from the main aquifer cannot contain any significant component of recharge from water precipitated during the last several decades. The inference is that the water in the aquifer considerably predates the period when nuclear weapons were tested in the atmosphere.

Preliminary interpretation of ^{14}C data for samples from the same five deep wells indicate that the water ranges in age from several thousand years to more than 10,000 years (Environmental Protection Group 1993, 0829).

2.6.2.4 Hydrologic Properties and Conditions of the Bandelier Tuff

At the central portion of the Laboratory, there is in excess of 1,000 ft of unsaturated volcanic tuff, sediments, and basalts of the Bandelier Tuff, the Puye Conglomerate, and the basaltic rocks of Chino Mesa. Numerous investigations focusing on hydrologic characterization of the upper 100 ft of the Bandelier Tuff have been conducted in the Los Alamos area since the 1950s (e.g., Abrahams et al. 1961, 0015; Weir and Purtymun 1962, 0228; Abrahams 1963, 0011; Purtymun and Koopman 1965, 0201; Purtymun and Kennedy 1971, 0200; Purtymun et al. 1978, 0207; Abeele

et al. 1981, 0009; Kearl et al. 1986, 0135; Purtymun et al. 1989, 0214; Stoker et al. 1991, 0715). The vadose zone below about 100 ft has not been adequately characterized. (The vadose zone is the zone between the ground surface and the main aquifer, excluding the alluvial and perched aquifers).

Most of the investigations of hydrogeologic properties of the Bandelier Tuff have been conducted on samples of crushed or disturbed tuff. Hydrologic property tests conducted since the mid-1980s largely have been on undisturbed cores (e.g., Kearl et al. 1986, 0135; Stoker et al. 1991, 0715). To aid the reader in evaluating the variablity in hydraulic properties, a summary of hydraulic properties measured in undisturbed cores from the Bandelier Tuff is presented in Table 2-2.

2.6.2.4.1 Effects of Physical Characteristics

Physical characteristics of the tuff that affect fluid flow result primarily from the degree of welding and jointing. The degree of welding, which varies markedly within and between tuff units, influences the nature and variability of hydrologic characteristics. Welding results in increased density, decreased porosity, and decreased hydraulic conductivity of the rock matrix (Purtymun and Koopman 1965, 0201). However, welded tuffs tend to be more highly fractured (jointed) than nonwelded tuff, and the overall permeability of the welded tuff may be locally enhanced (Crowe et al. 1978, 0041).

2.6.2.4.2 Porosity

Porosity measurements by Abrahams (1963, 0011) range from 20% to 60% by volume, generally decreasing with increasing degree of welding. Measurements reported by IT Corporation (1987, 0327) are higher, from approximately 39% to 74%. A great deal of the high porosity occurs when pumice fragments are incorporated in the tuff. The higher porosities are comparable to those of the upper ranges found in fine clays. Such high porosities, however, are unusual for indurated materials. Extreme changes in porosity over a short vertical distance have been observed (Abrahams 1963, 0011).

2.6.2.4.3 Moisture Content

A number of hydraulic properties of the Bandelier Tuff vary with changing moisture content. The tuff is only partially saturated throughout the Laboratory, even beneath stream channels containing alluvial perched groundwater systems. The moisture contents of the tuff beneath mesa tops are very low, typically less than 5% by volume (Abrahams 1963, 0011). Abrahams shows that tuff moisture contents are higher beneath disturbed soils than beneath undisturbed soils and, generally, moisture content decreases with depth. At sites with relatively high near-surface moisture contents, the volumetric moisture content decreases rapidly with depth to less than 5% (Abrahams 1963, 0011). Moisture contents of the tuff beneath the canyon bottoms are considerably higher than those beneath the mesas, typically ranging from 20% to 50% by volume (Weir and Purtymun 1962, 0228; Stoker et al. 1991, 0715). Field studies in Mortandad, Sandia, and Potrillo canyons show that moisture content varies greatly with depth, depending on texture (Stoker et al. 1991, 0715; Environmental Protection Group 1993, 0829). Generally, moisture content decreases with depth below stream channels.

TABLE 2-2. SUMMARY OF HYDRAULIC PROPERTIES DATA FOR BANDELIER TUFF OBTAINED SINCE 1984*

Geologic Unit	Bulk Density (g/cm^3)	Residual Sat. (%, cm^3/cm^3)	Calculated Porosity (%, cm^3/cm^3)	Alpha (1/cm)	N (dimensionless)	Saturated Hydraulic Conductivity (cm/s)
Tshirege Member						
Minimum	0.94	1	40	0.001	1.08	0.0000056
Median	1.18	6	53	0.009	1.49	0.00011
Maximum	1.49	43	74	1.765	4.35	0.0035
Number of Observations	43	47	71	58	57	83
Tsankawi Pumice						
Minimum	0.9	3	35	0.001	1.34	0.000058
Median	1.25	12	49	0.023	1.46	0.0013
Maximum	1.6	21	63	0.104	1.6	0.0043
Number of Observations	18	7	18	8	8	9
Otowi Member						
Minimum	0.98	2	44	0.004	1.34	0.000011
Median	1.18	4	55	0.008	1.57	0.00028
Maximum	1.49	26	63	1.866	9.65	0.0078
Number of Observations	31	29	31	29	29	29

*These data represent a partial compilation by B. Gallaher (in preparation, 1019) of available hydraulic property determinations on undisturbed core samples taken between 1984 and 1992. Field and laboratory data from USGS work in the 1950s and 1960s and air/water injection tests conducted by Bendix Corporation in the mid-1980s (Kearl et al.1986, 0135) are not included in the compilation because of concerns relating to the comparibility of different measurement techniques.

2.6.2.4.4 Moisture Characteristic Curves

The relationship between moisture content and soil-water potential has been obtained from undisturbed mesa top cores at TA-54 (Kearl et al. 1986, 0135). The data indicate (1) extremely high residual moisture contents, ranging up to 80%, and (2) a low air-entry pressure head. Purtymun and Stoker (1987, 0204) indicate that at TA-49 specific retention (residual moisture content) ranged from 11% to 27%. These latter results are fairly consistent with recent tests on undisturbed tuff samples in Mortandad Canyon (Stoker et at. 1991, 0715). However, detailed analyses in Mortandad Canyon show that there are significant differences in moisture retention characteristics between and within formational units. Abrahams (1963, 0011) determined the energy relationship with moisture content of a moderately welded tuff. The saturated moisture content of the tuff was about 41% by volume. When moisture contents are below about 4%, there is no movement of water; from about 4% to 8%, moisture is redistributed by diffusion; from about 8% to 23%, distribution is by gravity and capillarity; and above 23%, movement is by drainage from gravity (Abrahams 1963, 0011).

2.6.2.4.5 Hydraulic Conductivity

Hydraulic conductivity is the parameter that describes rate of flow of fluid through a porous medium in response to a hydraulic gradient; it is a function of both the fluid and the medium. Saturated hydraulic conductivities have been measured for tuff many times under laboratory and field conditions, with values ranging from 1.9×10^{-5} to 2.3×10^{-2} cm/s (0.054 to 6.5 ft/day), comparable to those of silty sand. In general, nonwelded tuff has greater saturated conductivity than welded tuff, and horizontal conductivities are greater than vertical conductivities (Abrahams 1963, 0011). Unsaturated hydraulic conductivities may be many orders of magnitude lower, typically ranging from 10^{-6} to 10^{-11} cm/s (Stoker et al. 1991, 0715; IT Corporation 1987, 0327), depending on in-situ moisture contents.

2.6.2.4.6 Joints

Joints formed by cooling of the ash flows or by later faulting typically divide the tuff into irregular blocks. The major joint sets are vertical or nearly vertical, with dips greater than 70°, and joint frequency increases with the degree of welding. Joints and fractures in moderately welded tuffs generally terminate in nonwelded tuffs (Baltz et al. 1963, 0024). The joints are often vertically limited to a single ash flow or ash fall unit (Purtymun and Kennedy 1971, 0200). Joint apertures range from closed to open as much as several centimeters. The joints are commonly filled with caliche near the surface, grading downward to clay, and may be open to depths greater than 30 ft (Purtymun et al. 1978, 0207; Abeele et al. 1981, 0009). Examination of cores obtained from horizontal drilling beneath a waste disposal site at TA-54 showed that about 80% of the joints were filled or plated with clay or secondary mineralization (Purtymun et al. 1978, 0207).

2.6.2.5 Movement of Moisture in the Bandelier Tuff

The movement of moisture in the Bandelier Tuff is governed by a complex interaction of many factors. Climatic and site-specific land use factors control the supply of

moisture available for infiltration, and hydrogeological characteristics control the redistribution of moisture in the tuff.

Perhaps the most significant aspect of the tuff is its ability to act as a sponge. Most of the pore spaces in the tuff are of capillary size and have a strong tendency to hold water against gravity by surface tension forces. Thus, a slug of water entering dry tuff is slowed or retained by capillary tension forces.

Water moves through the tuff in two ways: (1) by liquid and vapor movement through the pores of the tuff and (2) by movement through open, interconnected joints (Abrahams, 1963, 0011). When moisture content is low, movement in the vapor (gaseous) phase becomes more preponderant, and liquid movement through the rock matrix is extremely slow. Water entering open, interconnected joints might move rapidly downward through the joints; however, to maintain continuous flow through the fractures, it is likely that large volumes and a continuous supply of water are necessary because of the sponge effect of the adjacent tuff that forms the wall of the fracture. The existence of a low-permeability coating on the wall of the fracture, on the other hand, could increase the travel depth of water flowing through fractures (Thoma et al. 1992, 0827). If the joints are not continuous through contacts between subunits of the tuff, the water might be perched above the contact and would tend to move laterally, potentially to the walls of canyons.

These factors are discussed as they pertain to subsurface contaminant transport beneath the mesa tops and canyon bottoms.

2.6.2.5.1 Migration of Moisture Beneath Mesa Tops

The natural moisture content of the tuff forming the mesas between the canyons is generally less than 5% by volume at depths greater than a few tens of feet, the zone affected by seasonal inputs of moisture and evapotranspiration. Weir and Purtymun (1962, 0228) attributed the low moisture content to the protective cap of clay soil derived by weathering of the tuff near the surface, low rainfall, and high evapotranspiration. The existence of low moisture content is further supported historically by the absence of weathering below 10 m (Wheeler et al. 1977, 0828) and the overall absence of perched water in the tuff at potential perching horizons.

Kearl et al. (1986, 0135) concluded that vapor phase transport is the predominant transport mechanism controlling the potential subsurface movement of contaminants beneath the mesa top at TA-54. Their evidence includes the low overall moisture content of the tuff and the relatively high moisture retention characteristics of the underlying rock. They also conclude that there is no interconnection or movement of liquid water in the interval of Bandelier Tuff examined (upper 100 ft of Tshirege Member). Other laboratory analyses on cores of moderately welded tuff support the possibility of vapor phase dominance at most mesa top locations (Abrahams 1963, 0011).

From a waste containment perspective, the possibility of vapor phase dominance is significant: in extremely dry rock, only contaminants existing in a gaseous state, such as tritium or volatile organic solvents, migrate through the rock matrix. Other radionuclides and metals can be removed from their original location only under wetter conditions, when the uninterrupted movement of liquid water (i.e., capillarity) is more predominant.

Unfortunately, no definitive field measurements exist by which to quantify natural recharge through mesa tops. However, the flux of liquid water through the rock matrix that could eventually become recharge can be estimated as being approximately equal to the in-situ unsaturated hydraulic conductivity (Kearl et al. 1991, 0652). A likely range for natural recharge through the rock matrix therefore is 10-6 to 10^{-11} cm/sec (1 ft/yr to 0.00001 ft/yr), based on the hydraulic conductivity values discussed above. At TA-54, Stephens et al. (1993, 1049) calculated maximum downward flux rates of 0.5 ft/yr. Because of geochemical interaction between the rock and dissolved constituents, the rate of constituent movement, except for those that are highly soluble, should be lower than that of water. These calculated flux rates are relatively low, implying very little water movement from the mesa tops to the main aquifer under natural conditions, which probably also applies to a one-time spill of contaminants at the land surface.

The greatest concern about subsurface migration is the potential for a large volume of contaminants to be chronically released in the vicinity of open and interconnected joints, which could occur beneath a surface impoundment or a leaky chemical storage tank. The movement of water through joints would negate the protection provided to the groundwater when water moves only through pores in the tuff (Abrahams 1963, 0011).

Filled fractures strongly inhibit moisture movement. Open fractures are effective barriers to liquid phase unsaturated flow but may provide preferential flow paths for vapor transport or rapid movement of liquid under saturated or near-saturated conditions (Abeele et al. 1981, 0009). Roots have been found in joints to depths of at least 42 ft (Weir and Purtymun 1962, 0228), which suggests that joints may be important local infiltration pathways. Several fracture zones at TA-54 show an increase in moisture content relative to adjacent porous media (Kearl et al. 1986, 0135).

Although fractures have a local effect on infiltration in the upper portions of the mesas, it is less clear to what depth they play a role, for three key reasons. First, water passing through a fracture system has a tendency to be "wicked" into the adjacent rock matrix by capillary suction forces in the tuff, provided the fracture/rock interface is not sealed with material of low permeability (Thoma et al. 1992, 0827). Second, most of the open fractures occur in the moderately welded to welded Tshirege Member of the Bandelier Tuff, and the underlying nonwelded Otowi Member is significantly less fractured (Baltz et al. 1963, 0024). Flow in the lower portions of the Bandelier Tuff, therefore, is far more likely to be dominated by the relatively slow process of capillarity.

Finally, although fractures may initially provide a pathway for movement of water into the mesas, they may later play a role in removing water (as water vapor) from within the mesa. Under low barometric pressure conditions, air transfers from the tuff to the atmosphere through boreholes (Purtymun et al. 1974, 0651). Barometric and air pressure variations along the canyon walls could cause the exchange of gas and water vapor between the atmosphere and the mesas, especially via interconnected fractures and joints, which are highly permeable to air. Air transfer has been documented in boreholes penetrating the tuff at TA-49 (Purtymun et al. 1974, 0651) and has been observed elsewhere on the plateau; however, studies at TA-54 have been inconclusive (Abeele et al. 1981, 0009; Kearl et al. 1986, 0135).

In conclusion, the combination of the Bandelier Tuff's low moisture content beneath the mesa tops, its associated hydraulic characteristics, and its thickness provides the

main aquifer a substantial degree of protection from the mesa tops. At suspected waste sites at which contaminated liquids have not been disposed, the risks to the main aquifer are quite low. Detailed characterization of the subsurface probably is not warranted for most such sites. Site-specific conditions must always be considered, however, before making such a determination. At waste sites with large potential contaminant source terms, such as material disposal areas, phased subsurface investigations should be conducted to verify that the waste is sufficiently contained.

Waste disposal activities that chronically released large volumes and highly contaminated liquids or that contain volatile contaminants have the potential for migration within the mesas and should also be investigated for subsurface transport. Open fractures may be a key factor in determining whether contaminants migrate to deeper sections of the tuff or travel laterally to release areas on the mesa walls. All of these subsurface investigations should initially focus on the upper 100 to 200 ft of the vadose zone.

2.6.2.5.2 Migration of Moisture Beneath Canyon Bottoms

The canyons with alluvial perched groundwaters are presumed to present a greater potential for downward movement than do the mesa tops because there is a constant driving force and because the moisture content of the tuff below the saturated alluvium is significantly higher than that beneath the mesas. Additionally, the depth to the main aquifer in the canyons is several hundred feet less than from the adjacent mesa tops. The effect of this greater potential for fluid flow, though, is somewhat compensated by the general lack of highly concentrated contaminant sources in the canyon bottoms.

Recent investigations provide some important information on the movement of moisture and contaminants in the unsaturated tuff. The best field evidence that can be used to estimate potential downward rates of movement beneath canyon bottoms is obtained from corehole data collected by Stoker et al. (1991, 0715) in Mortandad Canyon. Because treated liquid radioactive effluents have been discharged to the canyon for almost 30 years, the radioactive constituents in effluent from the Laboratory serve as accurate tracers for fluid and contaminant migration studies.

The basic conclusions of the Mortandad study regarding the movement of radioactive contaminants below the alluvial perched groundwater are (1) soluble and particulate radioactive constituents have moved less than about 10 ft into the unsaturated zone beneath the alluvial perched groundwater; and (2) tritium, as tritiated water (HTO), has moved at least 150 ft below the alluvial perched groundwater to a total depth of 195 ft. Tritium concentrations in Corehole MCM-5.9 (the deepest corehole drilled so far in the canyon) decrease by a factor of about 100 between 150 and 195 ft, suggesting the possibility that tritium has not moved much deeper in the almost 30 years since effluents were first released from the TA-50 treatment plant (Stoker et al. 1991, 0715). The tritium data suggest a downward rate of movement of at least 6 ft/yr . However, this conclusion must be considered tentative until additional, deeper coreholes can confirm the pattern.

Stoker et al. (1991, 0715) evaluated the moisture content in tuff beneath the alluvial perched groundwater in Mortandad Canyon. Most values for gravimetric moisture content in the Tshirege tuff beneath the alluvial perched groundwater ranged from 10% to 30%, corresponding to about 20% to 60% of saturation. Several peaks

occurred at higher values, approaching 90% of saturation near the contact with or in the Tsankawi tuff and fluvial Cerro Toledo rhyolite deposits on the top of the Otowi member of the tuff at depths around 100 ft. In the Otowi tuff, the gravimetric moisture content decreased and leveled off at about 12% to 18%, which corresponds to 20% to 40% saturation. A similar pattern occurred in a corehole farther downstream in Mortandad Canyon past the end of the alluvial perched groundwater (Stoker et al. 1991, 0715) and also in Sandia and Potrillo canyons (Environmental Protection Group 1993, 0829).

The data suggest that there are complex variations in hydrologic properties in the layers from the base of the Tshirege through to the top of the Otowi tuff that significantly affect the movement of moisture in the unsaturated zone. There is also a suggestion that moisture conditions in the Otowi tuff become very uniform with only moderate differences in magnitude, depending on whether there are saturated conditions in overlying layers (Environmental Protection Group 1993, 0829). Additional field data and theoretical interpretation are required to confirm the patterns and quantify movement.

2.6.3 Special Studies

Two ongoing studies are of particular relevance to the ER Program: cover and stabilization pilot studies and geochemical studies of soils and Bandelier Tuff. The details of these studies are provided in Appendices C and D, respectively.

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3.0 DESCRIPTION OF THE ENVIRONMENTAL RESTORATION PROGRAM

This chapter of the Installation Work Plan (IWP) describes the Environmental Restoration (ER) Program that the Department of Energy (DOE)/University of California (UC) are implementing for Los Alamos National Laboratory (the Laboratory). The processes presented in the sections below are designed to meet the following goals of the ER Program at the Laboratory:

- to ensure that the environmental impacts associated with past and present activities at the Laboratory are thoroughly investigated and that appropriate corrective action is taken to protect human health and the environment;
- to comply with the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Environmental Policy Act (NEPA), the Atomic Energy Act (AEA), their implementing regulations, DOE orders, and other applicable rules by establishing procedures and schedules for efficiently developing and implementing corrective actions at the Laboratory and monitoring the results of those actions; and
- to provide both formal and informal mechanisms through which all interested parties, [e.g., DOE, Environmental Protection Agency (EPA) Region VI, New Mexico Environment Department (NMED), and the public] can participate in the corrective action review process at the Laboratory.

The Hazardous and Solid Waste Amendments (HSWA) Module provides the principal framework for implementing the ER Program at the Laboratory. However, sites to be investigated and evaluated include not only the solid waste management units (SWMUs) described in the HSWA Module but sites that contain radioactive materials and other substances not addressed by RCRA. The latter sites are called areas of concern (AOCs). In this document, SWMUs and AOCs are collectively referred to as potential release sites (PRSs).

3.1 The Department of Energy's Environmental Restoration Program

In 1984, DOE's Albuquerque Operations Office (DOE/AL) created an environmental cleanup program entitled the Comprehensive Environmental Assessment and Response Program (CEARP) (DOE 1987, 0264) to fulfill DOE's obligations under several statutes and regulations, including

- CERCLA, as amended by the Superfund Amendments and Reauthorization Act;
- RCRA (40 CFR 260-270 and 40 CFR 300), as amended by HSWA in 1984;
- NEPA (40 CFR 1500-1508); and
- the AEA of 1954 (10 CFR 200-1060).

DOE/AL began to implement CEARP at the Laboratory in 1984. CEARP provided guidance for implementing and conducting assessment and remediation activities from 1984 until March 1987, when DOE Headquarters (DOE/HQ) created a national ER Program for all DOE Defense Program facilities at the request of the House Armed Services Committee. This request arose from congressional concern over a 1987 General Accounting Office report that indicated that DOE could not account for funds used to conduct cleanup activities. In addition, public concern over environmental problems at DOE facilities was increasing throughout the country.

Responsibility for the DOE's ER Program, which includes decontamination and decommissioning (D&D), is currently located in the Office of Environmental Restoration and Waste Management at DOE/HQ (DOE 1991, 0549). The authority to implement the ER Program is derived from the following DOE orders:

- Radioactive Waste Management [DOE Order 5820.2A (DOE 1988, 0074];
- Hazardous and Mixed Waste Management [DOE Order 5400.3 (DOE 1989, 0526);
- Comprehensive Environmental Response, Compensation, and Liability Act Requirements [DOE Order 5400.4 (DOE 1989, 0078)];
- Environmental Compliance Issue Coordination [DOE Order 5400.2A (DOE 1989, 0077);
- Environment, Safety and Health Program for Department of Energy Operations [DOE Order 5480.1B (DOE 1990, 0730)];
- Environmental Protection, Safety, and Health Protection Standards [DOE Order 5480.4 (DOE 1984, 0059]; and
- National Environmental Policy Act Compliance Program [DOE Order 5440.1E (DOE 1992, 0993) and Order AL 5440.1B (DOE/AL 1982, 0430)].

The primary purposes of DOE's ER Program are to

- implement RCRA Sections 3004(u) and (v), RCRA facility assessment (RFA), RCRA facility investigation (RFI), RCRA corrective measures study (CMS), and RCRA corrective measures for existing SWMUs;
- implement CERCLA preliminary assessment/site inspection, remedial investigation, feasibility study, remedial design, and remedial action, as appropriate;
- carry out corrective actions at RCRA-regulated land units in operation before March 1987, including those at which underground storage tanks are located;
- decontaminate and decommission surplus facilities;

- develop and demonstrate the technologies necessary to clean up;
- manage expenses associated with cooperative multiparty cleanup plans and activities;
- protect natural resources and restore those damaged by contamination from past release of hazardous substances;
- install long-term environmental monitoring systems; and
- conduct any CERCLA assessments necessary before considering disposition of real property.

Significant items explicitly excluded from DOE's ER Program include

- RCRA compliance for active waste streams;
- emergency response to spills and releases and reporting of releases under CERCLA 103(a) and (b);
- new waste management facilities, except as an integral part of remedial actions; and
- routine monitoring of the postclosure environment and maintenance of postclosure monitoring systems.

To implement the ER Program, DOE/HQ requires that a five-year plan be prepared for all facilities. That plan is designed to consolidate the plans for all DOE installations into a single plan to coordinate all environmental restoration activities conducted by DOE and is reviewed and revised annually. The five-year plans for FYs 91-94 have been prepared and released to the public. The plan prioritizes ER activities and is used by DOE for scheduling and budgeting purposes.

The Laboratory's D&D Project is integrated in the Laboratory's ER Program as part of the DOE's ER Major System Acquisition (MSA AL-1). The Program Management Plan (Annex I) provides additional detail on the Laboratory's portion of ER MSA AL-1. The two programs were integrated because PRSs and D&D projects at the Laboratory are often collocated; thus, operations of these programs often affect the operations of the other, and integrating the two programs is intended to make cleanup more efficient.

3.2 The Environmental Restoration Program at Los Alamos National Laboratory

In the 1970s, DOE/UC began a formal program to identify contamination problems resulting from early defense activities, and, in 1983, they began a formal program to characterize these contaminated sites. As a result, the Laboratory remediated several sites, implemented institutional controls, and collected the information that serves as a starting point for current investigations.

Between 1984 and 1987, the Laboratory was evaluated under CEARP. A major objective of this program was to determine whether past waste disposal practices—practices in effect before recognition of environmental hazards and passage of

extensive environmental legislation—created environmental problems that require remedial action today.

During Phase I of CEARP, DOE/UC conducted and documented preliminary assessment/site inspection activities specified by CERCLA in the first comprehensive attempt to identify potentially hazardous waste sites at the Laboratory. The results are summarized in the CEARP Phase I report (DOE 1987, 0264). DOE submitted this document to EPA's Region 6 in October of 1987 to fulfill the CERCLA 103(c) notification requirement. The CEARP Phase I report was also distributed to the state and to the public.

After establishing the ER Program at DOE/HQ, DOE/UC established the ER Program Office to implement the program at the Laboratory. Although the ER and CEARP programs differ somewhat in scope, the intent is to fulfill DOE/UC's obligations under both CERCLA and RCRA. The ER Program retains the need for agency approval and oversight and for public review and comment during site characterization activities (RFI), selection of the appropriate remedial alternative (CMS), and implementation of the selected remedial action. SWMUs identified by EPA for corrective action have been included in the Laboratory's ER Program.

The DOE/UC ER Program at the Laboratory has been modified to address the requirements of the HSWA Module, which became effective May 23, 1990, and to incorporate site-specific needs, as well as DOE's requirements for organizing, managing, reporting, funding, and tracking the program.

3.3 Structure of the Environmental Restoration Program at Los Alamos National Laboratory

The UC plan for managing the DOE's ER MSA AL-1 is presented in Annex I of this IWP. The HSWA Module requires inclusion in the program of four additional planning and implementing elements, which are discussed in Annexes II through V: an overview of the ER Program's Quality Program Plan, the Health and Safety Program Plan, the Records Management Program Plan, and the Public Involvement Program Plan.

The ER Program Office (Figure 3-1) tracks and manages the ER Program and D&D Project. The ER Program Manager, who reports to the Program Director for Environmental Restoration and Waste Management Programs (Figure 3-2), is responsible for the effective implementation of the ER Program throughout the Laboratory. Two deputy program managers assist the ER Program Manager in day-to-day execution of the program.

Programmatic project leaders (PPLs) are the principal points of contact between the operable unit project leaders (OUPLs) and technical team leaders (TTLs) and the deputy program managers in the ER Program Office. Working with the ER Program Office, PPLs provide technical and administrative guidance to the OUPLs and TTLs. The PPL assists OUPLs and TTLs in obtaining appropriate and sufficient resources to perform their assigned duties; reviews the progress of OUPLs and TTLs; performs technical and policy reviews of documents prepared for the ER Program by OUPLs, TTLs, and affiliated staff; and reviews and recommends management action, as appropriate, for scopes of work, proposals, and requests for work to be supported by the ER Program.

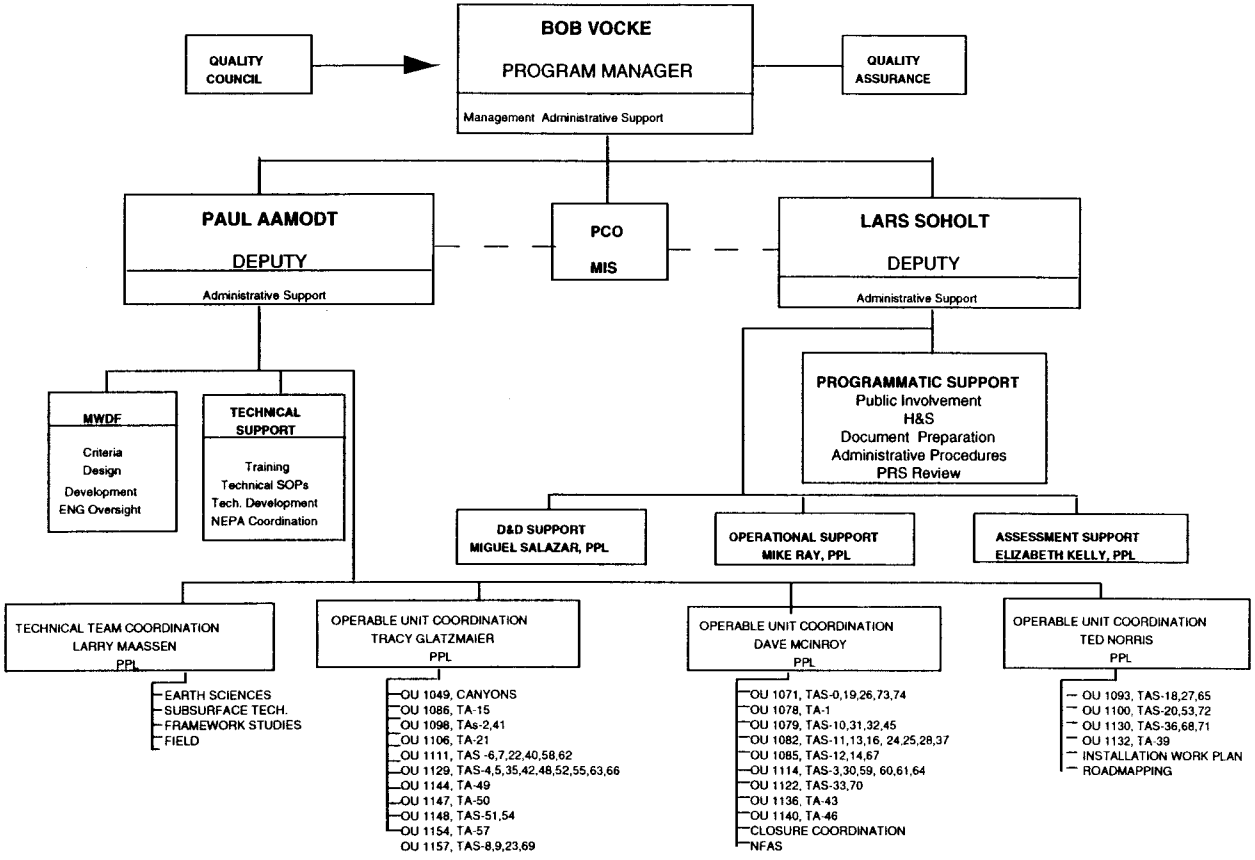

Figure 3-1. Organization of ER Program.

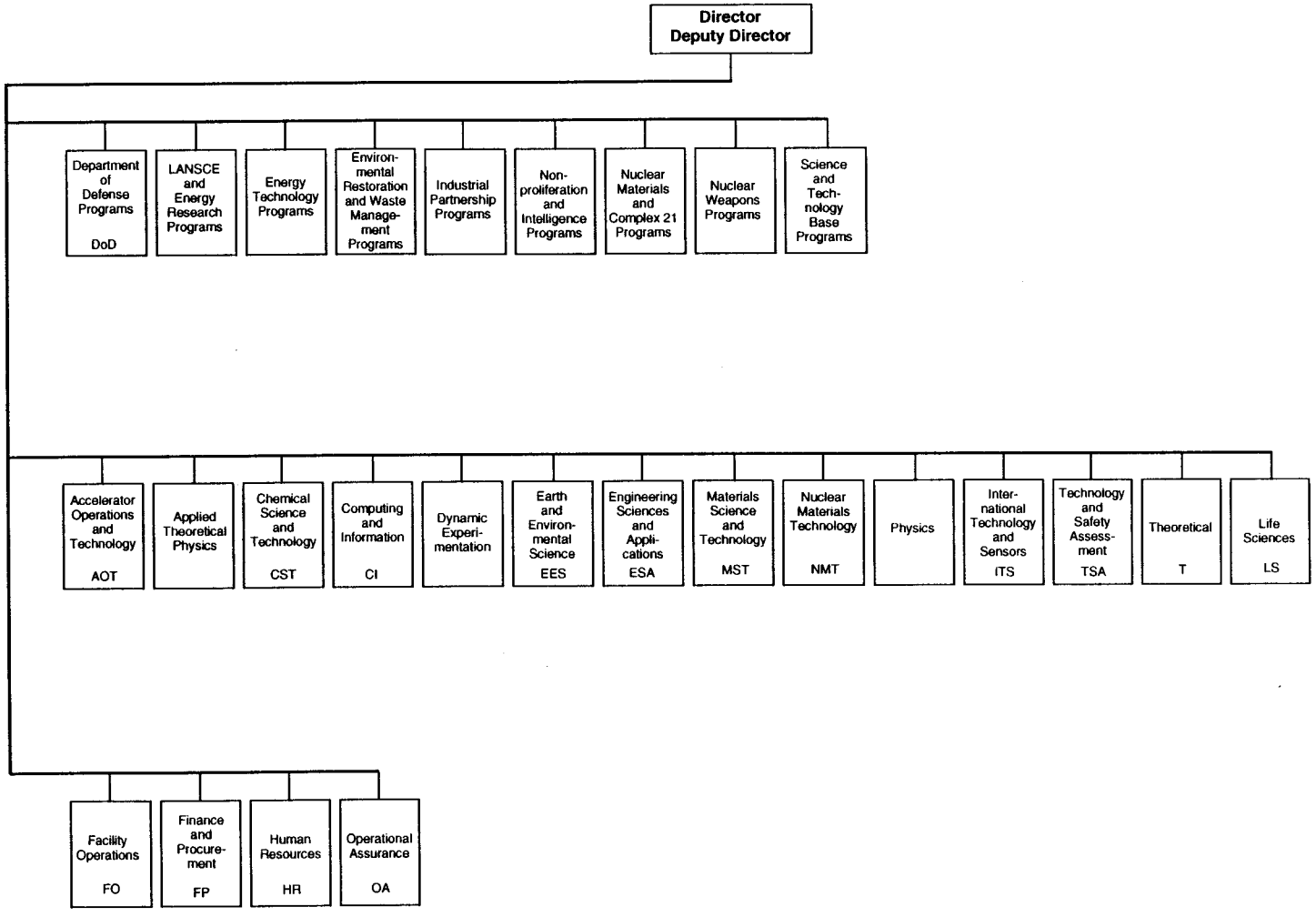

Figure 3-2. Organization of Los Alamos National Laboratory.

OUPLs, who report to the program office through PPLs, are responsible for ensuring that the work they perform for the ER Program meets all regulatory requirements. OUPLs are responsible for managing the corrective action process for their respective operable units. The project leaders for quality, health and safety, records management, the Facility for Information Management, Analysis, and Display (FIMAD), and public involvement are responsible for managing their areas to support the OUPLs. Additional details on responsibilities are presented in the ER Program's administrative and quality procedures.

The ER Program is a large, interdisciplinary program that will continue for several decades. To assist the OUPLs, the Laboratory is creating technical teams from various groups and divisions of the Laboratory. External support (from various contractors, universities and DOE facilities) may be included. The technical teams provide the ER Program Office with technical resources for implementing the program. Team members interact with OUPLs to provide them with the expertise (e.g., geochemistry) needed to meet program goals. For each team, the ER Program Office has appointed a PPL, who is responsible for establishing and overseeing the team. The PPL interacts with the TTLs to assign personnel to projects, to schedule effort, and to resolve conflicts among programs. Outside contractors are used for program activities when limitations in Laboratory resources threaten the Laboratory's ability to meet the requirements of the HSWA Module or when outside contractors can perform the required work more economically or otherwise more advantageously than would be possible if the work were performed by the Laboratory.

In 1992, to aid in resolving problems that arise in this complex program, program managers created a quality council. The composition and function of the council and of each technical team are described in the following subsections.

3.3.1 ER Program Quality Council

The Quality Council consists of five members—one from each of the following groups: program management, PPL, OUPL, and TTL; the fifth member is an at-large member. The purposes of the council are to

- provide a forum for identifying problems,
- analyze the problem to identify the process that needs improvement,
- identify an owner of the process to address the problem (and make recommendations concerning how to develop solutions to the problem, as appropriate), and
- track the improvement (and re-evaluate, as appropriate).

The text of the Quality Council's charter is provided in Appendix E.

3.3.2 ER Program Technical Teams

3.3.2.1 Public Involvement Team

The ER Program's Public Involvement Team integrates the community relations needs of the ER Program with existing community relations and public affairs programs and policies at the Laboratory in an efficient and cost-effective manner (Annex V). The primary function of the Public Involvement Team is to keep the public informed of ER Program activities and to receive and respond to public input on those activities, which it does by means of the Public Involvement Program Plan (Annex V). The plan includes provisions for (1) providing the community with information about ER Program activities in a timely manner, (2) establishing two-way communication between interested parties and the Laboratory, (3) being proactive in providing information to the public and in soliciting participation, (4) affording opportunities for public input on ER Program activities, and (5) providing for effective management of public involvement.

3.3.2.2 Document Preparation Team

The Document Preparation Team is composed of members of the Communications Resources Group (IS-1), supported as necessary by the Photography and Printing Group (IS-9). The goal of this team is to produce readable and technically sound documents for the ER Program. The Classification Office (OS-6) reviews all documents to ensure that no classified information is released.

3.3.2.3 Earth Sciences Team

The Earth Sciences Team is headed by a TTL who is supported by principal investigators for geology, geophysics, hydrology, and geochemistry. The TTL is responsible for providing personnel resources to OUPLs for the RFI/CMS process and for the development of a geologic, hydrologic, and geochemical baseline for the Pajarito Plateau area (framework studies), which is required by the HSWA Module. This information is used to guide certain site characterization activities and is especially useful for evaluating data necessary for risk assessment as sites are being assessed for radiological or hazardous constituents above natural levels.

3.3.2.4 Facility for Information Management, Analysis, and Display Team

The FIMAD Team supports the electronic information needs of the ER Program and is responsible for acquiring and maintaining the programwide electronic data base. The principal task of the FIMAD is to provide all program participants, interested agencies, and the general public with access to information on ER Program activities. The FIMAD is an open, upgradable system, and ongoing efforts are directed toward a user-friendly interface to data, data analysis tools, and supporting documentation for program activities. A network of UNIX work stations and X terminals at various sites throughout the Laboratory and townsite provides access to the ER Program's data base. Data links are also being established with key regulatory offices with NMED and EPA. Data-processing activities currently supported on the network include management and analysis of geographical and

technical data and generation of maps. Future support and tools will include document management, video and image management, visualization through two- and three-dimensional graphics, data compression and conversion, geostatistics, data integration, and possibly project and program management.

3.3.2.5 Mixed-Waste Disposal Facility Team

The goals of the Mixed-Waste Disposal Facility (MWDF) Team are to select a suitable site, develop facility and operating criteria, and design and construct a proposed new MWDF at Los Alamos. Associated tasks include preparing appropriate documentation in accordance with NEPA and site suitability studies, obtaining required RCRA permits from the state (NMED), and ensuring compliance with all required quality assurance (QA) and health and safety (H&S) requirements. When constructed, the MWDF will be used primarily for waste generated by the Laboratory's ER Program activities. The need for treatment facilities to accommodate the ER Program is yet to be fully addressed, but existing waste treatment facilities will be used to the extent they are available.

3.3.2.6 Project Control, Planning, Scheduling, Cost-Estimating, and Reporting Team

The Project Control, Planning, Scheduling, Cost-Estimating, and Reporting Team consists of ER Program Office personnel, as well as personnel from other Laboratory organizations. The goal of the team is to provide the ER Program with the planning, scheduling, cost-estimating, and reporting needed to ensure effective implementation, oversight, and management of the ER Program.

This team develops detailed schedules and cost estimates for all program activities. The schedules/cost estimators work closely with ER Program project leaders to identify the activities and elements that require scheduling logic and cost estimates for establishing the program's scope, schedule, and cost baselines against which performance will be measured. The planning, reporting, tracking, and control functions are described in Annex I.

3.3.2.7 Records Management Team

The Records Management Team supports the ER Program by providing and maintaining the integrity and protection of ER Program records for the legal and technical defensibility of records required under the HSWA Module. The three principal support tasks of the Records-Processing Facility (RPF) are assistance with archival searches for RFI work plan development, document control and controlled distributions, and records-processing support (receive, index, prepare, microfilm, inspect, enter data, catalog, and transfer for long-term storage). Other support includes relational data base queries, records retrievals, and maintenance of an ER Program reference library (compiled reports, photos, drawings, and regulatory documents). ER Program records are handled in a manner demonstrably consistent with regulatory deadlines, which includes integrating quality program guidelines and developing the CERCLA administrative record index functional to both FIMAD and the Community Reading Room.

3.3.2.8 Sample Coordination Facility Team

It is projected that several hundred thousand samples will be collected for chemical analysis to support the ER Program. The coordination between the proposed sampling activities and the requested analytical support for each sampling project is critical to the success of these programs. The Environmental Chemistry Group maintains a data base for this purpose.

The Sample Coordination Facility Team is responsible for entering all samples in the data base, distributing samples to appropriate analytical laboratories, and checking the completeness of the analytical data returned by the laboratories. It also orders sampling containers and distributes them to the sampling teams, along with forms specified by the ER Program. The entire process is conducted under chain-of-custody procedures.

3.3.2.9 Assessments Technical Teams

The Statistics and Data Quality Objectives (DQOs), Decision Analysis, Human Health Risk Assessment, Ecological Risk Assessment, and Environmental Evaluations technical teams are collectively called the assessments technical teams. These teams are managed by technical team leaders on the Laboratory's staff, who report to the ER Program's PPL for assessments. Under the direction of the PPL, the assessments technical teams work together to support the development, documentation, and communication of the ER Program's technical approach for data collection and data evaluation to support decision making in the ER Program (described in Chapter 4). This technical approach is evolving and will continue to evolve as the ER Program matures. The technical approach developed for the ER Program provides one of the first comprehensive realizations of the streamlined approach for environmental restoration in the DOE complex, integrating the DQO process and the observational approach in a risk-based, decision- oriented investigation and remediation strategy. This approach follows guidance in DOE-ER-STD-6001-92.

3.3.2.9.1 Statistics and Data Quality Objectives Team

The Statistics and DQO Team supports both the ER Program Office and individual OUs as part of an integrated assessments component of the ER Program. Specific areas of support include

- development of DQOs, that is, requirements for sampling and analysis to ensure that data collection activities are focused toward providing appropriate information to support decisions;
- statistical design of sampling and analysis plans to meet specified DQOs;
- data quality assessment to verify that DQOs have been met;
- statistical environmental data to support decisions pertaining to OU investigation and remediation.

The team works closely with the other assessments technical teams to ensure that data quality and statistical evaluation support programmatic risk assessment and risk management.

3.3.2.9.2 Environmental Evaluations Technical Team

The Environmental Evaluations Technical Team is composed of three elements: NEPA compliance, biological resource evaluations, and cultural resources evaluations. The principal investigators (PIs) for these three components reside in the Environmental Protection Group. The purpose of the Environmental Evaluations Technical Team is to ensure that the ER Program is in compliance with various laws, orders (executive and DOE), and statutes related to the environment. Each PI in the technical team assists OUPLs and ER Program managers in interpreting applicable regulations. The NEPA PI assists with issues related to NEPA, including the preparation of the DOE's environmental checklist, which is used to help decide what NEPA documentation is necessary. In some cases, the NEPA PI may prepare an environmental assessment, which leads either to a finding of no significant impact or to an environmental impact statement (EIS). The Cultural Resources PI conducts surveys and prepares reports on compliance with the Historic Preservation Act and the American Indian Religious Freedom Act. The Biological Resource Evaluations PI conducts surveys and prepares reports needed for compliance with the Endangered Species Act, executive orders pertaining to floodplains and wetlands, and a number of other state and federal regulations protecting biota. Baseline environmental data acquired to comply with these regulations also support ecological risk assessments and natural resource damage assessments. The cultural and biological resource information is also used by the NEPA PI to prepare the environmental checklist.

3.3.2.9.3 Human Health Risk Assessment Technical Team

The objective of the Human Health Risk Assessment Technical Team is to develop, document, and communicate a consistent and defensible approach and methodology to support environmental restoration decision making. This broad objective requires

- developing logic and criteria for the screening assessment decision, including the development of screening action levels (SALs),
- identifying exposure pathways to the public,
- developing selection criteria for potential and actual contaminants of concern,
- developing risk criteria to be used in the decision-making process,
- specifying current and future land use scenarios,
- identifying potential receptors,
- developing risk model parameters and associated uncertainties,

- identifying and developing exposure and transport models specific to Los Alamos for baseline risk assessments,
- developing logic and criteria for establishing site-specific cleanup levels, and
- developing approaches to risk communication.

The Human Health Risk Assessment Technical Team's activities include (1) assisting OUPLs in incorporating risk assessment criteria and methodology in sampling plan designs, (2) calculating site-specific risks for contaminants of concern and calculating risk attributable to remedial alternatives, (3) providing preliminary risk assessments based on available data so that cleanup priorities can be set, (4) reviewing work plans and phase reports to ensure that decisions are based on correct interpretations of data, and (5) working with OUPLs to help them understand the significance of risk-based decisions and assisting them with communicating risk to the public and the regulators.

3.3.2.9.4 Ecological Risk Assessment Technical Team

The purpose of the Ecological Risk Assessment Team is to develop an integrated approach to natural resource damage assessments, ecological risk assessments, and ecological baseline studies for the purpose of analyzing environmental impacts. Methods for conducting ecological risk assessments have not been standardized, and there is little consensus among ecologists on approaches to ecological risk assessment.

Important activities for the Ecological Risk Assessment Technical Team include developing ecological endpoints and spatial scales for determining ecological effects, developing and testing a screening model, developing and testing a dynamic model, and gathering ecological baseline data at control and potentially impacted sites (control sites and ecological baseline data required by 43 CFR 11 guidance).

3.3.2.9.5 Decision Analysis Technical Team

At the OU level of decision making, the objectives of the Decision Analysis Technical Team are to develop decision methodologies, software support, documentation, and application support so that OUPLs may have a consistent, logical, and defensible method of identifying and evaluating alternative characterization approaches and corrective actions and to help in the systematic prioritization of these activities. Similarly, the objectives at the programmatic level are to support strategic decision making and to prioritize programwide activities.

The Decision Analysis Technical Team will attempt to meet the above objectives through a combination of programwide activities and coordination of support for the individual OUPLs. Specific activities include determining decision criteria that reflect both program priorities and those of stakeholders such as NMED, EPA, and DOE and the public; developing and applying the site-ranking system to assist with prioritization of characterization and remediation activities; developing improved archiving procedures; developing decision models for materials disposal areas; assisting in updating the IWP; and developing decision logic diagrams for RFI, voluntary corrective action (VCA), CMS, and corrective measures implementation (CMI) decision making.

3.3.2.10 Subsurface Studies Team

The Subsurface Studies Team is responsible for all drilling, borehole geophysical logging, and sample management activities in support of RFI and CMS investigations. A drilling package written for each OU is site-specific and responds to the sampling needs of individual OUs. The drilling package consists of a detailed drilling plan and drilling specifications, a borehole geophysical logging plan, and a sample management plan. The team is responsible for preparing and overseeing all drilling and borehole geophysical logging contracts. The team is designing and will operate a permanent sample management facility and mobile support facilities. In addition, the team performs pilot studies to validate new drilling technologies.

3.4 Approach to Remediation

3.4.1 Grouping Potential Release Sites

PRSs exist throughout the Laboratory, and several exist off Laboratory land. Under the ER Program, the sites have been aggregated into OUs so that site characterization and potential remediation can be addressed in an efficient, cost-effective manner. These OUs are logical groupings of PRSs. Such groupings may include geographical aggregations that have similar physical features, contaminant sources or types, schedules, or likely response actions. The geographical boundaries of OUs and Laboratory technical areas do not necessarily coincide. Some OUs may encompass more than one technical area (e.g., OU 1071 includes TAs -0, -19, -26, -73, and -74).

3.4.2 Schedule for Completing RFI Work Plans

Each of the 24 OUs has a separate work plan, 19 of which have been submitted to EPA, satisfying the requirement of the HSWA Module to address one set of SWMUs on a priority basis. Four of the remaining five work plans will be submitted in 1994. The 24th in the series, which addresses the canyons, is likely to be submitted in phases.

3.4.3 Potential Release Site Data Base

In early 1987, EPA Region 6 performed an RFA to identify all potential SWMUs at the Laboratory. The RFA was completed in August 1987 but was not formally released. Upon receipt of the RFA, DOE/UC prepared a SWMU report (International Technology Corporation 1988, 0329) in an attempt to incorporate additional information in the RFA SWMU list and to correct inaccuracies in the RFA. This report was released in December 1988, and it combined lists from the CEARP Phase I report (DOE 1987, 0264), the RFA, and internal records searches and interviews. The report identified approximately 1,100 PRSs. The EPA selected the 603 SWMUs identified in the HSWA Module from this report, based on the agency's preliminary assessment of the potential impact to human health and safety.

In 1989, the Laboratory further revised and verified existing information, which was compiled in a data base (Appendix G, LANL 1990, 0145) completed in November

1990. This undertaking involved site visits and discussions with operating groups. No sites were eliminated, but many were combined, some were added, and AOCs (which are not regulated under HSWA but are within the scope of the DOE's ER Program) were included. The field information was coupled with an extensive search of maps and archives. Each PRS is coded with a unique identification number that ties it to a particular technical area.

The PRS data base provides a list of PRSs for the program, including those that have been recommended for no further action. The list is updated as information is obtained to reflect the current status of each PRS in the program (Appendix F).

3.4.4 Site Prioritization Paradigm

The DOE, together with its New Mexico installations (Los Alamos and Sandia national laboratories), has developed a site prioritization paradigm. This paradigm provides a method for evaluating the relative risk posed by all the PRSs at the two laboratories. Additionally, the paradigm incorporates other prioritization criteria (e.g., regulatory concerns and potential for VCA) to aid decision makers in allocating available resources according to the degree of risk at each site. The paradigm was developed with input from EPA and NMED and provides for public involvement in the ranking assessment.

3.4.5 Notification of New Units

As new PRSs are identified during the RFI process, environmental surveillance, audits, or other activities, DOE notifies EPA of a proposed new SWMU within 15 days of its concurrence with identification of the new SWMU. This notification includes a SWMU summary data sheet containing all information available at that time [e.g., location, type of unit, dimensions, waste types (known and suspected), and period of operation]. In addition to this technical information, DOE submits to EPA a plan for future action. If required by EPA, an action plan will be prepared, which may include, as appropriate,

- completing the PRS summary data sheet, using historical and operational information from records searches and interviews with long-term employees;
- assigning the new PRS to an existing OU for which an RFI is to be conducted; and
- addressing proposed interim remedial measures.

This procedure is outlined in Administrative Procedure (AP) LANL-ER-AP-04.1, "Identification and Reporting of Solid Waste Management Units and Identification of Other Areas of Concern for the Environmental Restoration Program," in accordance with Section F of the HSWA Module. After reviewing the action plan, EPA either approves it or instructs DOE/UC to prepare a formal SWMU assessment plan.

Because DOE/UC have been identifying and investigating SWMUs for the past few years, it seems unlikely that SWMUs posing a significant environmental threat have yet to be discovered. In the unlikely event that a potentially significant threat to

human health or the environment is discovered, DOE/UC will prepare a formal SWMU assessment plan. Upon receipt of information on the newly identified SWMU, EPA will notify DOE/UC of its selection of the proposed action as discussed in the SWMU assessment plan. EPA may at that time request a SWMU assessment plan. DOE/UC will prepare such plans to be consistent with Section F.2-6 of the HSWA Module. The assessment plan will contain a sampling and analysis plan adequate to determine the nature and extent of contamination. EPA will either approve the proposed assessment plan, provide comments for revision, or revise the plan. DOE/UC will implement the plan within 15 days of receipt of a written notice of approval.

Within 60 days of completion of the SWMU assessment, DOE/UC will submit a SWMU assessment report. The report will present the findings of the investigation and will include, as appropriate for each unit,

- location,
- type and function,
- description of the structure(s),
- period of operation,
- type and volume of wastes managed, and
- results of sampling and analysis.

EPA will review the assessment report and will determine the need for additional investigation or corrective measures. DOE/UC may be required to prepare an additional plan for these activities, which will be incorporated in an RFI work plan for EPA review and approval.

Discovery of new releases of hazardous materials from existing SWMUs or sites previously identified as needing no further action will be reported to EPA within 24 hours of discovery. DOE/UC will follow oral notice with a written notification that presents existing information related to the location, nature, and type of release and proposed corrective measures. For the purposes of the DOE/UC ER Program, a release is considered to exist when hazardous wastes are found adjacent to a SWMU in concentrations exceeding the action levels in proposed Subpart S of 40 CFR 264 (EPA 1990, 0432) as criteria for determining that no further corrective action is required at a SWMU after an RFI. These levels are discussed further in Section 3.5. DOE/UC propose that most newly discovered releases at existing SWMUs be incorporated in the RFI work plan for the OU in which the SWMU is located. For those few instances when it is impractical to incorporate the SWMU in an RFI work plan(e.g., when the RFI is almost complete), an assessment plan will be prepared if EPA so requests.

This process is described in detail in LANL-ER-AP-04.2, "Reporting of Newly Identified Releases from Solid Waste Management Units" (June 25, 1991) to meet the requirements of Section G of the HSWA Module.

3.4.6 Summary Data Sheets for Potential Release Sites

The summary data sheets for PRSs are contained in the Potential Release Site Data Base, which is maintained at the FIMAD. These sheets summarize the status of currently known PRSs and provide a brief description of each SWMU and of the potential environmental problems to be addressed by the ER Program. A detailed discussion of PRSs is provided in the SWMU report (LANL 1990, 0145), which was submitted with the original IWP (LANL 1990, 0144).

In March of 1993, the Laboratory submitted a request for a permit modification to EPA. If the modification is approved, the total number of SWMUs will increase. A list of these SWMUs and AOCs (PRSs) is provided in Appendix F.

3.5 Requirements of the HWSA Process

This section describes the reports and requirements of the HSWA process. Two types of progress reports are prepared periodically. A report describing certain management functions is submitted monthly. In addition, at quarterly intervals, DOE/UC submit technical progress reports on the cleanup effort, as required by the HSWA Module. These reports are provided to EPA and DOE and are available to the public.

3.5.1 Requirements for the RFI

To comply with applicable regulations and to keep all interested parties informed of progress made during the corrective action process, the ER Program prepares several types of plans and reports. The schedule for preparing the RFI, CMS, and CMI plans and reports varies from OU to OU and is provided in individual RFI work plans.

3.5.1.1 RFI Work Plan

The ER Program is preparing work plans for conducting RFIs. The generic requirements for preparing RFI work plans can be found in proposed Subpart S regulations (EPA 1990, 0432). The specific requirements are described in detail in the HSWA Module (Table 1-1), and EPA has provided specific guidance in Volume I of the interim final RFI guidance (EPA 1989, 0088). This IWP provides the framework for the preparation of individual work plans for the 24 OUs. Information of general nature is contained in this IWP so that RFI work plans need not repeat generic material.

Each RFI work plan must include a description of the overall approach, technical and analytical approaches and methods, QA procedures, and data management procedures. The HSWA Module also specifically requires the concurrent development of five plans as part of the RFI work plan: the Project Management Plan, Quality Project Plan, Records Management Project Plan, the Health and Safety Project Plan, and the Public Involvement Project Plan. However, the HSWA Module allows the Laboratory to deviate from the specific guidance if the RFI work plan still covers the essential elements discussed above.

It is the policy of the ER Program Office to adhere to Section 2, Volume I, of EPA's RFI guidance document to the extent practicable (EPA 1989, 0088). To facilitate compliance with this detailed guidance while complying with the HSWA Module's requirements, the ER Program has developed a standard outline (Table 3-1) for RFI work plans. The outline is intended to provide flexibility in work plan preparation while incorporating the information required by the HSWA Module. The outline may be modified to accommodate the variations in OUs, but each plan must comply with RFI guidance, permit requirements, and regulatory requirements. DOE/UC RFIs will also comply with the substantive requirements of CERCLA. The outline is designed to guide the development of the RFI toward a logical and reasonably minimized sampling program by moving from the analysis of existing data to identifying data gaps in the conceptual model and finally to proposing a sampling plan to fill those gaps. One of the first responsibilities of the OUPL during the development of the work plan is to identify logical aggregations of SWMUs in a manner that facilitates the RFI in accordance with the definition in proposed Subpart S.

3.5.1.2 Phase Reports and RFI Reports

Within 60 days of the completion of the RFI, the Laboratory is required to submit an RFI report and a summary report. The 60-day period begins at the time DOE determines that the RFI has been completed (i.e., approval of RFI report).

Phase reports may be prepared to document a completed state of the RFI before completing the RFI. During the course of the RFI, the data collected sometimes indicate that the sampling plans presented in the RFI work plans should be modified. In this case, Phase I reports are prepared to document the results of the initial sampling plans and the reasons for subsequent modifications. Phase II and subsequent phase reports present the results of investigations performed under these modifications. All phase reports are compiled in the final RFI report.

The requirements for the content of phase reports and the RFI report are given in the HSWA Module, Section P, Task V—Reports. The purpose of the reports is to "describe the procedures, methods, and results of all investigations of SWMUs and their releases, including information on the type and extent of contamination at the facility, sources and migration pathways, and actual or potential receptors."

The RFI report and phase reports include executive summaries that provide the technical information in a briefer format. The Laboratory proposes to use the executive summary for the RFI report as a stand-alone section to fulfill the obligation to submit a summary report. This executive summary will also be submitted to interested parties on the ER Program mailing list.

Each phase report is written as a stand-alone document that can be understood without consulting other documents for details of the investigation being described. However, information such as site and program descriptions is presented in summary form, and the reader is referred to the IWP and the appropriate RFI work plan for details.

The ER Program proposes to use the outline in Table 3-2 for phase reports or for major sections in phase reports and in the final RFI report. Each major section will describe a logical and self-contained segment of RFI work. The partitioning of the RFI investigations at an operable unit into such segments for reporting purposes is performed at the discretion of the OUPL.

TABLE 3-1

OUTLINE OF WORK PLANS FOR RESOURCE CONSERVATION AND RECOVERY ACT FIELD INVESTIGATIONS

EXECUTIVE SUMMARY

1.0 INTRODUCTION

- 1.1 Statutory and Regulatory Background
- 1.2 Installation Work Plan
- 1.3 Description of OU ____
- 1.4 Organization of This Work Plan

2.0 BACKGROUND INFORMATION FOR OPERABLE UNIT

- 2.1 Description
- 2.2 History
- 2.3 Waste Management Practices

3.0 ENVIRONMENTAL SETTING

- 3.1 Physical Description
- 3.2 Climate
- 3.3 Biological and Cultural Resources
- 3.4 Geology
- 3.5 Conceptual Hydrologic Model
- 3.6 Conceptual Three-Dimensional Geologic/Hydrologic Model of OU____

4.0 TECHNICAL APPROACH

- 4.1 Aggregation of Potential Release Sites
- 4.2 Approaches to Site Characterization
- 4.3 Conceptual Exposure Models
- 4.4 Potential Response Actions and Evaluation Criteria
- 4.5 Sampling Strategies and Sampling Methods
- 4.6 Field Surveys

5.0 EVALUATION OF POTENTIAL RELEASE SITES

- 5.1 First PRS or PRS Aggregate
  - 5.1.1 Background
    - 5.1.1.1 Description and History
    - 5.1.1.2 Conceptual Exposure Model
      - 5.1.1.2.1 Nature and Extent of Contamination
      - 5.1.1.2.2 Potential Pathways and Exposure Routes
      - 5.1.1.2.3 Potential Public Health and Environmental Impacts
  - 5.1.2 Remediation Decisions and Investigation Objectives
  - 5.1.3 Data Needs and Data Quality Objectives
    - 5.1.3.1 Data Needs for Evaluating Health and Safety Risks
      - 5.1.3.1.1 Source Characterization
      - 5.1.3.1.2 Environmental Setting
      - 5.1.3.1.3 Potential Receptors
    - 5.1.3.2 Data Needs for Evaluating Other Impacts
  - 5.1.4 Sampling and Analysis Plans

TABLE 3-1 (continued)

OUTLINE OF WORK PLANS FOR RESOURCE CONSERVATION AND RECOVERY ACT FIELD INVESTIGATIONS

5.2 Second PRS or PRS Aggregate, etc.

6.0 UNITS PROPOSED FOR NO FURTHER ACTION

6.1 First Unit Proposed for No Further Action

6.1.1 Description and History
6.1.2 Rationale for Recommendation of No Further Action

6.2 Second Unit Proposed for No Further Action, etc.

ANNEX I Project Management Plan

ANNEX II Quality Assurance Project Plan

ANNEX III Health and Safety Project Plan

ANNEX IV Records Management Project Plan

ANNEX V Community Relations Project Plan

APPENDIX A List of Preparers

Other appendices, as appropriate.

3.5.2 Interim Remedial Measures

The HSWA Module provides for interim remedial measures (IRMs). The paragraphs below discuss the two types of IRMs to which EPA refers in Section I of the HSWA Module.

3.5.2.1 Interim Remedial Measures Based on Health Risks

If EPA determines that a release of hazardous waste or its constituents poses a threat to human health or the environment, it may mandate that DOE/UC implement IRMs to mitigate the risk. EPA may also specify a schedule (by modifying the HSWA Module) for implementing the interim measure and may require the Laboratory to prepare and submit a work plan to be approved before action is initiated. To date, EPA has not required the Laboratory to take any IRMs because no imminent threats to human health or the environment have been identified. However, in the unlikely event that EPA requires an interim measure in the future, DOE/UC will modify the work plan. DOE/UC may at that time request EPA to modify the schedule of compliance for the corrective action.

In determining the need for IRMs based on health risks, at least the following factors will be considered:

- the time required to implement a final remedy,

TABLE 3-2

OUTLINE FOR PHASE REPORTS AND RFI REPORT SECTIONS

Summary

1.0 Introduction

- 1.1 Background
- 1.2 RFI Objectives

2.0 Investigation Methods

- 2.1 Field Program
- 2.2 Analytical Methods
- 2.3 Data Evaluation

3.0 Investigation Results

- 3.1 PRS 1 (or first investigation aggregate, as appropriate)
  - 3.1.1 Site Description
  - 3.1.2 Site Investigation and Analyses
  - 3.1.3 Evaluation of Results
  - 3.1.4 Conclusions
- 3.2 PRS 2

  Etc.

4.0 Phase II Sampling and Analysis Plan (if applicable)

References

Appendix A	Data
Appendix B	Data Quality Assessment and Statistical Calculations
Appendix C	Risk Assessment Calculations (if applicable)
Appendix D	Field Logs and Forms
Appendix E	Subcontractor Results and Reports

- actual and potential exposure of human and environmental receptors,
- actual and potential contamination of drinking water supplies and sensitive ecosystems,
- the presence of hazardous waste that may pose a threat of release,
- the presence of hazardous waste or constituents in soil that have the potential to migrate to groundwater or surface water,
- weather conditions, and
- risks of fire, explosion, or accident.

3.5.2.2 Interim Remedial Measures Based on Institutional Needs

Other IRMs referred to in the HSWA Module are triggered by institutional need. The HSWA Module states, "If, for institutional reasons not related to permit work, i.e., routine construction, an interim measure is required, the permittee will submit

appropriate documentation to the Administrative Authority (EPA) for approval." DOE/UC will conduct interim measures based on institutional needs consistent with the proposed Subpart S provisions concerning VCAs.

3.5.3 Voluntary Corrective Action

In some cases (examples), which can be identified any time after the RFI begins, it may be necessary or desirable to expedite remedial action. In those instances where an obvious and effective remedy is available that meets treatment and disposal restrictions and other limiting criteria, the ER Program may propose VCA, as described in Section 4.1.

3.5.4 Requirements for the CMS

This section provides information to satisfy the requirements of Sections K, L, M, N, and parts of O and Q of the HSWA Module. The CMS process will be developed and implemented in accordance with EPA guidance (EPA 1988, 0295).

If required by EPA, DOE/UC will submit for review and approval a CMS work plan (CMS plan) that lays out the activities to be conducted during the CMS. The draft CMS plan is due at EPA within 90 days of notification of the requirement to conduct a CMS. EPA will review and approve the CMS plan or will suggest revisions to DOE/UC.

DOE/UC will begin to implement the study no later than 15 days after receiving written notice that EPA has approved the CMS plan. DOE/UC will conduct the CMS in accordance with the approved CMS plan, and the CMS will include

- evaluating performance of the remedy(ies),
- assessing effectiveness,
- assessing the time required for implementation,
- estimating costs of implementation, and
- assessing institutional requirements.

A draft CMS report will be prepared within 60 days after the CMS has been completed. The draft report will be based on the results of the study, evaluating corrective measures and recommending the final corrective measure for the release site or groups of sites. EPA will approve the proposed DOE/UC remedy based on the proposed remedy's ability to meet the criteria established for selecting the remedy. The criteria will be developed through implementation of the CMS process as discussed in the following sections. At a minimum, these criteria will address

- standards for remedies,
- remedy selection criteria,
- schedule for implementing the remedy,

- media cleanup standards, and
- compliance with media cleanup standards.

Because of the wide variety of PRSs at the Laboratory, each study will be tailored to the needs of each site. In many cases, site conditions may not require extensive evaluation of several alternatives. Often, a study as detailed as that discussed in the following sections will not be necessary. In those cases in which the number of possible remedies is limited, the process will be as focused and streamlined as possible, consistent with the nature and extent of contamination, to expedite the cleanup process. In those instances in which there is only one obvious remedy, DOE/UC will propose that single option, which will be implemented as a VCA.

3.5.4.1 Corrective Measures Study Work Plan

The first step in the process of selecting alternatives for remedial action is to prepare the CMS plan. The CMS plan is used to identify and develop a scheme for evaluating alternatives for final remediation of the PRSs. The plan will provide sufficient information to allow EPA to evaluate the appropriateness and adequacy of the activities proposed for evaluating potential cleanup alternatives. The CMS is to be flexible enough to allow evaluation and proposal of only one alternative whenever site-specific conditions permit. Each OU-specific CMS will be unique to the environmental setting and nature of contamination in the unit.

The ER Program will develop an outline for the OU-specific CMS plan as the program approaches the CMS phase and will include it in a later IWP for EPA review and approval. The overall Laboratory RFI/CMS schedule is such that no OUs will be in or near the CMS phase of the process before the mid-1990s. The CMS plan will be consistent with the scope of work for a CMS, Section Q, Task VI, of the HSWA Module. The plan will also be consistent with proposed Subpart S (EPA 1990, 0432), as applicable, and will be incorporated in the IWP when Subpart S becomes final.

At a minimum, the plan will contain

- a description of the general approach to investigating and evaluating potential alternatives (e.g., only reasonable alternatives will be considered);
- a definition of the overall objectives of the study;
- a description of the specific remedial alternatives to be studied;
- a plan for conducting treatability (bench- or pilot-scale) studies to determine the suitability of alternatives for site restoration;
- a plan for evaluating remedial alternatives to ensure compliance with the standards for remedies as specified in EPA guidance;
- a schedule for conducting the CMS; and
- a proposed format for the presentation of the results (CMS report).

In addition to the requirements discussed above, DOE/UC will integrate RCRA and NEPA compliance through the CMS process. The CMS plan will be used to trigger a determination of whether an environmental assessment (EA) is required. The CMS report will fulfill the requirement for an EA, if an EA is required. In the event that a full environmental impact statement (EIS) is required, the CMS report will be a support document for that effort. In addition, natural resource damage assessments will be considered during the CMS process.

After receiving written approval of the CMS plan and after the plan has been revised as necessary, DOE/UC will initiate the study within 15 days. The conduct of the OU-specific CMS will comply with the CMS plans approved by EPA, consistent with the scope of work for a CMS provided in Section Q of the HSWA Module, Task VII, and other specified permit requirements. The scope and level of technical detail in the study will be adequate to allow DOE/UC to propose a remedy based on the results of the study and to allow EPA to review and approve that choice. The evaluation of the alternative(s) will be based on technical, environmental, human health, and institutional concerns.

3.5.4.2 Corrective Measures Study Report

Within 60 days of completing the CMS, a draft report will be prepared that summarizes the results of that study. The results of the study will be provided to EPA by the CMS report. The format of the CMS report is not presented here but will be developed as part of the CMS plan. At a minimum, the report will present the evaluation of alternatives consistent with the scope of work for a CMS report described in the HSWA Module.

The primary purpose of the CMS report is to enable DOE/UC to justify and recommend a corrective measure alternative for EPA approval. The report will include a detailed description of the remedies assessed and will describe how the proposed remedy meets the standards for remedies specified in the CMS plan. The primary criteria from which the standards for selecting the remedy will be developed are

- long-term reliability and effectiveness;
- reduction of toxicity, mobility, or volume of contaminants;
- short-term effectiveness;
- implementability; and
- cost.

Within 120 days of receipt of the draft report, EPA will approve or request a revision of the CMS report. EPA's response will consider comments received from NMED and the public. DOE/UC will finalize the draft CMS report, incorporating comments received from EPA within 30 days of receipt.

3.5.4.3 Selection of the Remedy

In selecting a final remedy, the EPA will evaluate the proposed alternative in light of several criteria to determine whether the alternative meets EPA guidance (EPA

1988, 0295). The basic decision factors to be used in this evaluation are discussed in the following sections and include

- general standards for remedies,
- factors considered in selecting the remedy,
- schedule for implementing the remedy,
- standards for cleaning up various media,
- determination that remediation of a release is not required,
- demonstration of compliance with cleanup standards, and
- conditional remedies.

If the selected remedy should leave in place residual contamination that could adversely impact natural resources, the DOE/UC may carry out a natural resources damage assessment under the provisions of CERCLA (EPA 1990, 0559, pp. 8665-8865; DOE 1991, 0560).

3.5.4.3.1 Standards for Remedies

The CMS will generate data sufficient to evaluate potential remedies for their ability to meet the following standards:

- protection of human health and the environment,
- attainment of established cleanup standards,
- control of the source of release, and
- compliance with waste management requirements.

These standards are broad and include the major technical requirements for controlling sources, conducting waste management activities, and cleaning up the environment. Waste management requirements for those sites that require excavation may be met through the proposed MWDF. The Laboratory will comply with media cleanup standards to the extent practicable. In all cases, however, the overriding concern in selecting remedies will be protection of human health and the environment.

3.5.4.3.2 Decision Factors

In order for DOE/UC to propose and for EPA to select a remedy, five specific criteria will be considered for the four general standards presented above. Because conditions at the OUs vary, the decision factors for each proposed remedy may be weighed differently at different OUs. Tradeoffs may be possible for some factors, but the overriding concern in selecting a remedy is protection of human health and the environment.

3.5.4.3.3 Schedule for Implementing the Remedy

DOE/UC will provide a schedule for implementing the proposed remedy to EPA for approval. As appropriate, the schedule will address the following factors, although additional factors may influence the timing of the implementation:

- extent and nature of contamination,
- DOE/UC's ability to implement the remedy,
- availability of treatment technology,
- desirability of currently unavailable technologies that may offer significant advantages,
- potential risks related to implementation of the remedy, and
- any other relevant factors.

DOE/UC recognize the need for innovative and more cost-effective remedial technologies. New technologies developed at the Laboratory should offer distinct advantages over currently available technologies. Although DOE/UC recognize that work must begin now on new and improved technologies (e.g., downhole monitors and stabilization techniques), it is conceivable that the desired technologies will not be fully developed at the time the remedy is selected. In such cases, DOE/UC may propose that EPA postpone selecting a remedy until these technologies are functional if there is a distinct technical, time, or cost advantage.

3.5.4.3.4 Media Cleanup Standards

Media cleanup standards will define contaminant levels that protect human health and the environment. Existing standards primarily address drinking water. Therefore, DOE/UC will use health-based risk assessments to determine the effort needed to clean up most contaminated soils, sediments, and soil vapor. Factors to be considered in determining cleanup standards include multiple contaminants, sensitive receptors, site-specific exposures, the effectiveness of the proposed treatment, and current and future land uses.

Risk-based determinations will be consistent with proposed Subpart S, which proposes that "cleanup standards for carcinogens shall be established at levels which represent an excess upper-bound lifetime individual risk between 1×10^{-4} and 1×10^{-6}." Cleanup standards for noncarcinogenic toxicants will be established to allow daily exposure without appreciable risk of deleterious effects during a lifetime.

Cleanup levels may be raised or lowered, depending on the circumstances at individual sites. Such circumstances may include a determination that concentration levels of certain contaminants must be lowered to protect human health and the environment, that higher concentrations will be permitted because background levels are elevated, and that groundwater that is not a potential source of drinking water or is not hydraulically connected to a drinking water source need not meet drinking water standards. In addition, the technical feasibility of remediation will be taken into account.

DOE/UC will propose for EPA approval the specifics for compliance with established standards. This proposal will address the point of compliance, monitoring and sampling locations, analytical parameters and methods, statistical analyses, and the period required for monitoring restored sites.

3.5.4.3.5 Determination That Cleanup Standards Cannot Be Met

Some sites at the Laboratory may require cleanup to action levels, e.g., soil excavation or treatment or some other method that physically removes the contaminant from the environment. However, there are sites at the Laboratory from which it would be impractical to physically remove all contaminants. Therefore, the definition of cleanup must include other remedies that involve controlling migration of contaminants from a source.

Cleanup refers to any measure taken to ensure protection of human health and the environment, not to total removal of a contaminant. Areas of widespread, very-low-level contamination, such as the canyons that drain the Laboratory site, are locations that may not be required to attain total cleanup. For example, low levels of risk to human health resulting from contamination in local canyons would not be significantly reduced by cleanup because contaminant concentrations are so close to background levels. Thus, cleanup will be approached on a case-by-case basis, and it will be the responsibility of DOE/UC to demonstrate to EPA that remediation would provide no significant reduction in risk.

One of the primary remedial measures that the Laboratory intends to propose for several materials disposal areas (MDAs) is in-place stabilization followed by long-term monitoring and institutional control, when an RFI supports such an approach. Appendix C describes landfill cover technology. This choice would not meet media cleanup criteria because the contaminants would remain in the environment. However, remediation of these large, mixed-waste landfills would be an extremely large, complex, and perhaps risky undertaking. In these cases, DOE/UC intend to propose that technical impracticability precludes attainment of media cleanup standards.

3.5.4.3.6 Demonstration of Compliance with Media Cleanup Standards

DOE/UC will propose for EPA approval several conditions for demonstrating that implementing a remedy complies with the cleanup standards. Those requirements include identifying

- the location where compliance levels must be achieved,
- the sampling and analytical methods that will be used to determine compliance, and
- the length of time that DOE/UC must monitor a site to demonstrate that levels of contamination after cleanup do not exceed standards.

The primary limiting cleanup standards for the Laboratory will be those for soils and sediments. In general, the point of human exposure will be the likely location for

demonstrating compliance. However, it may be that the point of compliance for some sites will have to be determined on a case-by-case basis. The program may provide innovative and unique methods and instrumentation for monitoring compliance, including a variety of downhole sensors and high-speed analytical units for use in the field. EPA approval of these methods and instruments for several OUs will be requested in future revisions of this IWP. Approval of those methods specific to an OU will be proposed in the CMS report for the individual unit.

3.5.4.4 Conditional Remedies

When EPA cannot select a final remedy or when DOE/UC and EPA agree that it is in the interest of the environment to delay implementation of the final remedy (e.g., to complete technology development or when reasonable DOE disposal capacity is not available), conditional remedies may be proposed and approved. Such remedies include prompt corrective measures that can reduce risk or incomplete cleanup when a total cleanup is impractical. Conditional remedies are appropriate for actively managed, financially viable facilities such as the Laboratory. When a conditional remedy is used, the site must be revisited after a preestablished period to determine whether the remedy can be considered final and certified as complete before terminating the specified schedule of compliance. Several criteria must be met before implementation. These criteria include

- protecting human health and the environment,
- achieving media cleanup standards beyond the facility boundary,
- preventing further significant environmental degradation,
- implementing institutional controls,
- continuing monitoring, and
- complying with waste management standards.

DOE/UC will propose site stabilization and long-term monitoring and institutional controls as a conditional remedy for some of the large MDAs, which are similar to large municipal landfills. The concentrations of contaminants in hazardous materials in the MDAs that meet criteria for conditional remedies do not currently threaten human health. Institutional controls currently provide long-term control of access and prevent potential exposure of Laboratory workers. For these reasons, DOE/UC believe that site stabilization and institutional controls will protect human health. Long-term monitoring will be conducted as necessary.

As practicable, the conditional remedy will be identified in the RFI work plan, and data collection will focus on obtaining information adequate to evaluate the effectiveness of the likely remedy. The RFI will be structured to support the ultimate selection of the proposed remedy. When possible, a treatability study will be incorporated in the RFI work plan, and the findings of that study will be presented in the RFI report. Data generated through the RFI will provide EPA with a basis for selecting a remedy sufficient to protect human health and the environment. When the results of the RFI support a single obvious remedy, which could include extensive pilot testing, a formal

CMS will not be conducted but the proposed remedy will be presented to EPA as part of an RFI report. Based on the results of the RFI, DOE/UC will request that the permit be modified to allow a conditional remedy. Upon EPA approval, DOE/UC will prepare a CMI plan for implementing the remedy. The CMI plan will provide for obtaining information adequate to design and implement the remedy, maintenance plans, schedule, QA program, progress reports, and a proposal for determining a complete and final remedy.

Because DOE/UC intend to propose in-place stabilization with long-term monitoring and institutional control as a remedial alternative for some PRSs, it is acknowledged that, to ensure compliance, sensitive and dependable instruments will be required for long-term monitoring; therefore, DOE/UC have initiated several efforts to develop appropriate equipment, such as polymer film field sensors, optical fiber-flow optrode, fieldable Raman with fiber optics, and tritium plume detectors.

DOE/UC realize that conditional remedies may not be final remedies; therefore, they propose that the remedy decision be reviewed after a period of implementation to compare the performance of the conditional remedy with established remedy standards. The conditional remedy may be declared the final remedy at that time, or EPA may require further corrective action to supplement or replace the conditional remedy. Final selection of the remedy and termination of the permit will comply with the procedures described in Section 4.5.

3.5.4.5 Permit Modification for Selection of the Remedy

The preliminary selection of the remedy based on EPA's response to the CMS report will be finalized by a major modification of the schedule of compliance given in the HWSA Module. The EPA will modify the permit to specify the remedy selected through the CMS process. The permit modification will be conducted according to the procedure established in Section N of the HSWA Module. The modification process will include a formal public comment and revision period before the written notice of the permit modification is issued, not before reissuance of the permit.

The remedy specified may be separated into phases, and the proposed modification will include

- a description of the technical features of the remedy;
- the media cleanup standards established through the CMS process;
- requirements for achieving compliance with media cleanup standards;
- requirements for complying with waste management standards, land disposal restrictions, etc.;
- requirements for final disposition of the equipment used to implement the remedy;
- schedule and major milestones for implementing the remedy, including submission of the CMI plan; and

- reports and documentation to be submitted by DOE/UC during the implementation of the remedy.

3.5.5 Requirements for the CMI

DOE/UC will prepare a CMI plan after approval of the permit modification and upon request of EPA. The outline for the DOE/UC CMI plan has not been developed but will be submitted for approval in a future revision of this IWP. In general, the CMI plan will include

- remedy design; i.e., detailed construction plans and specifications to implement the selected remedy;
- type and frequency of reports to be submitted on the progress of implementation;
- type of EPA reviews of implementation;
- requirements for completion of the remedy;
- determination of technical impracticability; and
- verification plans.

3.5.5.1 Remedy Design

The CMI plan will contain a section that provides detailed construction plans for implementing the remedy. In some cases, the technical details may have been provided in the CMS report. The CMI plan may cite those specifics and propose to EPA that they be adopted in the final design. In either case, EPA approval of the CMI plan will constitute approval of the remedy design and schedule. The remedy design should include

- design specifications for PRSs,
- implementation and long-term maintenance plans,
- major milestones,
- project schedule, and
- a QA plan for the construction.

EPA will approve or revise the CMI plan, and DOE/UC will implement the remedy as approved. The approved CMI plan will be placed in the Laboratory's community reading room (Annex V). DOE/UC will provide written notice of the availability of the approved plan to all individuals on the ER Program mailing list. In addition, the cost estimate provided in the CMS report will be revised as necessary.

3.5.5.2 Corrective Measures Progress Reports

Depending on the type of remedial action being implemented, it may be necessary to provide frequent and detailed information about the effectiveness and progress of the remedy. The data on which the reports are based are maintained in the RPF and are available for public review.

The schedule and content of the progress reports will be developed in the CMI plan and will thus be tailored to each OU. The reports may include

- summaries of progress,
- problems encountered and resolutions,
- personnel changes,
- upcoming work for the next reporting period, and
- laboratory and field sampling reports.

3.5.5.3 Review of Remedy Implementation

EPA will periodically review the progress of the remedy and may recommend modification of the schedule of compliance or additional remedial measures. The reviews may consist of reviews of the progress reports and visits. Because each remedy will require varying levels of EPA oversight, CMI plans will be tailored to each site according to the level of review and progress evaluation required.

3.5.5.4 Completion of Remedies

The CMI plan will contain the criteria to be used to demonstrate completion of the remedy. Upon completion of the remedy, DOE/UC will submit a request for termination of the schedule of compliance for the corrective action. The request will contain a certification that DOE/UC have met or exceeded all of the criteria established for this purpose. The request to EPA will include verification that

- all media cleanup standards have been achieved,
- actions required for source control have been satisfied, and
- procedures for final disposition of equipment and materials associated with the remedial action have been followed.

EPA will review the request, along with public comments, to determine whether the remedy has been completed in accordance with the requirements of the HSWA Module and CMI plan. After such determination, the EPA will modify the HSWA Module to terminate the schedule of compliance for the corrective action (Section 3.11).

3.5.5.5 Determination of Technical Impracticability

For numerous reasons, it may be technically impractical to achieve compliance with the requirements for the remedy. DOE/UC expect to minimize such situations through the use of new and innovative remedial technologies developed by and for the Laboratory. However, if compliance is impossible for technical reasons, DOE/UC will propose that EPA modify the permit so that additional or alternate methods may be used. This approach will be developed further in an update of this plan.

3.6 Coordination of Corrective Actions with Resource Conservation and Recovery Act Closures

Several SWMUs listed in the HSWA Module are subject to both the corrective action and closure provisions of RCRA (e.g., RCRA hazardous wastes were intentionally managed at these sites after November 19, 1980). DOE/UC will manage all of these sites in a manner consistent with the management of all of the other PRSs listed in the Laboratory's PRS data base. As a result, the corrective action process will occur concurrently with the closure process, thereby satisfying both sets of regulations. It is understood that the NMED will maintain its role as the lead regulatory agency for these sites in spite of the change in approach.

DOE/UC will implement this strategy for several reasons: (1) The RFI/CMS portions of the corrective action process ensure that releases are identified and mitigated as part of a final remedy (simple compliance with closure standards does not always guarantee mitigation). (2) The strategy allows for a consistent, coherent approach to environmental restoration (e.g., some OUs currently contain PRSs subject only to RCRA corrective action and PRSs subject to both corrective action and closure). (3) This strategy prevents duplication of effort. (4) The strategy is consistent with the preamble to proposed Subpart S, which states EPA's intent to allow extension of closure deadlines as necessary to complete corrective actions.

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4.0 TECHNICAL APPROACH

This chapter presents the Los Alamos National Laboratory (the Laboratory) Environmental Restoration (ER) Program's technical approach to the corrective action process. This work is conducted under the Resource Conservation and Recovery Act (RCRA) as amended by the Hazardous and Solid Waste Amendments (HSWA). Because it is the Laboratory's policy to comply with the requirements of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as well as those of RCRA, this approach includes elements of the CERCLA process. In particular, the approach is applicable to all potential release sites (PRSs), including those that are not subject to the provisions of the HSWA Module (Module VIII of the Laboratory's permit to operate under RCRA).

The technical approach used at Los Alamos is modeled on the Department of Energy's (DOE's) streamlined approach for environmental restoration (SAFER) (Gianti et al.1993, 1021), which combines elements of the observational approach (Appendix G) and the Environmental Protection Agency's (EPA's) data quality objectives (DQO) process for designing data collection to support environmental decisions (Section 3 of Appendix H). The Los Alamos approach is embedded in a decision framework that provides for phased site investigations, early identification of important problems to facilitate prioritization, and timely implementation of corrective actions. The DQO process is used to design the field investigations for site characterization, remedy selection, cleanup verification, and site monitoring that provide data to support specific decisions.

The decision points in the general framework correspond to decisions described in RCRA corrective action guidance (EPA 1990, 0432; 0088). The ER Program has developed detailed decision criteria to supplement this regulatory guidance. In particular, the program has determined that a risk-based approach to site prioritization and remediation is generally appropriate, given the great variety of PRSs that have been identified and the complexity of the natural environment on the Pajarito Plateau. However, other criteria are also important because remedial decisions entail significant monetary, social, and legal consequences that must be incorporated in a technical framework. These decision criteria are described briefly in Sections 4.2 and 4.3. Appendix I describes decision strategies for the ER Program. Site-screening criteria are derived in Appendix J, and Appendix K provides detailed information about human-health-risk-based decision criteria. Appendix L discusses ecological risk assessment and natural resource damage assessment.

Sections 4.4 and 4.5 of this chapter provide brief surveys of technological options for site characterization and corrective action that may be considered during the investigative and remedial stages of the program.

Defined below are several terms used frequently in this chapter that carry meanings specific to the ER Program decision processes and to risk assessment. Additional definitions may be found in the glossary at the end of this document.

Baseline risk assessment A risk calculation that uses an appropriate, site-specific exposure scenario but that assumes no mitigating or corrective measures beyond those already in place.

Background levels The distribution of concentrations of naturally occurring or widely distributed anthropogenic constituents in environmental media.

Cleanup levels Media-specific target concentration levels for contaminants that must be met by a selected corrective action. Cleanup levels are established at the conclusion of the corrective measures study (CMS) using criteria such as protection of human health and the environment; compliance with regulatory requirements; reduction of toxicity, mobility, or volume through treatment; long- and short-term effectiveness; implementability; cost; and public acceptance.

CMS risk assessment A risk calculation that estimates the expected reduction in risk resulting from a proposed corrective measure under an appropriate, site-specific exposure scenario.

Contaminant, contaminant of concern Any constituent present in environmental media or on structural debris at a concentration that may present a risk to human health or the environment.

Constituent Any compound or element present in environmental media, including both naturally occurring and anthropogenic compounds.

Deferred investigation Postponement of complete evaluation of a PRS, which may be proposed when investigation would have negative impacts on current Laboratory operations.

Environmental medium Any medium capable of receiving or transporting constituents released from a PRS, including tuffs, soils, and sediments derived from these tuffs; surface water; groundwater; air; structural surfaces; and debris.

Exposure unit The bounded area or volume within which a person or other receptor may be exposed to contaminants that have been released to the environment. The size of an exposure unit is determined by the receptor activities as described by the exposure scenario.

No further action (NFA) A decision that no further investigation or remediation is warranted for a PRS.

Regulatory standard, regulatory concentration criteria Media-specific contaminant concentration levels of potential concern that are mandated by federal or state legislation or regulation (e.g., the Safe Drinking Water Act, New Mexico Water Quality Control Commission regulations).

Risk assessment Estimation of the likelihood of human health or environmental risk from contamination of environmental media. Risk assessment includes hazard identification, exposure assessment, and dose response analysis.

Screening action levels (SALs) Media-specific concentration levels for constituents derived using conservative intake assumptions and used during the RCRA field investigation (RFI), primarily to identify contaminants of concern.

Screening assessment Evaluation of information about a PRS to determine whether hazardous or radioactive constituents are present above the levels of concern defined by media-specific SALs or regulatory standards.

Voluntary corrective action (VCA) Selection and implementation of an obvious and effective corrective action during or following the RFI.

4.1 RFI and Corrective Action Strategies

4.1.1 Decisions During the RCRA Process

The RCRA process outlined in Chapter 1 is designed to generate and implement appropriate decisions concerning corrective actions for PRSs identified by the RCRA facility assessment (RFA). Following RFA identification of potentially significant releases, the RCRA process generally proceeds through RFI, CMS, and corrective measures implementation (CMI), as illustrated in Figure 1-1. Progress is demarcated by several decision points, as illustrated in Figure 4-1. Many of these decisions require the collection and assimilation of environmental data. The Los Alamos technical approach to environmental restoration begins with statements of these decisions and the associated decision criteria that are sufficiently explicit to guide the design of field investigations and the evaluation of the resulting data.

Decisions required during the RFI include

- determining whether contaminants have been released to the environment (the site screening decision in Figure 4-1),
- determining whether corrective action is required for the site (a risk-based decision that may be made before or after CMS has been initiated), and
- determining whether a formal CMS is required to select and design an appropriate corrective action.

Usually environmental data will need to be acquired during the RFI in order to support these decisions.

The possible outcomes of the RFI, in addition to proceeding with a CMS, include

- proposing NFA,
- deferring action, and often deferring investigation as well, until an active site becomes inactive,
- VCA, or
- interim measures.

NFA may be proposed for administrative reasons (e.g., the PRS was incorrectly listed, corrective action is being or will be undertaken outside the ER Program) or on the basis of existing information. It may also be proposed following a determination that no environmental release has occurred or that no human health or environmental risks are associated with the site, based on new information collected during the RFI. If the PRS is listed in the HSWA Module, the Laboratory will submit a permit modification request following the procedures described in the HSWA Module and 40 CFR 270. When proposing NFA for PRSs not listed in the HSWA Module, the ER Program will observe similar procedures; however, formal delisting is not required in this case.

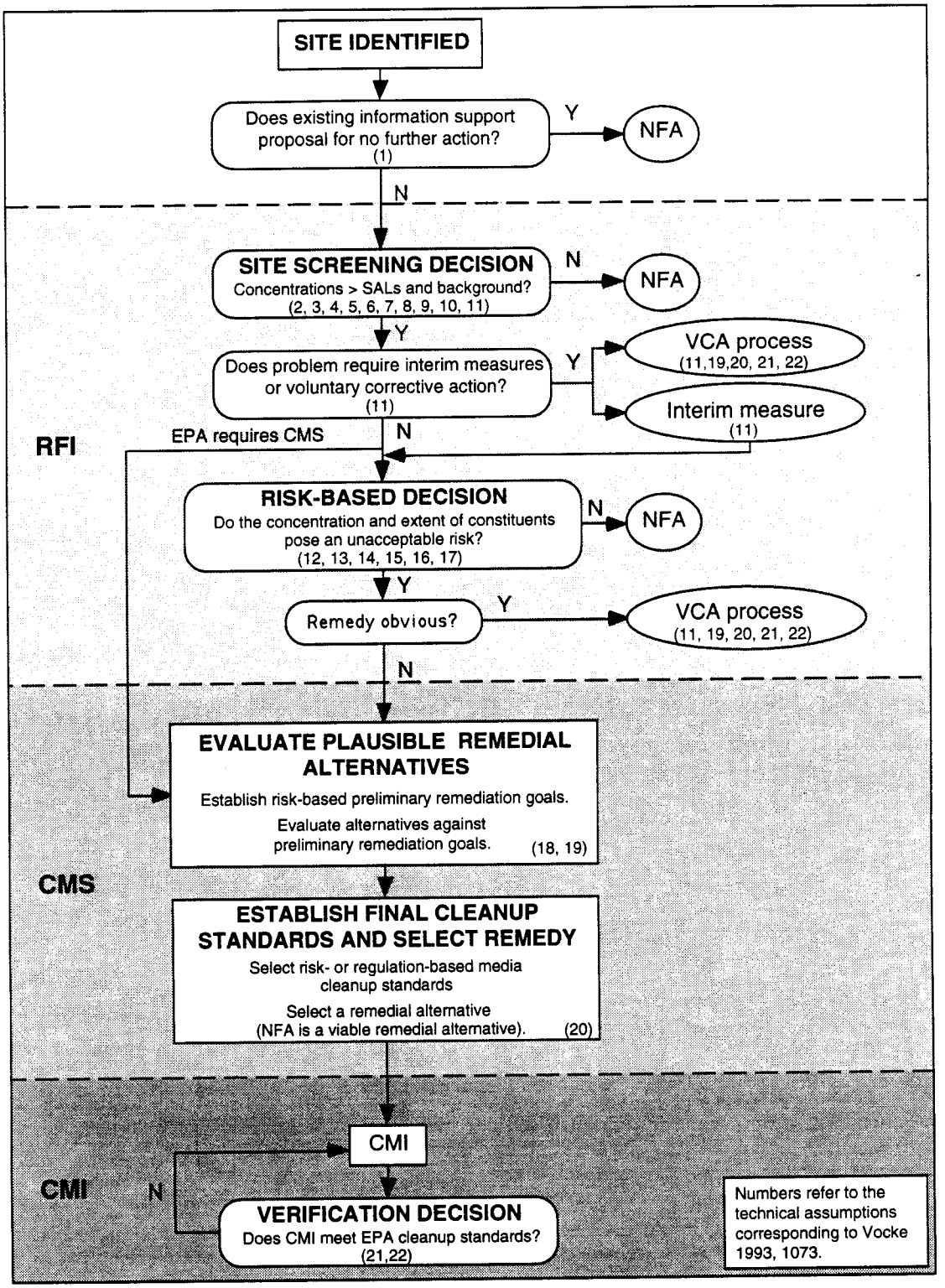

Figure 4-1. RCRA decisions requiring environmental data.

Deferred investigation is the postponement of site evaluation at a PRS that is either active or is so closely associated with an active site that immediate investigation would negatively affect current Laboratory operations. A proposal for deferred investigation must be accompanied by a determination that the PRS poses no unacceptable current risk to human health or the environment from either direct exposure to or migration of contamination, which sometimes requires a limited RFI, such as perimeter sampling. Proposals to defer investigation in the RFI work plan are subject to EPA approval.

VCA is an expedited remediation option described in proposed Subpart S to RCRA (EPA 1990, 0432). The ER Program's implementation of this option is illustrated in Figure 4-2. A decision to propose a VCA may be made at any time during the RFI when an obvious and effective remedy is available and meets treatment and disposal restrictions and other limiting criteria.

If DOE approves the proposal to proceed with a VCA, a VCA plan is developed. Table 4-1 presents the table of contents for the VCA plan. Site-specific cleanup standards proposed in the VCA plan may be developed using risk-based criteria.

Before a VCA can be implemented, DOE must approve the VCA plan. Some VCAs may require permit modifications or temporary authorizations, as described in proposed Subpart S to RCRA (EPA 1990, 0432), in which case EPA approval is also required. VCAs that will produce mixed waste will be postponed until the Mixed-Waste Disposal Facility is available unless the site is not on DOE property or conditions at the site pose an immediate health hazard. Whether approval is required or not, VCA plans will be submitted to EPA and the New Mexico Environment Department, and the public will be informed of VCAs in public meetings.

EPA approval of VCAs as final remedies will be requested, and a final report will be submitted to EPA and NMED, provided that cleanup standards have been attained and DOE has approved the final report. (The table of contents for the final report is shown in Table 4-2). In other cases, VCAs may serve merely as interim measures, followed by a return to the normal RFI/CMS process.

If a CMS is performed to evaluate remedial alternatives, the following additional decisions must be made:

- determining cleanup standards for contaminated environmental media (also required for VCAs, as shown in Figure 4-2) and
- selecting a corrective measure to meet these standards.

The final stage of the corrective action process is the CMI. The principal decisions that may be required during this stage are

- identifying significant deviations from expected site conditions that require modifying the corrective measure, if they exist,
- verifying that cleanup standards have been obtained, and
- verifying the satisfactory performance of a conditional remedy, if applicable

Again, all of these CMI decisions generally require the collection of environmental data.

TABLE 4-1
OUTLINE FOR VCA PLAN

EXECUTIVE SUMMARY

1.0 INTRODUCTION

2.0 SITE BACKGROUND AND ENVIRONMENTAL SETTING

- 2.1 Detailed Description of PRS(s) for Which VCA Is Scheduled
  - 2.1.1 Operational History
  - 2.1.2 Environmental Conditions
  - 2.1.3 Regulatory Status of Unit (e.g., RCRA vs. HSWA)
- 2.2 Summary of Previous Investigations, Environmental Data, and Archival Information
- 2.3 Types and Volumes of Waste Present
- 2.4 Potential Pathways of Contaminant Migration
- 2.5 Potential Impacts on Public Health and the Environment

3.0 VCA PLAN RATIONALE

- 3.1 Extent of Contamination Is Limited
- 3.2 Remedy Is Obvious
- 3.3 Site for Waste Treatment/Storage/Disposal Is Available
- 3.4 Permit Requirements Are Met
- 3.5 Impacts on Human Health and Environment and/or Cost or Overall Cleanup Schedule Are Reduced

4.0 TASK VCAs

- 4.1 Detailed Description of Corrective Action Activities
- 4.2 Characterization of Materials for Disposal
- 4.3 Criteria to Determine Effectiveness of VCA
- 4.4 VCA Verification Plan
- 4.5 Site Restoration Plan

5.0 PROJECT MANAGEMENT

- 5.1 Staffing
- 5.2 DOE Approval
- 5.3 Regulatory Notifications/Permit Modifications
- 5.4 Stakeholder Notifications
- 5.5 Resource Requirements
- 5.6 Schedule

6.0 REFERENCES

ANNEXES

Implementation SOPs
Quality Assurance Project Plan
Health and Safety Project Plan
Records Management Project Plan
Public Involvement Project Plan

TABLE 4-2
OUTLINE FOR VCA FINAL REPORT

EXECUTIVE SUMMARY

1.0 INTRODUCTION

2.0 SITE BACKGROUND

Summary of VCA Plan Information

3.0 DESCRIPTION OF VCA

3.1 Description of Sampling
3.2 Results of Sampling
3.3 Description of Remediation
3.4 Waste Treatment, Storage, and/or Disposal

4.0 RESULTS OF POST-VCA VERIFICATION

5.0 FINAL SITE CONSIDERATIONS

5.1 Effectiveness of VCA
5.2 Visual Documentation

6.0 REGULATORY NOTIFICATIONS/PERMIT MODIFICATIONS

7.0 STAKEHOLDER NOTIFICATIONS

APPENDICES

VCA Data

4.1.2 The Streamlined Approach to Environmental Restoration

The DOE's SAFER parallels the Los Alamos technical approach to investigations to support the decisions outlined above. The streamlined approach implements many of the suggestions for improving CERCLA's remedial investigation/feasibility study process, which evolved from an EPA review of early Superfund projects (EPA 1987, 0821). SAFER emphasizes planning, strong links between data collection and decision-making needs, explicit recognition and management of uncertainty, early convergence on a remedy, and participation by key stakeholders (DOE 1992,1022).

In particular, the streamlined approach implements a program of phased site characterization that continues beyond the RFI into the corrective action stages of the process. Such a phased approach is recommended in proposed Subpart S (EPA 1990, 0432). This phased or observational approach avoids the delays that would result from attempting an excessively detailed characterization of the site during the RFI. It expedites corrective action by early consideration of possible remedial alternatives and by progressing to the later steps of the RCRA process as soon as

possible. Although understanding of the site (the "probable conditions," in observational approach terminology) may change as more site detail is revealed by CMI activities, "reasonable deviations" from the probable conditions can be accommodated by contingency planning during the CMS and site monitoring during the CMI. Thus, the goal of RFI site characterization is first to determine whether the problem warrants corrective action and, second, to develop an understanding of probable site conditions that is adequate to design a corrective measure that includes contingency alternatives. More detailed characterization, designed to evaluate whether one of these modifications should be invoked, is carried out during the CMI.

The first step in the decision flow for site investigations begun during the RFA consists of evaluating the existing information about a PRS by

- reviewing the operations that created the site;
- constructing a preliminary conceptual exposure model to summarize current knowledge about potential contamination of environmental media at the site, migration pathways through the environment, and biological receptors; and
- outlining potential response actions.

Depending on the nature of the site and quality of this information, it may be possible to propose NFA without field investigations at this point. Alternatively, when a good historical data base for the site is available, existing information may be sufficiently complete to proceed immediately with VCA or with a formal CMS, or a decision to defer investigation until the site becomes inactive may be appropriate.

In general, however, the site will require RFI site characterization. Figure 4-2 shows two RFI activities that may require collecting new data: the screening assessment and baseline risk assessment for a risk-based decision. For the majority of PRSs at the Laboratory, the first investigation phase will support a screening assessment (Section 4.1.4). If the contaminants of concern have been identified by previous work or can be determined from archival information, it may be possible to design the first phase of the RFI work to support a risk-based decision. In some cases, a field investigation can be designed to support both decisions, although such a design may be less than optimal for either purpose. Rarely, the first phase of the RFI may be designed to establish probable conditions and reasonable deviations as part of the VCA process or in preparation for evaluating remedial alternatives during CMS.

A key element of the technical approach used at the Laboratory is the design of focused data collection efforts. The primary tool for ensuring that a sampling and analysis plan will produce data of the required types, quantity, and quality is the DQO process (EPA 1992, 0981). Well- formulated decision criteria, together with a list of specific decision alternatives, are central to the process. For a screening assessment, the explicit decision statement might take the following form:

> Are hazardous constituents present above SALs in the soils at this site? If so, a baseline risk assessment will be performed to evaluate the associated risks (which may require the collection of additional data); if not, no further action will be proposed.

A risk-based decision statement could be

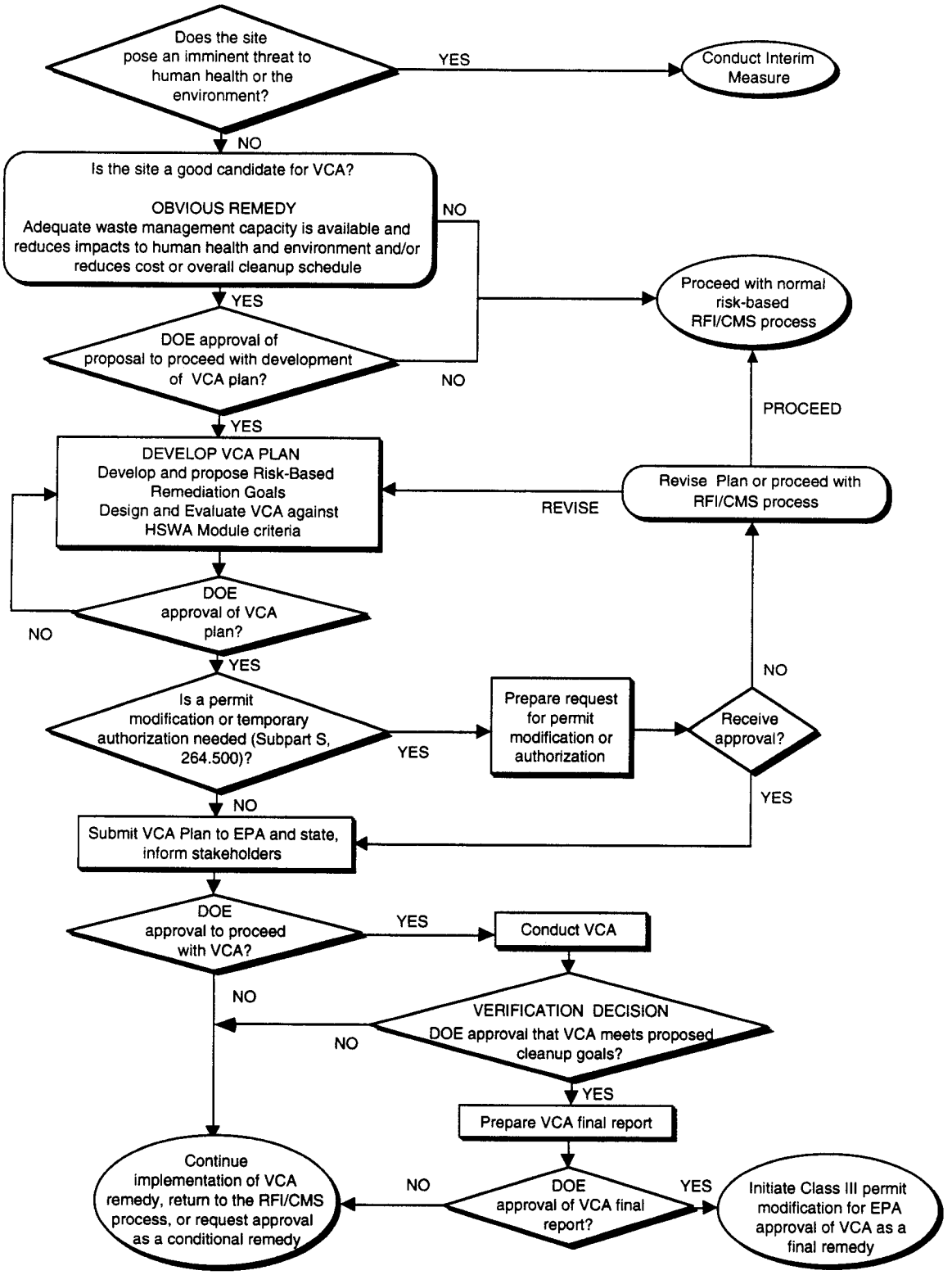

Figure 4-2. VCA decision logic.

> Do the level and extent of contamination at this site pose a health risk greater than 10^{-6} to future recreational users of the area? If so, VCA will be evaluated as an alternative to CMS/CMI; if not, NFA will be proposed.

Formulating an appropriate problem statement requires evaluating the current state of knowledge about the site. This evaluation is the first step of the seven-step DQO process outlined in Section 3 of Appendix H. At the beginning of the RCRA process, archival information is used to construct a preliminary conceptual model for the problem. For later investigations, this step updates the conceptual model using data from previous investigations. Step 2 of the DQO process specifies the decision and decision alternatives. Subsequent steps specify what types of measurements are needed, where and when measurements should be made, and how the data will be used to support the decision. Design criteria that must be met in order to reduce uncertainty in the decision to a manageable level are developed in Step 6. The final step of the process is the preparation of a sampling and analysis plan that balances investigation costs against the expected reduction in uncertainty about site conditions. Although not all of the PRSs in the ER Program require that DQOs be developed following an extended formal process, the products of this process—the DQOs—are essential to ensuring that field investigations produce the necessary information.

4.1.3 Sampling Decisions in a Phased Investigation

A phased approach to site investigation helps to ensure that sampling decisions remain closely tied to the ultimate goal of selecting an appropriate corrective action and that they incorporate what is already known about the site. The costs associated with repeated mobilizations of personnel and equipment must be weighed against the benefits of collecting fewer samples overall. However, in situations where a large number of sites must be screened and many may prove to be of little or no concern, the benefits of a phased approach far outweigh these potential extra costs.

The first phase of RFI field work collects information for the first decision that cannot be made on the basis of existing information alone (Figure 4-1). For many of the Laboratory's PRSs, this decision turns out to be determining whether contaminants of concern are present at the site. The most frequent criterion for this screening decision is the presence of constituents in environmental media above SALs. Sampling plans for screening assessment are often small and may incorporate directed sampling based on professional judgment or field survey results in their design to increase the probability of detecting any contamination. The screening decision may be based on a single observation of a contaminant above its SAL.

Risk-based decisions are not based on comparisons of individual observations with SALs, both because the intake assumptions used in the SAL calculation are not site-specific and because risk depends on the extent of contamination, as well as the level. Risk-based decisions use site-specific exposure assessments to estimate the intake of contaminants under reasonable, site-specific exposure scenarios. If the exposure scenario involves receptors located at the site, exposure assessment uses estimates of the mean contaminant levels over exposure units whose size depends on assumed patterns of land use and other exposure assumptions. (Appropriate land use and exposure assumptions will be determined after stakeholder input has been received.) For receptors off the site, mean contaminant levels in exposure units removed from the source in space and time must be estimated, and it may be

necessary to characterize potential environmental transport pathways or potential receptors, as well as the level and extent of contamination at the site.

An investigation designed to support a baseline risk assessment may not provide the amount or type of detail about the site that is necessary to design a corrective measure. If corrective action is necessary, additional site characterization may be required to establish the most probable site conditions, together with reasonable deviations from those conditions. The goal of such additional sampling may be improved understanding of the spatial distribution of the contaminants, better characterization of hazardous constituents for treatment or disposal purposes, or better knowledge of the geological and hydrological factors that control their migration. These diverse goals lead to diverse sampling designs.

Two possible RFI sampling decisions are actually decisions not to sample. Proposing NFA may be an appropriate decision based on archival information. Deferred investigation may be proposed for a PRS when any necessary corrective action will be postponed until an associated active site is closed. Deferred investigation may also be proposed for a site where VCA is planned. In this case, sampling (for example, sampling to document the nature of the wastes for disposal or to verify that cleanup standards have been attained) is integrated with the VCA.

When complete characterization of a site is being postponed until VCA or until the site becomes inactive, an RFI screening assessment may still be appropriate. Screening assessment or perimeter monitoring may be required at a site where full investigation will be deferred. A limited RFI investigation may be designed to forestall unpleasant surprises such as the discovery of a large organic vapor plume under an old septic tank during VCA.

Site characterization to detect deviations from probable conditions is handled by appropriate monitoring of the site during the CMI. Site monitoring may include in-situ measurement and/or sampling. If sampling is performed, fast turnaround of analyses is important (i.e., indicator measurements that can be performed in a field laboratory are preferred whenever possible). Devices for long-term monitoring of the site perimeter may be installed to verify the continuing effectiveness of the corrective measure. The design of the monitoring system depends on the purpose for which monitoring data will be used; however, timely data analysis and predefined responses to potential anomalous observations are two important components of any monitoring plan.

Sampling to verify attainment of cleanup standards is the final step in many corrective actions. In some respects, verification sampling is far more straightforward than sampling for site characterization. Guidance for this type of sampling is found in EPA documents (e.g., EPA 1989, 0794).

4.1.4 Screening Assessment

The goal of screening assessment is to identify contaminants of concern, that is, constituents whose concentration levels in one or more environmental medium are above a level of concern, usually defined by media-specific SALs. The logic of a screening assessment is shown in Figure 4-3. The starting point is the identification of constituents and environmental media of potential concern, based on knowledge of the process or processes that occurred at the PRS. Eliminating other constituents from further consideration should be justified by reference to these processes.

Screening for the identified constituents is then carried out using either existing data or new data collected during the RFI. It is essential to identify decision criteria (levels of concern) because the data, whether old or new, should be collected using procedures whose detection limits are below the levels of concern.

Usually, the maximum observed concentration of each constituent of potential concern, rather than averages of several observations, is compared with SALs in order to identify contaminants of concern for the screening assessment. In some cases, observations made on composite samples, or averages of closely related samples such as field duplicates, may be used. If SALs are not exceeded for any constituent, then the site may be a candidate for NFA; however, in some cases, additional site evaluation may be necessary. In particular, if two or more constituents are detected at elevated levels, even if below SALs, further evaluation is needed to determine their combined effects, as described in Appendix J.

SAL comparisons will be based on measured concentrations, unadjusted for natural or anthropogenic background concentrations. At Los Alamos, constituents with positive natural background concentrations include radioactive and nonradioactive inorganic constituents of the tuffs, soils, and sediments of the Pajarito Plateau. Anthropogenic background constituents include low levels of radionuclides from worldwide fallout. For some constituents, SALs are below background levels, and, for these, background comparisons will also be necessary. Background comparisons will be performed using a series of statistical tests to compare the distributions of concentrations measured at a site with background distributions (Appendix H). Constituents whose concentrations are statistically indistinguishable from background will not be identified as contaminants of concern, even if these concentrations exceed the calculated SALs.

Constituents whose concentrations exceed both background levels and SALs or that are identified as contaminants of concern because they may present a risk in combination with other constituents present require further evaluation and possibly remediation. Further evaluation may include comparing the observed levels with regulatory standards (such as the guidelines for PCBs given in the Toxic Substances Control Act). Additional evaluation may also include baseline risk assessment for which additional field investigation may be necessary.

4.1.5 Risk-Based Decisions

The presence of contaminant concentrations above SALs may not in itself warrant corrective action for any of a number of reasons. SALs are purposely set at very low levels, levels to which sensitive receptors could be exposed on a daily basis without appreciable risk of adverse effects during their lifetimes. The extent and overall level of contamination may be such as to preclude negative impacts under a realistic exposure scenario for the actual site. Therefore, in general, the presence of contaminant concentrations about the SALs will lead to further evaluation of the site.

Further decisions about the site must take into consideration the risks associated with the identified contaminants under actual or potentially realistic exposure conditions. Among these risk-based decisions are determining whether corrective action is needed, establishing target cleanup levels for corrective actions, and defining levels of concern for site monitoring as part of a conditional remedy.

Risk-based decisions take into consideration not only contamination levels at the site but also the mechanisms by which biological organisms (human or other) might be

exposed to this contamination under exposure scenarios that are consistent with current or reasonably likely future land use patterns. (The most conservative choices of exposure scenarios—the choices that lead to the highest risk estimates—are based on residential land use; however, Los Alamos plans to propose to its stakeholders alternative scenarios for areas that are remote from current residential areas, as described in Appendix K.) The risk associated with contamination depends on the dose to these receptors, which, in turn, is proportional to the intake of contaminants by the receptor integrated over both the areas and duration of exposure. Therefore, a risk-based decision is most appropriately based on an estimate of the distribution of contamination throughout an exposure unit whose definition depends on the exposure scenario for which risk is being calculated. An exposure unit may not be the same as the PRS; it may be smaller or larger. When it is smaller, a risk-based decision for the PRS is actually a set of decisions—one for each exposure unit in the PRS.

Decision criteria for a risk-based decision can be formulated in two ways. Generally, one calculates the total risk from all of the contaminants of concern in an exposure unit using all of the potential exposure pathways for those contaminants. This total risk is compared with a target risk level. Alternatively, if individual contaminants of concern have only one or two significant exposure pathways, the risk model translates the target risk level into a medium-specific target concentration level. These target concentration levels are compared with estimates of the average concentration over the exposure unit.

4.1.6 Data Quality Assurance

Data quality assurance is an integral part of the decision-oriented approach to the field investigations described in the preceding sections because many additional assumptions must be made in the process of deriving sampling strategies from decision criteria and design specifications. For example, in determining appropriate sample sizes for estimating the mean concentration of a contaminant in an exposure unit, assumptions are made about the expected types and sizes of errors arising from sampling and analytical measurement. The DQO process exposes these assumptions for both regulatory and public review and calls attention to important areas to be addressed by the data quality assurance program.

The purpose of data quality assurance is to ensure that the data are fit for their intended use in support of an environmental decision. A complete data quality assurance program has several aspects. It begins with a complete set of data quality objectives derived from the decision criteria and design specifications. It is implemented in accordance with a project-specific quality assurance project plan (QAPjP) that includes several components:

- in-line quality control (QC) measurements, such as calibration checks and replicate analyses;
- formal and informal process audits, ranging from inspections by independent evaluators to daily "tailgate" briefings of the field crews;
- the collection of quality assessment samples that will be used to evaluate critical assumptions identified during the DQO process.

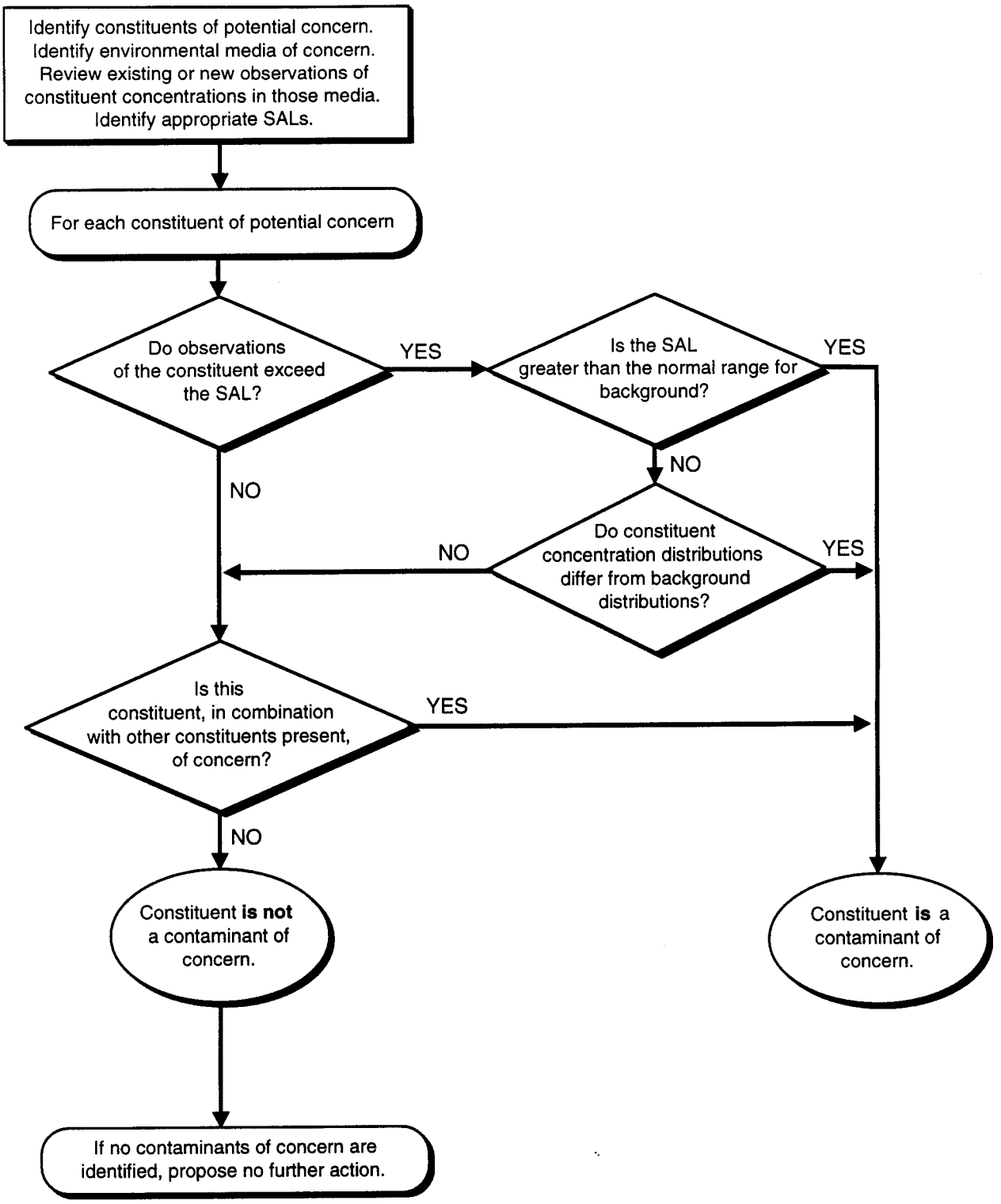

Figure 4-3. Decision logic for screening assessments.

The final aspect of data quality assurance is data validation and assessment. Validation includes verification of completeness and review of documentation supporting the analytical results, as well as an analytical data assessment process that includes a review of calibration data; analyses of blanks, duplicates, and matrix spike samples; and other supporting information. The final step, data quality assessment, evaluates the results in the context of the assumptions, the decision-based requirements, and the environmental conditions at the site.

4.2 Evaluation Factors and Criteria

4.2.1 Evaluation Factors for the Laboratory's ER Program

In the Laboratory's ER Program, criteria used to evaluate decisions are based on common sets of evaluation factors. The five major categories of concern for the Laboratory's ER Program are the same categories used by the Laboratory for many other decisions:

- impacts on human health and safety,
- environmental risks,
- impacts on the social and economic well-being of both the local community and the general public,
- management concerns related to compliance and operations, and
- monetary costs.

The HSWA Module (EPA 1990, 0306) and the DOE Office of Environmental Restoration and Waste Management explicitly state that the primary concern of the ER Program is impacts on human and environmental health and safety, that is, the first two categories listed above. These priorities are reflected by the technical approach adopted throughout the ER Program.

Human health and safety include impacts on both site workers and members of the general public. Public and worker health effects are commonly estimated by risk assessment relative to two endpoints: excess lifetime cancer risk and noncarcinogenic toxicological impacts. Safety impacts are most often estimated for site workers; however, for some sites, such as those where undetonated explosives or ordnance may remain, public safety may also be a major concern. Safety impacts can also be quantified using probabilistic measures of the risk of loss of life or faculties. Health and safety concerns include not only the impacts associated with an actual or potential operational release but also those occurring as a result of remediation efforts.

Environmental risks will be evaluated through ecological risk assessments. Ecological risk quantifies the effect of releases of hazardous substances and the physical disturbance caused by sampling and remediation on endpoints that represent impacts to individuals, populations, and ecosystems. The ER Program is developing a strategy to conduct ecological risk assessment that is coordinated with existing environmental laws, regulations, and guidelines (Appendix L). The federal regulatory framework for evaluating environmental risks includes the National Environ-

mental Policy Act, the Endangered Species Act, and the National Contingency Plan (for natural resource damage assessments).

Social and economic concerns include impacts on commercial and potentially developable natural resources; impacts on the local community, such as the need to absorb large numbers of new, possibly temporary, workers; and public alarm over actual or potential releases of toxic materials to the atmosphere and major aquifers.

Direct impacts on the Laboratory include both operational impacts (such as disruption of normal research and development activities) and penalties for noncompliance with legislative or regulatory directives.

The final category of concerns, costs, includes not only the direct monetary costs of performing RCRA investigations and corrective actions but also other impacts of these activities on ER Program operations, including the program's ability to coordinate resources such as mobile laboratories, analytical laboratories, and personnel.

Methods for decision making to satisfy multiple objectives, especially in the presence of uncertainty, range from the intuitive approaches used in everyday life to formal decision analysis as described in Appendix I. Given the legal and other ramifications of RCRA process decisions, methods near the formal end of this spectrum may be preferred to less formal approaches. However, the primary RCRA requirement is that the decision process be technically sound and well documented.

4.2.2 Screening Action Levels

SALs are media-specific concentration levels for constituents that can be compared with measurements of concentration levels made during RFIs in order to arrive at preliminary or even final decisions about the site. SALs are used

- to identify contaminants of concern, should a more thorough risk assessment be required;
- to prioritize RFI/CMS activities, focusing resources appropriately for timely and cost-effective investigations and corrective actions; and
- to indicate PRSs at which constituent concentrations are very unlikely to be of concern from the perspective of human health and the environment and that are therefore appropriate to propose for NFA. In addition, an evaluation of the NFA proposal will incorporate consideration of as low as reasonably achievable (ALARA) guidelines, appropriate regulatory standards, ecological impacts, and the potential for effects from multiple contaminants.

Appendix J provides tables of SALs for some potential chemical and radiological constituents of PRSs at the Laboratory. SALs to be used as above should be conservative. The calculated values are conservative, partially because they are based on assumed non-site-specific intake levels that could occur only under the most conservative exposure scenarios. Therefore, detection of constituents in concentrations greater than SALs does not necessarily indicate the need for

corrective action, only for more site-specific evaluation and possibly further site characterization. A site-specific baseline risk assessment using more realistic exposure assumptions, as discussed in Section 4.3, may indicate that NFA is appropriate. For a few contaminants, cleanup standards that exceed the SALs calculated in Appendix J are established by law.

There are a small number of constituents for which detection limits lower than SALs are not technically achievable. The available analytical method with the lowest detection limit will be selected for these constituents, and this detection limit will be used as a SAL.

4.2.2.1 Nonradiological Constituents

The ER Program has derived SALs for nonradiological constituents following the methodology published in EPA's RFI guidance (EPA 1989, 0088) and proposed Subpart S (EPA 1990, 0432). The list of action levels provided in the supporting materials for proposed Subpart S includes a limited number of organic and inorganic constituents but does not address all potential constituents of concern at the Laboratory. SALs for additional nonradiological hazardous constituents are shown in Table J-3 of Appendix J.

The following principles, as given in proposed Subpart S, are used to develop SALs for the RFI:

- SALs must be determined in a manner consistent with the principles and procedures set forth in EPA guidelines for assessing the health risks of environmental pollutants.

- Toxicology studies must be scientifically valid and must be conducted in accordance with the good-laboratory-practice standards set forth in 40 CFR 272 (EPA 1989, 0433). Because the verification of these requirements is labor-intensive, SALs will be based, when possible, on toxicity values available from the most recent version of EPA's Integrated Risk Information System (IRIS) data base (EPA 1992, 0830) or on EPA's health effects assessment summary tables (HEAST) document (EPA 1991, 0658). When IRIS or HEAST does not provide toxicity values for a constituent, other toxicological data may be used.

- For Class A and B nonradiological carcinogens (known and probable, respectively), SALs must be consistent with a 10^{-6} upper-bound excess cancer risk. For Class C (possible) carcinogens, SALs must be consistent with a 10^{-5} upper-bound excess cancer risk.

- Concentrations of systemic toxicants should be set so that a human population could be exposed on a daily basis without appreciable risk of adverse health effects over an extended period of exposure. This method of evaluation uses "reference doses" as toxicity values; these values are concentrations below which adverse effects have not been observed and which incorporate uncertainty factors.

- When more restrictive federal and state regulatory standards exist, then, following proposed Subpart S (EPA 1990, 0432), they will be used as SALs.

SALs for soil, groundwater, surface water, and air will be based on the default intake assumptions recommended in Subpart S (EPA 1990, 0432). In general, the receptor is assumed to be a long-term (i.e., 70-yr) resident at the PRS and is assumed to be present 365 days/yr, drink 2 L of water per day, and inhale 20 m^3 of air per day. Following Subpart S guidance, soil ingestion scenarios assume that the receptor is a child who ingests 200 mg/day of soil (for systemic toxicants) or an adult who ingests 100 mg/day of soil (for carcinogenic constituents).

At Los Alamos, SALs for nonradiological constituents are needed primarily for soil materials, and direct soil ingestion is the dominant exposure route for most constituents. When volatile constituents are present in soils or tuff, or when entrained particles are present in the air, exposure via inhalation is also possible. The exposure assumptions given above are applicable to surface soils (e.g., the upper 2 ft of earth) and also to near-surface soils (e.g., the upper 12 ft of earth) for locations where excavation for housing or commercial/industrial development could bring subsurface soils to the surface (EPA 1989, 0088). Because the EPA has not recommended special criteria for sediments, soil SALs will be used for sediments as well.

If constituents are detected above background levels in unsaturated deep soils, for which the direct exposure scenarios underlying the definition of SALs for surface soils are inappropriate, the RFI will evaluate the potential for these constituents to migrate to an aquifer in concentrations exceeding the SALs for groundwater.

SALs for water will apply to groundwater, alluvial aquifers, and perennial surface waters. (As defined in 40 CFR 260.10, an aquifer is a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of groundwater to wells or springs.) If regulatory standards, such as maximum contaminant levels specified in the Safe Drinking Water Act (40 CFR 141.11;141.61) exist that are lower than calculated values, these lower values will be used as SALs.

Currently, there are no operating emission sources (e.g., stacks) at the PRSs to be evaluated under the ER Program for which SALs for air will be needed. Exposure to volatile contaminants in soils and to entrained particles will be evaluated using soil screening criteria. However, if needed, SALs for air will be applied at the point of closest public access to the PRS under investigation.

4.2.2.2 Radiological Constituents

To allow consideration of all relevant and applicable standards for the protection of human health and the environment in accordance with DOE orders stipulating that corrective actions meet the requirements of CERCLA, the ER Program is addressing radiological as well as nonradiological constituents. Considerations that influence the development of SALs for radiological constituents include the following:

- Most current radiation protection standards [e.g., 40 CFR 190; 40 CFR 141.16; DOE Orders 5400.5 (DOE 1990, 0080) and 5480.11 (DOE 1990, 0732);10 CFR 61; and 10 CFR 20] are based on dose limits rather than on concentration limits in

environmental media. The generally accepted radiation dose limit for the individual in the general public who receives the maximum exposure is 100 mrem/yr over background (DOE 1990, 0080; ICRP 1991, 0777; NCRP 1988, 0778; and 10 CFR 20). Radiation dose to the public is further limited to 25 mrem/yr from individual waste management sources [e.g., 40 CFR 190-192; DOE Order 5820.2A (DOE 1988, 0074); and 10 CFR 61]. (These are cumulative limits for all radioactive constituents and pathways.)

- Radiation dose to humans from background radiation [approximately 330 mrem/yr in Los Alamos (Environmental Protection Group 1992, 0740) is much higher than limits established in radiation protection standards for the public. The terrestrial component of this background radiation (that is, naturally occurring radioactivity in the earth's surface) is approximately 40 mrem/yr in Los Alamos County (Environmental Protection Group 1992, 0740).

- SALs must also be high enough to allow discrimination between areas of manmade contamination and uncontaminated areas, given the limitations of current instruments and the variability of natural background levels.

In view of the above considerations, an annual dose limit of 10 mrem/yr for the maximally exposed individual (incremental above background and cumulative over all exposure routes) is proposed here as the basis for deriving SALs for the radioactive constituents in soils. The rationale for this proposed dose limit is as follows:

- The proposed dose limit of 10 mrem/yr is less than half of the current regulatory standard of 25 mrem/yr from a single source and less than 20% of the dose attributable to the terrestrial component of background radiation in Los Alamos County.

- The dose limit of 10 mrem/yr is specified in DOE Order 5400.5 as a reporting level for doses to the general public resulting from activities conducted under DOE programs.

- The recommended dose limit is comparable to the direct detection limit for current instruments designed to detect gamma radiation in the field (10-20 mrem/yr).

- Lower doses may not be distinguishable from variability in the terrestrial component of background radiation.

Screening levels for radionuclides based on the proposed dose limit can be derived using the RESRAD code (Gilbert et al. 1989, 0754; Yu et al. 1993, 1014), whose use is mandated by DOE Order 5400.5 (DOE 1990, 0080) for release of lands from DOE control. RESRAD can be used to model exposure to multiple radionuclides from multiple environmental media, including soil, air, surface water, groundwater, and food products by multiple exposure routes. SALs for radionuclides are derived based on the assumption of residential land use to obtain the most conservative (i.e., lowest) SALs. Other environmental parameter values (e.g., soil properties, rainfall) required by the code are set appropriately for the Pajarito Plateau.

Existing regulatory standards for certain radionuclides [such as 4 mrem/yr for manmade beta-gamma emitters in drinking water (40 CFR 141.16)] will be used as SALs, as appropriate.

If all radiological constituents in a PRS are determined to be below SALs, the DOE nonetheless requires that a further evaluation be conducted to determine whether levels are as low as reasonably achievable (DOE 1990, 0080). If social, technical, economic, and public policy considerations indicate that lower levels are achievable, remediation may be required.

4.2.3 Cleanup Criteria

SALs are not cleanup criteria; they are used only to identify contaminants of concern and to guide further sampling efforts. Because they are conservative, their use as media cleanup goals might be unnecessarily restrictive and often impracticable as well. Development of appropriate media cleanup standards is one of the tasks for the VCA plan or the CMS for each site (Chapter 3, Section 3.5.2). There are also some regulatory cleanup standards, such as those provided for polychlorinated biphenyls (PCBs) to implement the Toxic Substances Control Act (40 CFR 761), that may be applied. Proposed media cleanup standards will be included in the RCRA permit modification that initiates the CMI (Chapter 3, Section 3.5.5).

EPA has recommended methodologies for establishing preliminary cleanup goals in CERCLA risk assessment guidance (EPA 1991, 0302). For nonradiological constituents, target cleanup levels are generally established within the protective risk range of 10^{-4} to 10^{-6}, as specified under proposed Subpart S guidance for CMS evaluations (EPA 1990, 0432). Among the radionuclides, EPA standards have been established only for radium and thorium (40 CFR 192); therefore, they will need to be derived for other radiological contaminants of concern.

In addition to protecting human health and the environment, a number of factors need to be considered in selecting a remedy. Factors mentioned in the National Contingency Plan [40 CFR 300 (EPA 1990, 0559)] include reduction of toxicity, mobility, and volume of wastes; short-term effectiveness; compliance with regulatory requirements; long-term effectiveness; implementability; public acceptance; and cost. The proposed Subpart S (EPA 1990, 0432) reserves to the EPA the right to set cleanup standards different from the preliminary target levels because those standards may be affected by remedy factors that cannot be fully evaluated until the CMS is completed.

4.3 Human-Health-Based Risk Assessment

4.3.1 Background

To meet the requirements of RCRA and CERCLA, the RFIs at the Laboratory characterize the nature, level, and extent of contamination at PRSs in order to evaluate the potential risks to human health associated with that contamination. Under the phased approach to site characterization and evaluation of potential health risk described in Section 4.1, baseline risk assessment may be carried out following the identification of contaminants of concern or following determination that corrective action may be needed based on other factors, including ALARA guidelines and ecological risks.

EPA has not published detailed risk assessment guidance for sites regulated under RCRA. The ER Program's approach to risk assessment generally follows the methods EPA has recommended for CERCLA sites (EPA 1989, 0305; EPA 1991, 0302; EPA 1991, 0831). However, the Laboratory's ER Program is modifying that approach somewhat, particularly by substituting a comparison of contaminant levels at a PRS with SALs for the CERCLA procedure for identifying contaminants of concern (EPA 1990, 0432).

The major elements of baseline risk assessments to be conducted for the Laboratory's ER Program are

- identification of contaminants of concern;
- exposure assessment, including the identification of appropriate land use scenarios, potential receptors and exposure routes, and the estimation of contaminant migration and intake parameters;
- toxicity assessment, the identification of significant toxic effects and routes of toxicity for contaminants of concern, and quantification of these effects in the form of dose response functions; and
- risk characterization, the estimation of noncarcinogenic toxic impacts, and excess cancer risks as a function of the dose resulting from the intake of contaminated media predicted by the exposure assessment.

These four steps can be applied to characterize the cumulative risk associated with multiple PRSs in an OU or across the Laboratory, as well as the impact of a single PRS.

For PRSs containing constituents in excess of SALs, baseline risk assessments may be performed using the data collected for the screening assessment if the data are adequate. In other cases, additional data may be required. Baseline risk assessment may serve either to support an RFI decision that no further action is required or to provide a point of comparison relative to which the benefits of a proposed corrective action can be evaluated. CMS risk assessments address both long-term risks remaining after implementing a proposed remedial alternative and the short-term risks to workers and the public of implementing the proposed alternatives.

4.3.2 Identification of Contaminants of Concern

PRS constituents measured at levels above SALs and background levels will be considered contaminants of concern that need to be considered in risk assessments for a given PRS. In addition, as noted in Section 4.1.4, some constituents may be identified as contaminants of concern even when below their SALs in cases where more than one hazardous constituent is present. Risk assessment will be conducted for these contaminants, only.

4.3.3 Conceptual Models for Exposure Assessment

Conceptual exposure models are used to describe the source or sources of contamination, the movement of contaminants through the environment, and the exposure of human receptors. These models will be used to help identify appropriate media and locations for sampling. The data will be used to estimate model parameters so that radiological doses and chemical intake by receptors can be estimated with site-specific information.

Contaminant sources can be categorized as primary or secondary. Examples of primary sources at the Laboratory are septic tanks, drainlines, buried structures and wastes, lagoons, debris on canyon walls, and landfills. Secondary sources are environmental media that have been contaminated as a result of a historical release from a primary source, such as channel sediments contaminated by releases from outfalls and soil and tuff beneath a leaking tank.

Potential mechanisms by which contamination may be released from a source to the environment include leakage, infiltration, leaching, re-entrainment of contaminated particulate matter by wind or surface run-off, particulate settling, erosion, human and animal intrusion, and evapotranspiration. Possible environmental migration pathways include air, surface water, the vadose zone, groundwater, plants and animals, and direct contact with soil or structural surfaces. Laboratory studies support the current assessment that extensive liquid-phase migration in the vadose zone is highly unlikely in the Bandelier Tuff because the tuff is extremely dry and infiltration of natural precipitation may not provide the quantities of water necessary to sustain movement of contaminants downward (Purtymun and Stoker 1988, 0205). However, vapor phase migration is possible in the vadose zone.

Potential contact media are those with which a receptor may come into contact: soil, groundwater, surface water, air, and the surfaces of structures or debris. Groundwater in the regional aquifer is not currently considered a potential contact medium because of the great depth to the water table and limited transport in the vadose zone. However, alluvial aquifers might serve as a source of domestic water in the future. Exposure may occur as a result of inhaling, ingesting, or coming in direct contact with these contaminated media.

Exposure to external radiation is a special type of exposure because transport of contaminants through environmental media is not necessary for the receptor to receive a dose. However, dose decreases exponentially with increasing distance from the source.

Assumptions about current and future land uses are important in identifying the receptors to be used in defining the important exposure routes. Current PRS land uses include residential, recreational, and continuing Laboratory operations. A few PRSs located in the town of Los Alamos are classified as residential. A few other PRSs that are neither located on Laboratory property nor are used residentially are categorized as tribal or recreational land use. In general, the current land use for OUs located on Laboratory property is commercial/industrial, although tribal and recreational use of a few unfenced sites may occur. However, many of the technical areas are fenced, and most are under some form of institutional control (i.e., access is restricted).

It is assumed that future use of all PRSs not currently located on Laboratory property will be residential. For most PRSs located on Laboratory property, continued

Laboratory use and eventual release of these lands for tribal (e.g., gathering) or recreational use (e.g., camping) will be proposed to stakeholders. Pending incorporation of stakeholder input, the Laboratory will consider residential land use assumptions for all sites. The use of nonresidential exposure scenarios for risk assessment is supported by proposed Subpart S, which states that

> "contaminated soil would be remediated to levels consistent with plausible future patterns of use... . At industrial sites or sites dedicated to long-term hazardous waste management, cleanup to less stringent levels (than residential cleanup levels) might be appropriate, although institutional controls could be necessary to ensure that the use pattern did not change." (EPA 1990, 0432).

The Laboratory plans long-term hazardous waste management for some of the material disposal areas (MDAs) and possibly for a small number of additional PRSs. For baseline risk assessments, it is assumed that these sites will be under institutional control for 100 years or more. Risk assessment for appropriate exposure scenarios (e.g., exposure of trespassers and offsite receptors) will be conducted for these areas.

Current occupational exposures to Laboratory workers are evaluated by the operating groups of various facilities or by the Health Physics Operations (HS-1), Safety and Risk Assessment (HS-3), and Industrial Hygiene (HS-5) groups in compliance with Occupational Health and Safety Act requirements and with DOE Order 5480.11 (DOE 1988, 0076). Risk assessment for future commercial/industrial use scenarios will use standard default exposure parameters for commercial/industrial workers, that is, for workers who may not have received the types of training assumed for current Laboratory workers.

4.3.4 Toxicity Assessment

Two types of toxicity will be considered: systemic toxicity and carcinogenic effects. Methods for estimating the carcinogenic effects of nonradiological contaminants differ from those to be used for radiological contaminants.

Systemic toxicity and carcinogenic risk for nonradiological contaminants of concern will be evaluated using toxicity values (if available) obtained from the most recent versions of EPA's IRIS data base and HEAST document (EPA 1991, 0658). Other toxicity values may be derived based on data from the literature if values are not available from IRIS or HEAST. The hazard index (Appendix J) provides a measure of systemic toxicity. Excess cancer risks will be estimated for potential carcinogens.

Exposure to radiological contaminants of concern will be evaluated initially by estimating annual doses for the appropriate potential receptors using the RESRAD code. These dose estimates can be converted to carcinogenic risk estimates using data from EPA (1989, 0781) and the National Research Council (BEIR 1988, 0030). Other potential toxicological effects of radiation exposure include genetic and reproductive effects. However, the risk that these effects will occur is generally much lower than the risk that cancer will be induced. Therefore, the EPA considers that carcinogenic risk assessment is sufficient evaluation of toxic effects for radionuclides (EPA 1989, 0305).

4.3.5 Risk Characterization

The exposure model and the toxicological model are used together to estimate the risk of systemic toxicity and carcinogenic effects associated with one or several PRSs impacting the same receptor. Risk estimates for nonradiological contaminants of concern will be compared with the acceptable risk range designated by EPA for exposure to the general public (target risk range). This risk range is 10^{-4} to 10^{-6} excess upper-bound lifetime cancer risk to an individual (EPA 1990, 0432) for carcinogens. For systemic toxicity, exposure levels will be evaluated by comparison with an acceptable hazard index equal to 1. For radiological contaminants of concern, estimated doses will be compared with target dose limits in the range of 10 to 25 mrem/yr.

Cumulative impacts across PRSs in an OU will be evaluated in OU-specific baseline risk assessments. The need for a separate risk assessment addressing cumulative health effects from multiple OUs is evaluated in Appendix K.

4.3.6 Risk Assessment for Corrective Actions

The CMS risk evaluations will generally follow the methodology used for baseline risk assessment. The risks for each alternative will be evaluated to determine how well the alternatives meet requirements for overall protection of human health and the environment. CMS assessments will generally focus on the long-term effectiveness of the corrective measure alternatives by evaluating the residual risks expected to remain after remediation. Short-term risks associated with the alternatives, including risks to workers implementing the proposed alternatives, will also be evaluated.

Following CMI or VCA, a final risk assessment may be performed to provide another measure (in addition to or instead of direct comparison with media cleanup standards) of the effectiveness of the implemented remedy. These evaluations will also follow the methodology used for baseline risk assessment but will incorporate data collected during the corrective action or by a longer-term monitoring program.

4.4 Field Analytical Measurements

Many field survey instruments have been developed for health and safety monitoring, and some of these may provide useful information for field investigations, as well. In addition, many new instruments intended for data collection in the field are becoming available commercially or in prototype. Another field option for the Los Alamos ER Program is the use of mobile field laboratories capable of providing rapid turnaround for many types of analyses that can be performed using modified laboratory procedures. A brief survey of these options is included here because appropriate use of these methods is an important component of any streamlined approach to site characterization and remediation.

Neither field survey measurements nor field laboratory analyses can replace fixed (offsite) analytical laboratories, but they can make decision making more efficient by improving timeliness, resource use, and data quality. During investigations for screening assessments, for example, field laboratory measurements may be used to bias sampling towards areas where contaminants of concern have higher concentrations. At a site where the contaminants of concern are known, it may be possible to calibrate a field survey instrument with sufficient accuracy and precision

to guide remedial work. The selection of appropriate field methods, like the selection among alternative laboratory procedures, must always be specific to the site decision being made.

4.4.1 Field Screening

Field screening instruments are usually hand-held or easily transportable devices that provide a direct data readout for a specific analyte or class of analytes (e.g., volatile organics or gamma emitters). Although quantitative readings may be obtained for an analyte or class of analytes, such readings often have high measurement uncertainty. Typically, these measurements are not used directly to make RFI or CMI decisions but are helpful in selecting biased samples for submission to field and offsite laboratories. Several of the field screening instruments are used primarily to identify contaminant levels that indicate a need for workers to use protective equipment.

4.4.1.1 Organic Vapor Surveys

A photoionization detector is a general survey instrument capable of detecting in real time the concentrations of many complex organic compounds, including volatile "straight-chain" hydrocarbons and volatile aromatic components. Compounds are detected when an ultraviolet light source of sufficient energy excites volatile organic compounds (VOCs) and ionizes them. The instrument reports concentration in parts per million based on some standard (typically benzene) on three scales: 0-20 ppm, 0-200 ppm or 0-2,000 ppm, with a nominal minimum detection level of 1 ppm.

A flame ionization detector may also be used as a general screening instrument to detect the presence of many organics. Its response to an unidentified sample is relative to the response to a gas, typically benzene, to which the instrument has been calibrated, with a nominal minimum detection level of 1 ppm.

The organic vapor analyzer is based on gas chromatography, which separates organic volatile compounds based on their retention time in a column. This instrument is typically not used to screen for health and safety purposes because it is relatively slow. It is useful at sites where the analytes have been identified and approximate boundaries of contamination need to be established. The nominal minimum detection limit is 1 ppm.

4.4.1.2 Inorganic Surveys

In laser-induced breakdown spectroscopy, a laser spark is used as an excitation source to analyze inorganic compounds via atomic emission spectroscopy. The laser pulse is focused on or in the material to be analyzed, vaporizing the material and forming a plasma in which analyte species of interest are identified by their emission spectra. The minimum detection limit for chromium compounds is 2 ppm, with a relative standard deviation of 20% and recovery of 80%. Performance depends on the species and may vary by an order of magnitude in either direction from these values.

X-ray fluorescence is used in the laboratory to measure metal concentrations in samples of dried soil or crushed debris placed in a sample chamber and in situ on soil or other surfaces. X-ray fluorescence can detect most target analyte list metals,

excluding beryllium. A key feature of x-ray fluorescence is that only the surface of a solid is excited by the sources, which means that repeated measurements of a poorly homogenized sample may provide variable results and in-situ measurements represent only the exposed surface. Minimum detection limits vary by element; manufacturer specifications for the instrument should be consulted. Some units have data storage capacity for several tens of samples.

4.4.1.3 High-Explosives Surveys

Los Alamos has developed a field spot-test kit to identify the presence of explosives as contaminants on equipment and materials. Three reagents in a carrying case with a portable ultraviolet lamp can be used to detect most of the common explosives used at Los Alamos, except picric acid, NC, and TATB. For checking soil contaminated with TNT, it is possible to detect a content as low as 0.01% (100 ppm). Other reported minimum detection limits are 100 ppm for tetryl and greater than 5% for HMX, RDX, PETN, and NQ.

4.4.1.4 Radiation Surveys

Three hand-held instruments are used, primarily for health and safety screening:

- The ESP beta/gamma probe detects beta and gamma radiation. The detector surface is placed on or just above the surface to be sampled for a standard counting time of 1 min. This instrument reports total counts and has an optional speaker to alert the operator to areas of very high radionuclide concentrations. Typical background readings are 200-300 cpm, and the health and safety action level is 800 cpm, which corresponds to an exposure of approximately 0.2 mRad/h.

- The micro-R meter detects highly energetic beta and gamma radiation. Measurements are reported in mrem/h. A typical background value is approximately 30 mrem/h.

- An alpha meter detects alpha particles. Because its external probe is easily damaged, the probe contains a special light sensor to indicate a problem. If the soil is even slightly damp, an alpha meter will not detect alpha particles. A typical background reading is 3 cpm.

The Field Instrument for Detection of Low-Energy Radiation (FIDLER) is used for low-energy gamma and x-ray surveys. The Violinist, a more recent version of the FIDLER, is capable of providing spectral data. These instruments are designed to detect low-energy photons such as the 60-keV gamma emission from ^{241}Am or the x-rays that accompany the decay of heavy radionuclides (e.g., thorium, plutonium, and other transuranic radionuclides) and some fission products (e.g., ^{137}Cs). The FIDLER detector is optimized to detect plutonium emissions. Surveys are conducted by placing the instrument close to the ground surface (a stand provides a fixed geometry) and observing the rate meter. A typical counting time for plutonium, americium, and cesium is 200 sec. Other radionuclides, such as ^{40}K, may require longer counting times. Instrument readings can be biased by overburden (snow, soil, moisture, etc.) covering the source.

4.4.1.5 Immunoassays

Immunoassays are newly emerging procedures for direct measurement and range quantification of contaminants such as petroleum products—benzene, toluene, ethyl benzene, and xylene-(BTEX)—polyaromatic hydrocarbons, trichloroethane (TCE), and several pesticides. The tests use enzymes developed to respond to the presence of a specific contaminant. Their specificity allows for a very low rate of false positive and false negative measurement findings. For example, the false positive and negative measurement findings for BTEX are less than 5%. For total polyaromatic hydrocarbons, the detection limit is 0.7 ppm in soil.

4.4.2 Mobile Field Laboratories

Two types of mobile laboratories—chemical and radiochemical—have been developed for use at Los Alamos. These mobile laboratories consist of trailers equipped with the required environmental controls and with power to support established and emerging analytical technologies. Analytical instrumentation and methods now available in these mobile laboratories generally parallel established fixed-base laboratory methods.

The mobile chemical laboratory is equipped with gas chromatography, gas chromatography/mass spectrometry, an infrared analyzer for total petroleum hydrocarbon analysis, and an x-ray fluorescence analyzer. Analytical procedures for volatile organics, semivolatile organics, and PCBs parallel methodology specified by EPA in SW-846 (EPA 1990, 0967). Analytical procedures performed in the mobile chemical analytical laboratory are designed to minimize sample preparation time, solvent/reagent use, and turnaround time. Differences between mobile chemical laboratory procedures and fixed-base laboratory procedures generally reflect the need to reduce the volume of extraction solvent and samples. This change can result in elevated reporting limits for the mobile chemical laboratory analyses compared with fixed-base laboratory analyses. Mobile chemical laboratory analyses generally target specific analytes (organic or inorganic compounds). Capability for identifying compound structure can be developed in some instances.

The mobile radiochemical laboratory is equipped to perform gross alpha/beta and gross gamma analyses, gamma spectroscopy, percent moisture determinations, and tritium analyses. Currently, available methods in the mobile radiochemical laboratory are based on established technologies for radiochemical analysis, although counting times for detection of radiological decay have been shortened to ensure rapid data turnaround. This shorter counting time results in a lowering of sensitivity for analytes (radionuclides). Greater sensitivity for radionuclides can be achieved only by increasing the duration of counting time with a corresponding reduction in sample throughput.

Modifications to fixed laboratory methods reflect the need to expedite field analysis so that quicker data turnaround is provided, consistent with the data needs for decision making. Analytical procedures for mobile laboratories are available for most major constituents of potential concern, and methods exist or are being developed to target other compounds. Generally, analytical procedures for both mobile laboratories can be tailored to meet site-specific needs. Analytical method performance data either exist (Environmental Chemistry Group 1993, 0968) or will be generated to evaluate the adequacy of data quality for decision-making.

Several levels of analytical quality control are written into the mobile laboratory methods to provide for different data quality needs. The level of quality control required depends both on the stability of the measurement process used and on the requirements of the decision it is supporting. Providing analytical data of unnecessarily high quality adversely affects costs and schedules.

The mobile laboratories may be brought to a site to provide real-time support, or they may be left at a fixed base to provide two- or three-day turnaround. Some analytical methods are not practical for field operations, and some site operations may not require real-time analytical support. Onsite mobile laboratory support may be indicated when data are used to

- direct subsequent sampling activities,
- determine the extent of vertical contamination leading to the decision to halt a drilling operation,
- determine whether excavated material is hazardous and thus needs special handling,
- determine transportation requirements for samples to be shipped offsite,
- assess risk for site workers,
- monitor for deviations from expected conditions during CMI, and
- direct cleanup activities.

4.5 Response Actions

4.5.1 RCRA Process Endpoints

The RCRA process may terminate at a number of points:

- after review and evaluation of archival information, without additional field investigations;
- after a screening assessment and review of the need for corrective action based on the results of the first phase of RFI;
- after baseline risk assessment; or
- after designing and implementing corrective actions.

There are a number of options at each of these endpoints, including NFA, deferring further investigation and/or corrective action until the site is decommissioned, VCA, conditional remediation, and final remediation. Interim actions may also be required.

4.5.1.1 No Further Action

A decision as to whether corrective action is required for a site is the principal decision made during the RFI. It may be made at any of the three RFI termination points listed above: after evaluating archival information, after the initial investigation of the site, or after a baseline risk assessment. A decision to propose NFA during the RFI implies that neither additional investigation nor corrective action is necessary.

A strategy for selecting and defending a proposal for NFA on the basis of archival information, only, is outlined in Appendix I. Such a proposal requires a review of archival information not only to ascertain that there are no health and safety risks associated with the site but also to evaluate many of the other factors discussed in Section 4.2.1.

For many PRSs at Los Alamos, existing nonquantitative information strongly suggests that no environmental release has occurred. Sampling to provide quantitative data for a screening assessment should provide enough information to complete a proposal for NFA in these cases.

The third point at which NFA might be proposed is following baseline risk assessment when this assessment shows that, although contamination is present and potential exposure pathways exist, the associated risks are nevertheless below levels of concern. Once again, before proposing NFA under these conditions, the other evaluation factors discussed in Section 4.2.1 will be reviewed.

4.5.1.2 Deferred Action

Deferred action, like NFA, may be proposed at any of the RFI endpoints. Deferred action may be appropriate for currently active sites or for inactive PRSs located in currently active sites. The proposal may be accompanied by plans for a limited site investigation, such as a screening investigation or perimeter monitoring. Otherwise, strategies for selecting and defending this alternative are quite similar to those described in Section 4.5.1. In evaluating health and environmental risks, it is primarily current risks that are of concern because only postponement—not cancellation of investigation and/or corrective action—is proposed.

4.5.1.3 Conditional Remedies

Conditional remedies, which combine a prompt corrective measure to reduce risk with ongoing site monitoring, may be proposed for sites where total cleanup is impractical or delaying implementation of the final remedy is in the interest of the environment (Chapter 3, Section 3.5.4.4). In particular, site stabilization using appropriate containment technologies (Section 4.5.2.2) will be implemented as a conditional remedy at some of the large MDAs. Continued institutional control to control public access, to track Laboratory activities in the area, and to prevent further degradation of the environment is a required administrative component.

4.5.1.4 Corrective Actions

When remedial action is necessary, an appropriate corrective measure is generally selected following a CMS. If an obvious and effective alternative exists, it may be proposed as a VCA without a formal CMS, either immediately after the evaluation of archival information or else after a limited screening investigation. VCAs tend to use removal with offsite treatment and disposal options rather than in-situ treatment or containment and therefore must meet restrictions on treatment and disposal of hazardous wastes and other restrictions that apply to alternatives of this type. If there are significant questions about the ability of the proposed option to meet these criteria, CMS and CMI are more appropriate than VCA.

4.5.2 Corrective Action Alternatives

Developing and implementing a comprehensive response action or corrective measure is a time-consuming process. Between the time a contaminant release at a PRS has been identified and a definitive corrective measure has been completed, several phases of screening, field investigation, and CMS may have occurred. Remedial objectives and potential response actions should be considered as early in the corrective action process as possible so that information needed to evaluate the alternatives and to initiate their design can be collected during the RFI. This introduction to remedial alternatives is provided to facilitate this process. The following brief descriptions of available remedial technologies are adapted from an EPA manual (EPA 1990, 0791). The discussion is not intended to be exhaustive but covers those technologies most likely to be useful for the Laboratory's ER Program.

4.5.2.1 Technical Considerations

Technical considerations in evaluating remedial alternatives include site characteristics, waste characteristics, and technology limitations.

Site conditions such as climatic setting, geology, hydrology, and the physical nature of contamination may limit or promote the use of certain remedial technologies. For example, the presence of very-low-permeability soils may preclude the use of in-situ stabilization methods because of the difficulty of mixing treatment reagents with contaminant constituents.

Waste characteristics, such as concentration, reactivity, solubility, toxicity, and treatability, may affect the feasibility of in-situ methods, direct treatment methods, and land disposal (on- or offsite).

The level of technology development, performance record, and inherent construction, operation, and maintenance problems need to be considered for each technology. For example, certain grouting and in-situ methods have not been developed to a point where they can be implemented in the complex geological conditions at the Laboratory without extensive research.

4.5.2.2 Containment Technologies

Capping is the process of covering contaminated materials to prevent direct contact with receptors, to control the infiltration of surface water and precipitation, and to

control the release of soil vapors. Various capping designs and materials are available, including

- soil caps consisting of a compacted layer of local soil and a layer of topsoil;
- hard caps made of asphaltic concrete or Portland cement concrete; and
- multilayered caps designed to meet RCRA standards, typically consisting of an upper vegetative (topsoil) layer, a drainage layer, and a low-permeability layer.

The Laboratory is conducting pilot studies to determine combinations of capping features that are most appropriate for the climatological conditions of the Pajarito Plateau (Appendix C).

Surface water control measures, including grading and terracing; ditches and channels; and structures such as berms, dikes, and flood walls, are used to control surface drainage on, around, and through an area. Surface run-off occurs over most of the Pajarito Plateau during severe storm events and rapid snow melt, and thus, some form of surface water control may become necessary at Laboratory sites with contaminated soils.

4.5.2.3 Removal Technologies

Although excavating earth materials and dredging in sediments are standard construction practices, their application to the removal of hazardous wastes entails some special technical considerations:

- Extensive safety procedures and monitoring may be required to ensure the protection of the workers and the public and to prevent collateral damage to the environment.
- Special equipment, adapted to minimize disturbance of the deposit and secondary migration, may be required.
- Areas containing drums, buried tanks, or similar obstructions may require significant amounts of hand and small-machine work.
- Selective removal of wastes to ensure the segregation of incompatible wastes and of wastes requiring different disposal and treatment methods may be required.
- Removed sediments must be dewatered, and the removed water must be treated for possible contamination.

Pumpable liquids and sludges can be removed from pits, ponds, lagoons, sumps, trenches, and tanks to prevent contamination of adjacent soils and aquifers. The waste must be categorized by phase (e.g., organic, aqueous, and heavy sludge phases) to determine appropriate removal method(s).

Standard gas collection and migration control systems for landfills are very effective in controlling emissions from municipal and similar landfills, whose gases are typically about half methane and half carbon dioxide, with small amounts of other gases. These systems consist of a combination of monitoring wells, negatively pressured perimeter control, and interior collection and recovery systems.

4.5.2.4 Treatment Technologies

Incineration, onsite or offsite, is a well-proven method of treating waste streams containing organics that routinely achieves destruction and removal efficiencies in excess of 99.99% for most organics and PCBs. Incineration is also used to reduce wastes to the minimum feasible volume and to reduce liquid wastes and sludges to residual solids. Solid residues must be collected and disposed separately. Potential barriers to applying this technology at the Laboratory are community resistance to the construction of an onsite incinerator and the distances to offsite incinerators that meet RCRA requirements.

In-situ biodegradation is a rapidly emerging technology that has been used very successfully to clean up aquifers contaminated with gasoline and other fuel hydrocarbons and is potentially applicable to any biodegradable organic compound, including high explosives. Because there are many site-specific factors that control the effectiveness and cost of in-situ biodegradation, bench- and pilot-scale studies are necessary.

In-situ solidification/stabilization refers to processes that can be implemented in place to improve the physical characteristics of waste by rendering wastes nonhazardous and nonleachable. These technologies are well established for treating inorganic wastes, less so for organic wastes.

Solidification techniques that depend on a reaction between lime and fine siliceous materials in the presence of water are most effective for wastes that have relatively high moisture content (e.g., sludges) and high levels of toxic metals and that possibly include some miscellaneous materials such as asbestos, sulfides, and solid plastics but typically not more than 10% to 20% organic constituents. Solidification processes limit solubility, detoxify the waste contaminants, and produce a monolithic block with some structural integrity; however, the product is still considered a hazardous waste unless it is delisted.

Soil slurry bioreactor systems can be used to remediate excavated sludges and soils containing organic contaminants. These hybrid systems use aerobic microbial action to degrade or detoxify the contaminants in a slurry reactor (a suspension of soil in water). Both pretreating the wastes, using such pretreatment methods as separating coarser materials and particle scrubbing, and posttreating the slurry and off-gases are generally necessary.

Soil vapor extraction is used when VOCs are the primary contaminants. At Los Alamos, a vapor extraction system is being developed for Area L, where the environmental medium is not soil but tuff. Extracted gas is either vented to the atmosphere, connected to a vapor-phase carbon adsorption system, or flared, depending on the nature and extent of VOC contamination.

4.5.2.5 Disposal Technologies

Some remedial alternatives will require the disposal of hazardous waste in a RCRA-approved landfill. In addition to RCRA permitting standards, such landfills must meet local, state, and other federal standards, which may result in a decrease in offsite disposal capacity in the future. Onsite RCRA-approved landfills are typically constructed in an uncontaminated area to minimize effects on cleanup operations, on the environment, and on costs and must meet current RCRA standards for design, operations, and closure. The Laboratory is proposing to build a Mixed-Waste Disposal Facility to handle materials with both hazardous and radioactive constituents.

Aqueous solutions (either raw or pretreated waste water), which generally contain low to moderate concentrations of pollutants, may undergo conventional treatment in a municipal waste water treatment plant. This option applies primarily to short-term discharges and to low-flow, longer-term situations, however, and may be a sensitive political issue. Another alternative when suitable land is available is water infiltration, a process in which treated effluent is applied to the soil surface using infiltration trenches, infiltration basins, or spray irrigation.

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1.0 INTRODUCTION

1.1 Background

In 1987, the US Department of Energy (DOE) established its Environmental Restoration (ER) Program as part of the Office of Environmental Restoration and Waste Management (EM), which also includes the Offices of Waste Operations and Technical Development. EM presents its goals, as well as projected schedules and costs, in its Five-Year Plan (DOE 1993, 0992), which is revised annually. The plan incorporates information provided in site-specific plans for each DOE installation, including Los Alamos National Laboratory (the Laboratory). The Laboratory is operated by the University of California (UC) for DOE.

DOE established its ER Program as DOE ER Major Systems Acquisition (MSA) Projects. One MSA project includes the national laboratories assigned to the DOE Operations Office in Albuquerque (ER MSA AL-1). MSA AL-1 at Los Alamos includes two integrated activities: one, the Remedial Action Project, hereafter referred to as the ER Program, addresses remedial actions at the Laboratory; the other is the Decontamination and Decommissioning (D&D) Project. The DOE's Los Alamos Area Office (LAAO) oversees MSA AL-1 at the Laboratory as part of its Environment, Safety, and Health Branch (Figure I-1). The Laboratory's ER Program Office (Figure I-2) tracks and manages the ER Program and D&D Project. Figure I-3 shows the ER Program's position in the Laboratory organization scheme. The ER Program Manager, who reports to the Program Director for Environmental Restoration and Waste Management Programs is responsible for the effective implementation of the ER Program throughout the Laboratory. The ER Program and D&D Project are conducted under the management principles outlined in DOE Order 4700.1, "Project Management System" (DOE 1992, 0823), and DOE Notice N4700.6, "Project Control System Guidelines" (DOE 1993, 1058).

1.2 Overview of the ER Program

In November 1989, the New Mexico Environment Improvement Division [now New Mexico Environment Department (NMED)] issued an operating permit authorized under the Resource Conservation and Recovery Act (RCRA) to the DOE/UC for operating the Laboratory (NMEID 1989, 0595). In addition, on March 8, 1990, the Environmental Protection Agency (EPA) issued a Hazardous and Solid Waste Amendments (HSWA) attachment to the permit, known as the HSWA Module, which went into effect on May 23, 1990 (EPA 1990, 0306). The HSWA Module sets forth the procedural requirements for assessing and remediating sites that meet the definition of solid waste management units (SWMUs). In New Mexico, the EPA currently enforces HSWA regulations.

The HSWA Module requires DOE/UC to complete the RCRA facility investigation (RFI)/corrective measures study (CMS) portion of the ER Program within 10 years. The purpose of the RFI/CMS is to evaluate existing and potential environmental impacts resulting from contaminated sites and to evaluate corrective measures proposed to mitigate these impacts. All corrective measures implemented at the Laboratory will comply specifically with RCRA regulations and the HSWA Module; with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), as appropriate; with the National Environmental Policy Act (NEPA); and with other applicable federal and state laws and regulations.

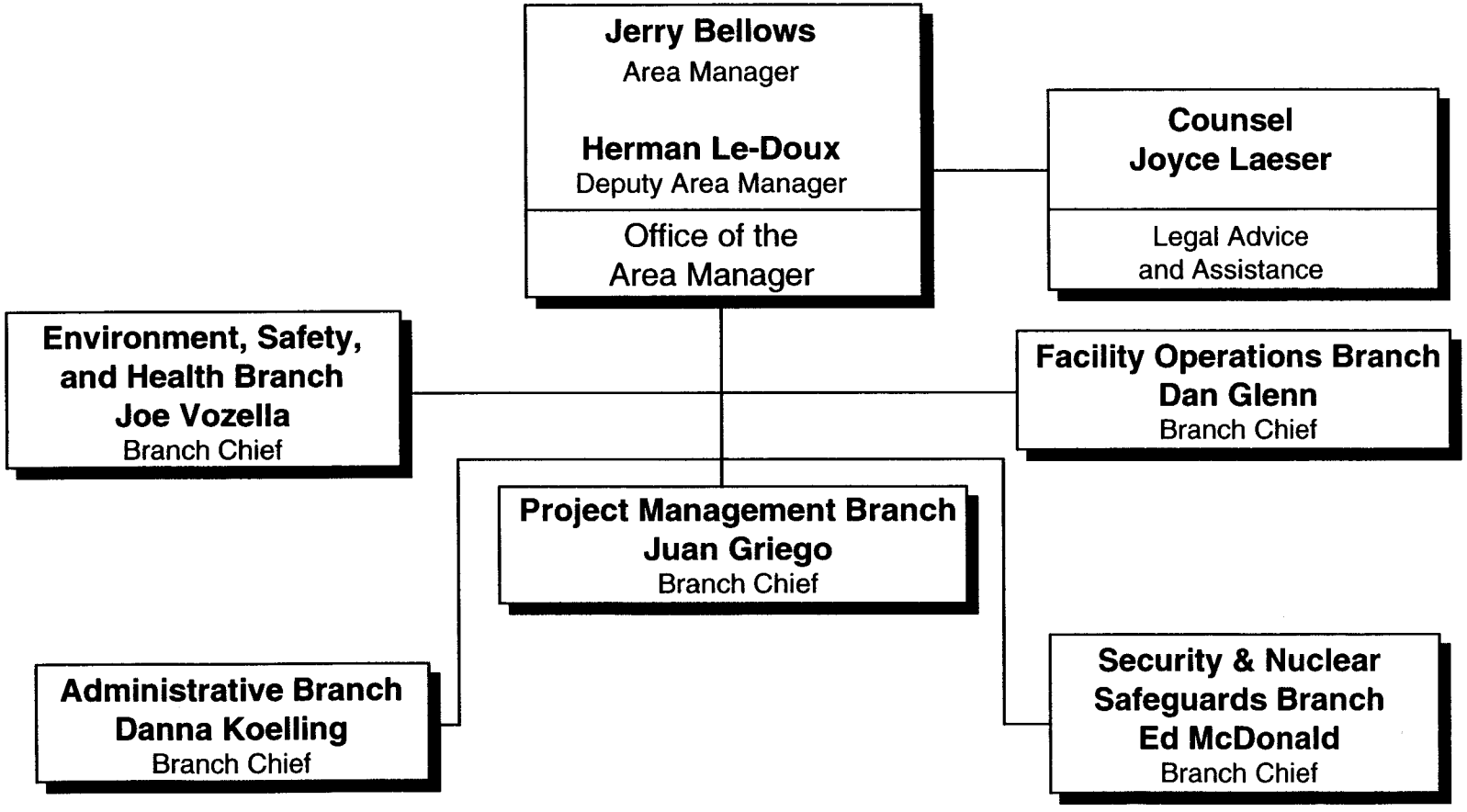

Figure I-1. Organization of DOE-LAAO.

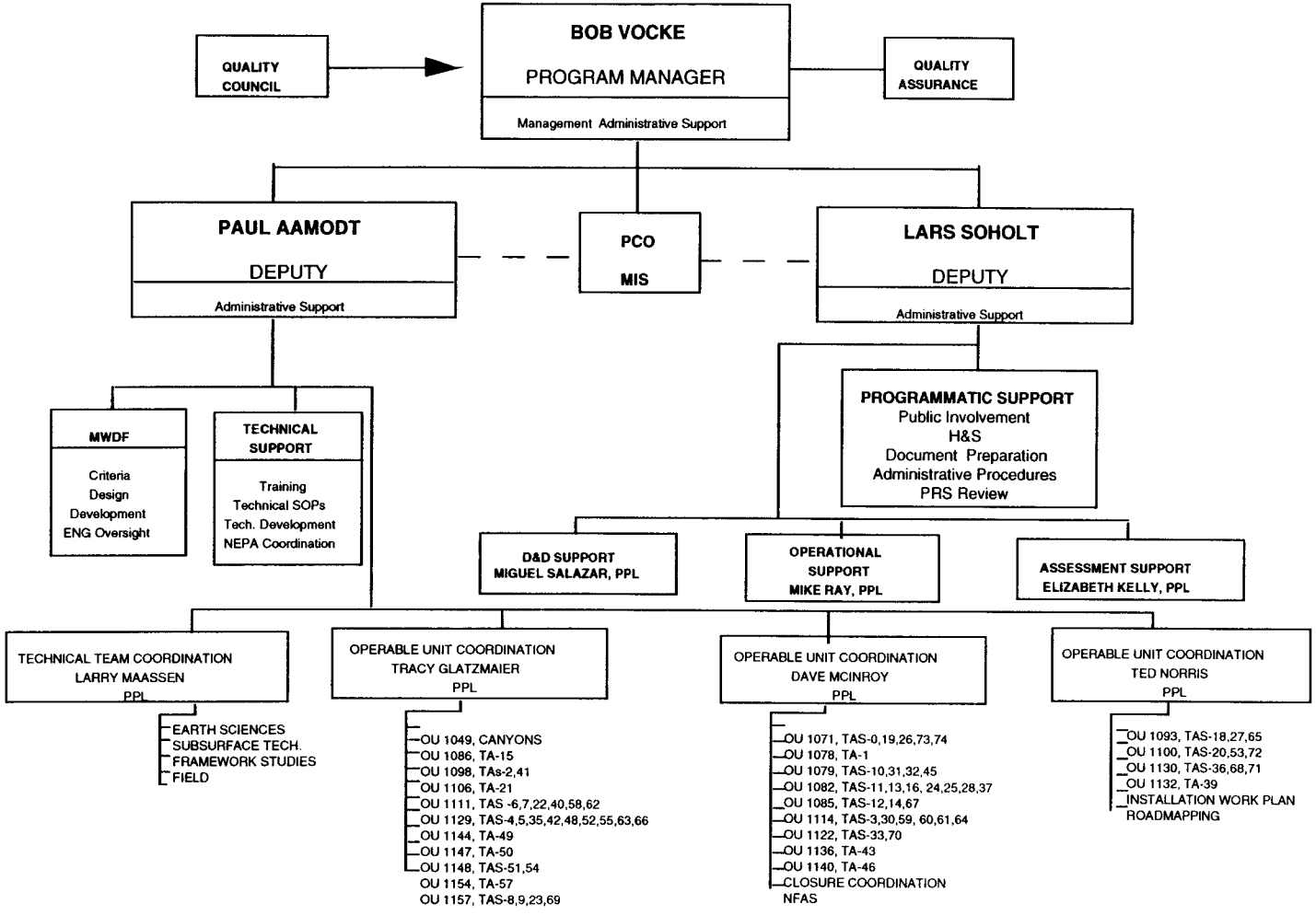

Figure I-2. Organization of Los Alamos National Laboratory ER Program Office.

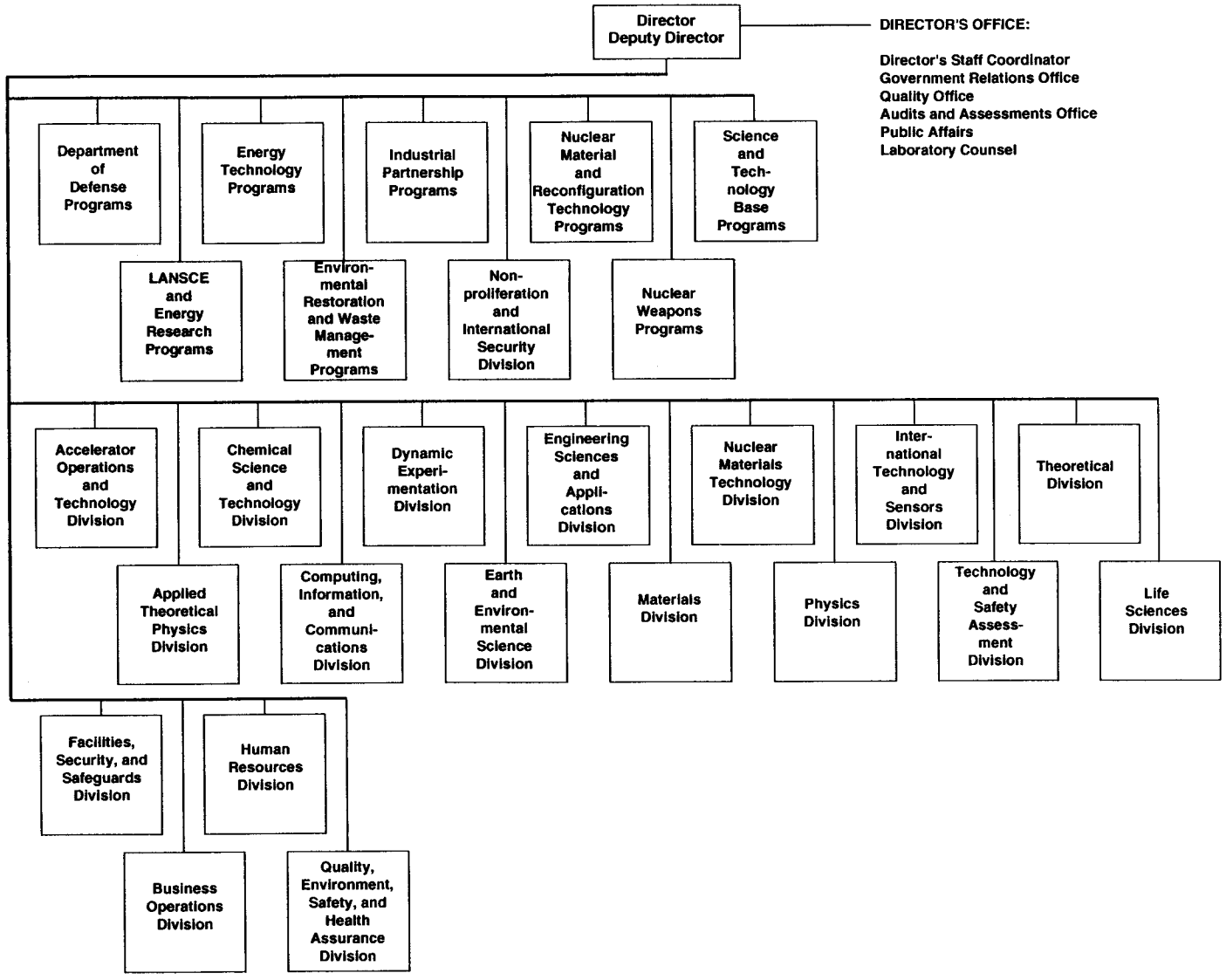

Figure I-3. Organization of Los Alamos National Laboratory.

Laboratory sites that are being investigated include SWMUs and areas of concern, collectively called potential release sites (PRSs), which are aggregated into operable units (OUs) based on geographical and other considerations. The OUs are assessed by means of the RFI/CMS, and the PRSs are remediated by means of either voluntary corrective actions (VCAs), corrective measures implementation (CMI), RCRA closure, or other remedial measures, as appropriate. The corrective action process for SWMUs mandated by HSWA is shown in Figure I-4.

1.3 Overview of the D&D Project

DOE/EM established the Laboratory's current D&D Project in 1989 to manage nonoperational, contaminated facilities. The D&D Project's primary responsibilities involve facility assessment and cleanup of inactive and surplus contaminated buildings, structures, and equipment not regulated under CERCLA or RCRA. D&D Project subprojects are conducted according to federal and state requirements and DOE orders applicable to nuclear and other facilities that generate radioactive and/or hazardous materials and wastes. D&D subprojects are conducted by the ER Program in coordination with its remediation projects.

The safe shutdown of facilities is not a part of the D&D Project; rather, it is the responsibility of the landlord organizations at the Laboratory, including operating groups. The responsibilities of these parties include removing all stored hazardous and radioactive materials, debris, and waste from process areas; identifying materials; and isolating and securing equipment. The D&D Project is responsible for coordinating the transfer of a facility from its operational owners to the D&D Project.

1.4 Integration of the ER Program and D&D Project

Because PRSs and D&D projects at the Laboratory are frequently collocated, operations of one of these programs often affect operations at the other. Corrective action under RCRA is a legal requirement and, as such, takes precedence over D&D subprojects; therefore, if D&D is scheduled much in advance of remediation at a PRS, VCA at the PRS may be accelerated to coincide with the D&D schedule. Likewise, D&D subprojects may be accelerated to coincide with remediation. In both cases, integrating the schedules depends on the availability of funding. If it is demonstrated that a PRS, such as a waste line associated with a facility, does not require remediation under RCRA or CERCLA, the D&D Project assumes complete responsibility, including provision of funding, as authorized, for removal. Early in this process, the ER Program determines the presence of substances regulated by RCRA and CERCLA through limited site characterization.

Operable unit project leaders (OUPLs), in cooperation with the D&D PL, develop integrated schedules to achieve regulatory and D&D project milestones. The UC MSA AL-1 Program Office is providing a common forum, including members of affected operating groups on a project-specific basis, to exchange information and to ensure integration of the two programs.

1.5 Scope

This Program Management Plan sets forth the plans, organization, and systems that UC uses to manage the Laboratory's MSA AL-1.

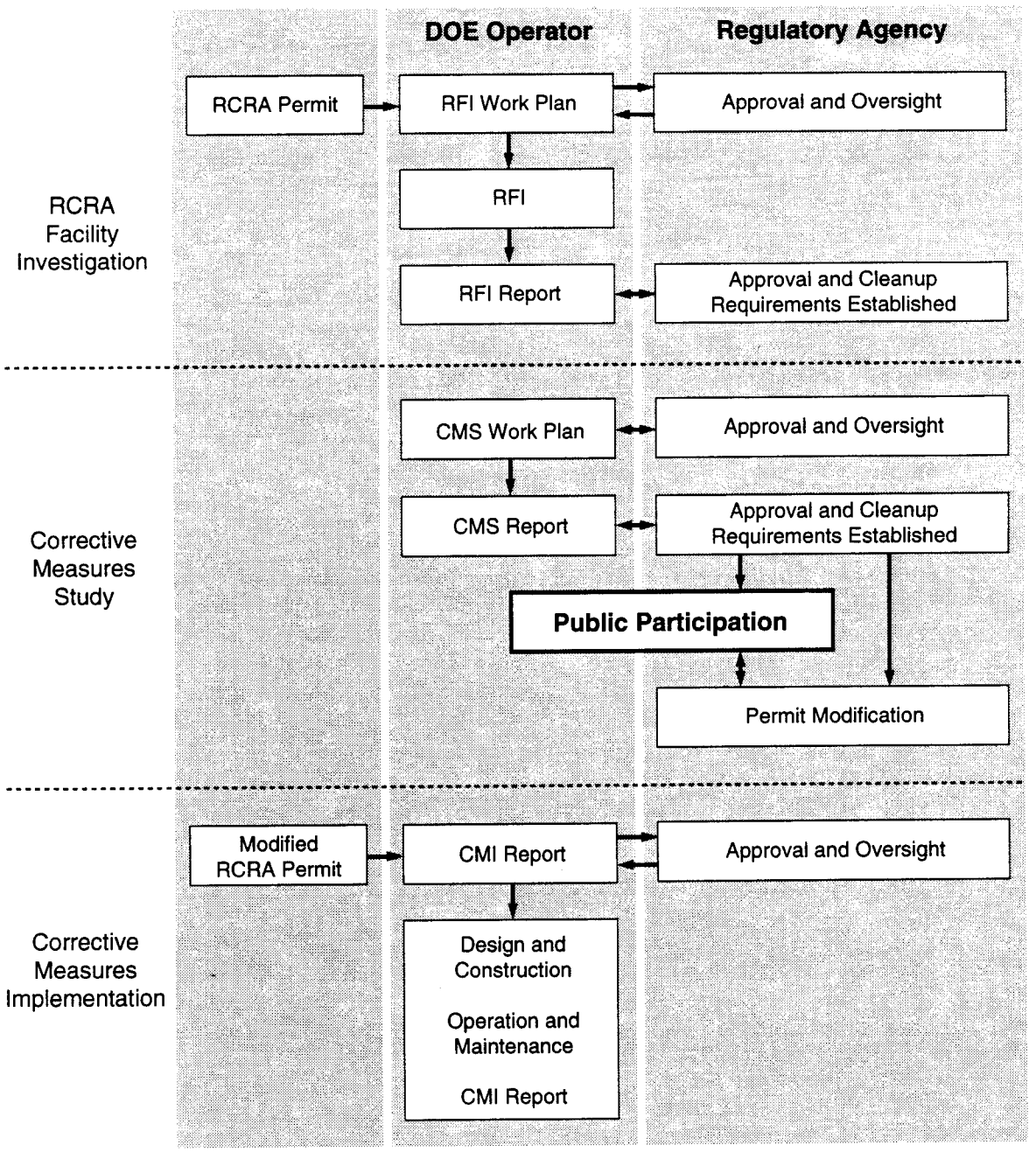

Figure I-4. RCRA corrective action process.

The primary responsibility of the ER Program is to formulate, assess, and implement remediation activities required for PRSs and aggregates thereof. The ultimate goal of the ER Program is to bring all PRSs under its purview into compliance with applicable environmental regulations and to protect public health and safety and the environment.

The scope of the ER Program includes

- implementing RCRA and CERCLA provisions and remediation and closure of PRSs operated before November 1988, including underground storage tanks;
- conducting CERCLA assessments, as necessary, before real property assets are considered for disposition;
- implementing new technologies necessary to conduct cleanup;
- managing expenses associated with cooperative, multiparty, cleanup plans and activities;
- protecting natural resources and restoring natural resources damaged as the result of past releases of hazardous substances; and
- installing long-term environmental monitoring systems.

The D&D Project is responsible for those activities essential to the D&D of surplus contaminated facilities at the Laboratory. The scope of the D&D Project includes

- conducting surveillance and maintenance of facilities, as appropriate, and
- assessing and remediating surplus facilities.

The wastes generated by or associated with the ER Program and D&D Project are managed by the Laboratory's Waste Management Group; waste treatment, storage, and disposal issues are identified early in the project-planning phase to ensure that responsibility and compliance are properly assigned.

1.6 Statutory and Regulatory Requirements

The principal requirements for the ER Program are those derived from RCRA Sections 3004(u) and (v), CERCLA, the Atomic Energy Act (AEA), and New Mexico state law. The ER Program must respond to RCRA requirements for assessing and cleaning up sites at active installations. Section 3004(u) provides for remediation of all hazardous waste sites at a given facility regulated under RCRA. Section 3004(v) extends this requirement to contaminated properties located beyond but near the Laboratory boundary.

D&D is conducted under the authority of the AEA. CERCLA applies mainly to assessing and remediating inactive sites. Hazardous materials are regulated both by RCRA and by CERCLA, and radioactive materials are regulated under the AEA

and/or CERCLA. The hazardous constituents of mixed waste are also subject to RCRA. New Mexico's authority in the assessment and remediation process is as authorized by the EPA under RCRA. DOE Order 5400.1 (DOE 1988, 0075) establishes the environmental protection program requirements, authorities, and responsibilities for DOE operations to ensure compliance with applicable federal, state, and local environmental protection laws, regulations, and executive orders. In addition, the ER Program complies with Laboratory policies, which are written as director's policies.

The statutes described in the following sections provide the criteria for evaluating the technical performance of the ER Program. Table I-1 lists the current environmental permits under which the ER Program at the Laboratory operates. The scope and status of other permits that control hazardous waste operations at the Laboratory are the responsibility of the Environmental Protection Group.

TABLE I-1

ENVIRONMENTAL PERMITS UNDER WHICH THE ER PROGRAM AT THE LABORATORY OPERATES

Permit Type	Permitted Activity	Issue Date	Expiration Date	Administering Agency
HSWA Module VIII	Environmental Restoration	May 23, 1990	December 31, 1999	EPA
RCRA Hazardous Waste Facility	Hazardous waste storage, treatment, and disposal	November 1990	November 1999	NMED

1.6.1 Resource Conservation and Recovery Act

RCRA governs the generation, transportation, treatment, storage, and disposal of hazardous and solid wastes and provides for the recovery of materials and energy resources from the wastes. HSWA Sections 201, 202, 203, 206, 207, 212, 215, and 224 modified Sections 3004 and 3005 of RCRA. HSWA requires corrective action for all releases of hazardous materials from any SWMU at a treatment, storage, or disposal facility.

Under RCRA, permits are issued by EPA or by states that have received authorization from EPA to administer their own compliance programs. Although the NMED has received authorization to issue RCRA operating permits for managing hazardous and mixed wastes, it is not yet authorized to enforce regulations promulgated under HSWA.

1.6.2 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA addresses liability, compensation, cleanup, and emergency response relating to the release of hazardous substances into the environment and cleanup of inactive hazardous waste disposal sites. Under the provisions of the National Contingency Plan, a plan prepared by EPA under CERCLA, the EPA ranks facilities

throughout the nation according to their potential hazard to human and environmental health and safety. The higher-ranking facilities listed on the National Priorities List are being assessed and cleaned up first. The Laboratory has not yet been evaluated to determine whether it should be on the National Priorities List.

1.6.3 Integration of the Provisions of RCRA and CERCLA

Even though the Laboratory is a designated RCRA facility and is not on the National Priorities List, DOE Order 5400.4 (DOE 1989, 0078) specifies that the Laboratory conform to CERCLA to the extent possible. DOE guidance resulting from Executive Order 12580, Superfund Implementation (DOE 1993, 0964), leads to the following interpretation:

- CERCLA applies if hazardous substances are released into the environment or if a substantial threat of release exists.
- CERCLA specifies that the remediation requirement applies equally to federal and nonfederal entities.

1.6.4 Integration of the Provisions of RCRA and NEPA

NEPA provides a national policy to promote efforts that prevent or eliminate damage to the environment, to enrich the understanding of ecological systems and natural resources, and to establish a Council on Environmental Quality. In accordance with the provisions of DOE Order 5400.4 (DOE 1989, 0078), NEPA procedural requirements and the RCRA process for assessing and cleaning up contaminated sites are integrated. In most cases, the primary instrument for this integration is the RFI/CMS process prescribed by RCRA.

1.6.5 Other Statutes and Regulations

1.6.5.1 Federal Statutes

The following federal acts also affect the conduct of UC's ER MSA AL-1 Project:

- The American Indian Religious Freedom Act of 1978 establishes a policy to protect and preserve for native Americans their inherent right to exercise their traditional religions.
- The Atomic Energy Act of 1948, as amended in 1954 and later years, authorizes energy research and development.
- The Clean Air Act of 1970, as amended, regulates emissions from a facility that could affect air quality. Such emissions must meet the performance standards established in this act.
- The Clean Water Act of 1972, as amended, seeks to restore and maintain the chemical, physical, and biological integrity of the nation's waters. The Clean Water Act regulates waste discharges to navigable waters and sets pretreatment stan-

dards for hazardous waste discharges to sewer lines that lead to publicly owned treatment works.

- The Department of Energy Organization Act of 1977 vests in DOE the responsibilities of ensuring that national environmental protection goals are incorporated in energy programs; of advancing the goals of restoration, protection, and enhancement of environmental quality; and of ensuring public health and safety.

- The Department of Transportation Act of 1966 defines the US Department of Transportation's regulatory responsibility for safety in the transportation of all hazardous materials, including radioactive materials.

- The Endangered Species Act of 1973, as amended, requires federal agencies, "in consultation with and with the assistance of" the Secretaries of Interior and Commerce, to ensure that their actions are "not likely to jeopardize the continued existence of any endangered species or threatened species or result in the destruction or adverse modification of the critical habitat of such species...".

- The Federal Facilities Compliance Act waives sovereign immunity for federal facilities with the effect that the government entities fine these facilities for violating environmental laws.

- The Fish and Wildlife Coordination Act ensures that fish and wildlife resources receive consideration equal to that given other values during the planning of development projects that affect water resources. Final regulations, which were proposed in 1979 and 1980 and were withdrawn in 1982, have not yet been promulgated. Meanwhile, guidance for implementing the Fish and Wildlife Coordination Act is based on court interpretations and past DOE experience.

- The National Historic Preservation Act of 1966 requires federal agencies to take into account the effects of their proposed actions on properties listed on, or eligible for, the National Register of Historic Places.

- The Occupational Safety and Health Act provides for the general welfare by ensuring that, so far as possible, every working man and woman in the nation has safe and healthful working conditions.

- The Safe Drinking Water Act, as amended, defines safety standards for public water systems. The maximum contaminant levels developed under the Safe Drinking Water Act are the levels with which drinking water must comply.

- The Toxic Substances Control Act, as amended, ensures that technological innovation and commerce in chemical substances and mixtures do not present an unreasonable risk of injury to health or the environment. The Toxic Substances

Control Act provides for the identification of toxic hazards posed by chemical substances and regulates their discharge into the environment.

1.6.5.2 State Statutes

This section lists state statutes that apply to UC's ER MSA AL-1 Project.

- The Air Quality Control Act of 1967 provides the basic framework for air pollution control in New Mexico.

- The Emergency Planning and Community Right-to-Know Act creates an emergency management task force to develop and distribute to emergency response personnel a comprehensive plan for assessing and managing hazardous materials spills. This plan stipulates the requirements for reporting spills and performing cleanup activities.

- The Ground Water Protection Act of 1990 provides for the regulation of hazards associated with leaks and spills from underground storage tanks, containment and remediation of pollution incidents, and funding of groundwater protection activities.

- The Hazardous Chemicals Information Act establishes state-level systems of emergency planning and notification to deal with releases of extremely hazardous substances and to provide a means whereby members of the public can learn about hazardous chemicals used in their communities and about any releases of those chemicals.

- The Hazardous Waste Act of 1977, as amended, establishes the State of New Mexico's program for hazardous waste management and control. Because this act meets federal requirements, EPA has granted the state authority to regulate site closures under RCRA (exclusive of HSWA).

- The Radiation Protection Act (1978) establishes the general rule of radiation protection. The Radiation Protection Act specifies that levels of radiation be kept as low as reasonably achievable, taking into account the state of technology and the costs of improvements in relation to public health and safety benefits and to the use of ionizing radiation in the public interest.

- The Radioactive and Hazardous Materials Act regulates the transportation of radioactive material on highways. Its requirements include a means of transportation that protects the health, safety, and welfare of the citizens and criteria for establishing the safest route.

- The Solid Waste Act of 1990 establishes a comprehensive statewide solid waste management program to regulate the reduction, storage, collection, transportation, separation, processing, recycling, and disposal of solid waste and to promote source reduction, recycling, reuse, treatment, and transformation of solid waste.

- The Water Quality Act gives the New Mexico Oil Conservation Division exclusive authority over the prevention of water pollution resulting from oil or gas operations.

1.6.5.3 DOE Orders, Executive Orders, and Secretary of Energy Notices

The DOE orders that apply to the ER MSA AL-1 Project are listed below:

DOE 1324.2A	Records Disposition
DOE 1332.1A	Uniform Reporting Systems
DOE 2200.4	Accounting Overview
DOE 2250.1C	Cost and Schedule Control Systems Criteria
DOE 3790.1A	Federal Employee Occupational Safety and Health Program
DOE 4700.1	Project Management System
DOE N4700.6	Project Control System Guidelines
DOE 5000.3B	Occurrence Reporting and Processing of Operations Information
DOE 5100.3	Field Budget Process
DOE 5400.1	General Environmental Protection Program
DOE 5400.2A	Environmental Compliance Issue Coordination
DOE 5400.3	Hazardous and Radioactive Mixed Waste Program
DOE 5400.4	Comprehensive Environmental Response, Compensation, and Liability Act Requirements
DOE 5400.5	Radiation Protection of the Public and the Environment
DOE 5440.1C	Implementation of the National Environmental Policy Act
DOE 5440.1D	National Environmental Policy Act Compliance Program
DOE 5480.3	Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes
DOE 5480.4	Environmental Protection, Safety, and Health Protection Standards
DOE-5480.5	Safety of Nuclear Facilities
DOE 5480.10	Contractor Industrial Hygiene Program
DOE 5480.11	Radiation Protection for Occupational Workers
DOE 5480.20	Personnel Selection, Qualification, Training, and Staffing Requirements at DOE Reactor and Nonreactor Nuclear Facilities
DOE 5480.23	Nuclear Safety Analysis Reports
DOE 5482.1B	Environment, Safety, and Health Appraisal Program
DOE 5483.1A	Occupational Safety and Health Program for DOE Contractor Employees at Government-Owned Contractor-Operated Facilities
DOE 5484.1	Environment, Safety, and Health Protection Information Reporting Requirements
DOE 5500.1B	Emergency Management System
DOE 5500.2B	Emergency Categories, Classes, and Notification and Reporting Requirements
DOE 5500.3A	Planning and Preparedness for Operational Emergencies

DOE 5500.4	Public Affairs Policy and Planning Requirements for Emergencies
DOE 5700.2C	Cost Estimating, Analysis, and Standardization
DOE 5700.6C	Quality Assurance
DOE 5700.7B	Work Authorization System
DOE 5820.2A	Radioactive Waste Management
DOE 6430.1	General Design Criteria

The following executive orders (EOs) are applicable to the ER MSA AL-1 Project:

EO 11988, May 24, 1977	Floodplain Management
EO 11990, May 24, 1977	Protection of Wetlands
EO 11991, May 24, 1977	Relating to Protection or Enhancement of Environmental Quality
EO 12580, January 23, 1987	Superfund Implementation

The following Secretary of Energy Notices (SENs) are applicable to the ER MSA AL-1 Project:

SEN-7-89, May 19, 1990	Policy on Line Management's Responsibility to Achieve Environmental Compliance
SEN-15-90, February 5, 1990	National Environmental Policy Act
SEN-24-90, June 25, 1990	Strengthening the Department of Energy Project Management System
SEN-25-90, July 24, 1990	Strategic Planning Initiative
SEN-27-90, August 15, 1990	Strengthening the Department of Energy Project Management System

2.0 OBJECTIVES

2.1 Project Management Objectives

The objectives of the UC's ER MSA AL-1 Project Management Plan are to

- establish and maintain a management control system and project control procedures for efficient baseline management;
- establish at the Laboratory through the ER Program a procedural framework and schedules for developing, implementing, coordinating, and monitoring corrective actions that comply with RCRA, CERCLA, and NEPA;
- prioritize projects related to resource availability, minimize duplication of analysis and documentation, and expedite corrective actions;
- provide both formal and informal mechanisms through which EPA, NMED, and the public can review, comment on, and participate in the corrective action review process at the Laboratory;
- record plans, procedures, costs, and other data and prepare progress and technical reports so that the knowledge and

experience can be used to manage later elements in a cost-effective manner;

- coordinate ER Program and D&D Project planning, provide a forum for the exchange of information among affected Laboratory organizations, and ensure integration of the ER Program and D&D Project; and

- complete decommissioning activities at all facilities currently designated and at those that may be designated as surplus facilities in the future.

2.2 Technical Objectives

The overall technical objectives of the Los Alamos ER MSA AL-1 Project are to effectively formulate, evaluate, implement, and manage characterization, remediation, and D&D in a manner that fully complies with environmental regulations and protects human health and the environment. These objectives will be met in a cost-effective manner by using existing technologies or through pilot studies that demonstrate the efficacy of simple corrective measures.

2.3 Quality Assurance Objectives

The intent of all quality programs is to ensure that appropriate controls are built into a program, project, or activity; that the quality of the results is known and documented; and that the effectiveness of the controls, as implemented, can be evaluated. The Laboratory's Quality Program Plan states the quality assurance (QA) objectives and requirements applicable to the ER MSA AL-1 Project and activities are planned, implemented, and maintained as required by the Laboratory's Quality Program Plan.

The ER MSA AL-1 Quality Program Plan has been prepared in accordance with Interim Guidelines and Specifications for Preparing Quality Assurance Program Plans (EPA 1980, 0283) and NQA-1, Quality Assurance Requirements for Nuclear Facilities (ANSI/ASME 1989, 0018), as specified by DOE Order 5700.6C (DOE 1991, 0703). The intent of the plan is to present a comprehensive, coherent QA program. Personnel implement the guidelines established in the Quality Program Plan through quality assurance project plans, quality procedures (QPs), and standard operating procedures (SOPs). A list of SOPs is provided in Appendix M.

2.4 Health and Safety Objectives

The ER MSA AL-1 Project is committed to performing its work in a manner that protects the health and safety of Laboratory workers and the public through compliance with all applicable federal, state, and local laws and regulations; with all applicable DOE orders and health and safety standards for the Laboratory; and with the health and safety requirements specified in the HSWA Module.

The Health and Safety Program Plan (Annex III) describes the health and safety issues of the corrective action process; is designed to identify, evaluate, and control safety and health hazards; and provides for emergency responses appropriate to the

potential hazards of waste characterization and remediation operations. Audits are regularly conducted to ensure that the Health and Safety Program Plan is implemented effectively.

2.5 Records Management Objectives

The statutory definition of "records" (44 USC 3301) includes technical data. The term is used in the Records Management Program Plan (Annex IV) to reflect the need to protect all records essential to the ER Program. The specific activities implemented to achieve records management are delineated in QPs and SOPs developed in cooperation with the Quality Program staff.

The Records Management Program ensures that records are managed to maintain their integrity and to ensure that ER Program actions are documented in an auditable manner. The ER Program Office has established the Records-Processing Facility to receive and process records and the Facility for Information Management, Analysis, and Display to provide program participants and the public with centralized access to information generated by the ER Program. The latter facility includes the hardware and software necessary to capture, display, and analyze data.

ER MSA AL-1 Project records, including technical data sets, are organized, indexed, and stored in a manner that provides efficient access to a diverse group of users. The information retrieval system is designed to protect the integrity of the data. The development of effective guidelines for handling record packages requires coordination with the quality, health and safety, resource planning, and public involvement programs.

2.6 Public Involvement Objectives

Laboratory policy requires a proactive approach to disseminating and exchanging ideas affecting the general public and Laboratory employees. In addition, the HSWA Module specifies that the Laboratory develop a public involvement plan (Annex V) to provide public access to information pertaining to the ER Program. To satisfy these requirements, the Laboratory is implementing a public involvement plan that

- provides information about technical issues in a timely manner;
- responds to communities' concerns in a manner that encourages two-way communication between the interested parties and the Laboratory;
- reaches the broadest audiences and takes into account a variety of educational backgrounds and technical expertise;
- provides for public comment on ER program activities as specified by regulation;
- provides a library for the general public that contains documentation on past, current, and proposed ER Program and D&D Project activities;

- encourages public participation as a way of increasing the public's understanding of the ER Program and D&D Project.

2.7 Procurement Plan Objectives

The ER MSA AL-1 Project follows the Laboratory's procurement policies and procedures set forth in Chapter 7 of the Laboratory Manual (LANL 1981, 0142), which is based on the federal acquisition regulation, the DOE's acquisition regulation, UC procurement policy, federal laws, and executive orders. Subcontracts are awarded competitively to the maximum extent practicable. Sources are selected in general accord with the procedures of the DOE's acquisition regulation handbook source evaluation board.

2.8 Site Prioritization Paradigm

The DOE, together with its New Mexico installations (Los Alamos and Sandia national laboratories), has developed a site prioritization paradigm. This paradigm provides a method for evaluating the relative risk posed by all the PRSs at the two laboratories. Additionally, the paradigm incorporates other prioritization criteria (e.g., regulatory concerns and potential for VCA) to aid decision makers in allocating available resources according to the degree of risk at each site. The paradigm was developed with input from EPA and NMED and provides for public involvement in the ranking assessment.

3.0 ORGANIZATION AND RESPONSIBILITIES OF MANAGEMENT

The DOE's Albuquerque Field Office (DOE-AL) is responsible for implementing the DOE-AL's ER Program. DOE-Headquarters (DOE-HQ) delegates authority for conducting the DOE-AL ER Program to the DOE-AL ER Project Office. The organizational chart for the DOE-AL ER Project Office is presented in Figure I-5. DOE area offices and their prime contractors execute approved assessment and remediation tasks at their installations. The DOE-LAAO is the primary line of communication with UC for day-to-day operations.

The responsibilities and functions of the DOE-LAAO and UC include

- serving as the primary contact (e.g., for conducting negotiations) with regulatory agencies;
- conducting public involvement activities;
- conducting RFI/CMS/CMI activities;
- preparing and reviewing RFI/CMS/CMI and NEPA documents;
- distributing RFI/CMS/CMI documents for DOE and regulatory review;
- designing and implementing corrective measures required by and RCRA 3004(u) and 3004(v) and CERCLA;

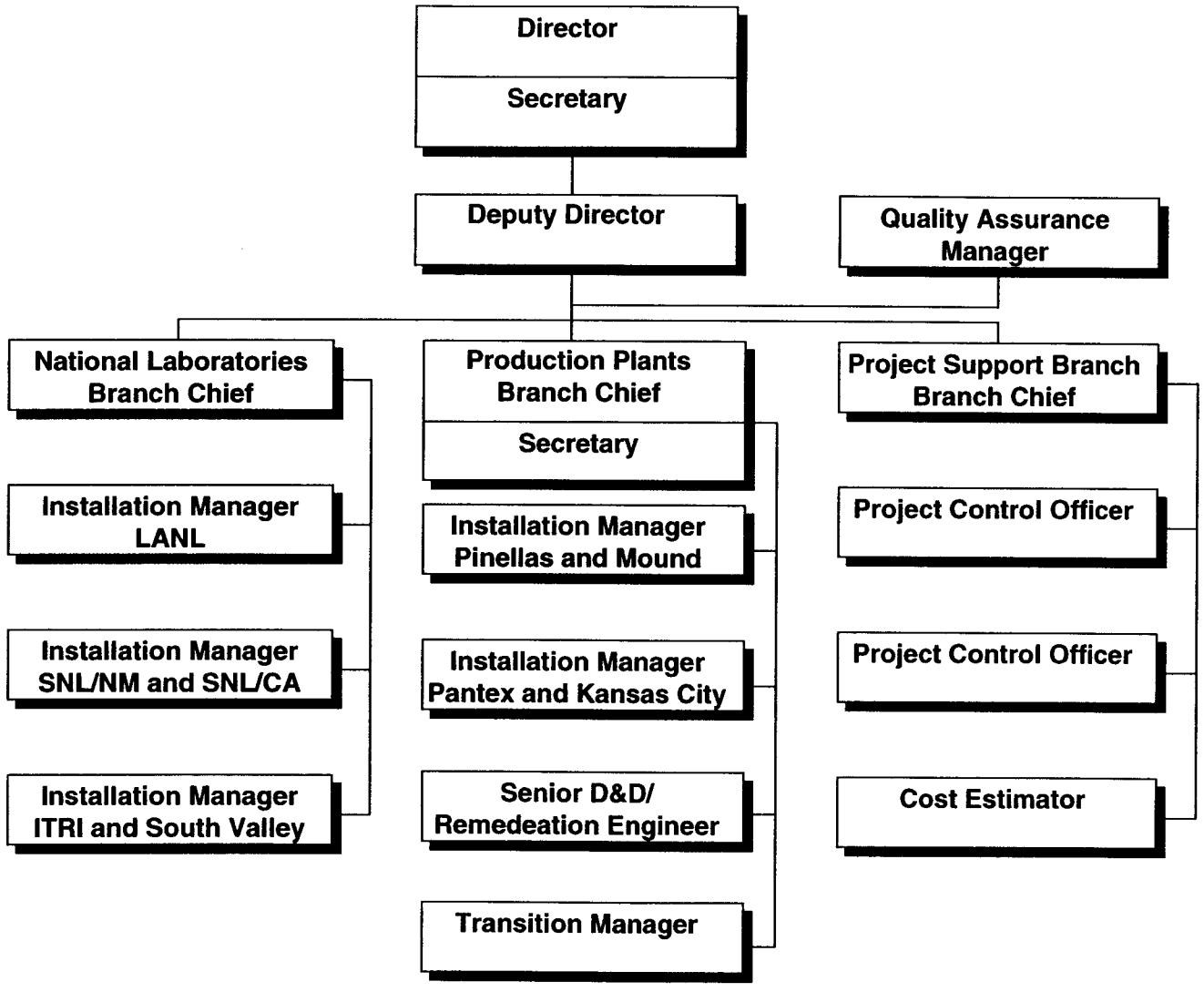

Figure I-5. Organization of the DOE Albuquerque Environmental Restoration Project Office.

- conducting activities related to RCRA closures, including NEPA documentation;
- proposing activities for budget-year submittal;
- planning and implementing D&D activities for surplus facilities;
- developing the Laboratory's Five-Year Plan for RFI/CMS/CMI activities and RCRA closures;
- developing the Laboratory's current-year work plan;
- preparing monthly management reports;
- preparing quarterly technical progress reports; and
- preparing completion reports for RCRA closures.

The education and experience of key participants in the program are summarized in Appendix N.

4.0 MANAGEMENT INFORMATION SYSTEM FOR UC'S ER MSA AL-1 PROJECT

The UC ER MSA AL-1 Project's Management Information System (MIS) is based on a management control system developed by DOE/UC consisting of a set of policies, procedures, practices, computer systems, forms, reports, and documents that collectively provide for the systematic and effective management of corrective action and D&D projects at the Laboratory.

The MIS collects, processes, and analyzes information for various individuals in the ER Program, including, for example, management staff, project leaders, and technical team leaders (TTLs). Based on these analyses, MIS personnel keep program managers informed of the status of the program's cost and schedule and identify problems and possible solutions. The Laboratory's "Management Control System and Project Control Procedures for Environmental Restoration" describes the management control system in detail (LANL in preparation, 0963).

The MIS follows the requirements of DOE Orders 4700.1 (DOE 1992, 0823) and N4700.6. and addresses (DOE 1993, 1058)

- planning,
- scheduling,
- cost estimating,
- budgeting,
- work authorization,
- cost accounting,

- progress reporting,
- performance measurement, and
- change control.

Under the direction of the program office, MIS implements guidance of DOE-HQ and DOE-AL. The MIS coordinates a large initial planning effort of all cost account managers, including the program managers, the project leaders, and the TTLs. All participants authorized to be cost account managers must analyze and act upon reports of past progress and future activities generated by the MIS each month.

The strict relationship between the Laboratory's program codes and the MIS codes makes it possible to measure performance on a planned-versus-actual basis. Monthly performance reports are submitted to DOE. When a difference between planned (before) and actual (after) exists in excess of a DOE-specified limit, a variance is said to exist. Each variance must be addressed by a statement containing a description of the problem and its cause, impact, and the action required or taken to correct the variance. The responsible parties must make this response and take action, as appropriate.

The ER Program Office's MIS consists of (1) a work breakdown structure (WBS), (2) a responsibility assignment matrix, (3) logic networks, (4) a network-based schedule, (5) detailed cost estimates based on network activities, and (6) actual cost information from the Laboratory's accounting department (FIN-3). All six components of the MIS are integrated in a highly disciplined and dynamic system baseline.

The WBS (Figure I-6) is used to define a project by relating elements of work to each other and to the end product. The WBS is the primary tool that DOE uses to identify its project elements and responsibilities. It conveniently formats the relationship of all project elements and provides a sound basis for planning and controlling technical costs and schedules. Each level of the structure is closely related to a management sphere within a program and provides the framework for relating time and cost summaries to appropriate levels of contractor, UC, and DOE management. A WBS provides both a basis and an integrating mechanism for managing key functions of a program and all subprojects.

The following documents describe the policy for managing the ER MSA AL-1 work for the DOE and are pertinent to the use of the WBS and operation of the MIS:

- OMB Circular A-109, Major System Acquisitions (OMB 1976, 0366);
- DOE Order 4700.1, Project Management System;
- DOE Order 4240.J, Designation of Major System Acquisitions and Major Projects;
- DOE Order N 4700.5, Project Control System Guidelines; and
- DOE Order 1332.1A, Uniform Reporting System.

Briefly, the MIS functions as follows: The WBS defines the work elements and objectives to be attained. A logic network, composed of tasks defined as time- and

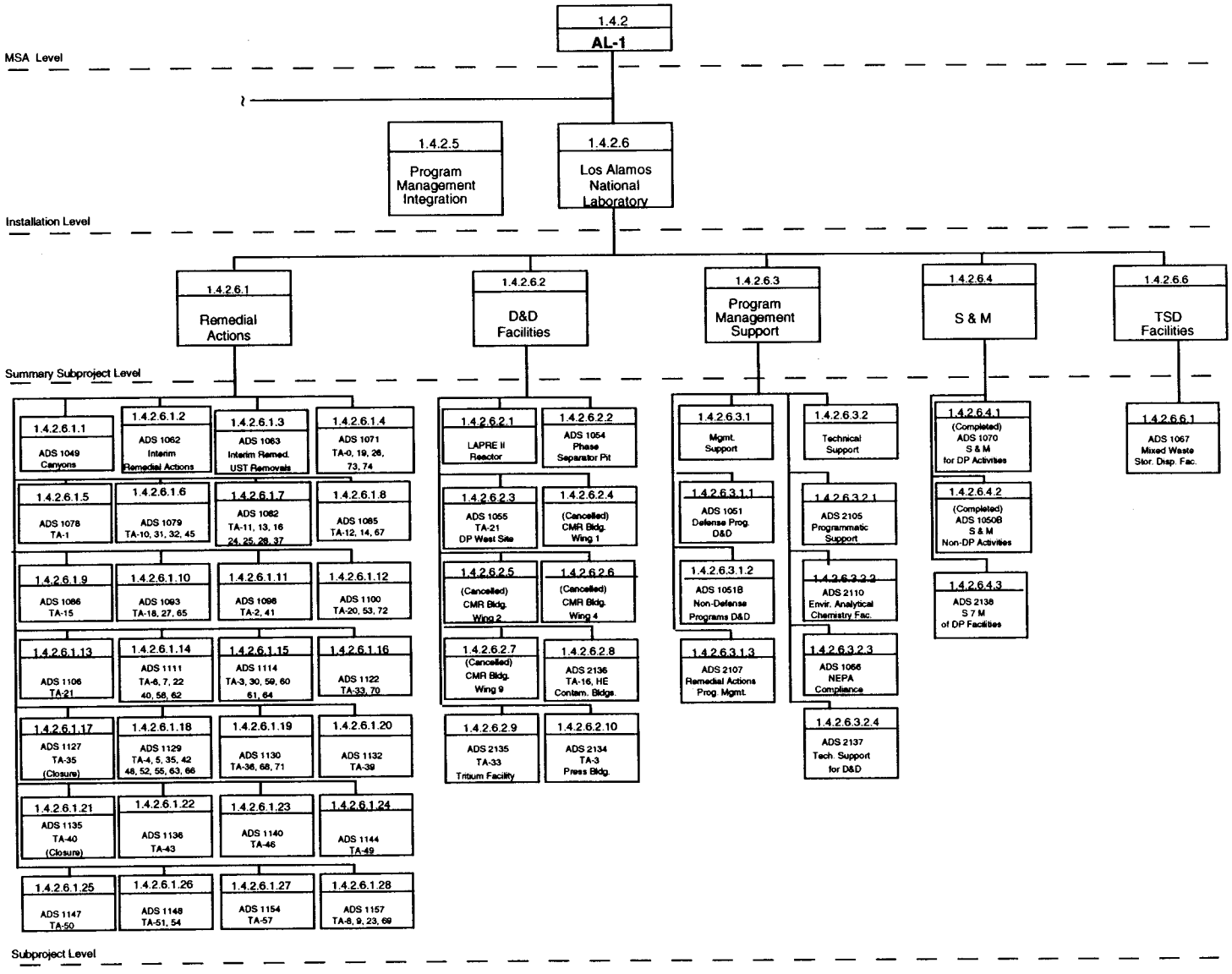

Figure I-6. WBS currently used by DOE/UCs ER MSA AL-1 Project.

resource-consuming elements of work, is then developed to produce a schedule of activities, including milestones.

Cost estimates are either generic throughout the project (e.g., the cost of developing a public involvement plan, which is a requirement for each OU) or are developed by the OUPLs in cooperation with cost estimators. Most cost estimates, however, are highly specific (reflecting, for example, estimates of the number of PRSs and D&D facilities identified at a site, the size of the PRSs and D&D facilities, and the physical location and grouping of sites). All estimates are prepared using the guidelines set forth in DOE Order 4700.1 and the DOE's cost-estimating, analysis, and standardization guidelines (DOE Order 5700.20).

The responsibility assignment matrix allocates resources to activities and ensures that all work in the WBS is assigned. Because the matrix integrates the planning and scheduling and the cost-estimating programs, all estimates are produced as a function of time. The matrix is also used to establish and control cost accounts. By comparing the estimated costs with actual reported costs, estimators are able to measure performance monthly.

Because the MIS addresses in a highly integrated manner a combination of what, how, who, when, and how much, it is also possible, for planning purposes, to create future scenarios and to determine their impacts before decisions are actually implemented.

5.0 ER MSA AL-1 PROJECT SCHEDULE

Major milestones that have been identified for the RFI/CMS/CMI include the initiation and completion of each of the following elements:

- RFI work plan,
- RFI,
- RFI report,
- CMS plan,
- CMS report,
- CMI plan, and
- CMI report.

Other major milestones that document important findings and events throughout the corrective action process are phase, quarterly, and monthly reports.

These milestones apply to individual OUs, not to the ER Program as an entity. As more information becomes available from the RFI, CMS, CMI, and associated investigations at individual OUs, detailed, achievable plans will be developed and refined to meet regulatory due dates.

D&D Project milestones are project-dependent. Typical milestones are completion of

- facility acceptance,
- assessment,
- project readiness review,
- remediation, and
- final report.

The current schedule for all OUs is shown in Appendix O; however, funding is constrained, and, if other resources, such as manpower and analytical capacity, prove to be unavailable over the course of the ER Program, DOE/UC may invoke the provisions of the HSWA Module to request further extensions. Because new target budget estimates for FY94 and the out years are planned, the funding schedules and estimates in Appendix O.

6.0 REPORTING REQUIREMENTS

The development and implementation of reporting requirements for the ER Program are mandated by DOE and by other responsible regulatory agencies through DOE/UC's permit to operate under RCRA. DOE-LAAO and UC, as copermittees, must sign the following certification for each deliverable to EPA, including monthly and quarterly technical progress reports.

> I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

All reporting data and documentation requirements conform to DOE Order 4700.1 and comply with applicable guidance from DOE-HQ, DOE-AL, DOE-LAAO, and internal UC criteria.

To comply with applicable regulations and to keep all interested parties informed of progress made during the corrective action process, the ER Program prepares several types of plans and reports. The major plans and reports are associated with the RFI, CMS, and CMI. In addition, OUPLs prepare monthly reports, quarterly technical progress reports, and phase reports.

It is the policy of the ER Program Office to see that all reports comply, to the extent feasible, with EPA's RFI guidance and DOE guidance regarding compliance with CERCLA. At a minimum, the reports describe the procedures, methods, and results of field investigations and include information on the type and extent of contamination, sources and migration pathways, and actual and potential receptors. The

reports contain information adequate to support further corrective action decisions (e.g., comparisons with screening action level criteria). OUPLs make all reports available to the public through the community reading room.

In addition, the D&D Project prepares formal Laboratory reports upon completion of a D&D project. The formal report provides background information, characterization data, D&D methods and techniques, final survey and release data, and any lessons learned. The purpose of the final report is to capture project history, and provide a formal record of completion.

References for Annex I

ANSI/ASME (American National Standards Institute/American Society of Mechanical Engineers), 1989. "Quality Assurance Requirements for Nuclear Facilities," NQA-1-1989, 345 East 47th Street, New York, New York. (ANSI/ASME 1989, 0018)

DOE (US Department of Energy), November 9, 1988. "General Environmental Protection Program," DOE Order 5400.1, Washington, DC. (DOE 1988, 0075)

DOE (US Department of Energy), October 6, 1989. "Comprehensive Environmental Response, Compensation, and Liability Act Requirements," DOE Order 5400.4, Washington, DC. (DOE 1989, 0078)

DOE (US Department of Energy), August 21, 1991. "Quality Assurance," DOE Order 5700.6C, Office of Nuclear Energy and Office of Environment, Safety, and Health, Washington, DC. (DOE 1991, 0703)

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DOE (US Department of Energy), June 7, 1993. "Project Control System Guidelines," DOE Notice N4700.6, Washington, DC. (DOE 199?, 1058)

DOE (US Department of Energy), January 1993. "Environmental Restoration and Waste Management Five-Year Plan, Fiscal Years 1994-1998," Volumes I and II, DOE/S-00097P, Washington, DC. (DOE 1993, 0992)

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EPA (US Environmental Protection Agency), April 10, 1990. Module VIII of RCRA Permit No. NM0890010515, EPA Region VI, issued to Los Alamos National Laboratory, Los Alamos, New Mexico, effective May 23, 1990, EPA Region VI, Hazardous Waste Management Division, Dallas, Texas. (EPA 1990, 0306)

LANL (Los Alamos National Laboratory), October 1981. "The Laboratory Manual, Procurement Policies and Procedures," Los Alamos, New Mexico. (LANL 1981, 0142)

LANL (Los Alamos National Laboratory,) in preparation. "Management Control System and Project Control Procedures for Environmental Restoration." (LANL in preparation, 0963)

NMEID (New Mexico Environmental Improvement Division), November 8, 1989. "Hazardous Waste Facility Permit," Permit No. NM0890010515-1 issued to Los Alamos National Laboratory, Los Alamos, New Mexico, effective February 19, 1990, Santa Fe, New Mexico. (NMEID 1989, 0595)

OMB (Office of Management and Budget), 1976. "Major System Acquisitions," Circular A-109, Washington, DC. (OMB 1976, 0366)

1.0 INTRODUCTION

The Environmental Restoration (ER) Program Office (EM-13) at Los Alamos National Laboratory (the Laboratory) builds quality into all program work processes by planning, organizing, directing, and controlling ER Program activities. The ER Program ensures the quality of data by providing written technical plans and procedures in accordance with Environmental Protection Agency (EPA) and Department of Energy (DOE) guidance and requirements. Plans and procedures are evaluated through formal internal and external review processes to ensure technically adequate documents. Qualified and properly trained personnel collect and analyze data and provide documentation of all aspects of planning and sampling activities.

The purpose of this annex is to identify the documents that contain quality assurance (QA) requirements applicable to the ER Program, to describe the QA procedures used to ensure the quality of data collected under the ER Program, and to describe the guidance provided to ER Program participants by the ER Program Office.

2.0 OVERVIEW OF ER PROGRAM DOCUMENTS

The planning, guidance, and requirements documents introduced below are used by ER Program personnel, including contractors, to develop their individual plans and procedures. Additionally, the guidance and requirements provide instructions for many functions and apply to, or are incorporated in, individual ER work processes, as appropriate.

2.1 Installation Work Plan

The Installation Work Plan (IWP) (LANL 1993, 1017) describes the overall mission, organization, and functional responsibilities of the ER Program. Each chapter and annex in the IWP provides essential information for ensuring the quality of program work processes. The IWP provides information that pertains to the entire program so that individual plans and procedures can incorporate generic information by reference to the appropriate location in the IWP. The IWP is distributed to programmatic project leaders, operable unit project leaders, technical team leaders, and other program participants, as appropriate.

2.2 Quality Program Plan and Procedures

The Quality Program Plan (QPP) for the ER Program (LANL 1991, 0781) was approved by EPA on July 12, 1991. The QPP states the basic QA requirements that DOE and EPA require for ER Program activities. It is the responsibility of each program participant to incorporate these requirements in his/her work processes.

The requirements of the QPP are implemented through standard operating procedures (SOPs) (LANL 1991, 0411), administrative procedures (APs), and quality procedures (QPs) developed specially for the ER Program and through the IWP. The QPP and appropriate procedures are distributed to program personnel on an as-needed basis via controlled distribution.

2.3 Generic Quality Assurance Project Plan

The Generic Quality Assurance Project Plan (QAPjP) (LANL 1992, 0782), which was approved by the EPA on July 12, 1991, was designed to serve as a framework for preparing QAPjPs specific to each of the ER Program's 24 operable units. Although previously included in the IWP, beginning in 1992, the generic QAPjP has been issued separately.

3.0 ER PROGRAM'S APPROACH TO DATA COLLECTION

The strategies for collecting data are described in individual RFI work plans. Guidance for developing investigation strategies is provided in the generic QAPjP and in the IWP, Chapter 4, Technical Approach. The requirements and guidance to assess analytical data precision, accuracy, representativeness, and completeness of measurement data are described in the generic QAPjP.

3.1 Data Usage

As stipulated in the generic QAPjP, individual RFI work plans describe the intended uses of data and the necessary level of precision and accuracy for the intended uses.

3.2 Data Assessment

The methods and procedures used to assess field data are located in the SOP manuals issued via controlled distribution. The SOPs are revised, as necessary, in accordance with APs and are distributed to manual holders.

The methods and procedures used to assess analytical data are located in a Laboratory health and environmental chemistry guidance document (LANL no date, 0520). This controlled document is maintained by the Laboratory's Health and Environmental Chemistry Group (EM-9).

3.3 Sampling and Field Measurements

The technical approach to determining sample collection strategies and decisions is included in Chapter 4 of the IWP. For example, applying the data quality objectives (DQO) process (EPA 1987, 0086) described in Chapter 4 enables the operable unit project leader to select appropriate sampling and field measurements, locations, depths, and number of samples for individual sampling plans. Additionally, the work plans identify sampling and field measurement sites in sufficient number to provide statistical accuracy and to describe the conditions under which sampling and field measurements should be conducted.

At a minimum, the QAPjP and SOPS describe administrative and field readiness review procedures; identify field sampling operations and techniques; and describe appropriate sample containers, sample preservation, and field documentation requirements, including chain-of-custody requirements. Procedures developed by other organizations, both internal and external to the Laboratory, are used when ER Program procedures do not exist.

3.4 Sample Analysis

The procedures for sample analysis, including EPA methods, are maintained by the Health and Environmental Chemistry Group (EM-9). EM-9 also maintains analytical procedures in its health and environmental chemistry guidance document (LANL no date, 0520). Additionally, EM-9 has a QA program that includes written plans and administrative procedures (e.g., chain of custody, records management, quality control) that are reviewed once a year, at a minimum, and are revised as necessary.

4.0 UPDATING GUIDANCE

The ER Program's major guidance document, the IWP, is updated annually; therefore, interim guidance, as needed, is distributed to program personnel through memoranda from the ER Program Office and through the programmatic project leaders. When it is necessary to update procedures, the ER Program document control system, described in controlled APs, is invoked. The system provides for the revision of controlled documents at any time.

References for Annex II

EPA (US Environmental Protection Agency), March 1987. "Data Quality Objectives for Remedial Response Activities, Development Process," EPA 540/G-87/003, OSWER Directive No. 9355.0-7B, prepared by CDM Federal Programs Corporation, Washington, DC. (EPA 1987, 0086)

LANL (Los Alamos National Laboratory), no date. "Health and Environmental Chemistry: Analytical Techniques, Data Management, and Quality Assurance," Los Alamos National Laboratory Report LA-10300-M, Volumes 1 and 2, Los Alamos, New Mexico. (LANL no date, 0520)

LANL (Los Alamos National Laboratory), May 1991. "Generic Quality Assurance Project Plan for RCRA Facility Investigations for the Los Alamos National Laboratory Environmental Restoration Program," Rev. 0, Environmental Restoration Program, Los Alamos, New Mexico. (LANL 1991, 0782)

LANL (Los Alamos National Laboratory), May 1991. "Environmental Restoration Standard Operating Procedures," Vols. I, II, and III, Los Alamos, New Mexico. (LANL 1991, 0411)

LANL (Los Alamos National Laboratory), June 1991. "Los Alamos National Laboratory Quality Program Plan for Environmental Restoration Activities," Rev. 0, Los Alamos National Laboratory Report LA-UR-91-1844, Los Alamos, New Mexico. (LANL 1991, 0781)

LANL (Los Alamos National Laboratory), November 1993. "Installation Work Plan for Environmental Restoration," Revision 3, Los Alamos National Laboratory Report LA-UR-93-3987, Los Alamos, New Mexico. (LANL 1993, 1017)

1.0 INTRODUCTION

This Health and Safety Program Plan of the Installation Work Plan (IWP) presents the concepts and methodologies to be used during environmental restoration activities at Los Alamos National Laboratory (the Laboratory). This Health and Safety Program Plan is an appendix to the IWP and provides an organized and rational approach for recognizing, evaluating, and controlling potential health and safety hazards that might arise from Environmental Restoration (ER) Program activities. The subsections that follow describe the program philosophy, requirements, and methods for applying the Health and Safety Program Plan to individual operable units (OUs).

1.1 Program Philosophy

The safety and health of employees, subcontractors, and visitors will be ensured through the identification, review, evaluation, and control of potential hazards associated with program activities. The Laboratory and its subcontractors are committed to limiting exposures to levels that are as low as reasonably achievable (ALARA). The Laboratory's radiation protection policy also applies ALARA principles to Laboratory-wide activities. Program personnel will be informed of known and potential hazards associated with the tasks to be performed so that they can effectively apply required safety precautions.

Maintaining a safe and healthful work environment is the responsibility of all project team members. Through a comprehensive training program, team members will be informed of hazard potentials, proper use of personal protective equipment, applicable procedural requirements, and their responsibilities for maintaining safe work environments. Trained personnel are required to adhere to all safety requirements.

Violations of environmental protection, health, and safety policies will not be tolerated. Personnel who develop a history of safety violations or who blatantly or willfully violate environmental protection, safety, and health procedures will be removed from the project.

1.2 Description

Several health and safety documents are relevant to the ER Program. Consequently, it is important to understand their relationship and hierarchy.

The highest-level document is the Health and Safety (HS) Division's Hazardous Waste Operations (HAZWOP) Program. The HAZWOP Program was developed in response to Occupational Safety and Health Administration (OSHA) regulation 29 CFR 1910.120, Hazardous Waste Operations and Emergency Response. This standard requires that employers develop and implement a written health and safety program for employees involved in hazardous waste operations.

The HAZWOP Program must incorporate an organizational structure, a comprehensive work plan, a site-specific health and safety plan, a health and safety training program, a medical surveillance program, the employer's standard operating procedures for health and safety, and any necessary interface between the general program and site-specific activities. Contractors and subcontractors are to be

informed of the hazards present on the site and of site emergency response procedures. The program must also address provisions for meeting excavation safety requirements. The written program is provided to contractors, employees (or their representatives), and officials with regulatory authority over the site. The HAZWOP Program also fulfills the requirements of the Environmental Protection Agency's (EPA's) Hazardous and Solid Waste Amendments (HSWA) Module of the Laboratory's Resource Conservation and Recovery Act (RCRA) permit. The HS Division has developed specific procedures to support the HAZWOP Program. Other Laboratory-wide procedures are also referenced.

This Health and Safety Program Plan is the highest of three levels of health and safety document for the ER Program. The other two levels of document are derived from this program plan: the health and safety project plan, which is prepared for and is specific to each OU, and the site-specific plan, which is prepared for each site in an OU.

The purpose of the project plan is to provide information to project leaders, health and safety professionals, Laboratory program managers, and regulators about health and safety programs and procedures as they relate to individual OUs.

Each OU contains potential release sites (PRSs). Similar PRSs are aggregated for purposes of remediation. Because planning, training, employee protection, and oversight measures are different at each site, site-specific plans are developed to address this variability. The site-specific plan addresses the potential health and safety hazards of each phase of site operations and includes the requirements and procedures for employee protection. Those performing the field work are responsible for preparing a site-specific plan for each PRS or aggregate. The site-specific plan must be approved by HS Division before field work begins.

Each of these health and safety documents (the HAZWOP Program, Health and Safety Program Plan, project plan, and site-specific plan) is related. They are prepared and reviewed in a consistent manner so that they focus on their intended purpose. Figure III-1 illustrates the hierarchy of these documents.

2.0 PURPOSE

The purpose of this program plan is to provide an organized and rational approach for recognizing, evaluating, and controlling potential health and safety hazards and to provide for emergency responses as they relate to ER Program activities. The plan is derived from the HS Division's HAZWOP Program. Project and site-specific plans and standard operating procedures (SOPs) are extensions of this program plan.

3.0 SCOPE

3.1 Organizations Affected

This document governs all Laboratory divisions involved in ER Program activities, including the HS, Environmental Management (EM), and Engineering divisions, and any other division participating in the assessment or remediation of a PRS. The activities of ER Program subcontractors are also governed by this program plan.

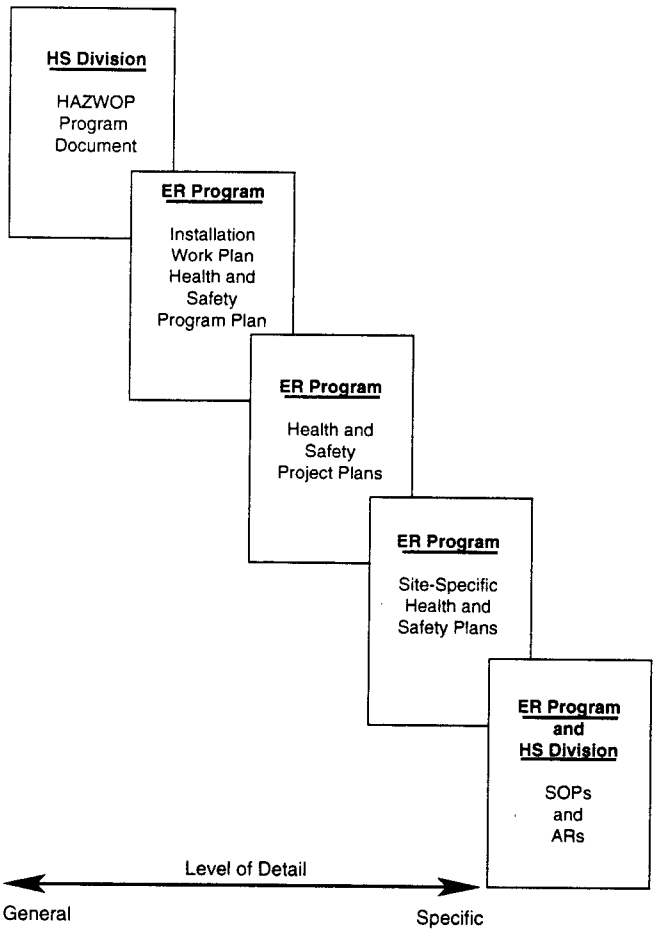

Figure III-1. Relationship of ER Program and HS Division documents.

3.2 Organizations Not Affected

Laboratory organizations and subcontractors not involved in environmental restoration activities are not affected by this program plan. Certain activities that are not conducted under the ER Program may occur at hazardous waste sites or at identified PRSs that may expose personnel to health hazards resulting from activities performed on the site. General health and safety requirements for these activities are described in the HS Division's HAZWOP Program.

3.3 Areas Affected

All PRSs are affected, including sites on land owned by the Department of Energy (DOE), Los Alamos County, the Town of Los Alamos, native Americans, and private citizens.

3.4 Areas Not Affected

Land outside the boundaries of PRSs is not affected. Waste treatment, storage, and disposal facilities are not affected.

3.5 Activities Affected

The requirements of this document apply to the following activities under the sponsorship of the ER Program:

- cleanup operations required by a governmental body, whether federal, state, or local, involving hazardous substances performed at PRSs;
- corrective actions involving cleanup operations at sites regulated under RCRA; and
- voluntary corrective actions at Laboratory PRSs.

3.6 Activities Not Affected

Operations at hazardous waste treatment, storage, and disposal facilities regulated under RCRA are not affected. Emergency response operations to control the release of hazardous substances without regard to the location of the hazard are specifically excluded.

4.0 REQUIREMENTS

The health and safety protection requirements applicable to ER Program activities at the Laboratory are set forth in DOE orders and directives, the HAZWOP Program, and applicable federal, state, and local regulations and standards. As a matter of policy, DOE and its contractors have committed to comply with applicable OSHA regulations, specifically 29 CFR 1910 and 1926.

DOE and its contractors have adopted the exposure guidelines for chemical and physical agents as given in 29 CFR 1910 and the permissible exposure limits and threshold limit values of the American Conference of Governmental Industrial Hygienists. When more than one standard exists, the most conservative value will generally be applied. DOE Order 5480.11 and the DOE's draft Radiological Control Manual establish radiological standards.

The HAZWOP Program and this program plan have been specifically developed to meet the requirements set forth in OSHA regulation 29 CFR 1910.120, Hazardous Waste Operations and Emergency Response (HAZWOPER). The HAZWOP Program references other OSHA requirements for general industry (29 CFR 1910) and construction (29 CFR 1926) and applicable DOE orders and directives.

Laboratory Director's Policies (DPs) define the requirements for establishing formality of operations relating to health and safety quality. The DPs also require compliance with applicable federal, state, and local regulations; DOE orders and

directives; and any other agreements relating to health and safety. ER Program activities are conducted under the guiding principles of the DPs. Additional policies and requirements are presented as administrative requirements (ARs) in the Laboratory's Environmental, Safety, and Health Manual.

All regulatory requirements, standards, and guidelines for ER Program activities are incorporated in the HAZWOP Program.

5.0 RESPONSIBILITIES

The DPs and ARs set forth policy for management and employee responsibilities for health and safety. The following paragraphs are quotations from that manual and are applicable to this program.

5.1 Management Responsibility

> "The primary responsibility for employee health and safety on the job as well as for environmental protection from Laboratory operations rests with line management; this responsibility will be given first priority before Laboratory operations are approved or carried out. Supervisors are expected to recognize and anticipate potential hazards, to inform employees of risks associated with their work, to specify protective measures, and to ensure that their employees receive appropriate training. Supervisors also will establish and maintain a system to ensure that appropriate consideration is given to significant changes made in operations, procedures, materials, or equipment that could affect the safety of an activity, including environmental impact."

5.2 Employee Responsibility

> "Employees are often in the best position to evaluate health and safety risks that might result in harm to themselves and their coworkers. Therefore, Laboratory employees are responsible for observing applicable health, safety, and environment procedures; for using prescribed personal protective equipment; for promptly reporting accidents, injuries, and unsafe conditions; and for participating in required medical and biological monitoring programs."

5.3 Safety of Subcontract Personnel and Visitors

> " A safe work environment will be provided for contract personnel and visitors. This includes certain health protection services provided by HS Division. The Laboratory's health, safety, and environment rules will be enforced for everyone visiting or working at the Laboratory..."

5.4 The Project Health and Safety Team

The project health and safety team consists of members from the Radiation Protection (HS-1), Occupational Medicine (HS-2), Risk Management Support (HS-3), Industrial Hygiene and Safety (HS-5), and Health Physics Policy and Programs (HS-12) groups. The function of the team is to ensure that ER Program activities comply with applicable Laboratory and regulatory requirements through oversight of programmatic elements and field activities.

5.5 Program Responsibilities

The ER Program manager and health and safety project leader (HSPL) are responsible for coordinating the development, review, revision, issuance, and implementation of this program plan. They will establish formality of operations that balances excellent environmental, safety, and health performance; scientific excellence; and high levels of productivity. A graded approach will be applied to each operation to ensure that the depth of detail required and the magnitude of resources expended on health and safety are commensurate with the potential hazard, the complexity of the operation, and the potential impact on health and safety.

Health and safety documents and procedures for ER Program activities are usually developed by the HS Division with input from the ER Program. The site-specific plans, which may be developed by subcontractors to the ER Program, are subject to the same review process used for plans developed by the Laboratory.

5.6 Implementation

Operable unit project leaders (OUPLs) are responsible for implementing health and safety policies and programs in the field. OUPLs must transmit this responsibility to the field team leader.

Each field team will have a field team leader and a site safety officer. The site safety officer works with the field team leader to see that work is performed safely. The field team leader does not have the authority to overrule the site safety officer on matters of health and safety. The field team leader may appeal to the HSPL.

The HSPL is the HS Division coordinator for all health and safety matters pertaining to ER Program activities. Document preparation and review, scheduling of health and safety field personnel, oversight of subcontractor health and safety programs, and conflict resolution are the responsibility of the HSPL.

The organizational structure for health and safety support of ER Program field activities is shown in Figure III-2.

6.0 RESOURCE REQUIREMENTS

Management of ER Program and health and safety activities will include assurance that work to be done has been identified, planned, scheduled, and budgeted before authorization and that there is proper control over initiation of or changes to

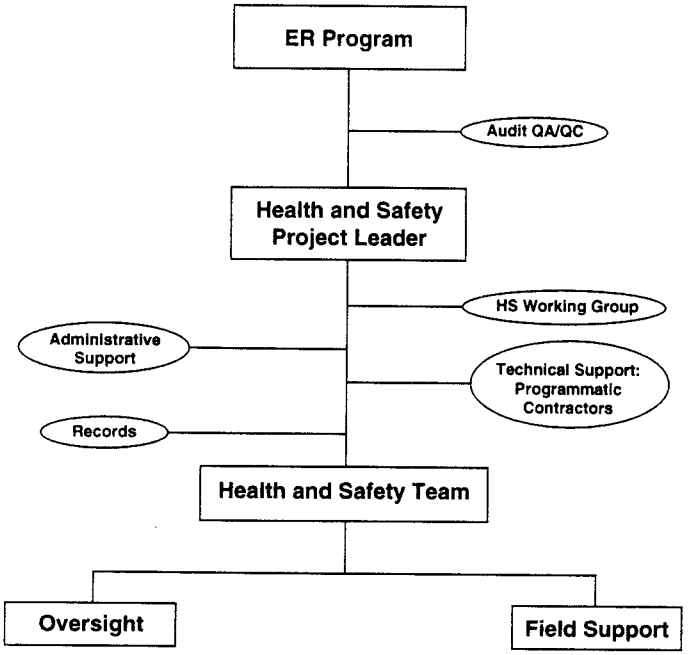

Figure III-2. Organization of health and safety support for the ER Program.

authorized activities. ER and HS management provide for planned procurement and contracting activities and realistic contingency planning.

6.1 Financial Resources

The HSPL will prepare budgets and track costs related to health and safety activities for the ER Program. HS Division requests for money from the ER Program will be channeled through the HSPL. Costs for health and safety services provided directly to the ER Program (e.g., field monitoring) may be recharged to the program.

6.2 Human Resources

HS Division will provide personnel for many ER Program health and safety functions, including industrial hygienists, safety professionals, health physicists, trainers, medical professionals, health and safety technicians, and support staff. HS Division will fully support the health and safety needs of Laboratory personnel.

Subcontractors to the ER Program are expected to provide health and safety support of their personnel unless other contractual arrangements have been made. HS Division will oversee subcontractor health and safety programs and will monitor compliance with Laboratory and regulatory requirements.

HS Division may subcontract for certain health and safety services to support the ER Program, when needed, or when it is to the Laboratory's advantage.

6.3 Equipment

Personnel engaged in ER Program activities will be appropriately equipped, trained, and medically monitored to safely execute assigned duties. The Laboratory provides industrial hygiene for Laboratory employees; radionuclide-monitoring equipment, personal protective equipment, and medical supplies for examination of Laboratory employees; training materials; and computer systems.

Subcontractors to the ER Program and HS Division are expected to provide their own monitoring equipment, personal protective equipment, training materials, computer systems, and other equipment unless other contractual arrangements have been made.

6.4 Facilities

The HS Division, ER Program, and subcontractors to these organizations are expected to provide their own facilities unless other contractual arrangements have been made.

7.0 PROGRAM ELEMENTS

The elements of the HAZWOP Program are explained in detail in the HS Division HAZWOP Program document. All of the health and safety aspects required by OSHA in 29 CFR 1910.120 are covered in that document. The elements as they relate to the ER Program are described in detail in the project plan for each OU. A list of the required program elements follows:

- hazard identification,
- site control,
- personal protective equipment,
- hazard controls,
- site monitoring,
- medical surveillance and monitoring,
- bioassay,
- decontamination,
- emergencies, and
- personnel training.

Each OU has or will have a health and safety plan that addresses these program elements. Project plans will be tailored to meet the unique needs and requirements of each OU.

8.0 IMPLEMENTATION

Implementation of this health and safety program plan is a cooperative effort between the ER Program and HS Division. Together, the two organizations establish milestones and schedules.

There are several key health and safety milestones for the ER Program. The ER Program Manager, HSPL, and OUPLs are responsible for identifying milestones and tracking accomplishments. The milestones identified for the RCRA field investigation include

- reviewing, updating, and approving this program plan on an annual basis;
- preparing, reviewing, and approving the boilerplate for the project plans annually;
- preparing, reviewing, and approving the project plans for each OU;
- reviewing, updating, and approving existing project plans.
- conducting health and safety kick-off meetings with ER Program subcontractors before field work begins;
- reviewing and approving subcontractor health and safety programs;
- preparing, reviewing, and approving boilerplate for site-specific plans;
- preparing, reviewing, and approving site-specific plans;
- conducting field readiness reviews with OUPLs, field team leaders, site safety officers, and subcontractors before executing field work; and
- providing health and safety support of ER Program field activities.

As OUs move into different phases of work, the milestones will be reviewed and adjusted.

Preparing and communicating schedules are essential for timely and cost-effective completion of ER Program activities. The ER Program manager, OUPLs, and HSPL will work together to maintain a schedule for health and safety activities.

The HSPL will use Management Information System Team support and scheduling and project management tools to assist in time and resource management. Printed schedules will be made available to HS personnel on a routine and periodic basis. HS Division will use the schedule for resource planning.

OUPLs must notify the HSPL of scheduling changes and conflicts. Failure to do so could lead to delays or work stoppage. The HSPL will give scheduled events a higher priority than unscheduled, nonemergency activities.

9.0 MEASURES OF PERFORMANCE

Performance will be measured to evaluate the effectiveness of the health and safety program. The ER Program manager and HSPL will use the performance measures to manage health and safety costs and activities. Upper Laboratory management and regulators may use these data to assess program management and compliance.

9.1 Unplanned Events

The absence of unplanned events will be a positive indicator of program performance. Unplanned events include fires, explosions, chemical or radionuclide releases, motor vehicle accidents, and property damage. All unplanned events will be investigated. Findings will be reported to the ER Program manager and HSPL, who will review the findings and determine whether corrective action is necessary. Complete documentation of unplanned events will be maintained.

9.2 Audit and Assessments

A program for assessments and audits will be established and maintained to support line management knowledge and understanding of organizational performance with respect to established directives and standards. All audits and assessments will be documented, root causes of deficiencies will be identified, action plans will be prepared, and corrective actions will be tracked to completion.

DOE audits or appraisals may be conducted. The findings (or lack of findings) will be a measure of program performance. The ER Program manager and HSPL will be responsible for addressing the findings and recommendations resulting from DOE audits.

9.3 Regulatory Agency Approvals

Approval of plans and documents submitted to EPA, DOE, and NMED are a measure of program performance. The timeliness of submittals and the number of changes and resubmittals are an indicator of time management skills and quality of work.

9.4 Injury and Illness Rates

The occurrence of injuries and illness is a measure of program failure. The performance of the ER Program will be judged on all measures, not just on the number of recorded injuries and illnesses.

The goal of the ER Program and HS Division is to have no injuries or illnesses. Rates of injury and illness approaching zero are a positive measure of performance. In all likelihood, some injuries and illnesses will occur. These occurrences will be recorded on the OSHA 200 Log in accordance with Laboratory procedures.

Subcontractors will also maintain injury and illness logs in accordance with OSHA regulations. HS Division will maintain oversight of these records.

9.5 Cost Competitiveness

The ER Program manager and HSPL may develop mechanisms to compare health and safety costs. This measure of performance can help determine the value of health and safety services provided.

9.6 Productivity

The ER Program manager and HSPL may also develop methods for measuring the productivity of health and safety personnel, which can help determine the contribution of individuals and the effectiveness of resource management tools.

1.0 INTRODUCTION

This document constitutes the Records Management Program Plan for the Environmental Restoration (ER) Program at Los Alamos National Laboratory (the Laboratory), which is being implemented by the Department of Energy (DOE) and the University of California (UC). At this stage of the ER Program, certain aspects of the plan are being redefined and are considered future goals. This plan is intended to establish general guidelines for records management, including technical data sets. The specific methods and details of protecting records are implemented through quality procedures (QPs), administrative procedures (APs), standard operating procedures (SOPs), and management guidance developed in cooperation with the ER Program's quality assurance staff and the Laboratory's Records Management Program requirements document (LANL 1992, 0814).

1.1 Organization of Records Management Program Plan

This program plan is organized to interface with the body of the Installation Work Plan (IWP) and is divided into seven major sections. The introduction presents the organization, regulatory mandate, purpose, objectives, and terminology of the plan. Section 2 describes a threefold approach to records management and how it will be implemented. The Records-Processing Facility (RPF) and the Facility for Information Management, Analysis, and Display (FIMAD) are described in Section 3. Sections 4 through 7 describe how the records management program will be coordinated with the quality program, the health and safety (H&S) program, management, and community relations activities.

1.2 Regulatory Mandate

The development and implementation of this plan are mandated by the Hazardous and Solid Waste Amendments (HSWA) Module of the DOE/UC's permit to operate the Laboratory under the Resource Conservation and Recovery Act (RCRA) (EPA 1990, 0306). General requirements for data management are presented in Task II, Section B (p. 7), of the HSWA Module, but many other references to technical data are made throughout the document. The manner in which records of work performed under the permit are managed is of primary importance in ensuring the integrity and intended function of the data and documentation contained in the records submitted to the Environmental Protection Agency (EPA). The ER Program's records also include the publicly accessible documentation composing the administrative record required by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) (DOE 1991, 0560; EPA 1990, 0559).

1.3 Purpose

The purposes of this Records Management Program Plan are to

- protect and manage records relevant to work conducted under the HSWA Module,
- provide an ongoing tool to support the technical efforts of UC and its ER Program contractors, and

- function as a support system for management decisions throughout the life of the program.

The plan addresses programmatic needs for all forms of technical data, program records, technical literature, and other documentation. The records are collected, organized, indexed, stored, and protected with the goal of providing efficient use and retrievability to a diverse group of users. This goal applies to both manual and automated methods of handling records. The plan enhances interactions with the local community, adjacent communities, the State of New Mexico Environment Department, EPA Region 6, the DOE, and other parties who may have an interest in the ER Program at the Laboratory.

1.4 Objective

This program plan establishes the general guidelines for managing records, regardless of their physical form or characteristics, generated and/or used by the ER Program at the Laboratory. It is important that the plan be consistently implemented to provide an auditable and legally defensible system for records management.

Coordination with other aspects of the ER Program (such as the quality and H&S programs) is important for achieving useful programwide guidelines for managing records and obtaining technical data, which, in some cases, may not be reproducible.

1.5 Terminology

It is important to use terms consistently to ensure that information is correctly conveyed to the reader of this plan. Definitions for records, technical data, information, and other terms are varied and rigorously debated. To ensure consistent use of terms, the statutory definition for "records" (44 USC 3301) is used. "Records" are defined as "...books, papers, maps, photographs, machine-readable materials, or other documentary materials, regardless of physical form or characteristics,...appropriate for preservation...because of the informational value of the data in them." Thus, the term records includes technical data and is used in this document to reflect the broader scope of protecting all ER Program records. This usage is also consistent with the General Records Schedules for environmental records, as defined by the National Archives and Records Administration (1989, 0357).

2.0 DESCRIPTION AND IMPLEMENTATION OF THE RECORDS MANAGEMENT PROGRAM

The general challenge addressed by this plan is summarized in the following question:

> "How will the ER Program's records be handled to ensure the integrity and protection of information, efficient and cost-effective access, and legal and technical defensibility?"

2.1 Plan Description

The plan incorporates a threefold approach based on records control and total commitment to quality program guidelines. This approach includes the following precepts:

- Structured work flow for records. Records control is maintained through a structured work flow and processing procedure for records.

- Use of approved procedures. Quality program requirements are met through the documented use of approved procedures by appropriately trained employees.

- Referable information base. ER Program records are submitted to an information base accessible to ER Program participants and the public while providing records protection through a documented process of change control.

2.2 Plan Implementation

2.2.1 Structured Work Flow for Records

The RPF functions both as an interim repository for records while they are being processed and as a reference library for the ER Program.

2.2.1.1 Submittal of Records

Participants are required to review their records as they are generated to determine whether the information represents an ER record as defined in Section 3.1 of the Procedure for LANL ER Records Management (LANL-ER-AP-02.1). This determination can be made in two ways:

- ER records are those specifically identified in QPs, APs, SOPs, ER Program plans, and management guidance documents.

- ER records are those identified at the discretion of ER Program participants as essential to the program and required for the continued functioning and/or interests of the ER Program.

Submittal of records must be performed as required by LANL-ER-AP-02.1. All technical data, including raw data, must be submitted to the RPF for processing and eventual inclusion in the FIMAD.

Records from program administrators, analytical teams, technical teams, and contractors must be submitted to the RPF in hard copy (i.e., paper, logbooks, or similar media) and, whenever possible, also on machine-readable electronic media. Requirements, formats, and constraints on transferring electronic records are defined in Attachment E of LANL-ER-AP-02.1.

2.2.1.2 Records Flow

Figure IV-1 is a detailed diagram of records flow in the ER Program. The model represents a top-down analysis of the general types of records, which shows how they will proceed through processing from the time of generation to final disposition.

2.2.2 Use of Approved Procedures

Only approved procedures are used for handling records. Personnel involved in processing records are trained in the use of applicable procedures.

2.2.3 Referable Information Base

Records sent to the RPF and the FIMAD provide a base of information to which all program participants can refer. They include records that document ER Program activities at the Laboratory, as well as certain records originating outside the Laboratory ER Program that have been submitted in accordance with the records management procedure.

When the originator needs to change a record in the referable information base, he/she completes an ER Record Correction Form as directed in procedure LANL-ER-AP-02.1. This process ensures that ER Program participants have access to the latest version of the record.

2.3 Special Topics

2.3.1 Operable Unit Work Plans

This Records Management Program Plan is the basis for managing records for all operable units in the ER Program at the Laboratory and meets the HSWA Module requirement for a data management plan. As such, it is cited in Annex IV of each operable unit work plan. The QPs, APs, and SOPs define records requirements for technical work and typically address such matters as how to document samples, measurements, survey locations, and activity logs. Project participants protect the resulting raw data and field records until they are submitted to the RPF in accordance with LANL-ER-AP-02.1.

2.3.2 Technical Data

2.3.2.1 Data Validation

Data validation may be needed to address replicate measurements, to identify outlying values, and to explain results determined to be below detection limits. These conditions are handled in accordance with ER Program SOPs and RCRA facility investigation guidance (EPA 1989, 0088, or later revisions), if applicable. The user may develop alternate means for handling inconsistencies in data as long as the method is documented, reproducible, and technically defensible. Any reduction of data must be documented in accordance with relevant SOPs.

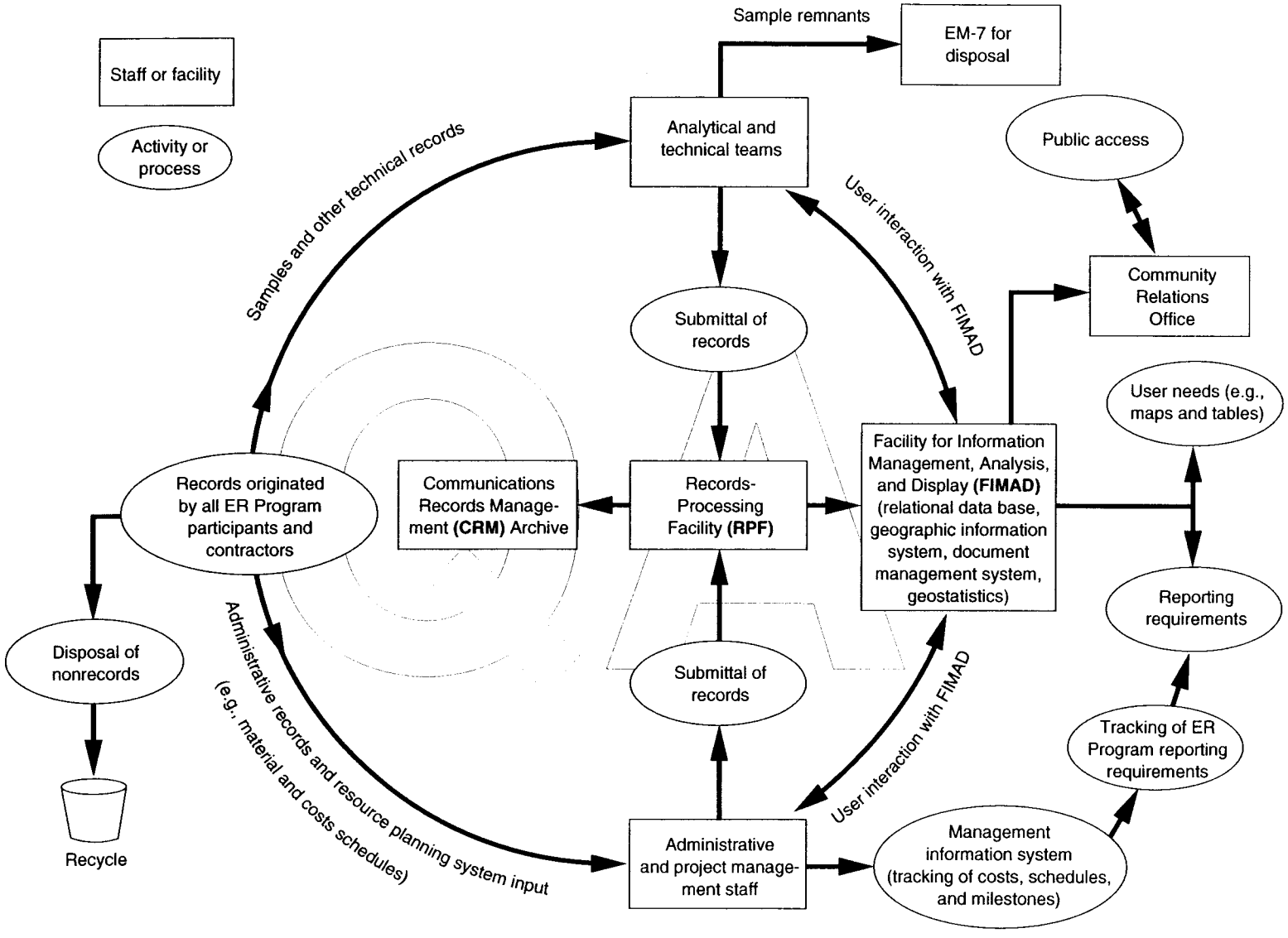

Figure IV-1. Overview of records flow in the ER Program.

2.3.2.2 Data Analysis

Once technical data have been submitted, they become part of the program's referable information base (Section 2.2.3 of this plan). The FIMAD will provide the necessary capabilities for preparing tabular and two- and three-dimensional graphical displays of data, generating maps, performing statistical analyses, sorting data according to various parameters, and meeting similar requirements as specified in ER Program SOPs and the Resource Conservation and Recovery Act (RCRA) corrective action plan (EPA 1988, 0295).

2.3.3 Records Working Group

An ad hoc team of program participants may need to meet periodically to resolve special issues related to records or specific sets of technical data. The group will comprise program participants with appropriate expertise and will be selected and activated as needed by the manager of the ER Program (or designee).

3.0 DESCRIPTION OF RECORDS MANAGEMENT PROGRAM FACILITIES

3.1 Records-Processing Facility

The RPF receives and processes ER Program records to prepare them for delivery to the FIMAD. The RPF, which is located at 2101 Trinity Drive in Los Alamos, currently houses records used in compiling site histories for potential release sites (PRSs). During processing, original records are retained at the RPF in 1-hr fire-rated equipment as defined in the Standard for the Protection of Records of the National Fire Protection Association, Inc. (1986, 0358). Either original documents or a micrographic copy, consistent with guidance obtained from the National Archives and Records Administration and the Laboratory's Records Management Program, are sent to the Laboratory's Communication and Records Management (CRM) Division or a similar long-term storage facility to ensure compliance with NQA-1 (ANSI/ASME 1989, 0018) requirements for retention and protection.

The RPF serves as a reference library that contains information that cannot or should not be entered in the FIMAD or that contains information that is accessed only occasionally (e.g., a large, multivolume, bound report from EPA). The RPF also provides the capability to retrieve records based on a variety of parameters such as keywords, technical areas, dates, PRSs, and structures.

3.2 Facility for Information Management, Analysis, and Display

The ER Program Office has established the FIMAD in Building SM 215, TA-3, which is equipped with the hardware and software necessary to facilitate capture, display, and analysis of data. This information is readily accessible to project participants through a network of work stations. The network will comprise "miniclusters" distributed throughout the Laboratory to allow users, including ER Program contractors and the public, access to the FIMAD. Each minicluster may include graphics work stations and other necessary hardware.

3.2.1 System Capabilities

The system will be capable of executing numerous tasks using X-11 windows in a UNIX operating environment. The planned capabilities are listed below:

- geographic analysis, using the ARC/INFO/ORACLE Geographic Information System (GIS) and the GEOEAS geostatistics package;
- the ORACLE relational data base management system;
- the TOPIC document management system;
- management of video images;
- two- and three-dimensional graphics support for modeling;
- storage, compression, and conversion support for certain types of data;
- integration of various types of information; and
- automated backup and copy to a disaster recovery facility.

3.2.2 System Configuration

The development of the local area network is based on the concept of "open systems," which adhere to existing standards and protocols. Commercial software is used whenever possible to address quality program concerns about code modification and to ensure the best use of limited resources. Software quality assurance guidelines are being developed. The initial system includes RISC-based UNIX work stations, which provide a good port to the ARC/INFO/ORACLE software. This software package is a critical component of the FIMAD because it is compatible with EPA's software.

3.2.3 Configuration Management

Configuration management is being implemented as a means of accounting for, controlling, and reporting the planned and actual design of components for the FIMAD. Configuration management ensures that the latest version of the whole computer system is always approved and accessible. The end product of configuration management is formal documentation of the process of systems development to permit identification of the relevant configuration at any given period in the life of the ER Program. The documentation follows accepted practices for designing and developing information systems. Configuration management during development of FIMAD will permit flexibility in selecting system components.

3.2.4 Electronic Data Acquisition and Quality Control

ER Program participants have access to FIMAD data bases for the purposes of reviewing and updating information; however, only authorized personnel (primarily members of the FIMAD staff) may modify data. The FIMAD staff are also responsible for ensuring the quality of data originating at FIMAD (e.g., orthophoto data and the major portion of the GIS data base). Program participants who provide data to the FIMAD for electronic conversion are responsible for the accuracy of the data they submit to FIMAD; the FIMAD ensures the precision of the electronic conversion only.

3.3 Integrated Capabilities of RPF and FIMAD

The ER Program uses a hybrid approach to records management that incorporates the power and functionality of imaging technology and the reliability and precedent of micrographics.

3.3.1 Optical Disk Storage

Optical storage systems, which efficiently store enormous volumes of paper records, consist of hardware and software that convert hard-copy documents to digital form. Both government agencies and private industry are considering these systems; however, the technology presents some formidable problems relative to industry standards, legal acceptance, longevity of the medium, and costs. Optical disk storage will be used at the FIMAD to efficiently store and disseminate information via the FIMAD network. Legal issues with optical disk storage will be accommodated through the use of micrographics, as described below.

3.3.2 Microfilm

Industry standards for microfilming technology are reliable and widely accepted; therefore, this technology is used for capturing most ER Program records. The ability of the human eye to read a record on microfilm compensates for the lack of hardware standards in some components of optical disk systems. Microfilm standards and legal defensibility are well established. Microfilm may also be used to transmit color graphics information.

3.3.3 File Standards and Compatibility

The ER Program uses several different operating systems, including MS-DOS, Apple, UNIX, and VMS, which are not directly compatible. The problem of file compatibility is neither unique to the ER Program nor is it simple. This plan specifies using systems that adhere to existing standards and protocols to exchange information.

3.4 Progress in Technology

The changes in hardware and software technology are frequent and substantial and demand that attention be given to industry standards. How a product fulfills regulatory requirements for records retention, data access, and legal defensibility

influences which products are selected. Personnel assigned to operate and maintain the RPF and FIMAD keep abreast of industry trends and recommend conversions and/or modifications to the system, as necessary, to keep it a viable component of the ER Program.

Retention requirements for many records extend well beyond the typical life of systems currently used. Retention requirements are met by converting records, where practicable, to archive quality micrographic media, subject to regulatory guidelines and approval.

4.0 COORDINATION WITH THE QUALITY PROGRAM

LANL-ER-AP-02.1, which is approved by the quality project leader, is used for managing program records. The procedures and any revisions are written in accordance with LANL-ER-AP-01.1, Preparation, Review, and Approval of Administrative Procedures. The procedure is applied uniformly throughout the ER Program to achieve the objectives of this plan and to fulfill the obligations defined in the HSWA Module.

4.1 Records Protection Before Submittal

Program participants should carefully manage records, documentation, and technical data resulting from ER Program activities. The originator should protect the records in a manner commensurate with the value of the information they contain until they are submitted to the RPF in accordance with LANL-ER-AP-02.1.

4.2 Records Protection During Submittal

Records submitted to the RPF are processed in accordance with LANL-ER-AP-02.1 and other relevant procedures specific to the RPF. The processing steps are summarized below.

- The originating organization sends records to the RPF.
- While the records are being processed, a copy of an indexing form and the original record are retained at the RPF in 1-hr fire-rated equipment as defined in the Standard for the Protection of Records of the National Fire Protection Association, Inc. (National Fire Protection Association, Inc., 1986, 0358).
- When the FIMAD is fully operational, a copy of the record will be forwarded to the FIMAD.

4.3 Records Protection after Submittal

After the records are received at the RPF, the following steps are taken:

- A detailed index form is completed for each record received.
- The records processor makes a microfilm copy of both the record and the index form.

- The information from the index form is entered in the ER record data base.

- A quarterly report of records received at the RPF is sent to the originator. The original record (or a microfilm copy), which has been temporarily stored at the RPF, is forwarded to CRM Division for long-term storage. Working copies of the records are made available at the RPF and will eventually be made available through the FIMAD.

5.0 COORDINATION WITH THE HEALTH AND SAFETY PROGRAM

Certain health and safety records that result from ER Program activities are to be included in the referable information base. This information pertains to safety training and medical surveillance of each person working at a PRS. Because of the confidential nature of certain types of medical information, many records are appropriately maintained in the Occupational Medicine Group's (HS-2's) data base or by participating contractors. For convenience, training records are maintained by the appropriate Laboratory organization or by the contractors, and the ER records contain only information about the completion of training, the dates of required refresher training, and the location of the training records. The information fields to be included are

- a unique identifier for each worker,
- employer,
- dates of work at each hazardous waste site,
- dates required training was completed,
- dates of medical examinations,
- locations of training and medical examination records, and
- dates of required refresher training.

6.0 COORDINATION WITH THE ER MANAGEMENT INFORMATION SYSTEM

The ER Program's management information system monitors costs, schedules, and deliverables. The software has the capability of monitoring the reporting documents required by the ER Program, all of which are integrated in the system (as milestones or deliverables) and are disseminated to ER Program staff at regular intervals. Specific regulatory requirements for reporting, including data types and report frequency, are incorporated in the systems information. Any special reporting requirements and applicable restrictions on data type and format (e.g., cost and schedule control systems criteria or major systems acquisition) are also included.

Work breakdown structure (WBS) and activity data sheet identifiers are being integrated in the indexing plan for records as an option for querying records. Concerns about changes in the WBS and similar identifiers are legitimate and justify the decision not to use these numbers as primary indices for records.

7.0 COORDINATION WITH THE COMMUNITY RELATIONS PROGRAM

RCRA and CERCLA require that records be made available to the public. Two complementary approaches that give the public access are under way; however, because protection of the data is imperative, system security is weighted heavily in determining the optimal solution. The RPF houses the administrative record required by CERCLA. Electronic copies will be accessible through FIMAD.

7.1 Hard Copy

Hard-copy files will supplement electronic records and will be retained in a reading room accessible to the public.

7.2 Electronic Access

The best approach to providing public access to data in a manner that protects the data base has not yet been finalized; however, a computer work station or optical reading device will be used.

References for Annex IV

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1.0 INTRODUCTION

In 1987, in order to address the cleanup of sites across the nation and to ensure human and environmental health and safety at its facilities around the country, the Department of Energy (DOE) formally established the Environmental Restoration (ER) Program. The ER Program is responsible for assessing, decontaminating and decommissioning, and cleaning up sites at DOE facilities and sites formerly used by DOE and its predecessors. Los Alamos National Laboratory (the Laboratory) is operated for the DOE by the University of California (UC) and is part of the DOE's national environmental restoration program.

In accordance with the requirements of the Resource Conservation and Recovery Act (RCRA) of 1976, the ER Program at the Laboratory is designed to protect human health and the environment from exposure to releases of hazardous and mixed wastes resulting from historical treatment, storage, and disposal practices at the Laboratory. In addition, the Laboratory is committed to meeting all other applicable statutory and regulatory requirements pertaining to environmental restoration. The program is described in detail in Chapters 3 and 4 of the Installation Work Plan (IWP) for Environmental Restoration (LANL 1993, 1017).

In accordance with RCRA as amended by the Hazardous and Solid Waste Amendments (HSWA) in 1984, the State of New Mexico has issued a permit to DOE/UC to operate the Laboratory as a hazardous waste treatment and storage facility (NMEID 1989, 0595). Module VIII of the permit, issued by the Environmental Protection Agency (EPA) and known as the HSWA Module (EPA 1990, 0306), sets forth a three-step corrective action process for managing and disposing of hazardous waste.

- The RCRA facility investigation (RFI) identifies the extent of contamination at the source and the environmental pathways along which contaminants could travel to human and environmental receptors. The ER Program is currently implementing this phase of the process.

- A corrective measures study (CMS) will be undertaken if the RFI indicates that corrective measures are needed. This portion of the corrective action process will evaluate the alternatives that may be used to clean up a site.

- Corrective measures implementation (CMI) will consist of performing remedies approved by DOE and EPA after the public has had an opportunity to provide input on the recommendations of the CMI.

Formal public participation is required only during the CMS. However, the ER Program provides opportunities for public input during each of these steps. Figure 1-1 shows the corrective action process and the opportunities provided by the ER Program for public participation. Figure V-1 shows the opportunities for public input during the first phase of the corrective action process (the RFI).

The RCRA corrective action process is being applied to the solid waste management units (SWMUs) identified in the HSWA Module. In addition, because RCRA and HSWA do not address several issues of concern at Los Alamos, DOE/UC's ER Program addresses radioactive as well as other hazardous substances not regulated by RCRA. The sites that contain potentially hazardous substances not regulated by RCRA are called areas of concern. The SWMUs and areas of concern,

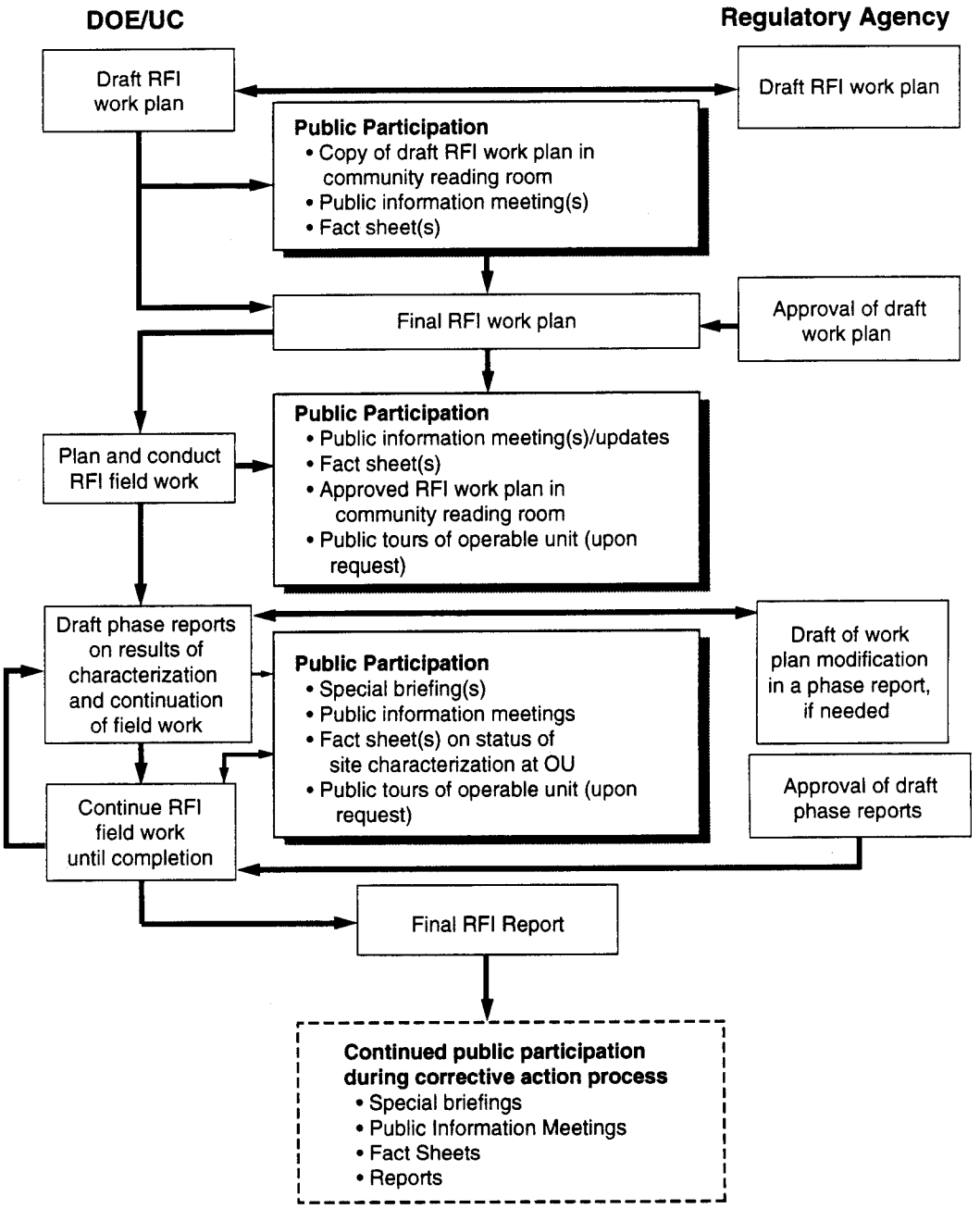

Figure V-1. Opportunities for public participation in the corrective action process.

collectively called potential release sites (PRSs), are grouped in operable units (OUs). At the Laboratory, approximately 1,700 PRSs in 68 technical areas have been aggregated in 24 OUs.

If a potential hazard is identified during the RFI, the extent of contamination is assessed, and the ER Program can implement an accelerated cleanup known as voluntary corrective action to reduce potential hazard to human health and the environment. The ER Program will inform the public of interim actions.

The HSWA Module also requires the ER Program to prepare a community relations plan that describes opportunities for public participation in the corrective action process. This Public Involvement Program Plan is designed to meet that requirement. The ER Program has changed the title from Community Relations Program Plan to Public Involvement Program Plan in accordance with recent DOE guidance concerning public involvement. In addition, the plan includes information obtained from a search of documents concerning the Laboratory's ER Program, as well as information obtained from interviews with nearby residents; representatives of organizations; and federal, state, and local officials.

Both the DOE and EPA have issued guidance documents for public participation in the ER Program, which are derived from the requirements of RCRA as amended by HSWA, the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), and EPA's guidance on corrective action (DOE 1991, 0798; EPA 1987, 0816; EPA 1988, 0294). This plan meets those criteria and includes the general requirements of the HSWA Module, which are summarized below:

- to provide to the public opportunities to learn about technical activities and regulatory processes in the Laboratory's ER Program and to present information in a timely manner;
- to maintain a public reading room that contains all ER Program plans and reports and other information pertinent to the program;
- to respond to community concerns about the ER Program in a manner that encourages two-way communication between interested parties and the program; and
- to afford opportunities for public input on ER Program activities.

This plan is divided into six main sections. In addition to the brief description of the ER Program provided in this first section, Section 2 provides background of the Laboratory and a short history of its environmental studies. Section 3 describes the community and its concerns about environmental issues at the Laboratory, and Section 4 contains the history of community involvement in general Laboratory and environmental issues. Section 5 summarizes the objectives of the plan, and Section 6 describes its major elements.

Because of the complexity of the Laboratory's organization and of the tasks to be performed under the ER Program, the Laboratory has designated a point of contact to assist the public in locating the information it needs. This coordinator is the

Public Involvement Project Leader
Environmental Restoration Program
Los Alamos National Laboratory
P.O. Box 1663, MS M773
Los Alamos, NM 87545
(505) 665-7112

In addition to serving as the ER Program's primary contact for the public, the public involvement project leader manages the ER Program's Public Involvement Program. The ER Program also provides information to the public through the Laboratory's community reading room located at the Museum Parke Complex, 1450 Central Avenue, Suite 101, in Los Alamos.

This Public Involvement Program Plan is an annex to the IWP (LANL 1993, 1017), which is available in the Laboratory's community reading room, the public library in Los Alamos, and the main branches of the Española and Santa Fe public libraries.

2.0 DESCRIPTION AND HISTORY OF LOS ALAMOS NATIONAL LABORATORY

2.1 Description

Historically, the principal mission of the Laboratory has been the design, development, and testing of weapons for the nation's nuclear arsenal. This effort is supported by extensive research programs in nuclear physics, hydrodynamics, conventional explosives, chemistry, metallurgy, radiochemistry, and biology. In addition to the weapons program, Laboratory personnel are involved in medium-energy physics; space nuclear systems; controlled thermonuclear fusion; laser research; environmental research; geothermal, solar, and fossil energy research; nuclear safeguards; biomedical research; and space physics. In 1992, the Laboratory expanded its mission to include development of new programs in three nationally significant areas for which it has special capabilities: health and biotechnology, environmental technologies, and industrial partnerships.

The Laboratory is located in north-central New Mexico on the Pajarito Plateau (Figure V-2), a volcanic shelf on the eastern slope of the Jemez Mountains at an approximate elevation of 7,500 ft. The Pajarito Plateau is cut by a number of steeply sloped, deeply eroded, water drainage canyons, which have formed isolated, finger-like mesas running west to east. Surface water flow crossing the Laboratory is intermittent or ephemeral and reaches the Rio Grande only during significant periods of run-off from snowmelt or thunderstorms. The main aquifer lies 600 to 1,200 ft below the surface and is separated from the surface by unsaturated tuff, a volcanic ash. There is no known hydrological connection between the surface and the main aquifer from which the municipal water supply for the Laboratory and Los Alamos is obtained.

The Laboratory is situated on approximately 27,500 acres (43 mi^2) of DOE land, 24,000 acres (87%) of which are located in Los Alamos County. The location and spacing of the 35 active technical areas reflect historical development patterns, topography, and functional relationship (Figure V-3). At present, the Laboratory's onsite population (including both employees and contractors) is approximately 11,000 people, who are housed in some 1,500 buildings encompassing about 7,000,000 ft^2.

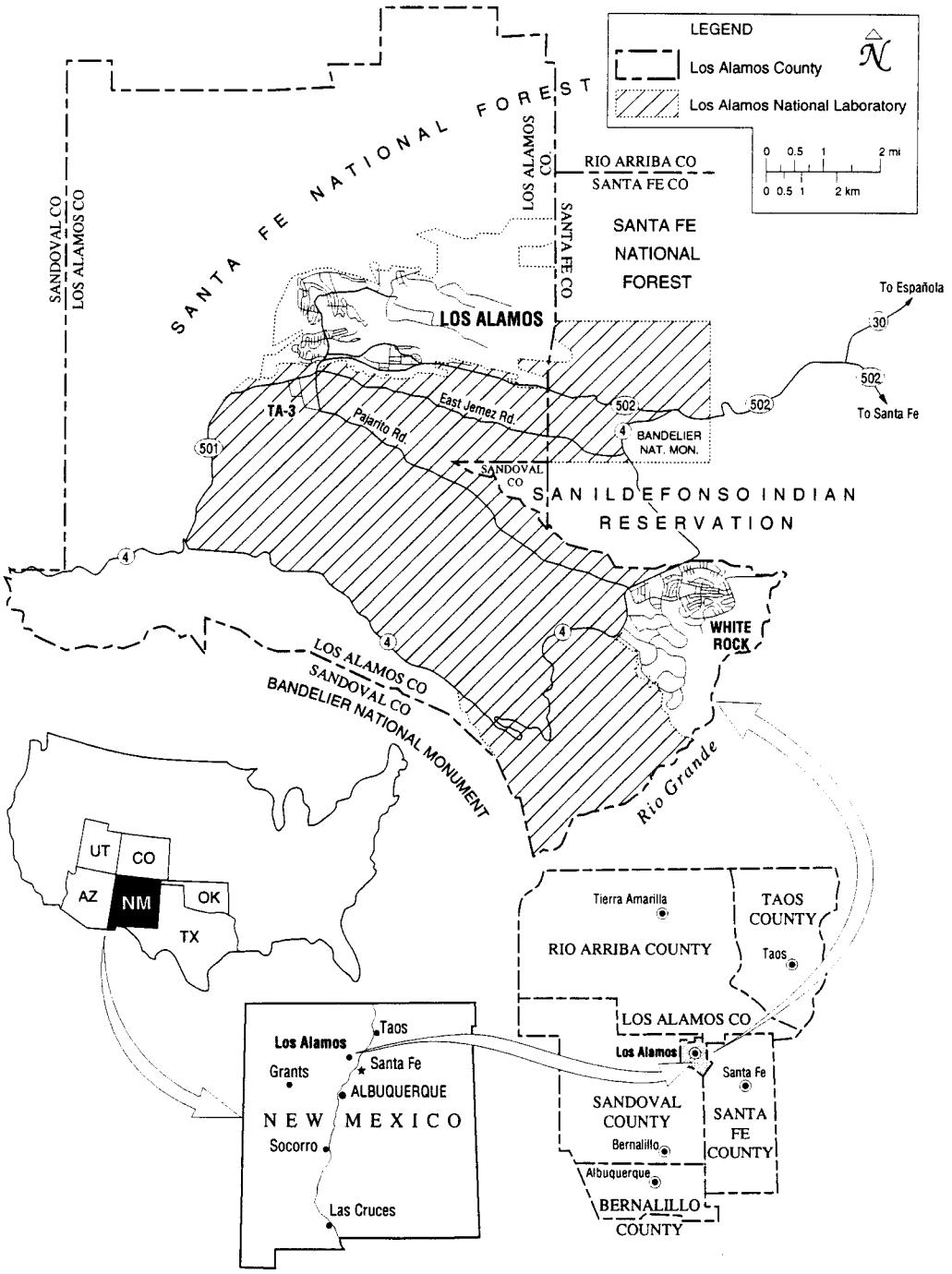

Figure V-2. Location of Los Alamos National Laboratory.

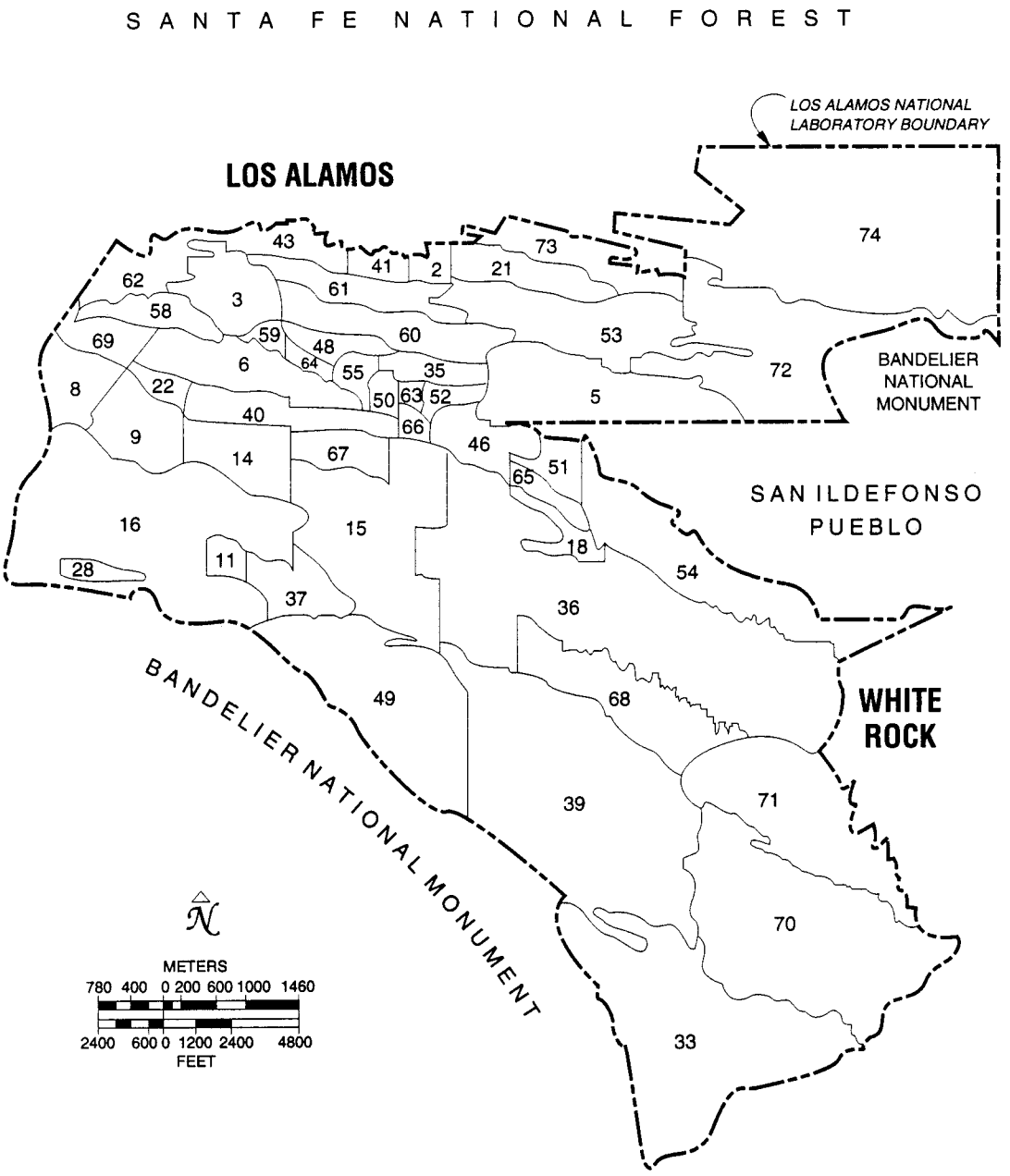

Figure V-3. Technical areas on the Laboratory site.

The surrounding area, including all of Los Alamos County and large portions of Sandoval, Rio Arriba, and Santa Fe counties, remains largely undeveloped, except for those areas occupied by Laboratory facilities and associated residential communities. Large tracts of land in the Jemez Mountains to the north, west, and south of the Laboratory site are held by the US Forest Service and US National Park Service. San Ildefonso Pueblo lands border the Laboratory on the east.

Adjacent land ownership patterns are shown in Figure V-4.

2.2 History of Los Alamos National Laboratory

The US Army Manhattan Engineer District was established in 1942 to perform the theoretical studies and to provide the production support leading to the development of the atomic bomb. The critical research quickly progressed to the point at which a remote site for experimental work was needed, and the Army decided to move the theoretical studies and bomb development, called "Project Y," to northern New Mexico. The project acquired over 49,500 acres of land, which included the Los Alamos Ranch School for Boys, nearby homesteads, and surrounding property managed by the US Forest Service. In 1943, this land became known as the Los Alamos Site, later Los Alamos Scientific Laboratory. The Laboratory's initial mission was to develop the world's first nuclear fission weapon, a project that lasted for the duration of World War II.

Laboratory activities were first conducted in wooden buildings south of the original ranch school in what is now downtown Los Alamos. Additional buildings were constructed for research, and army-style barracks, as well as temporary and prefabricated structures, provided housing.

With the end of World War II and the growth of international competition, a national policy of maintaining pre-eminence in the field of atomic energy was established. Congress chose to sustain the Los Alamos site; the Atomic Energy Commission received control of the Laboratory from the Army and renewed the operating contract with UC. Thereafter, a major construction program was started south of Los Alamos Canyon, and most Laboratory operations were moved to the south mesa. During subsequent years, the Laboratory continued to expand at a steady rate—first under the Atomic Energy Commission, later under the Energy Research and Development Administration, and today under DOE.

2.3 The Environmental Restoration Program at Los Alamos

The primary objective of the ER Program at the Laboratory is to implement the environmental assessment and remediation activities required for PRSs. The ultimate goal is to bring these PRSs into compliance with current environmental regulations and to do so in a manner that protects the environment and public health and safety.

From the 1950s through the late 1980s, the Laboratory identified and cleaned up several sites known to have been contaminated by Laboratory operations and testing. Under the federal regulations in existence at the time, the cleanup included removing and disposing of soil, building debris, and radioactively contaminated equipment and waste.

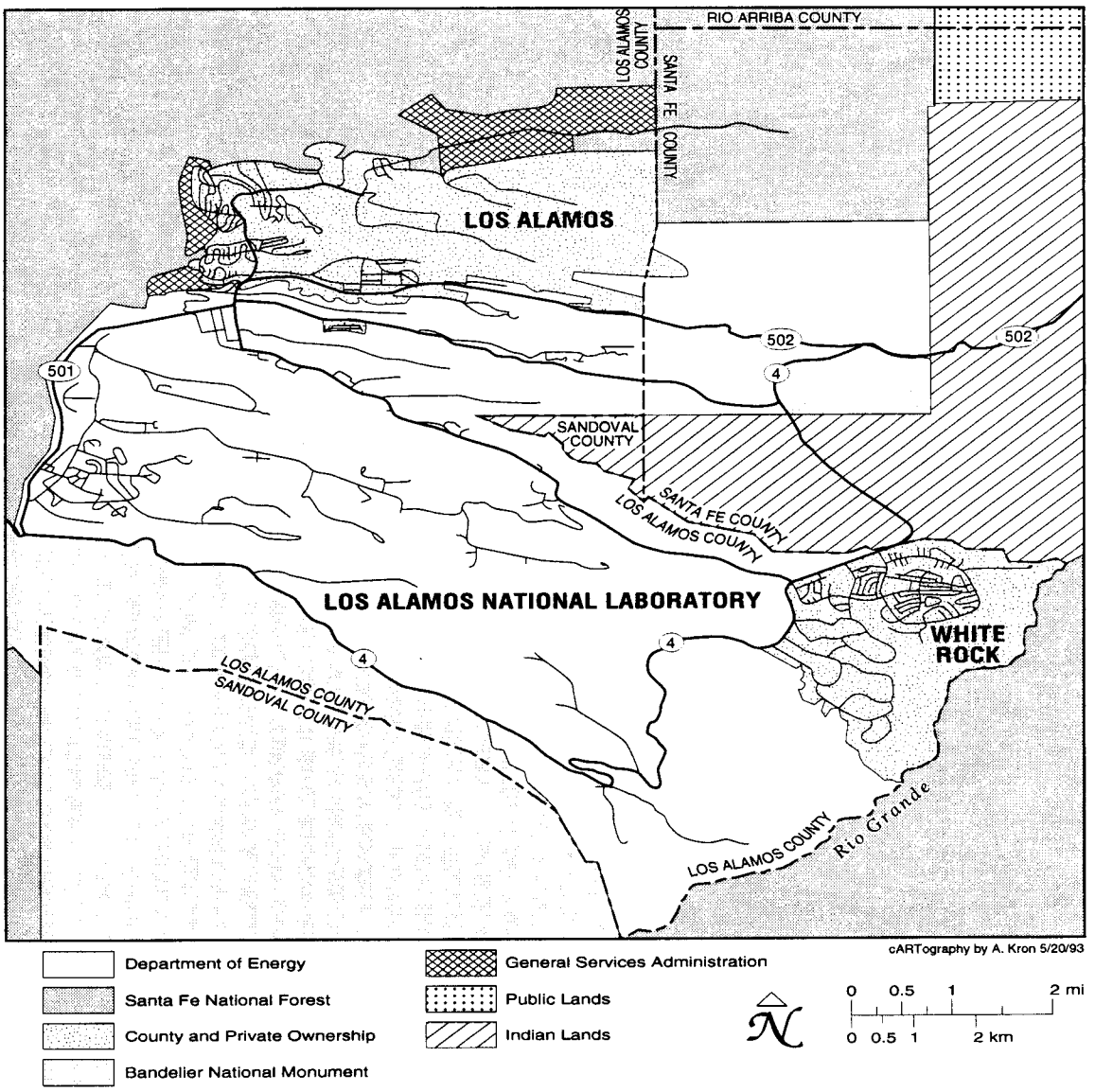

Figure V-4. Land ownership in the Los Alamos area.

Since the early 1970s, the Laboratory has operated a formal environmental surveillance program that routinely samples air, water, soil, and foodstuffs throughout northern New Mexico, as well as at a number of Laboratory sites, to determine levels of contamination. The data collected under this program are published annually for distribution to the public and to local, state, and federal agencies. These data indicate that Laboratory operations do not threaten human health or the environment (Environmental Protection Group 1992, 0740).

The ER Program at the Laboratory augments the environmental surveillance program by identifying potential threats to human health and the environment caused by historic operations and by implementing efficient corrective actions that comply with applicable environmental regulations. Corrective actions include such measures as source containment to prevent contaminant migration, controls on future land use, and excavation and treatment of the contaminant source to permanently eliminate hazards to human health and the environment.

The ER Program has begun to characterize the SWMUs listed by EPA in the HSWA Module and the areas of concern identified by the ER Program at which an RFI should be performed. These PRSs are grouped in 24 OUs. Work plans for all OUs are scheduled for completion by 1996, and all CMSs are scheduled for completion early in the next century. The work plans describe how the general approach provided in the IWP is tailored to each OU; the CMS will outline remediation alternatives specific to each PRS.

3.0 DESCRIPTION OF LOS ALAMOS AND REGIONAL COMMUNITIES

The Laboratory is located in north-central New Mexico, 25 mi northwest of Santa Fe. Los Alamos County, which was incorporated in 1968 and is operated by a joint city and county government, has two residential areas: the townsite, located north of Los Alamos Canyon, and White Rock, located south of the Laboratory between State Road 4 and White Rock Canyon, a tributary of the Rio Grande. The population is estimated to be 20,000. Sixty percent of the Laboratory's employees reside in Los Alamos County. The Laboratory is by far the largest employer in Los Alamos, although, in the last 10-15 years, several companies that provide support services to the Laboratory have settled in Los Alamos (LANL 1992, 0799).

Most of the remainder of the Laboratory's employees live in Santa Fe and Rio Arriba counties, which are adjacent to Los Alamos County on the southeast and north, respectively. The City of Santa Fe is the capital of New Mexico and is a significant center of tourism. Santa Fe County is the only area of northern New Mexico in which significant population growth is expected over the next 20 years.

The area has a rich cultural history, as evidenced by the Indian ruins at Bandelier National Monument, which is located adjacent to the Laboratory's southwestern border. Numerous archaeological sites on Laboratory property have been identified and are actively protected. San Ildefonso Pueblo and Santa Clara Pueblo are located east of Los Alamos County. These pueblos are part of the Eight Northern Indian Pueblos Council, which also includes the San Juan, Taos, Picurís, Nambe, Pojoaque, and Tesuque pueblos. Cochiti Pueblo is south of the Laboratory in the Rio Grande drainage basin, and the Jemez Pueblo is located west of Los Alamos, near the Fenton Hill geothermal site.

Economic development is a significant regional concern, and the Laboratory is an important factor in the economy of northern New Mexico. As the largest employer in northern New Mexico, the Laboratory currently accounts for 38% of the jobs in that area and about 6% of the state's economic activity. Although direct employment at the Laboratory is not expected to grow, DOE's technology transfer effort is expected to increase employment opportunities by enhancing the opportunity for new industry to develop in the region (Greenwood et al. 1990, 0800).

4.0 HISTORY OF COMMUNITY INVOLVEMENT IN LABORATORY ISSUES AND CURRENT COMMUNITY CONCERNS

4.1 History of the Laboratory's Communications and Public Involvement Efforts

The Laboratory has actively communicated with the public about environmental and other issues since 1985. Some examples of these exchanges are described below.

The Laboratory has sponsored a Community Council consisting of approximately 150 members, including leaders of surrounding communities and representatives of regional organizations, DOE, and Laboratory staff. The council has met periodically since 1985 to discuss topics of concern to members and, in 1993, still meets regularly.

Representatives of the Laboratory continue to participate in the Working Group to Address Los Alamos Community Health Concerns. Initially, this group formed because of allegations that Laboratory operations are responsible for a higher-than-average incidence of brain tumors in Los Alamos. As a result of the efforts of the working group, the DOE has earmarked monies for independent epidemiological studies to be performed for the group's use. In addition, the Laboratory has conducted epidemiological studies of the work place since 1976. Selected small groups have been followed since the 1950s. The Working Group to Address Los Alamos Community Health Concerns still meets regularly, and other environmental topics have been included in its agenda.

To guide the Laboratory in more effective communication with New Mexicans, the Laboratory's Public Affairs Office has contracted with the University of New Mexico's Institute for Public Policy to conduct quarterly random-sample surveys of New Mexicans. Although the questions asked in each survey were slightly different, New Mexicans were asked their general attitudes toward the Laboratory and toward specific Laboratory issues. The Laboratory uses these surveys to evaluate the communication needs of the surveyed population and to identify trends.

4.2 Environmental Restoration Program's Past Public Involvement Effort

Planning for opportunities to involve the public in the ER Program began with development of the Community Relations Program Plan published in the first IWP (LANL 1990, 0144) and the opening of the ER Program's community reading room in Los Alamos in December 1990. Subsequent efforts to interact with the public include participation of ER Program staff in regular public meetings on different topics related to the ER Program, including preparation of five-year plans, introduction of OUs, and other activities of the ER Program. These meetings are held

regularly in Los Alamos, Santa Fe, Española, and Taos and generally have been well attended. Special briefings or meetings on how homeowners may be affected by the sampling efforts in the Los Alamos townsite are held whenever circumstances dictate. ER Program staff members also participate in community events such as the yearly "Bridge the Gap" festival in Los Alamos and the fiesta associated with the opening of the new armory in Española (November 1992). The ER Program has held approximately three public meetings a year since 1992.

In addition to the regular public information meetings, the ER Program, on occasion, holds special meetings (such as hearings on proposed permit modifications). In September 1993, the DOE conducted an evening forum and a one-day hearing in Los Alamos to discuss changes in the scope of the programmatic environmental impact statement that addresses the reorganization of the DOE's nuclear weapons complex. The hearing drew many comments and was attended by approximately 100 people from Los Alamos, Santa Fe, Española, Taos, and Albuquerque. Many of the comments were directed at what DOE plans to do about the impact of existing and past releases on the environment and on the health of employees and residents of surrounding communities.

Representatives of the ER Program have also presented environmental restoration issues to groups such as the Los Alamos County Council, Community Council, state legislators, Rotary and Kiwanis clubs, chambers of commerce, and local neighborhood associations. In 1992, a special briefing on ER issues was presented to the Los Alamos realtors to bring them up to date on the cleanup in the townsite and to discuss the impact on property sales.

DOE and Laboratory representatives exchange information on the status of the ER Program with San Ildefonso and Santa Clara pueblo leaders and also periodically update the Eight Northern Indian Pueblos Council. Additionally, DOE and the Laboratory have designated a staff person who acts as liaison with the pueblos and who provides pueblo members with information on environmental issues.

4.3 Development of Public Involvement in Environmental Restoration Program

To gain a better understanding of how the public perceives the Laboratory and the opportunities it provides for public involvement in the ER Program, 21 interviews were conducted in June and July 1992 with local and regional regulators; representatives of federal agencies; environmental, ethnic, and community groups; Laboratory staff; local and regional elected officials; representatives of the media; and business leaders. This exchange constituted the ER Program's initial effort to establish what the public's ideas were regarding public participation. Those interviewed were also asked to comment on regional environmental issues and to evaluate media coverage of those issues. The ER Program continues to solicit input on tailoring the public involvement program to the public's needs.

4.3.1 Role of the Media and the Information Repositories in Disseminating Environmental Information

The interviews revealed that only four respondents did not get their news from radio or television and that no television or radio news station was listened to more than any other. The Los Alamos *Monitor* was the most widely read newspaper (by nine

persons) and had the highest credibility about environmental issues and specifically about the Laboratory's ER Program. As many persons believed the Santa Fe *New Mexican* does a good job as believed it does a bad job in covering environmental issues. The Albuquerque *Journal* was considered to be fair in its coverage of environmental news.

Generalizations cannot be made about the population at large based on the results of such a small survey. However, Los Alamos County mailed a questionnaire to over 7,000 Los Alamos households in early 1992 and received a 45% response. Over 30% of Los Alamos residents in that survey said that they read the *Monitor;* fewer than 15% and 5%, respectively, read the *Journal* and *New Mexican.* Over 10% said that they watch KOAT-TV (Channel 7) news and listen to KRSN radio news. Almost 25% said that they watched the Los Alamos cable station (PAC-8 TV) occasionally (County of Los Alamos 1992, 0801).

Almost half of those interviewed had visited the ER Program community reading room in Los Alamos, primarily to attend public meetings. Over half also said that another information repository should be established in addition to the reading room in Los Alamos and information repository in Española: four persons suggested public libraries; three suggested Santa Fe. Other suggestions included DOE headquarters, New Mexico Community College, pueblos, and the Southwest Research and Information Center in Albuquerque. Early in 1993, the ER Program established information repositories at the public libraries in Los Alamos, Santa Fe and Española.

In August 1993, the ER Program sent a questionnaire to approximately 1,400 individuals on its mailing list to solicit opinion on establishing a site-specific advisory board consisting of representatives of different communities, interest groups, the Laboratory, and DOE. Although the response was low (70 out of 1,400), the ER Program identified several areas of high interest, such as future land use and the site prioritization system, which will be used to assist in identifying the PRSs at the Laboratory to be cleaned up first.

4.3.2 Expanding Opportunities for Public Participation in the Environmental Restoration Program

Suggestions for expanding communication and opportunities for public participation included requests for written updates and for explanations of complex, technical information in understandable language. Requests also included a mailing list for this information and notification of meetings. Despite the desire of some interviewees for brief information, many still wanted to have easy access to complete information, raw data or funding to conduct parallel studies to verify the Laboratory's sampling.

The pueblos and the Forest Service requested notification by phone or by letter of any significant environmental release, particularly as it might affect their lands and people. Representatives of the media also requested immediate notice. The Laboratory and the DOE need to keep the pueblos informed of new discoveries of environmental contamination.

4.3.3 Potential Public Participation in Ongoing Environmental Restoration

Program Activities

Most interviewees said they would be willing to participate on a site-specific advisory board or community advisory committee for the ER Program if one were formed. Many said, however, that they were more concerned about broader Laboratory issues. The interviewees expressed different views about public participation at the Laboratory. Some said that they thought the Laboratory's efforts to involve the public (through such means as public meetings) were adequate. Other suggestions included using radio and television more effectively to inform the public of upcoming meetings, making a sincere effort to include community groups in the process, and providing staff for tours of PRSs. Public briefings and meetings can also be televised via the Los Alamos public access channel.

4.3.4 Other Issues Potentially Affecting Public Perception of the Laboratory and the ER Program

Northern New Mexicans are very quick to detect environmental issues. To date, the most important environmental issues discussed with the public include health concerns associated with past and present Laboratory emissions, air and water quality, mining and logging in the Jemez Mountains, transportation of waste on public roads, storage of radioactive waste, the Ojo line extension project, the incineration of mixed waste at the Laboratory, and the expansion of the Santa Fe Ski Basin. The most frequently cited nonenvironmental issue at the Laboratory was the future of the Laboratory as an area employer and the fear that cutbacks in employment would adversely affect the economy of northern New Mexico.

5.0 OBJECTIVES OF THE PUBLIC INVOLVEMENT PROGRAM

This Public Involvement Program Plan has five objectives, which were developed after considering the information presented in Sections 2, 3, and 4 of this plan. These objectives will govern public participation throughout the corrective action process and will be adjusted as circumstances dictate.

5.1 Objective 1—Provide a Forum for Effective Public Input to the ER Program

The ER Program will continue to provide timely and accurate information about its activities to the public. Information will be disseminated through fact sheets, information releases, and public notices to the media, Laboratory personnel, concerned residents, public interest groups, elected officials, and government agencies. Additionally, the ER Program will continue to hold informal public meetings and to maintain information repositories at the Laboratory's community reading room and public library in Los Alamos and at the main branches of the Española and Santa Fe public libraries. The ER Program will work with EPA, DOE, and the New Mexico Environment Department (NMED) to coordinate public involvement efforts and information releases. All regulatory agencies will be kept informed of ongoing activities.

5.2 Objective 2—Enhance Two-Way Communication Between Interested

Parties and the Laboratory

Regular communication with the regional community during the RFI and subsequent steps in the corrective action process will allow the public to provide input on program-related issues, allowing the ER Program to evaluate and incorporate the public's concerns in the corrective action process. Frequent communication during this process will enable the ER Program to develop cleanup alternatives in CMS plans that respond to community concerns. In addition to holding regular informal public meetings, the ER Program will continue to schedule presentations and informal discussions, as well as formal meetings, with local business representatives, public interest groups, pueblo leaders, and the general public. Information releases and fact sheets will also be used to respond to community concerns and to keep the public abreast of current events.

5.3 Objective 3—Continue to Be Proactive in Providing Information to the Public and in Soliciting Participation

The ER Program will provide informal public meetings, oral and written response to queries, speakers for the Laboratory's speakers bureau, briefings to groups with special interests, tours, and exhibits to address issues of public concern. In addition, the ER Program will solicit suggestions on agenda items for public meetings. The public may address questions to the public involvement project leader at the address and phone number given in Section 1 of this plan.

5.4 Objective 4—Continue to Afford Opportunities for Public Comment on Environmental Restoration Program Activities

Although the public is encouraged to provide input throughout the corrective action process, a public hearing on proposed corrective measures alternatives, followed by a comment period of at least 30 days, will be held to receive formal comments from the community.

If a significant modification of the HSWA Module is necessary, the public will be notified via the ER Program mailing list, and a public meeting will be scheduled. An announcement will be published in the major, general-circulation newspapers in the area that states the purpose of the proposed modifications and where the public can obtain copies of the proposed permit modification. The public will have 60 days to comment on the proposed modifications.

If the proposed changes fall in the category of a Class III modification (the class of modification that involves the least extensive change of three classes) and if the public requests a public hearing, the EPA will schedule a formal hearing. If a public hearing is not requested, EPA will publish the decision without a hearing. In the case of Class III modification, the EPA will provide a 45-day comment period after the public hearing before the modifications become part of the permit. Although transcripts of public hearings are optional, if EPA decides to prepare transcripts, they will be available to the public in the Laboratory's community reading room and in the document repositories in the main public libraries in Los Alamos, Española, and Santa Fe.

After the close of the comment period, the ER Program will provide a summary of public concerns, which will include responses to the concerns, and will continue communication with the public. If two or more OUs are at the same point in the corrective action process, a single public hearing may address both OUs.

5.5 Objective 5—Provide for Effective Management of Public Involvement

Implementation and if necessary, restructuring of the Public Involvement Program Plan, will continue throughout the corrective action process. Although it is the ER Program's responsibility to arrange opportunities for public participation, the ER Program will work with DOE, EPA, and NMED in planning these events. To ensure that the community's information needs are met, the ER Program will continue to solicit input from the public.

6.0 ELEMENTS OF THE ENVIRONMENTAL RESTORATION PROGRAM'S PUBLIC INVOLVEMENT PROGRAM PLAN

The elements of the Public Involvement Program Plan are discussed in this section. A description of these elements is provided in a brief narrative and is summarized in schedule format in Table V-1.

plan outlines how the ER Program intends to provide information to and receive input from area residents. It is a dynamic document, which establishes ER Program policy on how to most effectively communicate information about the progress of the ER Program. This Public Involvement Program Plan is the third revision since the first edition of the IWP was prepared in 1990, and it will continue to be updated as necessary during the corrective action process and when the corrective measures design (implementation) phase begins.

6.1 Public Notification

6.1.1 Mailing Lists

The ER Program's Public Involvement Program maintains a mailing list of individuals and groups interested in the Laboratory's ER Program. Federal, state, and local officials, regional media, community and environmental groups, and interested area residents are included. The mailing list has expanded to include interested Laboratory employees. Those on this list receive the *Environmental Update* publication, public meeting notices, and other announcements pertaining to the ER Program.

6.1.2 Public Notices

Once a draft of an RFI or CMS document for any of the OUs at the Laboratory has been distributed to DOE, EPA, and NMED, the community is invited to provide input. The *Environmental Update* or, in some cases, a special announcement is sent to all interested citizens on the mailing list. Public notices are used to announce public information meetings, formal public hearings, and public comment periods for proposed permit modifications and certain other activities. In addition, an announcement is mailed to those on the ER Program mailing list.

The public has at least 30 days to review the documents (located at the Laboratory's community reading room and at the information repositories in the main branches of the public libraries in Los Alamos, Española and Santa Fe) and, if appropriate, to provide comments. If the document or permit modification is the subject of a public hearing, the public can provide comments to the person, organization, and address provided in the public notice.

6.1.3 News Releases

News releases are issued to local news media when a technical milestone in the corrective action process has begun or has been completed and to announce public meetings or public hearings on significant occurrences.

In addition to topics addressed in news releases issued for the ER Program by the Laboratory's Public Affairs Office, reporters often request that the Laboratory provide information on special topics. Media requests are handled through the Public Affairs Office with assistance from the ER Program's public involvement project leader. Requests for media interviews or tours of ER Program sites are honored as quickly as possible.

6.1.4 Special Notices

Special notices are issued in the three situations described below.

6.1.4.1 Notification of Offsite Releases

Part D, No. 8, of the HSWA Module provides for "procedures for immediate notification of the San Ildefonso Pueblo or other affected parties in case of a newly discovered offsite release that could impact them." Any new releases from existing, identified PRSs are brought to the attention of the ER Program, which works with the DOE's and the Laboratory's tribal liaison to coordinate notification of the potentially affected parties.

6.1.4.2 Interim Measure Notification

In the event that the investigation of an OU indicates the need for immediate remedial action, an interim measure will be taken. The public involvement project leader, together with the OU project leader, will evaluate the types of communications necessary. At a minimum, the ER Program's project leader will work with the Public Affairs Office so that a news release about the interim measure can be distributed to all local media. The public involvement project leader will also arrange briefings with ER Program personnel upon request.

6.1.4.3 Notification of Voluntary Corrective Action

Documentation of voluntary corrective action will be submitted to EPA in phase reports and other appropriate documentation. When the voluntary corrective action at PRSs listed in the HSWA Module serves as the final remedy, a request for a formal permit modification for no further action will be made. These issues will be discussed in the public information meetings.

6.2 PUBLIC HEARINGS AND PUBLIC MEETINGS

Formal hearings are required whenever a major permit modification is requested. Such changes include deletions of SWMUs from the permit, significant changes in the schedule, and CMI. At the public hearing following release of the CMS plan, the cleanup alternatives will be explained. Other public meetings or hearings to present RFI and CMS findings will be scheduled as necessary. A court reporter will be present to prepare a verbatim transcript of the hearings. Opportunities for public input are provided before, during, and after each public hearing.

The DOE is required to prepare a responsiveness summary after the public hearings and subsequent comment period have ended. The responsiveness summary consists of a transcript of the hearing and all comments submitted during the comment period, together with DOE's responses. Responsiveness summaries are placed in the Laboratory's community reading room and in the information repositories for public review.

Public information meetings will be held regularly so that the public can become familiar with ER Program documents. These meetings will allow the public to become familiar enough with ER Program activities to provide meaningful comments on work plans and other ER Program initiatives. The meeting format is open house, and technical staff are present to answer questions and explain the results of investigations. Exhibits on specific OUs, corrective actions, and other aspects of the ER Program are presented. Part of the meeting is devoted to presentations by DOE or ER Program personnel on the subjects shown in the exhibits and on any subject about which the public has indicated it would like more information.

6.3 METHODS OF DISTRIBUTING GENERAL INFORMATION

6.3.1 The Laboratory's Community Reading Room and Information Repositories

The Laboratory maintains a community reading room and three information repositories to provide public access to ER Program technical documents, reports, and related communications, as well as other Laboratory documents. The information for the ER Program is managed by the public involvement project leader with support from the ER Program's Records-Processing Facility.

The main location for these documents is the Laboratory's community reading room in Los Alamos, and secondary locations are at the public library in Los Alamos and the main branches of the Española and Santa Fe public libraries. Locations and hours are listed in Table V-2.

6.3.2 Fact Sheets and *Environmental Update*

The ER Program prepares fact sheets that are updated regularly and an ER Program publication entitled *Environmental Update*, both of which are available at the Laboratory's community reading room and in the information repositories. All fact sheets and information releases include the address and telephone number of the public involvement project leader.

TABLE V-2

LOCATIONS AND HOURS OF ENVIRONMENTAL RESTORATION PROGRAM INFORMATION REPOSITORIES

Location	Address and Phone Number	Hours
Community Reading Room	1450 Central Avenue, Suite 101 Los Alamos, NM 87544 (505) 665-2127	Monday-Friday: 9:00 am –5:00 pm*
Española Public Library	314A Onate Street Española, NM 87532 (505) 753-3860	Monday, Tuesday, Thursday, and Friday 10:00 am–6:00 pm Wednesday: : 10:00 am–8:00 pm Saturday: 10:00 am–1:00 pm
Mesa Public Library	1742 Central Los Alamos, NM 87544 (505) 662-8250	Monday-Thursday: 10:00 am-9:00 pm Friday: 10:00 am–6:00 pm Saturday: 9:00 am–5:00 pm Sunday: 11:00 am–5:00 pm
Santa Fe Public Library	145 Washington Avenue Santa Fe, NM 87501 (505) 984-6780	Monday-Thursday: 10:00 am-9:00 pm Friday-Saturday: 10:00 am-–6:00 pm Sunday: 1:00–5:00

*Arrangements to use the reading room at other times can be made by calling (505) 665-2127.

The ER Program Office publishes *Environmental Update* regularly to provide information to anyone interested in the progress of the ER Program. In addition to providing general information about the ER Program, upcoming meetings and related events are announced. Those wishing to be added to the mailing list for the *Update* (and other information) should contact the public involvement project leader at the Laboratory at (505) 665-7112.

6.3.3 Informal Public Meetings

Informal public meetings are scheduled regularly or when an ER Program action generates significant public inquiry or concern. ER Program staff and the appropriate OU project leaders and technical experts are present at each meeting to provide up-to-date information, to respond to technical questions, and to meet individually with members of the public. Although informal public meetings are scheduled regularly, individuals and groups often want an update on specific elements of the program. The public is invited to write or call the ER Program's public involvement project leader at any time during the corrective action process to schedule a meeting or presentation. DOE, EPA, and NMED officials are informed of plans for these meetings.

6.3.4 Special Briefings, Tours, and Exhibits

If ER Program issues directly affect Los Alamos County, representatives of the ER Program will brief the Los Alamos County Council, whose meetings are usually aired on PAC-8. ER Program personnel meet regularly with Los Alamos County personnel to discuss ER Program activities.

Site tours are also offered to public groups and individuals who wish to observe the activities and progress of the project. Depending on public need and available Laboratory resources, these tours are scheduled either at a specified time for large groups or as requested by individuals.

When a public group identifies a specific concern or a highly complex technical issue important to that group that could be too technically detailed or too narrowly focused for a general public audience, a special briefing or workshop, to be held in Los Alamos or in the group's local community, may be scheduled. Technical personnel from the ER Program who have expertise in the field(s) of concern to the group will be available to allow an exchange of information in an informal setting.

Exhibits about various aspects of the program are kept on file and can be set up at conferences, community events, fairs, or other locations to raise the awareness of the public about the ER Program.

6.3.5 Speakers Bureau

The Laboratory's speakers bureau provides speakers to community organizations to address topics about the Laboratory, including the ER Program. The public involvement project leader identifies and calls upon appropriate ER Program staff to make presentations to the public. Requests for ER Program speakers may be made through the public involvement project leader. Speakers on general Laboratory topics may be requested by calling the speakers bureau coordinator in PA-3, (505) 665-5000.

6.3.6 Participation in Public Forums

If a request is made in a meeting or forum for discussion of a topic related to the ER Program, the public involvement project leader will provide a speaker for the group raising the issue.

6.3.7 Communications Training

Because information pertaining to the ER Program is complex, the public involvement project leader coordinates and participates in training programs for key personnel so that they are able to communicate complex technical issues clearly.

6.3.8 Responding to Inquiries

The ER Program gives high priority to responding to public inquiries. The public involvement project leader works closely with Laboratory management, the Laboratory's Public Affairs Office, and ER Program staff to ensure that timely and

accurate information is provided. The public involvement project leader will coordinate responses to detailed and complex technical inquiries with the appropriate technical experts in the ER Program.

6.3.9 Environmental Awareness Workshops

Special workshops, geared to children as well as to adults, on radioactivity, water quality, volatile organic compounds, principles of toxicology, and other topics relevant to the ER Program will be scheduled at various Indian pueblos and schools upon request.

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APPROXIMATE CONVERSION FACTORS FOR SELECTED SI (METRIC) UNITS

Multiply SI (Metric) Unit	**by**	**To Obtain US Customary Unit**
Cubic meters (m^3)	35.3	Cubic feet (ft^3)
Centimeters (cm)	0.39	Inches (in.)
Meters (m)	3.3	Feet (ft)
Kilometers (km)	0.62	Miles (mi)
Square kilometers (km^2)	0.39	Square miles (mi^2)
Hectares (ha)	2.5	Acres
Liters (L)	0.26	Gallons (gal.)
Grams (g)	0.035	Ounces (oz)
Kilograms (kg)	2.2	Pounds (lb)
Micrograms per gram (μg/g)	1	Parts per million (ppm)
Milligrams per liter (mg/L)	1	Parts per million (ppm)
Celsius (°C)	9/5 + 32	Fahrenheit (°F)

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■ APPENDIX A

Descriptions of Technical Areas at Los Alamos National Laboratory

DESCRIPTIONS OF TECHNICAL AREAS AT LOS ALAMOS NATIONAL LABORATORY

The locations of the 49 technical areas (TAs) operated by Los Alamos National Laboratory (the Laboratory) in Los Alamos County are shown in Chapter 2, Figure 2-2. The main programs conducted at each of the active, developed areas are listed in this appendix.

TA-2, Omega Site

The Omega West Reactor, an 8-MW nuclear research reactor, is located at TA-2. The reactor provides neutrons for fundamental studies in nuclear physics and associated fields.

TA-3, South Mesa Site

The main technical area of the Laboratory, TA-3 includes the Administration Building in which the Director's office and other administrative offices and laboratories for several divisions are located. Other buildings house the central computing facility, administrative offices, materials division, chemistry and materials science laboratories, physics laboratories, technical shops, cryogenics laboratories, a Van de Graaff accelerator, and the main cafeteria.

TA-6, Two-Mile Mesa South Site

Two-Mile Mesa Site is one of three sites (TA-22 and TA-40 are the other two) used in the development of special detonators to initiate high-explosive systems. Fundamental and applied research conducted at this site includes investigating phenomena associated with initiating high explosives and research in rapid shock-induced reactions.

TA-8, GT Site (or Anchor Site West)

Nondestructive testing is conducted at this site for the entire Laboratory. The test facilities maintain capability in all modern nondestructive testing techniques to ensure the quality of material ranging from test weapons components to high-pressure dies and molds. The principal activities involve radiographic techniques (using x-ray machines to 1,000,000 V and a 24-MeV betatron), radioactive isotope techniques, ultrasonic and penetrant testing, and electromagnetic test methods.

TA-9, Anchor Site East

At this site, the physical properties and feasibility of fabricating explosives are explored, and new organic compounds are investigated for possible use as explosives. Storage and stability problems are also studied.

TA-11, K Site

The facilities at this site test explosive components and systems under a variety of extreme physical environments. The facilities are arranged so that testing may be controlled and observed remotely and so that devices containing explosives or radioactive materials, as well as those containing nonhazardous materials, may be tested.

TA-14, Q Site

This firing site is used for running various tests on relatively small explosive charges and for determining the impact of fragments.

TA-15, R Site

This site is the home of PHERMEX, a multiple-cavity electron accelerator capable of producing a very large flux of x-rays for certain weapons development problems and tests. The site is also used for investigating how weapons function and systems behave in nonnuclear tests, principally by electronic recording means.

TA-16, S Site

The facilities at this site house the development, engineering design, pilot production, and environmental testing of nuclear weapons warhead systems. Other functions include stockpile production liaison; development and testing of high explosives, plastics, and adhesives; and research on process development for manufacture of items using these and other materials.

TA-18, Pajarito Laboratory Site

The fundamental behavior of nuclear chain reactions with simple, low-power reactors called critical assemblies is studied here in buildings known as kivas. Experiments are operated by remote control and are observed by closed-circuit television. The reactors are used primarily to provide a controlled means of assembling a critical amount of fissionable materials to study the effects of various shapes, sizes, and configurations. The assemblies are also used to produce large quantities of fission neutrons for experimental purposes.

TA-21, DP Site

This site has two primary research areas: DP-West, a chemistry research facility, and DP-East, a research site for high-temperature chemistry and tritium.

TA-22, TD Site

See TA-6.

TA-28, Magazine Area A

The Laboratory uses this site as one of two storage areas for explosives.

TA-33, HP Site

A major high-pressure tritium-handling facility is located at HP Site. Laboratory and office space for the Geosciences Division's hot dry rock geothermal project is also located at this site.

TA-35, Ten Site

Nuclear safeguards research and development conducted here are concerned with nondestructive techniques for detecting, identifying, and analyzing fissionable isotopes. Research in reactor safety and laser fusion also occurs at this site.

TA-36, Kappa Site

Various explosive phenomena, such as detonation velocity, are investigated at Kappa Site.

TA-37, Magazine Area C

See TA-28.

TA-39, Ancho Canyon Site

Nonnuclear weapons behavior is studied here, primarily by photographic techniques. Various phenomenological aspects of explosives, interactions of explosives, and explosions involving other materials are also investigated at this site.

TA-40, DF Site

See TA-6.

TA-41, W Site

Personnel at this site are engaged primarily in engineering design and development of nuclear components, including fabrications and evaluation of test materials for weapons.

TA-43, Health Research Laboratory

The Biomedical Research Group does research here in cellular radiobiology, biophysics, mammalian radiobiology, and mammalian metabolism. A large medical library, special counters used to measure radioactivity in humans and animals, and quarters for dogs, mice, and monkeys are also located in this building.

TA-46, WA Site

Applications for photochemistry, which include development of technology for laser isotope separation and laser enhancement of chemical processes, are investigated here. Solar energy research, particularly in the area of passive solar heating for residences, also occurs at this site.

TA-48, Radiochemistry Site

Using analytical and physical chemistry, scientists and technicians at this site study the nuclear properties of radioactive materials. Radioactive substances are measured in hot cells, which permit remote handling of radioactive materials.

TA-49, Frijoles Mesa

Frijoles Mesa has been used primarily as the site of underground hydronuclear experiments, conducted in 1960 and 1961, and as a buffer zone for nearby firing sites. The site is currently used for high-power microwave research and for training the Laboratory's hazardous devices team.

TA-50, Waste Management Site

Personnel at this site have responsibility for treating and disposing of most industrial liquid waste received from Laboratory technical areas, for developing improved methods of solid waste treatment, and for containing the radioactive materials removed by treatment. Radioactive liquid waste from most technical areas is piped to this site for treatment.

TA-51, Environmental Research Site

Experiments conducted at this facility explore waste cover and stabilization alternatives, land reclamation, contaminant movement, and ecology.

TA-52, Reactor Development Site

A wide variety of activities related to nuclear reactor performance and safety is conducted at this site.

TA-53, Meson Physics Facility

The Los Alamos Meson Physics Facility, a linear particle accelerator, is used to conduct research in areas of basic physics, cancer treatment, materials studies, and isotope production. The Los Alamos Neutron Scattering Center and the proton storage ring are also located on this site.

TA-54, Waste Disposal Site

Solid radioactive and toxic wastes that meet regulatory acceptance criteria are disposed at this site.

TA-55, Plutonium-Processing Facilities

These facilities process plutonium and house research in plutonium metallurgy.

TA-57, Fenton Hill Site

The Laboratory's hot dry rock geothermal project is located at Fenton Hill, where scientists are studying the possibility of producing energy by circulating water through hot, dry rock located hundreds of meters below the earth's surface. After the water is heated, it is brought to the surface to drive electric generators.

TA-59, Environment, Safety, and Health Site

Occupational health and environmental science activities are conducted at this site.

TA-60, East Jemez Road

This area contains physical support facilities for the Laboratory, including the existing landfill.

TA-63, Pajarito Road Service Site

This area contains physical support facilities operated by Johnson Controls, Inc.

TA-74, Los Alamos Airport

This area contains the DOE-owned airport that serves the Laboratory.

■ APPENDIX B

Maps of Wetlands, Drainages, and Well Locations

1.0 INTRODUCTION

The maps located at the end of this appendix are representative of the maps that are available at Los Alamos National Laboratory (the Laboratory). These maps have been scaled to fit a normal page format for ease of reproduction with the rest of this document. The Geographical Information System—which is part of the Facility for Information Management, Analysis, and Display—contains topographical information in digital form derived from recent aerial photography. Topographic maps with high resolution can be generated from this system by computer. If maps are needed with higher resolution of particular features than are provided in this appendix, requests should be submitted to the Environmental Restoration Program's community reading room, Los Alamos National Laboratory, PO Box 1663, MS M314, Los Alamos, New Mexico 87545.

2.0 WETLANDS

Four federal agencies have responsibility for identifying and delineating wetlands: the Army Corps of Engineers, Environmental Protection Agency (EPA), Fish and Wildlife Service (FWS), and Soil Conservation Service (SCS). The Corps and EPA are responsible for wetlands regulated under Section 404 of the Clean Water Act. Under Section 404, the Secretary of the Army, acting through the Chief of Engineers, is authorized to issue permits for the discharge of dredged or fill materials into the waters of the United States, including wetlands. The FWS has been involved in a nationwide identification of wetlands through the National Wetlands Inventory (NWI). The SCS becomes involved in identifying wetlands through the "swampbusters" provision of the Food Security Act of 1985 (Army Corps of Engineers et al. 1989, 0237).

The FWS has undertaken a project to map and characterize those wetlands in accordance with the NWI. This inventory includes all wetlands and deepwater habitats throughout the United States, including rivers, lakes, streams, marshes, bogs, and ponds.

The NWI meets four long-range objectives set forth by the FWS: (1) to describe ecological units that have similar natural attributes, (2) to arrange these units in a system that will aid decisions about resource management, (3) to delineate units for inventory and mapping, and (4) to provide uniformity in concepts and terminology throughout the United States (Illinois Department of Conservation 1988, 0322).

Under Section 404 of the Clean Water Act, a wetland is defined as "those areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions." Wetlands include swamps, marshes, bogs, and similar areas. This definition emphasizes hydrology, vegetation, and saturated soils. In addition, Section 404 regulates other "waters of the United States" such as open water areas, mud flats, coral reefs, riffle and pool complexes, vegetated shallows, and other aquatic habitats.

The FWS in cooperation with other federal and state agencies, private organizations, and individuals, developed a wetlands definition for conducting an inventory of the nation's wetlands. This definition was published by Cowardin et al. (1979, 0248). In the NWI, wetlands are defined as "lands transitional between aquatic and terrestrial systems where the water table is usually at or near the surface, or the land

is covered by shallow water." In addition, the definition in the Federal Manual for Identifying and Delineating Jurisdictional Wetlands requires that the land support predominantly hydrophytes and that the substrate be undrained hydric soils.

Under the Resource Conservation and Recovery Act (RCRA) and the Hazardous and Solid Waste Amendments (HWSA) Module of the Laboratory's operating permit, the EPA required a determination of all wetlands located in areas that either lie within Laboratory boundaries or that drain Laboratory land (Figure B-1).

2.1 National Wetlands Inventory Maps

The FWS designed the NWI maps only to provide guidance and did not intend to define the limits of proprietary jurisdiction or to establish geographic scope. The maps are prepared primarily by stereoscopic analysis of high-altitude aerial photographs. The FWS identified wetlands from the vegetation, visible water features, and geography observed in these photographs.

The NWI mapping protocol is hierarchical and is structured around a combination of ecological, hydrological, and substrate characteristics. This approach is consistent throughout the United States. The system consists of five components: marine (open ocean and associated coastline); estuarine (salt marshes and ponds); lacustrine (lakes and deep ponds); riverine (rivers, creeks, streams); and palustrine (shallow ponds, marshes, swamps, bogs). The system proceeds in a hierarchical manner through subsystem, class, and subclass and includes modifiers that describe the degree of wetness (water regime), water chemistry, soil, and manmade changes (diking, draining, etc.).

The wetlands at Los Alamos were mapped by FWS personnel from the Region 2 office in Albuquerque, New Mexico, using US Geological Survey quadrangle maps as base maps and infrared high-altitude aerial maps. To cover all of the watersheds that drain the Laboratory site, five quadrangles were mapped (Frijoles, White Rock, Guaje, Valle Toledo, and Puye). In addition to the watershed of the Laboratory proper, the Seven Springs quadrangle, which gives the location of the Laboratory's geothermal site at Fenton Hill, was mapped.

2.2 Results

The NWI maps all wetlands without emphasizing any particular type or location and is not restricted to mapping wetlands regulated by federal, state, or local regulatory agencies. The aerial maps typically reflect conditions during the specific year and season in which they were taken. A detailed on-the-ground and historical analysis of single sites is being conducted by personnel in the Environmental Protection Group (EM-8) to delineate and characterize individual wetlands.

No perennial streams traverse Laboratory lands. Wetlands within Laboratory boundaries fall primarily into two classifications: palustrine and riverine. Palustrine wetlands (ponds and marshes) have been identified in Sandia, Pajarito, and Pueblo canyons and small ones in other parts of the Laboratory. Wetlands in Sandia and Pueblo canyons are primarily maintained by effluent releases. Beds of ephemeral and intermittent streams that traverse the Laboratory have been classified as temporarily flooded riverine wetlands.

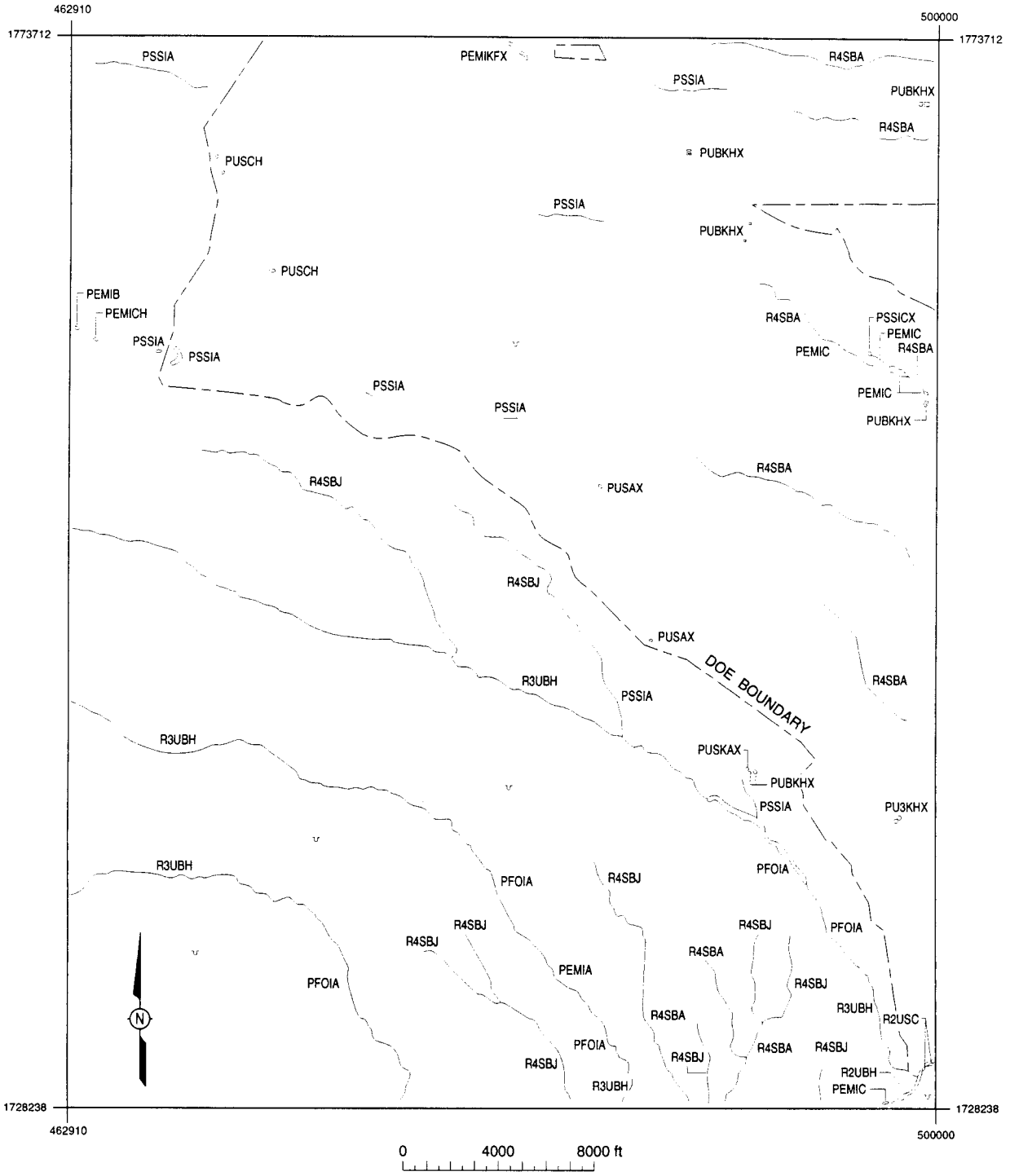

Figure B-1. Map of wetlands for Los Alamos County (p. 1 of 2).

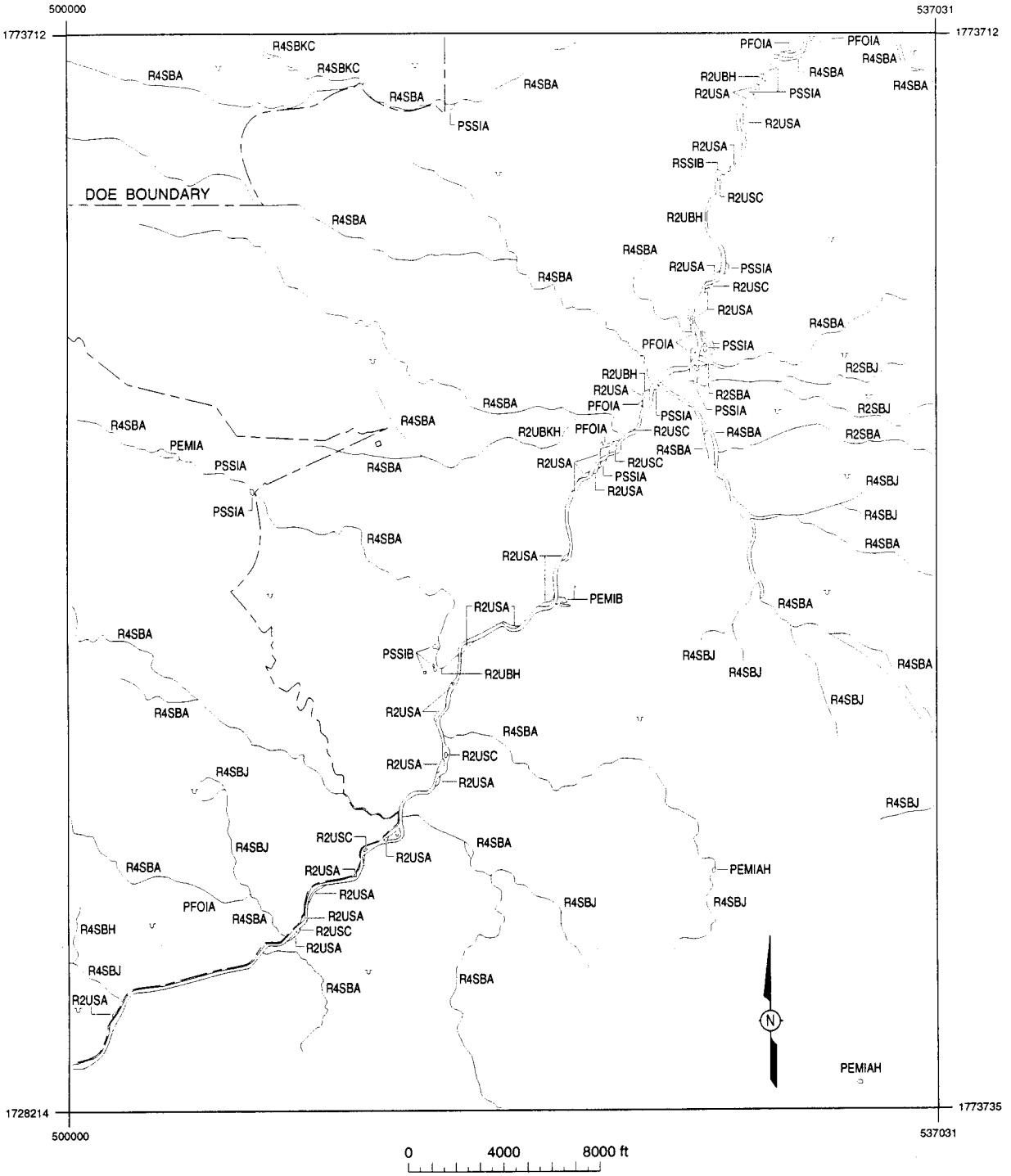

Figure B-1. Map of wetlands for Los Alamos County (p. 2 of 2).

2.3 Future Studies

Because the NWI maps are broad in scope and are not restricted to wetlands regulated by federal, state, or local regulatory agencies, a more detailed delineation of each wetland has been undertaken to determine jurisdictional status. During the summer of 1990, palustrine wetlands in Pajarito and Sandia canyons were characterized and delineated. In addition, use of the wetlands by various plant and animal species is being monitored. Because of the importance of these palustrine wetlands to diversity in plant and animal life, they will be monitored for more than a year to provide baseline data that will permit a determination of changes related to Laboratory activities.

In addition to monitoring the palustrine wetlands, riverine wetlands throughout the Laboratory will be characterized and delineated within the next 3 years as part of the RCRA facility investigation work plans. Most wetland mapping will be associated with the operable unit for the canyons system (OU 1049). The first step in characterization is to make an inspection of each canyon system from the headwaters to the Rio Grande, mapping small wetlands and delineating the boundaries.

3.0 WELL LOCATIONS

Figure B-2 shows the locations of wells in Los Alamos County and in adjacent locales. Wells LA-1, LA-3, LA-4, and LA-6 have been abandoned and plugged. The symbols on the map indicate where these wells were located.

Well LA-1B has been a water supply well. Now it is a test well, as indicated by its symbol on the map.

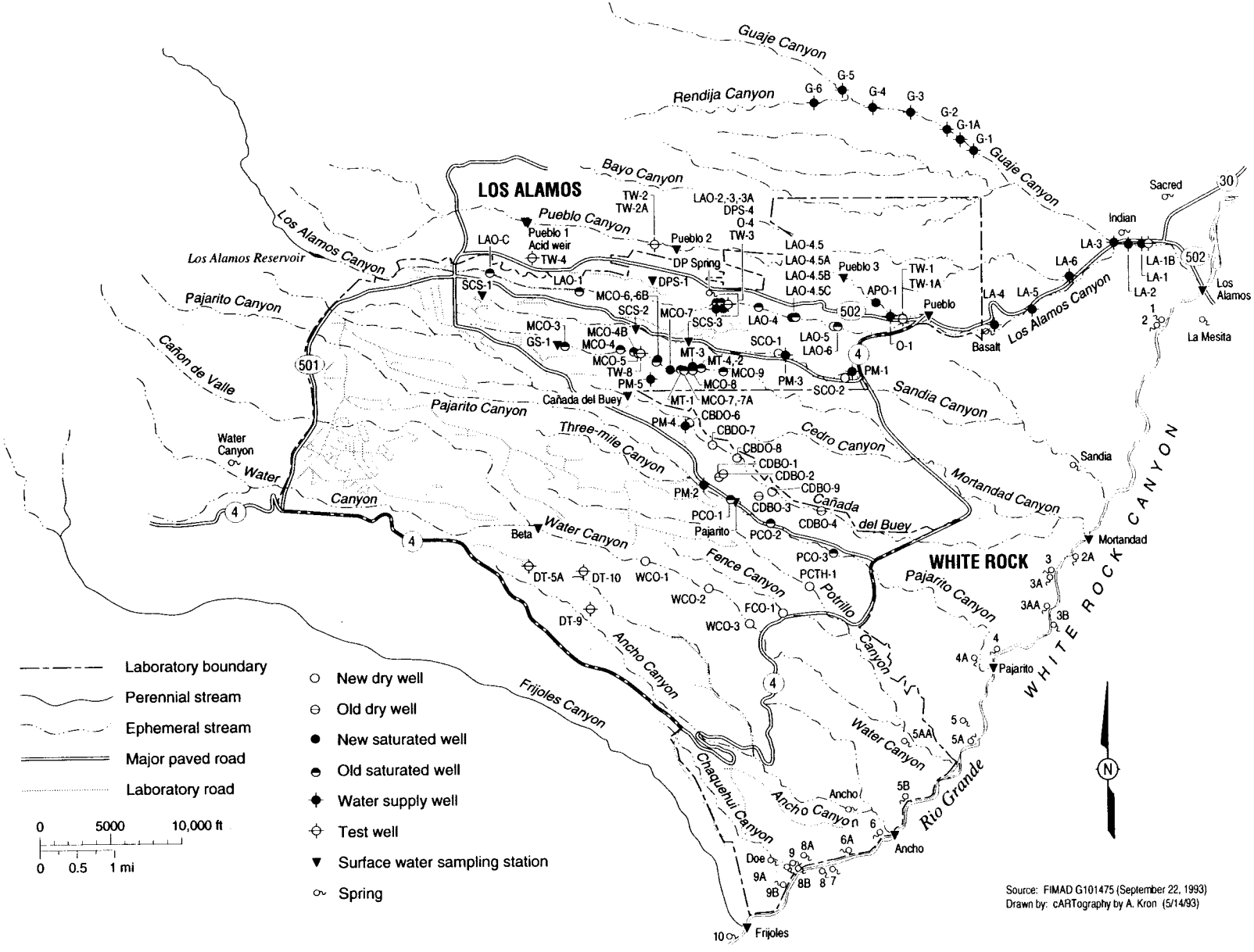

Figure B-2. Well locations in Los Alamos County and in adjacent locales.

References for Appendix B

Army Corps of Engineers, US Environmental Protection Agency, US Fish and Wildlife Service, US Soil Conservation Service, January 1989. "Federal Manual for Identifying and Delineating Jurisdictional Wetlands," Washington, DC. (Army Corps of Engineers et al. 1989, 0237)

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe, 1979. "Classification of Wetlands and Deepwater Habitats of the United States," Office of Biological Services, Fish and Wildlife Service, US Department of Interior, Washington, DC. (Cowardin et al. 1979, 0248)

Illinois Department of Conservation, 1988. "A Field Guide to Wetlands of Illinois," Springfield, Illinois. (Illinois Department of Conservation 1988, 0322)

■ APPENDIX C

Cover and Stabilization Pilot Studies

1.0 INTRODUCTION

The overall objective of the pilot studies program initiated by the Environmental Science Group in 1990 (LANL 1990, 0144) is to develop landfill cover technology for the DOE Environmental Restoration Program. More specifically, the pilot studies program

- provides data to support the remedial site closure alternative of capping material disposal areas (MDAs) and leaving the wastes in place;
- provides field data to be used for the site closure design of landfill covers for the Mixed Waste Disposal Facility and for radioactive and municipal waste disposal facilities;
- develops and evaluates new technologies to measure water balance parameters in the field that can be used as post-closure monitoring techniques;
- provides field data on natural systems to evaluate the long-term performance of landfill covers used to close out a site; and
- provides hydrologic field data which can be used in the assessment of risks for a waste site.

Because protective barriers currently have a high probability of success at a low cost compared with other candidate technologies, this technology has been chosen for evaluation in pilot-scale field tests. Barrier technologies are cheaper than exhuming and treating waste because they permit some types of wastes to remain in place. A considerable portion of the ER Program's budget could be saved if the Laboratory can safely dispose of wastes in place. Ordinarily, natural precipitation and recharge drive the movement of contaminants from the unsaturated zone; however, protective barriers can reduce the amount of recharge reaching the waste, thereby reducing contaminant migration and, therefore, useful for long-term isolation of waste.

Currently, neither field data nor experience exist to support long-term projections regarding the effectiveness of engineered barriers in landfill covers for long-term containment of either radionuclides (Bedinger 1989, 0894) or other waste forms. Even though the successful performance of the entire landfill is a function of interactive water balance processes, traditional remedial engineering solutions have ignored these processes, leading to numerous landfill failures (Jacobs et al. 1980, 0330; Hakonson et al. 1982, 0122). Field water balance data do not exist to enable the site operator to define and engineer suitable barriers to prevent the migration of waste materials out of the landfill.

Field and laboratory research funded by the US Department of Energy (DOE) at Los Alamos over the last 10 years has provided a basic understanding of the many environmental factors that influence the performance of landfills in response to hydrologic influences. That research has led to the development of landfill cover technology for controlling the precipitation that falls on a landfill. This cover technology is based on the combined results of studies on soil erosion (Nyhan et al. 1984, 0167;1986, 0169; Nyhan and Lane 1986, 0159), subsidence (Abeele 1984, 0002; 1984, 0003; 1984, 0004), biointrusion barriers (Hakonson et al. 1982, 0124;

1982, 0122; 1983, 0125; 1986, 0115; Felthauser and McInroy 1983, 0098), and capillary and hydraulic barriers (Abeele and DePoorter 1984, 0007; Nyhan et al. 1986, 0169). The approach to developing an effective landfill cover technology combines the results of ten years of individual shallow land burial studies at Los Alamos and Utah (Nyhan et al. 1990, 0173; 1990, 0922) with current European research (Anonymous 1988, 0890); Berger et al. 1991, 0895, pp. 407-418; Gregersen et al. 1991, 0907; Hotzl and Wohnlich 1992, 0910; von der Hude 1991, 0929; 1991, 0930, pp. 165-176; Matter 1991, 0912; Melchior et al. 1990, 0914; 1990; 0915; 1991, 0916; 1992, 0917; Melchior and Miehlich 1988, 0913, pp. 673-675; Miehlich and Melchior 1992, 0918; Mock et al. 1991, 0919; Wohnlich 1990, 0936, pp. 429-430; 1991, 0937). The results and methods of the several of the latter studies were used in the design of the Protective Barrier Landfill Cover Demonstration described in this appendix and were the subject of the DOE International Technology Exchange Program studies funded at Los Alamos in FY92.

Much of Los Alamos County is located on the Pajarito Plateau, which extends from the eastern flank of the Jemez Mountains in north-central New Mexico. About 47% of the land area of the county lies between 6,800 and 8,000 ft; 32% of the county lies above 8,000 ft. Changes in elevation and orientation of topographical features exert a strong influence on local precipitation and climate, which, in turn, influence the distribution of soils, flora, and fauna. MDAs from both ends of this water balance/ topographic continuum were chosen (LANL 1990, 0144) to bracket the final design recommendations and potential risks of containing waste in place: MDA F (PRS (potential release site) 6-007), at an elevation of 7,575 ft in a ponderosa pine forest; MDA B (PRS 21-015), at an elevation of 7,150 ft (piñon juniper woodland with scattered ponderosa pines); and MDA G (PRS 54-00), at elevations ranging from 6,650 to 6,890 ft within a piñon juniper woodland. This diversity of locations is manifested in the milestone chart for the program (Figure C-1).

One of the major criticisms of closure plans for waste sites is that mandated waste site stability periods are so long that they will certainly be impacted by plant succession during the postclosure period. For low-level radioactive waste landfills, 10 CFR, Part 61, mandates stability of the waste site for 500 years (NRC 1982, 0361). For hazardous and mixed wastes at DOE facilities, 40 CFR, Parts 264 and 265, Subpart N, mandates 30 years of post-closure care (DOE 1990, 1029). Natural succession at these MDAs in Los Alamos will most likely result in woodland vegetation during these time periods. The purpose of establishing study areas in both the Mesita del Buey piñon/juniper woodland in 1987 and the ponderosa pine forest in 1992 was to provide an opportunity to study how natural woodland ecosystem processes affect the hydrology of waste disposal sites and how effectively they preserve the integrity of the disposal site. The results will be used in all pilot studies at the Laboratory that address the issue of maintaining site integrity after active maintenance has been discontinued, since these natural ecosystems are over a million years old.

Weather variability and vegetation changes are important complicating factors at Los Alamos. Not only is the amount of precipitation important, but seasonal distribution and very-short-term precipitation rates can also have a profound effect on the water balance. During the 5 years that the pilot study at MDA B has been operating, significant changes have occurred in the vegetation. These changes affect run-off, interception and evapotranspiration and thus affect the soil's capacity to store water and produce seepage. Preliminary comparisons between the evapotranspiration rates at MDA B and the piñon/juniper woodland study area show that evapotranspiration is higher in the late winter and early spring in the woodland.

To achieve these pilot study objectives, both modeling studies and field demonstrations are being used to identify the key factors that influence site integrity, followed by a determination of how to manage these factors and to implement site-specific designs (Figure C-2). The modeling used to identify data needs and prioritize additional studies will be expanded into a program of evaluating existing hydrologic and ecosystem models for relevance to local environmental conditions. The results of the field studies may indicate a need to further develop existing models. The modeling program will assist in the design of certain aspects of field studies. Finally, both the modeling program and the data bases obtained from these pilot studies will be used to develop a generic methodology for site closure at Los Alamos (Figure C-2).

This report describes pilot demonstrations of landfill cover technology in the field at the Laboratory with the idea in mind that a more detailed description of the pilot studies program is available in last year's Installation Work Plan (IWP) (LANL 1992, 0768). Progress made in FY93 on the landfill cover studies is presented in Section 2.0, with the natural system studies presented in the following section. A final summary section is then presented in an attempt to set forth program integration and modeling activities.

2.0 LANDFILL COVER STUDIES

The pilot studies program is currently performing field studies to develop landfill cover technology at two locations at Los Alamos. The Protective Barrier Landfill Cover Demonstration and the Integrated Test Plot Demonstration are both being performed at the Los Alamos Experimental Engineered Test Facility (EETF) at Technical Area (TA) -51. The studies on the 12 plots on the current MDA B landfill cover at TA-21 are also producing valuable field data. Demonstrations at a much larger field scale are also planned in FY94 for MDAs G and F.

2.1 Protective Barrier Landfill Cover Demonstration

The purpose of the Protective Barrier Landfill Cover Demonstration was to monitor and compare water balance on the Conventional Landfill Cover design—a design similar to that used in Los Alamos and the waste management industry for waste disposal (Jacobs et al. 1980, 0330)—with three other designs containing engineered barriers. The performance of all four designs was evaluated at dominant downhill slopes of 5%, 10%, 15%, and 25%. These plots were installed during the spring, summer, and fall of 1991 at the EETF, a 20-acre field test facility located about 2 mi west of MDA G (DePoorter 1980, 0045), and were instrumented so that a determination of water balance for the plots could be measured. The plots were constructed and instrumented to provide measures of run-off and interflow, as well as seepage and soil water storage as functions of slope and slope length.

2.1.1 Plot Construction, Design, and Rationale

The technology for controlling soil water erosion on all cover designs consisted of applying a 70% surface cover of medium gravel (8.0- to 25-mm diam). Dominant downhill slopes up to 25% were used on the plot surfaces to insure a range of slopes up to the maximum slope that would be allowable for the safe operation of large earth-moving equipment at a landfill.

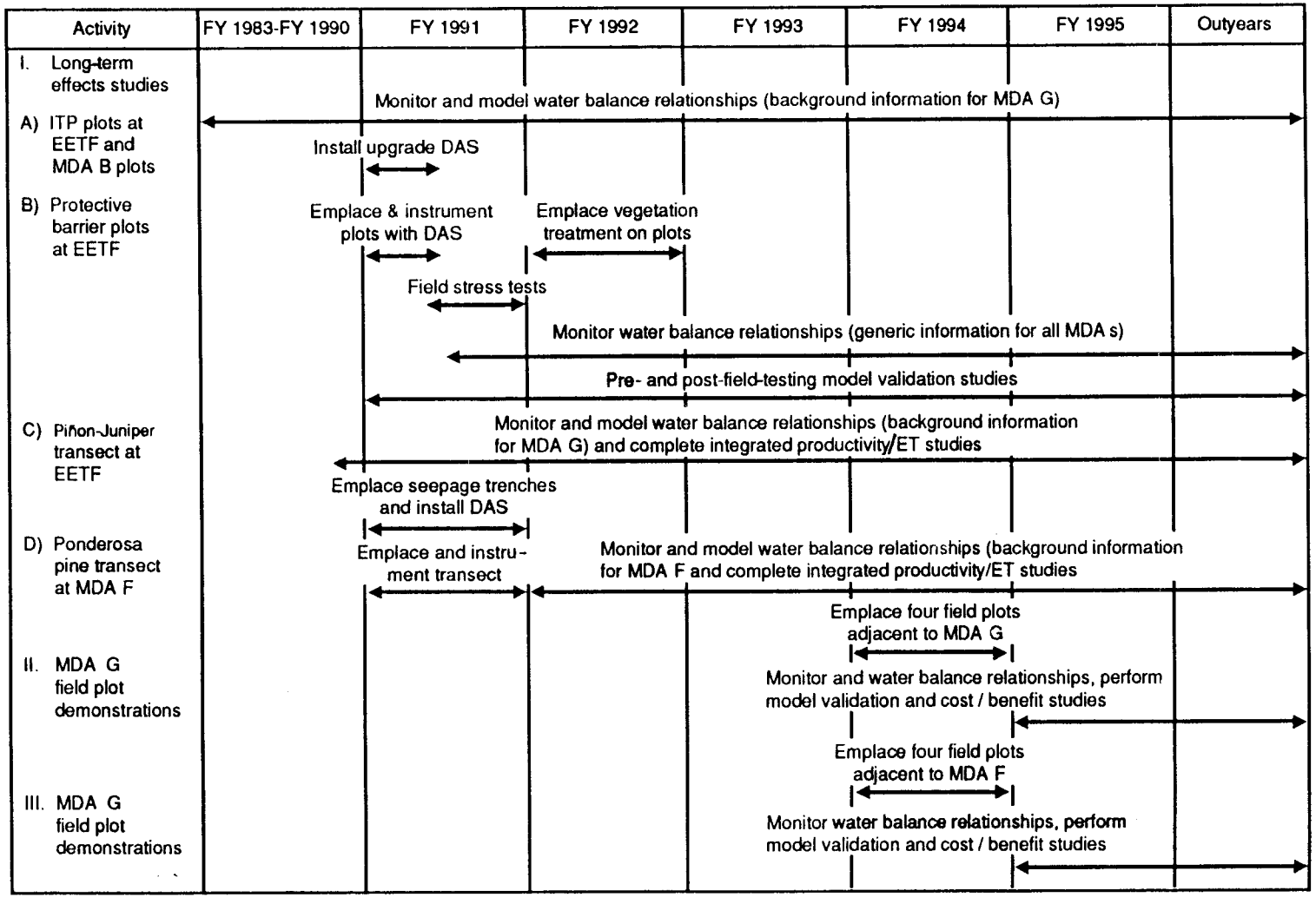

Figure C-1. Milestone chart for pilot studies.

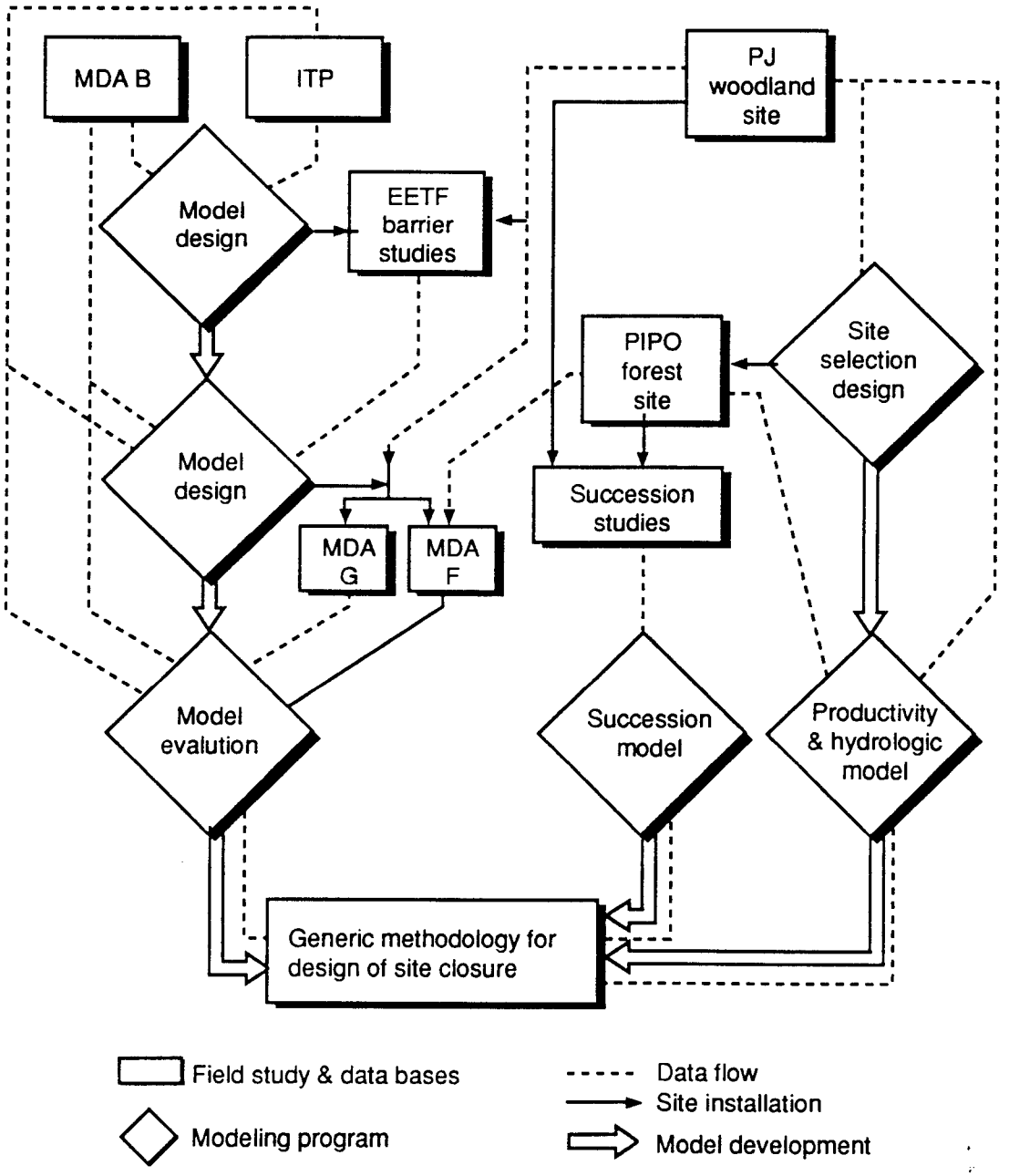

Figure C-2. Interdependence of field and modeling studies in pilot study program.

The Protective Barrier Landfill Cover Demonstration was emplaced on an east-facing 10.7- by 37.5-m parcel of land with crushed tuff backfill on the surface (Nyhan et al. 1984, 0167). This backfill is used in landfills at Los Alamos as a result of excavating disposal trenches in local Bandelier Tuff, which is then crushed and emplaced around the waste materials. This area was surveyed into four 10.7- m-long areas, each of which received additional crushed tuff to establish the varying downhill slopes. The crushed tuff on each of these pads was then compacted and resurveyed to confirm the desired slopes. A south-facing 4.6-m-wide, 40-m-long ramp that abutted the lower ends of these four east-facing pads was constructed similarly, only with a 2% dominant downhill slope. A set of four 1.0- by 10.0-m plots with common sidewalls was then constructed on the center of each pad, with a distance of 3.05 m between each set of plots. All of the plot walls except the downhill endplates were fabricated using two pieces of plywood (1.27 cm by 1.88 m by 1.22 m) emplaced within a framework consisting of vertically placed iron I-beams (2.5 by 5.1 by 0.32 cm) on 1.22-m centers, with channel iron (2.5 by 5.1 by 0.32 cm) top and bottom framing. The endplates were fabricated from 14-gauge sheet metal and had 7.62-cm- and 10.2-cm-diam steel half couplings welded into the endplate wall to connect plumbing used for the collection of seepage and interflow, respectively. The interflow collection system consisted of a 1.0-m-long, 30.5-cm-deep, 30.5-cm-wide 14-gauge metal trough welded to the inside of the plot's endplate. The run-off collection system was also fabricated using 14-gauge sheet metal and consisted of a 1.0-m-long, 15.2-cm-wide trough with a floor that sloped to divert run-off (30.5 cm deep at the low end and only 25.4 cm deep at the high end); this trough was welded to the top of each endplate and had a 15.2-cm-diam steel half coupling welded into the trough wall to connect plumbing used to collect run-off.

A seepage collection system was installed in the bottom of each of the plots and was designed to evaluate seepage as a function of slope length. Sixty-eight 2.02- by 0.76-m pans with a depth of 0.30 m were fabricated from 14-gauge sheet metal. Each pan was designed with a 5.0-cm-tall, 2.02-m-long channel iron foot that was welded to the bottom of the pan; this foot insured a slope on the bottom of the pan for seepage water to flow out of the pan through a standard 1.3-cm-diam pipe coupling that was welded into a corner of the pan. Four of these pans were placed end to end in the bottom of each plot and were attached to each other at the top of each pan using a sheet metal clip. An 11.4-cm-wide space was purposely left between each sidewall of the plot and the pan to minimize sidewall effects in this experiment, which might allow water to migrate down the sidewalls of the plot and be incorrectly measured as seepage. Each pan and the rest of the bottom of each plot were then filled with medium gravel (8.0- to 25-mm diam). A sharp interface between this gravel layer and the above-lying soil layers was maintained with a high-conductivity (0.024 m/s) geotextile (600X Brand, manufactured by MIRAFI, El Toro, CA) with a range in apparent opening size of 300 to 850 μm between the polypropylene strands of the fabric.

After every plot corner was resurveyed to make sure of the final slopes, 15 cm of backfill was emplaced around the outside of each of the four sets of plots and compacted with a walk-behind dual drum trench roller with a cleated drum width of 0.38 m capable of exerting 3.08 metric tons of applied force (Model MDR-T38S, Mikasa USA, Multiquip, Carson, CA) and a vibratory plate compactor with a 0.50- by 0.56-m plate capable of exerting 1.52 metric tons of applied force (Model MVC-90A, Mikasa USA, Multiquip, Carson, CA). The next step involved emplacing 15 cm of various soil materials inside each of the plots using a Clark Bobcat Model 975 skid-steer trencher (American Trencher Inc., Delhi, IA) and a 15.9-m-long Model HSDU-52 conveyor with a hydraulic cleated belt (Clearfield Conveyors Corp., Clearfield,

UT). These two consecutive steps were repeated until the last soil layer was added to the plots.

All of the soil materials used in each landfill cover design except the medium gravel were compacted using the equipment described above for each 15-cm lift of soil emplaced in each plot. Laboratory compaction tests were performed on the sands using Standard Test Methods for Maximum Index Density of Soils Using a Vibratory Table [Test Method D4253-83 (ASTM 1979, 0889)] and on the other soils using the Modified Proctor Method [Test Method D1557 (ASTM 1979, 0889)]. After the first lift of each type of soil material was added to a plot and compacted, a set of 13 nuclear gauge readings of soil water content and bulk density was collected over the depth of the lift every 61 cm down the length of the plot. A semivariogram analysis of these data was performed to determine how many Proctor determinations would be necessary to characterize the compaction of each lift of soil added to the plots. The two topsoils, the sands, and the tuff-clay mixture were compacted to 85%, 95% and 90% of the maximum dry unit weight from standard Proctor compaction, respectively.

Schedule 40 PVC pipe was used to connect the water collection systems for run-off, interflow, and seepage to the automated water flow datalogging system. Each of the four pans of the seepage collection system was plumbed with 2.5-cm-diam pipe, which were then emplaced in a 7.62-cm-diam pipe outside the plot endplate for added protection against crushing as the pipes were buried with additional backfill. The interflow and run-off collection systems were plumbed with 10.2- and 15.2-cm-diam pipe, respectively. All of this pipe was initially laid on the 4.6-m-wide ramp at the bottom of the plots to insure the gravity flow of water with a minimal 2% slope.

The plots with the Conventional Landfill Cover design contained 15 cm of a loam topsoil consisting of a 2:1:1 (V:V:V) mixture of an uncharacterized topsoil with a large organic matter content, sand, and aged sawdust (<9.5-mm diam). This topsoil was underlain by 76 cm of crushed tuff backfill described previously (Nyhan et al. 1984, 0167; 1990, 0173). The crushed tuff backfill beneath a depth of about 1 m in a profile like this would normally contain wastes in an actual waste disposal site at Los Alamos.

One set of plots contained the EPA-recommended final cover design (EPA 1989, 0928). These plots contained 61 cm of the loam topsoil described previously (this corresponds to the EPA "vegetated topsoil layer"), emplaced on top of 30 cm of a medium sand (8.0- to 25-mm-diam) made in a sand classifying/blending tank system (Portec Kolberg Division, Yankton, SD). The latter layer corresponds to the EPA "drainage layer" and was overlain with the MIRAFI geotextile layer described above, to provide the EPA-recommended filter layer necessary to prevent fine soil particles from migrating into the drainage layer. The bottom layer in the EPA-recommended final cover, called the "low-permeability layer," usually consists of a 20-mil (0.5-mm) minimum thickness flexible membrane liner (FML) on top of a 60-cm-thick layer of soil with an in-place saturated hydraulic conductivity of $<1 \times 10^{-9}$ m/s. Since the plastic FML would last less than 35 years (Pertusa 1980, 0177), this feature of the EPA design was omitted in our EPA design to evaluate the worst possible case. The results of previous research on mixtures of local crushed tuff and sodium-saturated bentonite (Abeele 1986, 0888; 1986, 0006, pp. 255-264) indicated that a 1:10 (W:W) mixture of finely ground Aquagel (Baroid Drilling Fluids, Farmington, NM) and crushed tuff should easily provide the low conductivity required for this layer. This mixture was prepared in a cement truck by adding 10 45.4-kg bags of dry Aquagel to 4.54 metric tons of <6.4-mm-diam crushed tuff that had been screened and dried

using an asphalt batch plant. This dry mixture was mixed for 40 min, approximately 200 L of water was added (for dust control and to optimize compaction), followed by an additional 30 min of mixing. A 15-cm-deep lift of mixture was finally added to each plot. After compaction this lift was covered to prevent the mixture from drying, and this lift was sprayed with water before adding the next 15-cm lift of mixture to promote the uniformity of the entire 61-cm layer.

Two designs contained capillary barriers varying only in the type of soil used in the uppermost layer. One of the designs contained 61 cm of the same loam mixture used in the previous designs, whereas the other design contained 61 cm of a local clay loam backfill classified (Nyhan et al. 1978, 0161) as a Lithic Aridic Haplustalf (clayey, mixed, mesic family) and used in two previous studies (Nyhan et al. 1984, 0167; 1990, 0173). These soils were emplaced on top of 76 cm of a fine sand (0.05- to 0.425-mm-diam) made in the sand classifier/blender described previously. The fine sand was specifically chosen to complement the underlying medium-sized gravel in terms of optimizing both the hydraulic conductivity and water-holding properties of the capillary barrier (Wohnlich 1991, 0937).

2.1.2 Measurement Techniques for Seepage, Interflow, Run-Off, Precipitation and Soil Water Content

Run-off, interflow, and seepage were collected in 100 100-L tanks housed in two instrument trailers that were heated in the winter to allow year-round hydrologic measurements. Water levels in each tank were measured with a microprocessor-controlled ultrasonic liquid level sensor (model DCU-7, Lundahl Instruments, Logan, UT) mounted in the top end of a 1.5-m-long stilling well (5.1-cm-diam PVC pipe) attached to the inside of the tank. The sensor output was connected to one of five multiplexer boards (model CIO-MUX32, CyberResearch, New Haven, CT) located in five junction boxes. This multiplexer board was organized as a pair of 16-to-1 multiplexers. The output of each multiplexer was connected by way of shielded flat cable to a digitizer card (model CIO-AD08, CyberResearch, New Haven, CT) in a computer with a widely used personal computer motherboard (model 386N33, Hauppauge Computer Works, Inc., Commack, NY) and a 200-megabyte hard drive (model ST1239A, Seagate Technology, Scotts Valley, CA). Two digitizer cards served the ten multiplexers in this system, in which the digitizer cards accepted 4 and 6 analog inputs, one from each multiplexer.

The computer was used to capture and store the water level data from each tank and to activate the draining of the tank when it was nearly full by actuating a 5.1-cm-diam electrically-actuated ball valve (115-V alternating current Electromni model, Asahi/America Inc., Medford, MA) mounted in the bottom of the tank. The digital output card in the computer (model PCL 722, CyberResearch, New Haven, CT) was organized as six channels of 24 bits each, with five channels being connected to five relay driver boards (model DB-3737, PERX, Inc., San Mateo, CA) located in the junction boxes. Thus, the computer read the water levels in the 100 tanks, made the decision to actuate the valves, and repeated this loop at a rep rate of approximately 1.5 hertz. The water levels in the tanks were routinely recorded hourly but much more frequently when the tank was emptying and when it was nearly full. These data was routinely copied into a single large file every 24 h.

Precipitation was measured using a tipping bucket rain gauge and a long-term event recorder (Weathermeasure Corp., Sacramento, CA).

Since the goals of this experiment were to provide field data to calibrate several

hydrologic models and to collect water balance data, it was necessary to measure soil water content at multiple points in space and time. Thus, soil water content was routinely monitored once every 6 h at each of 212 locations throughout the 16 plots using time domain reflectrometry (TDR) techniques with the help of an automated and multiplexed measurement system. Volumetric water content was measured with a pair of stainless steel waveguides (60-cm-long, 3-mm-diam soil moisture probes; model number 6860, Campbell Scientific, Logan, UT) which are buried parallel and 5 cm apart in the soil. One set of waveguides was emplaced vertically in every soil layer above the bottom end of each of the metal pans in the seepage collection system; these waveguides allowed investigators to determine soil water inventory in four locations in each field plot. A second set of waveguides was emplaced horizontally in several soil layers to provide a more detailed picture of soil water dynamics close to the interfaces of a few soil layer.

Each set of waveguides was connected to 4.6 m of shielded twin-lead antenna cable matched to a molded balun attached to a 26-m length of RG-8/U coaxial cable. An instrument trailer housed a 256-to-1 coaxial switch that connected one set of waveguides at a time to a TDR cable tester (model 1502B, Tektronix Inc., Beaverton, OR) through a system of 37 8-to-1 coaxial switches (model 610-007A, Autek Systems Corp., Santa Clara, CA). The computerized TDR system captured and stored the information from each pair of waveguides as a 220-point waveform (which represented an average of 16 waveform determinations). The personal computer (model 386-20, Compaq Computer Co., Austin, TX) stored the waveform data on a hard disk, which was then used to determine the water content of the soil through a calibration curve relating water content to measured dielectric constant (Topp et al. 1980, 0927).

2.1.3 Field Estimates of Precipitation, Seepage, Interflow, and Run-Off

In New Mexico, average annual precipitation ranges from less than 25 cm over much of the southern desert and the Rio Grande valley to more than 50 cm at higher elevations in the state. Los Alamos has a semiarid, temperate mountain climate with an average total annual precipitation of 46.9 cm for the years 1911 through 1986 (Nyhan et al. 1989, 0417). July and August are the rainiest months, with 48% of the annual precipitation falling at this time in Los Alamos as intense thundershowers. These months are also characterized by warm temperatures and high evapotranspiration, with the net result that precipitation occurring in the winter and spring results in seepage production within landfill covers (Nyhan et al. 1990, 0922, pp. 1205-1206; 1990, 0155, pp. 169-184).

Precipitation data collected at the Protective Barrier Landfill Cover Demonstration (Figure C-3) show that 37.4 cm of precipitation occurred during 1992, with a total of 53.0 cm occurring between November 1991 through January 1993. The precipitation received during the winter of 1991-1992 amounted to 4.65 cm, making this a dry winter compared with the 1911-1986 average of 6.71 cm for winter (Nyhan et al. 1989, 0417). However, this was followed by a wet spring in which 12.4 cm of precipitation occurred compared with the long-term average of 9.37 cm. The precipitation during the dry summer of 1992 amounted to 13.3 cm, only 59% of the long-term summer average precipitation.

Very little field data are available on the flow of water through landfill cover designs, making the data gathered in this field study unique. Each of the 100 different estimates of seepage, interflow, and run-off in the experiment resulted in a hydrograph chart with flow data for approximately 14,000 sampling times (a computer file of

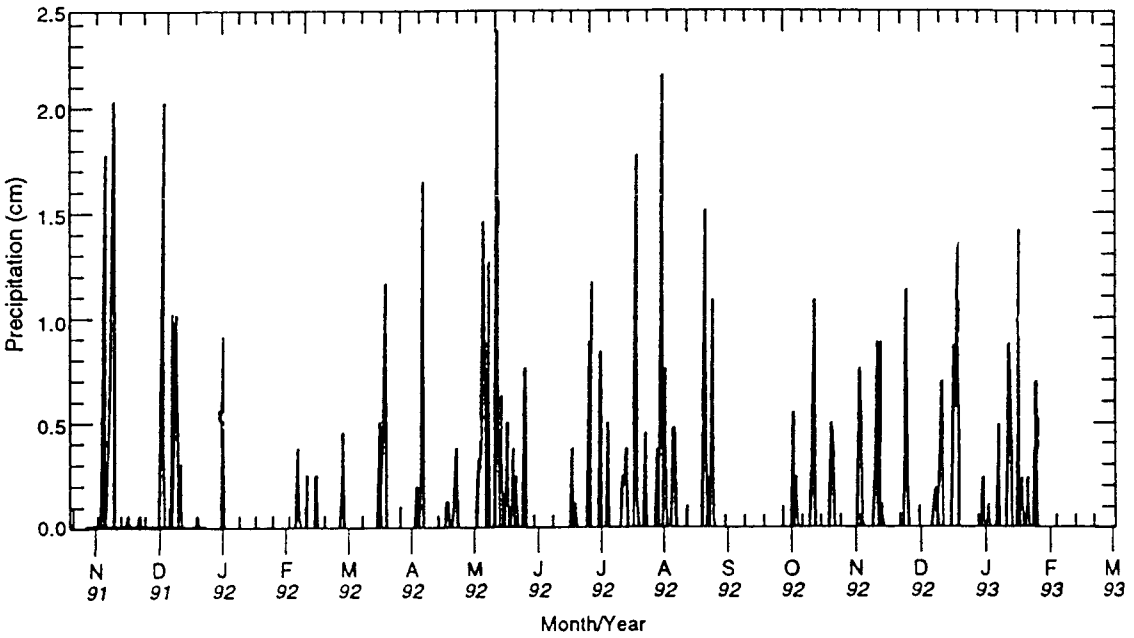

Figure C-3. Precipitation data collected at the Protective Barrier Landfill Cover Demonstration in Los Alamos, New Mexico, from November 1991 through January 1993 (total: 53.0 cm).

about 0.6 megabytes) for the 15 months of this study. These hourly data were reduced to daily flow estimates (Figure C-4), which represent interflow estimates for two of the capillary barrier designs with dominant downhill slopes of 5%. The capillary barrier design with the loam topsoil exhibited maximum daily interflow production rates approaching 0.24 cm, with 3.45 cm of total interflow occurring from February through April of 1992. The design with the clay loam topsoil exhibited maximum daily interflow rates of only 0.034 cm, with only 0.71 cm of interflow occurring during this time period. Most of this large difference in interflow can probably be attributed to the fact that the clay loam has a low conductivity (Nyhan et al. 1984, 0167), compared with the loam topsoil, which limited the flow of soil water into the fine sand layer in this design.

The estimates of interflow and seepage on all 16 plots for the first 15 months of this study are summarized in Table C-1. These data show that all of the capillary and hydraulic barriers are preventing seepage at all slopes and slope lengths tested in the study. Total interflow for the first 15 months of the study ranged from 3.4 to 6.1 cm on all of the EPA and capillary barrier designs containing the loam topsoil. In contrast, the conventional design, which did not contain an engineered barrier, produced seepage in almost every case tested and most of this seepage occurred from February through April of 1992, during and following a relatively dry winter (Figure C-3).

For the conventional design evaluated on the 5% slope, this 15-month total seepage occurred in the seepage collection system located 3.64 to 5.66 m downslope (0.21 cm), 5.66 to 7.68 m downslope (0.37 cm), and 7.68 to 9.70 m downslope (2.86 cm). This design only produced seepage 5.66 to 9.70 m downslope with a 15% slope and 7.68 to 9.70 m downslope with a 25% slope.

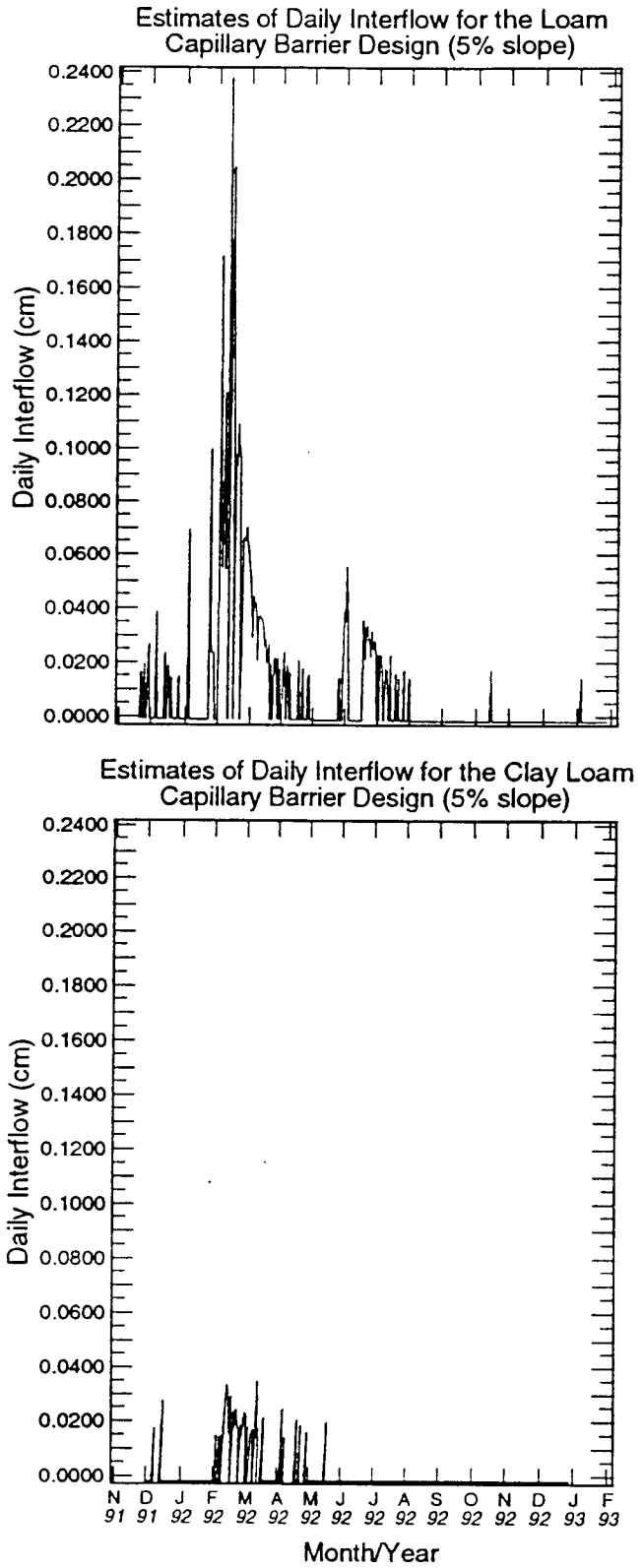

Figure C-4. Estimates of daily interflow for the Loam and Clay Capillary Barrier designs (5% slope) at the Protective Barrier Landfill Cover Demonstration in Los Alamos, New Mexico.

TABLE C-1

INTERFLOW AND SEEPAGE ESTIMATES FOR THE PROTECTIVE BARRIER LANDFILL COVER DEMONSTRATION AT LOS ALAMOS, NEW MEXICO (NOVEMBER 1991 THROUGH JANUARY 1993)

	Interflow (Seepage), in cm, for Dominant Downhill Slopes of			
Landfill Cover Design	**5%**	**10%**	**15%**	**25%**
Conventional	3.2 (3.4)	8.8 (0)	5.8 (4.0)	4.6(0.41)
EPA	5.4 (0)	6.1 (0)	4.3 (0)	4.5 (0)
Loam Capillary Barrier	4.8 (0)	5.1 (0)	3.4 (0)	3.9 (0)
Clay Loam Capillary Barrier	0.78 (0)	3.2 (0)	0.12 (0)	0.36 (0)

Run-off occurred on these unvegetated plots, from December 1991 through February 1992, as a result of snow melt, and during May and August 1992, as a result of thunderstorm activity. The total run-off from all 16 plots is summarized in Table C-2 for the first 15 months of the study. The largest daily run-off (0.54 cm) occurred on the EPA design with the 25% slope after a 2.16-cm precipitation event on August 24, 1992.

No consistent relationship exists between slope and run-off for either the clay loam topsoil used on the clay loam capillary barrier design or the loam topsoil used on all the other designs. Less than 15% of this total run-off (Table C-2) usually came from snow melt events during the first winter of the study, but this is not surprising since almost 30% of the total precipitation for the entire 15 months was received in May and August 1991 (Figure C-3).

TABLE C-2

RUN-OFF ESTIMATES FOR THE PROTECTIVE BARRIER LANDFILL COVER DEMONSTRATION AT LOS ALAMOS, NEW MEXICO (NOVEMBER 1991 THROUGH JANUARY 1993)

	Run-Off, in cm, for Dominant Downhill Slopes of			
Landfill Cover Design	**5%**	**10%**	**15%**	**25%**
Conventional	1.3	0.48	0.87	0.10
EPA	0.27	0.50	0.72	0.74
Loam Capillary Barrier	0.31	2.6	0.79	1.6
Clay Loam Capillary Barrier	0.88	2.1	1.7	3.3

2.1.4 Soil Water Data

Each of the 212 locations throughout the 16 plots was monitored for soil water content once every 6 h from November 1991 through December 1992, resulting in several 60-megabyte monthly computer files of TDR waveforms. These waveform data were then reduced to soil water content data.

Soil water data are presented for several layers of the conventional design evaluated at a position 9.7 m downslope in the plots with dominant downhill slopes of 5%

(Figure C-5) and 15% (Figure C-6). The water content of the loam topsoil is presented in the upper graphs in each of these two figures, representing the readings of a horizontally-emplaced pair of waveguides within the 15-cm-deep topsoil (at an actual depth of 5 to 10 cm). The water content of the crushed tuff backfill is presented in the lower graphs in the two figures.

The topsoil water content data from these two plots can be used to demonstrate the influence of aspect on snow melt dynamics during the short daylight periods of the winter when the sun is at a low angle on the horizon. For the plot with the 15% slope (Figure C-6, top), the volumetric water content of the loam topsoil rises from 14.2% on December 10, 1991 (at 6:20 am), to 27.9% on December 11 (at 2:44 pm) as a result of a snow event that accounted for 2.4 cm of precipitation added to the surface of the site. The volumetric water content steadily decreased to 7.1% on December 15 (at 5:08 am). All of this happened as the snow melted on the surface of this high-aspect plot, unlike what happened on the loam topsoil plot with the 5% slope (Figure C-5, top). This plot retained snow cover and only demonstrated a small increase in volumetric water content—to 19.0% on December 11, 1991 (at 2:44 pm).

The lower graphs in Figures C-5 and C-6 contain the soil water content data for the crushed tuff layer of the conventional design at a depth of 15 to 91 cm. The vertically-emplaced waveguides measured the average tuff water content from 20 to 80 cm, and the horizontally-emplaced waveguides measured the water content at the bottom of the crushed tuff layer (80- to 86-cm depth). These latter data, collected at the bottom and toward the end of the plot (9.7 m downslope), give a good representation of the influence of slope and seepage on water dynamics in these two plots. Seepage occurred in January, April, May, and June of 1992 on the plot with the 15% slope and finally stopped, resulting in an enormous decrease in volumetric water content (Figure C-6). The conventional design on the 5% slope demonstrated a gradual increase in tuff water content resulting in seepage starting in February 1991 (Figure C-5) instead of January 1991 (Figure C-6). The average tuff water content of the 20- to 80-cm depth was also significantly larger in the plot with the 5% slope (Figure C-5) than in the plot with the steeper slope (Figure C-6).

Soil water content data are presented in Figure C-7 for the EPA design with the 25% dominant downhill slope. The TDR data presented in the upper graph represent the measurements collected from a pair of 60-cm-long waveguides emplaced vertically in this soil layer. Many of the same snow melt relationships shown for the topsoil in the conventional design with the 15% slope (Figure C-6) can also be observed in this plot for December 1991. Soil water in the topsoil decreased as water drained into the medium sand layer (the EPA "drainage layer") at a depth of 61 to 91 cm. The horizontally-emplaced waveguides in this medium sand layer detected increased soil water content when interflow occurred in December 1991, as well as in the succeeding months of January and in late May through June. During the time that the interflow was occurring, the water content of the top portion (96- to 102-cm depth) of the hydraulic layer (the clay-tuff mixture) gradually increased from 10% to 20%, followed by a substantial increase to 36% by the end of the summer of 1992, as water from thunderstorms infiltrated the highly conductive loam topsoil (Figure C-7). The water content of both the medium sand layer and the top of the underlying hydraulic layer then decreased with reduced precipitation events in the fall of 1992.

The TDR data presented for the loam capillary barrier designs at slopes of 5% (Figure C-8) and 25% (Figure C-9) are meant to demonstrate the dynamics of three-dimensional water movement through the loam topsoil and underlying fine sand layers. Since no seepage occurred in either of these two designs, the soil water content data presented here can be used to understand why the barrier was a

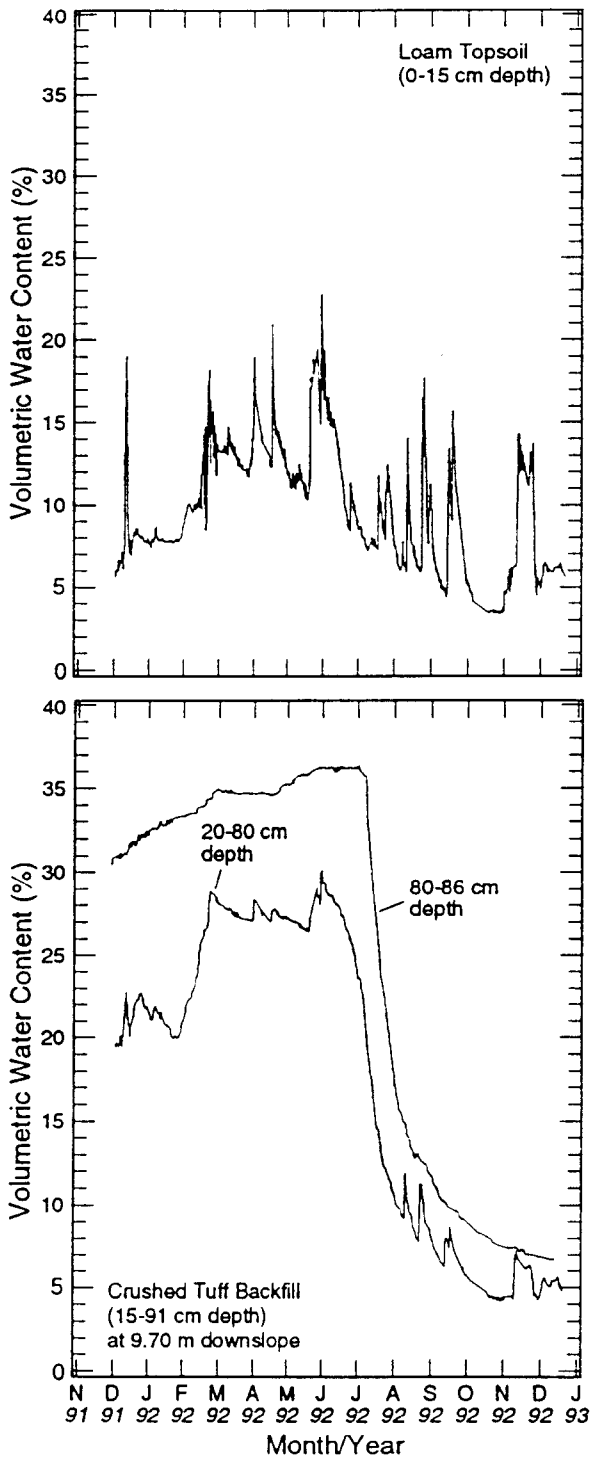

Figure C-5. TDR soil water content data collected for the Conventional Landfill Cover design with the 5% dominant downhill slope at the Protective Barrier Landfill Cover Demonstration in Los Alamos, New Mexico.

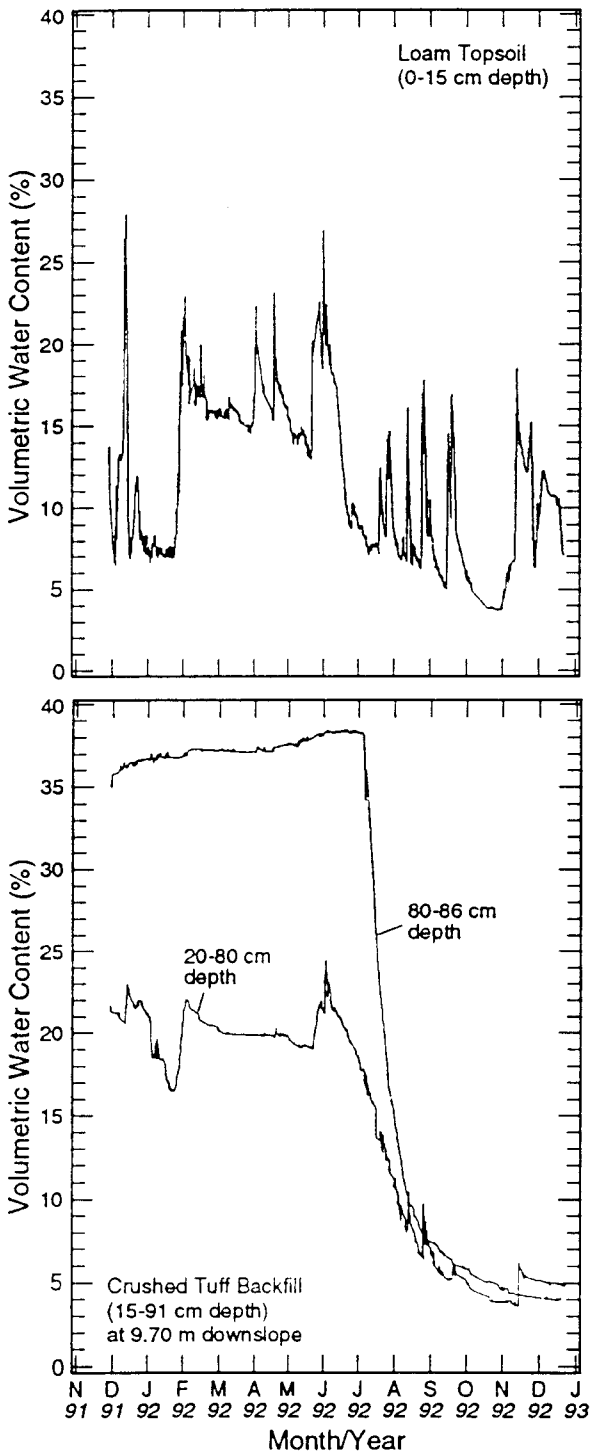

Figure C-6. TDR soil water content collected for the Conventional Landfill Cover design with the 15% dominant downhill slope at the Protective Barrier Landfill Cover Demonstration in Los Alamos, New Mexico.

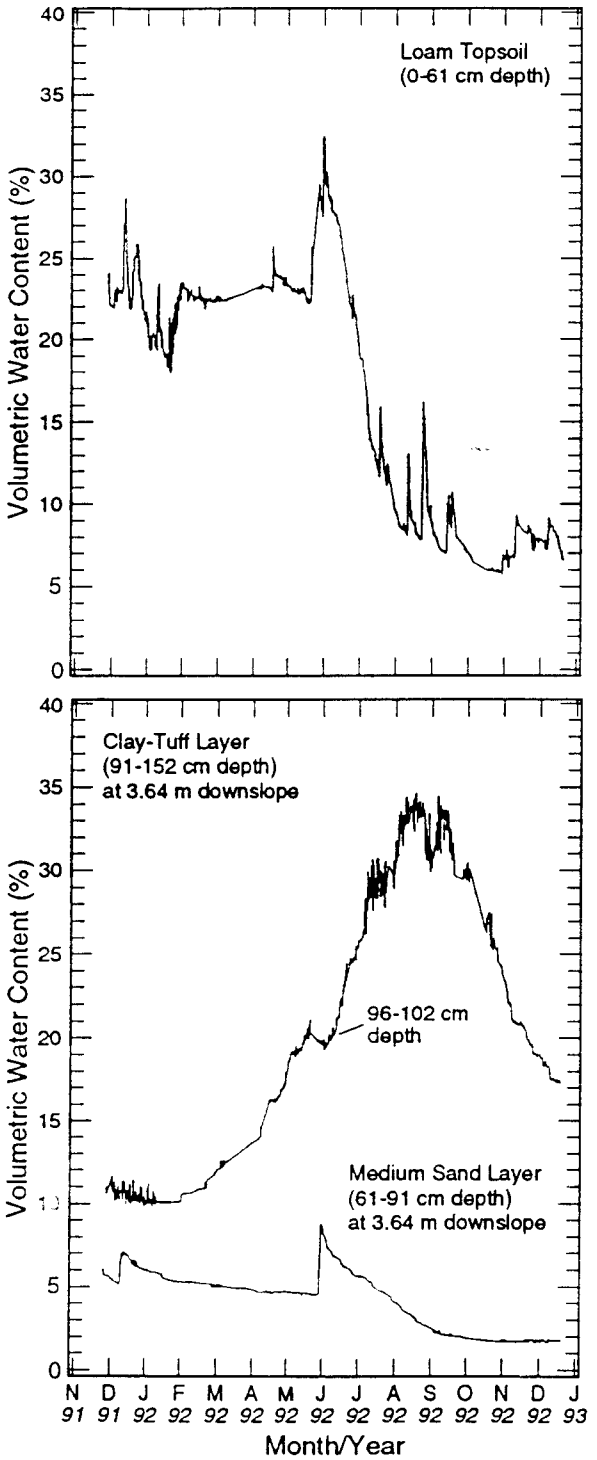

Figure C-7. TDR soil water content data collected for the EPA Landfill Cover design with the 25% dominant downhill slope at the Protective Barrier Landfill Cover Demonstration in Los Alamos, New Mexico.

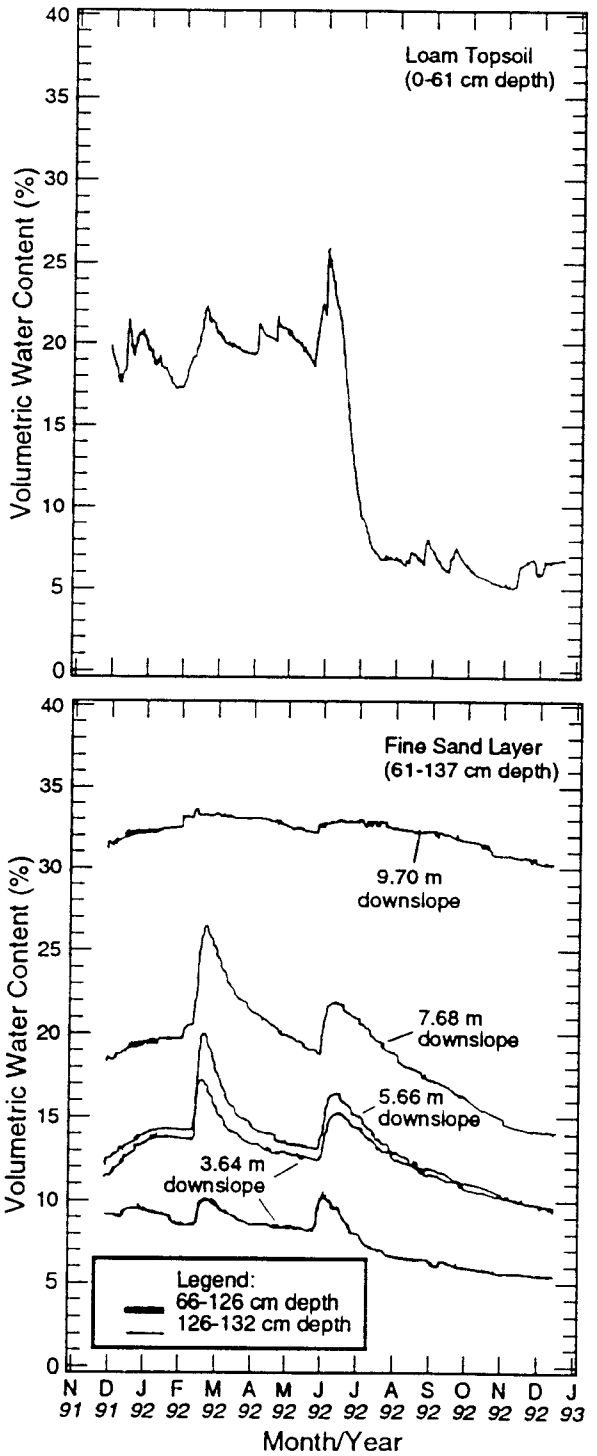

Figure C-8. TDR soil water content data collected for the Loam Capillary Barrier Landfill Cover design with the 5% dominant downhill slope at the Protective Barrier Landfill Cover Demon stration in Los Alamos, New Mexico.

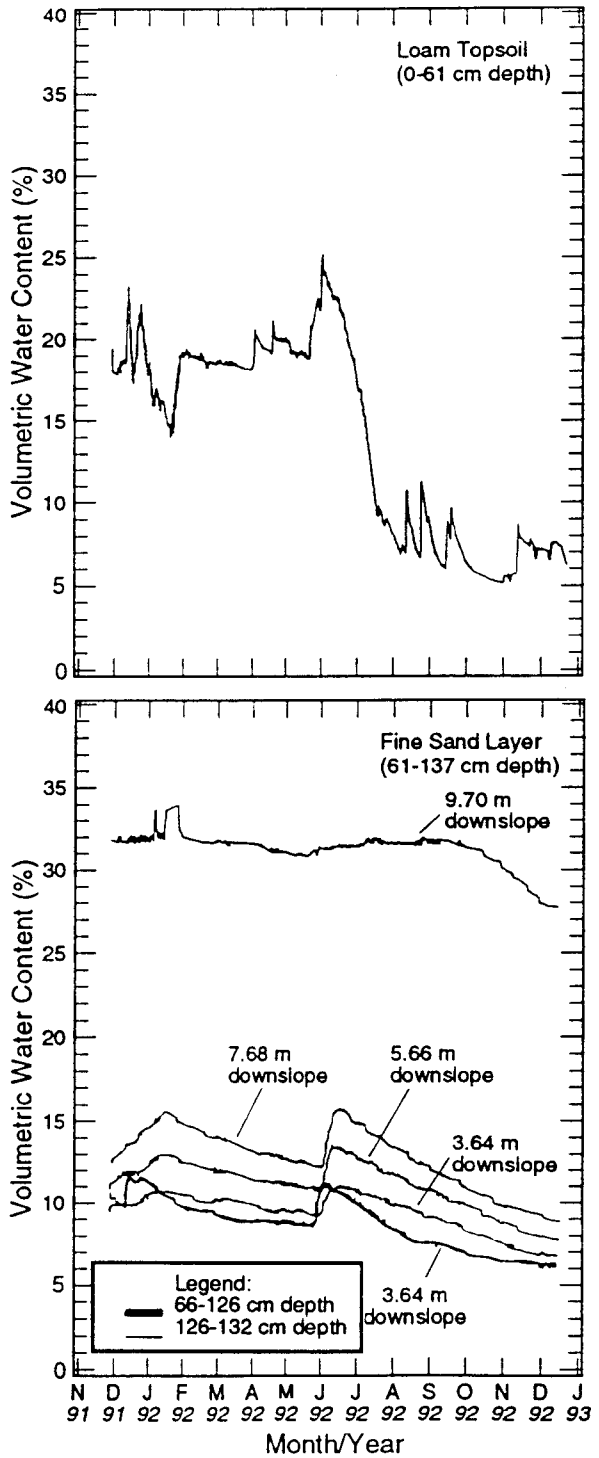

Figure C-9. TDR soil water content data collected for the Loam Capillary Barrier Landfill Cover design with the 25% dominant downhill slope at the Protective Barrier Landfill Cover Demonstration in Los Alamos, New Mexico.

success hydrologically and will be used to field validate several hydrologic models. The interflow data presented in Figure C-4 correspond with the TDR data presented in Figure C-8 for the loam capillary barrier design with the 5% slope. Approximately 3.5 cm of water moved out of the topsoil in this plot from January through March 1992, resulting in a dramatic increase in the water content of the underlying fine sand layer. TDR data (lower graph in Figure C-8) were collected to evaluate the water status of the layer of fine sand extending from a depth of 66 to 126 cm, as well as that of the bottom of the fine sand layer (126- to 132-cm depth) for four downslope positions within the plot. These data show that the water content at the bottom of the fine sand layer is considerably larger than the average water content of the entire layer. The TDR data also demonstrate that the water content at the bottom of the fine sand layer increased during interflow as a function of slope length, resulting in volumetric water content values observed at the maximum slope length (9.7 m downslope) in excess of 33% (Figure C-8). Thus, even at this location in the capillary barrier, the rate of infiltration of water into the fine sand layer was less than the capillary barrier's ability to conduct water laterally: matrix potential forces were still able to hold the water within the fine sand at the interface between the fine sand and the medium gravel.

The TDR data presented for the loam capillary barrier with the 25% slope (Figure C-9) show several of the same relationships discussed above for the same design evaluated on a 5% slope. Due to a much steeper slope, probably resulting in enhanced lateral flow rates, smaller differences were observed in the water content of the fine sand as a function of slope length than for the data from the 5% plot (Figure C-8). However, the same conclusions can be made for both plots for the data collected at the bottom of the fine sand layer at the maximum slope length tested (9.7 m downslope).

The TDR data for the clay loam capillary barrier design with the dominant downhill slope of 25% are presented in Figure C-10 to demonstrate the effect of a low-conductivity topsoil on capillary barrier dynamics. The daily interflow data presented in Figure C-4 for this design, evaluated on a 5% slope, are typical for this design compared with similar data from the plots on the other three slopes. The soil water content data for the bottom of the fine sand layer (25% slope) do not demonstrate multiple large pulses of water coming through the clay loam topsoil (Figure C-10), in contrast to what happened on the capillary and hydraulic barrier plots with the highly conductive loam topsoil (Figs. C-7 through C-9). Instead, investigators observed a pattern indicating a very slow drainage rate of water from the clay loam layer into the underlying fine sand layer, whose soil water content dramatically decreased from September through December 1992 (notice the TDR data at the 9.70-m downslope position), following the decrease in soil water content of the soil layer about 1 month previous to this time period (upper graph in Figure C-10).

2.1.5 Usefulness of Study and Future Directions

The most practical comparisons among the four landfill cover designs for a semiarid region, in terms of their usefulness to the burial site operator, should be the overall performance comparison of the water balance parameters for the duration of this field study. Ultimately, the site operator wants a design for a specific slope and slope length that minimizes long-term run-off and seepage and maximizes interflow and evapotranspiration. These water balance parameters are interdependent and need to be evaluated in the field using techniques and field data similar to those in this study.

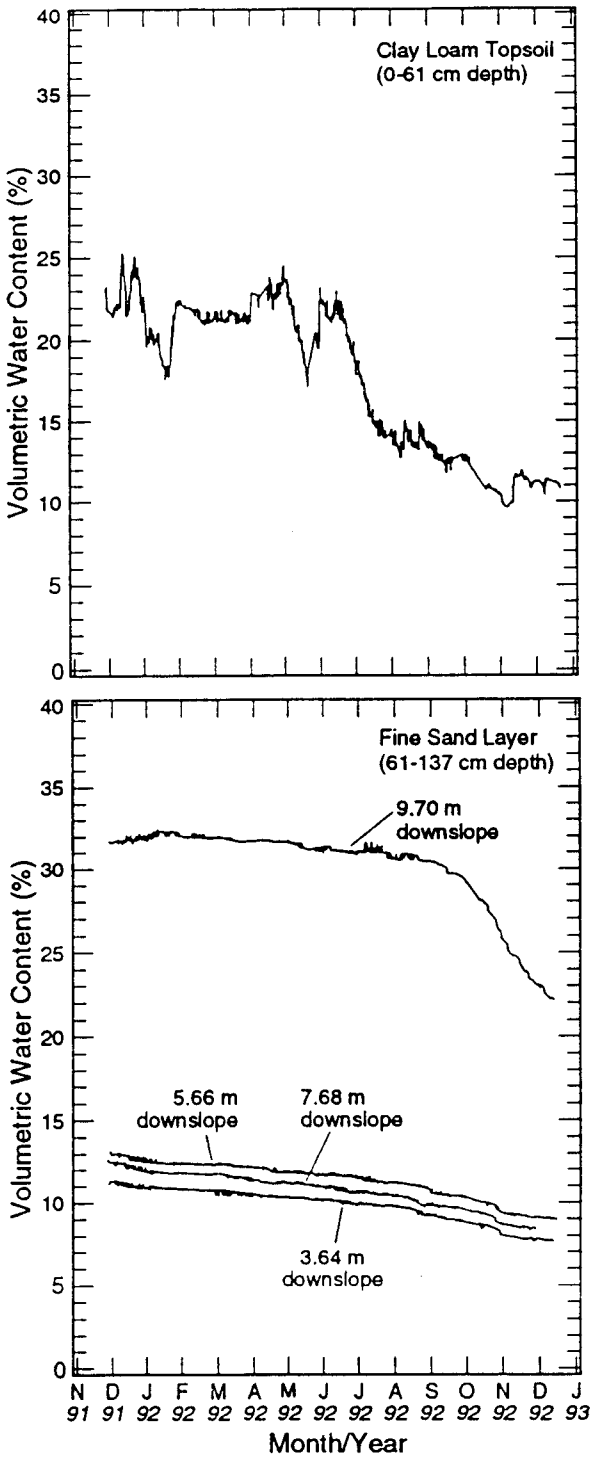

Figure C-10. TDR soil water content data collected for the Clay Loam Capillary Barrier Landfill Cover design with the 25% dominant downhill slope at the Protective Barrier Landfill Cover Demonstration in Los Alamos, New Mexico.

Only 15 months of data are presented in this manuscript for this study, yet investigators are already struggling to keep up with data analysis. Many of the commonly used computer software programs and hardware do not have the capacities to handle such large data sets, so personnel are in the process of connecting measurement systems for water flow and TDR to a local area net of computers to solve this problem. This will allow routine system diagnostic checks on the hydrologic sensors and to calculate water balance estimates on this entire data set. Once this is accomplished, investigators can evaluate important issues such as the time scale necessary to adequately describe a landfill cover design for waste management purposes. Coupled with this effort will be a major activity to develop field-calibrated hydrologic models that then can be used to evaluate future performance of the designs, such as the effect of a 100-year precipitation event on the design. The cost effectiveness and practicality of various designs can then be evaluated with the help of burial site operators and regulators, who will have major inputs into the selection of a final closure design for low-level radioactive and hazardous waste sites.

In FY94, the 16 field plots will be used to evaluate water balance relationships when artificial precipitation is added to the plots. The field plots will receive precipitation that simulates a 100-year event, an amount of water designed to make the capillary or hydraulic barrier (in the protective barrier) fail. All of these plots will be devoid of vegetation and, thus, will represent a worst possible case: minimal evapotranspiration and maximum interflow and seepage.

In FY94, the same plots will be used to determine the interaction between evapotranspiration and capillary/hydraulic barriers. The field plots will receive a plant cover consisting of a dominant local plant species (to be determined but may consist of piñon, rabbitbrush, and a mixture of range grasses). The data obtained from these field plots over the long term will allow determination of

- whether evapotranspiration can reduce the stress on the capillary/hydraulic barrier, thus improving the performance of the protective barrier;
- whether plant roots have an appreciable effect on the integrity of the capillary/hydraulic barrier; and
- whether the slope of the landfill cover has any solar-radiation-related effects on the interaction between plant cover and the performance of the capillary/hydraulic barrier.

2.2 Integrated Test Plot Demonstration

The pilot study of the Integrated Test Plot (ITP) Demonstration is documented in detail in the work plan [Appendix D in the 1992 IWP (LANL 1992, 0768)]. The ITP plots were emplaced at the EETF at TA-51. Two types of cover designs were tested: a Conventional Landfill Cover design similar to that already being used by the Laboratory and the waste management industry (Jacobs et al. 1980, 0330) and an improved design developed by the Laboratory.

Investigators installed four demonstration plots, two for each type of cover, at the EETF during the spring and summer of 1984 (DePoorter 1980, 0045) and provided instrumentation to measure and record precipitation, run-off, soil water storage, and seepage. The amount of seepage was determined by measuring leachate collected

by drains that had been installed in the plots. Except for a small amount of water added to the plots in mid 1984 to aid in establishing vegetation, the plots received only natural precipitation during the course of the study. In both cover designs, the technology for controlling erosion caused by soil water consisted of covering 60% to 70% of the plots' surface with gravel (<0.75 in. in diameter) and covering the remainder of the surface with blue grama and western wheat grass. A dominant downhill slope of only 0.5% was used on the plot surfaces to ensure that little or none of the rainfall would run off over the course of the experiment (both to maximize the potential for percolation and to simplify estimating the other parameters in the water balance equation). Each plot was designed to measure run-off (Nyhan et al. 1984, 0167).

Field data for FY93 are currently undergoing data analysis.

2.3 MDA B Studies

The pilot study at MDA B is documented in detail in the work plan for TA-21 [Appendix Q in the 1990 IWP (LANL 1990, 0144)]. Briefly, this pilot study consisted of 12 study plots (10 by 80 ft) that were installed in 1987 on an inactive waste site at which two different soil profiles had been used in the trench caps. Four surface treatments (grass/gravel mulch, grass/no mulch, shrub/gravel mulch, and shrub/no mulch) were used on plots at each of three locations on the site. Soil moisture, run-off, precipitation, and surface conditions have been monitored since 1987; sediment transport was monitored between 1987 and 1989 on some or all of the plots.

The pilot study at MDA B had used manual data acquisition of water balance parameters until 1993. An automated electronic data acquisition system was designed in FY91 and finally installed during 1993. Run-off from the 12 plots is collected in tanks located on the south side of the pilot study area. Each of these tanks is now equipped with a submersible pressure detector to continuously measure the water pressure and, thus, the water depth occurring during snow melt and summer run-off events. A submersible sump pump in the bottom of the tank pumps water from this tank to a second large tank for backup and overflow measurement. Pressure monitoring, data logging, and pump control are performed by a personal computer in a weatherproof enclosure mounted on the south fence.

Druck Inc. model 940 depth transducers are placed horizontally on the bottom of the tanks. The device is a temperature-compensated balanced bridge that is excited by 9 V dc and has a nominal output of zero V. The device output is ratiometric; the output is proportional to the excitation. In order to accurately measure the excitation over a 50-ft cable, the excitation is provided by one pair of wires and is measured using a second pair of wires connected directly to the device. This arrangement eliminates errors due to excitation voltage loss in the 50-ft cable. Volume data are logged to disk storage hourly plus whenever a significant event occurs, such as a pump turning on or off. Thus, data indicate the increase in water volume occurring in hours to months as an upward ramp in the volume data. When the water level nears the top of the tank, the pump is turned on for approximately 20 s to return the water level to near the bottom of the tank. Water volume calibration is achieved by logging pressure sensor output at five levels of manually measured water volume.

The instruments, computer, and pump operate from 12-V batteries that are recharged and maintained by a conventional charger and small transformers. In case of ac power interruption, the electronics and pumps will operate for more than one hour on a full charge. The water heaters for freeze protection operate at 28 V ac.

Campbell Scientific model 107B temperature probes are placed alongside the pressure sensors, as well as in the personal computer, the battery charger enclosure, and external to the enclosure, for measurement of ambient temperature. These devices incorporate a thermistor and resistor in series with a 1-kΩ sensing resistor. Excitation of minus 9 V is applied to the device. The voltage drop across the 1-kΩ sensing resistor indicates the current through the device and, therefore, the resistance of the thermistor. Since the output is ratiometric, it is necessary to measure the excitation voltage accurately.

A Smith-Gates model 450-50A2 watertight automatic water warmer rests in the bottom of each run-off tank to keep the run-off from freezing in the winter. It includes an automatic internal thermostat, but power applied to it is controlled by the computer. It has a power rating of 450 watts at 120 V ac, which corresponds to 24.5 watts at 28 V ac. The temperature of the water is sensed as described above and the heater is controlled to maintain a water temperature above 2°C. The only space heated is the collected water in the 12-in.-diameter tanks. A temperature sensor in the bottom of the tank is monitored by the microcomputer, which connects 28 V ac to a submersible heating element when the temperature reaches 2°C.

Lightning-induced transients on the incoming power line are snubbed and blocked by the varistors and a filter. Further suppression of power line voltage transients is by additional varistors. The purpose of the diode networks and adapters is to protect the electronics from lightning-induced transients.

Preliminary results that were further elucidated from the field data collected during FY93 show that the presence of a gravel/mulch cover reduces run-off and sediment transport because the gravel/mulch cover increases infiltration, which, in turn, increases the biomass and, thus, evapotranspiration. Shrub plots tend to have a drier soil profile than that of the grass plots, resulting in greater storage capacity for soil moisture during spring snow melt. This site will be monitored until 1998 to provide a long-term data base of responses to variations in the local climate.

2.4 Field Demonstrations at MDAs F and G

The pilot study field demonstrations will consist of four proposed landfill cover plots to be emplaced in each disposal area to evaluate the basic concepts embodied in the Protective Barrier Landfill Cover Demonstration at a larger field scale These demonstrations will contribute to the understanding of water balance relationships as a function of time (proposed for FY94 through the life of the task). Natural precipitation will be the input term. The most important characteristic of this final phase of the pilot studies will be the field scale of the study; the landfill cover designs will be tested on plots closer to the size of potential release sites (PRSs) than to the smaller size of the plots used for the field studies described previously. The soil type, slope, and profile components will be taken from the designs that performed the best at MDA B and at the EETF. Plant cover will be a variable in these field studies and will be chosen to match plant species native to each location and contained in the long-term woodland transects at each MDA (ponderosa pines and native grasses at MDA F and piñon and native grasses at MDA G). Thus, every variable in the water balance equation will be tested in each of four landfill cover designs adjacent to each disposal area, and testing of individual components and long-term testing will be performed in the other portions of the pilot study.

3.0 Natural System Studies

One of the major criticisms of closure plans for waste sites is that mandated waste site stability periods are so long that they will certainly be impacted by plant succession during the postclosure period. The long-term natural systems pilot studies at the EETF and MDA F will evaluate water balance relationships in a natural ecosystem that has evolved over a time span of over a million years. Specific goals for the long-term pilot studies of natural systems over the next 8 years are to

- complete the water balance studies at the sites by installing means to measure run-off, infiltration, and lateral flow over selected portions of the site and to continue measurement of evapotranspiration and storage of soil water; and

- complete the integrated ecosystem studies of productivity and evapotranspiration, using both field and modeling studies, and apply the models to remediated sites to estimate long-term effects.

These studies are being conducted at several scales in the field with the idea of developing landscape ecology relationships which will directly apply to the field scale of the waste sites to be remediated. In the first subsection, a hillslope hydrology study is described that was implemented in the summer of 1992 at TA-69 (adjacent to MDA F); this site is representative of a ponderosa pine community that over time will establish itself at MDA F. A description of the improvements in the piñon/juniper transect at the EETF is then presented describing field data and the addition of plots for determining run-off and sediment movement; a hillslope study similar to the one at TA-69 was initiated in the summer of 1993 adjacent to the piñon/juniper transect at TA-51. In the final subsection several remote sensing studies are mentioned with the idea in mind of including landscape ecology relationships in the program.

3.1 Ponderosa Pine Site at MDA F

In order to better understand how water moves in the higher elevation zones of the Pajarito Plateau, investigators have established a field experiment whereby soil moisture, surface run-off, interflow, and climatic data are continuously monitored on a 900-m^2 hillslope. Operational since January of 1993, this study has already begun to yield useful data, and some of the preliminary results are presented in this subsection.

The study site is a 900-m^2 hillslope in an open ponderosa pine woodland with an understory of grasses and forbs. The hillslope has been instrumented such that soil water, surface run-off, interflow, and weather conditions are continuously monitored. Soils in this area have been mapped by Nyhan et al. (1978, 0161) as Carjo soils, which are classified as Mollic Eutroboralfs. Site-specific information was provided by Watt and McFadden (1992, 0960), who described the soil at two locations in the 16-m interflow collection trench at the bottom of the hillslope. These soils, which developed primarily from alluvium overlying Bandelier Tuff, exhibited considerable variability in horizons, color, texture, horizon thickness and degree of development. A loess cap, about 200 mm thick, overlies the alluvium. The soil at the north end of the trench (and probably at the north side of the hillslope) is better developed and probably older than the soil at the south end. In the middle of the pit, the soil is thinner and overlays a bedrock high. As has been noted by others, there are near-surface

fractures in the Bandelier Tuff that are often filled with translocated clays or carbonates. Such fractures were present in the trench, where they were filled with carbonate lined red clays.

Data on surface run-off, interflow, soil moisture, and weather are collected continuously using a Campbell Scientific 21X data logger. The experimental setup is shown in Figure C-11. Surface run-off is measured individually from each of three contributing areas: (1) 735 m^2 on the north side of the hillslope; (2) 135 m^2 on the south side; and (3) a 10- x 3-m plot at the northeast corner. The total contributing area, then, is 900 m^2. Surface collectors are constructed from 10-in.-diameter PVC irrigation pipe. Longitudinal slots, 0.5-m long by 0.05-m wide, are cut into the collector pipe; the slots are separated by intervals of 0.1 m along the length of the pipe. The collectors are buried such that the bottom of the slots are even with the soil surface. A metal mesh covering the slots prevents large debris from being washed into the collectors. During run-off, water from each collector drains into a collection well, where its depth is measured by a pressure transducer. Water is then pumped into stock tanks for temporary storage.

Interflow is measured within a trench 16 m long by 2 m wide by 1.5 m deep, which was placed at the bottom of the hillslope, parallel to the slope and equipped with 12-m-long gutters at depths of 0.2 and 0.95 m. The trench was then backfilled with gravel. The gutters carry water to collection wells instrumented with Druck pressure transducers. A sump pump removes water from the wells when a specified depth, controlled by conductivity level sensors, is reached, and the amount of water pumped out is measured by a Great Plains Industry flow meter.

Soil water content and soil temperature data are being collected at the site. Soil moisture is monitored using TDR technology (Zeglin et al. 1992, 1048, pp. 187-208). The location of each TDR probe pair in the collection area is shown in Figure C-11. The probe pairs are placed vertically into the soil, at a depth of 0.3 m in the small plot and 0.6 m in other locations of the hillslope. In addition, a trench (instrument trench) about 1.5 m deep was dug adjacent to the northern boundary of the hillslope. In this trench were installed three columns of 10 probe pairs, each placed horizontally into the soil at depths of 0.02, 0.05, 0.4, 0.6, 0.8, 1.0, and 1.3 m. (The deepest probe in the west column was only 1.2 m.) About every 2 weeks, soil moisture is also measured using a neutron moisture probe at 12 locations on the hillslope. At each location, soil moisture is determined every 0.15 m to a depth of 1.5 m; below 1.5 m, measurements are made every 0.3 m to a depth of 3 m. Soil temperature is monitored by means of temperature probes emplaced adjacent to the TDR probes in the instrument trench.

The periods of most active run-off are the late winter (snowmelt) and the summer rainy season. Preliminary data indicate that water movement is most dynamic during the winter. Table C-3 shows the water budget for winter 1993 (November 1992-March 1993). During this period, 256 mm of precipitation (mostly snow) fell on the hillslope. A very small proportion was lost as surface run-off: most of the water was stored in the soil (water stored in the soil is available for evaporation and transpiration) and lost through interflow.

The conclusion that deep percolation was minimal during the observation period is based on the neutron probe measurements, showing no change in soil moisture below a depth of 1.8 m (see Figure C-12). This means than if any water were moving below this depth it would be in steady state and unsaturated conditions (and would be very small quantities). Another possibility is that water is moving preferentially through fractures in the tuff, bypassing each of the neutron probe locations.

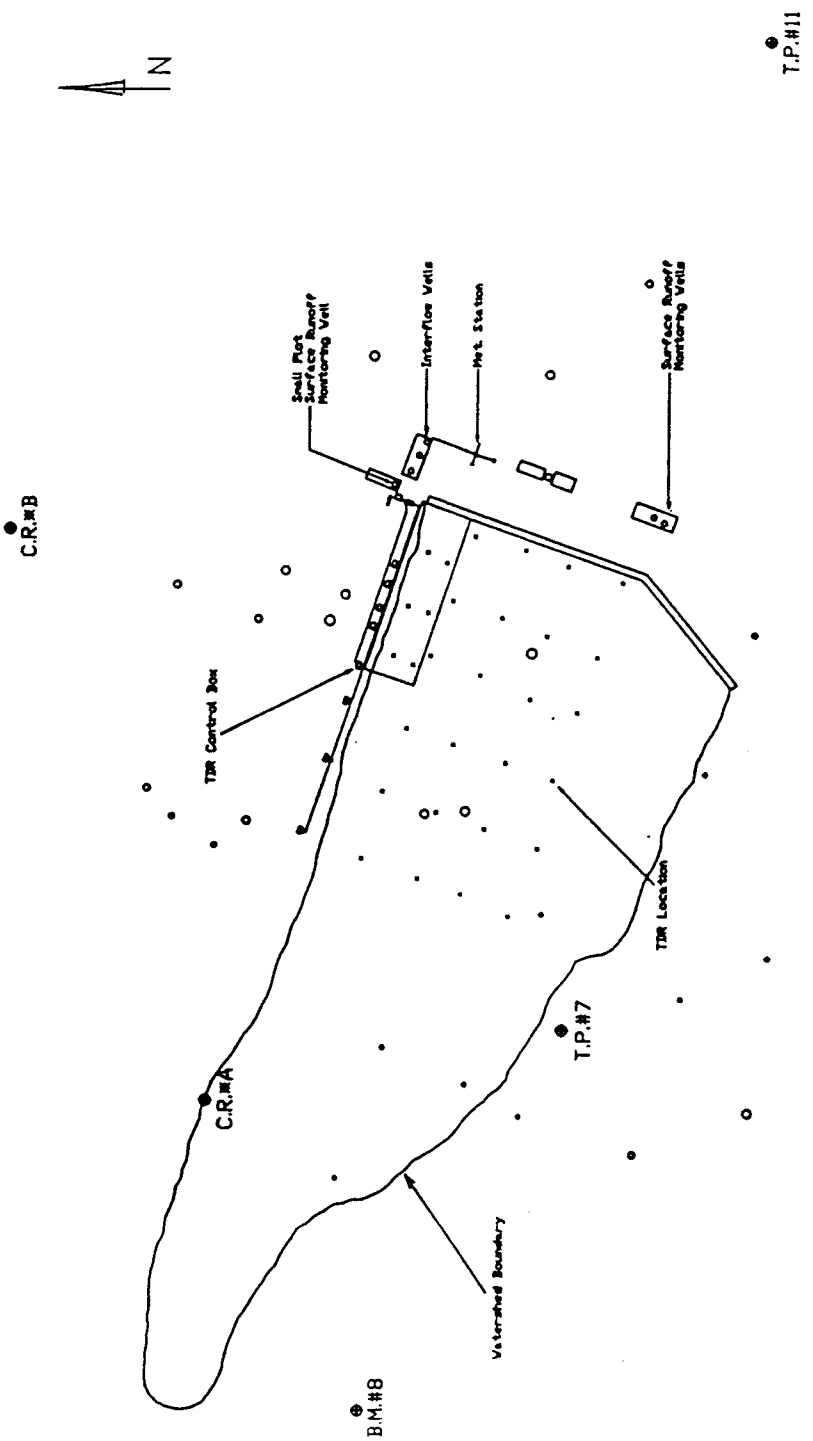

Figure C-11. Ponderosa pine hydrologic study at TA-6.

TABLE C-3

WINTER WATER BALANCE PARAMETERS FOR THE PONDEROSA STUDY AREA (NOVEMBER 1992 THROUGH MARCH 1993).

Water Balance Parameter	Amount (mm)
Precipitation	256
Soil storage	184
Run-off	2
Interflow, A horizon	5
Interflow, B horizon	44

The most dynamic component of the water budget was interflow. Collectors were placed such that interflow through the two major soil horizons could be sampled separately. As previously explained, the A horizon, about 20 cm thick, was made up mostly of a fine sand. The B horizon in contrast was quite thick (about 75 cm) and very clayey. Daily monitoring of interflow through these soil horizons showed that it began around the middle of February and ended around the first of April (Figure C-13). Three peaks were recorded; the first two were related to melting snow as temperatures rose and a third related to a rain-on-snow event. Figure C-13 shows daily interflow measurements in relation to temperature for this period. In Figure C-14, a more detailed picture of the dynamics of interflow is presented: hourly interflow for the B horizon is shown in relation to hourly ambient temperature over a 6-day period. Temperature and interflow both have strong diurnal dynamics. There appears to be about a 6-h lag between peak ambient air temperature and peak interflow.

These data suggest that water is moving very rapidly though this hillslope, much more rapidly than would be explained by the hydraulic conductivity of the soil matrix. Laboratory determinations of hydraulic conductivity for one location on the hillslope (Stephens and Associates, Inc., 1993, 1039) indicate that saturated hydraulic conductivity is much too low (7.5×10^{-5} and 2.5×10^{-8} cm/sec for the A and the B horizon, respectively) to explain the rapid interflow that was observed. One possible explanation for this observation is that water is moving rapidly through the soil via preferential flow paths, such as in macropores—very large pores created in the soil by plant and animal activity.

The analysis presented above is preliminary, but even at this early stage of observation and data analysis, significant advances have been made in our understanding of water movement on the Pajarito Plateau. Before this study, interflow had been very little discussed or acknowledged as a potential mechanism of contaminant movement on the Pajarito Plateau. Investigators now have strong evidence that in the higher-elevation regions of the Plateau, interflow is potentially a major mechanism by which contaminants move. This study and others like it will provide a framework for a much better understanding of water movement on the Pajarito Plateau.

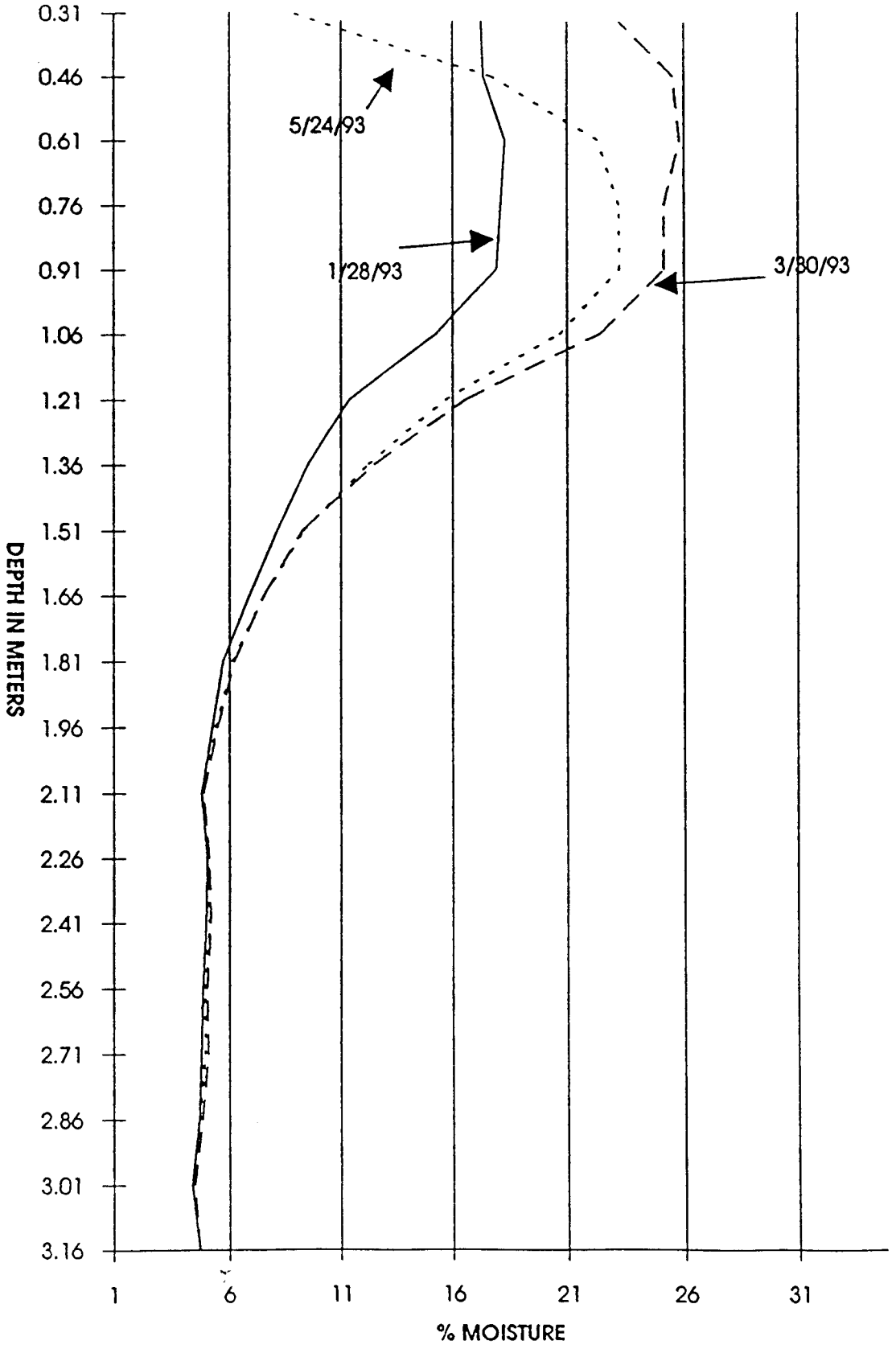

Figure C-12. Neutron probe soil moisture data collected at the Ponderosa Study Site.

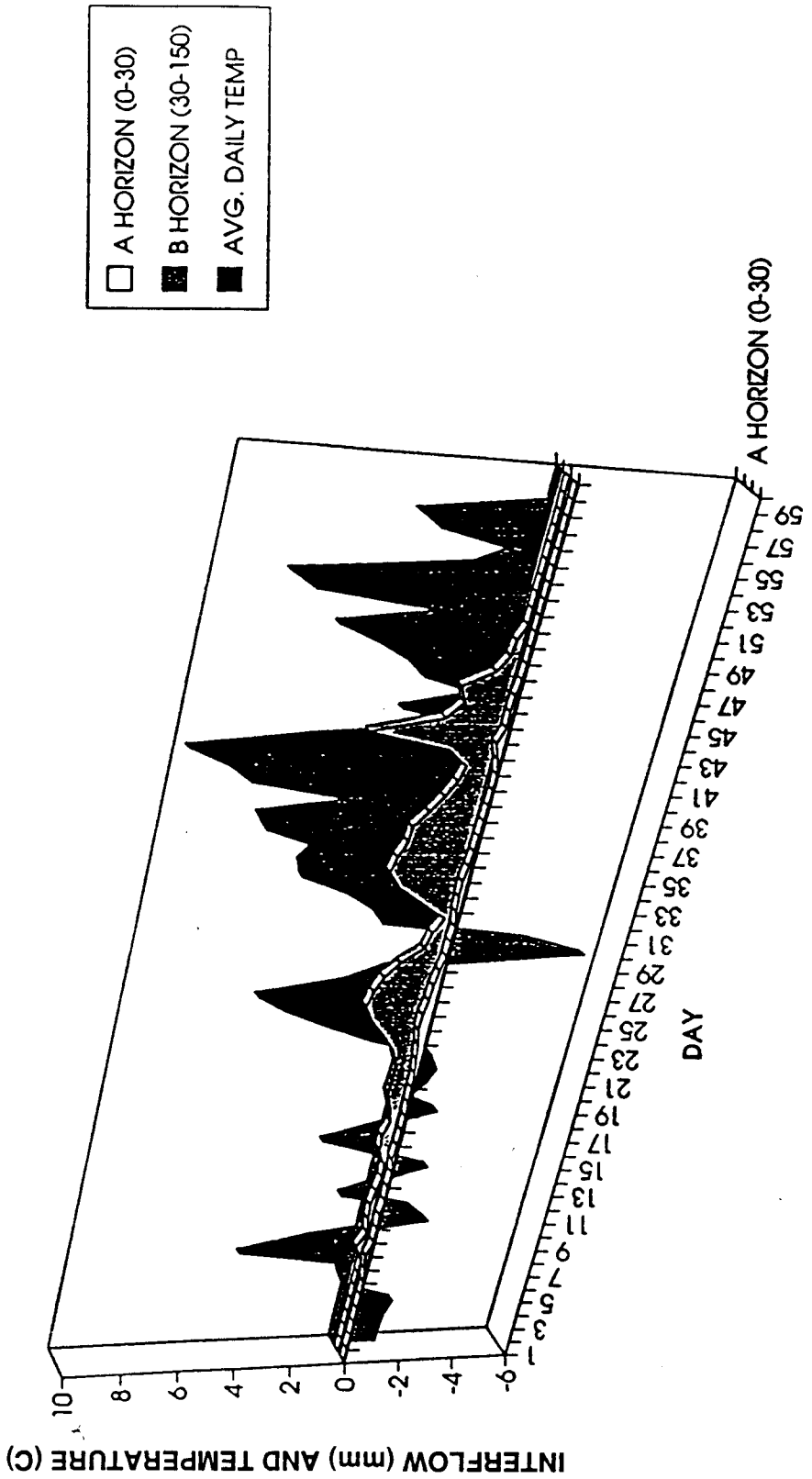

Figure C-13. Interflow and temperature data collected at the Ponderosa Study Site.

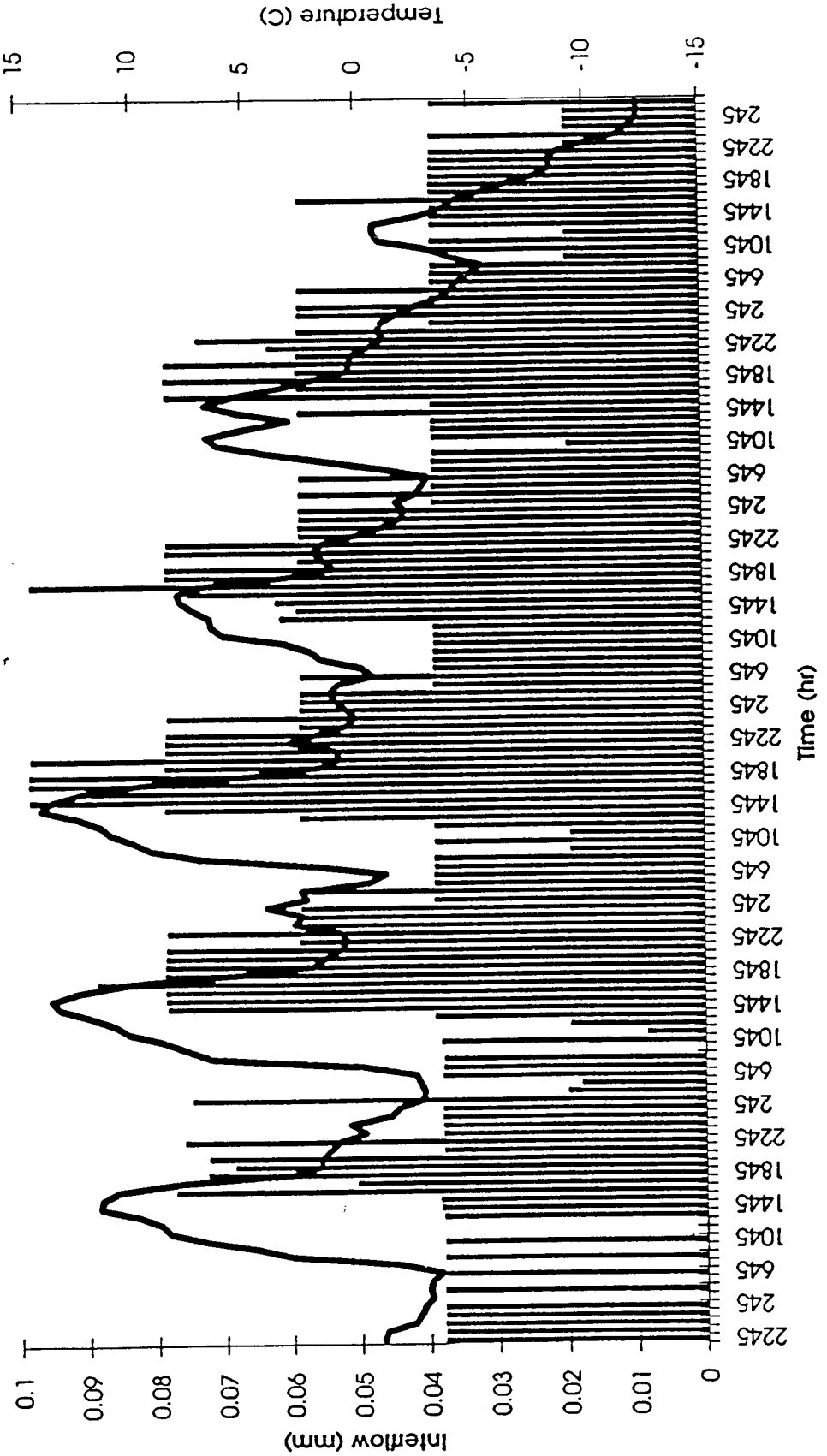

Figure C-14. Hourly interflow and temperature data collected at the Ponderosa Study Site (the solid line represents temperature, and the bars represent interflow).

3.2 Piñon/Juniper Woodland Site at TA-51

3.2.1 Plant Community Studies

Available soil moisture is viewed as a dominant constraint on plant community structure in semiarid regions, yet few studies have demonstrated how variability in soil moisture differentially influences herbaceous and woody life forms within the same community. Plant and soil moisture relationships for three dominant species in a semiarid woodland, *Bouteloua gracilis*, *Juniperus monosperma*, and *Pinus edulis*, were studied for 1.5 years to test for differences in soil moisture as a function of depth, plant cover, and spatial arrangement of woody vegetation (Breshears, in preparation, 1027). Soil moisture was most variable in the top 20 cm and decreased with depth from 40 cm downward. These patterns were modified by plant cover. Soil moisture in early spring was greater in intercanopy patches that separate trees than beneath tree canopies; these trends reversed as the soil profile dried. Upper soil (30 cm) was generally drier beneath junipers than piñons. Seasonal depletion of moisture beneath trees was not modified significantly by the spatial arrangement of neighboring trees.

Plant water potential and conductance differed among species and was related to spatial variability in precipitation input and corresponding changes in soil water content. Preliminary analyses along the 100-m transect in the piñon/juniper study site continued in FY93 at 2-week intervals and indicated that soil water content at the woodland site (a 3-year record obtained from neutron activation and/or TDR measurements) shows strong seasonal variation corresponding to precipitation inputs (Barnes et al. 1992, p. 43, 0892). Precipitation infiltrated to a depth of 40 to 60 cm, with only small changes in tuff water content observed below 60 cm. Water potential for blue grama was most correlated with soil water content in the uppermost layer (0-15 cm) of intercanopy spaces, while that of junipers was correlated with uppermost soil moisture in both canopy and intercanopy soil layers and with deeper (60 to 100 cm) layers in the intercanopy. Piñon water potential, which was least variable, was not significantly correlated with any single depth or patch type. Piñons had consistently greater maximum conductance rates than junipers, even though piñon conductance was more sensitive to reductions in soil moisture.

A detailed topographic survey (0.5-ft contours) of the piñon/juniper transect was conducted in FY92. Each tree was tagged and mapped, and basal diameter and height were measured. These data were entered into the ARC/INFO Geographical Information System (GIS) data base at ER Program's Facility for Information Management and Display (FIMAD) in FY93. This data set will form the basis for studies on variability in the woodland area and the interaction between surface variability and hydrologic response. Additional measurements of the fine-scale variability in surface soil moisture were taken in August and November 1991 and are being correlated with the canopy structure data obtained along the transect in FY91. Canopy architecture was determined (Barnes et al. 1992, 0892) from tree mapping, fish-eye photographic records, and light-gap fraction recorded at ground level. Spatial variability in soil moisture can be related to interception of precipitation by the canopies and possibly also to radiation inputs at the ground level. Obtaining such measures of the fine-scale temporal and spatial variability in sensitive parameters are essential if investigators are to bound the reliability of prediction of performance of a site over the long term.

Analysis of data from a prior study in piñon/juniper woodlands indicated that the differences among life forms in plant/soil moisture relationships in this study translate into differences in community structure. The ratio of seasonally integrated water potential of herbaceous species to that of woody species was negatively correlated with the ratio of herbaceous to woody cover across six locations along an elevational gradient. These results support Walter's two-layer hypothesis, which predicts that the ratio of herbaceous to woody biomass at a site is a dependent on the proportion of soil moisture available to the deeper roots of woody plants. In addition, these results suggest that a feedback between spatial variability in soil moisture and plant community structure could modify the predictions of the two-layer hypothesis. Such a feedback is plausible because 1) soil moisture varies with plant cover, as well as depth, and 2) herbaceous and woody plants obtain water differentially from canopy versus intercanopy and upper versus lower soil regions. This feedback may provide a useful framework for understanding why the proportion of woody vegetation increases dramatically following disturbance in many semiarid ecosystems.

Plant physiologic measurements were obtained along the piñon/juniper transect at TA-51 every 2 to 4 weeks during the 1992 growing season. These data (predawn plant water potentials, stomatal conductance, and transpiration rates) are essentials for modeling water balance in the woodland. Changes in these parameters as a function of soil moisture availability and other environmental parameters (e.g., air and soil temperatures, light availability, and nutrient status) will be required for modeling both the hydrologic regimes and site stability across the areas of interest. Measurements of these parameters were continued in FY93. A hillslope run-off and sediment collection study was also initiated in FY93; the area for this study is somewhat larger than the erosion plots, and the study is currently being installed on a gradual slope with woody vegetation. Techniques developed for the ponderosa pine hillslope study were used at this site.

3.2.2 Hydrologic Soils Studies

In addition to the plant community studies described above, several hydrologic soils studies were performed in FY93 within intercanopy zones of the piñon/juniper woodland at TA-51. Investigators established six plots for monitoring in intercanopy zones of a piñon/juniper woodland, each measuring 3.04 x 10.64 m (Intercanopy zones were selected for study because they are assumed to be the major source areas for run-off.). The study area is near the upper limit for piñon/juniper on the Pajarito Plateau (Barnes 1986, 1025). Soils at the site are described by Nyhan et al. (1978, 0161) as Hackroy series (Alfisols of the subgroup Lithic Aridic Haplustalf and family clayey, mixed, mesic). These are shallow soils that have developed on the volcanic tuff parent material and are characterized by a loam or sandy-clay-loam surface texture with a strong clay or clay-loam argillic horizon at a depth of about 10 cm.

Four of these plots (C, D, E, and F) had been used earlier for rainfall simulation studies associated with the development of the WEPP soil erosion model (Simanton and Renard 1992, 1038). All vegetation (including root crowns), cryptogamic crust, litter, and rock cover had been removed from two of these (C and F) in 1987; there has been regrowth, but grass cover—and especially cryptogamic crust cover—is much more sparse, and bare ground is more extensive than on the other plots (Plot F recovered the least and has the most bare ground). Vegetation on plots A, B, D, and E was left undisturbed. The dominant grass species on all the plots is blue grama (*Bouteloua gracilis*), and common semishrubs and forbs are bitterweed (*Hymenoxys richardsonii*), fringed sagebrush (*Artemisia frigida*), Navajo tea (*Thelesperma filifolium*)

and Indian paintbrush (*Castilleja integra*). Although grazing by domestic livestock had a profound effect on the original composition of the vegetation in this region, such grazing has been prohibited for the past 50 years.

All six plots were modified in July 1991 to collect naturally occurring run-off. A metal gutter was installed across the width of each plot at the downslope end. Two collection tanks, a primary and an overflow, having a combined capacity of about 600 L, were placed 20 to 30 m downslope, and each was calibrated such that the water volume can be estimated from the depth. A drainline connected to a hole in the bottom of the gutter carries the run-off to the tanks, which are kept covered with plywood to prevent evaporation. (The degree of slope and the extent of basal cover of each plot are given in Table C-4.) Basal cover was determined from point measurements taken every 5 cm along five transects running the width of each plot (at intervals of 2 m).

Throughout the study, the plots were inspected regularly for signs of leakage under the collection plate, and soil was added at the juncture if needed. (Such leakage is most pronounced in late winter, when frequent thawing and refreezing increases the likelihood of separation of the collection plate from the soil.)

Run-off and erosion data were collected from July 1991 to March 1993. Run-off volume was measured for each event, including snowmelt. Because only plots A and B were completely operational during the first two run-off events of 1991, volumes for those events for the other four plots were estimated using a regression relationship (Plot B run-off versus that of plots C through F for the next six run-off events). The coefficient of determination (R^2) was found to range from 0.70 to 0.88.

Investigators were unable to collect any winter run-off from Plot C because of recurrent freezing of the drainline. In the case of Plot E—and possibly F, as well—leakage problems during the second winter (1992-93) lowered the amount of run-off water collected in the tanks.

To calculate rates of erosion, investigators collected sediment samples from each plot for each summer run-off event (except, for the first event, no samples were obtained; and for the second, samples were obtained from plots A and B, only). Because sediment concentrations are much less variable during the winter, samples were taken only for selected events, on the basis of which a mean concentration was calculated for each plot. These sediment concentration values were generally based on three samples from each plot, but in some cases only one or two samples were collected.

TABLE C-4

PLOT SLOPE AND BASAL COVER CONDITIONS

Plot	Slope (%)	Degree of Disturbance	Basal Cover (%)						
			Grass	Shrub	Forb	Cryptogamic Crust, Moss	Litter	Bare Ground	Other*
A	4.4	Negligible	12.3	2.7	0.3	51.6	20.5	12.0	0.6
B	4.8	Negligible	8.1	1.0	1.4	43.7	16.3	26.8	2.8
C	4.4	Severe	5.4	6.5	2.2	29.1	10.1	46.8	0.0
D	5.2	Negligible	22.7	1.4	1.7	50.2	17.9	6.2	0.0
E	5.3	Negligible	10.8	3.1	1.0	53.9	18.0	13.2	0.0
F	5.7	Severe	4.4	4.1	1.0	26.6	2.4	61.1	0.3

*includes rock, lichen, and cactus

Summer precipitation was measured on a daily basis using on-site volumetric precipitation collectors. These gauges are not suitable for measuring snowfall, for which investigators used a heated, tipping-bucket rain gauge located about 3 km southeast of the site.

3.2.2.1 Field Data

A monthly summary of run-off from April 1991 to March 1993, averaged across all the plots, is presented in Figure C-15 (although no data were collected until July 1991, investigators were able to extend the record back to April because on-site observation confirmed that no run-off had occurred in the interim). These data show clearly that run-off in piñon/juniper woodlands in northern New Mexico typically has two "seasons": mid summer and mid-to-late winter. Summer run-off is generated from intense thundershowers, and winter run-off is produced by snowmelt augmented by frozen soil conditions and, at times, rain-on-snow. Run-off and precipitation amounts for the two seasons are compared in Table C-5. Figure C-16, which compares the frequency of summer and winter run-off events with the amount of run-off, shows that (1) large run-off events were much less frequent than small run-off events, and (2) the largest run-off events occurred during the summer months.

During the 2-yr study period, run-off accounted for 10% to 18% of the water budget for undisturbed plots and up to 28% for disturbed plots (Table C-5), which is a higher proportion than at most of the piñon/juniper sites studied to date. The most likely explanations are the small scale of the study (as will be discussed later) and the high elevation of the study area, which is near the limit for piñon and juniper (as was seen in the Beaver Creek studies, run-off increased dramatically at the higher elevations).

The amount of run-off collected the first summer (1991) represented a significant portion of the summer water budget—in contrast with the second summer (1992), when run-off was almost negligible (Table C-5). Long-term precipitation data (1911-1992) collected at a Los Alamos site about 300 m higher than the study site indicate that summer 1991 was wetter than average, whereas summer 1992 precipitation was about average (Figure C-17). Investigators conclude from this that summer run-off in 1991 was higher than average. Figure C-18 shows the relationship between precipitation and run-off amounts during the summer of 1991 for Plot F, where the greatest amount of run-off was measured. Note that from about mid July to mid August, when thundershowers were very frequent, run-off amounts were much higher with respect to precipitation amounts than during previous drier periods, and some run-off was generated during almost every precipitation event. The likely explanation for this is that as soil moisture increases, soil infiltration capacity decreases—a phenomenon well documented in the rangeland hydrology literature (e.g., Wilcox et al. 1988, 1042). Soil moisture data collected during the summer of 1991 from a woodland area adjacent to the study site show that soil moisture increased from around 15% in May to about 35% in early August (Barnes et al. 1992, 0892).

Figure C-19 compares cumulative precipitation with cumulative run-off by plot for both summers, 1991 and 1992. The very different patterns of precipitation are evident: not only was there less precipitation overall in 1992 than 1991, it was also more spread out. The other major observation was the difference in run-off between the undisturbed and the disturbed plots. Run-off amounts for both summer seasons were substantially higher for plots C and F than for the other plots (see also Table C-5). It was especially high for plot F, where there was less regrowth of vegetation (Table C-4).

TABLE C-5

RUN-OFF AND PRECIPITATION, BY SEASON

Season	Precip-itation (mm)		Plot Run-Off A	B	C	D	E	F	Avg
Summer 1991	365	Total (mm)	26.9	50.0	86.1	42.2	60.9	87.7	59.9
		%	7.4	13.7	23.6	11.6	16.7	24.0	16.2
Summer 1992	247	Total (mm)	2.1	1.1	7.4	2.5	1.8	24.6	7.0
		%	0.8	0.4	3.0	1.0	0.7	10.0	2.8
Winter 1991-2	118	Total (mm)	47.8	25.6	*	41.8	71.8	74.0	52.2
		%	40.5	21.7	*	35.4	60.9	62.7	44.2
Winter 1992-3	151	Total (mm)	31.7	18.0	*	60.4	32.5	74.5	43.4
		%	21.0	11.9	*	40.1	21.6	49.4	28.8
Totals, Apr 91-Feb 93	929	Total (mm)	108.5	94.7		146.9	167.0	260.8	
		%	11.7	10.2		15.8	18.0	28.1	

*Plot C was not operational during the winter.

Run-off measured during the two winter seasons (1991-92 and 1992-93) was appreciable, averaging more than 52 mm for winter 1991-92 and nearly 43.5 mm for winter 1992-93 (Figure C-15, Table C-6). Even though the amount measured during the second winter was probably somewhat underestimated because of leakage problems at plots E and F—especially E—the overall results show higher run-off the first winter. This is particularly clear in the case of plots A and B, where investigators are reasonably certain there was no leakage. The only plot where more run-off was measured the second winter was Plot D. What is especially interesting is that the winter with the higher run-off was also the winter with the lower precipitation (Table C-6); as a percentage of the winter water budget, run-off accounted for more than 44% the first winter versus less than 29% the second winter.

A more comprehensive picture of winter run-off patterns is presented in Figure C-20, where cumulative run-off for each plot is compared with cumulative precipitation. This figure shows, first, that during the winter of 1991-92, most of the run-off came from snowmelt in the absence of precipitation; during the following winter, most of the run-off was produced by rain-on-snow events (as seen in the figure, at least three such events were recorded, on Julian days 7, 39, and 50). Second, general

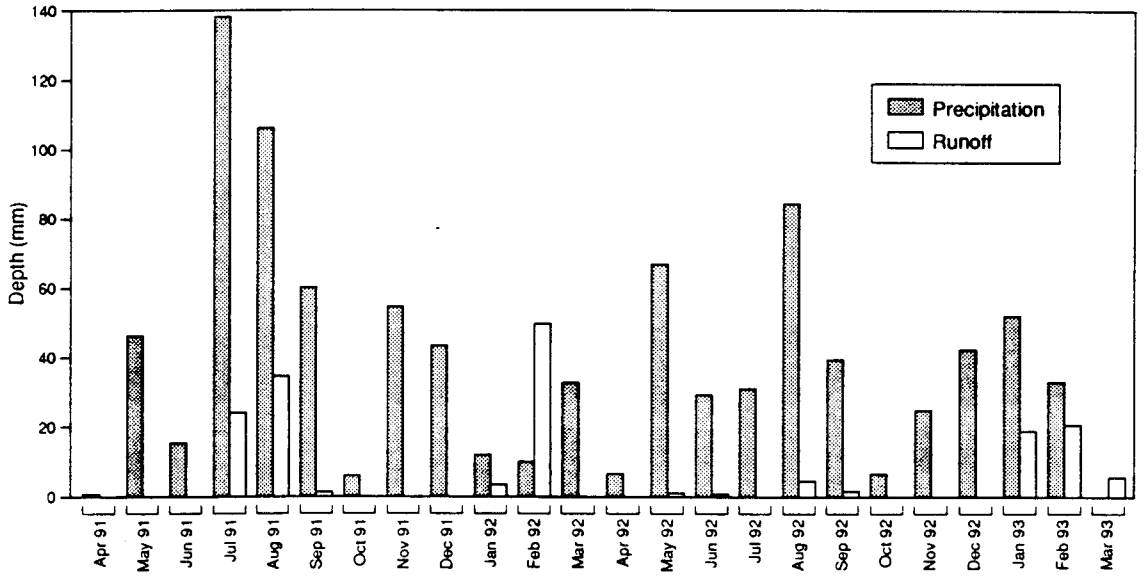

Figure C-15. Monthly precipitation vs run-off (totals averaged for all plots), April 1991 through March 1993.

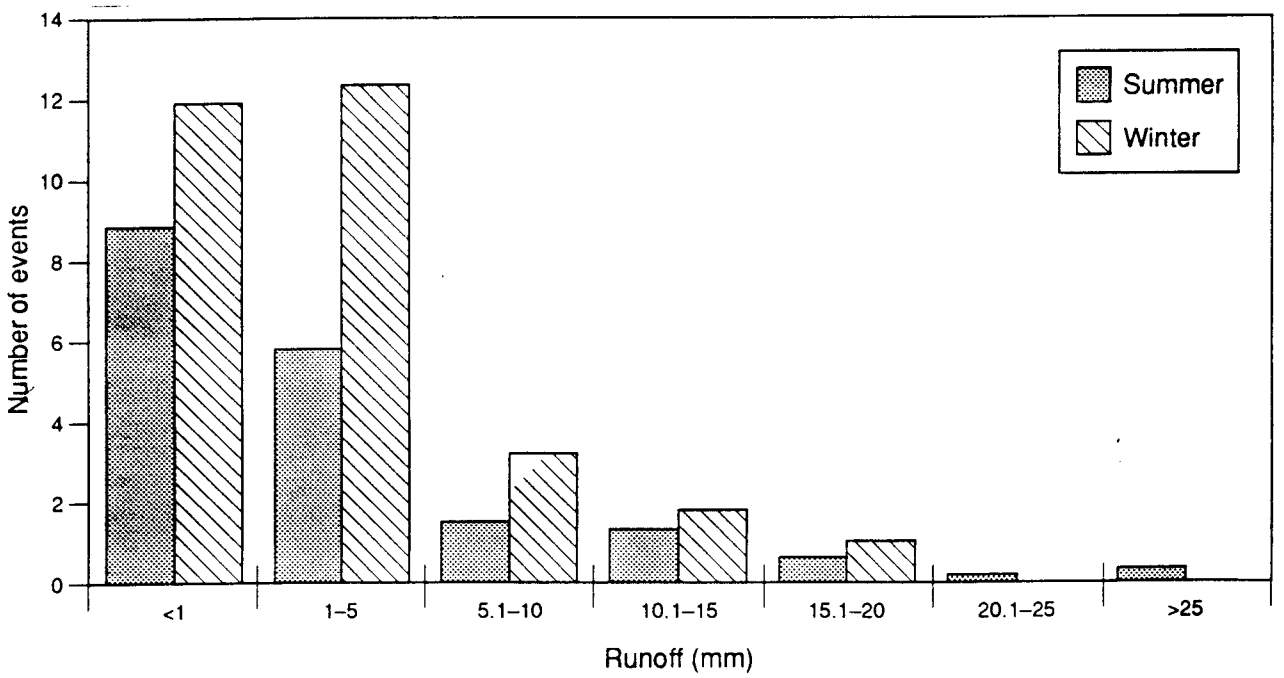

Figure C-16. Frequency distribution of summer and winter run-off events (averaged across all plots), April 1991 through March 1993.

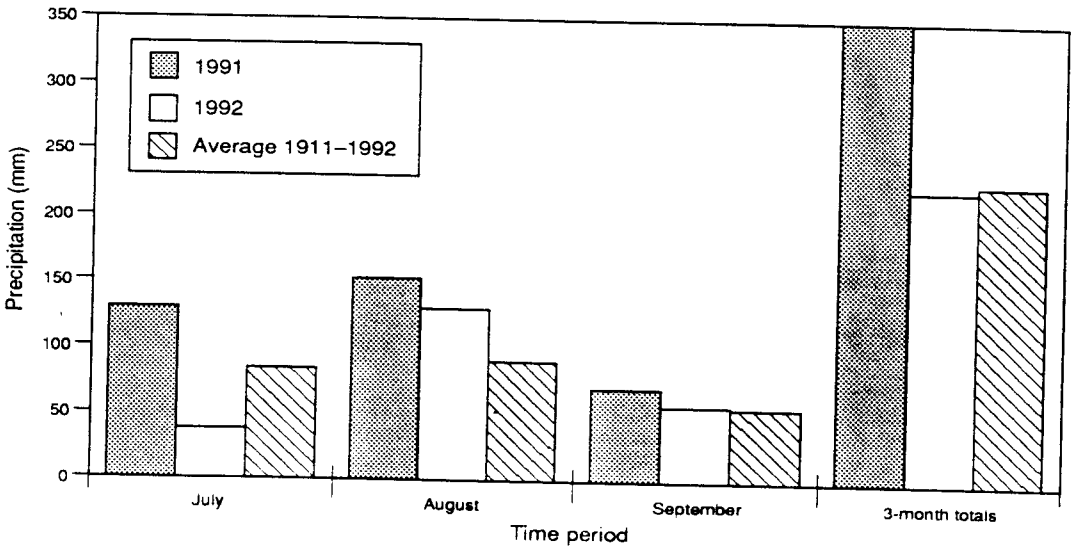

Figure C-17. Comparison of 1991, 1992, and averaged (1911-1992) summer precipitation amounts.

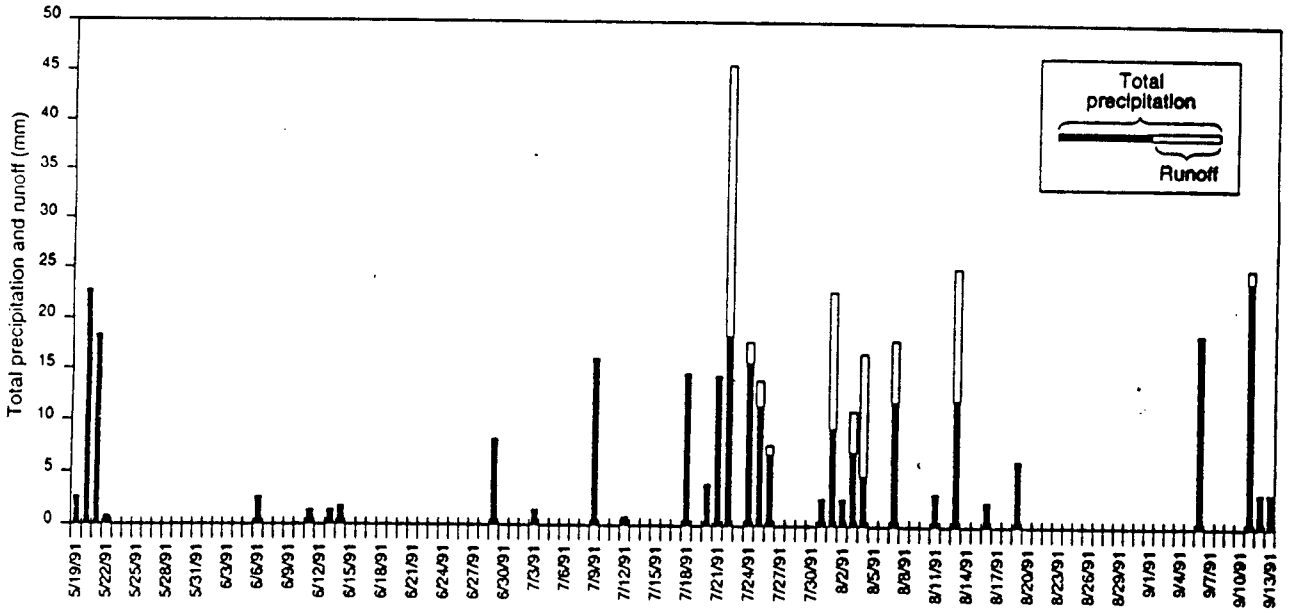

Figure C-18. Relationship between precipitation and run-off for Plot F, summer 1991.

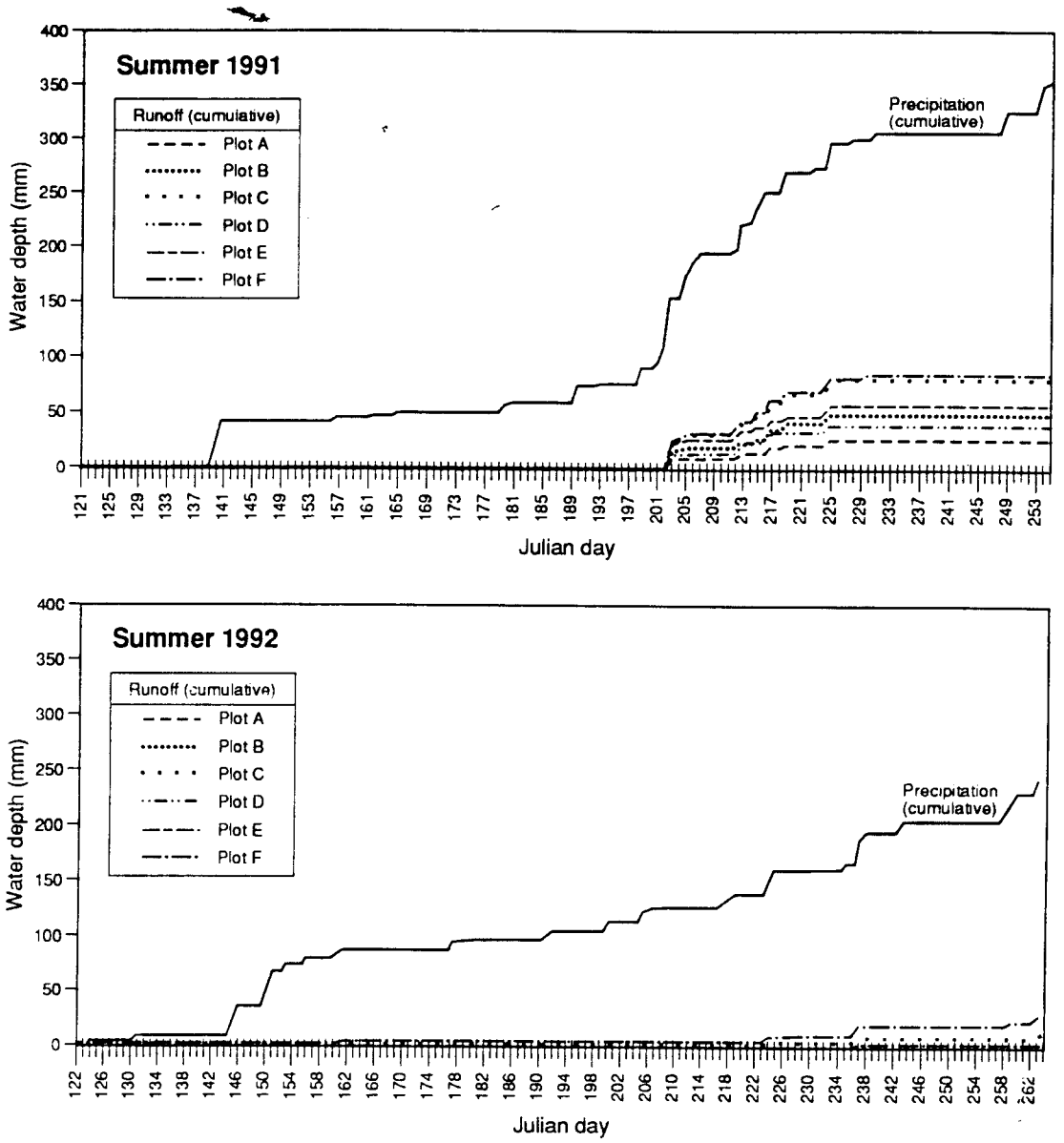

Figure C-19. Cumulative summer precipitation versus run-off, 1991 and 1992.

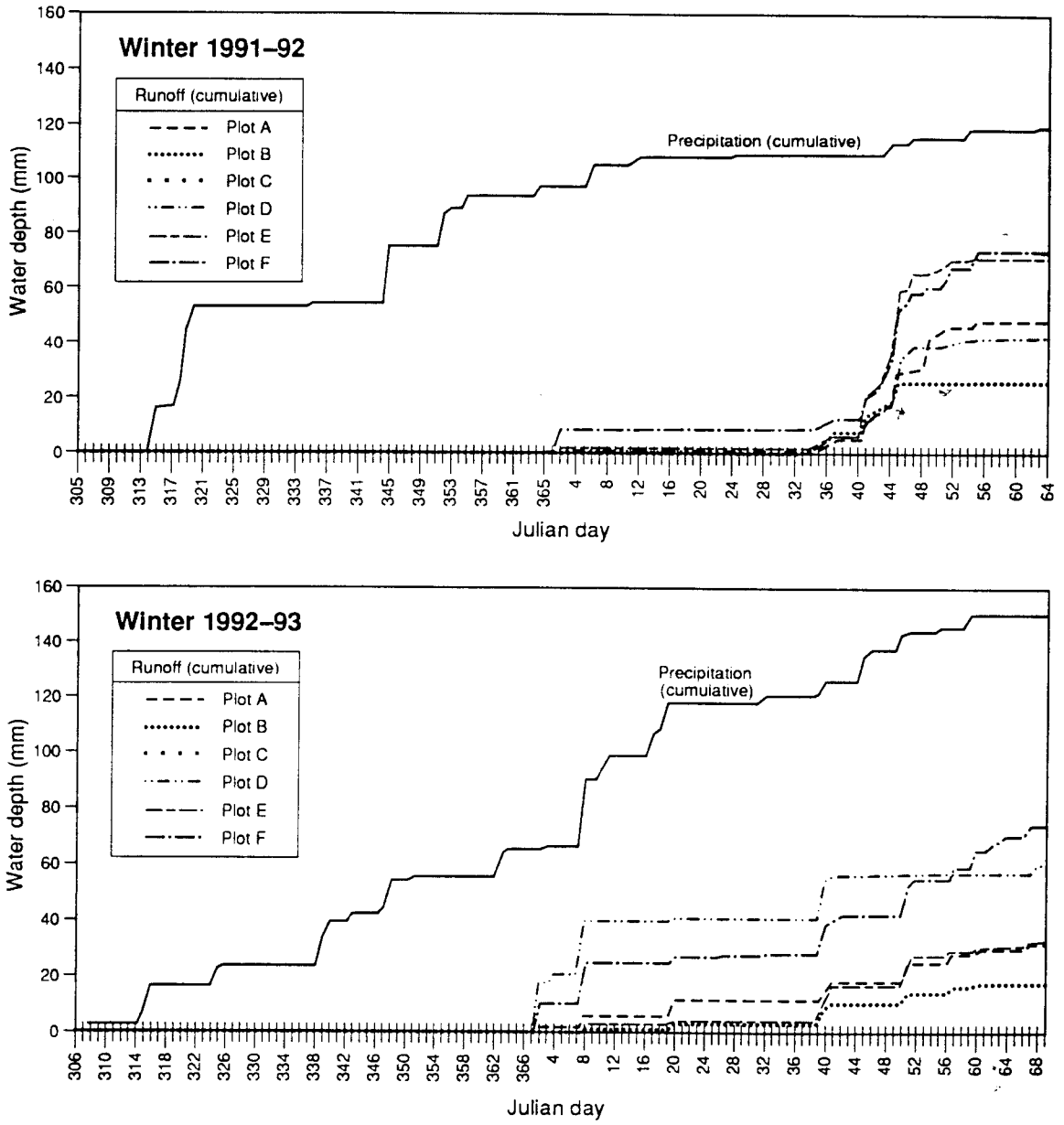

Figure C-20. Cumulative winter precipitation vs run-off, 1991-2 and 1992-3.

TABLE C-6

EROSION PLOTS, BY SEASON

	Sediment (kg/ha)			
Plot	Summer 1991	Summer 1992	Winter 1991-2	Winter 1992-3
A	13	13	53	56
B	560	5	10	32
C	1,089	42	*	*
D	280	5	67	107
E	2,868	25	79	57
F	10,831	255	118	131
Average	2,656	58	65	77

*Plot C was not operational during the winter.

snowmelt began about 20 days earlier the first winter than it did the second. In early February of 1992, investigators began to observe a daily thawing and refreezing of the upper 5 to 10 cm of soil (which, when thawed, was completely saturated). Below that depth, the soils remained frozen through the period of active run-off. The second winter, snowmelt did not begin until late February, by which time the soil was probably more deeply thawed. No definite pattern of nightly refreezing was apparent.

On the basis of these observations, investigators theorize that soil frost dynamics in combination with the timing of general snowmelt could explain the higher amounts of run-off (despite lower precipitation) during the winter of 1991-92. Although no specific data were collected to support this idea, the earlier snowmelt in concert with frozen soils, which would inhibit infiltration, almost certainly contributed to the increased run-off measured the first winter. On the other hand, the later snowmelt combined with more deeply thawed soils the second winter would have encouraged more infiltration of water into the soil.

With respect to the effects of plot disturbance on winter run-off, the results of the study are not decisive, because one of the disturbed plots (Plot C) malfunctioned both winters. Winter run-off was greatest from plot F, the most disturbed; but it was also quite high from other plots that were not disturbed (Table C-5).

The study also yields some data relevant to another discussion. Dortignac had concluded, on the basis of data from earlier watershed investgations, that in the piñon/juniper woodlands of northern New Mexico, run-off is mainly a summer phenomenon (Dortignac 1960, p. 74, 0902). The large amounts of winter run-off investigators measured contrast sharply with that earlier data, and they believe the difference is explained by effects of scale: whereas Dortignac's conclusions were based on data collected from watersheds of 30 to 3000 ha and focused on measurement of run-off in the stream channel, the study in question used plots many orders of magnitude smaller. Even during the periods of most active winter run-off, investigators found no water in the stream channel several hundred meters downslope of the plots. Apparently it was being absorbed en route, into "sink" or recharge areas such as piñon/juniper canopy spaces, snow drifts, and/or alluvial flood-plain sediments.

In other words, winter run-off appears to be locally important as a mechanism of redistribution of water, but these effects can be seen only at the smaller scales.

Amerman and McGuinness (1967,1023, pp. 464-466) were among the first to note the effects of scale on measured run-off and cautioned against "scaling up" plot data to predict hydrologic behavior at larger scales. Other researchers have also observed that the generation of run-off in arid and semiarid environments can vary greatly with scale. In the southwestern United States this phenomenon is usually attributed to channel transmission losses, primarily on the basis of work conducted at the Walnut Gulch Experimental Watershed in Arizona (Renard 1970, 1034). More recent work in Israel (Yair and Lavee 1985, 1046, pp. 183-220) has demonstrated that scale-related differences in measured run-off are also a function of differences in the infiltration capacity of hillslope soils. Because of these differences, some areas (lower-infiltration) function as *source areas* for run-off while others (higher-infiltration) serve as *sinks* for run-off.

Observations indicate that redistribution of water by run-off is occurring in piñon/juniper communities. Ecological investigators have suggested that this phenomenon is a major determinant of vegetation patterns in semiarid environments, and hydrological/ecological interactions is an area of active research (Yair and Danin 1980, 1045; Moorhead et al. 1989, 1033; Schlesinger et al. 1989, 1035; Cornet et al. 1992, 1028, pp. 327-345).

The extent of erosion varied considerably, both by season and by plot (Table C-6). Over the two-year study, most of the erosion resulted from a few large events the first summer. (Other studies have also found that erosion was produced mainly by large run-off events—e.g., Hjelmfelt et al. 1986, 1031, pp. 1-9). Another finding, that sediment concentrations tended to decrease as the summer run-off season advanced—which investigators observed the first summer, when there were a large number of precipitation events—is similarly reflected in other studies. For example, Yair et al. (1980, 1047, pp. 183-220) observed that in arid regions of the northern Negev, sediment concentrations decreased progressively with repeated run-off events. In piñon/juniper areas, it is possible that fine particles loosened by the freeze-thaw cycle of the previous winter are washed away early, and the remaining surface soil then becomes compacted. Schumm and Lusby (1963, 1036) demonstrated for the Mancos Shale that seasonal variations in soil erodibility and infiltration capacity were tied to variations in frost dynamics and the force of rainfall. This is probably equally true of piñon/juniper woodlands and other semiarid environments.

Erosion rates were very high from the most disturbed plot, Plot F (Table C-6), which had much more bare ground than the other plots. However, one undisturbed plot (E) also showed a quite high erosion rate. The reason for this is not obvious.

Finally, investigators noted that even when run-off was higher during the winter than the summer, snowmelt run-off produced very little erosion. This is consistent with the findings of Ellison (1948, 1030) that erosion is much lower in the absence of rainfall impact on the soil surface.

3.2.2.2 Conclusions

The measurements made during the study support the following conclusions about run-off and erosion in intercanopy areas of piñon/juniper woodlands in northern New Mexico.

Run-off takes place during two times of the year: mid summer (generated by thunderstorms) and mid-to-late winter (generated by snowmelt). At least on smaller scales, run-off can make up a substantial part of the winter water budget. During the

2-yr study period, run-off accounted for between 10% and 18% of the water budget for undisturbed sites (up to 28% for disturbed sites). This is higher than has been observed for many other piñon/juniper studies (Table C-7), which is probably explained partially by the high elevation of the site and partially by the small scale of the study.

Erosion from intercanopy piñon/juniper sites having little bare ground is minimal and increases as the extent of bare ground increases. Most of the erosion is produced by large summer thunderstorms. Erosion is slight during the winter, even when run-off is high, because of the absence of raindrop impact.

Both run-off and erosion are greater on disturbed sites during the summer. The effect of disturbance (extent of bare ground) is less pronounced during the winter.

Observations made during the course of this study suggest that the following hypotheses proposed for other semiarid landscapes are applicable to piñon/juniper woodlands as well.

Hypothesis 1 *Run-off amounts vary with scale; that is, run-off decreases as the size of the contributing area increases and provides more opportunities for infiltration).* Other investigators have noted that in semiarid regions, run-off varies with scale—because of either transmission losses in the stream channel or differences in soil infiltration capacities. Investigators believe that in the piñon/juniper communities of New Mexico, effects of scale are especially pronounced during the winter because run-off is generated from discrete points in the landscape (snowmelt will vary, depending on topographic position). The study allowed investigators to observe that winter run-off can be substantial locally but that the water travels little distance before being absorbed into "sink" areas.

Hypothesis 2 *The infiltration capacity of soils is dynamic; it is closely tied to soil moisture content and/or soil frost conditions and is a major determinant of run-off amounts.* Rainfall simulation studies, such as those of Thurow et al. (1988, 1040), have demonstrated the dynamic nature of infiltration capacity. Investigators believe that at the site in question, the two most important factors affecting soil infiltration capacity are soil moisture changes during the summer and soil freezing during the winter. The impact of soil frost on run-off in other semiarid environments is well recognized (for example, the sagebrush steppe—Johnson and McArthur 1973, 1032, pp. 359-369; Seyfried et al. 1990, 1037, pp. 125-134); but the phenomenon has been little studied in piñon/juniper landscapes.

Hypothesis 3 *Soil erodibility follows an annual cycle; it is highest at the end of the freeze-thaw period of late winter and lowest at the end of the summer rainy season, when soils have been compacted by repeated rainfall.* Observations suggest that this hypothesis, proposed by Schumm and Lusby (1963, 1036) for the Mancos Shale areas in western Colorado, also applies to piñon/juniper woodlands. During the first summer of the study, when run-off was frequent, sediment concentrations tended to decrease as the summer advanced.

These conclusions and hypotheses have important implications, among them that surface run-off is an important mechanism for the redistribution of water, sediments, nutrients, and contaminants in piñon/juniper woodlands, especially on a local scale. In these environments, it may be said that run-off is often a small-scale phenomenon and that on the small scale, it can make up a large portion of the total water budget. Adequate prediction of surface run-off in these environments will require models that

appropriately simulate both the spatial (Hypothesis 1) and the temporal (Hypotheses 2 and 3) variability of these environments—one of the major challenges currently facing hydrological researchers.

3.3 Remote Sensing for Site Characterization

In FY92, Laboratory investigators collaborated with other scientists studying state-of-the-art remote sensing technology to characterize surface conditions at several PRSs. These tests are designed to show the capability of the technology and to interface with several other DOE programs. This collaboration may lead to more efficient assessment of surface conditions for the ER Program. Its only cost to the program in FY92 was that of the staff time needed to arrange the logistics at Los Alamos. The three remote sensing projects in which Los Alamos took part are briefly outlined below.

Investigators at EG&G/EM, Inc., proposed to use Los Alamos as a test site for their technology development program funded under the DOE's research, development, demonstration, testing, and evaluation program. The goals are to develop remote sensing techniques to detect contaminants on the soil surface and the effects of contaminant plumes on surrounding vegetation. The objectives of the FY92 test were to obtain high-resolution scanning spectrometer data over both control (clean) and contaminated sites (PRSs) and then to evaluate the potential of the technology for detecting vegetative stress. The natural system study sites are ideal control sites for such a study. The Los Alamos investigators worked with operable unit project leaders in the ER Program to select PRSs suitable for the tests and coordinated site access and safety for the tests. In May 1992, almost continuous heavy rains during the entire flight window of 10 days prevented obtaining a useful data set. EG&G plans additional flights during September 1992 and again in FY93. In FY93, Los Alamos investigators obtained ground truth data in support of the overflights and assisted in integrating the data bases into the GIS system at FIMAD. They will also participate in evaluating the utility of the technology for remote characterization of PRSs in FY94.

Late in FY92, EG&G/EM, Inc., personnel from Goleta, California, visited the Laboratory to test laser-induced fluoroscopy instrumentation to measure the signal from uranium-contaminated soils and the chlorophyll reflectance of vegetation growing on both control and contaminated sites. This system has the potential for airborne sensing of surface contamination and localized effects on vegetation. The ER Program assisted EG&G/EM, Inc., tests by ground truthing the measurements of plant response.

ER Program investigators have communicated with National Aeronautics and Space Administration (NASA) scientists about their remote sensing studies. A NASA overflight of the Laboratory by the AVIRIS sensors was requested for late FY92. Los Alamos participants will contribute to the ground truthing for this overflight to evaluate the potential of using this technology for characterizing PRSs. The natural systems study sites will be used as controls for the PRSs. The primary responsibilities of the Los Alamos participants will be to obtain ground cover and soil moisture data. Depending on the timing of the flight, basic physiological data on the vegetation will also be collected.

4.0 MODELING AND SYSTEM INTEGRATION

4.1 Landfill Cover Studies

The data to be collected in the pilot field tests were initially used to calibrate a simple, one-dimensional model (CREAMS) in the field without extensive input parameters (Nyhan 1990, 0155). This study will produce for the first time (with the exception of the preliminary calibration on the ITP plots, which was performed with only 3 years of field data) direct measurements of all of the water balance components, making it possible to compare the measurements with model-simulated values instead of merely comparing the observed and predicted values of soil water content to evaluate the success of the hydrologic simulation. During FY93, investigators have taken the preliminary steps to validate a multidimensional finite element model that uses data collected in field studies such as the ITP plots, the protective barrier landfill cover plots, and the natural systems plots to predict variations in soils, vegetation, and climate. Such models can be used to optimize the design of landfill covers at specific sites. CREAMS can also be used to design landfill covers based on 20- to 50-year projections of meteorological conditions that encompass average and record wet years so that the effectiveness of the cover designs can be assessed. The cost effectiveness and practicality of various designs will be evaluated with the help of the site operator, who will have a major influence on the selection of a final closure design for low-level radioactive and hazardous waste sites.

4.2 Plant Community Studies

Links to the FIMAD data bases have been established. The topographic and surface mapping of the woodland study site has been imported into ARC/INFO, and existing data bases will be incorporated during FY93. Initial analyses have indicated that the 10-m spacing for the 0- to 3-m-depth soil moisture measurements are essentially independent measurements. Further statistical analyses of the fine-scale measurements (TDR and canopy gap fractions) were performed in FY93 to determine the characteristic scales of the surface soil moisture and vegetative covers.

In FY93, investigators made substantial progress on the overall modeling approaches for integrating the pilot studies for the purposes of developing a generic methodology for site closure and prediction of stability. The influence of canopy patches on redistribution of incoming precipitation is being modeled for the woodland community. Competition between tree species and between tree and intercanopy (grass) patches is being modeled and will be validated using data obtained from FY91 experiments that used tritiated water spikes in intercanopy patches.

This latter exercise considered physiological constraints on transpiration by grass and trees, which were incorporated into a hydrology model to predict water balance in semiarid woodlands (Breshears et al. 1992, 0898). The FOREST-BGC model for closed-canopy forests was modified for a heterogeneous woodland and parameterized using phytotron and field data. Tree transpiration and evaporation from intercanopy soil were predicted to dominate the annual water budget. Predicted annual evapotranspiration compared favorably to estimates from a hydrology model that did not include physiological constraints. Predictions for tree transpiration also compared favorably with estimates derived from field measurements of leaf water potential. These results indicate that predictions of transpiration driven by site meteorology and constrained by physiology may be applicable to a wide range of plant communities.

Construction of a GIS-linked radiation budget model is under way with the assistance of contractors from Kansas State University. In this model (Hetrick et al. 1993, 0909) investigators are addressing the fact that solar radiation flux governs such critical ecological processes as heat and gas exchange, primary productivity, and rates of nutrient cycling. Investigators have developed a GIS-based (ARC/INFO) solar radiation flux model (SOLARFLUX) based on surface orientation, seasonal and daily shifts in solar angle, shadows caused by topographic features, and variation in atmospheric conditions. Radiation flux for any spatial location is calculated by integrating direct and diffuse radiation components over the hemisphere of sky directions for a specified time period. Atmospheric conditions can be specified using either empirical or theoretical functions. Solar radiation flux can be calculated for any complex surface across a broad range of spatial scales, locally along the surface of plant canopies or more broadly across the landscape. Investigators are applying SOLARFLUX at the Los Alamos National Environmental Research Park, New Mexico, to examine near-ground radiation balance in piñon/juniper woodland; there the scale of spatial patterning is strongly related to clumped tree distributions. SOLARFLUX is also being used to develop microclimate habitat models for natural reserves in both temperate and tropical latitudes at Big Creek Reserve, California, and La Amistad Biosphere Reserve, Costa Rica; in these topographically diverse natural areas, microclimate heterogeneity determines habitat heterogeneity and thereby leads to higher biodiversity.

The model is initially being developed to represent the radiation budget on the protective barrier plots on any date and time of day. This capability will allow interpretation of the movement of water and surface evapotranspiration during the FY93 experiments and modeling of the surface energy budget. This model, which will use the slope/aspect/elevation modeling capability of ARC/INFO, will be applicable to the entire Laboratory site. Because the evapotranspiration processes (both soil evaporation and plant transpiration) are driven by the energy budget, this development is essential to the overall modeling effort of the pilot studies program.

Influences of canopy geometry on near-ground solar radiation and water balances were studied in FY93 in piñon/juniper and ponderosa pine woodlands (Lin et al., 1992, 0911). Canopy geometry was characterized using overstory mapping techniques; daily and seasonal near-ground solar radiation regimes were calculated using hemispherical photography and Sunfleck Ceptometer techniques; and soil moisture was assessed using TDR and neutron scattering techniques. Canopy geometry directly influenced near-ground solar radiation penetration, which in turn correlated negatively with soil moisture, particularly during the summer. The distribution of canopy openings as a function of zenith angle gave a unique geometric signature for each of the canopies studied, a result that may be generalizable to other canopies.

4.3 Hillslope-Scale Studies in Piñon/juniper Woodlands

During FY93 investigators reviewed past and current hillslope-scale hydrologic studies to ensure that they could make the integration between landfill cover and natural cover studies being performed at different field scales and the prediction of hydrologic processes occurring at the field scale of a landfill.

Most of the watershed- and hillslope-scale hydrologic studies in piñon/juniper woodland environments were conducted in the 1960s and 70s (Table C-7). The management objectives of the day did not call for a process-based understanding

TABLE C-7

WATERSHED- AND HILLSLOPE-SCALE HYDROLOGIC STUDIES IN PIÑON/JUNIPER ENVIRONMENTS

Watershed Studies

Location	No. Sites	Size (ha)	Yrs Active	Study Purpose	Precip (mm)	Run-Off mm[a]	Run-Off %	Dominant Run-Off Season (% Total Run-Off during That Season)	References
Beaver Creek (AZ) (Watersheds 1, 2, 3—Utah Juniper)	3	51-146	22	Evaluate effect of P/J control (cabling, handslashing, burning, herbicide)	458	27	6	Winter (85%)	Clary et al., 1974, 0899 Baker 1982, 0891 Baker 1984, 1024
Beaver Creek (AZ) (Watersheds 4, 5, 6—Alligator Juniper)	3	24-140	22	Evaluate effect of P/J control (cabling, handslashing, burning, herbicide)	526	121	23	Winter (97%)	Clary et al., 1974, 0899 Baker 1982, 0891 Baker 1984, 1024
Carrizzo Creek (AZ)	1	61,382	12	Evaluate effect of P/J control (chaining, handslashing, burning)	457	18	4	Winter (90%)	Collings and Myrick 1966, 0900)
Corduroy Creek (AZ)	1	55,166	12	Evaluate effect of P/J control (chaining, handslashing, burning)	457	24	5	Winter (93%)	Collings and Myrick 1966, 0900)
Mexican Springs (NM)	9	1,391-3,437	6-20 2-6	SCS[b] characterization of P/J environment	283	13	5	Summer	Dortignac 1960, 0902
Santa Fe (NM)	3	31-319	10	SCS[b] characterization of P/J environment	327	7	2	Summer	Dortignac 1960, 0902

TABLE C-7 (cont.)

Hillslope Studies

Location	No. Sites	Size (ha)	Yrs Active	Study Purpose	Precip (mm)	Run-Off mm[a]	Run-Off %	Dominant Run-Off Season	References
Beaverhead (NM)	20	0.04	2	Evaluate impact of fuelwood cutting and burning	325	28	8	Run-off data collected only during the summer	Wood 1991, 1044
Baird (TX)	6	0.02-0.19	2	Evaluate impact of burning juniper	613	23	4	Summer and winter	Wright et al. 1976, 0938
Milford and Blanding (UT)		0.04	3	Evaluate effect of P/J control (chaining, windrowing; chained debris left in place)	426	3	1	Summer	Gifford 1975, 0903

a. Data are for untreated (control) areas except where no control data were available.
b. SCS = Soil Conservation Service.

of run-off and erosion; rather, the impetus for most of these studies was to test the hypothesis that removing the piñon/juniper overstory would increase both water yield and forage production.

The best-documented of the watershed-scale studies was done at Beaver Creek, Arizona (Clary et al. 1974, 0899; Baker 1982, 0891; Baker 1984, 1024). It was initiated following a severe drought in the 1950s, when several researchers began optimistically forecasting water-yield improvements from clearing of piñon/juniper cover (Barr 1956, 0893). Several treatments, including herbicide application and mechanical removal, were applied to small watersheds dominated by Utah juniper (1585- to 1680-m elevations) and alligator juniper (1889- to 1950-m elevations). Water yields increased slightly in the herbicide-treated areas but not in the areas where trees were removed mechanically. Baker (1984) suggested that this was because the trees killed by herbicide not only had ceased to draw water from the soil, but were still providing shade, both of which had the effect of reducing evapotranspiration. Later, when the dead trees were removed, water yield diminished.

The hydrologic impact of piñon/juniper removal was also examined in Arizona on a much larger scale (Collings and Myrick 1966, 0900). Like Beaver Creek, these studies showed that there was little if any increase in water yield from such removal. At Beaver Creek, dramatic increases in run-off were seen at the higher elevations, where evapotranspiration is lower (as shown in Table C-7, run-off was about 5 times higher from the alligator-juniper watersheds than from the Utah-juniper watersheds).

Dortignac (1960, 0902) compared the early Beaver Creek findings with those of some little-known watershed work conducted in New Mexico (see Table C-7) and concluded that the run-off regimes of the Arizona and New Mexico watersheds were different— that whereas in New Mexico most of the run-off is generated by intense summer thunderstorms and is of short duration, in Arizona it is generally a winter phenomenon, produced by frontal rain storms, rain-on-snow, and/or snowmelt.

The effects of clearing of piñon and juniper on surface run-off and erosion has also been examined in several hillslope-scale studies. Wood (1991, 1044) and Gifford (1975, 0903) found that run-off was greater if slash and debris were removed. When these were left in place, run-off was lower—presumably because the increased surface storage capacity allows more time for water to infiltrate. Wright et al. (1976, 0938) found that in central Texas, burning of juniper increased run-off on steeper slopes for a period of 15 to 30 months (until regrowth took hold) but produced little change on smaller-gradient slopes.

A number of rainfall simulation studies have been conducted on piñon/juniper woodlands. Some of the earlier studies compared infiltration and erosion patterns within different plant communities (Smith and Leopold 1941, 0926; Blackburn and Skau 1974, 0897; Blackburn 1975, 0896); others evaluated the effects on hydrologic events of piñon/juniper control strategies (Williams et al. 1969, 1043; Gifford et al. 1970, 0906; Williams et al. 1972, 0935; Roundy et al. 1978, 0924). More recent rainfall simulation studies in piñon/juniper woodlands have focused on the development of parameter values for hydrologic and erosion models (Ward 1986, 0931; Ward and Bolin 1989, 0932; Ward and Bolin 1989, 0933; Ward and Bolton 1991, 0934).

As Hawkins observed (1986, 0908, pp. 493-503), piñon/juniper woodlands exist in diverse climatic, edaphic, topographic, and geologic settings. For this reason, there is no unique hydrologic behavior for the areas characterized by this plant community. Very generally, investigators can say that in piñon/juniper woodlands, evapotranspiration is the dominant mechanism of water loss. Run-off typically accounts for less than 10% of the water budget (the high-elevation piñon/juniper regions are probably an exception—for example, the Arizona alligator-juniper watershed studies, where run-off was around 20%—see Table C-7). Attempts to increase run-off by removing the overstory cover, in the hope of reducing evapotranspiration, have not been successful. Increases in run-off have been achieved when soils were disturbed and/or compacted to the point that infiltration capacity was reduced—but such artificial means are generally not desirable: they lead to ecosystem degradation both by aggravating soil erosion and by diminishing the quantities of water available for plants.

Investigators can also say that in piñon/juniper woodlands streamflow is usually ephemeral; it is generated by intense summer thunderstorms, prolonged frontal storms, or melting snow, but the underlying mechanism by which water reaches stream channels has been little studied. It is probably mostly Hortonian overland flow rather than subsurface flow. A possible exception to this is the sustained winter streamflow, lasting several months, seen in the higher-elevation piñon/juniper woodlands of Arizona (Clary et al. 1974, 0899; Baker 1982, 0891), which may be the result of subsurface flow (the mechanisms of run-off generation at these sites was not explicitly discussed).

Finally, groundwater recharge is generally believed to be very small to nonexistent in piñon/juniper woodlands because of the high rates of evapotranspiration (Dortignac 1960, 0902; Gifford 1975, 0904).

Over the last decade, there has been a dramatic shift of focus of hydrological investigations in piñon/juniper woodlands. The traditional resource issues of increasing water yield and grazing capacity through vegetation manipulation have given way to issues of ecosystem sustainability, the effects of climate change, soil and water contamination, and impacts on riparian areas. Recognizing that the then-current understanding of piñon/juniper hydrology was inadequate, Schmidt (1986, 0925) called for a comprehensive network of watershed studies in piñon/juniper woodlands across the United States. These would employ a much more detailed investigative methodology, aimed at acquiring a process-based understanding of hydrological events.

Carrying out the type of studies of natural systems currently being performed in the pilot studies program is especially challenging in semiarid environments (Pilgrim et al. 1988, 0923). One major problem has been the difficulty of maintaining and monitoring equipment in remote locations (but recent advances in data acquisition technology have greatly ameliorated this problem). Another problem is that development of a suitable hydrologic record could take decades because run-off events are usually infrequent and of short duration, making important events easy to miss. Despite the challenges they present, studies of this kind are the only means for significantly advancing our understanding of water dynamics in semiarid ecosystems.

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■ APPENDIX D

Geochemical Studies of Soils and Bandelier Tuff

1.0 INTRODUCTION

During the spring and summer of 1992, Watt and McFadden (1992, 0960) sampled the Bandelier Tuff and several soil series to determine background concentrations of several elements. Figures D-1 and D-2 show sampling locations in the Bandelier Tuff and different soil series, respectively. This investigation is relevant to the Environmental Restoration (ER) Program at Los Alamos National Laboratory (the Laboratory) because background concentrations of various elements are used in determining screening action levels for different contaminants. These data are also needed to enable investigators to distinguish between contaminated and noncontaminated media. Thirty-eight samples of the Bandelier Tuff and 75 soil samples were submitted for chemical analyses.

The samples of Bandelier Tuff include all stratigraphic units present in the Tshirege Member in the central and eastern portions of the Laboratory, and the background concentrations in these strata are probably representative of tuff elsewhere in these units at the Laboratory. Additional higher stratrigraphic units of the Tshirege Member are present, however, in the western portion of the Laboratory, and these units have not yet been analyzed.

The soil samples were collected from seven very different soils found around the Laboratory. The sites were selected so that soils influenced by a range of parent materials, topographic settings, local climate, and time could be analyzed. The limited number of sample sites precluded investigating all types of soil present at the Laboratory. Morever, because only one soil profile was sampled from each setting, the variability of natural background levels in soils occurring at similar settings has not yet been evaluated. Because of these concerns, this data set should not be considered statistically representative of all soils present at the Laboratory and may not include the full range of natural concentrations for all elements.

Rock and soil samples were analyzed for antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, silver, thorium, and uranium. These elements are of primary concern to the ER Program because numerous potential release sites at the Laboratory potentially contain elevated concentrations of these elements. Other elements of secondary importance to the ER Program include aluminum, bromine, calcium, cesium, chlorine, cobalt, copper, gallium, gold, hafnium, indium, iodine, iron, magnesium, manganese, potassium, rare earth elements, rubidium, scandium, selenium, sodium, strontium, tantalum, titanium, tungsten, vanadium, zinc, and zirconium .

This appendix summarizes background concentrations of elements of the Bandelier Tuff and soils collected within and adjacent to the Laboratory boundaries. An additional report will be made available in the winter of 1993, which will consist of statistical evaluation and interpretation of chemical, physical, and mineralogical data collected during this investigation.

2.0 METHODS

Background samples of the Bandelier Tuff were collected at two locations in Bandelier National Monument south and upwind from potential release sites at the Laboratory. The locations of the sections from which the samples were taken are shown in Figure D-1. The locations of the samples within the sections are shown in Figures D-3 and D-4. The samples were taken from exposed surfaces, but material

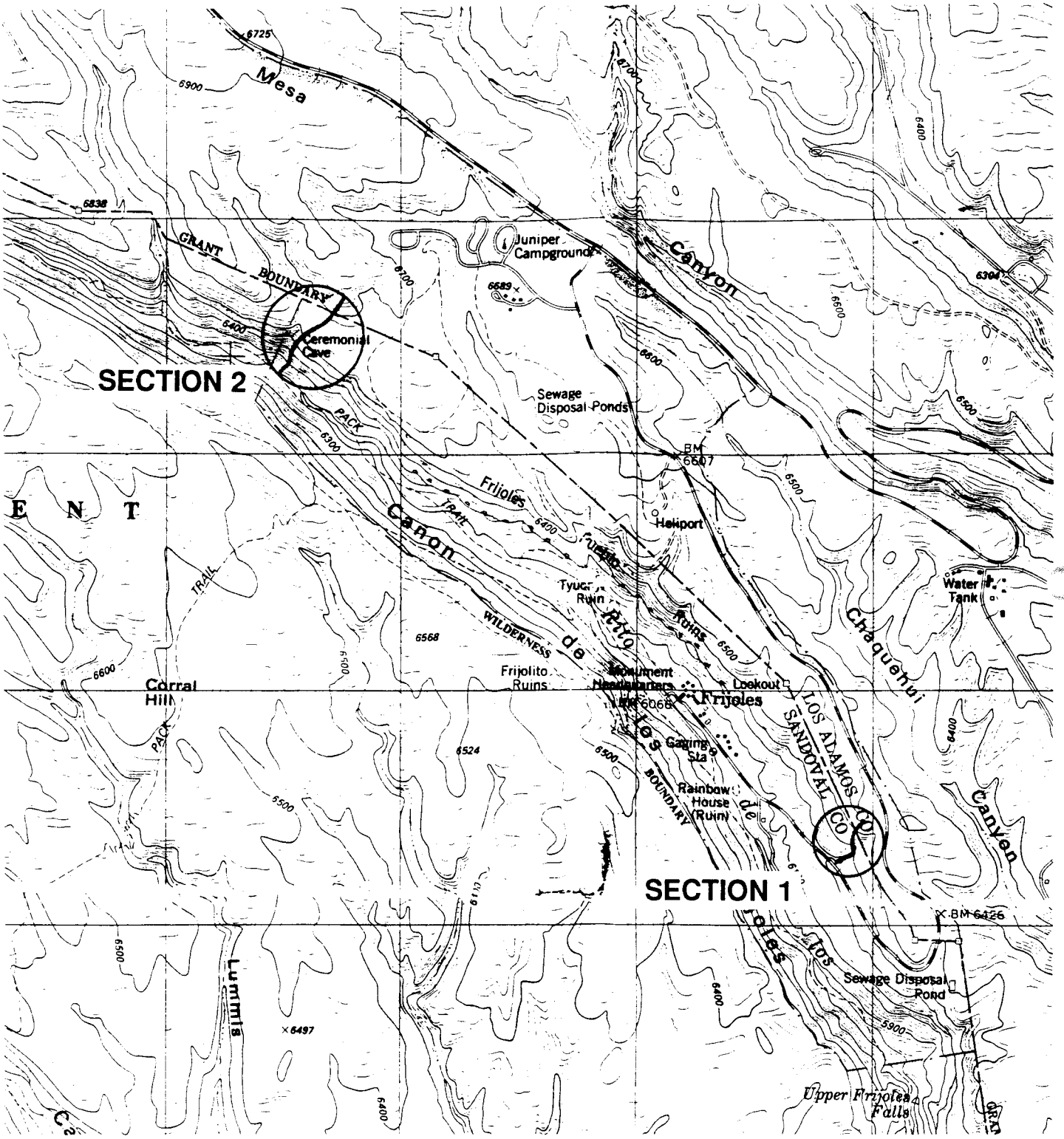

Figure D-1. Map of sampling locations in Bandelier Tuff

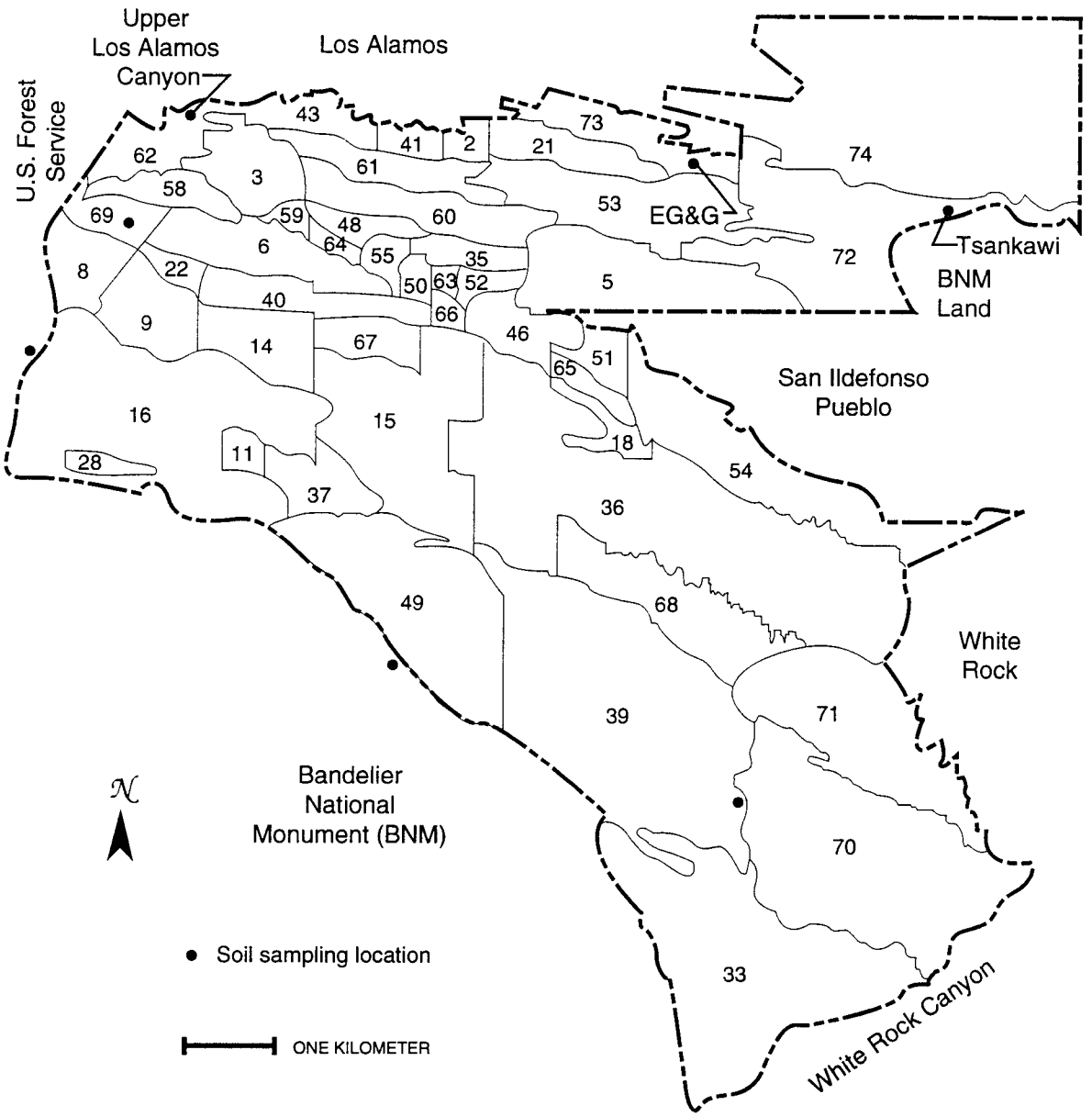

Figure D-2. Locations of soil samples collected for background soil study

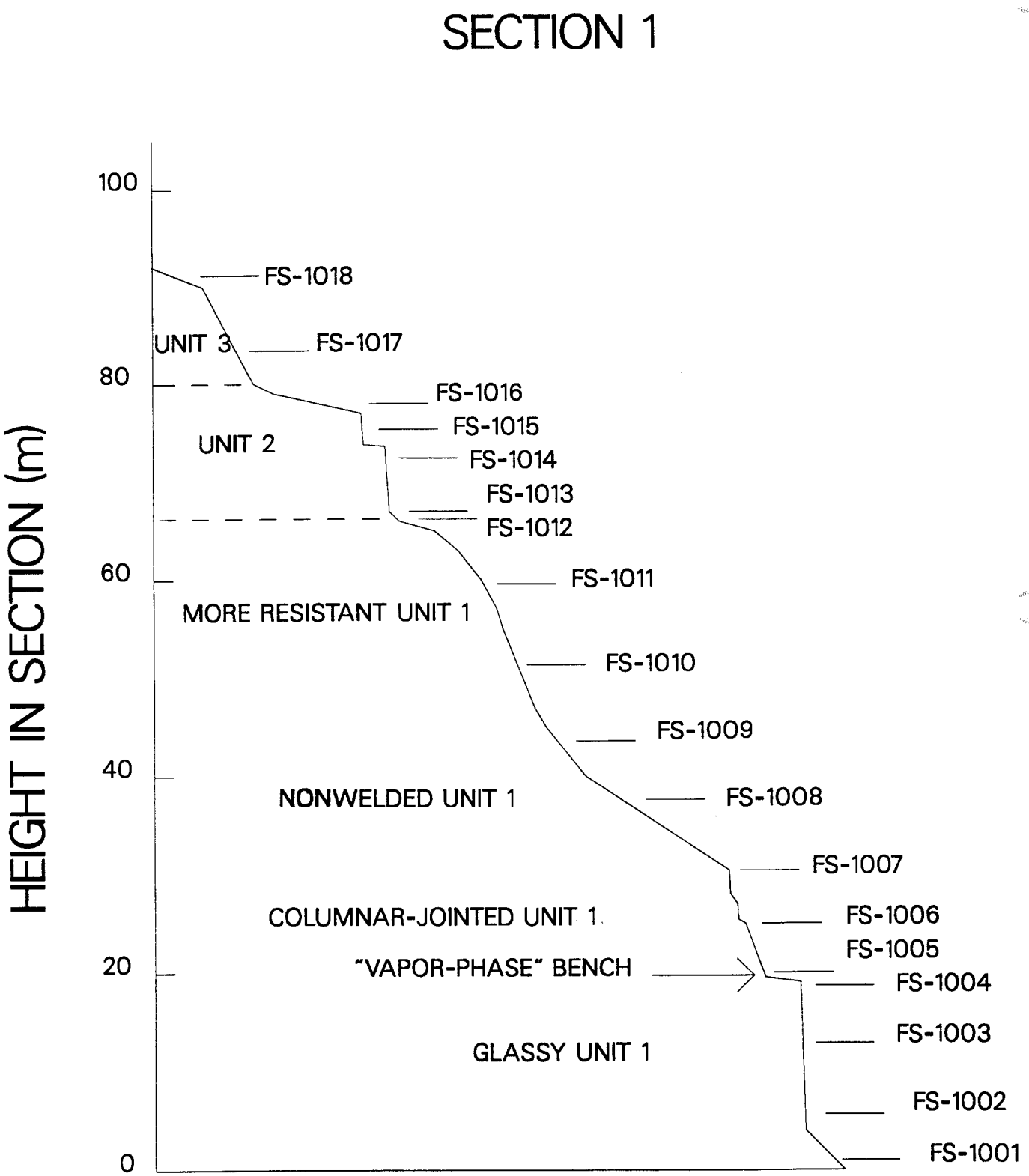

Figure D-3. Locations of Bandelier Tuff samples in Section 1

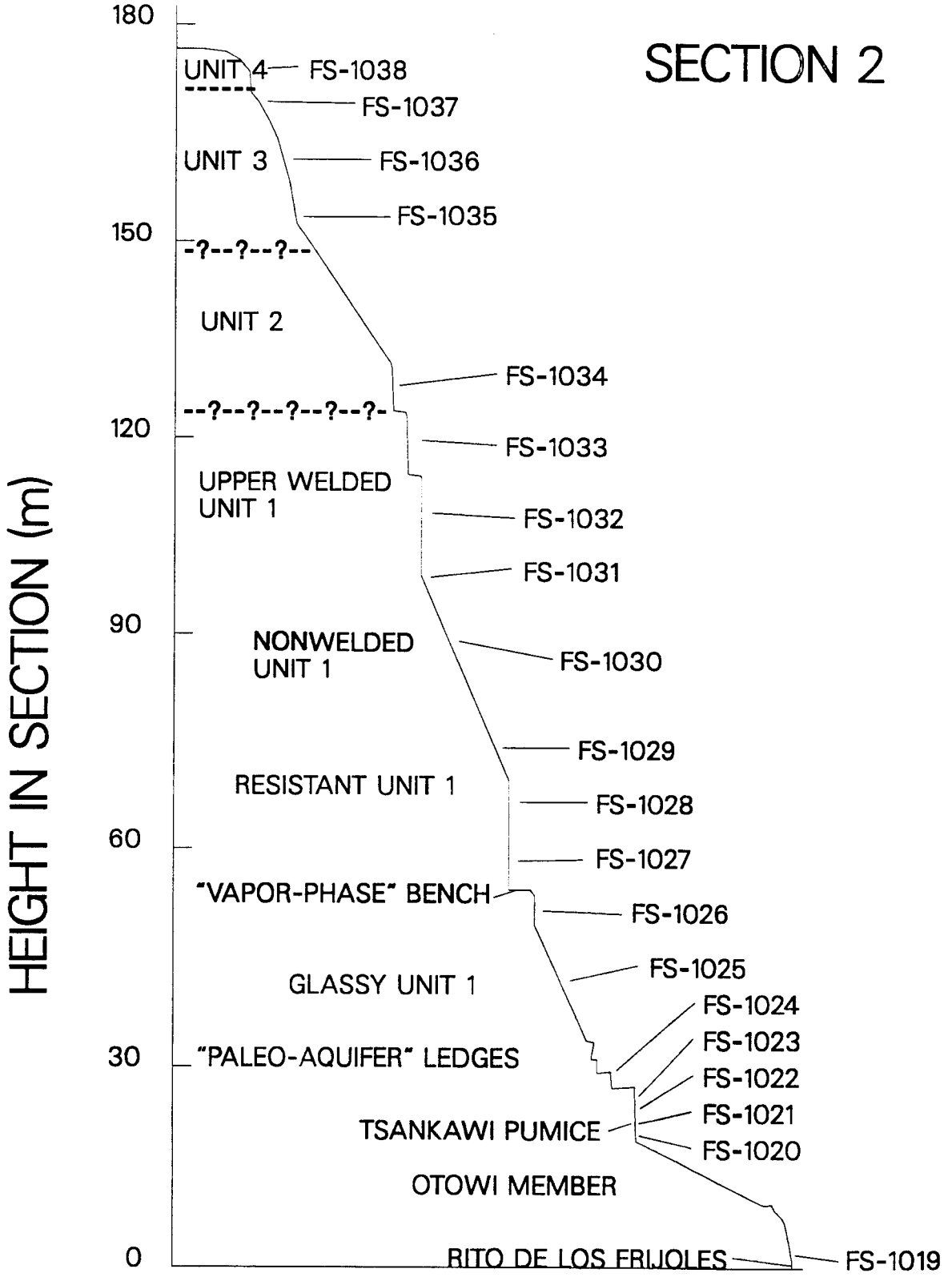

Figure D-4. Locations of Bandelier Tuff samples in Section 2

from obvious weathering rinds was excluded. Up to this point, sampling has been largely limited to the upper (Tshirege) member of the Bandelier Tuff, with only two samples from the lower (Otowi) member.

Locations of background soil samples were based on sites that are not impacted by Laboratory operations. Trenches were dug to minimize any potential surface contamination. Variations in elemental concentrations are results of the physical, chemical, and biological processes that occur in soils. The sites are characterized by variability in soil development, which controls distribution of elements. Soil samples were collected from seven localities in which the sides of drainage channels provided excellent soil exposure or in which trenches were excavated. These localities include upper Los Alamos Canyon (south of the road to the reservoir on the north-facing canyon slope), TA-69 (west of any developments and/or disturbances), TA-16 (west of State Road 4), TA-49 (south of State Road 4), TA-39 (west of State Road 4), Tsankawi (north of Los Alamos Creek, west of State Road 4), and south of EG&G (south of State Road 502). These localities provide a wide geographical distribution of soil series and allow partial sampling of the varying degree of soil development on the Pajarito Plateau.
At each location, soil samples were collected at different depths (0 to 300 cm) corresponding to the different soil horizons.

The different soil horizons were classified and characterized according to their texture, consistency (wet/dry), particle size distribution, color, clay mineral content, calcium carbonate content, organic carbon content, soil pH, cation exchange capacity, and bulk density (Watt and McFadden 1992, 0960). Soil samples were passed through a 20-mesh sieve to remove pebbles and twigs. Both the tuff and soil samples were either air-dried or dried in a forced-air circulation oven at 60°C for 48 h and were then ground with a corundum mortar and pestle. Because the tuff was indurated, the tuff samples had to be ground longer than the soil samples.

After the samples had been prepared, they were submitted to INC-15 for instrumental and delayed neutron activation analyses (INAA and DNAA) and to EM-9 for inductively coupled argon plasma (ICP) spectroscopy. Beryllium, cadmium, and lead were analyzed by ICP, and the other elements were analyzed by INAA and DNAA. INAA and DNAA (SW-846, EPA 1990, 0967) methods are nondestructive methods for analyzing for total analyte concentration in a sample, whereas sample preparation for ICP consists of partial sample dissolution using nitric acid below pH 1. Therefore, most of the elemental data represent total analyte concentrations, whereas beryllium, cadmium, and lead concentrations do not represent total analyte concentrations because the samples are not completely dissolved before ICP analysis. Analytical results obtained using SW-846 methods will provide data on elements that are leachable from samples at pH 1, and element concentrations will probably be lower than those obtained from INAA and DNAA. Additional analyses will be performed on soil and Bandelier Tuff samples to compare analyte concentrations using INAA, DNAA, and ICP, which will allow for a more direct comparison of background elemental data with chemical data collected during field investigations at operable units.

The procedures used for these analyses are described in detail in studies by Gautier and Gladney (1986, 0955), Gladney et al. (1981, 0957), and Garcia (1991, 0954). Quality assurance was provided by concurrent analysis of different reference materials provided by the National Institute of Standards and Technology, Environmental Protection Agency , and United States Geological Survey (Gladney et al. 1981, 0957; Garcia 1991, 0954).

3.0 RESULTS

Table D-1 summarizes the means and ranges of elements in the Bandelier Tuff and soil series. The soil samples are enriched in aluminum, arsenic, barium, cadmium, cesium, chromium, cobalt, and iron relative to the Bandelier Tuff samples. The Bandelier Tuff samples, however, are enriched in beryllium, lead, potassium, sodium, thorium, and uranium relative to soils. Variations in concentrations of elements in soil are related to the physical and chemical characteristics of a particular soil horizon, climate, topography, vegetation, time, biotic activity, and the parent material, which consists of alluvial fans, sheet wash material, colluvium, and the Bandelier Tuff. Generally, these data agree well with soil data reported from the sources summarized in Table D-2. Longmire et al. (1993, 0958) have tabulated the results of individual analyses.

TABLE D-1

SUMMARY OF TUFF AND SOIL ANALYSIS (VALUES IN PPM)

ELEMENT		SAMPLES ABOVE DETECTION LIMIT				SAMPLES BELOW DETECTION		
		NUMBER OF SAMPLES	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF SAMPLES	MINIMUM DETECTION LIMIT	MAXIMUM DETECTION LIMIT
Be								
	TUFF	38	0.42	7.50	4.72	0		
	SOIL	75	1.00	4.40	2.37	0		
Na								
	TUFF	38	13960.00	36230.00	31050.88	0		
	SOIL	75	2700.00	32560.00	17948.52	0		
Mg								
	TUFF	3	3035.00	6571.00	4301.00	35	2060.00	4173.00
	SOIL	53	1331.00	16790.00	6182.64	22	1597.00	4325.00
Al								
	TUFF	38	50600.00	76531.66	66370.31	0		
	SOIL	74	49680.00	113600.00	76767.63	1	1524.00	1524.00
Cl								
	TUFF	30	102.60	1883.00	593.43	8	104.40	173.40
	SOIL	36	69.12	966.90	326.63	39	51.79	198.20
K								
	TUFF	38	28760.00	47920.00	37944.74	0		
	SOIL	75	10390.00	42000.00	25418.80	0		
Ca								
	TUFF	15	1745.00	16960.00	5667.44	23	1777.00	2530.00
	SOIL	71	1911.00	80380.00	8639.29	4	1114.00	3002.00
Sc								
	TUFF	38	0.88	5.59	1.52	0		
	SOIL	75	1.29	18.80	6.56	0		
Ti								
	TUFF	6	432.50	1943.00	1199.64	32	3365.00	7024.00
	SOIL	72	1185.00	5438.00	2913.13	3	3607.00	5780.00
V								
	TUFF	3	9.63	42.25	24.46	35	5.79	10.49
	SOIL	72	11.54	113.10	48.95	3	6.40	8.84
Cr								
	TUFF	31	1.17	49.85	5.60	7	0.91	2.66
	SOIL	74	2.03	71.07	34.74	1	1.60	1.60
Mn								
	TUFF	38	360.40	834.50	551.71	0		
	SOIL	75	185.70	1552.00	507.77	0		

TABLE D-1 (continued)

ELEMENT		SAMPLES ABOVE DETECTION LIMIT				SAMPLES BELOW DETECTION		
		NUMBER OF SAMPLES	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF SAMPLES	MINIMUM DETECTION LIMIT	MAXIMUM DETECTION LIMIT
Fe								
	TUFF	38	8818.00	22850.00	11529.60	0		
	SOIL	75	10860.00	48640.00	23704.27	0		
Co								
	TUFF	35	0.49	8.88	1.30	3	0.29	0.35
	SOIL	75	0.44	23.35	7.14	0		
Cu								
	TUFF	0				38	260.80	444.40
	SOIL	0				75	158.90	456.60
Zn								
	TUFF	35	39.85	131.30	81.85	3	6.42	46.20
	SOIL	36	19.97	146.20	64.58	39	5.32	71.93
Ga								
	TUFF	10	14.53	34.21	26.62	28	23.63	62.06
	SOIL	10	7.81	37.39	21.10	65	16.54	99.75
As								
	TUFF	16	0.94	3.15	1.89	22	2.29	4.55
	SOIL	67	1.20	10.81	5.04	8	2.58	5.21
Se								
	TUFF	0				38	1.14	4.92
	SOIL	0				75	1.71	7.72
Br								
	TUFF	9	1.70	6.73	2.79	29	2.55	5.42
	SOIL	64	1.38	46.88	6.48	11	1.77	4.67
Rb								
	TUFF	38	79.13	488.40	187.15	0		
	SOIL	75	43.95	159.00	108.69	0		
Sr								
	TUFF	1	653.90	653.90	653.90	37	236.90	483.80
	SOIL	2	170.40	242.20	206.30	73	164.90	746.10
Zr								
	TUFF	38	144.10	368.82	228.82	0		
	SOIL	70	148.00	704.30	350.64	5	128.40	316.30
Ag								
	TUFF	0				38	1.71	2.95
	SOIL	1	1.61	1.61	1.61	74	1.59	7.52

TABLE D-1 (continued)

ELEMENT		SAMPLES ABOVE DETECTION LIMIT				SAMPLES BELOW DETECTION		
		NUMBER OF SAMPLES	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF SAMPLES	MINIMUM DETECTION LIMIT	MAXIMUM DETECTION LIMIT
Cd								
	TUFF	0				38	1.00	1.00
	SOIL	3	1.20	1.70	1.50	72	1.00	1.00
In								
	TUFF	0				38	0.21	0.40
	SOIL	3	0.07	0.17	0.12	72	0.15	0.69
Sb								
	TUFF	2	0.24	0.70	0.47	36	0.24	0.67
	SOIL	57	0.27	1.59	0.69	18	0.25	0.51
I								
	TUFF	0				38	14.23	32.05
	SOIL	9	4.05	29.42	9.99	66	9.93	40.59
Cs								
	TUFF	38	1.79	8.10	4.38	0		
	SOIL	75	2.19	10.71	4.87	0		
Ba								
	TUFF	24	79.85	413.70	151.18	14	48.02	339.60
	SOIL	75	124.80	828.90	459.05	0		
La								
	TUFF	38	42.71	75.94	57.18	0		
	SOIL	75	31.70	93.50	47.31	0		
Ce								
	TUFF	38	81.71	157.10	112.28	0		
	SOIL	75	58.19	161.80	88.80	0		
Nd								
	TUFF	38	30.36	71.58	48.38	0		
	SOIL	75	6.68	71.68	34.33	0		
Sm								
	TUFF	38	0.81	13.21	10.08	0		
	SOIL	75	3.64	12.55	6.25	0		
Eu								
	TUFF	32	0.08	0.84	0.25	6	0.13	0.18
	SOIL	75	0.24	2.15	0.83	0		
Tb								
	TUFF	38	1.11	2.65	1.96	0		
	SOIL	73	0.40	1.96	0.87	2	0.10	0.16

TABLE D-1 (continued)

ELEMENT		SAMPLES ABOVE DETECTION LIMIT				SAMPLES BELOW DETECTION		
		NUMBER OF SAMPLES	MINIMUM	MAXIMUM	AVERAGE	NUMBER OF SAMPLES	MINIMUM DETECTION LIMIT	MAXIMUM DETECTION LIMIT
Dy								
	TUFF	38	4.61	15.57	11.09	0		
	SOIL	75	2.68	10.38	4.88	0		
Yb								
	TUFF	38	2.96	10.63	6.87	0		
	SOIL	75	1.33	5.87	3.50	0		
Lu								
	TUFF	38	0.51	1.40	0.95	0		
	SOIL	75	0.22	0.75	0.48	0		
Hf								
	TUFF	38	6.34	12.13	8.96	0		
	SOIL	75	4.16	18.56	9.76	0		
Ta								
	TUFF	38	2.66	9.70	6.03	0		
	SOIL	75	1.27	5.67	2.44	0		
W								
	TUFF	23	2.04	20.03	6.01	15	3.10	9.62
	SOIL	22	1.62	17.07	5.96	53	1.47	13.21
Au								
	TUFF	0				38	0.01	0.02
	SOIL	4	0.02	0.04	0.03	71	0.01	0.02
Hg								
	TUFF	0				38	0.35	0.69
	SOIL	0				75	0.34	1.37
Pb								
	TUFF	34	18.00	57.00	35.79	4	14.00	14.00
	SOIL	73	18.00	56.00	28.36	2	14.00	14.00
Th								
	TUFF	38	12.90	37.06	23.71	0		
	SOIL	75	10.09	27.30	16.06	0		
U								
	TUFF	38	2.88	10.13	6.27	0		
	SOIL	75	1.54	6.73	3.41	0		

TABLE D-2

CONCENTRATIONS OF ELEMENTS IN SOILS

	Ferenbaugh et al. (1990, 0099)		Schacklette and Boerngen (1984, 0418)	
Element*	**Mean**	**Range**	**Mean**	**Range**
Aluminum (%)	5.8	5.3-6.7	5.8	0.5 ->10
Arsenic	3.9	1.3-6.7	5.5	<0.1- 97
Barium	410	120-810	580	70-5,000
Beryllium	1.9	1.1-3.3	0.68	<1-15
Bromine	1.9	0.40-5.7	0.52	<0.5-11
Cadmium (ppb)	170	30-520	-	-
Chlorine	<100	-	-	-
Chromium	27	4.2-136	41	3-2,000
Copper	10	2.0-18	21	2- 00
Iron	240	50-390	280	<10-1,900
Iron (%)	1.7	1.0-2.6	2.1	0.1->10
Lead	24	8.0-98	17	<10-700
Mercury (ppb)	18	7.0-29	46	<10-4,600
Manganese	510	330-840	380	30-5,000
Niobium	8.9	1.6-19	15	<5-700
Rubidium	120	90-160	69	<20-210
Thorium	-	-	9.1	2.4-31
Titanium (%)	0.26	0.079-0.49	0.22	0.05-2.0
Uranium	-	-	2.5	0.68-7.9
Zinc	54	38-71	55	10-2,100

*Data are reported in parts per million (ppm) unless otherwise noted.

References for Appendix D

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■ APPENDIX E

Quality Council Charter

1.0 PURPOSE

The Quality Council will provide a forum and process for improving quality in all aspects of the Environmental Restoration (ER)Program. Each participant in this program should be aware of the opportunity for continuous improvement without hindrance by organizational barriers. The Quality Council seeks to motivate everyone to find creative ways to solve problems. The goal of the Quality Council is to achieve quality by action rather than by reactions to inspections and audits.

2.0 PROCESSES

The Quality Council will

- provide a forum for program participants to identify problems that diminish quality operations;
- analyze the problem to identify the processes that need improvement;
- identify an owner of the process to address the problem (and make recommendations concerning how to develop solutions to the problem, as appropriate); and
- track the improvement (and re-evaluate, as appropriate).

3.0 AUTHORITY

The Quality Council is authorized by ER Program management to fulfill its charter. Program management will be represented on the Quality Council. The Quality Council has direct access to program management for conflict resolution, as needed.

4.0 CUSTOMERS

The customers of the Quality Council are the participants in the Los Alamos National Laboratory's ER Program.

5.0 MEMBERSHIP

The Quality Council consists of five members, all of whom will be University of California employees.

One member will be from each of the following four categories:

- program management,
- programmatic project leader,
- operable unit project leader, and
- technical team leader.

The member from each of these four groups will be selected by the persons in that group.

The fifth member will be an "at large" position who is not a person in any of the four categories listed above and who is elected by ER Program participants.

The ER Program's quality program project leader will be an *ex officio* member of the Quality Council.

6.0 TERM OF OFFICE

Each member of the Quality Council will serve for a one-year term. Three members will take office on January 1 of each year, and two members will take office on July 1.

7.0 SPECIFIC RESPONSIBILITIES

The Quality Council will designate its own chairperson. However, the chair will not be the program management representative.

The quality program project leader will record the minutes of the meetings and will distribute the minutes to all program participants.

8.0 FREQUENCY OF MEETINGS

The Quality Council will decide its meeting schedule but will meet at least once each month.

■ APPENDIX F

Potential Release Sites at Los Alamos National Laboratory

Codes and Abbreviations Used for PRS Data Base

PRS Class Codes

HSWA	Listed in HSWA Module (one of the 605 SWMUs in the 1990 RCRA permit).
HSWA PM	Unit added in the permit modification proposed in February 1993.
RCRA	Unit regulated by RCRA; does not appear in 1990 HSWA Module.
RCRA PM	Unit regulated by RCRA; appears in 1990 HSWA Module but is one of 38 SWMUs de leted from the module by the permit modification proposed in March 1993.
AOC/PRS	Unit may not be a SWMU as defined by RCRA, but ER Program is investigating.

Abbreviations of Potential Contaminants

RAD	Possible radioactive waste.
HE	Possible high explosives.
HAZ CONST	Possible volatile organic compounds, semivolatile organic compounds, metals, etc.
OTHER	Non-RCRA constituents (e.g., asbestos, PCBs)

Codes for Potential Remedial Action

CARBC	Clean to acceptable risk-based criteria
ISIC	In-place stabilization; institutional controls
rec NFA	Recommended in RFI work plan for no further action
NFA	Likely that no further action will be recommended after site characterization.

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
11-001(a)	11-001(a)	11-001(a)	11	HSWA	Firing site	Inactive	0		NFA
11-001(b)	11-001(b)	11-001(b)	11	HSWA	Firing site	Inactive	0		NFA
11-001(c)	11-001(c)	11-001(c)	11	HSWA	Firing site	Inactive	0		NFA
11-002	11-002	11-002	11	HSWA	Burn site	Active	0		NFA
11-003(a)	11-003(a)	11-003(a)	11	AOC/PRS	Mortar impact area	Inactive	0		Rec NFA
11-003(b)	11-003(b)	11-003(b)	11	AOC/PRS	Firing range	Inactive	20	Hazardous const.	CARBC
11-004(a)	11-004(a)	11-004(a)	11	HSWA	Drop tower	Active	4000	Rad, hazardous const., HE	CARBC
11-004(b)	11-004(b)	11-004(b)	11	HSWA	Drop tower	Active	4000	Rad, hazardous const., HE	CARBC
11-004(c)	11-004(c)	11-004(c)	11	HSWA	Drop tower	Active	4000	Rad, hazardous const., HE	CARBC
11-004(d)	11-004(d)	11-004(d)	11	HSWA	Drop tower	Active	4000	Rad, hazardous const., HE	CARBC
11-004(e)	11-004(e)	11-004(e)	11	HSWA	Drop tower	Active	4000	Rad, hazardous const., HE	CARBC
11-004(f)	11-004(f)	11-004(f)	11	AOC/PRS	Drop tower	Active	4000	Rad, hazardous const., HE	CARBC
11-005(a)	11-005(a)	11-005(a)	11	HSWA	Septic system	Active	0		NFA
11-005(b)	11-005(b)	11-005(b)	11	HSWA	Septic system	Active	0		NFA
	11-005(c)	11-005(c)	11	HSWA PM	Ind. or san. wastewater treat.	Inactive	0		NFA
11-006(a)	11-006(a)	11-006(a)	11	006HSWA	Sump	Active	1	Rad, haz. const., HE, other	CARBC
11-006(b)	11-006(b)	11-006(b)	11	HSWA PM	Tank and/or assoc. equip.	Active	5	Rad, haz. const., HE, other	CARBC
11-006(c)	11-006(c)	11-006(c)	11	HSWA PM	Tank and/or assoc. equip.	Active	5	Rad, haz. const., HE, other	CARBC
11-006(d)	11-006(d)	11-006(d)	11	HSWA PM	Tank and/or assoc. equip.	Active	5	Rad, haz. const., HE, other	CARBC
11-007	11-007	11-007	11	HSWA	Surface disposal	Inactive	0		Rec NFA
11-008	11-008	11-008	11	AOC/PRS	Surface disposal	Inactive	0		Rec NFA
11-009	11-009	11-009	11	HSWA	Material disposal area	Active	0		Rec NFA
11-010(a)	11-010(a)	11-010(a)	11	AOC/PRS	Container storage	Active	0		Rec NFA
11-010(b)	11-010(b)	11-010(b)	11	AOC/PRS	Container storage	Inactive	0		NFA
	11-011(a)	11-011(a)	11	HSWA PM	Ind. or san. wastewater treat.	Active	0		NFA
	11-011(b)	11-011(b)	11	HSWA PM	Ind. or san. wastewater treat.	Active	0		NFA
	11-011(c)	11-011(c)	11	HSWA PM	Ind. or san. wastewater treat.	Active	0		NFA
	11-011(d)	11-011(d)	11	HSWA PM	Ind. or san. wastewater treat.	Active	0		NFA
	11-012(a)	11-012(a)	11	AOC/PRS	Building	Removed	0		NFA

	11-012(b)	11-012(b)	11	AOC/PRS	Building	Removed	0		NFA
	11-012(c)	11-012(c)	11	AOC/PRS	Building	Removed	0		NFA
	11-012(d)	11-012(d)	11	AOC/PRS	Building	Removed	0		NFA
	C-11-001	C-11-001	11	AOC/PRS	Laboratory	Removed	0		NFA
	C-11-002	C-11-002	11	AOC/PRS	Laboratory	Removed	0		NFA
	C-11-003	C-11-003	11	AOC/PRS	One-time release site	Inactive	0		Rec NFA
13-001	13-001	13-001	13	HSWA PM	Firing site	Decommissioned	5000	Rad, haz. const., HE, other	CARBC
13-002	13-002	13-002	13	HSWA	Landfill	Decommissioned	500	Rad, haz. const., HE, other	CARBC
13-003(a)	13-003(a)	13-003(a)	13	HSWA PM	Septic tank	Decommissioned	0		NFA
13-003(b)	13-003(b)	13-003(b)	13	AOC/PRS	Septic system	Decommissioned	0		NFA
13-004	13-004	13-004	13	HSWA	Disposal pit	Inactive	0		NFA
16-001(a)	16-001(a)	16-001(a)	16	HSWA PM	Tank	Inactive	0		NFA
16-001(b)	16-001(b)	16-001(b)	16	HSWA	Dry wells	Inactive	0		NFA
16-001(c)	16-001(c)	16-001(c)	16	HSWA	Tank	Inactive	0		NFA
16-001(d)	16-001(d)	16-001(d)	16	HSWA	Dry well	Inactive	0		NFA
16-001(e)	16-001(e)	16-001(e)	16	HSWA	Dry well	Inactive	4	Hazardous const., HE	CARBC
16-002	deleted**				**Tritium tank did not become operational				
16-003(a)	16-003(a)	16-003(a)	16	HSWA	Sump	Inactive	12	Rad, hazardous const., HE	Def. D&D
16-003(b)	16-003(b)	16-003(b)	16	HSWA	Sump	Inactive	12	Hazardous const., HE	Def. D&D
16-003(c)	16-003(c)	16-003(c)	16	HSWA	Sump	Active	12	Rad, hazardous const., HE	Def. D&D
16-003(d)	16-003(d)	16-003(d)	16	HSWA	Sump	Inactive	14	Hazardous const.	Def. D&D
16-003(e)	16-003(e)	16-003(e)	16	HSWA	Sump	Inactive	14	Hazardous const., HE	Def. D&D
16-003(f)	16-003(f)	16-003(f)	16	HSWA	Sump	Inactive	14	Hazardous const.	Def. D&D
16-003(g)	16-003(g)	16-003(g)	16	HSWA	Sump	Inactive	14	Hazardous const.	Def. D&D
16-003(h)	16-003(h)	16-003(h)	16	HSWA	Sump	Inactive	12	Rad, hazardous const., HE	Def. D&D
16-003(i)	16-003(i)	16-003(i)	16	HSWA	Sump	Inactive	12	Rad, hazardous const., HE	Def. D&D
16-003(j)	16-003(j)	16-003(j)	16	HSWA	Sump	Inactive	12	Rad, hazardous const., HE	Def. D&D
16-003(k)	16-003(k)	16-003(k)	16	HSWA	Sump	Active	60	Rad, hazardous const., HE	Def. D&D
16-003(l)	16-003(l)	16-003(l)	16	HSWA	Sump	Inactive	16	Hazardous const., HE	Def. D&D
16-003(m)	16-003(m)	16-003(m)	16	HSWA	Sump	Inactive	14	Hazardous const., HE	Def. D&D
16-003(n)	16-003(n)	16-003(n)	16	HSWA	Sump	Active	12	Rad, hazardous const., HE	Def. D&D

16-003(o)	16-003(o)	16-003(o)	16	HSWA	Sump	Active	16	Rad, hazardous const., HE	Def. D&D
16-003(p)	16-029(a)								
16-003(q)	16-029(b)								
16-003(r)	16-029(c)								
16-003(s)	16-029(d)								
16-003(t)	16-029(e)								
16-003(u)	16-029(f)								
16-003(v)	16-029(g)								
	16-003(p)	16-003(p)	16	AOC/PRS	Sump	Inactive	40	Rad, hazardous const., HE	CARBC
	16-003(q)	16-003(q)	16	AOC/PRS	Sump	Inactive	0		NFA
16-004(a)	16-004(a)	16-004(a)	16	HSWA	Waste water treatment facility	Inactive	0		NFA
16-004(b)	16-004(b)	16-004(b)	16	HSWA	Waste water treatment facility	Inactive	0		NFA
16-004(c)	16-004(c)	16-004(c)	16	HSWA	Waste water treatment facility	Inactive	0		NFA
16-004(d)	16-004(d)	16-004(d)	16	HSWA	Waste water treatment facility	Inactive	0		NFA
16-004(e)	16-004(e)	16-004(e)	16	HSWA	Waste water treatment facility	Inactive	0		NFA
16-004(f)	16-004(f)	16-004(f)	16	HSWA	Waste water treatment facility	Inactive	0		NFA
	16-004misc				Unit does not exist				NFA
16-005(a)	16-005(a)	16-005(a)	16	HSWA PM	Septic tank	Decommissioned	10	Hazardous const., HE	CARBC
16-005(b)	16-005(b)	16-005(b)	16	HSWA PM	Septic tank	Decommissioned	0		NFA
16-005(c)	16-005(c)	16-005(c)	16	HSWA PM	Septic tank	Decommissioned	0		NFA
16-005(d)	16-005(d)	16-005(d)	16	HSWA PM	Septic tank	Decommissioned	3	Hazardous const., HE	CARBC
16-005(e)	16-005(e)	16-005(e)	16	HSWA PM	Septic tank	Decommissioned	2	Hazardous const., HE	CARBC
16-005(f)	16-005(f)	16-005(f)	16	HSWA PM	Septic tank	Decommissioned	2	Hazardous const., HE	CARBC
16-005(g)	16-005(f)	16-005(f)							
16-005(h)	16-005(f)	16-005(f)							
16-005(i)	16-005(g)	16-005(g)	16	HSWA PM	Burn Site	Active	1	Hazardous const., HE	Def. D&D
16-005(j)	16-005(h)	16-005(h)	16	HSWA PM	Septic tank	Decommissioned	0		NFA
16-005(k)	16-005(i)	16-005(i)	16	HSWA PM	Septic tank	Decommissioned	0		NFA
16-005(l)	16-005(j)	16-005(j)	16	HSWA PM	Septic tank	Decommissioned	2	Hazardous const., HE	CARBC
16-005(m)	16-029(h2)	16-029(h2)	16	AOC/PRS	Manhole	Inactive	2	Hazardous const.	CARBC
16-005(n)	16-005(k)	16-005(k)	16	HSWA PM	Septic tank	Decommissioned	0		NFA

16-005(o)	16-005(l)	16-005(l)	16	HSWA PM	Grease trap	Decommissioned	3	Hazardous const., HE	CARBC
	16-005(m)	16-005(m)	16	HSWA PM	Chemical pit	Decommissioned	3	Rad, hazardous const., HE	CARBC
16-006(a)	16-005(n)	16-005(n)	16	006(a)HSWA	Septic system	Decommissioned	0		Rec NFA
16-006(g)	16-005(o)	16-005(o)	16	006(g)HSWA	Septic system	Decommissioned	0		Rec NFA
16-006(b)	16-006(a)	16-006(a)	16	HSWA	Septic system	Active	0		NFA
16-006(c)	16-006(b)	16-006(b)	16	AOC/PRS	Septic system	Active	0		Rec NFA
16-006(d)	16-006(c)	16-006(c)	16	006d HSWA	Septic system	Active	0		NFA
16-006(e)	16-006(d)	16-006(d)	16	006e HSWA	Septic system	Active	0		NFA
16-006(f)	16-006(e)	16-006(e)	16	006f HSWA	Septic system	Active	0		NFA
16-006(h)	16-006(f)	16-006(f)	16	006h HSWA	Septic system	Active	0		Rec NFA
25-002(a)	16-006(g)	16-006(g)	16	HSWA PM	Septic tank	Inactive	0		NFA
25-002(b)	16-006(h)	16-006(h)	16	HSWA PM	Pump pit	Inactive	0		NFA
	16-006(i)	16-006(i)	16	HSWA PM	Septic tank	Active	1	Rad, hazardous const., HE	CARBC
16-007	16-007(a)	16-007(a)	16	007 HSWA	Surface impoundment	Decommissioned	0		NFA
	16-007(b)	16-007(b)	16	HSWA PM	Surface disposal site	Decommissioned	0		Rec NFA
16-008(a)	16-008(a)	16-008(a)	16	HSWA	Surface impoundment	Inactive	450	Rad, hazardous const., HE	CARBC
16-008(b)	16-008(b)	16-008(b)	16	RCRA	Surface impoundment	Inactive	0		Rec NFA
16-009(a)	16-009	16-009	16	009a HSWA	Burn site	Decommissioned	100	Rad, hazardous const., HE	CARBC
16-009(b)	16-019	16-019	16	009b HSWA	Material disposal area	Inactive	7000	Rad, hazardous const., HE	CARBC
16-010(a)	16-010(a)	16-010(a)	16	HSWA	Burn site	Inactive	200	Hazardous const., HE	CARBC
16-010(b)	16-010(b)	16-010(b)	16	**RCRA PM**	Burn site	Active	100	Hazardous const., HE	Def. D&D
16-010(c)	16-010(c)	16-010(c)	16	**RCRA PM**	Burn site	Active	5	Hazardous const., HE	Def. D&D
16-010(d)	16-010(d)	16-010(d)	16	**RCRA PM**	Burn site	Active	10	Hazardous const., HE	Def. D&D
16-010(e)	16-010(e)	16-010(e)	16	**RCRA PM**	Burn site	Active	1	Hazardous const., HE	Def. D&D
16-010(f)	16-010(f)	16-010(f)	16	**RCRA PM**	Burn site	Active	1	Hazardous const., HE	Def. D&D
16-010(g)	16-010(g)	16-010(g)	16	HSWA	Waste water treatment facility	Active	0		Rec NFA
16-010(h)	16-010(h)	16-010(h)	16	HSWA	Burn site	Inactive	0		NFA
16-010(i)	16-010(i)	16-010(i)	16	HSWA	Burn site	Inactive	0		NFA
16-010(j)	16-010(j)	16-010(j)	16	**RCRA PM**	Burn site	Active	1	Hazardous const., HE	Def. D&D
16-010(k)	16-010(k)	16-010(k)	16	HSWA	Trough	Inactive	0		NFA
16-010(l)	16-010(l)	16-010(l)	16	HSWA	Trough	Inactive	0		NFA

16-010(m)	16-010(m)	16-010(m)	16	HSWA	Trough	Inactive	0		NFA
	16-010(n)	16-010(n)	16	HSWA PM	Trough	Inactive	0		NFA
16-011	16-011	16-011	16	RCRA	Incinerator	Inactive	10	Hazardous const., HE	Def. D&D
		*16-011(b) See notation at end of data base							
16-012(a)	16-012(a)	16-012(a)	16	HSWA	Container storage	Active	0		Rec NFA
	16-012(a2)	16-012(a2)	16	AOC/PRS	Container storage	Active	0		Rec NFA
16-012(b)	16-012(b)	16-012(b)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(c)	16-012(c)	16-012(c)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(d)	16-012(d)	16-012(d)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(e)	16-012(e)	16-012(e)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(f)	16-012(f)	16-012(f)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(g)	16-012(g)	16-012(g)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(h)	16-012(h)	16-012(h)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(i)	16-012(i)	16-012(i)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(j)	16-012(j)	16-012(j)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(k)	16-012(k)	16-012(k)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(l)	16-012(l)	16-012(l)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(m)	16-012(m)	16-012(m)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(n)	16-012(n)	16-012(n)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(o)	16-012(o)	16-012(o)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(p)	16-012(p)	16-012(p)	16	**RCRA PM**	Container storage	Active	0		Rec NFA
16-012(q)	16-012(q)	16-012(q)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(r)	16-012(r)	16-012(r)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(s)	16-012(s)	16-012(s)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(t)	16-012(t)	16-012(t)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(u)	16-012(u)	16-012(u)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(v)	16-012(v)	16-012(v)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(w)	16-012(w)	16-012(w)	16	HSWA	Container storage	Active	0		Rec NFA
16-012(x)	16-012(x)	16-012(x)	16	**RCRA PM**	Satellite storage	Active	0		Rec NFA
16-012(y)	16-012(y)	16-012(y)	16	HSWA	Container storage	Active	0		Rec NFA
16-013(b)	16-012(z)	16-012(z)	16	013b HSWA	Container storage	Active	0		Rec NFA

16-013(a)	16-013	16-013	16	013a HSWA	Container storage	Decommissioned	0		NFA
16-014	16-014*				*Deleted because tritium facility is not operational and does not generate waste				
16-015(a)	16-015(a)	16-015(a)	16	AOC/PRS	Operational facility	Decommissioned	5	Hazardous const., HE	CARBC
16-015(b)	16-015(b)	16-015(b)	16	AOC/PRS	Operational facility	Decommissioned	5	Hazardous const., HE	CARBC
16-015(c)	16-015(c)	16-015(c)	16	AOC/PRS	Operational facility	Decommissioned	5	Hazardous const., HE	CARBC
16-015(d)	16-015(d)	16-015(d)	16	AOC/PRS	Operational facility	Decommissioned	5	Hazardous const., HE	CARBC
16-016(a)	16-016(a)	16-016(a)	16	016 HSWA	Landfill	Inactive	0		NFA
16-016(b)	16-016(b)	16-016(b)	16	HSWA PM	Landfill	Inactive	0		NFA
16-016(c)	16-016(c)	16-016(c)	16	HSWA PM	Landfill	Inactive	10	Hazardous const., HE	CARBC
	16-016(d)	16-016(d)	16	HSWA PM	Surface disposal site	Inactive	0		NFA
	16-016(e)	16-016(e)	16	HSWA PM	Surface disposal site	Inactive	5	Other	CARBC
	16-016(f)	16-016(f)	16	AOC/PRS	Landfill	Inactive	0		NFA
	16-016(g)	16-016(g)	16	HSWA PM	Surface disposal site	Inactive	5	Hazardous const.	CARBC
16-017	16-017	16-017	16	HSWA PM	Abandoned building & appurtenanc	Inactive	2000	Hazardous const., HE	Def. D&D
16-018	16-018	16-018	16	**RCRA PM**	Material disposal area	Inactive	15000	Rad, haz. const., HE, other	CARBC
16-019	16-019	16-019	16	HSWA	Material disposal area	Inactive	7000	Rad, haz. const., HE, other	CARBC
16-020	16-020	16-020	16	HSWA	Silver recovery unit	Active	100	Hazardous const.	CARBC
16-021	16-021(a)	16-021(a)	16	021 HSWA	Systematic release site	Active	0		NFA
	16-021(b)	16-021(b)	16	AOC/PRS	Systematic leak	Inactive	0		NFA
	16-021(c)	16-021(c)	16	HSWA PM	Ind. or san. waste water treatmer	Active	1000	Rad, hazardous const., HE	CARBC
16-022	16-022(a)	16-022(a)	16	RCRA	Underground tank	Inactive	2	Hazardous const.	CARBC
	16-022(b)	16-022(b)	16	RCRA	Underground tank	Inactive	2	Hazardous const.	CARBC
16-023(a)	16-023(a)	16-023(a)	16	AOC/PRS	Incinerator	Decommissioned	0		NFA
16-023(b)	16-023(b)	16-023(b)	16	AOC/PRS	Incinerator	Decommissioned	0		NFA
	16-024(a)	16-024(a)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
	16-024(b)	16-024(b)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
	16-024(c)	16-024(c)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
	16-024(d)	16-024(d)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
	16-024(e)	16-024(e)	16	AOC/PRS	Operational facility	Decommissioned	25	HE	CARBC
	16-024(f)	16-024(f)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
	16-024(g)	16-024(g)	16	AOC/PRS	Magazine	Decommissioned	0		NFA

16-024(h)	16-024(h)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(i)	16-024(i)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(j)	16-024(j)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(k)	16-024(k)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(l)	16-024(l)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(m)	16-024(m)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(n)	16-024(n)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(o)	16-024(o)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(p)	16-024(p)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(q)	16-024(q)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(r)	16-024(r)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(s)	16-024(s)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(t)	16-024(t)	16	AOC/PRS	Operational facility	Inactive	0		NFA
16-024(u)	16-024(u)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-024(v)	16-024(v)	16	AOC/PRS	Magazine	Decommissioned	0		NFA
16-025(a)	16-025(a)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	5	Rad, HE	CARBC
16-025(a2)	16-025(a2)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Hazardous const., HE	CARBC
16-025(b)	16-025(b)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Rad, hazardous const., HE	CARBC
16-025(b2)	16-025(b2)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Rad, hazardous const., HE	CARBC
16-025(c)	16-025(c)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(c2)	16-025(c2)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(d)	16-025(d)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(d2)	16-025(d2)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(e)	16-025(e)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	20	Hazardous const., HE	CARBC
16-025(e2)	16-025(e2)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Rad, hazardous const., HE	CARBC
16-025(f)	16-025(f)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	30	Hazardous const., HE	CARBC
16-025(f2)	16-025(f2)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(g)	16-025(g)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Hazardous const., HE	CARBC
16-025(g2)	16-025(g2)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(h)	16-025(h)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Hazardous const., HE	CARBC
16-025(h2)	16-025(h2)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	35	Hazardous const., HE	CARBC

16-025(i)	16-025(i)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Hazardous const., HE	CARBC
16-025(j)	16-025(j)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Hazardous const., HE	CARBC
16-025(k)	16-025(k)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	25	Hazardous const., HE	CARBC
16-025(l)	16-025(l)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	50	Hazardous const., HE	CARBC
16-025(m)	16-025(m)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(n)	16-025(n)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(o)	16-025(o)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(p)	16-025(p)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	50	Hazardous const., HE	CARBC
16-025(q)	16-025(q)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	50	Hazardous const., HE	CARBC
16-025(r)	16-025(r)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	50	Hazardous const., HE	CARBC
16-025(s)	16-025(s)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	10	Rad, hazardous const., HE	CARBC
16-025(t)	16-025(t)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	100	Rad, hazardous const., HE	CARBC
16-025(u)	16-025(u)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	550	Hazardous const., HE	CARBC
16-025(v)	16-025(v)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	50	Hazardous const., HE	CARBC
16-025(w)	16-025(w)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(x)	16-025(x)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	50	Rad, hazardous const., HE	CARBC
16-025(y)	16-025(y)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	0		NFA
16-025(z)	16-025(z)	16	HSWA PM	Abandoned building & appurtenanc	Decommissioned	100	Rad, hazardous const., HE	CARBC
16-026(a)	16-026(a)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(a2)	16-026(a2)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(b)	16-026(b)	16	HSWA PM	Outfall	Inactive	10	Rad, hazardous const., HE	CARBC
16-026(b2)	16-026(b2)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(c)	16-026(c)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(c2)	16-026(c2)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(d)	16-026(d)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(d2)	16-026(d2)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(e)	16-026(e)	16	HSWA PM	Outfall	Inactive	10	Hazardous const., HE	CARBC
16-026(e2)	16-026(e2)	16	HSWA PM	Outfall	Inactive	2	Hazardous const., HE	CARBC
16-026(f)	16-026(f)	16	HSWA PM	Outfall	Inactive	2	Hazardous const., HE	CARBC
16-026(f2)	16-026(f2)	16	HSWA PM	Outfall	Inactive	2	Rad, haz. const., HE	CARBC
16-026(g)	16-026(g)	16	HSWA PM	Outfall	Inactive	2	Hazardous const., HE	CARBC

16-026(g2)	16-026(g2)	16	HSWA PM	Outfall	Inactive	2	Hazardous const., HE	CARBC
16-026(h)	16-026(h)	16	HSWA PM	Outfall	Inactive	2	Hazardous const., HE	CARBC
16-026(h2)	16-026(h2)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(i)	16-026(i)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(i2)	16-026(i2)	16	HSWA PM	Outfall	Inactive	0		Rec NFA
16-026(j)	16-026(j)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(j2)	16-026(j2)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(k)	16-026(k)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(k2)	16-026(k2)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(l)	16-026(l)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(m)	16-026(m)	16	HSWA PM	Outfall	Inactive	2	Rad, hazardous const., HE	CARBC
16-026(n)	16-026(n)	16	HSWA PM	Outfall	Inactive	2	Rad, hazardous const., HE	CARBC
16-026(o)	16-026(o)	16	HSWA PM	Outfall	Inactive	2	Rad, hazardous const., HE	CARBC
16-026(p)	16-026(p)	16	HSWA PM	Outfall	Inactive	2	Rad, hazardous const., HE	CARBC
16-026(q)	16-026(q)	16	HSWA PM	Outfall	Decommissioned	2	Hazardous const., HE	CARBC
16-026(r)	16-026(r)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(s)	16-026(s)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(t)	16-026(t)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(u)	16-026(u)	16	HSWA PM	Outfall	Inactive	2	Hazardous const.	CARBC
16-026(v)	16-026(v)	16	HSWA PM	Outfall	Active	10	Rad, hazardous const., HE	CARBC
16-026(w)	16-026(w)	16	HSWA PM	Outfall	Decommissioned	2	Rad, haz. const., HE	CARBC
16-026(x)	16-026(x)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(y)	16-026(y)	16	HSWA PM	Outfall	Inactive	0		NFA
16-026(z)	16-026(z)	16	HSWA PM	Outfall	Inactive	0		NFA
16-027(a)	16-027(a)	16	AOC/PRS	Transformer	Active	0		NFA
16-027(b)	16-027(b)	16	AOC/PRS	Transformer	Active	0		NFA
16-027(c)	16-027(c)	16	AOC/PRS	Transformer	Active	0		NFA
16-027(d)	16-027(d)	16	AOC/PRS	Transformer	Active	0		NFA
16-028(a)	16-028(a)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
16-028(b)	16-028(b)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
16-028(c)	16-028(c)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA

	16-028(d)	16-028(d)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
	16-028(e)	16-028(e)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
16-003(p)	16-029(a)	16-029(a)	16	003(p) HSWA	Sump	Inactive	14	Rad, hazardous const., HE	Def. D&D
	16-029(a2)	16-029(a2)	16	AOC/PRS*	Sump	Decommissioned	0		NFA
16-003(q)	16-029(b)	16-029(b)	16	003(q) HSWA	Sump	Inactive	14	Hazardous const., HE	Def. D&D
	16-029(b2)	16-029(b2)	16	HSWA PM	Sump	Decommissioned	12	Hazardous const., HE	CARBC
16-003(r)	16-029(c)	16-029(c)	16	003(r)HSWA	Sump	Inactive	14	Hazardous const., HE	Def. D&D
	16-029(c2)	16-029(c2)	16	AOC/PRS*	Sump	Decommissioned	12	Rad, hazardous const., HE	CARBC
16-003(s)	16-029(d)	16-029(d)	16	003(s)HSWA	Sump	Inactive	14	Hazardous const., HE	Def. D&D
	16-029(d2)	16-029(d2)	16	AOC/PRS*	Sump	Decommissioned	12	Hazardous const., HE	CARBC
16-003(t)	16-029(e)	16-029(e)	16	003(t)HSWA	Sump	Inactive	14	Hazardous const., HE	Def. D&D
	16-029(e2)	16-029(e2)	16	AOC/PRS*	Sump	Decommissioned	13	Hazardous const., HE	CARBC
16-003(u)	16-029(f)	16-029(f)	16	003(u)HSWA	Sump	Active	12	Hazardous const., HE	Def. D&D
	16-029(f2)	16-029(f2)	16	HSWA PM	Outfall	Decommissioned	11	Hazardous const., HE	CARBC
16-003(v)	16-029(g)	16-029(g)	16	003(v) HSWA	Sump	Active	12	Hazardous const.	Def. D&D
	16-029(g2)	16-029(g2)	16	HSWA PM	Pump pit	Decommissioned	0		NFA
	16-029(h)	16-029(h)	16	HSWA PM	Sump	Inactive	11	Rad, hazardous const., HE	CARBC
	16-029(h2)	16-029(h2)	16	AOC/PRS*	Drain line and outfall	Decommissioned	11	Hazardous const., HE	CARBC
	16-029(i)	16-029(i)	16	HSWA PM	Outfall	Inactive	11	Rad, hazardous const., HE	Def. D&D
	16-029(j)	16-029(j)	16	HSWA PM	Outfall	Inactive	11	Rad, hazardous const.,HE	CARBC
	16-029(k)	16-029(k)	16	HSWA PM	Sump	Inactive	11	Hazardous const., HE	CARBC
					*Subunit or ancillary unit to HSWA unit				
	16-029(l)	16-029(l)	16	HSWA PM	Sump	Inactive	11	Hazardous const., HE	CARBC
	16-029(m)	16-029(m)	16	AOC/PRS*	Sump	Decommissioned	12	Hazardous const., HE	CARBC
	16-029(n)	16-029(n)	16	AOC/PRS*	Sump	Decommissioned	12	Hazardous const., HE	CARBC
	16-029(o)	16-029(o)	16	AOC/PRS*	Sump	Decommissioned	12	Hazardous const., HE	CARBC
	16-029(p)	16-029(p)	16	AOC/PRS*	Sump	Decommissioned	12	Hazardous const., HE	CARBC
	16-029(q)	16-029(q)	16	HSWA PM	Sump	Inactive	13	Hazardous const., HE	CARBC
	16-029(r)	16-029(r)	16	AOC/PRS*	Outfall	Decommissioned	12	Hazardous const., HE	CARBC
	16-029(s)	16-029(s)	16	HSWA PM	Sump	Inactive	15	Hazardous const., HE	CARBC
	16-029(t)	16-029(t)	16	HSWA PM	Sump	Inactive	15	Hazardous const., HE	CARBC

16-029(u)	16-029(u)	16	HSWA PM	Sump	Inactive	15	Hazardous const., HE	CARBC
16-029(v)	16-029(v)	16	HSWA PM	Sump	Decommissioned	11	Hazardous const., HE	CARBC
16-029(w)	16-029(w)	16	AOC/PRS*	Sump	Decommissioned	11	Hazardous const., HE	CARBC
16-029(x)	16-029(x)	16	HSWA PM	Sump	Inactive	60	Hazardous const., HE	CARBC
16-029(y)	16-029(y)	16	AOC/PRS*	Sump	Decommissioned	11	Rad, hazardous const., HE	CARBC
16-029(z)	16-029(z)	16	AOC/PRS*	Sump	Decommissioned	11	Hazardous const., HE	CARBC
16-030(a)	16-030(a)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
16-030(b)	16-030(b)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
16-030(c)	16-030(c)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
16-030(d)	16-030(d)	16	AOC/PRS	Outfall	Inactive	10	Rad, hazardous const., HE	CARBC
				*Subunit or ancillary unit to HSWA Unit				
16-030(e)	16-030(e)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
16-030(f)	16-030(f)	16	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
16-030(g)	16-030(g)	16	AOC/PRS	Outfall	Inactive	5	Hazardous const., HE	CARBC
16-030(h)	16-030(h)	16	HSWA PM	Ind. or san. waste water treatmer	Inactive	5	Hazardous const., HE	CARBC
16-031(a)	16-031(a)	16	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
16-031(b)	16-031(b)	16	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
16-031(c)	16-031(c)	16	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
16-031(d)	16-031(d)	16	HSWA PM	Ind. or san. waste water treatmer	Decommissioned	0		NFA
16-031(e)	16-031(e)	16	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
16-031(f)	16-031(f)	16	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
16-031(g)	16-031(g)	16	HSWA PM	Ind. or san. waste water treatmer	Decommissioned	0		NFA
16-031(h)	16-031(h)	16	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
16-032(a)	16-032(a)	16	AOC/PRS*	Sump	Decommissioned	1	Hazardous const., HE	CARBC
16-032(b)	16-032(b)	16	AOC/PRS*	Shed	Decommissioned	1	Hazardous const.	CARBC
16-032(c)	16-032(c)	16	AOC/PRS*	Sump	Decommissioned	1	Hazardous const., HE	CARBC
16-032(d)	16-032(d)	16	HSWA PM	Sump	Decommissioned	1	Hazardous const., HE	CARBC
16-032(e)	16-032(e)	16	HSWA PM	Water pump pit	Decommissioned	0		NFA
16-033(a)	16-033(a)	16	AOC/PRS	Underground tank	Decommissioned	5	Hazardous const.	CARBC
16-033(b)	16-033(b)	16	AOC/PRS	Underground tank	Decommissioned	5	Hazardous const.	CARBC
				*Subunit or ancillary unit to HSWA unit				

16-033(c)	16-033(c)	16	AOC/PRS	Underground tank	Decommissioned	15	Hazardous const.	CARBC
16-033(d)	16-033(d)	16	AOC/PRS	Tank and/or assoc. equip	Decommissioned	0		NFA
16-033(e)	16-033(e)	16	AOC/PRS	Underground tank	Decommissioned	10	Hazardous const.	CARBC
16-033(f)	16-033(f)	16	AOC/PRS	Underground tank	Decommissioned	5	Hazardous const.	CARBC
16-033(g)	16-033(g)	16	AOC/PRS	Underground tank	Decommissioned	5	Hazardous const.	CARBC
16-033(h)	16-033(h)	16	AOC/PRS	Underground tank	Decommissioned	5	Hazardous const.	CARBC
16-033(i)	16-033(i)	16	AOC/PRS	Underground tank	Decommissioned	5	Hazardous const.	CARBC
16-033(j)	16-033(j)	16	AOC/PRS	Underground tank	Decommissioned	5	Hazardous const.	CARBC
16-034(a)	16-034(a)	16	HSWA PM	Soil contamination area	Decommissioned	30	Hazardous const., HE	CARBC
16-034(b)	16-034(b)	16	HSWA PM	Soil contamination area	Decommissioned	100	Hazardous const., HE	CARBC
16-034(c)	16-034(c)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(d)	16-034(d)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(e)	16-034(e)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(f)	16-034(f)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(g)	16-034(g)	16	HSWA PM	Soil contamination area	Inactive	0		NFA
16-034(h)	16-034(h)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(i)	16-034(i)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(j)	16-034(j)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(k)	16-034(k)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(l)	16-034(l)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(m)	16-034(m)	16	HSWA PM	Soil contamination area	Decommissioned	10	Hazardous const., HE	CARBC
16-034(n)	16-034(n)	16	HSWA PM	Soil contamination area	Decommissioned	0		NFA
16-034(o)	16-034(o)	16	HSWA PM	Soil contamination area	Decommissioned	100	Hazardous const., HE	CARBC
16-034(p)	16-034(p)	16	HSWA PM	Soil contamination area	Inactive	5	Hazardous const., HE	CARBC
16-035	16-035	16	HSWA PM	Soil contamination area	Inactive	0		NFA
16-036	16-036	16	HSWA PM	Soil contamination area	Inactive	150	Rad, hazardous const., HE	CARBC
16-037	16-037	16	AOC/PRS	Aboveground tank	Active	1	Hazardous const.	CARBC
C-16-001	C-16-001	16	AOC/PRS	Building	Removed	0		NFA
C-16-002	C-16-002	16	AOC/PRS	Building	Removed	0		NFA
C-16-003	C-16-003	16	AOC/PRS	Septic system	Removed	0		NFA
C-16-004	C-16-004	16	AOC/PRS	Building	Removed	0		NFA

C-16-005	C-16-005	16	AOC/PRS	Building	Decommissioned	50	Hazardous const., HE	CARBC
C-16-006	C-16-006	16	AOC/PRS	Building	Decommissioned	0		NFA
C-16-007	C-16-007	16	AOC/PRS	Building	Removed	0		NFA
C-16-008	C-16-008	16	AOC/PRS	Building	Removed	0		NFA
C-16-009	C-16-009	16	AOC/PRS	Building	Removed	0		NFA
C-16-010	C-16-010	16	AOC/PRS	Building	Removed	0		NFA
C-16-011	C-16-011	16	AOC/PRS	Building	Removed	0		NFA
C-16-012	C-16-012	16	AOC/PRS	Building	Removed	0		NFA
C-16-013	C-16-013	16	AOC/PRS	Storage area	Removed	0		NFA
C-16-014	C-16-014	16	AOC/PRS	Building	Removed	0		NFA
C-16-015	C-16-015	16	AOC/PRS	Building	Removed	0		NFA
C-16-016	C-16-016	16	AOC/PRS	Building	Removed	0		NFA
C-16-017	C-16-017	16	AOC/PRS	Building	Removed	0		NFA
C-16-018	C-16-018	16	AOC/PRS	Aboveground tank	Removed	0		NFA
C-16-019	C-16-019	16	AOC/PRS	Building	Removed	0		NFA
C-16-020	C-16-020	16	AOC/PRS	Building	Removed	0		NFA
C-16-021	C-16-021	16	AOC/PRS	Building	Removed	0		NFA
C-16-022	C-16-022	16	AOC/PRS	Building	Removed	0		NFA
C-16-023	C-16-023	16	AOC/PRS	Warehouse	Removed	0		NFA
C-16-024	C-16-024	16	AOC/PRS	Building	Removed	0		NFA
C-16-025	C-16-025	16	AOC/PRS	Building	Removed	0		NFA
C-16-026	C-16-026	16	AOC/PRS	Building	Removed	0		NFA
C-16-027	C-16-027	16	AOC/PRS	Building	Removed	0		NFA
C-16-028	C-16-028	16	AOC/PRS	Building	Removed	0		NFA
C-16-029	C-16-029	16	AOC/PRS	Building	Removed	0		NFA
C-16-030	C-16-030	16	AOC/PRS	Building	Removed	0		NFA
C-16-031	C-16-031	16	AOC/PRS	Building	Removed	1	Hazardous const.	CARBC
C-16-032	C-16-032	16	AOC/PRS	Building	Removed	0		NFA
C-16-033	C-16-033	16	AOC/PRS	Warehouse	Removed	0		NFA
C-16-034	C-16-034	16	AOC/PRS	Aboveground tank	Removed	0		NFA
C-16-035	C-16-035	16	AOC/PRS	Aboveground tank	Removed	0		NFA

C-16-036	C-16-036	16	AOC/PRS	Septic system	Removed	0		NFA
C-16-037	C-16-037	16	AOC/PRS	Storage area	Removed	0		NFA
C-16-038	C-16-038	16	AOC/PRS	Storage area	Removed	0		NFA
C-16-039	C-16-039	16	AOC/PRS	Building	Removed	0		NFA
C-16-040	C-16-040	16	AOC/PRS	Building	Removed	0		NFA
C-16-041	C-16-041	16	AOC/PRS	Building	Removed	0		NFA
C-16-042	C-16-042	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-043	C-16-043	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-044	C-16-044	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-045	C-16-045	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-046	C-16-046	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-047	C-16-047	16	AOC/PRS	Transport area	Removed	1	Hazardous const.	CARBC
C-16-048	C-16-048	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-049	C-16-049	16	AOC/PRS	Building	Removed	0		NFA
C-16-050	C-16-050	16	AOC/PRS	Building	Removed	0		NFA
C-16-051	C-16-051	16	AOC/PRS	Transport area	Removed	1	Hazardous const.	CARBC
C-16-052	C-16-052	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-053	C-16-053	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-054	C-16-054	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-055	C-16-055	16	AOC/PRS	Generation area	Removed	0		NFA
C-16-056	C-16-056	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-057	C-16-057	16	AOC/PRS	Manhole	Removed	0		NFA
C-16-058	C-16-058	16	AOC/PRS	Transport area	Removed	1	Hazardous const.	CARBC
C-16-059	C-16-059	16	AOC/PRS	Generation area	Removed	0		NFA
C-16-060	C-16-060	16	AOC/PRS	Building	Removed	75	Rad, hazardous const.	CARBC
C-16-061	C-16-061	16	AOC/PRS	Building	Removed	0		NFA
C-16-062	C-16-062	16	AOC/PRS	Generation area	Removed	0		NFA
C-16-063	C-16-063	16	AOC/PRS	Generation area	Removed	0		NFA
C-16-064	C-16-064	16	AOC/PRS	HE scrap pick-up	Removed	1	Hazardous const., HE	CARBC
C-16-065	C-16-065	16	AOC/PRS	Storage area	Inactive	0		NFA
C-16-066	C-16-066	16	AOC/PRS	Storage area	Removed	0		NFA

	C-16-067	C-16-067	16	AOC/PRS	Storage area	Removed	0		NFA
	C-16-068	C-16-068	16	AOC/PRS	Building	Removed	15	Hazardous const.	CARBC
	C-16-069	C-16-069	16	AOC/PRS	Building	Removed	0		NFA
	C-16-070	C-16-070	16	AOC/PRS	Underground tank	Inactive	40	Hazardous const.	CARBC
	C-16-071	C-16-071	16	AOC/PRS	One-time spill	Removed	0		NFA
	C-16-072	C-16-072	16	AOC/PRS	Tank	Unknown	40	Hazardous const.	CARBC
	C-16-073	C-16-073	16	AOC/PRS	Underground tank	Active	40	Hazardous const.	CARBC
	C-16-074	C-16-074	16	AOC/PRS	Storage	Active	0		NFA
25-001	25-001	25-001	25	AOC/PRS	Disposal pit	Decommissioned	0		NFA
	C-25-001	C-25-001	25	AOC/PRS	Building	Removed	5	Hazardous const.	CARBC
37-001	37-001	37-001	37	AOC/PRS	Septic system	Inactive	0		Rec NFA

*16-011(b) Identified in HSWA PM but it doesn't really exist, so it's been deleted from database

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
12-001(a)	12-001(a)	12-001(a)	12	HSWA	Firing site	Inactive	10	Rad, hazardous const., HE	CARBC
12-001(b)	12-001(b)	12-001(b)	12	HSWA	Firing site	Inactive	10	Rad, hazardous const., HE	CARBC
12-002	12-002	12-002	12	HSWA PM	Open burning ground	Inactive	0		NFA
12-003	12-003	12-003	12	AOC/PRS	Storage area	Inactive	0		NFA
12-004(a)	12-004(a)	12-004(a)	12	AOC/PRS	Operational facility	Inactive	10	Rad, hazardous const., HE	CARBC
12-004(b)	12-004(b)	12-004(b)	12	AOC/PRS	Operational facility	Inactive	1	Rad, hazardous const., HE	CARBC
	C-12-001	C-12-001	12	AOC/PRS	Building	Removed	10	Hazardous const., HE	CARBC
	C-12-002	C-12-002	12	AOC/PRS	Building	Removed	10	Hazardous const., HE	CARBC
	C-12-003	C-12-003	12	AOC/PRS	Building	Decommissioned	10	Hazardous const., HE	CARBC
	C-12-004	C-12-004	12	AOC/PRS	Building	Decommissioned	0	Hazardous const.	CARBC
	C-12-005	C-12-005	12	AOC/PRS	Building	Decommissioned	0	HE	CARBC
	C-12-006	C-12-006	12	AOC/PRS	Building	Inactive	0		NFA
14-001(a)	14-001(a)	14-001(a)	14	AOC/PRS	Firing site	Active	1	Rad, hazardous const., HE	Def. D&D
14-001(b)	14-001(b)	14-001(b)	14	AOC/PRS	Firing site	Active	1	Rad, hazardous const., HE	Def. D&D
14-001(c)	14-001(c)	14-001(c)	14	AOC/PRS	Firing site	Active	1	Rad, hazardous const., HE	Def. D&D
14-001(d)	14-001(d)	14-001(d)	14	AOC/PRS	Firing site	Active	1	Rad, hazardous const., HE	Def. D&D
14-001(e)	14-001(e)	14-001(e)	14	AOC/PRS	Firing site	Active	1	Rad, hazardous const., HE	Def. D&D
14-001(f)	14-001(f)	14-001(f)	14	AOC/PRS	Firing site	Active	2	Rad, hazardous const., HE	Def. D&D
14-001(g)	14-001(g)	14-001(g)	14	AOC/PRS	Firing site	Active	3	Rad, hazardous const., HE	Def. D&D
14-002(a)	14-002(a)	14-002(a)	14	HSWA	Firing site	Decommissioned	1	Rad, hazardous const., HE	Def. D&D
14-002(b)	14-002(b)	14-002(b)	14	HSWA	Firing site	Decommissioned	1	Rad, hazardous const., HE	Def. D&D
14-002(c)	14-002(c)	14-002(c)	14	HSWA	Building	Decommissioned	12	Rad, hazardous const., HE	CARBC
14-002(d)	14-002(d)	14-002(d)	14	HSWA	Firing site	Decommissioned	12	Rad, hazardous const., HE	CARBC
14-002(e)	14-002(e)	14-002(e)	14	HSWA	Firing site	Decommissioned	12	Rad, hazardous const., HE	CARBC
14-002(f)	14-002(f)	14-002(f)	14	HSWA	Firing site	Decommissioned	1	Rad, hazardous const., HE	Def. D&D
14-003	14-003	14-003	14	HSWA PM	Open burning ground	Inactive	10	Rad, hazardous const., HE	CARBC
14-004(a)	14-004(a)	14-004(a)	14	AOC/PRS	Storage area	Active	1		NFA
14-004(b)	14-004(b)	14-004(b)	14	HSWA	Storage area	Active	1		NFA
14-004(c)	14-004(c)	14-004(c)	14	AOC/PRS	Storage area	Active	4		NFA

14-005	14-005	14-005	14	HSWA	Incinerator	Active	1	Rad, hazardous const., HE	Def. D&D
14-006	14-006	14-006	14	HSWA PM	Tank and/or assoc. equip.	Active	7	Hazardous const., HE	Def. D&D
14-007	14-007	14-007	14	HSWA	Septic system	Inactive	3	Rad, hazardous const., HE	CARBC
14-008	14-008	14-008	14	AOC/PRS	Landfill and surface disposal	Inactive	0		NFA
14-009	14-009	14-009	14	HSWA PM	Surface disposal site	Active	74	Rad, hazardous const., HE	Def. D&D
	14-010	14-010	14	HSWA PM	Sump	Decommissioned	7	Rad, hazardous const., HE	Def. D&D
	C-14-001	C-14-001	14	AOC/PRS	Building	Decommissioned	10	Hazardous const., HE	CARBC
	C-14-002	C-14-002	14	AOC/PRS	Building	Removed	10	Rad, hazardous const., HE	Def. D&D
	C-14-003	C-14-003	14	AOC/PRS	Building	Removed	10	Rad, hazardous const., HE	Def. D&D
	C-14-004	C-14-004	14	AOC/PRS	Building	Removed	10	Hazardous const., HE	Def. D&D
	C-14-005	C-14-005	14	AOC/PRS	Building	Removed	10	Rad, hazardous const., HE	Def. D&D
	C-14-006	C-14-006	14	AOC/PRS	Building	Removed	4	Hazardous const., HE	Def. D&D
	C-14-007	C-14-007	14	AOC/PRS	Building	Removed	4	Hazardous const., HE	Def. D&D
	C-14-008	C-14-008	14	AOC/PRS	Building	Removed	4	Hazardous const., HE	Def. D&D
	C-14-009	C-14-009	14	AOC/PRS	Building	Decommissioned	4	Hazardous const., HE	Def. D&D

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
15-001	15-001	15-001	15	AOC/PRS	Surface disposal	Active	93	Rad, hazardous const.	CARBC
15-002	15-002	15-002	15	HSWA	Disposal pit and burn site	Inactive	4	Rad, hazardous const., HE	CARBC
15-003	15-003	15-003	15	**RCRA PM**	Firing site	Active	24850	Hazardous const., HE	Def. D&D
15-004(a)	15-004(a)	15-004(a)	15	HSWA PM	Firing site	Inactive	100	Rad, hazardous const., HE	CARBC
15-004(b)	15-004(a)	15-004(a)							
15-004(c)	15-004(b)	15-004(b)	15	HSWA PM	Firing site	Inactive	100	Rad, hazardous const., HE	CARBC
15-004(d)	15-004(b)	15-004(b)							
15-004(e)	15-004(c)	15-004(c)	15	0-004eHSWA	Firing site	Inactive	100	Rad, hazardous const., HE	CARBC
15-004(f)	15-004(d)	15-004(d)	15	**HSWA PM**	Firing site	Inactive	100	Rad, hazardous const., HE	CARBC
15-004(g)	15-004(e)	15-004(e)	15	AOC/PRS	Unit does not exist		0		Rec NFA
15-004(h)	15-004(f)	15-004(f)	15	HSWA PM	Machine firing site	Inactive	10000	Rad, hazardous const., HE	CARBC
15-004(i)	15-004(g)	15-004(g)	15	HSWA PM	Machine firing site	Inactive	100	Rad, hazardous const., HE	CARBC
15-004(j)	15-004(g)	15-004(g)							
15-004(k)	15-004(h)	15-004(h)	15	AOC/PRS	Firing site	Inactive	100	Rad, hazardous const., HE	CARBC
15-004(l)	15-004(c)	15-004(c)							
15-004(m)	15-004(f)	15-004(f)							
15-004(n)	15-004(g)	15-004(g)							
15-004(o)	15-004(h)	15-004(h)							
	15-004(i)	15-004(i)	15	AOC/PRS	Detonation ground	Inactive	0		Rec NFA
15-005(a)	15-005(a)	15-005(a)	15	AOC/PRS	Storage area	Active	1	Rad, hazardous const., HE	CARBC
15-005(b)	15-005(b)	15-005(b)	15	AOC/PRS	Storage area	Active	1	Rad, hazardous const., HE	CARBC
15-005(c)	15-005(c)	15-005(c)	15	AOC/PRS	Storage area	Active	1	Rad, hazardous const., HE	CARBC
	15-005(d)	15-005(d)	15	AOC/PRS	Storage area	Active	0		Rec NFA
15-006(a)	15-006(a)	15-006(a)	15	HSWA	Firing site	Active	24850	Rad, hazardous const., HE	Def. D&D
15-006(b)	15-006(b)	15-006(b)	15	HSWA	Firing site	Active	9308	Rad, hazardous const., HE	Def. D&D
15-006(c)	15-006(c)	15-006(c)	15	HSWA	Firing site	Active	5236	Rad, hazardous const., HE	Def. D&D
15-006(d)	15-006(d)	15-006(d)	15	HSWA	Firing site	Active	5236	Rad, hazardous const., HE	Def. D&D
	15-006(e)	15-006(e)	15	AOC/PRS	Not in TA-15		0		NFA
15-007(a)	15-007(a)	15-007(a)	15	HSWA	Landfill MDA-N	Inactive	2420	Rad, hazardous const., HE	IS:IC

15-007(b)	15-007(b)	15-007(b)	15	HSWA	Landfill MDA-Z	Inactive	16133	Rad, hazardous const., HE	CARBC
15-007(c)	15-007(c)	15-007(c)	15	HSWA	Shaft	Inactive	0		Rec NFA
15-007(d)	15-007(d)	15-007(d)	15	HSWA	Shaft	Inactive	0		Rec NFA
15-008(a)	15-008(a)	15-008(a)	15	HSWA	Surface disposal	Inactive	2778	Rad, hazardous const.	CARBC
15-008(b)	15-008(b)	15-008(b)	15	HSWA	Surface disposal	Inactive	926	Rad, hazardous const., HE	CARBC
15-008(c)	15-008(c)	15-008(c)	15	HSWA	Surface disposal	Inactive	463	Rad, hazardous const., HE	CARBC
15-008(d)	15-008(d)	15-008(d)	15	HSWA	Surface disposal	Inactive	116	Hazardous const.	Def. D&D
	15-008(e)	15-008(e)	15	AOC/PRS	Surface disposal	Inactive	0		Rec NFA
	15-008(f)	15-008(f)	15	AOC/PRS	Not in TA-15		0		NFA
	15-008(g)	15-008(g)	15	AOC/PRS	Surface disposal	Inactive	370	Rad, hazardous const.	Def. D&D
15-009(a)	15-009(a)	15-009(a)	15	HSWA	Septic system	Active	6	Hazardous const.	Rec NFA
15-009(b)	15-009(b)	15-009(b)	15	HSWA	Septic system	Active	7	Hazardous const.	Def. D&D
15-009(c)	15-009(c)	15-009(c)	15	HSWA PM	Septic tank	Active	142	Hazardous const.	Def. D&D
15-009(d)	15-009(d)	15-009(d)	15	HSWA PM	Septic tank	Active	0		Rec NFA
15-009(e)	15-009(e)	15-009(e)	15	HSWA PM	Septic tank	Active	142	Hazardous const.	CARBC
15-009(f)	15-009(f)	15-009(f)	15	HSWA PM	Septic tank	Active	355	Hazardous const.	CARBC
15-009(g)	15-009(g)	15-009(g)	15	HSWA PM	Septic tank	Active	96	Hazardous const.	Def. D&D
15-009(h)	15-009(h)	15-009(h)	15	HSWA PM	Septic tank	Active	117	Hazardous const.	Def. D&D
15-009(i)	15-009(i)	15-009(i)	15	HSWA PM	Septic tank	Active	145	Hazardous const.	Def. D&D
15-009(j)	15-009(j)	15-009(j)	15	HSWA PM	Septic tank	Active	145	Hazardous const.	CARBC
15-009(k)	15-009(k)	15-009(k)	15	HSWA PM	Septic tank	Active	141	Hazardous const.	CARBC
15-010(a)	15-010(a)	15-010(a)	15	HSWA	Septic system	Inactive	0		Rec NFA
15-010(b)	15-010(b)	15-010(b)	15	HSWA	Septic system	Inactive	118	Rad, hazardous const., HE	CARBC
15-010(c)	15-010(c)	15-010(c)	15	HSWA	Operational release	Inactive	112	Hazardous const.	CARBC
15-011(a)	15-011(a)	15-011(a)	15	HSWA	Sump	Inactive	142	Hazardous const., HE	CARBC
15-011(b)	15-011(b)	15-011(b)	15	HSWA	Dry well	Inactive	23	Hazardous const.	CARBC
15-011(c)	15-011(c)	15-011(c)	15	HSWA	Sump	Inactive	142	Hazardous const.	CARBC
15-012(a)	15-012(a)	15-012(a)	15	HSWA	Surface disposal	Inactive	0		Rec NFA
15-012(b)	15-010(c)	15-010(c)	15	012(b)HSWA	Outfall	Inactive	10	Rad, hazardous const.	CARBC
	15-012(b)	15-012(b)	15	HSWA PM	Surface disposal site	Inactive	9	Rad, hazardous const.	CARBC
15-012(c)	15-014(m)	15-014(m)	15	012(c)HSWA	Outfall	Active	0		Rec NFA

15-012(d)	15-014(k)	15-014(k)	15	012(d)HSWA	Outfall	Active	94	Hazardous const.	CARBC
15-012(e)	15-014(l)	15-014(l)	15	012(e)HSWA	Outfall	Active	0		Rec NFA
15-012(f)	15-014(i)	15-014(i)	15	012(f)HSWA	Outfall	Active	94	Hazardous const.	CARBC
15-012(g)	15-014(j)	15-014(j)	15	012(g)HSWA	Outfall	Active	94	Hazardous const.	CARBC
	15-013(a)	15-013(a)	15	AOC/PRS	Underground tank	Removed	0		Rec NFA
	15-013(b)	15-013(b)	15	AOC/PRS	Underground tank	Removed	0		Rec NFA
	15-014(a)	15-014(a)	15	HSWA PM	Ind. or san. waste water treat.	Active	940	Hazardous const.	CARBC
	15-014(b)	15-014(b)	15	HSWA PM	Ind. or san. waste water treat.	Active	94	Hazardous const.	CARBC
	15-014(c)	15-014(c)	15	HSWA PM	Ind. or san. waste water treat.	Active	0		Rec NFA
	15-014(d)	15-014(d)	15	HSWA PM	Ind. or san. waste water treat.	Active	0		Rec NFA
	15-014(e)	15-014(e)	15	HSWA PM	Ind. or san. waste water treat.	Active	0		Rec NFA
	15-014(f)	15-014(f)	15	HSWA PM	Ind. or san. waste water treat.	Active	0		Rec NFA
	15-014(g)	15-014(g)	15	HSWA PM	Ind. or san. waste water treat.	Active	0		Rec NFA
	15-014(h)	15-014(h)	15	AOC/PRS	Outfall	Active	94	Hazardous const.	CARBC
	C-15-001	C-15-001	15	AOC/PRS	Surface disposal	Inactive	19	Rad, hazardous const.	CARBC
	C-15-002	C-15-002	15	AOC/PRS	Surface disposal	Inactive	0		Rec NFA
	C-15-003	C-15-003	15	AOC/PRS	Surface disposal	Inactive	0		Rec NFA
	C-15-004	C-15-004	15	AOC/PRS	Transformers	Removed	0	Other	CARBC
	C-15-005	C-15-005	15	AOC/PRS	Laboratory and building	Removed	370	Rad, hazardous const.	CARBC
	C-15-006	C-15-006	15	AOC/PRS	Building	Removed	370	Hazardous const.	CARBC
	C-15-007	C-15-007	15	AOC/PRS	Non-intentional release	Inactive	4	Hazardous const.	CARBC
	C-15-008	C-15-008	15	AOC/PRS	Non-intentional release	Inactive	0		Rec NFA
	C-15-009	C-15-009	15	AOC/PRS	Underground tank	Inactive	0		Rec NFA
	C-15-010	C-15-010	15	AOC/PRS	Underground tank	Removed	74	Hazardous const.	CARBC
	C-15-011	C-15-011	15	AOC/PRS	Underground tank	Inactive	37	Hazardous const.	CARBC
	C-15-012	C-15-012	15	AOC/PRS	Underground tank	Active	0		Rec NFA
	C-15-013	C-15-013	15	AOC/PRS	Underground tank	Inactive	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
18-001	18-001(a)	18-001(a)	18	001 HSWA	Lagoon	Active	0		NFA
	18-001(b)	18-001(b)	18	HSWA	Sewer lines	Active	0		NFA
	18-001(c)	18-001(c)	18	HSWA	Sump	Active	0		NFA
18-002(a)	18-002(a)	18-002(a)	18	HSWA	Firing site	Abandoned	0		NFA
18-002(b)	18-002(b)	18-002(b)	18	HSWA	Firing site	Abandoned	0		NFA
18-002(c)	18-002(c)	18-002(c)	18	AOC/PRS	Drop tower	Abandoned	0		NFA
18-003(a)	18-003(a)	18-003(a)	18	HSWA	Settling pit	Active	46	Rad, hazardous const.	Def. D&D
18-003(b)	18-003(b)	18-003(b)	18	HSWA	Septic system	Active	46	Rad, hazardous const.	Def. D&D
18-003(c)	18-003(c)	18-003(c)	18	HSWA	Septic system	Active	54	Rad. hazardous const.	Def. D&D
18-003(d)	18-003(d)	18-003(d)	18	HSWA	Septic system	Active	49	Rad, hazardous const.	Def. D&D
18-003(e)	18-003(e)	18-003(e)	18	HSWA	Septic system	Inactive	65	Rad, hazardous const.	CARBC
18-003(f)	18-003(f)	18-003(f)	18	HSWA	Septic system	Inactive	65	Rad, hazardous const.	CARBC
18-003(g)	18-003(g)	18-003(g)	18	HSWA	Septic system	Active	0		NFA
18-003(h)	18-003(h)	18-003(h)	18	HSWA	Septic system	Active	0		NFA
18-004(a)	18-004(a)	18-004(a)	18	HSWA PM	Waste lines containment	Inactive	0		NFA
18-004(b)	18-004(b)	18-004(b)	18	HSWA	Pit	Decommissioned	0		NFA
18-005	18-005(a)	18-005(a)	18	005 HSWA	Storage area	Decommissioned	0		NFA
	18-005(b)	18-005(b)	18	HSWA	Storage area	Decommissioned	0		Rec NFA
	18-005(c)	18-005(c)	18	HSWA	Storage area	Decommissioned	0		Rec NFA
18-006	18-006	18-006	18	AOC/PRS	Storage pipe	Inactive	1	Rad	Def. D&D
18-007	18-007	18-007	18	HSWA	Buried armored vehicle	Unknown	0		NFA
	18-008	18-008	18	AOC/PRS	Underground tank	Decommissioned	0	Hazardous const.	CARBC
	18-009(a)	18-009(a)	18	AOC/PRS	Transformer	Decommissioned	0		Rec NFA
	18-009(b)	18-009(b)	18	AOC/PRS	Transformer	Decommissioned	0		Rec NFA
	18-009(c)	18-009(c)	18	AOC/PRS	Transformer	Decommissioned	0		Rec NFA
	18-009(d)	18-009(d)	18	AOC/PRS	Transformer	Decommissioned	0		Rec NFA
	18-009(e)	18-009(e)	18	AOC/PRS	Transformer	Decommissioned	0		Rec NFA
	18-010(a)	18-010(a)	18	AOC/PRS	Outfall	Active	0		Rec NFA
	18-010(b)	18-010(b)	18	AOC/PRS	Outfall	Active	0		NFA

	18-010(c)	18-010(c)	18	AOC/PRS	Outfall	Active	0		NFA
	18-010(d)	18-010(d)	18	AOC/PRS	Outfall	Active	0		NFA
	18-010(e)	18-010(e)	18	AOC/PRS	Outfall	Active	0		NFA
	18-010(f)	18-010(f)	18	AOC/PRS	Outfall	Active	0		NFA
	18-011	18-011	18	AOC/PRS	Soil containment	Decommissioned	0		NFA
	18-012(a)	18-012(a)	18	HSWA PM	Ind. or san. waste water treat.	Active	0		NFA
	18-012(b)	18-012(b)	18	HSWA PM	Ind. or san. waste water treat.	Active	0		NFA
	18-012(c)	18-012(c)	18	AOC/PRS	Sump and drain lines	Active	0		NFA
	18-012(d)	18-012(d)	18	AOC/PRS	Drain line	Unknown	0		Rec NFA
	C-18-001	C-18-001	18	AOC/PRS	Laboratory	Decommissioned	0		Rec NFA
	C-18-002	C-18-002	18	AOC/PRS	Building	Removed	0		Rec NFA
	C-18-003	C-18-003	18	AOC/PRS	Storage area	Unknown	0		Rec NFA
27-001	27-001	27-001	27	HSWA	Buried naval guns	Unknown	0		NFA
27-002	27-002	27-002	27	HSWA	Firing sites	Abandoned	0		NFA
27-002(a)	27-002	27-002	27	HSWA	Firing sites	Abandoned	0		NFA
27-002(b)	27-002	27-002	27	HSWA	Firing sites	Abandoned	0		NFA
27-002(c)	27-002	27-002	27	HSWA	Firing sites	Abandoned	0		NFA
27-002(d)	27-002	27-002	27	HSWA	Firing sites	Abandoned	0		NFA
27-002(e)	27-002	27-002	27	HSWA	Firing sites	Abandoned	0		NFA
27-003	27-003	27-003	27	HSWA	Bazooka impact area	Inactive	5556	HE	CARBC
	27-004	27-004	27	AOC/PRS	Building	Decommissioned	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
2-001	2-001	2-001	2	HSWA PM	Open burning ground	Inactive	0		Rec NFA
2-002	2-002	2-002	2	AOC/PRS	Storage area	Inactive	0		Rec NFA
2-003(a)	2-003(a)	2-003(a)	2	AOC/PRS	Reactor facility	Decommissioned	8	Rad, hazardous const.	CARBC
2-003(b)	2-003(b)	2-003(b)	2	AOC/PRS	Reactor facility	Decommissioned	5	Rad, hazardous const.	CARBC
2-003(c)	2-003(c)	2-003(c)	2	AOC/PRS	Reactor facility	Decommissioned	1	Rad, hazardous const.	CARBC
2-003(d)	2-003(d)	2-003(d)	2	AOC/PRS	Reactor facility	Decommissioned	3	Rad, hazardous const.	CARBC
2-003(e)	deleted, same as 2-009(c)								
2-004(a)	2-004(a)	2-004(a)	2	AOC/PRS	Reactor facility	Active	3	Rad, hazardous const.	CARBC
2-004(b)	2-004(b)	2-004(b)	2	AOC/PRS	Reactor facility	Active	6	Rad, hazardous const.	CARBC
2-004(c)	2-004(c)	2-004(c)	2	AOC/PRS	Reactor facility	Active	6	Rad, hazardous const.	CARBC
2-004(d)	2-004(d)	2-004(d)	2	AOC/PRS	Reactor facility	Active	6	Rad, hazardous const.	CARBC
2-004(e)	2-004(e)	2-004(e)	2	AOC/PRS	Reactor facility	Active	21	Rad, hazardous const.	CARBC
2-004(f)	2-004(f)	2-004(f)	2	AOC/PRS	Reactor facility	Active	13	Rad, hazardous const.	CARBC
	2-004(g)	2-004(g)	2	AOC/PRS	Aboveground tank	Active	2	Rad, hazardous const.	CARBC
2-005	2-005	2-005	2	HSWA	Systematic leak	Inactive	741	Hazardous const.	CARBC
2-006	2-006(a)	2-006(a)	2	HSWA PM	Ind. or san. waste water treat.	Active	1	Rad, hazardous const.	CARBC
	2-006(b)	2-006(b)	2	HSWA PM	Ind. or san. waste water treat.	Active	167	Rad. hazardous const.	CARBC
	2-006(c)	2-006(c)	2	AOC/PRS	Waste line	Active	167	Rad, hazardous const.	CARBC
	2-006(d)	2-006(d)	2	AOC/PRS	Waste line	Active	167	Rad, hazardous const.	CARBC
	2-006(e)	2-006(e)	2	AOC/PRS	Waste line	Active	167	Rad, hazardous const.	CARBC
2-007	2-007	2-007	2	HSWA	Septic system	Decommissioned	15	Rad, hazardous const.	CARBC
2-008	2-008(a)	2-008(a)	2	008 HSWA	Outfall	Inactive	19	Rad, hazardous const.	CARBC
	2-008(b)	2-008(b)	2	HSWA PM	Ind. or san. waste water treat.	Inactive	19	Hazardous const.	CARBC
	2-008(c)	2-008(c)	2	AOC/PRS	Outfall	Active	19	Hazardous const.	CARBC
2-009(a)	2-009(a)	2-009(a)	2	HSWA	Non-intentional release	Inactive	449	Rad, hazardous const.	CARBC
2-009(b)	2-009(b)	2-009(b)	2	HSWA	Non-intentional release	Inactive	148	Rad, hazardous const.	CARBC
2-009(c)	2-009(e)	2-009(e)	2	HSWA	Reactor facility	Decommissioned	2	Rad, hazardous const.	CARBC
2-009(d)	deleted, same as 2-003(b)						0		NFA
2-009(e)	2-009(c)	2-009(c)	2	AOC/PRS	Non-intentional release	Inactive	5000	Rad, hazardous const.	CARBC

2-009(f)	2-009(c)	2-009(c)	2	AOC/PRS	Non-intentional release	Inactive	5000	Rad, hazardous const.	CARBC
2-009(g)	2-009(c)	2-009(c)	2	AOC/PRS	Non-intentional release	Inactive	5000	Rad, hazardous const.	CARBC
2-009(h)	2-009(c)	2-009(c)	2	AOC/PRS	Non-intentional release	Inactive	5000	Rad, hazardous const.	CARBC
2-009(i)	deleted, same as 2-003d						0		NFA
	2-009(d)	2-009(d)	2	AOC/PRS	Non-intentional release	Inactive	93	Rad, hazardous const.	CARBC
2-010	2-010	2-010	2	AOC/PRS	Building	Inactive/d	94	Rad, hazardous const.	CARBC
2-011	2-011(a)	2-011(a)	2	AOC/PRS	Storm drain and outfall	Active	228	Rad, hazardous const.	CARBC
	2-011(b)	2-011(b)	2	AOC/PRS	Storm drain and outfall	Active	1	Rad, hazardous const.	CARBC
	2-011(c)	2-011(c)	2	AOC/PRS	Storm drain and outfall	Active	1	Rad, hazardous const.	CARBC
	2-011(d)	2-011(d)	2	AOC/PRS	Storm drain and outfall	Active	37	Hazardous const.	CARBC
	2-011(e)	2-011(e)	2	AOC/PRS	Storm drain and outfall	Active	37	Hazardous const.	CARBC
	2-012	2-012	2	AOC/PRS	Underground tank	Inactive	2	Hazardous const.	CARBC
	2-013	2-013	2	AOC/PRS	Storage area	Active	0		Rec NFA
41-001	41-001	41-001	41	HSWA	Septic system	Inactive	2	Rad, hazardous const.	CARBC
41-002(a)	41-002(a)	41-002(a)	41	HSWA	Waste water treatment facility	Active	25	Rad, hazardous const.	CARBC
41-002(b)	41-002(b)	41-002(b)	41	HSWA	Waste water treatment facility	Active	42	Rad, hazardous const.	CARBC
41-002(c)	41-002(c)	41-002(c)	41	HSWA	Waste water treatment facility	Active	17	Rad, hazardous const.	CARBC
41-XXX	41-003	41-003	41	AOC/PRS	Sump	Active	1	Hazardous const.	CARBC
	41-004	41-004	41	AOC/PRS	Container storage	Active	0		Rec NFA
	C-41-001	C-41-001	41	AOC/PRS	Sump	Inactive	0		NFA
	C-41-002	C-41-002	41	AOC/PRS	Underground tank	Active	0		NFA
	C-41-003	C-41-003	41	AOC/PRS	Underground tank	Inactive	0		NFA
	C-41-004	C-41-004	41	AOC/PRS	Storm drains	Active	370	Hazardous const.	CARBC
	C-41-005	C-41-005	41	AOC/PRS	Underground tank	Inactive	10	Hazardous const.	CARBC

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
20-001(a)	20-001(a)	20-001(a)	20	HSWA	Landfill	Inactive	1778	Rad, hazardous const., HE	CARBC
20-001(b)	20-001(b)	20-001(b)	20	HSWA	Landfill	Inactive	5185	Rad, hazardous const., HE	CARBC
20-001(c)	20-001(c)	20-001(c)	20	HSWA	Landfill	Inactive	1333	Rad, hazardous const., HE	CARBC
20-002	20-002(a)	20-002(a)	20	HSWA	Firing site	Removed	10	Rad, hazardous const., HE	CARBC
	20-002(b)	20-002(b)	20	HSWA PM	Firing site	Removed	10	Rad, hazardous const., HE	CARBC
	20-002(c)	20-002(c)	20	HSWA PM	Firing site	Inactive	20	Rad, hazardous const., HE	CARBC
	20-002(d)	20-002(d)	20	HSWA PM	Firing site	Inactive	20	Rad, hazardous const., HE	CARBC
20-003(a)	20-003(a)	20-003(a)	20	HSWA	Firing site	Decommissioned	0		Rec NFA
20-003(b)	20-003(b)	20-003(b)	20	AOC/PRS	Firing site	Decommissioned	20	Rad, hazardous const., HE	CARBC
20-003(c)	20-003(c)	20-003(c)	20	AOC/PRS	Firing site	Decommissioned	20	Rad, hazardous const., HE	CARBC
20-003(d)	20-003(d)	20-003(d)	20	AOC/PRS	Firing site	Decommissioned	0		Rec NFA
20-004(a)	20-005	20-005	20	HSWA PM	Septic tank	Decommissioned	2	Hazardous const.	CARBC
20-004(b)	20-004	20-004	20	AOC/PRS	Septic system	Inactive	3	Hazardous const.	CARBC
	C-20-001	C-20-001	20	AOC/PRS	Storage building	Removed	0		Rec NFA
	C-20-002	C-20-002	20	AOC/PRS	Storage building	Removed	0		Rec NFA
	C-20-003	C-20-003	20	AOC/PRS	Building	Removed	0		Rec NFA
53-001(a)	53-001(a)	53-001(a)	53	RCRA PM	Storage area	Active	48	Hazardous const.	CARBC
53-001(b)	53-001(b)	53-001(b)	53	RCRA PM	Storage area	Removed	48	Hazardous const.	CARBC
53-001(c)	53-001(c)	53-001(c)	53	RCRA	Storage area	Removed	6	Hazardous const.	CARBC
53-001(d)	53-001(d)	53-001(d)	53	RCRA	Storage area	Removed	24	Hazardous const.	CARBC
	53-001(e)	53-001(e)	53	RCRA	Storage area	Removed	1	Hazardous const.	CARBC
	53-001(f)	53-001(f)	53	RCRA	Storage area	Active	0		Rec NFA
	53-001(g)	53-001(g)	53	RCRA	Storage area	Active	1	Hazardous const.	CARBC
	53-001(h)	53-001(h)	53	RCRA	Storage area	Active	0		Rec NFA
	53-001(i)	53-001(i)	53	RCRA	Storage area	Active	0		Rec NFA
	53-001(j)	53-001(j)	53	RCRA	Storage area	Active	1	Hazardous const.	CARBC
	53-001(k)	53-001(k)	53	RCRA	Storage area	Active	1	Hazardous const.	CARBC
	53-001(l)	53-001(l)	53	RCRA	Storage area	Removed	1	Rad, hazardous const.	CARBC
	53-001(m)	53-001(m)	53	RCRA	Storage area	Active	0		Rec NFA

	53-001(n)	53-001(n)	53	RCRA	Storage area	Active	0		Rec NFA
	53-001(o)	53-001(o)	53	RCRA	Storage area	Active	0		Rec NFA
53-002(a)	53-002(a)	53-002(a)	53	RCRA PM	Disposal lagoon	Active	14974	Rad, hazardous const.	IS:1C
53-002(b)	53-002(b)	53-002(b)	53	RCRA PM	Disposal lagoon	Active	9733	Rad, hazardous const.	IS:1C
53-003	53-003	53-003	53	AOC/PRS	Septic tank	Active	0		Rec NFA
53-004	53-004	53-004	53	AOC/PRS	Operational facility	Active	0		Rec NFA
53-005	53-005	53-005	53	HSWA	Disposal pit	Decommissioned	5	Hazardous const., other	CARBC
53-006(a)	53-006(a)	53-006(a)	53	AOC/PRS	Underground tank	Inactive	8	Rad, hazardous const.	CARBC
53-006(b)	53-006(b)	53-006(b)	53	HSWA	Underground tank	Active	13	Rad, hazardous const.	CARBC
53-006(c)	53-006(c)	53-006(c)	53	HSWA	Underground tank	Active	13	Rad, hazardous const.	CARBC
53-006(d)	53-006(d)	53-006(d)	53	HSWA	Underground tank	Active	20	Rad, hazardous const.	CARBC
53-006(e)	53-006(e)	53-006(e)	53	HSWA	Underground tank	Active	20	Rad, hazardous const.	CARBC
	53-006(f)	53-006(f)	53	HSWA PM	Underground tank	Active	20	Rad, hazardous const.	CARBC
53-007(a)	53-007(a)	53-007(a)	53	HSWA	Aboveground tank	Active	20	Rad, hazardous const.	CARBC
53-007(b)	53-007(b)	53-007(b)	53	HSWA	Aboveground tanks (2)	Removed	0		Rec NFA
53-008	53-008	53-008	53	AOC/PRS	Storage area	Active	0		Rec NFA
53-009	53-009	53-009	53	AOC/PRS	Aboveground tanks (3)	Removed	3	Hazardous const.	CARBC
	53-010	53-010	53	AOC/PRS	Container storage	Decommissioned	35	Hazardous const.	CARBC
	53-011(a)	53-011(a)	53	AOC/PRS	Transformer	Active	0		Rec NFA
	53-011(b)	53-011(b)	53	AOC/PRS	Transformer	Active	0		Rec NFA
	53-011(c)	53-011(c)	53	AOC/PRS	Transformer	Active	0		Rec NFA
	53-011(d)	53-011(d)	53	AOC/PRS	Transformer	Active	0		Rec NFA
	53-011(e)	53-011(e)	53	AOC/PRS	Transformer	Active	0		Rec NFA
	53-012(a)	53-012(a)	53	AOC/PRS	Outfall	Active	0		Rec NFA
	53-012(b)	53-012(b)	53	AOC/PRS	Outfall	Active	0		Rec NFA
	53-012(c)	53-012(c)	53	AOC/PRS	Outfall	Active	0		Rec NFA
	53-012(d)	53-012(d)	53	AOC/PRS	Outfall	Active	0		Rec NFA
	53-012(e)	53-012(e)	53	AOC/PRS	Outfall	Active	0		Rec NFA
	53-012(f)	53-012(f)	53	AOC/PRS	Outfall	Active	0		Rec NFA
	53-012(g)	53-012(g)	53	AOC/PRS	Outfall	Active	0		Rec NFA
	53-012(h)	53-012(h)	53	AOC/PRS	Outfall	Active	0		Rec NFA

	C-53-001	C-53-001	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-002	C-53-002	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-003	C-53-003	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-004	C-53-004	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-005	C-53-005	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-006	C-53-006	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-007	C-53-007	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-008	C-53-008	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-009	C-53-009	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-010	C-53-010	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-011	C-53-011	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-012	C-53-012	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-013	C-53-013	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-014	C-53-014	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-015	C-53-015	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-016	C-53-016	53	AOC/PRS	Transformer	Active	0		Rec NFA
	C-53-017	C-53-017	53	AOC/PRS	One-time spill	Unknown	0		Rec NFA
	C-53-018	C-53-018	53	AOC/PRS	One-time spill	Removed	0		Rec NFA
	C-53-019	C-53-019	53	AOC/PRS	One-time spill	Unknown	0		Rec NFA
0-015(a)	72-001	72-001	72	AOC/PRS	Firing range	Active	405	Hazardous const.	CARBC
0-011(f)	72-002	72-002	72	HSWA PM	Firing site	Inactive	0		Rec NFA
	72-003(a)	72-003(a)	72	AOC/PRS	Septic system	Active	936	Hazardous const.	CARBC
	72-003(b)	72-003(b)	72	AOC/PRS	Septic system	Inactive	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
21-001	21-001	21-001	21	AOC/PRS	Container storage	Active	234	Rad, hazardous const.	CARBC
21-002	21-002(a)	21-002(a)	21	HSWA	Container storage	Inactive	0	Hazardous const.	CARBC
	21-002(b)	21-002(b)	21	AOC/PRS	Container storage	Inactive	80700	Hazardous const.	IS:IC
21-003	21-003	21-003	21	**RCRA PM**	Container storage	Inactive	347	Hazardous const., other	CARBC
21-004(a)	21-004(a)	21-004(a)	21	AOC/PRS	Aboveground tank	Active	1	Rad, hazardous const.	CARBC
21-004(b)	21-004(b)	21-004(b)	21	HSWA PM	Tank and/or assoc. equipment	Active	25	Rad, hazardous const.	CARBC
21-004(c)	21-004(c)	21-004(c)	21	HSWA PM	Tank and/or assoc. equipment	Active	25	Rad, hazardous const.	CARBC
	21-004(d)	21-004(d)	21	AOC/PRS	Outfall	Active	72	Rad, hazardous const.	CARBC
21-005	21-005	21-005	21	HSWA	Disposal pit	Decommissioned	0		NFA
21-006(a)	21-006(a)	21-006(a)	21	HSWA	Disposal pit	Inactive	242	Rad, hazardous const.	Def. D&D
21-006(b)	21-016(c)	21-016(c)	21	006b HSWA	Material disposal area	Inactive	2566	Rad, hazardous const.	CARBC
21-006(c)	21-006(b)	21-006(b)	21	006c HSWA	Disposal pit	Inactive	270	Rad, hazardous const.	Def. D&D
21-006(d)	21-006(c)	21-006(c)	21	006d HSWA	Disposal pit	Inactive	242	Rad, hazardous const.	Def. D&D
21-006(e)	21-006(d)	21-006(d)	21	006e HSWA	Disposal pit	Inactive	242	Rad, hazardous const.	Def. D&D
	21-006(e)	21-006(e)	21	HSWA PM	Surface disposal site	Inactive	242	Rad, hazardous const.	Def. D&D
	21-006(f)	21-006(f)	21	AOC/PRS	Disposal pit	Inactive	242	Rad, hazardous const.	Def. D&D
21-007	21-007	21-007	21	HSWA	Incinerators	Decommissioned	0		NFA
21-008	21-008	21-008	21	AOC/PRS	Incinerator	Decommissioned	0		NFA
21-009	21-009	21-009	21	AOC/PRS	Waste treatment lab	Decommissioned	0		NFA
21-010(a)	21-010(a)	21-010(a)	21	HSWA	Waste treatment facility	Decommissioned	0		NFA
21-010(b)	21-010(b)	21-010(b)	21	HSWA	Waste treatment facility	Decommissioned	0		NFA
21-010(c)	21-010(c)	21-010(c)	21	HSWA	Waste treatment facility	Decommissioned	0		NFA
21-010(d)	21-010(d)	21-010(d)	21	HSWA	Waste treatment facility	Decommissioned	0		NFA
21-010(e)	21-010(e)	21-010(e)	21	HSWA	Waste treatment facility	Decommissioned	0		NFA
21-010(f)	21-010(f)	21-010(f)	21	HSWA	Waste treatment facility	Decommissioned	0		NFA
21-010(g)	21-010(g)	21-010(g)	21	HSWA	Waste treatment facility	Decommissioned	0		NFA
21-010(h)	21-010(h)	21-010(h)	21	HSWA	Waste treatment facility	Decommissioned	0		NFA
21-011(a)	21-011(a)	21-011(a)	21	HSWA	Waste treatment facility	Active	21511	Rad, hazardous const.	IS:IC
21-011(b)	21-011(b)	21-011(b)	21	HSWA	Sump	Active	34	Rad, hazardous const.	IS:IC

21-011(c)	21-011(c)	21-011(c)	21	HSWA	Tank	Active	20	Rad, hazardous const.	IS:IC
21-011(d)	21-011(d)	21-011(d)	21	HSWA	Aboveground tank	Active	75	Rad, hazardous const.	IS:IC
21-011(e)	21-011(e)	21-011(e)	21	HSWA	Aboveground tank	Active	75	Rad, hazardous const.	IS:IC
21-011(f)	21-011(f)	21-011(f)	21	HSWA	Aboveground tank	Active	75	Rad, hazardous const.	IS:IC
21-011(g)	21-011(g)	21-011(g)	21	HSWA	Aboveground tank	Active	75	Rad, hazardous const.	IS:IC
21-011(h)	21-011(i)	21-011(i)	21	011(h) HSWA	Aboveground tank	Active	5	Rad, hazardous const.	IS:IC
	21-011(h)	21-011(h)	21	AOC/PRS	Aboveground tank	Active	11	Rad, hazardous const.	IS:IC
21-011(i)	21-011(j)	21-011(j)	21	011(i) HSWA	Aboveground tank	Active	4	Rad, hazardous const.	IS:IC
		21-011(k)	21	HSWA PM	Outfall	Inactive	5000	Rad, hazardous const.	IS:IC
21-012	21-012(a)	21-012(a)	21	012(a) HSWA	Dry well	Inactive	0		Rec NFA
	21-012(b)	21-012(b)	21	HSWA PM	Surface disposal site	Inactive	0		NFA
21-013(a)	21-013(a)	21-013(a)	21	HSWA	Surface disposal site	Inactive	4	Rad, hazardous const.	CARBC
21-013(b)	21-013(b)	21-013(b)	21	HSWA	Surface disposal site	Inactive	74	Rad, hazardous const.	CARBC
21-013(c)	21-013(c)	21-013(c)	21	HSWA	Surface disposal site	Inactive	1152	Rad, hazardous const.	CARBC
	21-013(d)	21-013(d)	21	HSWA PM	Surface disposal site	Inactive	0		NFA
	21-013(e)	21-013(e)	21	HSWA PM	Surface disposal site	Inactive	0		NFA
	21-013(f)	21-013(f)	21	AOC/PRS	Surface disposal site	Inactive	1111	Rad, hazardous const.	CARBC
	21-013(g)	21-013(g)	21	AOC/PRS	Surface disposal site	Inactive	0		NFA
21-014	21-014	21-014	21	HSWA	Material disposal area	Inactive	7007	Rad, hazardous const.	IS;IC
21-015	21-015	21-015	21	HSWA	Material disposal area	Inactive	210473	Rad, hazardous const.	IS;IC
21-016(a)	21-016(a)	21-016(a)	21	HSWA	Material disposal area	Inactive	69395	Rad, hazardous const.	IS;IC
21-016(b)	21-016(a)	21-016(a)	21	HSWA	Material disposal area	Inactive	"	Rad, hazardous const.	IS;IC
21-016(c)	21-016(a)	21-016(a)	21	HSWA	Material disposal area	Inactive	"	Rad, hazardous const.	IS;IC
21-016(d)	21-016(a)	21-016(a)	21	HSWA	Material disposal area	Inactive	"	Rad, hazardous const.	IS;IC
21-016(e)	21-016(a)	21-016(a)	21	HSWA	Material disposal area	Inactive	"	Rad, hazardous const.	IS;IC
21-016(f)	21-016(b)	21-016(b)	21	HSWA	Material disposal area	Inactive	1	Rad, hazardous const.	IS;IC
21-016(g)	21-016(c)	21-016(c)	21	HSWA	Material disposal area	Inactive	2566	Rad, hazardous const.	IS;IC
21-017(a)	21-017(a)	21-017(a)	21	HSWA	Material disposal area	Inactive	20186	Rad, hazardous const., oth	IS;IC
21-017(b)	21-017(b)	21-017(b)	21	HSWA	Material disposal area	Inactive	20186	Rad, hazardous const., oth	IS;IC
21-017(c)	21-017(c)	21-017(c)	21	HSWA	Material disposal area	Inactive	20186	Rad, hazardous const., oth	IS;IC
21-018(a)	21-018(a)	21-018(a)	21	HSWA	Material disposal area	Inactive	241939	Rad, hazardous const.	IS;IC

21-018(b)	21-018(b)	21-018(b)	21	HSWA	Material disposal area	Inactive	3573	Rad, hazardous const.	IS;IC
21-019(a)	21-019(a)	21-019(a)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(b)	21-019(b)	21-019(b)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(c)	21-019(c)	21-019(c)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(d)	21-019(d)	21-019(d)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(e)	21-019(e)	21-019(e)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(f)	21-019(f)	21-019(f)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(g)	21-019(g)	21-019(g)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(h)	21-019(h)	21-019(h)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(i)	21-019(i)	21-019(i)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(j)	21-019(j)	21-019(j)	21	AOC/PRS	Filter system	Active	0		NFA
21-019(k)	21-019(k)	21-019(k)	21	AOC/PRS	Filter system	Inactive	0		NFA
21-019(l)	21-019(l)	21-019(l)	21	AOC/PRS	Filter system	Inactive	0		NFA
21-019(m)	21-019(m)	21-019(m)	21	AOC/PRS	Filter system	Active	0		NFA
21-020(a)	21-020(a)	21-020(a)	21	AOC/PRS	Filter system	Decommissioned	0		NFA
21-020(b)	21-020(b)	21-020(b)	21	AOC/PRS	Filter system	Decommissioned	0		NFA
21-021	21-021	21-021	21	HSWA	Systematic realease site	Active	0		NFA
21-022(a)	21-022(a)	21-022(a)	21	HSWA	Waste lines	Decommissioned	3	Rad, hazardous const.	IS;IC
21-022(b)	21-022(b)	21-022(b)	21	HSWA	Waste lines	Decommissioned	188	Rad, hazardous const.	IS;IC
21-022(c)	21-022(c)	21-022(c)	21	HSWA	Waste lines	Decommissioned	217	Rad, hazardous const.	IS;IC
21-022(d)	21-022(d)	21-022(d)	21	HSWA	Waste lines	Decommissioned	173	Rad, hazardous const.	IS;IC
21-022(e)	21-022(e)	21-022(e)	21	HSWA	Waste lines	Decommissioned	193	Rad, hazardous const.	IS;IC
21-022(f)	21-022(f)	21-022(f)	21	HSWA	Waste lines	Decommissioned	175	Rad, hazardous const.	IS;IC
21-022(g)	21-022(g)	21-022(g)	21	HSWA	Waste lines	Decommissioned	21	Rad, hazardous const.	IS;IC
21-022(h)	21-022(h)	21-022(h)	21	HSWA	Waste lines	Decommissioned	7	Rad, hazardous const.	IS;IC
	21-022(i)	21-022(i)	21	HSWA PM	Tank and/or assoc. equipment	Decommissioned	9	Rad, hazardous const.	IS;IC
	21-022(j)	21-022(j)	21	HSWA PM	Tank and/or assoc. equipment	Decommissioned	9	Rad, hazardous const.	Def. D&D
21-023(a)	21-023(a)	21-023(a)	21	HSWA	Septic system	Decommissioned	11	Rad, hazardous const.	Def. D&D
21-023(b)	21-023(b)	21-023(b)	21	HSWA	Septic system	Decommissioned	4	Rad, hazardous const.	Def. D&D
21-023(c)	21-023(c)	21-023(c)	21	HSWA	Septic system	Decommissioned	14	Rad, hazardous const.	CARBC
21-023(d)	21-023(d)	21-023(d)	21	HSWA	Septic system	Decommissioned	4	Rad, hazardous const.	Def. D&D

21-024(a)	21-024(a)	21-024(a)	21	HSWA	Septic system	Inactive	38	Rad, hazardous const.	IS;IC
21-024(b)	21-024(b)	21-024(b)	21	HSWA	Septic system	Inactive	9	Rad, hazardous const.	CARBC
21-024(c)	21-024(c)	21-024(c)	21	HSWA	Septic system	Inactive	8	Rad, hazardous const.	IS;IC
21-024(d)	21-024(d)	21-024(d)	21	HSWA	Septic system	Inactive	33	Rad, hazardous const.	CARBC
21-024(e)	21-024(e)	21-024(e)	21	HSWA	Septic system	Inactive	14	Rad, hazardous const.	CARBC
21-024(f)	21-024(f)	21-024(f)	21	HSWA	Septic system	Inactive	0		NFA
21-024(g)	21-024(g)	21-024(g)	21	HSWA	Septic system	Inactive	0		NFA
21-024(h)	21-024(h)	21-024(h)	21	HSWA	Septic system	Inactive	17	Rad, hazardous const.	CARBC
21-024(i)	21-024(i)	21-024(i)	21	HSWA	Septic system	Inactive	16	Rad, hazardous const.	CARBC
21-024(j)	21-024(j)	21-024(j)	21	HSWA	Septic system	Inactive	5	Rad, hazardous const.	CARBC
21-024(k)	21-024(k)	21-024(k)	21	HSWA	Septic system	Inactive	18	Rad, hazardous const.	CARBC
	21-024(l)	21-024(l)	21	HSWA PM	Ind. or san. waste water treat.	Inactive	0		NFA
	21-024(m)	21-024(m)	21	HSWA PM	Ind. or san. waste water treat.	Inactive	0		NFA
	21-024(n)	21-024(n)	21	HSWA PM	Ind. or san. waste water treat.	Inactive	1	Rad, hazardous const.	CARBC
	21-024(o)	21-024(o)	21	HSWA PM	Ind. or san. waste water treat.	Inactive	1	Rad, hazardous const.	CARBC
21-025(a)	21-025(a)	21-025(a)	21	AOC/PRS	Operational facility	Active	0		Rec NFA
21-025(b)	21-025(b)	21-025(b)	21	AOC/PRS	Operational facility	Active	0		Rec NFA
21-026(a)	21-026(a)	21-026(a)	21	HSWA PM	Ind. or san. waste water treat.	Active	636	Rad, hazardous const.	Def. D&D
21-026(b)	21-026(b)	21-026(b)	21	HSWA PM	Surface disposal site	Active	295	Rad, hazardous const.	CARBC
21-026(c)	21-026(c)	21-026(c)	21	AOC/PRS	Waste water treatment facility	Active	2	Rad, hazardous const.	Def. D&D
		21-026(d)	21	AOC/PRS	Outfall	Active	2000	Rad, hazardous const.	CARBC
21-027	21-027	21-027(a)	21	HSWA PM	Ind. or san. waste water treat.	Inactive	0		NFA
		21-027(b)	21	HSWA PM	Ind. or san. waste water treat.	Inactive	0		NFA
		21-027(c)	21	HSWA PM	Ind. or san. waste water treat.	Inactive	0		NFA
		21-027(d)	21	HSWA PM	Ind. or san. waste water treat.	Inactive	0		NFA
21-028(a)	21-028(a)	21-028(a)	21	**RCRA PM**	Container storage	Active	0		Rec NFA
21-028(b)	21-028(b)	21-028(b)	21	**RCRA PM**	Container storage	Active	0		NFA
21-028(c)	21-028(c)	21-028(c)	21	**RCRA PM**	Container storage	Active	0		NFA
21-028(d)	21-028(d)	21-028(d)	21	**RCRA PM**	Container storage	Active	0		NFA
	21-028(e)	21-028(e)	21	**RCRA PM**	Container storage	Active	0		Rec NFA
	21-029	21-029	21	HSWA PM	Soil contamination area	Active	0		Rec NFA

C-21-001	C-21-001	21	AOC/PRS	One-time spill	Removed	0	NFA
C-21-002	C-21-002	21	AOC/PRS	Non-intentional release area	Removed	0	Rec NFA
C-21-003	C-21-003	21	AOC/PRS	Non-intentional release area	Removed	0	Rec NFA
C-21-004	C-21-004	21	AOC/PRS	Non-intentional release area	Removed	0	Rec NFA
C-21-005	C-21-005	21	AOC/PRS	One-time spill	Removed	0	NFA
C-21-006	C-21-006	21	AOC/PRS	Non-intentional release area	Removed	0	NFA
C-21-007	C-21-007	21	AOC/PRS	Non-intentional release area	Active	0	NFA
C-21-008	C-21-008	21	AOC/PRS	One-time spill	Removed	0	Rec NFA
C-21-009	C-21-009	21	AOC/PRS	One-time spill	Removed	0	NFA
C-21-010	C-21-010	21	AOC/PRS	Systematic leak	Removed	0	Rec NFA
C-21-011	C-21-011	21	AOC/PRS	One-time spill	Removed	0	Rec NFA
C-21-012	C-21-012	21	AOC/PRS	One-time spill	Removed	0	NFA
C-21-013	C-21-013	21	AOC/PRS	Disposal pit	Inactive	0	Rec NFA
C-21-014	C-21-014	21	AOC/PRS	Warehouse	Active	0	Rec NFA
C-21-015	C-21-015	21	AOC/PRS	Building	Removed	0	Rec NFA
C-21-016	C-21-016	21	AOC/PRS	Storage area	Removed	0	Rec NFA
C-21-017	C-21-017	21	AOC/PRS	Storage area	Removed	0	Rec NFA
C-21-018	C-21-018	21	AOC/PRS	Storage area	Removed	0	Rec NFA
C-21-019	C-21-019	21	AOC/PRS	Storage area	Removed	0	Rec NFA
C-21-020	C-21-020	21	AOC/PRS	Storage area	Removed	0	Rec NFA
C-21-021	C-21-021	21	AOC/PRS	Storage area	Removed	0	Rec NFA
C-21-022	C-21-022	21	AOC/PRS	Laboratory	Removed	0	Rec NFA
C-21-023	C-21-023	21	AOC/PRS	Laboratory	Removed	0	Rec NFA
C-21-024	C-21-024	21	AOC/PRS	Warehouse	Removed	0	Rec NFA
C-21-025	C-21-025	21	AOC/PRS	Building	Removed	0	Rec NFA
C-21-026	C-21-026	21	AOC/PRS	Building	Removed	0	Rec NFA
C-21-027	C-21-027	21	AOC/PRS	Machinery	Active	0	NFA
C-21-028	C-21-028	21	AOC/PRS	Tank	Removed	0	Rec NFA
C-21-029	C-21-029	21	AOC/PRS	Aboveground tank	Removed	0	Rec NFA
C-21-030	C-21-030	21	AOC/PRS	Aboveground tank	Removed	0	Rec NFA
C-21-031	C-21-031	21	AOC/PRS	Tank	Removed	0	Rec NFA

C-21-032	C-21-032	21	AOC/PRS	Machinery and tanks	Active	0	Rec NFA
C-21-033	C-21-033	21	AOC/PRS	One-time spill	Removed	0	NFA
C-21-034	C-21-034	21	AOC/PRS	Tank	Removed	0	NFA
C-21-035	C-21-035	21	AOC/PRS	Aboveground tank	Removed	0	NFA
C-21-036	C-21-036	21	AOC/PRS	Aboveground tank	Removed	0	NFA
C-21-037	C-21-037	21	AOC/PRS	Aboveground tank	Removed	0	NFA
	EPA-02A129	21	AOC/PRS	EPA permitted outfall	Active	0	NFA
	EPA-03A035	21	AOC/PRS	EPA permitted outfall	Active	0	NFA
	EPA-03A036	21	AOC/PRS	EPA permitted outfall	Active	0	NFA
	EPA-03A037	21	AOC/PRS	EPA permitted outfall	Active	0	NFA
	EPA-04A142	21	AOC/PRS	EPA permitted outfall	Active	0	NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
6-001(a)	6-001(a)	6-001(a)	6	HSWA	Septic system	Inactive	6	Rad, Hazardous const., HE	CARBC
6-001(b)	6-001(b)	6-001(b)	6	HSWA	Septic system	Inactive	5	Rad, Hazardous const., HE	CARBC
6-002	6-002	6-002	6	HSWA	Septic system	Decommissioned	6	Hazardous const., HE	CARBC
6-003(a)	6-003(a)	6-003(a)	6	HSWA PM	Firing site	Inactive	2327	Rad, hazardous const., HE	CARBC
6-003(b)	6-003(b)	6-003(b)	6	AOC/PRS	Firing site	Inactive	0		Rec NFA
6-003(c)	6-003(c)	6-003(c)	6	HSWA	Firing site	Inactive	7	Rad, hazardous const., HE	CARBC
6-003(d)	6-003(d)	6-003(d)	6	HSWA PM	Firing site	Inactive	101	Hazardous const., HE	CARBC
6-003(e)	6-003(e)	6-003(e)	6	HSWA PM	Firing site	Inactive	93	Hazardous const., HE	CARBC
		6-003(f)	6	HSWA PM	Firing site	Inactive	10	Rad, hazardous const., HE	CARBC
	C-6-002	6-003(g)	6	HSWA PM	Firing site & building	Inactive	37	Hazardous const., HE	CARBC
		6-003(h)	6	**HSWA PM**	Firing site	Inactive	100	Hazardous const., HE	CARBC
6-004	6-004	6-004	6	AOC/PRS	Sump	Nonexistent	0		Rec NFA
6-005	6-005	6-005	6	HSWA PM	Firing site	Decommissioned	96	Rad, hazardous const., HE	IS:1C
6-006	6-006	6-006	6	HSWA	Storage area	Inactive	222	Hazardous const., other	CARBC
6-007	6-007(a)	6-007(a)	6	007 HSWA	Material disposal area	Inactive	1222	Rad, hazardous const., HE	IS:1C
6-007	6-007(b)	6-007(b)	6	HSWA PM	Landfill	Inactive	622	Rad, hazardous const., HE	IS:1C
6-007	6-007(c)	6-007(c)	6	HSWA PM	Landfill	Inactive	8	Rad, hazardous const., HE	IS:1C
6-007	6-007(d)	6-007(d)	6	HSWA PM	Landfill	Inactive	1	Rad, hazardous const., HE	IS:1C
6-007	6-007(e)	6-007(e)	6	HSWA PM	Landfill	Inactive	44	Rad, hazardous const., HE	IS:1C
6-007	6-007(f)	6-007(f)	6	HSWA PM	Surface disposal	Inactive	2	Rad, hazardous const., HE	CARBC
	C-6-004	6-007(g)	6	HSWA PM	Building & surface disposal	Inactive	37	Rad, hazardous const., HE	CARBC
	6-008	6-008	6	AOC/PRS	Underground tank	Decommissioned	10	Rad, hazardous const., HE	CARBC
	C-6-001	C-6-001	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-002	C-6-002	Renumbered 6-003(g)				0		NFA
	C-6-003	C-6-003	6	AOC/PRS	Building	Removed	370	Hazardous const., HE	CARBC
	C-6-004	C-6-004	Renumbered 6-007(g)				0		NFA
	C-6-005	C-6-005	6	AOC/PRS	Building	Removed	370	Hazardous const., HE	CARBC
	C-6-006	C-6-006	6	AOC/PRS	Building	Removed	370	Hazardous const., HE	CARBC
	C-6-007	C-6-007	6	AOC/PRS	Building	Removed	370	Hazardous const.	CARBC

	C-6-008	C-6-008	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-009	C-6-009	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-010	C-6-010	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-011	C-6-011	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-012	C-6-012	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-013	C-6-013	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-014	C-6-014	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-015	C-6-015	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-016	C-6-016	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-017	C-6-017	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-018	C-6-018	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-019	C-6-019	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
	C-6-020	C-6-020	6	AOC/PRS	Building	Removed	0		Rec NFA
	C-6-021	C-6-021	6	AOC/PRS	Building	Removed	37	Hazardous const., HE	CARBC
7-001(a)	7-001(a)	7-001(a)	7	HSWA	Firing site	Inactive	105	Hazardous const., HE	CARBC
7-001(b)	7-001(b)	7-001(b)	7	HSWA	Firing site	Inactive	105	Hazardous const., HE	CARBC
		7-001(c)	7	HSWA PM	Firing site	Inactive	10	Hazardous const.,HE	CARBC
		7-001(d)	7	HSWA PM	Firing site	Inactive	100	Hazardous const., HE	CARBC
22-001	22-001	22-001	22	RCRA	Building	Closed	0		Rec NFA
22-002(a)	22-003(a)	22-003(a)	22	RCRA	Satellite storage	Active	0		Rec NFA
22-002(b)	22-003(g)	22-003(g)	22	RCRA	Satellite storage	Active	0		Rec NFA
22-003	22-003(b)	22-003(b)	22	RCRA	Satellite storage	Active	0		Rec NFA
	22-003(c)	22-003(c)	22	RCRA	Satellite storage	Active	0		Rec NFA
	22-003(d)	22-003(d)	22	RCRA	Satellite storage	Active	0		Rec NFA
	22-003(e)	22-003(e)	22	RCRA	Satellite storage	Active	0		Rec NFA
	22-003(f)	22-003(f)	22	RCRA	Satellite storage	Active	0		Rec NFA
22-004(a)	22-014(a)	22-014(a)	22	HSWA PM	Ind. or san. waste water treat.	Active	16	Hazardous const., HE	CARBC
22-004(b)	22-014(a)	22-014(a)	22						
22-005	22-014(b)	22-014(b)	22	005 HSWA	Sump	Active	2	Hazardous const., HE	CARBC
	22-014(c)	22-014(c)	22	AOC/PRS	Unit does not exist		0		Rec NFA
22-006	22-015(a)	22-015(a)	22	006 HSWA	Drain lines and dry wells	Inactive	52	Hazardous const.	CARBC

22-007	22-015(b)	22-015(b)	22	007 HSWA	Sump and outfall	Inactive	2	Hazardous const., HE	CARBC
22-008	22-015(c)	22-015(c)	22	008 HSWA	Outfall	Inactive	1	Hazardous const.	CARBC
22-009	22-015(d)	22-015(d)	22	009 HSWA	Drain line and outfall	Inactive	2	Hazardous const., HE	CARBC
	22-015(e)	22-015(e)	22	HSWA PM	Ind. or san. waste water treat.	Inactive	0	Hazardous const., HE	CARBC
22-010(a)	22-016	22-016	22	010a HSWA	Septic system	Inactive	17	Rad, hazardous const., HE	CARBC
22-010(b)	22-010(a)	22-010(a)	22	010b HSWA	Septic system	Inactive	7	Rad, hazardous const.	CARBC
22-010(c)	22-010(c)	22-010(c)	22	010c HSWA	Septic system	Inactive	43	Rad, hazardous const., HE	CARBC
22-011	22-011	22-011	22	HSWA	Disposal pit	Nonexistent	0		Rec NFA
22-012	22-012	22-012	22	HSWA PM	Decontamination facility	Inactive	2	Hazardous const., HE	CARBC
22-013	22-013	22-013	22	RCRA	Aboveground tanks	Active	0		Rec NFA
40-001(a)	40-001(a)	40-001(a)	40	HSWA	Septic system	Nonexistent	0		Rec NFA
40-001(b)	40-001(b)	40-001(b)	40	HSWA	Septic system	Active	6	Hazardous const., HE	CARBC
40-001(c)	40-001(c)	40-001(c)	40	HSWA	Septic system	Active	3	Hazardous const., HE	CARBC
40-002(a)	40-002(a)	40-002(a)	40	RCRA	Storage area	Active	0		Rec NFA
40-002(b)	40-002(b)	40-002(b)	40	RCRA	Storage area	Active	0		Rec NFA
	40-002(c)	40-002(c)	40	RCRA	Storage area	Active	0		Rec NFA
40-003(a)	40-003(a)	40-003(a)	40	RCRA	Firing site	Inactive	0		Rec NFA
40-003(b)	40-003(b)	40-003(b)	40	RCRA	Firing site	Inactive	0		Rec NFA
40-004	40-004	40-004	40	HSWA	Oper. release	Decommissioned	10	Hazardous const.	CARBC
40-005	40-005	40-005	40	HSWA	Sump	Active	5	Hazardous const., HE	CARBC
40-006(a)	40-006(a)	40-006(a)	40	HSWA	Firing site	Active	3	Rad, hazardous const., HE	Def. D&D
40-006(b)	40-006(b)	40-006(b)	40	HSWA	Firing site	Active	1	Rad, hazardous const., HE	Def. D&D
40-006(c)	40-006(c)	40-006(c)	40	HSWA	Firing site	Active	1	Rad, hazardous const., HE	Def. D&D
40-007(a)	40-007(a)	40-007(a)	40	RCRA	Storage area	Active	26	Hazardous const., HE	Def. D&D
40-007(b)	40-007(b)	40-007(b)	40	RCRA	Storage area	Active	1	Hazardous const., HE	Def. D&D
40-007(c)	40-007(c)	40-007(c)	40	RCRA	Storage area	Active	17	Hazardous const., HE	Def. D&D
40-007(d)	40-007(d)	40-007(d)	40	RCRA	Storage area	Active	15	Hazardous const., HE	Def. D&D
40-007(e)	40-007(e)	40-007(e)	40	RCRA	Storage area	Active	50	Hazardous const., HE	Def. D&D
40-008	40-008	40-008	40	RCRA	Storage area	Decommissioned	0		Rec NFA
40-009	40-009	40-009	40	HSWA	Landfill	Inactive	12800	Rad, hazardous const., HE	CARBC
		40-010	40	HSWA PM	Surface disposal site	Inactive	5	Rad, hazardous const., HE	CARBC

C-40-001	C-40-001	40	AOC/PRS	Usage site	Inactive	0	Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
3-001(a)	3-001(a)	3-001(a)	3	HSWA	Satellite storage	Active	0		Rec NFA
3-001(b)	3-001(b)	3-001(b)	3	HSWA	Satellite storage	Active	0		Rec NFA
3-001(c)	3-001(c)	3-001(c)	3	HSWA	<90 day storage	Active	0		Rec NFA
3-001(d)	3-001(d)	3-001(d)	3	AOC/PRS	Satellite storage	Active	0		NFA
3-001(e)	3-001(e)	3-001(e)	3	AOC/PRS	<90 day storage	Active	0		NFA
3-001(f)	3-001(f)	3-001(f)	3	AOC/PRS	Satellite storage	Active	0		NFA
3-001(g)	60-001(a)								
3-001(h)	60-001(b)								
3-001(i)	3-001(g)	3-001(g)	3	AOC/PRS	Satellite storage	Active	0		NFA
3-001(j)	3-001(h)	3-001(h)	3	AOC/PRS	Satellite storage	Active	0		NFA
3-001(k)	3-001(i)	3-001(i)	3	AOC/PRS	Satellite storage	Decommissioned	1	Hazardous const.	CARBC
3-001(k)	3-056(b)								
3-001(l)	3-001(j)	3-001(j)	3	AOC/PRS	Satellite storage	Active	0		NFA
3-001(m)	3-001(k)	3-001(k)	3	001(m)HSWA	Satellite storage	Active	0		Rec NFA
3-001(n)	3-001(l)	3-001(l)	3	AOC/PRS	<90 day storage	Active	0		NFA
3-001(o)	3-001(m)	3-001(m)	3	AOC/PRS	Satellite storage	Active	1	Hazardous const.	CARBC
3-001(s)	3-056(d)								
3-001(t)	3-056(e)								
3-001(u)	3-056(h)								
	3-001(n)	3-001(n)	3	AOC/PRS	Satellite storage	Removed	0		NFA
	3-001(o)	3-001(o)	3	AOC/PRS	Satellite storage	Decommissioned	0		NFA
	3-001(p)	3-001(p)	3	AOC/PRS	Satellite storage	Active	0		Rec NFA
	3-001(q)	3-001(q)	3	AOC/PRS	Satellite storage	Removed	0		NFA
	3-001(r)	3-001(r)	3	AOC/PRS	Satellite storage	Active	0		Rec NFA
	3-001(s)	3-001(s)	3	AOC/PRS	Satellite storage	Active	0		NFA
	3-001(t)	3-001(t)	3	AOC/PRS	Satellite storage	Inactive	0		Rec NFA
	3-001(u)	3-001(u)	3	AOC/PRS	Satellite storage	Removed	0		NFA
	3-001(v)	3-001(v)	3	AOC/PRS	Satellite storage	Active	0		NFA
	3-001(w)	3-001(w)	3	AOC/PRS	Satellite storage	Active	0		NFA

	3-001(x)	3-001(x)	3	AOC/PRS	Satellite storage	Active	0		NFA
	3-001(y)	3-001(y)	3	AOC/PRS	Satellite storage	Active	0		NFA
3-002(a)	3-002(a)	3-002(a)	3	HSWA PM	Container storage area	Active	0		NFA
3-002(b)	3-002(b)	3-002(b)	3	HSWA	Storage area	Inactive	0		NFA
3-002(c)	3-002(c)	3-002(c)	3	HSWA	Storage area	Inactive	2	Hazardous const.	CARBC
	3-002(d)	3-002(d)	3	HSWA PM	Container storage area	Removed	0		NFA
3-003(a)	3-003(a)	3-003(a)	3	HSWA	Storage area	Inactive	1	Hazardous const.	CARBC
3-003(b)	3-003(b)	3-003(b)	3	HSWA	Storage area	Inactive	1		CARBC
	3-003(d)	3-003(d)	3	AOC/PRS	Storage area	Active	1	Other	CARBC
	3-003(e)	3-003(e)	3	AOC/PRS	Storage area	Removed	0		NFA
	3-003(f)	3-003(f)	3	AOC/PRS	Storage area	Active	0	Other	NFA
	3-003(g)	3-003(g)	3	AOC/PRS	One-time spill	Removed	0		NFA
	3-003(h)	3-003(h)	3	AOC/PRS	Storage area	Active	1	Other	CARBC
	3-003(i)	3-003(i)	3	AOC/PRS	Storage area	Active	0		NFA
	3-003(j)	3-003(j)	3	AOC/PRS	Storage area	Inactive	2	Other	CARBC
	3-003(k)	3-003(k)	3	AOC/PRS	Storage area	Decommissioned	1	Other	CARBC
	3-003(l)	3-003(l)	3	AOC/PRS	Storage area	Active	1	Other	CARBC
	3-003(m)	3-003(m)	3	AOC/PRS	Storage area	Active	3	Other	CARBC
	3-003(n)	3-003(n)	3	AOC/PRS	Storage area	Inactive	0		NFA
	3-003(o)	3-003(o)	3	AOC/PRS	Storage area	Active	0		NFA
	3-003(p)	3-003(p)	3	AOC/PRS	Storage area	Inactive	0		NFA
3-004	3-004(a)	3-004(a)	3	AOC/PRS	Container storage	Inactive	0		NFA
3-004	3-004(b)	3-004(b)	3	AOC/PRS	Container storage	Inactive	0		NFA
	3-004(c)	3-004(c)	3	AOC/PRS	Storage area	Active	20	Rad, hazardous const.	CARBC
	3-004(d)	3-004(d)	3	AOC/PRS	Storage area	Removed	0		NFA
	3-004(e)	3-004(e)	3	AOC/PRS	Storage area	Active	0		NFA
	3-004(f)	3-004(f)	3	AOC/PRS	Storage area	Inactive	0		NFA
3-006(b)	3-006	3-006	3	AOC/PRS	Burn site	Decommissioned	0		Rec NFA
3-007	3-007	3-007	3	AOC/PRS	Firing site	Decommissioned	10	HE	CARBC
3-008(a)	3-008(a)	3-008(a)	3	AOC/PRS	Firing site	Decommissioned	0		NFA
3-008(b)	3-008(b)	3-008(b)	3	AOC/PRS	Firing site	Decommissioned	0		NFA

3-009(a)	3-009(a)	3-009(a)	3	HSWA	Surface disposal	Inactive	0		Rec NFA
3-009(b)	3-009(b)	3-009(b)	3	HSWA	Surface disposal	Inactive	0		Rec NFA
3-009(c)	3-009(c)	3-009(c)	3	HSWA	Surface disposal	Inactive	0		Rec NFA
3-009(d)	3-009(d)	3-009(d)	3	HSWA	Surface disposal	Inactive	0		Rec NFA
3-009(e)	3-009(e)	3-009(e)	3	HSWA	Surface disposal	Inactive	0		Rec NFA
3-009(f)	3-009(f)	3-009(f)	3	HSWA	Surface disposal	Inactive	0		Rec NFA
3-009(g)	3-009(g)	3-009(g)	3	HSWA	Surface disposal	Inactive	0		Rec NFA
3-009(h)	3-009(h)	3-009(h)	3	HSWA	Surface disposal	Inactive	0		Rec NFA
3-009(h)	60-002*				*part of 3-009(h) became 60-002				
	3-009(i)	3-009(i)	3	HSWA PM	Surface disposal site	Inactive	0		NFA
	3-009(j)	3-009(j)	3	HSWA PM	Surface disposal site	Inactive	0		NFA
3-010	3-010(a)	3-010(a)	3	010 HSWA	Systematic release site	Inactive	20	Rad, hazardous const.	CARBC
	3-010(b)	3-010(b)	3	AOC/PRS	Operational release	Inactive	0		Rec NFA
	3-010(c)	3-010(c)	3	AOC/PRS	Operational release	Inactive	0		Rec NFA
	3-010(d)	3-010(d)	3	AOC/PRS	Operational release	Inactive	0		Rec NFA
3-011	3-011	3-011	3	HSWA PM	Systematic product release	Inactive	0		NFA
3-012(a)	3-012(a)	3-012(a)	3	HSWA	One-time spill	Inactive	0		Rec NFA
3-012(b)	3-012(b)	3-012(b)	3	HSWA	Operational release and outfall	Inactive	150	Rad, hazardous const.	CARBC
3-013	3-013(a)	3-013(a)	3	013 HSWA	Operational release	Active	33	Hazardous const.	CARBC
3-013	3-013(b)	3-013(b)	3	013 HSWA	Operational release	Active	53	Hazardous const.	CARBC
3-013	3-013(c)	3-013(c)	3	HSWA PM	Operational release	Inactive	0		Rec NFA
	3-013(d)	3-013(d)	3	AOC/PRS	Operational release	Active	0		Rec NFA
	3-013(e)	3-013(e)	3	HSWA PM	Operational release	Active	0		Rec NFA
	3-013(f)	3-013(f)	3	AOC/PRS	Operational release	Inactive	0		Rec NFA
	3-013(g)	3-013(g)	3	HSWA PM	Operational release	Inactive	0		Rec NFA
	3-013(h)	3-013(h)	3	AOC/PRS	Operational release	Active	0		Rec NFA
3-014(a)	3-014(a)	3-014(a)	3	HSWA	Waste water treatment facility	Active	46	Rad, hazardous const.	Def. D&D
	3-014(a2)	3-014(a2)	3	AOC/PRS	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
3-014(b)	3-014(b)	3-014(b)	3	HSWA	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
	3-014(b2)	3-014(b2)	3	AOC/PRS	Outfall	Active	1	Rad, hazardous const.	Def. D&D
3-014(c)	3-014(c)	3-014(c)	3	HSWA	Waste water treatment facility	Active	20	Hazardous const.	Def. D&D

	3-014(c2)	3-014(c2)	3	AOC/PRS	Outfall	Inactive	1	Rad, hazardous const.	Def. D&D
3-014(d)	3-014(d)	3-014(d)	3	HSWA	Waste water treatment facility	Active	36	Hazardous const.	Def. D&D
3-014(e)	3-014(e)	3-014(e)	3	HSWA	Waste water treatment facility	Active	20	Rad, hazardous const.	Def. D&D
3-014(f)	3-014(f)	3-014(f)	3	HSWA	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
3-014(g)	3-014(g)	3-014(g)	3	HSWA	Waste water treatment facility	Active	111	Hazardous const.	Def. D&D
3-014(h)	3-014(h)	3-014(h)	3	HSWA	Waste water treatment facility	Active	36	Hazardous const.	Def. D&D
3-014(i)	3-014(i)	3-014(i)	3	HSWA	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
3-014(j)	3-014(j)	3-014(j)	3	HSWA	Waste water treatment facility	Active	93	Hazardous const.	Def. D&D
3-014(k)	3-014(k)	3-014(k)	3	HSWA	Waste water treatment facility	Active	6	Hazardous const.	Def. D&D
3-014(l)	3-014(l)	3-014(l)	3	HSWA	Waste water treatment facility	Active	15	Hazardous const.	Def. D&D
3-014(m)	3-014(m)	3-014(m)	3	HSWA	Waste water treatment facility	Active	15	Hazardous const.	Def. D&D
3-014(n)	3-014(n)	3-014(n)	3	HSWA	Waste water treatment facility	Active	15	Hazardous const.	Def. D&D
3-014(o)	3-014(o)	3-014(o)	3	HSWA	Waste water treatment facility	Active	400	Hazardous const.	Def. D&D
3-014(p)	3-014(p)	3-014(p)	3	HSWA	Waste water treatment facility	Active	19	Hazardous const.	Def. D&D
3-014(q)	3-014(q)	3-014(q)	3	HSWA	Waste water treatment facility	Active	92	Hazardous const.	Def. D&D
3-014(r)	3-014(r)	3-014(r)	3	HSWA	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
3-014(s)	3-014(s)	3-014(s)	3	HSWA	Waste water treatment facility	Active	8	Hazardous const.	Def. D&D
3-014(t)	3-014(t)	3-014(t)	3	HSWA	Waste water treatment facility	Active	8	Hazardous const.	Def. D&D
3-014(u)	3-014(u)	3-014(u)	3	HSWA	Waste water treatment facility	Active	17	Hazardous const.	Def. D&D
	3-014(v)	3-014(v)	3	AOC/PRS	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
	3-014(w)	3-014(w)	3	AOC/PRS	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
	3-014(x)	3-014(x)	3	AOC/PRS	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
	3-014(y)	3-014(y)	3	AOC/PRS	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
	3-014(z)	3-014(z)	3	AOC/PRS	Waste water treatment facility	Active	1	Hazardous const.	Def. D&D
3-015	3-015	3-015	3	HSWA	Outfall	Inactive	100	Hazardous const.	CARBC
3-016(a)	3-016(a)	3-016(a)	3	AOC/PRS	Septic system	Active	0		NFA
3-016(b)	3-016(a)								
3-016(c)	60-006(a)								
3-016(d)	60-006(a)								
3-017(c)	3-016(b)	3-016(b)	3	AOC/PRS	Septic system	Active	0		NFA
3-017(a)	3-016(c)	3-016(c)	3	AOC/PRS	Septic system	Active	0		NFA

	3-016(d)	3-016(d)	3	AOC/PRS	Septic system	Active	0		NFA
	3-016(e)	3-016(e)	3	AOC/PRS	Septic system	Active	0		NFA
		3-016(f)	3	AOC/PRS	Septic system	Active	0		NFA
3-017(b)	61-004(a)								
3-017(c)	3-016(b)								
3-018	3-018	3-018	3	HSWA	Septic system	Inactive	0		Rec NFA
3-019	3-019	3-019	3	HSWA PM	Septic tank	Decommissioned	0		NFA
3-020	3-020(a)	3-020(a)	3	020 HSWA	Disposal pit	Inactive	0		Rec NFA
	3-020(b)	3-020(b)	3	HSWA PM	Surface disposal site	Inactive	0		Rec NFA
3-021	3-021	3-021	3	HSWA PM	Surface disposal site	Inactive	10	Hazardous const.	CARBC
3-022	3-022	3-022	3	AOC/PRS	Sump	Active	198	Hazardous const.	Def. D&D
3-023	3-023	3-023	3	AOC/PRS	Sump	Inactive	2	Hazardous const.	CARBC
3-024	3-024	3-024	3	HSWA PM	Tank and/or assoc. equipment	Active	0		NFA
3-025(a)	3-025(a)	3-025(a)	3	HSWA PM	Tank and/or assoc. equipment	Active	0		NFA
3-025(b)	3-025(b)	3-025(b)	3	HSWA PM	Tank and/or assoc. equipment	Active	0		NFA
	3-025(c)	3-025(c)	3	AOC/PRS	Tank and/or assoc. equipment	Active	10	Rad, hazardous const.	Def. D&D
3-026	3-026(a)	3-026(a)	3	AOC/PRS	Sump	Active	22	Hazardous const.	Def. D&D
	3-026(b)	3-026(b)	3	HSWA PM	Sumps	Active	8	Hazardous const.	Def. D&D
	3-026(c)	3-026(c)	3	HSWA PM	Tank and/or assoc. equipment	Active	0		NFA
	3-026(d)	3-026(d)	3	HSWA PM	Tank and/or assoc. equipment	Active	1	Hazardous const.	Def. D&D
3-027(a)	60-003								
3-027(b)	3-027	3-027	3	AOC/PRS	Separation site	Active	0		NFA
3-028	3-028	3-028	3	HSWA	Surface impoundment	Active	0		Rec NFA
3-029(a)	60-005(a)								
3-029(b)	3-029	3-029	3	029(b)HSWA	Landfill	Inactive	0		Rec NFA
3-030(a)	60-005(b)								
3-030(b)	3-030	3-030	3	AOC/PRS	Surface impoundment	Inactive	0		NFA
3-031	3-031	3-031	3	HSWA PM	Tank and/or assoc. equipment	Active	104	Rad, hazardous const.	Def. D&D
3-032	3-032	3-032	3	HSWA PM	Tank and/or assoc. equipment	Active	0		NFA
3-033	3-033	3-033	3	HSWA	Sump	Inactive	5	Hazardous const.	CARBC
3-034	3-034(a)	3-034(a)	3	HSWA PM	Tank and/or assoc. equipment	Inactive, standby	1	Rad, hazardous const.	Def. D&D

	3-034(b)	3-034(b)	3	HSWA PM	Tank and/or assoc. equipment	Active	0		NFA
3-035(a)	3-043(e)								
3-035(b)	3-035(a)	3-035(a)	3	035(b)HSWA	Underground tank	Removed	0		Rec NFA
3-035(c)	deleted*				*No visible contamination during decommissioning in 1989				
3-035(d)	3-035(d)	3-035(b)	3	AOC/PRS	Underground tank	Removed	0		NFA
3-036(a)	3-036(a)	3-036(a)	3	HSWA	Aboveground tanks	Inactive	0		Rec NFA
3-036(b)	3-036(b)	3-036(b)	3	AOC/PRS	Aboveground tanks	Active	0	Hazardous const.	Def. D&D
3-036(c)	deleted*				*deleted because catchment basin was never used				
	3-036(d)	3-036(c)	3	036(d)HSWA	Aboveground tanks	Inactive	0		Rec NFA
	3-036(e)	3-036(d)	3	036(e)HSWA	Aboveground tanks	Inactive	0		Rec NFA
		3-036(e)	3	AOC/PRS	Aboveground tank	Inactive	0		Rec NFA
	3-036(f)	3-036(f)	3	AOC/PRS	Aboveground tank	Removed	0		NFA
	3-036(g)	3-036(g)	3	AOC/PRS	Aboveground tank	Active	0		NFA
	3-036(h)	3-036(h)	3	AOC/PRS	Aboveground tank	Active	0		NFA
	3-036(i)	3-036(i)	3	AOC/PRS	Aboveground tank	Active	0		NFA
	3-036(j)	3-036(j)	3	AOC/PRS	Aboveground tanks	Active	0		NFA
3-037	3-037	3-037	3	HSWA	Underground tank	Inactive	25	Hazardous const.	Def. D&D
3-038(a)	3-038(a)	3-038(a)	3	HSWA	Acid tank	Decommissioned	0		Rec NFA
3-038(b)	3-038(b)	3-038(b)	3	HSWA	Acid tank	Decommissioned	0		Rec NFA
	3-038(c)	3-038(c)	3	AOC/PRS	Waste lines	Decommissioned	0		NFA
	3-038(d)	3-038(d)	3	AOC/PRS	Waste lines	Inactive	0		NFA
	3-038(e)	3-038(e)	3	AOC/PRS	Waste lines	Inactive	0		NFA
	3-038(f)	3-038(f)	3	AOC/PRS	Waste lines	Inactive	0		NFA
3-039	3-039(a)	3-039(a)	3	039 HSWA	Silver recovery unit	Inactive	0		Rec NFA
	3-039(b)	3-039(b)	3	AOC/PRS	Silver recovery unit	Active	0		Rec NFA
	3-039(c)	3-039(c)	3	AOC/PRS	Silver recovery unit	Inactive	0		Rec NFA
	3-039(d)	3-039(d)	3	AOC/PRS	Silver recovery unit	Active	0		Rec NFA
	3-039(e)	3-039(e)	3	AOC/PRS	Silver recovery unit	Inactive	0		Rec NFA
3-040	3-040(a)	3-040(a)	3	AOC/PRS	Storage area	Active	0		NFA
	3-040(b)	3-040(b)	3	AOC/PRS	Storage area	Decommissioned	0		NFA
3-041	3-041	3-041	3	AOC/PRS	Underground tank	Unused	0		NFA

3-042	3-042	3-042	3	AOC/PRS	Sump	Removed	1	Hazardous const.	CARBC
	3-043(a)	3-043(a)	3	AOC/PRS	Aboveground tank	Removed	0		NFA
	3-043(b)	3-043(b)	3	AOC/PRS	Aboveground tank	Removed	0		NFA
3-043	3-043(c)	3-043(c)	3	HSWA PM	Tank and/or assoc. equipment	Decommissioned	0		NFA
	3-043(d)	3-043(d)	3	AOC/PRS	Aboveground tank	Decommissioned	0		NFA
3-035(a)	3-043(e)	3-043(e)	3	035(a)HSWA	Underground tank	Decommissioned	0		NFA
	3-043(f)	3-043(f)	3	AOC/PRS	Aboveground tank	Decommissioned	0		NFA
	3-043(g)	3-043(g)	3	AOC/PRS	Aboveground tank	Decommissioned	0		NFA
	3-043(h)	3-043(h)	3	AOC/PRS	Aboveground tank	Decommissioned	0		NFA
	3-043(i)	3-043(i)	3	AOC/PRS	Aboveground tank	Removed	0		NFA
3-044	3-044(a)	3-044(a)	3	044 HSWA	Container storage	Decommissioned	0		Rec NFA
	3-044(b)	3-044(b)	3	AOC/PRS	Container storage	Decommissioned	0		Rec NFA
3-045	3-045(a)	3-045(a)	3	HSWA PM	Ind. or san. waste water treatmer	Removed	100	Hazardous const.	CARBC
3-045	3-045(b)	3-045(b)	3	HSWA PM	Ind. or san. waste water treatmer	Inactive	100	Hazardous const.	CARBC
	3-045(c)	3-045(c)	3	HSWA PM	Ind. or san. waste water treatmer	Inactive	100	Hazardous const.	CARBC
	3-045(d)	3-045(d)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
	3-045(e)	3-045(e)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
	3-045(f)	3-045(f)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
	3-045(g)	3-045(g)	3	HSWA PM	Ind. or san. waste water treatmer	Decommissioned	0		NFA
	3-045(h)	3-045(h)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
	3-045(i)	3-045(i)	3	HSWA PM	Ind. or san. waste water treatmer	Unknown	0		NFA
	3-046	3-046	3	HSWA PM	Physical, chem. &/or bio. treat.	Active	0		NFA
	3-047(a)	3-047(a)	3	AOC/PRS	Storage area	Active	0		NFA
	3-047(b)	3-047(b)	3	AOC/PRS	Storage area	Active	0		NFA
	3-047(c)	3-047(c)	3	AOC/PRS	Storage area	Active	0		NFA
	3-047(d)	3-047(d)	3	AOC/PRS	Storage area	Active	0		NFA
	3-047(e)	3-047(e)	3	AOC/PRS	Storage area	Active	0		NFA
	3-047(f)	3-047(f)	3	AOC/PRS	Storage area	Active	0		NFA
	3-047(g)	3-047(g)	3	AOC/PRS	Storage area	Active	0		NFA
	3-047(h)	3-047(h)	3	AOC/PRS	Storage area	Active	0		NFA
	3-047(i)	3-047(i)	3	AOC/PRS	<90 day storage	Active	0		NFA

3-047(j)	3-047(j)	3	AOC/PRS	Storage area	Inactive	0		NFA
3-047(k)	3-047(k)	3	AOC/PRS	Storage area	Active	0		NFA
3-048	3-048	3	AOC/PRS	Storage area	Active	0		NFA
3-049(a)	3-049(a)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
3-049(b)	3-049(b)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
3-049(c)	3-049(c)	3	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
3-049(d)	3-049(d)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
3-049(e)	3-049(e)	3	HSWA PM	Ind. or san. waste water treatmer	Unknown	0		NFA
3-050(a)	3-050(a)	3	HSWA PM	Off-gas scrubber of HEPA filter s	Active	0	Rad, hazardous const.	IS;IC
3-050(b)	3-050(b)	3	AOC/PRS	Off-gas scrubber of HEPA filter s	Active	0		NFA
3-050(c)	3-050(c)	3	AOC/PRS	Off-gas scrubber of HEPA filter s	Active	0		NFA
3-050(d)	3-050(d)	3	HSWA PM	Off-gas scrubber of HEPA filter s	Inactive	0		NFA
3-050(e)	3-050(e)	3	HSWA PM	Off-gas scrubber of HEPA filter s	Active	0		NFA
3-050(f)	3-050(f)	3	HSWA PM	Off-gas scrubber of HEPA filter s	Active	0		NFA
3-050(g)	3-050(g)	3	HSWA PM	Off-gas scrubber of HEPA filter s	Active	0		NFA
3-051(a)	3-051(a)	3	AOC/PRS	Soil contamination	Active	0		NFA
3-051(b)	3-051(b)	3	AOC/PRS	Soil contamination	Active	0		NFA
3-051(c)	3-051(c)	3	AOC/PRS	Soil contamination	Active	0		NFA
3-051(d)	3-051(d)	3	AOC/PRS	Soil contamination	Active	0		NFA
3-052(a)	3-052(a)	3	HSWA PM	Ind. or san. waste water treatmer	Active	26	Hazardous const.	CARBC
3-052(b)	3-052(b)	3	AOC/PRS	Storm drainage	Active	20	Hazardous const.	CARBC
3-052(c)	3-052(c)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
3-052(d)	3-052(d)	3	AOC/PRS	Storm drainage	Active	0		NFA
3-052(e)	3-052(e)	3	HSWA PM	Ind. or san. waste water treatmer	Active	5	Hazardous const.	CARBC
3-052(f)	3-052(f)	3	HSWA PM	Ind. or san. waste water treatmer	Active	5	Hazardous const.	CARBC
3-053	3-053	3	AOC/PRS	Operational facility	Active	14	Rad, hazardous const.	Def. D&D
3-054(a)	3-054(a)	3	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
3-054(b)	3-054(b)	3	HSWA PM	Ind. or san. waste water treatmer	Active	5	Hazardous const.	CARBC
3-054(c)	3-054(c)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
3-054(d)	3-054(d)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
3-054(e)	3-054(e)	3	HSWA PM	Ind. or san. waste water treatmer	Active	5	Hazardous const.	CARBC

	3-055(a)	3-055(a)	3	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
	3-055(b)	3-055(b)	3	AOC/PRS	Outfall	Inactive	0		Rec NFA
	3-055(c)	3-055(c)	3	HSWA PM	Ind. or san. waste water treatmer	Active	0		NFA
	3-055(d)	3-055(d)	3	HSWA PM	Ind. or san. waste water treatmer	Inactive	0		NFA
3-001(p)	3-056(a)	3-056(a)	3	001(p)HSWA	Storage area	Active	23	Hazardous const.	Def. D&D
3-001(k)	3-056(b)	3-056(b)	3	AOC/PRS	Storage area	Active	0		Rec NFA
3-001(r)	3-056(c)	3-056(c)	3	001(r)HSWA	Storage area	Inactive	1	Hazardous const., other	CARBC
3-001(s)	3-056(d)	3-056(d)	3	HSWA PM	Container storage area	Active	0		NFA
3-001(t)	3-056(e)	3-056(e)	3	AOC/PRS	Storage area	Unknown	0		NFA
3-001(n)	3-056(f)	3-056(f)	3	AOC/PRS	Storage area	Unknown	0		NFA
	3-056(g)	3-056(g)	3	AOC/PRS	Storage area	Active	0		NFA
3-001(u)	3-056(h)	3-056(h)	3	AOC/PRS	Storage area	Inactive	0		NFA
	3-056(i)	3-056(i)	3	AOC/PRS	Storage area	Unknown	0		NFA
	3-056(j)	3-056(j)	3	AOC/PRS	Storage area	Unknown	0		NFA
	3-056(k)	3-056(k)	3	AOC/PRS	Storage area	Unknown	0		NFA
	3-056(l)	3-056(l)	3	HSWA PM	Container storage area	Not located	0		NFA
	3-056(m)	3-056(m)	3	HSWA PM	Container storage area	Unknown	0		NFA
	3-056(n)	3-056(n)	3	HSWA PM	Container storage area	Inactive	0		NFA
	3-057	3-057	3	AOC/PRS	Sump/Grease trap	Inactive	0		NFA
	3-058	3-058	3	AOC/PRS	Container storage	Active	0		NFA
	3-059	3-059	3	HSWA PM	Storage area	Inactive	889	Hazardous const., other	CARBC
	C-3-001	C-3-001	3	AOC/PRS	Gas trap	Active	0		NFA
	C-3-002	C-3-002	3	AOC/PRS	One-time spill	Inactive	0		NFA
	C-3-003	C-3-003	3	AOC/PRS	One-time spill	Unknown	0		NFA
	C-3-004	C-3-004	3	AOC/PRS	One-time spill	Inactive	0		NFA
	C-3-005	C-3-005	3	AOC/PRS	One-time spill	Inactive	556	Hazardous const.	Def. D&D
	C-3-006	C-3-006	3	AOC/PRS	One-time spill	Inactive	111	Rad, hazardous const.	CARBC
	C-3-007	C-3-007	3	AOC/PRS	Storage area	Inactive	0	Rad	Def. D&D
	C-3-008	C-3-008	3	AOC/PRS	Storage area	Active	0	Rad	Def. D&D
	C-3-009	C-3-009	3	AOC/PRS	Storage area	Active	0	Hazardous const.	Def. D&D
	C-3-010	C-3-010	3	AOC/PRS	Ind. sanitary sys.	Removed	0		NFA

	C-3-011	C-3-011	3	AOC/PRS	Tank	Removed	0		NFA
	C-3-012	C-3-012	3	AOC/PRS	Storage area	Active	0		NFA
	No C-3-013 in data base								
	C-3-014	C-3-014	3	AOC/PRS	Storage area	Inactive	0		NFA
	C-3-015	C-3-015	3	AOC/PRS	Underground dist. tank	Active	0		NFA
	C-3-016	C-3-016	3	AOC/PRS	Tank	Active	5	Hazardous const.	Def. D&D
	C-3-017	C-3-017	3	AOC/PRS	Underground dist. tank	Removed	0		NFA
	C-3-018	C-3-018	3	AOC/PRS	Underground dist. tank	Removed	0		NFA
	C-3-019	C-3-019	3	AOC/PRS	Underground tank	Not located	0		NFA
	C-3-020	C-3-020	3	AOC/PRS	Underground tanks	Inactive	0		NFA
	C-3-021	C-3-021	3	AOC/PRS	Underground tank	Removed	0		NFA
	C-3-022	C-3-022	3	AOC/PRS	Tank	Removed	0		NFA
30-001	30-001	30-001	3 *	AOC/PRS	Surface disposal and landfill	Inactive	0	*Now in TA-3	Rec NFA
59-001	59-001	59-001	59	HSWA	Septic system	Decommissioned	0		Rec NFA
59-002	59-002	59-002	59	AOC/PRS	Container storage area	Active	0		Rec NFA
59-003	59-003	59-003	59	HSWA PM	Tank and/or assoc. equip.	Active	0		Rec NFA
	59-004	59-004	59	AOC/PRS	Outfall	Active	37	Rad, hazardous const.	CARBC
	C-59-001	C-59-001	59	AOC/PRS	Transformer	Active	0		NFA
3-001(g)	60-001(a)	60-001(a)	60	AOC/PRS	Storage area	Active	0		Rec NFA
3-001(h)	60-001(b)	60-001(b)	60	AOC/PRS	Storage area	Active	0		Rec NFA
	60-001(c)	60-001(c)	60	AOC/PRS	Storage area	Active	0		Rec NFA
	60-001(d)	60-001(d)	60	AOC/PRS	Storage area	Active	0		Rec NFA
3-009(h)	60-002	60-002	60	009(h)HSWA	Surface disposal	Active	0		Rec NFA
3-027(a)	60-003	60-003	60	AOC/PRS	Oil-water separator	Active	0		Rec NFA
3-005(a)	60-004(a)	60-004(a)	60	AOC/PRS	Storage area	Active	0		Rec NFA
3-005(b)	60-004(b)	60-004(b)	60	AOC/PRS	Storage area	Inactive	10	Hazardous const.	CARBC
3-005(c)	60-004(c)	60-004(c)	60	AOC/PRS	Storage area	Inactive	3	Hazardous const., other	CARBC
	60-004(d)	60-004(d)	60	AOC/PRS	Storage area	Inactive	10	Hazardous const.	CARBC
	60-004(e)	60-004(e)	60	AOC/PRS	Storage area	Active	10	Hazardous const., other	CARBC
3-029(a)	60-005(a)	60-005(a)	60	029(a)HSWA	Surface impoundment	Inactive	124	Rad, hazardous const.	CARBC
3-030(a)	60-005(b)	60-005(b)	60	AOC/PRS	Surface impoundment	Inactive	0		Rec NFA

3-016(c)	60-006(a)	60-006(a)	60	HSWA PM	Septic tank	Active	5	Hazardous const.	CARBC
	60-006(b)	60-006(b)	60	AOC/PRS	Septic system	Inactive	0		Rec NFA
	60-006(c)	60-006(c)	60	HSWA PM	Septic tank	Active	0		Rec NFA
	60-007(a)	60-007(a)	60	HSWA PM	Systematic or intent. prod. releas	Inactive	1	Hazardous const.	CARBC
	60-007(b)	60-007(b)	60	HSWA PM	Systematic or intent. prod. releas	Inactive	6	Hazardous const., other	CARBC
	C-60-001	C-60-001	60	AOC/PRS	Underground tank	Removed	0		NFA
	C-60-002	C-60-002	60	AOC/PRS	Underground tank	Removed	0		NFA
	C-60-003	C-60-003	60	AOC/PRS	One-time spill	Inactive	0		NFA
	C-60-004	C-60-004	60	AOC/PRS	Underground tank	Removed	0		NFA
	C-60-005	C-60-005	60	AOC/PRS	Storage area	Active	2	Hazardous const.	CARBC
3-001(q)	61-001	61-001	61	AOC/PRS	Storage area	Active	0		Rec NFA
3-003(c)	61-002	61-002	61	003(c) HSWA	Storage area	Decommissioned	269	Other	CARBC
3-006(a)	61-003	61-003	61	AOC/PRS	Burn sites	Does not exist	0		NFA
3-017(b)	61-004(a)	61-004(a)	61	HSWA PM	Septic tank	Inactive	0		Rec NFA
0-022	61-004(b)	61-004(b)	61	HSWA PM	Septic tank	Inactive	0		Rec NFA
		61-004(c)	61	AOC/PRS	Septic system	Inactive	0		Rec NFA
0-006	61-005	61-005	61	006 HSWA	Landfill	Active	313630	Hazardous const.	Def. D&D
0-002	61-006	61-006	61	002 HSWA	Container storage	Active	0	Hazardous const.	Def. D&D
0-023	61-007	61-007	61	023 HSWA	Systematic leak	Inactive	600	Other	Rec NFA
	C-61-001	C-61-001	61	AOC/PRS	Transformer	Removed	0		NFA
	64-001	64-001	64	AOC/PRS	Storage area	Active	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
33-001(a)	33-001(a)	33-001(a)	33	HSWA	Material disposal area	Inactive	292	Rad, hazardous const.	CARBC
33-001(b)	33-001(b)	33-001(b)	33	HSWA	Material disposal area	Inactive	175	Rad, hazardous const.	CARBC
33-001(c)	33-001(c)	33-001(c)	33	HSWA	Material disposal area	Inactive	4	Rad, hazardous const.	CARBC
33-001(d)	33-001(d)	33-001(d)	33	HSWA	Material disposal area	Inactive	389	Rad, hazardous const.	CARBC
33-001(e)	33-001(e)	33-001(e)	33	HSWA	Material disposal area	Inactive	0		NFA
	33-001misc	33-001misc			Unit does not exist		0		NFA
33-002(a)	33-002(a)	33-002(a)	33	HSWA	Septic tank	Active	157	Rad, hazardous const.	CARBC
33-002(b)	33-002(b)	33-002(b)	33	HSWA	Sump	Inactive	203	Rad, hazardous const.	CARBC
33-002(c)	33-002(c)	33-002(c)	33	HSWA	Sump	Inactive	203	Rad, hazardous const.	CARBC
	33-002(d)	33-002(d)	33	HSWA PM	Drain line and outfall	Inactive	1	Rad, hazardous const.	CARBC
	33-002(e)	33-002(e)	33	HSWA PM	Drain line and outfall	Active	1	Rad, hazardous const.	CARBC
33-003(a)	33-003(a)	33-003(a)	33	HSWA	Material disposal area	Inactive	0		NFA
33-003(b)	33-003(b)	33-003(b)	33	HSWA	Material disposal area	Inactive	0		NFA
33-004(a)	33-004(a)	33-004(a)	33	HSWA	Septic system	Active	0		NFA
33-004(b)	33-004(b)	33-004(b)	33	HSWA	Septic system	Active	0		NFA
33-004(c)	33-004(c)	33-004(c)	33	HSWA	Septic system	Active	0		NFA
33-004(d)	33-004(d)	33-004(d)	33	HSWA	Septic system	Inactive	0		NFA
33-004(e)	33-004(e)	33-004(e)	33	HSWA	Seepage pit	Inactive	0		Rec NFA
33-004(f)	33-004(f)	33-004(f)	33	HSWA	Septic system	Inactive	0		Rec NFA
	33-004(g)	33-004(g)	33	HSWA PM	Outfall	Inactive	0		NFA
	33-004(h)	33-004(h)	33	HSWA PM	Outfall	Inactive	0		NFA
	33-004(i)	33-004(i)	33	HSWA PM	Outfall	Inactive	0		NFA
	33-004(j)	33-004(j)	33	HSWA PM	Outfall	Inactive	0		NFA
	33-004(k)	33-004(k)	33	HSWA PM	Outfall	Inactive	0		NFA
	33-004(l)	33-004(l)	33	AOC/PRS	Outfall	Inactive	0		Rec NFA
	33-004(m)	33-004(m)	33	HSWA PM	Septic system	Active	0		NFA
	33-004(n)	33-004(n)	33	AOC/PRS	Septic system	Inactive	0		Rec NFA
	33-004misc	33-004misc			Unit does not exist		0		NFA
33-005(a)	33-005(a)	33-005(a)	33	HSWA PM	Septic system	Decommissioned	0		NFA

33-005(b)	33-005(b)	33-005(b)	33	HSWA PM	Septic system	Decommissioned	0	NFA
33-005(c)	33-005(c)	33-005(c)	33	HSWA PM	Septic system	Decommissioned	0	NFA
33-006(a)	33-006(a)	33-006(a)	33	HSWA PM	Firing site	Decommissioned	0	NFA
33-006(b)	33-006(b)	33-006(b)	33	HSWA PM	Firing range	Decommissioned	0	NFA
33-007	33-007(a)	33-007(a)	33	007 HSWA	Firing range	Decommissioned	0	NFA
	33-007(b)	33-007(b)	33	HSWA PM	Firing range	Decommissioned	0	NFA
	33-007(c)	33-007(c)	33	HSWA PM	Firing range	Decommissioned	0	NFA
33-008(a)	33-008(a)	33-008(a)	33	HSWA	Landfill	Inactive	0	NFA
33-008(b)	33-008(b)	33-008(b)	33	HSWA	Landfill	Inactive	0	NFA
33-009	33-009	33-009	33	HSWA	Surface disposal	Decommissioned	0	NFA
33-010(a)	33-010(a)	33-010(a)	33	HSWA	Surface disposal	Inactive	0	NFA
33-010(b)	33-010(b)	33-010(b)	33	HSWA	Surface disposal	Inactive	0	NFA
33-010(c)	33-010(c)	33-010(c)	33	HSWA	Surface disposal	Inactive	0	NFA
	33-010(d)	33-010(d)	33	HSWA PM	Surface disposal	Inactive	0	NFA
	33-010(e)	33-010(e)	33	AOC/PRS	Surface disposal	Inactive	0	NFA
	33-010(f)	33-010(f)	33	HSWA PM	Surface disposal	Inactive	0	NFA
	33-010(g)	33-010(g)	33	HSWA PM	Surface disposal	Inactive	0	NFA
	33-010(h)	33-010(h)	33	HSWA PM	Surface disposal	Inactive	0	NFA
33-011	33-011(a)	33-011(a)	33	011 HSWA	Storage area	Inactive	0	NFA
	33-011(b)	33-011(b)	33	AOC/PRS	Storage area	Inactive	0	NFA
	33-011(c)	33-011(c)	33	HSWA PM	Storage area	Inactive	0	NFA
	33-011(d)	33-011(d)	33	HSWA PM	Storage area	Inactive	0	NFA
	33-011(e)	33-011(e)	33	HSWA PM	Storage area	Inactive	0	NFA
33-012(a)	33-012(a)	33-012(a)	33	HSWA	Satellite storage	Active	0	NFA
33-012(b)	33-012(b)	33-012(b)	33	AOC/PRS	Satellite storage	Active	0	Rec NFA
33-012(c)	33-012(c)	33-012(c)	33	AOC/PRS	Satellite storage	Active	0	Rec NFA
33-012(d)	33-012(d)	33-012(d)	33	AOC/PRS	Satellite storage	Active	0	Rec NFA
33-013	33-013	33-013	33	HSWA	Storage area	Inactive	0	NFA
33-014	33-014	33-014	33	HSWA	Burn site	Inactive	0	NFA
33-015	33-015	33-015	33	HSWA PM	Incinerator	Inactive	0	NFA
33-016	33-016	33-016	33	HSWA PM	Sump	Inactive	0	NFA

33-017	33-017	33-017	33	HSWA	Operational release	Inactive	0	NFA
	C-33-001	C-33-001	33	AOC/PRS	Transformer	Active	0	NFA
	C-33-002	C-33-002	33	AOC/PRS	Transformer	Inactive	0	NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (YD3)	Potential Contaminants	Potential Remediation
4-001	4-001	4-001	4	HSWA	Firing Site	Decommissioned	741	Rad, Hazardous Const., HE	CARBC
4-002	4-002	4-002	4	HSWA	Surface disposal	Inactive	35	Rad, Hazardous Const., HE	CARBC
	4-003(a)	4-003(a)	4	HSWA PM	Outfall	Unknown	116	Rad, Hazardous Const.	CARBC
	4-003(b)	4-003(b)	4	HSWA PM	Outfall	Inactive	116	Rad, Hazardous Const.	CARBC
	4-004	4-004	4	AOC/PRS	Soil contamination beneath bldgs.	Inactive	17	Rad, Hazardous Const.	CARBC
	C-4-001	C-4-001	4	AOC/PRS	Soil contamination beneath bldgs.	Removed	0		Rec NFA
5-001(a)	5001(a)	5-001(a)	5	HSWA	Firing Site	Decommissioned	748	Rad, Hazardous Const, HE	CARBC
5-001(b)	5-001(b)	5-001(b)	5	HSWA	Firing Site	Decommissioned	748	Rad, Hazardous Const, HE	CARBC
	5-001(c)	5-001(c)	5	AOC/PRS	Firing Site	Decommissioned	748	Hazardous Const., HE	CARBC
5-002	5-002	5-002	5	HSWA	Canyonside disposal	Inactive	726	Rad, Hazardous Const.	CARBC
5-003	5-003	5-003	5	HSWA	Calibration chamber	Inactive	0	Rad, Hazardous Const.	CARBC
5-004	5-004	5-004	5	HSWA	Septic system	Decommissioned	9	Rad, Hazardous Const.	CARBC
5-005	5-005(a)	5-005(a)	5	005HSWA	French drain	Decommissioned	111	Rad, Hazardous Const.	CARBC
	5-005(b)	5-005(b)	5	HSWA PM	Outfall	Inactive	111	Rad. hazardous Const.	CARBC
	5-006(a)	5-006(a)	5	HSWA PM	Soil contamination beneath bldgs.	Inactive	0		Rec NFA
	5-006(b)	5-006(b)	5	HSWA PM	Soil contamination beneath bldgs.	Inactive	3	Rad, Hazardous Const.	CARBC
	5-006(c)	5-006(c)	5	HSWA PM	Soil contamination beneath bldgs.	Inactive	3	Hazardous Const., HE	CARBC
	5-006(d)	5-006(d)	5	HSWA PM	Soil contamination beneath bldgs.	Inactive	0		Rec NFA
	5-006(e)	5-006(e)	5	HSWA PM	Soil contamination beneath bldgs.	Inactive	2	Rad, Hazardous Const.	CARBC
	5-006(f)	5-006(f)	5	HSWA PM	Soil contamination beneath bldgs.	Inactive	0		Rec NFA
	5-006(g)	5-006(g)	5	HSWA PM	Soil contamination beneath bldgs.	Inactive	0		Rec NFA
	5-006(h)	5-006(h)	5	HSWA PM	Soil contamination beneath bldgs.	Inactive	1	Rad, Hazardous Const.	CARBC
	C-5-001	C-5-001	5	AOC/PRS	Buildings	Unknown	3704	Hazardous Const.	CARBC
35-001	35-001	35-001	35	HSWA PM	Material disposal area	Decommissioned	0		Rec NFA
35-002	35-002	35-002	35	HSWA	Material disposal area	Inactive	0		Rec NFA
35-003(a)	35-003(a)	35-003(a)	35	HSWA	Waste water treatment facility	Inactive	3800	Rad, Hazardous Const.	CARBC
35-003(b)	35-003(b)	35-003(b)	35	HSWA	Waste water treatment facility	Inactive	3800	Rad, Hazardous Const.	CARBC
35-003(c)	35-003(c)	35-003(c)	35	HSWA	Waste water treatment facility	Inactive	3800	Rad, Hazardous Const.	CARBC
35-003(d)	35-003(d)	35-003(d)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC

35-003(e)	35-003(e)	35-003(e)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
35-003(f)	35-003(f)	35-003(f)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
35-003(g)	35-003(g)	35-003(g)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
35-003(h)	35-003(h)	35-003(h)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const	CARBC
35-003(i)	35-003(i)	35-003(i)	35	HSWA	Waste water treatment facility	Removed	0		Rec NFA
35-003(j)	35-003(j)	35-003(j)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
35-003(k)	35-003(k)	35-003(k)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
35-003(l)	35-003(l)	35-003(l)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
35-003(m)	35-003(m)	35-003(m)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
35-003(n)	35-003(n)	35-003(n)	35	HSWA	Waste water treatment facility	Inactive	3800	Rad, Hazardous Const.	CARBC
35-003(o)	35-003(o)	35-003(o)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
35-003(p)	35-003(p)	35-003(p)	35	HSWA	Waste water treatment facility	Decommissioned	0		Rec NFA
35-003(q)	35-003(q)	35-003(q)	35	HSWA	Waste water treatment facility	Removed	3800	Rad, Hazardous Const.	CARBC
	35-003(r)	35-003(r)	35	AOC/PRS	Outfall	Inactive	3986	Rad, Hazardous Const.	CARBC
35-004(a)	35-004(a)	35-004(a)	35	HSWA PM	Storage areas	Active/Inactive	1	Hazardous Const.	CARBC
35-004(b)	35-004(b)	35-004(b)	35	HSWA PM	Storage areas	Active/Inactive	1	Hazardous Const.	CARBC
35-004(c)	35-004(c)	35-004(c)	35	HSWA PM	Storage areas	Active/Inactive	0		Rec NFA
35-004(d)	35-004(d)	35-004(d)	35	HSWA PM	Container storage area	Active	0		Rec NFA
35-004(e)	35-004(e)	35-004(e)	35	HSWA	Container storage area	Active	0		Rec NFA
35-004(f)	35-004(f)	35-004(f)	35	AOC/PRS	Container storage area	Inactive	0		Rec NFA
35-004(g)	35-004(g)	35-004(g)	35	HSWA PM	Container storage area	Active	1	Hazardous Const.	CARBC
35-004(h)	35-004(h)	35-004(h)	35	HSWA PM	Container storage area	Inactive	1	Hazardous Const.	CARBC
35-004(i)	35-004(i)	35-004(i)	35	AOC/PRS	Container storage area	Inactive	0		Rec NFA
35-004(j)	35-004(j)	35-004(j)	35	AOC/PRS	Container storage area	Active	0		Rec NFA
	35-004(k)	35-004(k)	35	AOC/PRS	Container storage area	Active	0		Rec NFA
	35-004(l)	35-004(l)	35	AOC/PRS	Container storage area	Inactive	0		Rec NFA
	35-004(m)	35-004(m)	35	AOC/PRS	Container storage area	Inactive	1	Hazardous Const.	CARBC
	35-004(n)	35-004(n)	35	AOC/PRS	Container storage area	Active	0		Rec NFA
	35-004(o)	35-004(o)	35	AOC/PRS	Container storage area	Active	0		Rec NFA
35-005(a)	35-005(a)	35-005(a)	35	RCRA	Surface impoundment	Decommissioned	0		Rec NFA
35-005(b)	35-005(b)	35-005(b)	35	RCRA	Surface impoundment	Decommissioned	0		Rec NFA

35-006	35-006	35-006	35	HSWA	Surface impoundment	Decommissioned	0		Rec NFA
35-007	35-007	35-007	35	AOC/PRS	Waste oil treatment	Active	0		Rec NFA
35-008	35-008	35-008	35	HSWA	Surface disposal and landfill	Inactive	1389	Hazardous Const.	CARBC
35-009(a,b,c)	35-009(a)	35-009(a)	35	HSWA	Septic system	Inactive	120	Hazardous Const.	CARBC
35-009(b,d,e)	35-009(b)	35-009(b)	35	HSWA	Septic system	Inactive	633	Hazardous Const.	CARBC
35-009(c,f,h)	35-009(c)	35-009(c)	35	HSWA	Septic system	Active	278	Hazardous Const.	CARBC
35-009(d,g)	35-009(d)	35-009(d)	35	HSWA	Septic system	Active	254	Hazardous Const.	CARBC
35-009(e)	35-009(e)	35-009(e)	35	HSWA	Septic system	Unknown	47	Hazardous Const.	CARBC
35-010(a)	35-010(a)	35-010(a)	35	HSWA	Sanitary lagoon & sand filters	Active	10489	Rad, Hazardous Const.	CARBC
35-010(b)	35-010(b)	35-010(b)	35	HSWA	Sanitary lagoon & sand filters	Active	8519	Rad, Hazardous Const.	CARBC
35-010(c)	35-010(c)	35-010(c)	35	HSWA	Sanitary lagoon & sand filters	Active	8944	Rad, Hazardous Const.	CARBC
35-010(d)	35-010(d)	35-010(d)	35	HSWA	Sanitary lagoon & sand filters	Active	3333	Rad, Hazardous Const.	CARBC
	35-010(e)	35-010(e)	35	AOC/PRS	Surface impoundment	Active	50		CARBC
35-011(a)	35-011(a)	35-011(a)	35	HSWA PM	Underground storage tank	Active	0		Rec NFA
35-011(b)	35-011(b)	35-011(b)	35	RCRA	Underground storage tank	Active	0		Rec NFA
35-011(c)	35-011(c)	35-011(c)	35	RCRA	Underground storage tank	Active	0		Rec NFA
35-011(d)	35-011(d)	35-011(d)	35	RCRA	Underground storage tank	Active	0		Rec NFA
35-012	35-012(a)	35-012(a)	35	AOC/PRS	Underground storage tank	Removed	0		Rec NFA
	35-012(b)	35-012(b)	35	AOC/PRS	Underground storage tank	Unknown	0		Rec NFA
35-013(a)	35-013(a)	35-013(a)	35	HSWA PM	Sump	Active	0		Rec NFA
35-013(b)	35-013(b)	35-013(b)	35	HSWA PM	Sump	Active	0		Rec NFA
35-013(c)	35-013(c)	35-013(c)	35	HSWA PM	Sump	Active	0		Rec NFA
35-013(d)	35-013(d)	35-013(d)	35	HSWA PM	Sump	Active	0		Rec NFA
35-014	35-014(a)	35-014(a)	35	HSWA	Operational release	Inactive	208	Rad, Hazardous Const.	CARBC
35-014	35-014(b)	35-014(b)	35	HSWA	Operational release	Inactive	1	Rad, haz. const., other	CARBC
	35-014(c)	35-014(c)	35	HSWA PM	Operational release	Inactive	0		Rec NFA
	35-014(d)	35-014(d)	35	AOC/PRS	Operational release	Inactive	1	Rad, Hazardous Const.	CARBC
	35-014(e)	35-014(e)	35	HSWA PM	Operational release	Inactive	2	Rad, Hazardous Const.	CARBC
	35-014(f)	35-014(f)	35	AOC/PRS	Operational release	Inactive	1	Rad, Hazardous Const.	CARBC
	35-014(g)	35-014(g)	35	HSWA PM	Soil contamination	Inactive	56	Rad, Hazardous Const.	CARBC
35-015(a)	35-015(a)	35-015(a)	35	HSWA PM	Soil contamination	Decommissioned	2667	Hazardous Const.	CARBC

35-015(b)	35-015(b)	35-015(b)	35	HSWA	Waste oil treatment	Decommissioned	556	Hazardous Const.	CARBC
	35-016(a)	35-016(a)	35	HSWA PM	Drains and outfalls	Inactive	47	Hazardous Const.	CARBC
	35-016(b)	35-016(b)	35	AOC/PRS	Outfall	Active	47	Hazardous Const.	CARBC
	35-016(c)	35-016(c)	35	HSWA PM	Outfall	Inactive	47	Hazardous Const.	CARBC
	35-016(d)	35-016(d)	35	HSWA PM	Outfall	Inactive	47	Hazardous Const.	CARBC
	35-016(e)	35-016(e)	35	AOC/PRS	Outfall	Inactive	93	Hazardous Const.	CARBC
	35-016(f)	35-016(f)	35	AOC/PRS	Storm drain	Active	94	Hazardous Const.	CARBC
	35-016(g)	35-016(g)	35	AOC/PRS	Outfall	Active	93	Hazardous Const.	CARBC
	35-016(h)	35-016(h)	35	AOC/PRS	Storm drain	Active	101	Hazardous Const.	CARBC
	35-016(i)	35-016(i)	35	HSWA PM	Drains and outfalls	Active	94	Hazardous Const.	CARBC
	35-016(j)	35-016(j)	35	AOC/PRS	Storm drain	Active	48	Hazardous Const.	CARBC
	35-016(k)	35-016(k)	35	HSWA PM	Drains and outfalls	Inactive	46	Hazardous Const.	CARBC
	35-016(l)	35-016(l)	35	AOC/PRS	Storm drain	Active	48	Rad, Hazardous Const.	CARBC
	35-016(m)	35-016(m)	35	HSWA PM	Drains and outfalls	Inactive	93	Hazardous Const.	CARBC
	35-016(n)	35-016(n)	35	AOC/PRS	Storm drain	Active	48	Hazardous Const.	CARBC
	35-016(o)	35-016(o)	35	HSWA PM	Drains and outfalls	Active	96	Hazardous Const.	CARBC
	35-016(p)	35-016 (p)	35	HSWA PM	Outfall	Active	93	Hazardous Const.	CARBC
	35-016(q)	35-016(q)	35	HSWA PM	Drains and outfalls	Active	315	Rad, Hazardous Const.	CARBC
	35-017	35-017	35	AOC/PRS	Soil contamination from Reactor	Decommissioned	1157	Rad, Hazardous Const.	CARBC
	35-018(a)	35-018(a)	35	AOC/PRS	Transformer	Unknown	0		Rec NFA
	35-018(b)	35-018(b)	35	AOC/PRS	Transformer	Removed	0		Rec NFA
	C-35-001	C-35-001	35	AOC/PRS	Former underground storage tank	Removed	0		Rec NFA
	C-35-002	C-35-002	35	AOC/PRS	Former underground storage tank	Removed	0		Rec NFA
	C-35-003	C-35-003	35	AOC/PRS	Former underground storage tank	Removed	0		Rec NFA
	C-35-004	C-35-004	35	AOC/PRS	Oil spill	Cleaned	0		Rec NFA
	C-35-005	C-35-005	35	AOC/PRS	Oil spill	Cleaned	0		Rec NFA
	C-35-006	C-35-006	35	AOC/PRS	Organic spill	Removed	0		Rec NFA
	C-35-007	C-35-007	35	AOC/PRS	Unknown spill	Unknown	0	Rad, Hazardous Const., otl	CARBC
	C-35-008	C-35-008	35	AOC/PRS	Leaking transformer	Unknown	0		Rec NFA
42-001(a)	42-001(a)	42-001(a)	42	HSWA PM	Incinerator complex.	Decommissioned	3161	Rad, Hazardous Const.	CARBC
42-001(b)	42-001(b)	42-001 (b)	42	HSWA PM	Incinerator complex.	Decommissioned	14	Rad, Hazardous Const.	CARBC

42-001(c)	42-001(c)	42-001(c)	42	HSWA PM	Incinerator complex.	Decommissioned	14	Rad, Hazardous Const.	CARBC
42-002	42-002(a)	42-002(a)	42	AOC/PRS	Decontam. facility	Decommissioned	3161	Rad, Hazardous Const.	CARBC
	42-002(b)	42-002(b)	42	HSWA PM	Decontam. facility	Unknown	14	Rad, Hazardous Const.	CARBC
42-003	42-003	42-003	42	HSWA PM	Septic system	Decommissioned	1573	Rad, Hazardous Const.	CARBC
	42-004	42-004	42	HSWA PM	Canyon disposal	Inactive	0		Rec NFA
	C-42-001	C-42-001	42	AOC/PRS	Canyon side disposal	Inactive	0		Rec NFA
48-001	48-001	48-001	48	AOC/PRS	Air exhaust system	Active	10895	Rad, Hazardous Const.	CARBC
48-002(a)	48-002(a)	48-002(a)	48	HSWA	Container storage area	Inactive	4	Hazardous Const.	CARBC
48-002(b)	48-002(b)	48-002(b)	48	HSWA	Container storage area	Inactive	3	Hazardous Const.	CARBC
	48-002(c)	48-002(c)	48	AOC/PRS	Container storage	Inactive	7	Hazardous Const.	CARBC
	48-002(d)	48-002(d)	48	AOC/PRS	Container storage	Inactive	0		Rec NFA
	48-002(e)	48-002(e)	48	AOC/PRS	Container storage	Inactive	0		Rec NFA
48-003(a)	48-003	48-003	48	HSWA	Septic system	Inactive	532	Rad, Hazardous Const.	CARBC
48-003(b)	48-003	48-003	48	HSWA	Septic system	Inactive	532	Rad, Hazardous Const.	CARBC
48-004(a)	48-004(a)	48-004(a)	48	HSWA PM	Sumps and tanks	Inactive	0		Rec NFA
48-004(b)	48-004(b)	48-004(b)	48	HSWA PM	Sumps and tanks	Inactive	0		Rec NFA
48-004(c)	48-004(c)	48-004(c)	48	HSWA PM	Sumps and tanks	Inactive	0		Rec NFA
48-004(d)	48-004(d)	48-004(d)	48	HSWA PM	Sumps and tanks	Inactive	0		Rec NFA
48-005	48-005	48-005	48	HSWA	Waste lines	Inactive	116	Hazardous Const.	CARBC
48-006	48-006	48-006	48	AOC/PRS	Septic system	Active	0		Rec NFA
	48-007(a)	48-007(a)	48	HSWA PM	Drains and outfalls	Active	116	Hazardous Const.	CARBC
	48-007(b)	48-007(b)	48	HSWA PM	Drains and outfalls	Active	116	Hazardous Const.	CARBC
	48-007(c)	48-007(c)	48	HSWA PM	Drains and outfalls	Active	116	Hazardous Const.	CARBC
	48-007(d)	48-007(d)	48	HSWA PM	Drains and outfalls	Active	93	Hazardous Const.	CARBC
	48-007(e)	48-007(e)	48	HSWA PM	Drains and outfalls	Active	0		Rec NFA
	48-007(f)	48-007(f)	48	HSWA PM	Drains and outfalls	Active	116	Hazardous Const.	CARBC
	48-008	48-008	48	AOC/PRS	Transformer leak	Unknown	0		Rec NFA
	48-009	48-009	48	AOC/PRS	Soil contamination	Active	0		Rec NFA
	48-010	48-010	48	HSWA PM	Surface impoundment	Active	417	Rad, Hazardous Const.	CARBC
		48-011	48	AOC/PRS	Disposal shaft	Inactive	0		Rec NFA
52-001(a)	52-001(a)	52-001(a)	52	HSWA	Uthrex equip.	Decommissioned	0		Rec NFA

52-001(b)	52-001(b)	52-001(b)	52	HSWA	Uthrex equip.	Decommissioned	0		Rec NFA
52-001(c)	52-001(c)	52-001(c)	52	HSWA	Uthrex equip.	Decommissioned	0		Rec NFA
52-001(d)	52-001(d)	52-001(d)	52	HSWA	Uthrex equip.	Inactive	0		Rec NFA
52-002(a)	52-002(a)	52-002(a)	52	HSWA	Septic system	Active	14	Rad, hazardous const.	CARBC
52-002(c)	52-002(b)	52-002(b)	52	HSWA	Septic system	Active	0		Rec NFA
52-002(d)	52-002(c)	52-002(c)	52	HSWA	Septic system	Unknown	0		Rec NFA
52-002(e)	52-002(d)	52-002(d)	52	HSWA	Septic system	Unknown	0		Rec NFA
52-002(f)	52-002(e)	52-002(e)	52	HSWA	Septic system	Active	0		Rec NFA
52-002(h)	52-002(b)	52-002(b)	52	HSWA	Septic system	Active	0		Rec NFA
52-002(i)	52-002(b)	52-002(b)	52	HSWA	Septic system	Active	0		Rec NFA
52-002(j)	52-002(f)	52-002(f)	52	HSWA	Septic system	Active	0		Rec NFA
52-002(k)	63-001(b)	63-001(b)	52	HSWA	Septic system	Active	11	Hazardous Const.	CARBC
	52-002(g)	52-002(g)	52	HSWA PM	Septic system	Active	0		Rec NFA
52-003	52-003	52-003	52	HSWA PM	Waste treatment facility	Decommissioned	0		Rec NFA
52-004	52-004	52-004	52	HSWA PM	Evaporator	Inactive	0		Rec NFA
	C-52-001	C-52-001	52	AOC/PRS	Transformer	Active	0		Rec NFA
	C-52-002	C-52-002	52	AOC/PRS	Transformer	Active	0		Rec NFA
55-001	55-001	55-001	55	AOC/PRS	Cement plant	Active	0		Rec NFA
55-002	55-002(a)	55-002(a)	55	AOC/PRS	Rad waste storage area	Active	0		Rec NFA
55-002	55-002(b)	55-002(b)	55	AOC/PRS	Rad waste storage area	Active	0		Rec NFA
		55-002(c)	55	AOC/PRS	Rad waste storage area	Active	0		Rec NFA
55-003	55-003	55-003	55	AOC/PRS	Containment area	Active	0		Rec NFA
55-004	55-004	55-004	55	AOC/PRS	Evaporator	Active	0		Rec NFA
55-005	55-005	55-005	55	AOC/PRS	Filtration Unit	Active	0		Rec NFA
55-006	55-006	55-006	55	AOC/PRS	Glass Breaker	Active	0		Rec NFA
55-007	55-007	55-007	55	AOC/PRS	Thermal treatment unit	Active	0		Rec NFA
55-008	55-008	55-008	55	HSWA PM	Sumps and tanks	Active	0		Rec NFA
55-009(a)**					**Delisted in 1989				
55-009(b)**					**Delisted in 1989				
55-010	55-009	55-009	55	HSWA PM	Sumps and tanks	Unknown	0		Rec NFA
	55-010	55-010	55	AOC/PRS	Solvent spills	Inactive	1	Rad, Hazardous Const.	CARBC

	55-011(a)	55-011(a)	55	AOC/PRS	Outfall	Active	20	Rad, Hazardous Const.	CARBC
	55-011(b)	55-011(b)	55	AOC/PRS	Outfall	Active	11	Rad, Hazardous Const.	CARBC
	55-011(c)	55-011(c)	55	AOC/PRS	Outfall	Active	9	Rad, Hazardous Const.	CARBC
	55-011(d)	55-011(d)	55	AOC/PRS	Outfall	Active	13	Rad, Hazardous Const.	CARBC
	55-011(e)	55-011(e)	55	AOC/PRS	Outfall	Active	8	Rad, Hazardous Const.	CARBC
	55-012	55-012	55	AOC/PRS	Storage area	Inactive	0		Rec NFA
	55-013(a)	55-013(a)	55	AOC/PRS	Storage area	Active	0		Rec NFA
	55-013(b)	55-013(b)	55	AOC/PRS	Storage area	Active	0		Rec NFA
	63-001(a)	63-001(a)	63	HSWA PM	Septic system	Active	11	Hazardous Const.	CARBC
52-002(k)	63-001(b)	63-001(b)	63	HSWA PM	Septic system	Active	11	Hazardous Const.	CARBC
		63-002	63	AOC/PRS	Container storage	Active	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
36-001	36-001	36-001	36	HSWA	Material disposal area	Inactive	13777	Rad, hazardous const., HE	NFA
36-002	36-002	36-002	36	HSWA	Sump	Active	1	Hazardous const., HE	CARBC
36-003(a)	36-003(a)	36-003(a)	36	HSWA	Septic system	Active	1330	Rad, hazardous const.	IS:1C
36-003(b)	36-003(b)	36-003(b)	36	HSWA	Septic system	Active	0		NFA
36-003(c)	36-003(c)	36-003(c)	36	HSWA	Septic system	Active	0		rec NFA
	36-003(d)	36-003(d)	36	AOC/PRS	Septic system	Active	0		rec NFA
36-004(a)	36-004(a)	36-004(a)	36	AOC/PRS	Firing site	Active	2327	Rad, hazardous const., HE	Def. D&D
36-004(b)	36-004(b)	36-004(b)	36	AOC/PRS	Firing site	Active	2327	Rad, hazardous const., HE	Def. D&D
36-004(c)	36-004(c)	36-004(c)	36	RCRA	Firing site	Active	20943	Rad, hazardous const., HE	Def. D&D
36-004(d)	36-004(d)	36-004(d)	36	AOC/PRS	Firing site	Active	9493	Rad, hazardous const., HE	Def. D&D
36-004(e)	36-004(e)	36-004(e)	36	AOC/PRS	Firing site	Inactive	2327	Rad, hazardous const., HE	Def. D&D
	36-004(f)	36-004(f)	36	AOC/PRS	Firing site	Active	20943	Rad, hazardous const., HE	Def. D&D
36-005	36-005	36-005	36	HSWA	Surface disposal site	Active	833	Rad, hazardous const.	CARBC
36-006	36-006	36-006	36	HSWA PM	Surface disposal site	Inactive	139	Hazardous const.	Def. D&D
36-007(a)	36-007(a)	36-007(a)	36	RCRA	Storage area	Active	0		rec NFA
36-007(b)	36-007(b)	36-007(b)	36	RCRA	Storage area	Active	0		rec NFA
36-007(c)	36-007(c)	36-007(c)	36	RCRA	Storage area	Active	0		rec NFA
36-007(d)	36-007(d)	36-007(d)	36	RCRA	Storage area	Active	0		rec NFA
36-007(e)	36-007(e)	36-007(e)	36	RCRA	Storage area	Active	8	Hazardous const., HE	rec NFA
36-007(f)	36-007(f)	36-007(f)	36	RCRA	Storage area	Inactive	8	Hazardous const., HE	rec NFA
36-008	36-004(c)	36-004(c)		Same as 36-004(c)			0		NFA
0-011(g)	36-009*	27-003	27	Same as 27-003			0		NFA
	C-36-001	C-36-001	36	AOC/PRS	Containment vessel	Inactive	0		Def. D&D
	C-36-002	C-36-002	36	AOC/PRS	Surface disposal	Inactive	0		rec NFA
	C-36-003	C-36-003	36	AOC/PRS	Storm drainages	Active	0		NFA
	C-36-006(e)	C-36-006(e)	36	AOC/PRS	Firing site	Active	2300	Rad, hazardous const., HE	Def. D&D

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
39-001(a)	39-001(a)	39-001(a)	39	HSWA	Landfill	Inactive	20,000	Rad, haz. const., other	CARBC
39-001(b)	39-001(a)	39-001(a)	39						
39-001(c)	39-001(b)	39-001(b)	39	001(c) HSWA	Material disposal area	Inactive	40,000	Rad, haz. const., other	CARBC
39-001(d)	39-001(b)	39-001(b)	39	001(d) HSWA					
39-001(e)	39-001(b)	39-001(b)	39	001(e) HSWA					
39-002(a)	39-002(a)	39-002(a)	39	HSWA	Storage area	Active	0		NFA
39-002(b)	39-007(b)								
39-002(c)	39-007(a)								
39-002(d)	39-002(c)	39-002(c)	39	AOC/PRS	Storage area	Active	0		NFA
39-002(e)	deleted								
39-002(f)	deleted								
39-002(g)	39-007(c)								
39-002(h)	39-007(d)								
	39-002(b)	39-002(b)	39	AOC/PRS	Storage area	Active	0		NFA
	39-002(d)	39-002(d)	39	AOC/PRS	Storage area	Active	0		NFA
	39-002(e)	39-002(e)	39	AOC/PRS	Storage area	Active	0		NFA
	39-002(f)	39-002(f)	39	AOC/PRS	Storage area	Active	0		NFA
	39-002(g)	39-002(g)	39	AOC/PRS	Storage area	Active	0		Rec NFA
39-003	39-003	39-003	39	HSWA	Incinerator	Decommissioned	0		Rec NFA
39-004(a)	39-004(a)	39-004(a)	39	AOC/PRS	Firing site	Inactive	58182	Rad, haz. const., HE, other	Def. D&D
39-004(b)	39-004(b)	39-004(b)	39	AOC/PRS	Firing site	Inactive	58182	Rad, haz. const., HE, other	Def. D&D
39-004(c)	39-004(c)	39-004(c)	39	HSWA	Firing site	Active	58182	Rad, haz. const., HE, other	Def. D&D
39-004(d)	39-004(d)	39-004(d)	39	HSWA	Firing site	Active	58182	Rad, haz. const., HE, other	Def. D&D
39-004(e)	39-004(e)	39-004(e)	39	HSWA	Firing site	Active	58182	Rad, haz. const., HE, other	Def. D&D
39-005	39-005	39-005	39	HSWA PM	Seepage pit	Decommissioned	1140	Hazardous const., HE	CARBC
39-006(a)	39-006(a)	39-006(a)	39	HSWA	Septic system	Active	448	Hazardous const.	CARBC
39-006(b)	39-006(b)	39-006(b)	39	HSWA	Septic system	Active	0		Rec NFA
39-002(c)	39-007(a)	39-007(a)	39	AOC/PRS	Storage area	Inactive	0		NFA
39-002(b)	39-007(b)	39-007(b)	39	AOC/PRS	Storage area	Inactive	0		Rec NFA

39-002(g)	39-007(c)	39-007(c)	39	AOC/PRS	Storage area	Inactive	0	Rec NFA
39-002(h)	39-007(d)	39-007(d)	39	AOC/PRS	Storage area	Inactive	0	NFA
	39-007(e)	39-007(e)	39	AOC/PRS	Storage area	Inactive	0	Rec NFA
	39-008	39-008	39	AOC/PRS	Firing range	Inactive	0	NFA
	39-009	39-009	39	AOC/PRS	Outfall	Active	0	Rec NFA
	C-39-001	C-39-001	39	AOC/PRS	One-time spill	Removed	0	NFA
	C-39-002	C-39-002	39	AOC/PRS	One-time spill	Removed	0	NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
43-001	43-001(a)	43-001(a)	43	001 HSWA	Waste lines	Inactive	0		NFA
	43-001(b)	43-001(b)	43	AOC/PRS	Outfall	Inactive	0		NFA
43-002	43-002	43-002	43	HSWA PM	Incinerator	Active	4	Rad, hazardous const.	Def. D&D
43-003	43-003	43-003	43	AOC/PRS	Storage	Active	0		NFA
43-004	43-004	43-004	43	AOC/PRS	Storage	Active	0		NFA
	43-005	43-005	43	AOC/PRS	Aboveground tank	Active	0		NFA
	C-43-001	C-43-001	43	AOC/PRS	Storm drainage	Active	0		NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
46-001	46-001	46-001	46	AOC/PRS	Aboveground tank	Inactive	0		Rec NFA
46-002	46-002	46-002	46	HSWA	Surface impoundment	Active	378	Rad, haz. const., other	CARBC
46-003(a)	46-003(a)	46-003(a)	46	HSWA	Septic system	Inactive	0		NFA
46-003(b)	46-003(b)	46-003(b)	46	HSWA	Septic system	Inactive	0		NFA
46-003(c)	46-003(c)	46-003(c)	46	HSWA	Septic system	Inactive	0		NFA
46-003(d)	46-003(d)	46-003(d)	46	HSWA	Septic system	Inactive	7	Rad, haz. const., other	CARBC
46-003(e)	46-003(e)	46-003(e)	46	HSWA	Septic system	Inactive	0		NFA
46-003(f)	46-003(f)	46-003(f)	46	HSWA	Septic system	Inactive	0		NFA
46-003(g)	46-003(g)	46-003(g)	46	HSWA	Septic system	Active	0		NFA
	46-003(h)	46-003(h)	46	HSWA PM	Operational release	Active	0		NFA
46-004(a)	46-004(a)	46-004(a)	46	HSWA	Waste line	Inactive	0		Rec NFA
		46-004(a2)	46	HSWA PM	Outfall	Active	0		NFA
46-004(b)	46-004(b)	46-004(b)	46	HSWA	Operational release	Inactive	0		Rec NFA
		46-004(b2)	46	HSWA PM	Operational release	Active	0		NFA
46-004(c)	46-004(c)	46-004(c)	46	HSWA	Sump	Active	117	Rad, haz. const., other	CARBC
		46-004(c2)	46	HSWA PM	Outfall	Active	0		NFA
46-004(d)	46-004(d)	46-004(d)	46	HSWA	Sump	Active	58	Rad, haz. const., other	CARBC
		46-004(d2)	46	HSWA PM	Stack emissions	Inactive	0		NFA
46-004(e)	46-004(e)	46-004(e)	46	HSWA	Sump	Active	58	Rad, haz. const., other	CARBC
46-004(f)	46-004(f)	46-004(f)	46	HSWA	Outfall	Active	0		NFA
46-004(g)	46-004(g)	46-004(g)	46	HSWA	Outfall/Stack Emissions	Act./Inactive	0		NFA
46-004(h)	46-004(h)	46-004(h)	46	HSWA	Outfall/Stack Emissions	Act./Inactive	0		NFA
	46-004(i)	46-004(i)	46	HSWA PM	Outfall	Inactive	0		Rec NFA
	46-004(j)	46-004(j)	46	HSWA PM	Outfall	Active	0		Rec NFA
	46-004(k)	46-004(k)	46	AOC/PRS	Outfall	Active	0		Rec NFA
	46-004(l)	46-004(l)	46	HSWA PM	Outfall	Inactive	0		Rec NFA
	46-004(m)	46-004(m)	46	HSWA PM	Outfall	Active	0		NFA
	46-004(n)	46-004(n)	46	AOC/PRS	Outfall	Inactive	0		Rec NFA
	46-004(o)	46-004(o)	46	AOC/PRS	Outfall	Active	0		Rec NFA

		46-004(p)	46	HSWA PM	Sump	Active	1	Hazardous const., other	CARBC
		46-004(q)	46	HSWA PM	Outfall	Unknown	0		NFA
		46-004(r)	46	HSWA PM	Outfall	Inactive	0		NFA
		46-004(s)	46	HSWA PM	Outfall	Active	0		NFA
		46-004(t)	46	HSWA PM	Outfall	Active	0		NFA
		46-004(u)	46	HSWA PM	Outfall	Active	0		NFA
		46-004(v)	46	HSWA PM	Outfall	Active	0		NFA
		46-004(w)	46	HSWA PM	Outfall	Active	0		NFA
		46-004(x)	46	HSWA PM	Outfall	Active	0		NFA
		46-004(y)	46	HSWA PM	Outfall	Active	0		NFA
		46-004(z)	46	HSWA PM	Outfall	Active	0		NFA
46-005	46-005	46-005	46	HSWA	Surface impoundment	Active	0		NFA
46-006(a)	46-006(a)	46-006(a)	46	HSWA	Operational release	Inactive	0		NFA
46-006(b)	46-006(b)	46-006(b)	46	HSWA	Operational release	Inactive	0		NFA
46-006(c)	46-006(c)	46-006(c)	46	HSWA	Operational release	Inactive	0		NFA
46-006(d)	46-006(d)	46-006(d)	46	HSWA	Operational release	Inactive	0		NFA
		46-006(e)	46	AOC/PRS	Surface Disposal	Active	0		Rec NFA
		46-006(f)	46	HSWA PM	Storage area	Active	0		NFA
		46-006(g)	46	HSWA PM	Operational Release	Active	0		NFA
46-007	46-007	46-007	46	HSWA	Operational Release	Inactive	0		NFA
46-008(a)	46-008(a)	46-008(a)	46	HSWA	Storage area	Inactive	0		NFA
46-008(b)	46-008(b)	46-008(b)	46	HSWA	Storage area	Inactive	0		NFA
46-008(c)	46-008(c)	46-008(c)	46	HSWA	Storage area	Inactive	0		Rec NFA
46-008(d)	46-008(d)	46-008(d)	46	HSWA	Storage area	Inactive	0		NFA
46-008(e)	46-008(e)	46-008(e)	46	HSWA	Storage area	Inactive	0		NFA
46-008(f)	46-008(f)	46-008(f)	46	HSWA	Storage area	Inactive	0		NFA
	46-008(g)	46-008(g)	46	HSWA PM	Storage area	Inactive	0		NFA
	46-008misc	46-008misc	46	AOC/PRS	Storage area	Inactive	0		Rec NFA
46-009	46-009(a)	46-009(a)	46	HSWA PM	Surface disposal	Inactive	0		NFA
	46-009(b)	46-009(b)	46	HSWA PM	Surface disposal	Inactive	0		NFA
	46-010(a)	46-010(a)	46	AOC/PRS	Storage area	Active	0		Rec NFA

46-010(b)	46-010(b)	46	AOC/PRS	Storage area	Inactive	0	Rec NFA
46-010(c)	46-010(c)	46	AOC/PRS	Storage area	Active	0	Rec NFA
46-010(d)	46-010(d)	46	HSWA PM	Operation release	Active	0	NFA
46-010(e)	46-010(e)	46	AOC/PRS	Storage area	Active	0	Rec NFA
46-010(f)	46-010(f)	46	AOC/PRS	Storage area	Active	0	Rec NFA
46-010misc	46-010misc	46	AOC/PRS	Storage area	Inactive	0	Rec NFA
C-46-001	C-46-001	46	AOC/PRS	One-time spill	Inactive	0	NFA
C-46-002	C-46-002	46	AOC/PRS	Stack Emissions	Inactive	0	NFA
C-46-003	C-46-003	46	AOC/PRS	Stack Emissions	Inactive	0	NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
49-001	49-001(a)	49-001(a)	49	001HSWA	Material disposal area	Inactive	3307	Rad, hazardous const., HE	IS:IC
	49-001(b)	49-001(b)	49	HSWA PM	Surface disposal area	Inactive	6732	Rad, hazardous const., HE	CARBC
	49-001(c)	49-001(c)	49	001HSWA	Material disposal area	Inactive	1686	Rad, hazardous const., HE	IS:IC
	49-001(d)	49-001(d)	49	001HSWA	Material disposal area	Inactive	2257	Rad, hazardous const., HE	IS:IC
	49-001(e)	49-001(e)	49	HSWA PM	Surface disposal area	Inactive	5557	Rad, hazardous const., HE	CARBC
	49-001(f)	49-001(f)	49	HSWA PM	Surface disposal area	Inactive	5580	Rad, hazardous const., HE	CARBC
	49-001(g)	49-001(g)	49	001HSWA	Material disposal area	Inactive	2581	Rad, hazardous const., HE	IS:IC
	49-001misc	49-001misc	49	001HSWA	Material disposal area	Inactive	1	Rad, hazardous const., HE	IS:IC
49-002	49-002	49-002	49	AOC/PRS	Operational facility	Inactive	404	Rad, hazardous const.	CARBC
49-003	49-003	49-003	49	HSWA	Leach field	Inactive	807	Rad, hazardous const.	CARBC
49-004	49-004	49-004	49	HSWA PM	Burn site and landfill	Inactive	5000	Hazardous const.	CARBC
49-005(a)	49-005(a)	49-005(a)	49	HSWA PM	Landfill	Inactive	4444	Hazardous const.	CARBC
49-005(b)	49-005(b)	49-005(b)	49	AOC/PRS	Landfill	Inactive	5	Hazardous const.	CARBC
49-006	49-006	49-006	49	HSWA PM	Sump	Inactive	19	Hazardous const.	CARBC
49-007(a)	49-007(a)	49-007(a)	49	AOC/PRS	Septic system	Active	0		Rec NFA
49-007(b)	49-007(b)	49-007(b)	49	AOC/PRS	Septic system	Active	0		Rec NFA
	49-008(a)	49-008(a)	49	AOC/PRS	Soil contamination	Inactive	33	Rad, hazardous const.	CARBC
	49-008(b)	49-008(b)	49	AOC/PRS	Soil contamination	Inactive	39	Rad, hazardous const.	CARBC
	49-008(c)	49-008(c)	49	AOC/PRS	Soil contamination	Inactive	6	Rad, hazardous const.	CARBC
	49-008(d)	49-008(d)	49	AOC/PRS	Firing sites	Inactive	18	Rad, hazardous const., HE	CARBC
	49-009	49-009	49	AOC/PRS	Underground tank	Decommissioned	37	Hazardous const.	CARBC

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
50-001	50-001(a)	50-001(a)	50	001HSWA	Waste treatment facility	Active	10962	Rad, hazardous const.	CARBC
	50-001(b)	50-001(b)	50	AOC/PRS	Waste lines and manholes	Active	77	Rad, hazardous const.	CARBC
50-002(a)	50-002(a)	50-002(a)	50	HSWA	Underground tanks	Active	954	Rad, hazardous const.	CARBC
50-002(c)	50-002(b)	50-002(b)	50	002(c) HSWA	Underground tank	Active	15	Rad, hazardous const.	CARBC
50-002(d)	50-002(c)	50-002(c)	50	002(d) HSWA	Underground tank	Active	15	Rad, hazardous const.	CARBC
	50-002(d)	50-002(d)	50	AOC/PRS	Underground tank	Active	34	Hazardous const.	CARBC
50-003(a)	50-003(a)	50-003(a)	50	AOC/PRS	Storage area	Active	163	Rad, hazardous const.	Def D&D
50-003(b)	50-003(b)	50-003(b)	50	RCRA	Storage area	Active	0		Rec NFa
50-003(c)	50-003(c)	50-003(c)	50	RCRA	Storage area	Active	0		Rec NFA
50-003(d)	50-003(d)	50-003(d)	50	RCRA	Storage area	Active	0		Rec NFA
50-003(e)	50-003(e)	50-003(e)	50	RCRA	Storage area	Inactive	0		Rec NFA
50-004	50-004(a)	50-004(a)	50	004HSWA	Waste lines	Decommissioned	4	Rad, hazardous const.	CARBC
50-002(b)	50-004(b)	50-004(b)	50	002(b)HSWA	Underground tanks	Decommissioned	37	Rad, hazardous const.	CARBC
	50-004(c)	50-004(c)	50	HSWA PM	Waste lines	Decommissioned	26	Rad, hazardous const.	CARBC
50-005	50-005	50-005	50	RCRA	Waste treatment facility	Active	0		Rec NFA
50-006	50-006(a)	50-006(a)	50	006HSWA	Operational release	Active	86	Rad, hazardous const.	CARBC
	50-006(b)	50-006(b)	50	AOC/PRS	Operational release	Decommissioned	0		Rec NFA
50-006	50-006(c)	50-006(c)	50	006HSWA	Operational release	Active	963	Rad, hazardous const.	CARBC
50-006	50-006(d)	50-006(d)	50	006HSWA	Effluent discharge	Active	20575	Rad, hazardous const.	CARBC
	50-006(e)	50-006(e)	50	AOC/PRS	Aboveground tank	Decommissioned	0		Rec NFA
50-007	50-007	50-007	50	RCRA	Incinerator	Active	0		NFA
50-008	50-008	50-008	50	RCRA	Reduction site	Active	0		NFA
50-009	50-009	50-009	50	HSWA	Material disposal area	Inactive	135185	Rad, hazardous const.	IS:IC
50-010	50-010	50-010	50	AOC/PRS	Decontamination facility	Active	367	Rad, hazardous const.	Def D&D
50-011(a)	50-011(a)	50-011(a)	50	HSWA	Septic system	Decommissioned	22	Rad, hazardous const.	CARBC
50-011(b)	50-011(a)	50-011(a)	50	HSWA	Septic system	Decommissioned	22	Rad, hazardous const.	CARBC
50-011(c)	50-011(a)	50-011(a)	50	HSWA	Septic system	Decommissioned	22	Rad, hazardous const.	CARBC
	50-011(b)	50-011(b)	50	AOC/PRS	Septic system	Active	5	Rad, hazardous const.	Def D&D
	50-011misc.	50-011misc.			Does not exist		0		NFA

C-50-001	C-50-001	50	AOC/PRS	Transformer	Active	0	NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
51-001	51-001	51-001	51	AOC/PRS	Septic system	Active	1	Hazardous const.	CARBC
51-002(a)	51-002(a)	51-002(a)	51	AOC/PRS	Usage site	Active	0		Rec NFA
51-002(b)	51-002(b)	51-002(b)	51	AOC/PRS	Usage site	Active	0		Rec NFA
	C-51-001	C-51-001	51	AOC/PRS	Storage area	Active	0		Rec NFA
	C-51-002	C-51-002	51	AOC/PRS	Buildings	Removed	0		Rec NFA
54-001(a)	54-001(a)	54-001(a)	54	HSWA	Storage area	Active	15	Hazardous const.	Def. D&D
54-001(b)	54-001(b)	54-001(b)	54	AOC/PRS	Storage area	Active	8	Hazardous const.	Def. D&D
54-001(c)	54-001(c)	54-001(c)	54	HSWA	Storage area	Inactive	0		Rec NFA
54-001(d)	54-001(d)	54-001(d)	54	AOC/PRS	Storage area	Active	59	Hazardous const., other	Def. D&D
54-001(e)	54-001(e)	54-001(e)	54	AOC/PRS	Storage area	Active	111	Hazardous const.	Def. D&D
	54-001(f)	54-001(f)	54	AOC/PRS	Storage area	Active	0		Rec NFA
54-002	54-002	54-002	54	AOC/PRS	Storage area	Active	7	Hazardous const.	Def. D&D
54-003(a)	54-003(a)	54-003(a)			deleted in SWMU report, addressed as 54-014, 54-017, 54-018, and 54-019.				NFA
54-004	54-004	54-004	54	HSWA	Material disposal area, except sh.	Inactive	432	Rad, hazardous const., HE	IS;IC
54-005	54-005	54-005	54	HSWA	Material disposal area	Active	14154	Rad, haz. const., HE, other	IS;IC
54-006	54-006	54-006	54	HSWA	Material disposal area	Inactive	20067	Rad, haz. const., HE, other	IS;IC
54-007(a)	54-007(a)	54-007(a)	54	HSWA	Septic system	Active	40	Rad, hazardous const.	IS;IC
54-007(b)	54-007(b)	54-007(b)	54	HSWA	Septic system	Active	0		Rec NFA
54-007(c)	54-007(c)	54-007(c)	54	HSWA	Septic system	Active	36	Hazardous const.	CARBC
	54-007(d)	54-007(d)	54	AOC/PRS	Septic system	Active	14	Hazardous const.	CARBC
	54-007(e)	54-007(e)	54	AOC/PRS	Septic system	Active	22	Hazardous const.	CARBC
	54-007misc	54-007misc	54		Unit does not exist		0		NFA
54-008	54-008	54-008	54	AOC/PRS	Underground tank	Active	0		Rec NFA
54-009	54-009	54-009	54	**RCRA PM**	Aboveground tank	Active	6	Hazardous const.	Def. D&D
54-010	54-010	54-010	54	AOC/PRS	Underground tank	Active	0		Rec NFA
54-012	54-012(a)	54-012(a)	54	AOC/PRS	Reduction site	Active	1	Rad, hazardous const.	CARBC
	54-012(b)	54-012(b)	54	HSWA PM	Reduction site	Active	4	Hazardous const.	CARBC
54-013	54-013(a)	54-013(a)	54	013 HSWA	Decontamination facility	Inactive	0		Rec NFA
	54-013(b)	54-013(b)	54	HSWA PM	Disposal Pit	Inactive	56	Rad, hazardous const.	IS:IC

	54-014(a)	54-014(a)	54	AOC/PRS	Storage shafts	Active	438	Rad, hazardous const.	Def. D&D
	54-014(b)	54-014(b)	54	HSWA PM	Storage pit	Active	28000	Rad, hazardous const.	CARBC
	54-014(c)	54-014(c)	54	HSWA PM	Storage shafts	Active	227	Rad, hazardous const.	CARBC
	54-014(d)	54-014(d)	54	HSWA PM	Storage trenches	Active	8316	Rad, hazardous const.	CARBC
	54-014misc	54-014misc	54		Unit does not exist		0		NFA
	54-015(a)	54-015(a)	54	AOC/PRS	Storage area	Active	5	Rad	CARBC
	54-015(b)	54-015(b)	54	AOC/PRS	Storage area	Active	5	Rad	CARBC
	54-015(c)	54-015(c)	54	AOC/PRS	Storage area	Active	4016	Rad	CARBC
	54-015(d)	54-015(d)	54	AOC/PRS	Storage area	Active	1931	Rad	CARBC
	54-015(e)	54-015(e)	54	AOC/PRS	Storage area	Active	4016	Rad	CARBC
	54-015(f)	54-015(f)	54	AOC/PRS	Storage area	Active	2273	Rad	CARBC
	54-015(g)	54-015(g)	54	AOC/PRS	Storage area	Inactive	0		Rec NFA
54-003(b)	54-015(h)	54-015(h)	54	003(b)HSWA	Storage area	Active	0		Rec NFA
	54-015(i)	54-015(i)	54	AOC/PRS	Storage area	Inactive	0		Rec NFA
	54-015(j)	54-015(j)	54	AOC/PRS	Storage area	Active	267	Rad, hazardous const.	CARBC
	54-015(k)	54-015(k)	54	AOC/PRS	Storage area	Active	574	Rad	CARBC
	C-54-001	54-016(a)	54	AOC/PRS	Sump	Active	0		Rec NFA
	54-016(b)	54-016(b)	54	AOC/PRS	Sump	Active	1	Rad, hazardous const.	CARBC
	54-017	54-017	54	HSWA PM	Disposal pits	Inactive	107713	Rad, hazardous const., HE	IS:IC
	54-017misc	54-017misc	54		Unit does not exist		0		NFA
	54-018	54-018	54	**HSWA PM**	Disposal pits	Active	104987	Rad, haz. const., other	IS:IC
	54-019	54-019	54	HSWA PM	Disposal shafts	Inactive	318	Rad, hazardous const.	IS:IC
	54-019misc	54-019misc	54		Unit does not exist		0		NFA
	54-020	54-020	54	**HSWA PM**	Disposal shafts	Active	1435	Rad, haz. const., other	IS:IC
	54-020misc	54-020misc	54		Unit does not exist		0		NFA
	54-021	54-021	54	AOC/PRS	Aboveground tank	Inactive	0		Rec NFA
	54-022	54-022	54	AOC/PRS	Transformer	Decommissioned	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
57-001(a)	57-001(a)	57-001(a)	57	AOC/PRS	Surface impoundment	Decommissioned	0		Rec NFA
57-001(b)	57-001(b)	57-001(b)	57	AOC/PRS	Surface impoundment	Decommissioned	300		CARBC
57-001(c)	57-001(c)	57-001(c)	57	AOC/PRS	Surface impoundment	Decommissioned	300		CARBC
57-002	57-002	57-002	57	AOC/PRS	Landfill	Active	6667	Hazardous const.	CARBC
57-003	57-003	57-003	57	AOC/PRS	Storage area	Active	0		Rec NFA
57-004	57-004(a)	57-004(a)	57	AOC/PRS	Surface impoundment	Active	300		CARBC
	57-004(b)	57-004(b)	57	AOC/PRS	Surface impoundment	Active	356	Hazardous const.	Def. D&D
57-005	57-005	57-005	57	AOC/PRS	Filter system	Active	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
8-001(a)	8-001(a)	8-001(a)	8	AOC/PRS	Buildings	Abandoned	19	Rad, hazardous const., HE	Def. D&D
8-001(b)	8-001(b)	8-001(b)	8	AOC/PRS	Buildings	Abandoned	4	Rad, hazardous const., HE	Def. D&D
8-002	8-002	8-002	8	HSWA	Firing site	Decommissioned	185	Rad, hazardous const.	CARBC
8-003(a)	8-003(a)	8-003(a)	8	HSWA	Septic system	Inactive	13	Hazardous const., HE	CARBC
8-003(b)	8-003(b)	8-003(b)	8	HSWA	Septic system	Inactive	0		Rec NFA
8-003(c)	8-003(c)	8-003(c)	8	HSWA	Septic system	Inactive	0		Rec NFA
8-004(a)	8-004(a)	8-004(a)	8	HSWA	Floor drain	Abandoned	1	Rad, hazardous const.	Def. D&D
8-004(b)	8-004(b)	8-004(b)	8	HSWA	Drain line	Abandoned	1	Rad, hazardous const.	Def. D&D
8-004(c)	8-004(c)	8-004(c)	8	HSWA	Floor drain	Abandoned	16	Rad, hazardous const.	Def. D&D
8-004(d)	8-004(d)	8-004(d)	8	HSWA	Drain	Active	1	Rad	CARBC
8-005	8-005	8-005	8	HSWA PM	Container storage area	Inactive	3	Hazardous const.	CARBC
8-006(a)	8-006(a)	8-006(a)	8	HSWA	Landfill	Inactive	356	Rad, hazardous const.	IS;IC
8-006(b)	8-006(b)	8-006(b)	8	HSWA	Landfill	Inactive	0		Rec NFA
8-007	8-007	8-007	8	HSWA	Silver recovery unit	Removed	0		Rec NFA
	8-008(a)	8-008(a)	8	AOC/PRS	Storage area	Removed	0		Rec NFA
	8-008(b)	8-008(b)	8	AOC/PRS	Storage area	Removed	0		Rec NFA
	8-008(c)	8-008(c)	8	AOC/PRS	Storage area	Removed	0		Rec NFA
	8-008(d)	8-008(d)	8	AOC/PRS	Storage area	Removed	0		Rec NFA
	8-009(a)	8-009(a)	8	HSWA PM	Ind. or san. wastewater treat.	Active	20	Hazardous const.	CARBC
	8-009(b)	8-009(b)	8	HSWA PM	Ind. or san. wastewater treat.	Active	0		Rec NFA
	8-009(c)	8-009(c)	8	AOC/PRS	Storm drain and outfall	Active	13	Hazardous const.	CARBC
	8-009(d)	8-009(d)	8	HSWA PM	Ind. or san. wastewater treat.	Active	1	Hazardous const.	CARBC
	8-009(e)	8-009(e)	8	HSWA PM	Ind. or san. wastewater treat.	Active	1	Hazardous const.	CARBC
		8-009(f)	8	AOC/PRS	Outfall	Active	10	Hazardous const.	CARBC
	8-010(a)	8-010(a)	8	AOC/PRS	Storage area	Active	0		Rec NFA
	8-010(b)	8-010(b)	8	AOC/PRS	Storage area	Active	0		Rec NFA
	8-010(c)	8-010(c)	8	AOC/PRS	Storage area	Active	0		Rec NFA
	8-011(a)	8-011(a)	8	AOC/PRS	Underground tank	Decommissioned	0		Rec NFA
	8-011(b)	8-011(b)	8	AOC/PRS	Underground tank	Decommissioned	0		Rec NFA

	C-8-001	C-8-001	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-002	C-8-002	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-003	C-8-003	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-004	C-8-004	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-005	C-8-005	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-006	C-8-006	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-007	C-8-007	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-008	C-8-008	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-009	C-8-009	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-010	C-8-010	8	AOC/PRS	Building	Removed	10	Hazardous const.	CARBC
	C-8-011	C-8-011	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-012	C-8-012	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-013	C-8-013	8	AOC/PRS	Building	Removed	0		Rec NFA
	C-8-014	C-8-014	8	AOC/PRS	Laboratory	Active	5	Hazardous const.	Def. D&D
	C-8-015	C-8-015	8	AOC/PRS	Building	Inactive	0		Rec NFA
	C-8-016	C-8-016	8	AOC/PRS	Building	Active	0		Rec NFA
	C-8-017	C-8-017	8	AOC/PRS	Storage area	Active	0		Rec NFA
	C-8-018	C-8-018	8	AOC/PRS	Storage area	Active	0		Rec NFA
	C-8-019	C-8-019	8	AOC/PRS	Storage area	Active	0		Rec NFA
	C-8-020	C-8-020	8	AOC/PRS	Disposal area	Inactive	0		Rec NFA
9-001(a)	9-001(a)	9-001(a)	9	HSWA PM	Firing sites	Decommissioned	24	Rad, hazardous const., HE	CARBC
9-001(b)	9-001(b)	9-001(b)	9	HSWA PM	Firing sites	Decommissioned	36	Rad, hazardous const., HE	CARBC
9-001(c)	9-001(c)	9-001(c)	9	HSWA PM	Firing sites	Decommissioned	43	Rad, hazardous const., HE	CARBC
9-001(d)	9-001(d)	9-001(d)	9	HSWA PM	Firing sites	Decommissioned	37	Rad, hazardous const., HE	CARBC
9-002	9-002	9-002	9	HSWA PM	Burn pit	Decommissioned	89	Rad, hazardous const., HE	CARBC
9-003(a)	9-003(a)	9-003(a)	9	HSWA	Settling tank	Decommissioned	2	Rad, hazardous const., HE	CARBC
9-003(b)	9-003(b)	9-003(b)	9	HSWA	Settling tank	Decommissioned	2	Rad, hazardous const., HE	CARBC
9-003(c)	9-003(c)	9-003(c)	9	HSWA	Electric manhole	Decommissioned	0		Rec NFA
9-003(d)	9-003(d)	9-003(d)	9	HSWA	Settling tank	Decommissioned	7	Hazardous const., HE	CARBC
9-003(e)	9-003(e)	9-003(e)	9	HSWA	Settling tank	Decommissioned	3	Hazardous const., HE	CARBC
9-003(f)	9-003(f)	9-003(f)	9	HSWA	Settling tank	Decommissioned			Rec NFA

	9-003(g)	9-003(g)	9	HSWA PM	Settling tank	Decommissioned	2	Hazardous const., HE	CARBC
	9-003(h)	9-003(h)	9	HSWA PM	Settling tank	Decommissioned	2	Hazardous const., HE	CARBC
	9-003(i)	9-003(i)	9	HSWA PM	Settling tank	Decommissioned	2	Hazardous const., HE	CARBC
9-004(a)	9-004(a)	9-004(a)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(b)	9-004(b)	9-004(b)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(c)	9-004(c)	9-004(c)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(d)	9-004(d)	9-004(d)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(e)	9-004(e)	9-004(e)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(f)	9-004(f)	9-004(f)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(g)	9-004(g)	9-004(g)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(h)	9-004(h)	9-004(h)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(i)	9-004(i)	9-004(i)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(j)	9-004(j)	9-004(j)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(k)	9-004(k)	9-004(k)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(l)	9-004(l)	9-004(l)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(m)	9-004(m)	9-004(m)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(n)	9-004(n)	9-004(n)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-004(o)	9-004(o)	9-004(o)	9	HSWA	Settling tank	Active	7	Hazardous const., HE	Def. D&D
9-005(a)	9-005(a)	9-005(a)	9	HSWA	Septic system	Removed	8	Hazardous const., HE	CARBC
9-005(b)	9-005(b)	9-005(b)	9	HSWA	Septic system	Inactive	0		Rec NFA
9-005(c)	9-005(c)	9-005(c)	9	HSWA	Septic system	Inactive	0		Rec NFA
9-005(d)	9-005(d)	9-005(d)	9	HSWA	Septic system	Inactive	20	Hazardous const., HE	CARBC
9-005(e)	9-005(e)	9-005(e)	9	HSWA	Septic system	Inactive	0		Rec NFA
9-005(f)	9-005(f)	9-005(f)	9	HSWA	Septic system	Inactive	0		Rec NFA
9-005(g)	9-005(g)	9-005(g)	9	HSWA	Septic system	Active	0		Rec NFA
9-005(h)	9-005(h)	9-005(h)	9	HSWA	Septic system	Inactive	0		Rec NFA
9-006	9-006	9-006	9	HSWA	Septic system	Decommissioned	5	Rad, haz. const, HE	CARBC
9-007	9-007	9-007	9	HSWA	Basket pit	Inactive	0		Rec NFA
	9-008(a)	9-008(a)	9	AOC/PRS	Surface impoundment	Inactive	0		Rec NFA
9-008	9-008(b)	9-008(b)	9	008HSWA	Surface impoundment	Inactive	217	Rad	CARBC
9-009	9-009	9-009	9	HSWA	Surface impoundment	Inactive	627	Rad	CARBC

9-010	9-010(a)	9-010(a)	9	AOC/PRS	Storage area	Inactive	7	Hazardous const., HE	CARBC
	9-010(b)	9-010(b)	9	AOC/PRS	Storage area	Removed	13	Hazardous const., HE	CARBC
	9-010(c)	9-010(c)	9	AOC/PRS	Storage area	Inactive	0		Rec NFA
9-011(a)	9-011(a)	9-011(a)	9	AOC/PRS	Storage area	Removed	0		Rec NFA
9-011(b)	9-011(b)	9-011(b)	9	AOC/PRS	Storage area	Inactive	1	Hazardous const., HE	CARBC
9-011(c)	9-011(c)	9-011(c)	9	AOC/PRS	Storage area	Inactive	1	Hazardous const., HE	CARBC
9-012	9-012	9-012	9	AOC/PRS	Disposal pit	Inactive	1111	Rad, hazardous const., HE	CARBC
0-009	9-013	9-013	9	009HSWA	Material disposal area	Inactive	576	Rad, haz. const., HE, other	IS:IC
23-001	9-014	9-014	9	AOC/PRS	Firing site	Decommissioned	70	Hazardous const., HE	CARBC
23-002	9-015	9-015	9	AOC/PRS	Manhole	Decommissioned	0		Rec NFA
	9-016	9-016	9	AOC/PRS	Underground tank	Decommissioned	0		Rec NFA
	C-9-001	C-9-001	9	AOC/PRS	Soil contamination	Active	370	Hazardous const.	CARBC
	C-9-002	C-9-002	9	AOC/PRS	Buildings	Removed	0		Rec NFA
	C-9-003	C-9-003	9	AOC/PRS	Buildings	Removed	0		Rec NFA
	C-9-004	C-9-004	9	AOC/PRS	Building	Removed	0		Rec NFA
	C-9-005	C-9-005	9	AOC/PRS	Building	Removed	0		Rec NFA
	C-9-006	C-9-006	9	AOC/PRS	Buildings	Removed	0		Rec NFA
	C-9-007	C-9-007	9	AOC/PRS	Building	Removed	0		Rec NFA
	C-9-008	C-9-008	9	AOC/PRS	Underground tank	Removed	0		Rec NFA
	C-9-009	C-9-009	9	AOC/PRS	Non-intentional release	Active	0		Rec NFA
	C-9-010	C-9-010	9	AOC/PRS	Burn site	Inactive	0		Rec NFA
	C-9-011	C-9-011	9	AOC/PRS	Burn site	Inactive	0		Rec NFA
0-013	69-001	69-001	69	HSWA PM	Incinerator and assoc. equip.	Inactive	1852	Hazardous const.	CARBC
0-XXX	69-002(a)	69-002(a)	69	AOC/PRS	Septic system	Active	0		Rec NFA
	69-002(b)	69-002(b)	69	AOC/PRS	Septic system	Active	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (YD3)	Potential Contaminants	Potential Remediation
10-001(a)	10-001(a)	10-001(a)	10	HSWA	Firing Site	Decommissioned	162963	Rad, HE, hazardous const.	CARBC
10-001(b)	10-001(b)	10-001(b)	10	HSWA	Firing Site	Decommissioned	162963	Rad, HE, hazardous const.	CARBC
10-001(c)	10-001(c)	10-001(c)	10	HSWA	Firing Site	Decommissioned	162963	Rad, HE, hazardous const.	CARBC
10-001(d)	10-001(d)	10-001(d)	10	HSWA	Firing Site	Decommissioned	162963	Rad, HE, hazardous const.	CARBC
	10-001(e)	10-001(e)	10	AOC/PRS	Firing Site	Decommissioned	0		Rec NFA
10-002(a)	10-002(a)	10-002(a)	10	HSWA	Disposal pit	Decommissioned	30	Rad, hazardous const.	CARBC
10-002(b)	10-002(b)	10-002(b)	10	HSWA	Disposal pit	Decommissioned	56	Rad, hazardous const.	CARBC
10-003(a)	10-003(a)	10-003(a)	10	HSWA	Disposal pit	Decommissioned	30	Rad, hazardous const.	CARBC
10-003(b)	10-003(b)	10-003(b)	10	HSWA	Disposal pit	Decommissioned	30	Rad, hazardous const.	CARBC
10-003(c)	10-003(c)	10-003(c)	10	HSWA	Disposal pit	Decommissioned	30	Rad, hazardous const.	CARBC
	10-003(d)	10-003(d)	10	HSWA PM	Disposal pit	Decommissioned	30	Rad, hazardous const.	CARBC
	10-003(e)	10-003(e)	10	HSWA PM	Disposal pit	Decommissioned	30	Rad, hazardous const.	CARBC
	10-003(f)	10-003(f)	10	HSWA PM	Disposal pit	Decommissioned	30	Rad, hazardous const.	CARBC
10-003(d)	10-003(g)	10-003(g)	10	HSWA	Manholes	Decommissioned	1	Rad, hazardous const.	CARBC
10-003(e)	10-003(h)	10-003(h)	10	HSWA	Manholes	Decommissioned	1	Rad, hazardous const.	CARBC
10-003(f)	10-003(i)	10-003(i)	10	HSWA	Septic tank	Decommissioned	1	Rad, hazardous const.	CARBC
	10-003(j)	10-003(j)	10	HSWA PM	Tank	Decommissioned	1	Rad, hazardous const.	CARBC
	10-003(k)	10-003(k)	10	HSWA PM	Tank	Decommissioned	1	Rad, hazardous const.	CARBC
	10-003(l)	10-003(l)	10	HSWA PM	Tank	Decommissioned	1	Rad, hazardous const.	CARBC
	10-003(m)	10-003(m)	10	HSWA PM	Waste line	Decommissioned	2	Rad, hazardous const.	CARBC
	10-003(n)	10-003(n)	10	HSWA PM	Leach field	Decommissioned	19	Rad, hazardous const.	CARBC
	10-003(o)	10-003(o)	10	HSWA PM	Leach field	Decommissioned	1	Rad, hazardous const.	CARBC
10-004(a)	10-004(a)	10-004(a)	10	HSWA	Septic system	Decommissioned	0		NFA
10-004(b)	10-004(b)	10-004(b)	10	HSWA	Septic system	Decommissioned	17	Rad, hazardous const.	CARBC
10-005	10-005	10-005	10	HSWA PM	Surface disposal	Decommissioned	4	Rad, hazardous const.	CARBC
10-006	10-006	10-006	10	HSWA	Burn site	Inactive	0		Rec NFA
10-007	10-007	10-007	10	HSWA PM	Landfill	Inactive	7407	Hazardous const.	CARBC
31-001	31-001	31-001	31	HSWA	Septic system	Decommissioned	0		NFA
	C-31-001	C-31-001	31	AOC/PRS	Buildings	Removed	0		Rec NFA

32-001	32-001	32-001	32	HSWA PM	Incinerator	Decommissioned	0		NFA
32-002(a)	32-002(a)	32-002(a)	32	HSWA	Septic tank	Inactive	0		NFA
32-002(b)	32-002(b)	32-002(b)	32	HSWA	Septic tank	Inactive	0		NFA
	C-32-001	C-32-001	32	AOC/PRS	Buildings	Removed	0		Rec NFA
45-001	45-001	45-001	45	HSWA	Waste water treatment facility	Decommissioned	26	Rad, HE, hazardous const.	CARBC
45-002	45-002	45-002	45	HSWA	Decontamination facility	Decommissioned	2	Rad,HE, hazardous const.	CARBC
45-003	45-003	45-003	45	HSWA	Waste lines	Decommissioned	3058	Rad, hazardous const.	CARBC
	45-004	45-004	45	HSWA PM	Soil contam. area	Inactive	0		NFA
	C-45-001	C-45-001	45	AOC/PRS	Generator site	Removed	111	Rad, hazardous const.	CARBC
1-002	1-002	1-002	45	HSWA	Outfall TA1 SWMU to be in TA45	Decommissioned	24925	Rad, hazardous const.	CARBC

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
0-001	0-001	0-001	0	HSWA	Surface impoundments	Active	8418	Rad, hazardous const.	IS;IC
	C-0-001	C-0-001	0	AOC/PRS	Canyon	Active	278000	HE, hazardous const.	CARBC
	C-0-002	C-0-002	0	AOC/PRS	Canyon	Active	31500	HE, hazardous const.	CARBC
	C-0-003	C-0-003	0	AOC/PRS	Canyon	Active	48900	HE, hazardous const.	CARBC
	C-0-004	C-0-004	0	AOC/PRS	Canyon	Active	685240	Rad, hazardous const.	CARBC
	C-0-005	C-0-005	0	AOC/PRS	Canyon	Active	703760	Rad, hazardous const.	CARBC
	C-0-006	C-0-006	0	AOC/PRS	Canyon	Active	1148240	Rad, hazardous const.	CARBC
	C-0-007	C-0-007	0	AOC/PRS	Canyon	Active	533376	Rad, hazardous const.	CARBC
	C-0-008	C-0-008	0	AOC/PRS	Canyon	Active	870440	Rad, hazardous const.	CARBC
	C-0-009	C-0-009	0	AOC/PRS	Canyon	Active	704000	Rad, hazardous const., HE	CARBC
	C-0-010	C-0-010	0	AOC/PRS	Canyon	Active	207424	Rad, hazardous const., HE	CARBC
	C-0-011	C-0-011	0	AOC/PRS	Canyon	Active	1074160	Rad, hazardous const.	CARBC
	C-0-012	C-0-012	0	AOC/PRS	Canyon	Active	107000	Rad, hazardous const., HE	CARBC
	C-0-013	C-0-013	0	AOC/PRS	Canyon	Active	629680	Rad, hazardous const.	CARBC
	C-0-014	C-0-014	0	AOC/PRS	Canyon	Active	333000	Rad, hazardous const., HE	CARBC
	C-0-015	C-0-015	0	AOC/PRS	Canyon	Active	194000	Rad, hazardous const., HE	CARBC
	C-0-016	C-0-016	0	AOC/PRS	Canyon	Active	1185280	Rad, hazardous const., HE	CARBC
	C-0-017	C-0-017	0	AOC/PRS	Canyon	Active	342000	Rad, hazardous const., HE	CARBC
	C-0-018	C-0-018	0	AOC/PRS	Canyon	Active	296000	Rad, hazardous const., HE	CARBC
	C-0-019	C-0-019	0	AOC/PRS	Canyon	Active	185000	Rad, hazardous const., HE	CARBC

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
0-003	0-003	0-003	0	HSWA	Container storage	Decommissioned	0		NFA
0-004	0-004	0-004	0	RCRA	Container storage	Active	0		NFA
0-005	0-005	0-005	0	HSWA	Landfill	Inactive	0		Rec NFA
0-007	73-001(a)	73-001(a)	73	007HSWA	Landfill	Inactive	1070	Rad, haz. const., HE, other	IS;IC
0-007	73-001(b)	73-001(b)	73	HSWA PM	Surface disposal site	Inactive	0	Hazardous const., other	CARBC
0-008	0-008	0-008	0	AOC/PRS	Surface disposal site	Inactive	0		Rec NFA
0-010	73-005	73-005	73	HSWA PM	Surface disposal site	Inactive	0		NFA
	0-010(a)	0-010(a)	0	AOC/PRS	Surface disposal site	Inactive	0		Rec NFA
		0-010(b)	0	AOC/PRS	Surface disposal site	Decommissioned	0		NFA
0-011(a)	0-011(a)	0-011(a)	0	HSWA PM	Mortar impact area	Inactive	0		NFA
0-011(b)	0-011(b)*				*RFI states 0-011(b) & (e) are the same, therefore 0-011(b) was eliminated.				
0-011(c)	0-011(c)	0-011(c)	0	HSWA PM	Mortar impact area	Inactive	0		NFA
0-011(d)	0-011(d)	0-011(d)	0	HSWA PM	Mortar impact area	Inactive	0		NFA
0-011(e)	0-011(e)	0-011(e)	0	HSWA PM	Mortar impact area	Inactive	0		NFA
0-012	0-012	0-012	0	HSWA	Underground tank	Decommissioned	0		NFA
0-014	73-002	73-002	73	0-014HSWA	Incinerator & surface disposal	Inactive	800	Hazardous const.	CARBC
0-015(b)	0-015	0-015	0	AOC/PRS	Firing range	Active	0		Rec NFA
0-016	0-016	0-016	0	HSWA PM	Firing range	Inactive	100	Hazardous const.	CARBC
0-017	0-017	0-017	0	HSWA	Waste lines	Inactive	283	Rad, hazardous const.	CARBC
0-018(a)	deleted in 90 because it never received Lab waste								
0-018(b)	0-018(a)	0-018(a)	0	AOC/PRS	Wastewater treatment plant	Inactive	2800	Rad, hazardous const.	CARBC
0-018(c)	0-018(b)	0-018(b)	0	AOC/PRS	Wastewater treatment plant	Active	0		NFA
0-019	0-019	0-019	0	HSWA PM	Wastewater treatment plant	Decommissioned	0		NFA
0-020	73-003	73-003	73	AOC/PRS	Operational facility	Decommissioned	0		NFA
0-021(a)	73-004(a)	73-004(a)	73	HSWA PM	Septic tank	Inactive	0		NFA
0-021(b)	73-004(b)	73-004(b)	73	HSWA PM	Septic tank	Inactive	0		NFA
	0-024	0-024	0	AOC/PRS	Cistern	Inactive	0		Rec NFA
	0-025	0-025	0	AOC/PRS	Landfill	Inactive	0		Rec NFA
	0-026	0-026	0	AOC/PRS	Landfill	Inactive	0		Rec NFA

0-027	0-027	0	AOC/PRS	Storage area	Inactive	0	Hazardous const.	CARBC
0-028(a)	0-028(a)	0	AOC/PRS	Effluent discharge	Inactive	0		NFA
0-028(b)	0-028(b)	0	AOC/PRS	Effluent discharge	Inactive	0		NFA
0-029(a)	0-029(a)	0	AOC/PRS	Transformer	Decommissioned	0		NFA
0-029(b)	0-029(b)	0	AOC/PRS	Transformer	Decommissioned	0		NFA
0-029(c)	0-029(c)	0	AOC/PRS	Transformer	Decommissioned	0		NFA
0-030(a)	0-030(a)	0	HSWA PM	Septic system	Inactive	0		NFA
0-030(b)	0-030(b)	0	HSWA PM	Septic system	Inactive	1600	Rad, hazardous const.	CARBC
0-030(c)	0-030(c)	0	AOC/PRS	Septic system	Inactive	20	Hazardous const.	CARBC
0-030(d)	0-030(d)	0	AOC/PRS	Septic system	Inactive	0		NFA
0-030(e)	0-030(e)	0	AOC/PRS	Septic system	Inactive	300	Hazardous const.	CARBC
0-030(f)	0-030(f)	0	AOC/PRS	Septic system	Inactive	300	Hazardous const.	CARBC
0-030(g)	0-030(g)	0	HSWA PM	Septic system	Inactive	0		NFA
0-030(h)	0-030(h)	0	AOC/PRS	Septic system	Inactive	0		NFA
0-030(i)	0-030(i)	0	AOC/PRS	Septic system	Inactive	300	Hazardous const.	CARBC
0-030(j)	0-030(j)	0	AOC/PRS	Septic system	Inactive	0		NFA
0-030(k)	0-030(k)	0	AOC/PRS	Septic system	Inactive	0		NFA
0-030(l)	0-030(l)	0	HSWA PM	Septic system	Inactive	300	Hazardous const.	CARBC
0-030(m)	0-030(m)	0	HSWA PM	Septic system	Inactive	300	Hazardous const.	CARBC
	0-030(n)	0	AOC/PRS	Septic system	Inactive	0		NFA
	0-030(o)	0	AOC/PRS	Septic system	Inactive	0		NFA
	0-030(p)	0	AOC/PRS	Septic system	Inactive	0		NFA
	0-030(q)	0	AOC/PRS	Septic system	Inactive	300	Hazardous const.	CARBC
0-031(a)	0-031(a)	0	AOC/PRS	Soil contamination beneath struc.	Removed	0	Hazardous const.	CARBC
0-031(b)	0-031(b)	0	AOC/PRS	Soil contamination beneath struc.	Inactive	230	Hazardous const.	CARBC
0-032	0-032	0	AOC/PRS	Operational facility	Inactive	0	Hazardous const.	CARBC
0-033	0-033	0	HSWA PM	Warehouses	Inactive	0		NFA
	0-034(a)	0	AOC/PRS	Landfill	Inactive	0		NFA
	0-034(b)	0	AOC/PRS	Landfill	Inactive	0		NFA
	0-035(a)	0	AOC/PRS	Surface disposal	Inactive	0		Rec NFA
C-0-020	C-0-020	0	AOC/PRS	Mortar impact area	Inactive	0		NFA

19-001	19-001	19-001	19	HSWA	Septic system	Inactive	300	Hazardous const.	CARBC
19-002	19-002	19-002	19	HSWA PM	Surface disposal site	Inactive	74	Hazardous const.	CARBC
	19-003	19-003	19	HSWA PM	Septic tank	Inactive	0		NFA
	C-19-001	C-19-001	19	AOC/PRS	Soil contamination	Removed	0		NFA
26-001	26-001	26-001	26	HSWA PM	Surface disposal site	Inactive	111	Rad, hazardous const.	CARBC
26-002	26-002(a)	26-002(a)	26	HSWA PM	Tank and/or assoc. equip.	Decommissioned	50	Rad, hazardous const.	CARBC
	26-002(b)	26-002(b)	26	HSWA PM	Ind. or san. waste water treat.	Decommissioned	50	Rad, hazardous const.	CARBC
26-003	26-003	26-003	26	HSWA PM	Septic tank	Decommissioned	100	Rad, hazardous const.	CARBC
	73-001(c)	73-001(c)	73	HSWA PM	Landfill	Inactive	0	Hazardous const., HE	IS;IC
	73-001(d)	73-001(d)	73	HSWA PM	Landfill	Inactive	0	Hazardous const.	IS;IC
	73-004(c)	73-004(c)	73	HSWA PM	Septic tank	Inactive	0		NFA
	73-004(d)	73-004(d)	73	HSWA PM	Septic tank	Inactive	0		NFA
	73-006	73-006	73	HSWA PM	Ind. or san. waste water treat.	Inactive	0		NFA
	C-73-001	C-73-001	73	AOC/PRS	Underground tank	Decommissioned	0		Rec NFA
	C-73-002	C-73-002	73	AOC/PRS	Underground tank	Decommissioned	0		Rec NFA
	C-73-003	C-73-003	73	AOC/PRS	Underground tank	Decommissioned	0		Rec NFA
	C-73-004	C-73-004	73	AOC/PRS	Underground tank	Decommissioned	0		Rec NFA

1988 #	1990 #	Current Yr	TA	Class	Site Type	Status	Waste Volume (Yd3)	Potential Contaminants	Potential Remediation
1-001(a)	1-001(a)	1-001(a)	1	HSWA	Septic tank 134	Inactive	0		NFA
1-001(b)	1-001(b)	1-001(b)	1	HSWA	Septic tank 135	Inactive	0		NFA
1-001(c)	1-001(c)	1-001(c)	1	HSWA	Septic tank 137	Inactive	10	Rad, hazardous const.	CARBC
1-001(d)	1-001(d)	1-001(d)	1	HSWA	Septic tank 138	Inactive	10	Rad, hazardous const.	CARBC
1-001(e)	1-001(e)	1-001(e)	1	HSWA	Septic tank 139	Inactive	6	Rad, hazardous const.	CARBC
1-001(f)	1-001(f)	1-001(f)	1	HSWA	Septic tank 140	Inactive	10	Rad, hazardous const.	CARBC
1-001(g)	1-001(g)	1-001(g)	1	HSWA	Septic tank 141	Inactive	0		NFA
1-001(h)	1-001(h)	1-001(h)	1	HSWA	Septic tank 142	Inactive	0		Rec NFA
1-001(i)	1-001(i)	1-001(i)	1	HSWA	Septic tank 143	Inactive	0		Rec NFA
1-001(j)	1-001(j)	1-001(j)	1	HSWA	Septic tank 149	Inactive	0		Rec NFA
1-001(k)	1-001(k)	1-001(k)	1	HSWA	Septic tank 268	Inactive	0		Rec NFA
1-001(l)	1-001(l)	1-001(l)	1	HSWA	Septic tank 269	Inactive	0		Rec NFA
1-001(m)	1-001(m)	1-001(m)	1	HSWA	Septic tank 275	Inactive	0		NFA
1-001(n)	1-001(n)	1-001(n)	1	HSWA	Septic tank 276	Inactive	0		Rec NFA
	1-001(o)	1-001(o)	1	AOC/PRS	Ind. or san. waste water treat.	Inactive	0		NFA
	1-001(p)	1-001(p)	1	AOC/PRS	Septic system	Inactive	0		Rec NFA
	1-001(q)	1-001(q)	1	AOC/PRS	Septic system	Inactive	0		Rec NFA
	1-001(r)	1-001(r)	1	AOC/PRS	Septic system	Inactive	0		Rec NFA
	1-001(s)	1-001(s)	1	**HSWA PM**	Septic system	Inactive	29	Rad, hazardous const.	CARBC
	1-001(t)	1-001(t)	1	**HSWA PM**	Septic system	Inactive	24	Rad, hazardous const.	CARBC
	1-001(u)	1-001(u)	1	**HSWA PM**	Septic system	Inactive	2	Rad, hazardous const.	CARBC
	1-001(v)	1-001(v)	1	AOC/PRS	Septic system	Inactive	0		Rec NFA
	1-001(w)	1-001(w)	1	AOC/PRS	Septic system	Inactive	0		Rec NFA
1-002	1-002	1-002	1	HSWA	Waste lines and outfall	Decommissioned	4000	Rad, hazardous const.	CARBC
1-003	1-003(a)	1-003(a)	1	1-003 HSWA	Landfill	Inactive	15000	Rad, hazardous const.	CARBC
	1-003(b)	1-003(b)	1	AOC/PRS	Surface disposal site	Inactive	0		NFA
	1-003(c)	1-003(c)	1	AOC/PRS	Surface disposal site	Inactive	0		NFA
	1-003(d)	1-003(d)	1	AOC/PRS	Surface disposal site	Inactive	0		NFA
	1-003(e)	1-003(e)	1	AOC/PRS	Surface disposal site	Inactive	0		NFA

1-004(a)	1-004(a)	1-004(a)	1	AOC/PRS	Incinerator	Decommissioned	0		Rec NFA
1-004(b)	1-004(b)	1-004(b)	1	AOC/PRS	Incinerator	Decommissioned	0		Rec NFA
1-005	1-005	1-005	1	AOC/PRS	Incinerator	Decommissioned	0		Rec NFA
	1-006(a)	1-006(a)	1	AOC/PRS	Drain lines & outfall	Inactive	0		NFA
	1-006(a)	1-006(b)	1	HSWA PM	Drain lines & outfall	Inactive	10	Rad, hazardous const.	CARBC
	1-006(a)	1-006(c)	1	**HSWA PM**	Drain lines and outfall	Inactive	10	Rad, hazardous const.	CARBC
	1-006(a)	1-006(d)	1	**HSWA PM**	Drain lines and outfall	Inactive	10	Rad, hazardous const.	CARBC
	1-006(a)	1-006(e)	1	AOC/PRS	Drain lines and outfall	Inactive	0		NFA
	1-006(b)	1-006(f)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(g)	1	AOC/PRS	Drain lines and outfall	Inactive	0		NFA
	1-006(b)	1-006(h)	1	**HSWA PM**	Drain lines and outfall	Inactive	10	Rad, hazardous const.	CARBC
	1-006(b)	1-006(i)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(j)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(k)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(l)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(m)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(n)	1	**HSWA PM**	Drain lines and outfall	Inactive	5	Rad, hazardous const.	CARBC
	1-006(b)	1-006(o)	1	**HSWA PM**	Drain lines and outfall	Inactive	5	Rad, hazardous const.	CARBC
	1-006(b)	1-006(p)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(q)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(r)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(s)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-006(b)	1-006(t)	1	AOC/PRS	Drain lines and outfall	Inactive	0		Rec NFA
	1-007(a)	1-007(a)	1	**HSWA PM**	Soil contamination area	Decommissioned	50	Rad, hazardous const.	CARBC
	1-007(a)	1-007(b)	1	HSWA PM	Soil contamination area	Decommissioned	50	Rad, hazardous const.	CARBC
	1-007(a)	1-007(c)	1	**HSWA PM**	Soil contamination area	Decommissioned	50	Rad, hazardous const.	CARBC
	1-007(b)	1-007(d)	1	**HSWA PM**	Soil contamination area	Decommissioned	5	Rad, hazardous const.	CARBC
	1-007(b)	1-007(e)	1	**HSWA PM**	Soil contamination area	Decommissioned	5	Rad, hazardous const.	CARBC
	1-007(b)	1-007(f)	1	AOC/PRS	Soil contamination area	Decommissioned	0		Rec NFA
	1-007(b)	1-007(g)	1	AOC/PRS	Soil contamination area	Decommissioned	0		Rec NFA
	1-007(b)	1-007(h)	1	AOC/PRS	Soil contamination area	Decommissioned	0		Rec NFA

1-007(b)	1-007(i)	1	AOC/PRS	Soil contamination area	Decommissioned	0		Rec NFA
1-007(b)	1-007(j)	1	**HSWA PM**	Soil contamination area	Decommissioned	1	Rad, hazardous const.	CARBC
1-007(b)	1-007(k)	1	AOC/PRS	Soil contamination area	Decommissioned	0		NFA
1-007(a)	1-007(l)	1	**HSWA PM**	Soil contamination area	Decommissioned	5	Rad, hazardous const.	CARBC
1-007(b)	1-007(m)	1	AOC/PRS	Soil contamination area	Decommissioned	0		Rec NFA
1-007(b)	1-007(n)	1	AOC/PRS	Soil contamination area	Decommissioned	0		Rec NFA
1-007(b)	1-007(o)	1	AOC/PRS	Soil contamination area	Decommissioned	0		Rec NFA
1-007(b)	1-007(p)	1	AOC/PRS	Soil contamination area	Decommissioned	0		Rec NFA

■ APPENDIX G

Observational Approach to Environmental Restoration

1.0 INTRODUCTION

1.1 Purpose and Scope

This appendix summarizes the observational approach to geotechnical engineering and describes how this approach can be applied to the Environmental Restoration (ER) Program at Los Alamos National Laboratory (the Laboratory). The observational approach is a major component of the Laboratory's streamlined approach for environmental restoration. The example case study is intended to illustrate the philosophy, general approach, and thought processes involved in the observational approach so that it can be adapted for use in remediating operable units (OUs) at the Laboratory as required by the Resource Conservation and Recovery Act (RCRA).

1.2 Overview of the Observational Approach

A flexible observational approach to remediating waste sites has been endorsed in concept by the US National Research Council (1989, 0387), the Department of Energy (DOE) (1990, 0079), and the Environmental Protection Agency (EPA) (1989, 0300). The observational approach described here is based on the observational method, which is a technique used by geotechnical engineers to manage uncertain surface designs. The observational method was first formalized by Karl Terzaghi (Peck 1969, 0369; Dunnicliff and Deere 1984, 0279). More recently, others (Wallace 1987, 0391; 1988, 0392; Sturges et al. 1988, 0380; Mark et al. 1989, 0350; Myers and Gianti 1989, 0355; Duplanic and Buckle 1989, 0280) have discussed the application of the observational method to remediation of waste sites.

The philosophy of the observational approach as it applies to waste remediation is that remedial action can and should be initiated without a "full" (that is, overly detailed) description of the nature and extent of contamination. Its use is based on the following observations, drawn from geotechnical engineering experience, from EPA, and from other experience with early environmental restoration efforts:

- Inherent uncertainties in waste remediation cannot be completely eliminated.
- Protracted investigations and characterization studies do little to reduce inherent uncertainties at waste sites.
- Confidence in any remediation effort is achieved only through field verification and monitoring of the waste site during and following remediation.

The observational approach, which provides a logical and effective approach to planning, designing, and implementing remedial actions, includes the following components:

- conducting sufficient characterization (investigation, modeling, etc.) to provide a general understanding of probable conditions and reasonable deviations (the appropriate level of site characterization is indicated by the historic uses of the site and the technologies proposed for remediation);

- evaluating all remedial alternatives based on probable site conditions;
- continuing site characterization until remaining reasonable deviations from probable conditions can be addressed by contingency plans incorporated in the remedial alternative that is optimal under the probable conditions;
- selecting a remedial alternative based on the probable conditions and planning and designing contingency plans to address reasonable deviations;
- selecting physical and chemical parameters to be monitored at the waste site to confirm probable conditions or to detect anticipated deviations;
- calculating or estimating the value of these physical and chemical parameters (e.g., hydraulic conductivity and contaminant concentrations) for the waste site expected during remediation both for the probable conditions and for all reasonable deviations;
- constructing and implementing the remedial design based on probable conditions;
- monitoring the selected physical and chemical parameters to identify deviations; and
- modifying the remedial action according to prepared contingency plans in response to the occurrence of deviations.

1.3 Overview of the General Case Example

The hypothetical example described in this appendix illustrates how the observational approach might apply to a potential release site (PRS) at the Laboratory. The relationship between the RCRA corrective action program and the observational approach is illustrated in the generalized decision diagram (Figure G-1), which defines the steps in the corrective action process when the observational approach is used. The steps of the RCRA process [i.e., RCRA facility assessment (RFA), RCRA facility investigation (RFI), corrective measures study (CMS), and corrective measures implementation (CMI)] are shown with the approximate corresponding portions of the decision diagram. Although these steps appear as discrete phases in many discussions of the RCRA process, they are actually closely interrelated and should not be treated as merely sequential components of the process. The interrelationship is shown in the decision diagram. For example, obtaining site characterization data is typically thought of as part of the RFA/RFI; however, additional site characterization data could be required in any part of the corrective action program. Indeed, in using the observational approach, action is initiated as soon as sufficient data are available. Additional data are expected to be collected at later stages of the corrective action process.

In this appendix, a hypothetical case that includes some of the measures the Laboratory expects to use for remediation is analyzed according to the process shown in the Figure G-1. The example begins with a description of a conceptual

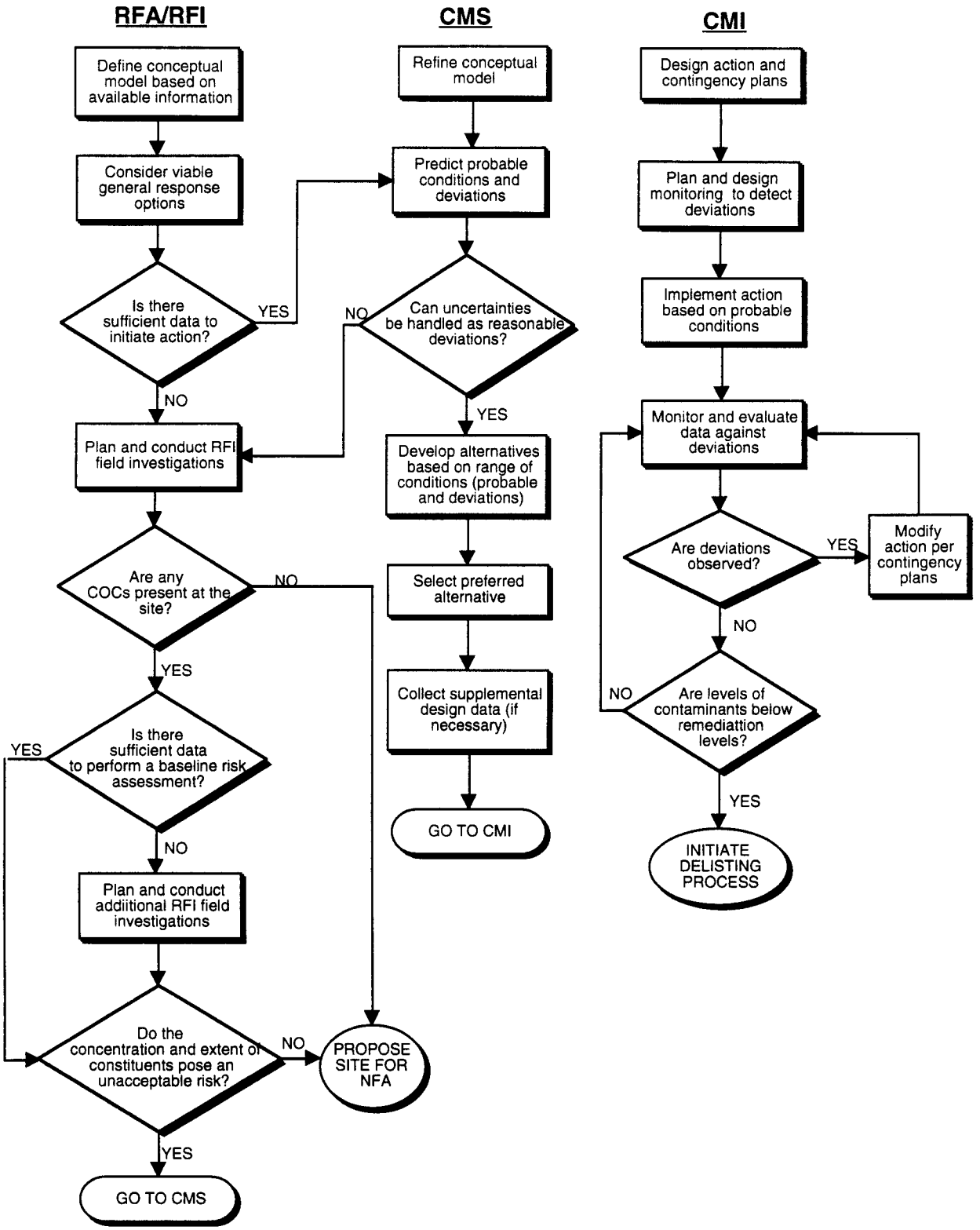

Figure G-1. Generalized decision diagram of the observational approach.

exposure model based on existing information and progresses through the corrective action process as described by the decision diagram. The case example is organized as sections that correspond approximately to the steps of the RCRA process.

The visible benefits of using the observational approach to site remediation at the Laboratory vary considerably, depending on site-specific conditions, and, in some cases, the benefits are not visible at all. For instance, the results of using the observational approach to clean up firing sites may not differ visibly from the results obtained without using the observational approach. Therefore, it is important to recognize the intangible benefits of the thought process inherent in the observational approach (i.e., recognizing that uncertainty exists, obtaining sufficient data, identifying probable conditions and reasonable deviations, and preparing contingency plans). Using this approach in every case is important because, without it, it is not possible to know whether existing data are sufficient to identify probable conditions and reasonable deviations that might occur and how to respond to them.

2.0 GENERAL CASE EXAMPLE

This example is intended to illustrate how the observational approach could be applied to planning and implementing remediation of material disposal areas (MDAs) and landfills at the Laboratory.

2.1 RCRA Facility Assessment/RCRA Facility Investigation

2.1.1 Facility Description

MDAs at the Laboratory typically contain a wide range of hazardous wastes and low-level radioactive wastes (LLW) (i.e., mixed wastes). Both solid and liquid wastes have been disposed in pits, trenches, adsorption beds, and shafts at MDAs. In general, the Laboratory sited the MDAs on mesa tops adjacent to technical areas.

The hypothetical MDA examined in this case example was identified as a PRS during the RFA. The MDA covers about 5 acres and is located on a mesa top (Figure G-2). A thin layer of soil on the mesa top covers low-permeability, fractured, welded tuff. Groundwater is approximately 1,000 ft beneath the mesa top. During the

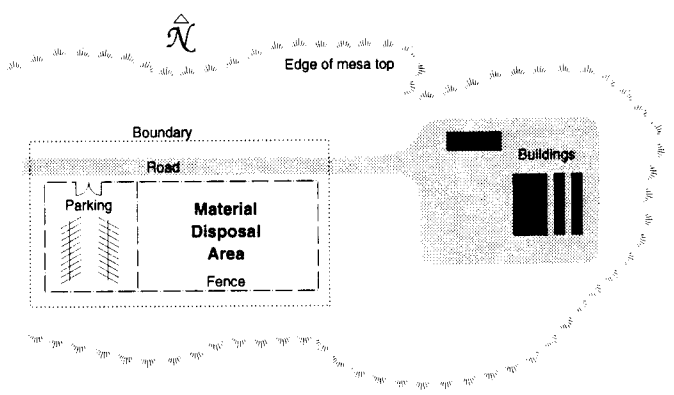

Figure G-2. Hypothetical case example.

summer, short, intense thunderstorms commonly cause surface run-off that may carry topsoil into the adjacent canyon. In addition, persistent erosion of surface soils is occurring at the southern edge of the mesa top. The eroded soil from the southern edge and possibly soil suspended in run-off could be transported into the adjacent canyon. Environmental monitoring records indicate that the canyon has ephemeral streamflow during thunderstorms.

Laboratory records show that radioactive solid waste and hazardous wastes consisting of liquids and corrosive gases were disposed at this MDA in the late 1940s. The MDA consists of a pit and trenches. It is not clear whether the pit is actually a series of separate pits or is one large pit that was expanded as necessary. The pit covers most of the MDA's surface area. The western portion of the MDA (which included some of the inactive pit area) was leased to the county in the 1960s and was subsequently paved with asphalt for use as parking space. Wastes buried in the pits are thought to consist primarily of solid LLW (e.g., contaminated clothing, pumps) generated during ordinary Laboratory operations. Solid waste known to be located at the MDA includes one truck contaminated with fission products and various isotopes of plutonium, polonium, uranium, americium, curium, and actinium. Trenches of an unknown number and size are thought to be located along the eastern edge of the MDA. Bottles disposed in the trenches are thought to contain various mixtures of unknown volatile organic chemicals and corrosive gases. There is no indication that contaminant migration has occurred at the MDA, nor is there any known surface or groundwater contamination.

The RFA determined that portions of the MDA contained concentrations of volatile organics that exceeded the action levels defined by EPA's interim RFI guidance (EPA 1989, 0088). Because of a lack of data, it was not possible to assess the levels of other possible mixed-waste contaminants. However, in anticipation that the RFI would lead EPA to require a CMS for the volatile organics, the Laboratory requested and received the designation of the entire MDA as a PRS.

2.1.2 Development of the Conceptual Model

Based on existing knowledge, a conceptual exposure model of the MDA was developed to identify possible contaminant sources, release mechanisms, contaminated media, migration pathways, and receptors. During this process, sources, pathways, and contaminated media determined to be unlikely candidates were screened out. The resulting conceptual model (Figure G-3) identifies the probable conditions at the site based on available data, information, and technical judgment at that time.

The conceptual exposure model of the MDA identified three possible contaminant sources: the pit(s) used for solid waste, the trenches used for bottled liquids and corrosive gases, and the paved portion of the MDA. Probable release mechanisms from these sources include unsaturated flow and transport, volatilization of organics, and erosion of surface soils. These release mechanisms may result in contamination of biota, vadose zone soils, surface soils, and air. Migration of the contaminants can occur through the vadose zone soils, surface soils, overland run-off, and air. The contamination could reach human and environmental receptors through direct dermal contact with soil, biota, and air; ingestion of soil, biota, and air; and inhalation of air. It is assumed that contaminant migration to the groundwater is not a concern because depth to the water table is more than 1,000 ft.

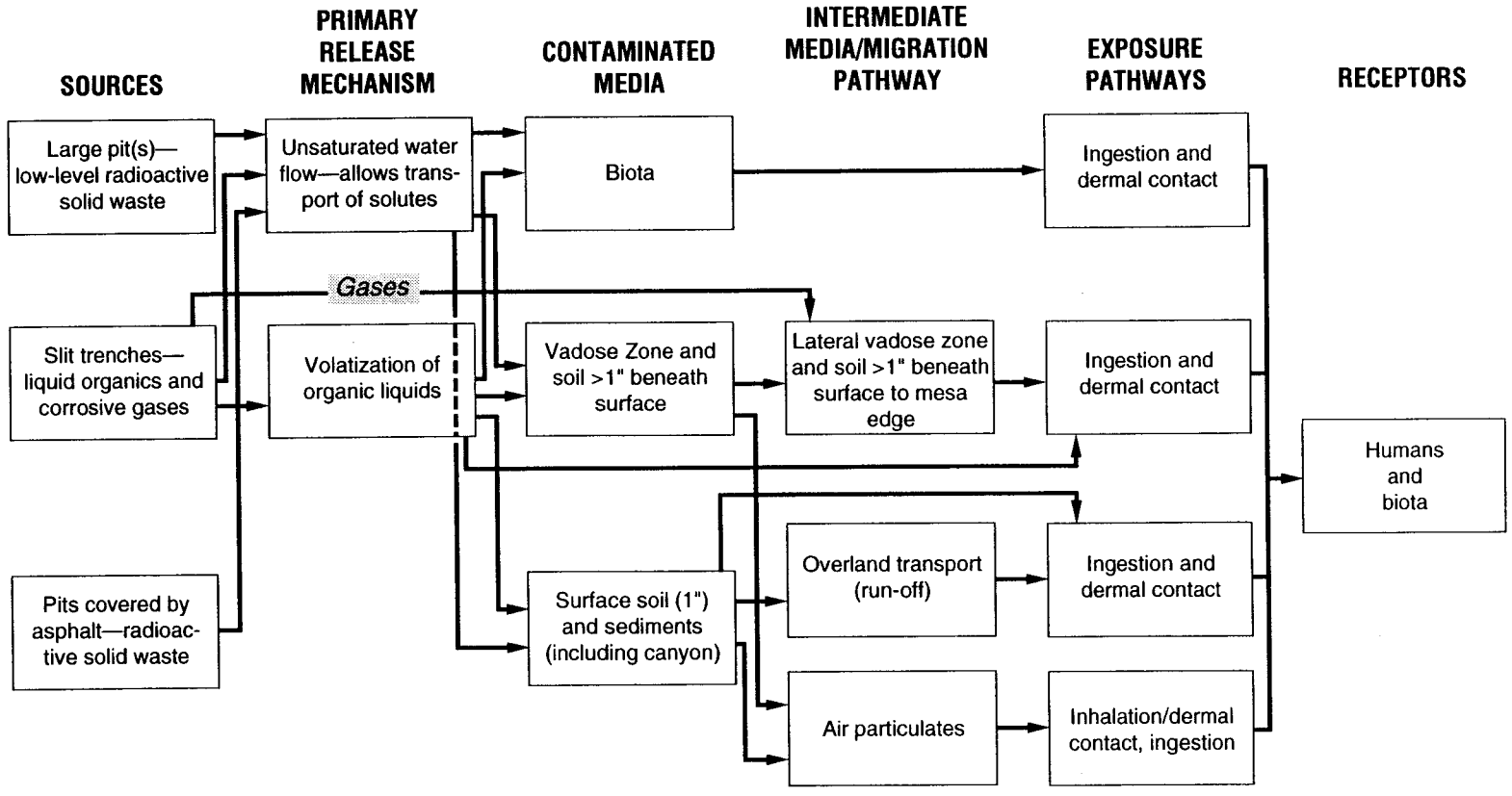

Figure G-3. Conceptual model of case example.

The conceptual model identified the following probable conditions:

- Surface soils and the upper part of the vadose zone have been contaminated by volatile organics to concentrations above action levels.
- During storms, run-off causes contaminant concentrations in the soils at the southern edge of the mesa to exceed action levels.
- Contaminant concentration levels in the air are below action levels.
- Because the ambient vadose zone moisture is extremely low, there is little opportunity for solid waste to migrate. Evidence obtained from other MDAs supports this assumption.
- Contaminants do not migrate to the groundwater because the distance to the water table is so great.
- The source term, which probably includes organic liquids, volatile organics, corrosive gases, and LLW, and which covers a large area, is very complex and dangerous.

Major uncertainties in the conceptual exposure model are

- the extent of lateral and vertical movement of volatile organics,
- the extent of contamination of the mesa's southern edge and the canyon,
- the nature of the chemicals, and
- the volume of liquid in the sources.

2.2 RCRA Facility Investigation/Corrective Measures Study

2.2.1 Screening Viable Responses

Even though there are uncertainties in the conceptual model that must be addressed, preliminary screening of responses based on existing data is possible and appropriate. The following responses are technically feasible and potentially appropriate for this MDA:

- institutional control (fencing, deed control),
- removal (excavation and disposal at an approved landfill),
- containment (capping, slurry walls), and
- in-situ treatment (vapor extraction, in-situ vitrification, stabilization).

Removal and certain in-situ treatments (such as in-situ vitrification) of volatile organics require extensive knowledge and, therefore, sampling of the source term. Because of the physical hazards associated with sampling the source term, these options were eliminated. For this MDA, the preferred response will probably consist of a combination of the remaining responses (i.e., institutional control in conjunction with containment and appropriate in-situ treatment).

2.2.2 Sampling and Analysis Plans

To identify the appropriate combination of corrective actions, it is necessary to refine the conceptual model. Uncertainties in the conceptual model include the location, size, and number of pits and trenches and the types of contaminants. Further evaluation of the general responses cannot be conducted until these uncertainties have been reduced. The goal is to reduce uncertainties to a level that permits identification of probable conditions, prediction of reasonable deviations, and preparation of contingency plans, which requires the following data:

- Identification of the probable location and size of the sources (i.e., pit and trenches). Characterization of the source term is not necessary for the responses under consideration. However, knowledge of the extent of the source is required to evaluate corrective actions. Specific factors include the distance from the sources to the boundaries of the MDA and the mesa edge.

- Better identification of the type and extent of contaminant migration. The specific parameters include lateral and vertical migration of volatile and solid contaminants.

The sampling plan to gather these data includes

- using surface geophysical techniques to identify the location of pits and trenches;

- conducting surveys of surface contamination;

- drilling slant boreholes under the pits and trenches to confirm the assumed vadose zone conditions (i.e., that vertical migration of contaminants is negligible); and

- using soil gas surveys to identify the extent of volatile contaminant migration. Because volatiles are much more mobile than solutes, the extent of volatile contaminant migration will be used as an indication of the maximum extent of contaminant migration.

2.2.3 Results of Reconnaissance Sampling

The data gathered by the RFI Phase I reconnaissance indicated the following:

- The MDA consists of one large pit covering approximately 2.5 acres in the fenced portion and under the paved portion of the

MDA and of two trenches, 40 ft long and 2 to 3 ft wide, approximately 200 ft from the southern edge of the mesa.

- No surface contamination is present.
- Soil gas surveys indicate limited migration of volatiles. The samples showed discontinuous and isolated migration a maximum of 5 ft laterally from the outside boundary of the trenches. Between the southern edge of the mesa and the trenches, migration also appears to be limited to 5 ft.
- Slant borehole samples did not indicate any downward vertical movement of contaminants.

2.2.4 Revision of the Conceptual Model

In accordance with the newly acquired data, the probable conditions were revised to reflect

- no contamination of the surface soils or the southern edge of the mesa,
- no vertical migration to groundwater,
- limited lateral and vertical migration of volatiles, and
- negligible lateral and vertical migration of solutes.

Uncertainties still exist as to the amount of organic and mixed liquids and corrosive gases remaining in the trenches. Two possibilities exist: (1) either the liquids and gases are still contained in their original containers in the trenches and have not yet migrated or (2) the organic liquids have volatilized and have been released with the corrosive gases.

Characterization of the source term could establish the existence of organic liquids and corrosive gases in the trenches, or their presence could be a deviation. However, because source characterization efforts involve physical risk, an attempt will be made to evaluate corrective actions in which the presence of organic liquids and corrosive gases is addressed as a reasonable deviation.

2.3 Corrective Measures Study and Corrective Measures Implementation

2.3.1 Corrective Action Evaluation and Contingency Plan Preparation

Following the criteria specified in proposed Subpart S [40 CFR Part 264.525 (a, b)] (EPA 1990, 0432) possible corrective actions were evaluated to determine whether they allowed the presence of organic liquids and corrosive gases to be handled as a reasonable deviation. A combination of corrective actions was assumed to be most appropriate for the MDA. An evaluation of the data gathered during reconnaissance sampling supported combining corrective actions.

The following information was used to evaluate the corrective actions:

- the extent of the MDA (pit and trenches),
- the danger involved in characterizing the source term further, and
- the ability of the corrective actions to address the presence of liquids and gases as a reasonable deviation.

Based on these criteria, a combination of institutional control and containment was selected as the preferred corrective action. The DOE will reacquire the paved portion of the MDA, and a fence will be constructed around the entire MDA. A modified cap has been identified as an appropriate corrective action to contain the source and to address the reasonable deviation of the presence of organic liquids and corrosive gases in the trench. The cap will be designed to inhibit infiltration of water and erosion of the soil covering the MDA and to divert surface run-off around the MDA.

To determine what level of detail was required for the contingency plans, the investigators evaluated cost, technical feasibility, and impact of the reasonable deviation. The contingency plan provides for a series of soil gas monitors to be installed under the cap. To respond to the deviation, the plan provides for a network of pipes to capture the volatilized organics and corrosive gases as they move out of the soil surface. It was determined that the pipe network was more feasible technically than attempting to extract soil gas through the installed cap. If migration of contaminants is detected, an air-stripping treatment train (air stripper, activated carbon filter, etc.) will be established to treat the off-gas removed via the pipe network.

The level of detail required for a contingency plan varies. The soil gas monitors and pipe network will be designed and installed with the cap. The treatment train will be designed but not built. The monitoring system will provide for advance notice of migration to allow the treatment train to be constructed.

2.3.2 Corrective Measures Implementation and Monitoring

The corrective actions have been implemented as designed. Monitoring the soil gas between the cap and the trenches has been initiated and is continuing. Monitoring for a deviation will continue for the period specified in the closure permit.

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■ APPENDIX H

Statistical Sampling and Data Analysis for Environmental Restoration

1.0 INTRODUCTION

The remediation of hazardous waste sites must be carried out with much less than perfect knowledge of true site conditions. Statistical methods are designed to deal with such uncertainties. The statistical methods discussed in this appendix are applied in the context of the decision framework described in Chapter 4. This approach requires that sampling and analysis plans be designed to provide information to make a well-specified decision and that the investigators assess data quality and use statistical data evaluation to determine whether the data suffice to support that decision.

2.0 MODELS AND DATA IN THE RCRA PROCESS

A model captures current understanding of a site or process and describes the framework within which new information is interpreted. The types of models used range from implicit models (sets of assumptions about the environment and its interactions with the site under study, which are often based on expert professional judgment but are sometimes poorly examined) through qualitative conceptual models to quantitative numerical or probabilistic models. Both qualitative and quantitative models play an important role in environmental restoration (ER) work because it is important that all assumptions be made explicit so that they can be reviewed by all stakeholders in the decision process. Implicit models are not sufficient for the decisions required under the Resource Conservation and Recovery Act (RCRA). The Environmental Protection Agency's (EPA's) data quality objectives (DQO) process provides a forum for eliciting and recording these assumptions.

The central model proposed in this Installation Work Plan (IWP) to organize information during the RCRA process is a conceptual exposure model (Appendix K). This model describes contaminant sources, potential current and future receptors, exposure pathways linking the sources and receptors, and the toxicological link between exposure and risk. These components are evaluated to estimate the risks associated with a potential release site (PRS). Although not all ER decisions are risk-based, a conceptual exposure model provides a useful framework within which to organize information about a site and to identify significant gaps in that information. Depending on the complexity of the site, refining and quantifying the conceptual exposure model throughout the RCRA process may entail constructing quantitative auxiliary models such as

- decision models (Appendix I) to evaluate decision alternatives and the impact of remaining uncertainties,
- statistical models (this appendix) to describe the relationship between the data and the environment,
- environmental transport models to predict potential exposure at points removed from the source of contamination in space and/or time,
- dose/response models for assessing the consequences of exposure under a postulated scenario, and

- engineering calculations to predict the effectiveness of proposed corrective measures as a function of detailed design alternatives.

The goal of site characterization is to provide the environmental data needed for these models at the level of detail needed to make the required decisions. There are several points during the RCRA process at which environmental (and possibly other) data will be collected. Site characterization is initiated during the RCRA field investigation (RFI), during which enough information is collected to perform a baseline risk assessment and to define site conditions for the corrective measures study (CMS). Additional data may be necessary to complete detailed remedial design and monitoring for unanticipated site conditions, as well as for the verification sampling or monitoring that will accompany the corrective measures implementation (CMI).

RCRA guidance for the RFI recommends a phased approach to ensure that a site is investigated in a manner that is cost-effective and that complies with the Hazardous and Solid Waste Amendments (HSWA) Module of the Laboratory's permit to operate under RCRA (EPA 1990, 0306). Each phase of the RFI concludes with a decision about the next step to be taken in the RCRA process based on evaluation of the data available at that point and on the conceptual model refined to reflect the data collected in the latest phase. The first phase of RFI work at a site is described in detail in the original RFI work plan. If a second RFI phase is necessary, its scope will depend on the outcome of that initial phase and therefore cannot be described in detail in the first RFI work plan. However, the potential objectives of subsequent phases can be outlined, and alternatives to additional investigations, such as no further action (NFA) or proceeding immediately to the CMS, can be outlined, along with the criteria to be used in selecting among them.

Frequently, the first phase of RFI work is designed to support a screening decision because existing data and other information are not sufficient to determine which constituents, if any, are contaminants of concern. Thus, for most Los Alamos sites, the initial investigation is designed to establish whether contamination is present above screening action levels (SALs). Sometimes the initial goal is to determine whether voluntary corrective action (VCA) is appropriate. In other cases, an initial investigation is required to establish that action may be deferred until site closure. For a few sites, a conceptual exposure model that is already partially quantified can be constructed before beginning the RFI. In this case, the initial investigation may be designed to support baseline risk assessment or remedial design. The investigation objectives must be tailored both to the specific site and to the remaining uncertainties that prevent the investigator from completing RFI decisions. The investigator determines the appropriate level of detail, using the principles of the observational approach (Appendix G) to exploit as appropriate the opportunities for further data collection that will arise during CMI. As field investigations progress in this way from generic screening toward detailed conceptual modeling, the importance of carefully specifying the investigation and DQOs increases.

3.0 DQOS: SPECIFICATIONS FOR SAMPLING AND ANALYSIS PLANS

As presented by EPA (1992, 0981), the DQO process is part common sense, part good management practice, and part statistics. It is the purpose of this section to describe the last of these aspects, relating the products of the process to the essential requirements for specifying a statistical sampling plan. Nevertheless, even

those steps of the process that require the most statistical input (Steps 5, 6, and 7) raise many nonstatistical issues. Thus, all steps of the process require participation by a DQO planning team consisting of program managers and a variety of technical experts, as well as a statistician.

The seven steps of the DQO process (EPA 1992, 0981) are illustrated in Figure H-1. The product of Step 1 (State the Problem) is a complete description of the site, its history, and its known and suspected problems, together with resources, time, and other practical limits on data collection. As suggested above, a conceptual exposure model can be used in this step to organize existing information so that the gaps in existing knowledge that significantly affect the investigator's ability to perform the required assessments are readily identified. A decision model (Appendix I) may be superimposed on this conceptual exposure model to assist this identification process. Also during this step, the planning team should consider the potential remedial alternatives and the types of information that may eventually be required to select among them.

It is neither feasible nor necessary to address all uncertainties at once. Step 2 of the DQO process (Identify the Decision) therefore focuses on the immediate decisions that need to be made—those that define the current phase of the project. The product of Step 2 is a statement of choices among alternative courses of action, framed as narrowly and as specifically as possible. The decisions must be stated in a way that makes it clear what the role of data will be in selecting among these alternatives. This focus differentiates data collection for environmental decision making, as required under RCRA, from data collection for research purposes, where the objective is simply to learn more about a site or phenomenon.

Occasionally, these first two steps may lead to a "decision" that can be made immediately—that is, archival information may indicate only one reasonable course of action, such as the NFA decision mentioned in Section 4.1.1. (Detailed criteria for proposing NFA based on archival information are discussed in Appendix I.) In these cases, it is not necessary to proceed further with the DQO process.

Otherwise, Step 3 of the DQO process (Identify Inputs to the Decision) begins to turn the decision statement into a set of specifications for a sampling and analysis plan. The product of this step is a list of types of information required to make the decision. These decision inputs are the environmental variables or parameters to be measured (called *outcome variables* in the statistical survey sampling literature). If none of the required inputs are environmental parameters for which new data must be collected, then again it is possible to exit the DQO process after the required existing information has been assembled.

When new environmental data are required, an additional series of questions must be addressed in order to complete the specification of the sampling and analysis plan to acquire them. These questions are developed in Steps 4, 5, and 6 of the DQO process. Step 4 (Define the Study Boundaries) specifies the *target population(s)* for environmental study. Both the spatial and temporal boundaries of the population to be sampled, as well as the media of interest, must be described. Examples of outcome variables and target populations are

- radionuclide concentrations in the top 6 in. of soil in a residential exposure unit, where the radionuclides of interest are assumed to be sufficiently stable that temporal boundaries need not be specified;

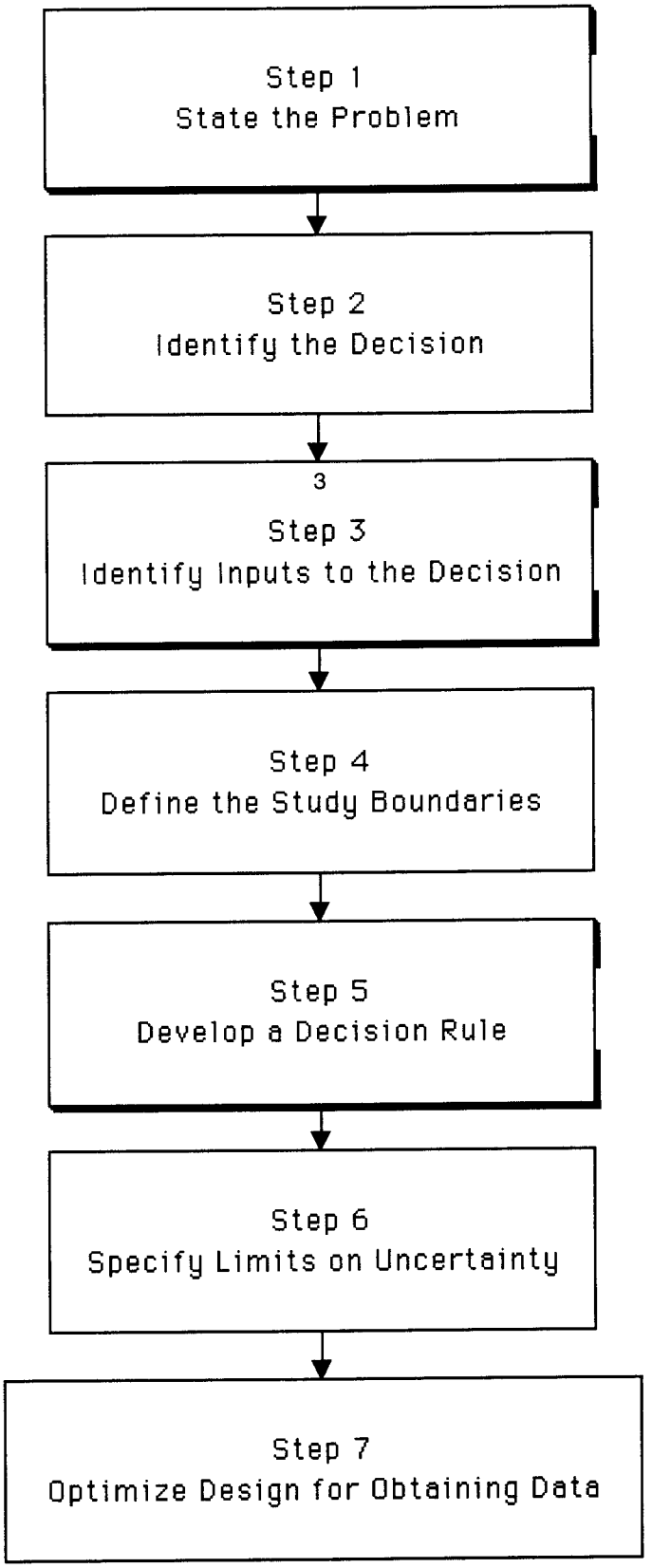

Figure H-1. The seven-step DQO Process.

- concentrations of semivolatile organic compounds in a shallow alluvial aquifer beneath and for 200 ft downgradient from a PRS; and

- particle density and size distribution in air within 500 m of the site's perimeter as a function of the time of year.

It is also necessary to specify quite precisely the physical methods that will be used to collect the sample and how measurements on this sample are assumed to be related to the population parameters of interest. Sometimes this relationship is fairly complex, as when filters left on a site for days, weeks, or months are used to sample particles in air. Even for surface soil, sieving or other methods of preparing samples may result in a sample whose relationship to the target population is not simple. The product of Step 5 (Develop a Decision Rule) is a statement that defines how environmental data will be aggregated and summarized (i.e., a statement that specifies the *statistic* or statistics to be calculated) and used to make the decision (the *criterion* for a statistical *hypothesis test*). The decision rule can vary from simple to very complex. For example, the data might be summarized by the sample maximum, which can be compared directly with a SAL. At the other extreme, concentration data might be interpolated on a three-dimensional grid and used in a numerical transport model to predict how long it will take for the contaminant to move offsite, and this predicted travel time is compared with regulatory requirements or contaminant decay times.

Step 6 (Specify Limits on Uncertainty) is necessary because environmental data are incomplete (decisions must be based on observations of a small fraction of the selected target population) and subject to errors of many kinds (errors introduced during sample collection and preparation, as well as analytical error). Thus, there is always a nonzero probability that use of the decision rule developed in Step 5 will produce the wrong answer, which, in turn, leads to selecting an incorrect decision in Step 2. The investigator must consider the impacts of various types of errors in the Step 2 decision:

- What are the possible decision errors: cleaning up a site that presents no significant risk to human health or the environment? failing to detect a significant release?

- What are the consequences of each type of error: excessive monetary costs? legal liability? negative public perception? unnecessary restrictions on Laboratory operations?

- How averse are decision makers to each type of error ? Specifically, in what situations is either decision acceptable? At what extremes do errors become highly unacceptable?

Turning these decision requirements into *design criteria* for the sampling and analysis plan is generally a difficult task, involving some assumptions about the likely sampling variability and probable site conditions. Nevertheless, some attempt should be made to address these questions because their answers provide some basis for determining sample sizes and analytical requirements that are both adequate and reasonable.

Step 6 completes the specifications for a sampling and analysis plan: what is to be measured? for what population? how will the data be used? and what is the margin for error? The seventh and final step of the DQO process (Optimize the Design for

Obtaining Data) is to design a sampling and analysis plan to meet these specifications efficiently. Here, a number of further options, such as the following, can be considered:

- How can relatively inexpensive field surveys and field screening results be used to direct the selection of samples for laboratory analysis or to supplement those analytical results?
- Should the target population be stratified to reduce the variability of the computed statistics?
- Can samples be composited to decrease analytical costs or to decrease decision error rates by increasing site coverage for the same cost?
- What level of analytical precision is required, and what analytical methods guarantee such levels?

4.0 SCREENING ASSESSMENT

The first phase of most investigations at Los Alamos consists of investigations to support a screening assessment. The usual criterion for determining that a release of contaminants to the environment has occurred is the presence at the site of contaminant concentrations in environmental media above the corresponding contaminant- and media-specific SALs; however, this decision criterion may require modification for some sites. When the medium of interest is soil or tuff whose natural constituents include elements at concentrations above the calculated SALs, a comparison of site observations with natural background levels is more appropriate for those constituents (Section 4.4, below). When multiple contaminants are present, a constituent whose concentration is not above the SAL may nevertheless be identified as a contaminant of concern because of its potential impact in combination with other constituents (Appendix J).

The objective of collecting data for screening assessments is to provide evidence about the nature of contamination at the site (that is, which of the potential contaminants are actually present above background levels) and about the range of concentrations relative to contaminant- and media-specific criteria. This objective contrasts with collecting data to support (1) a risk-based decision, which requires information about the distribution of a contaminant of concern throughout the site in order to compare the associated human health or environmental risks with a criterion risk level (Section 5 of this appendix) or (2) a remedial decision, which may require detailed information about the extent of the contaminated volume in order to evaluate the feasibility or effectiveness of a proposed corrective action.

The ER Program at Los Alamos is currently using three sampling strategies for screening assessments. These strategies include a nonstatistical strategy, a classical statistical approach, and a Bayesian statistical approach. Both of the statistical strategies use formal statistical models to determine the number of samples and other design parameters, based on the expected consequences of making incorrect decisions and on available information (if any) about the distribution of potential contaminants of concern. The approaches differ in their use of prior information, including expert opinion and existing data, and also in the way the conclusions are stated. Data collected using a design based solely on professional judgment cannot be evaluated statistically; however, the ER Program recognizes

that nonstatistical modes of inference play a significant role in much scientifically sound work.

4.1 Professional Judgment as a Basis for Sampling Design

Use of professional judgment assumes that knowledge about the process that was responsible for the potential problem, together with knowledge about the behavior of the potential contaminants in the environment, is sufficient to specify the design of a sampling and analysis plan. That is, professional judgment can be used to determine both the number and placement of samples and the more qualitative aspects of the design such as the selection of analytical methods. For well-defined sites (the interiors of septic tanks, small spills where soil contamination is visible to the eye or to field instruments, and similar small problems), statistical design principles are often not very useful, especially when the problem has been formulated as a screening decision.

More often, professionals are comfortable with selecting sample locations but lack a judgmental basis for determining the appropriate number of samples. Therefore, a common alternative to a completely judgmental specification is the use of a statistical method to determine the number of samples needed, together with professional judgment or auxiliary information such as field survey data to determine the placement of those samples. The underlying assumption is that biasing the sample locations in this way increases the probability of detecting contaminants of concern, if present. Like other design assumptions, this one could be tested as part of a quality assurance sampling program (Section 7 of this appendix).

4.2 Binomial Sampling Strategy

This statistical strategy assumes that the decision maker can specify the minimum probability with which contamination above the SAL should be detected in the sample as a function, $P_{min(f)}$, of the unknown fraction f of the site that is actually contaminated above the SAL. Because the consequences of failing to detect widespread contamination are more serious than the consequences of failing to detect contamination that affects only a small fraction of the site, P_{min} is always an increasing function off, but the exact shape of this function can vary from one site to another. For example, for a spatially heterogeneous, highly toxic constituent, the contamination of even a small fraction of the site could be of large concern. Conversely, when contamination, if present, can be expected to be relatively homogeneous or of low toxicity, P_{min} increases more slowly as a function of f.
The screening decision criterion used with the binomial sampling strategy is that a constituent will be identified as a contaminant of concern if one or more sample measurements yields a result that exceeds the SAL (that is, the sample maximum exceeds the SAL). Given this decision rule, together with the design specification $P_{min}(f)$, the required sample size, n, can be derived as follows. If n samples are selected at random from the site and if measurement error is ignored, the actual probability of getting at least one observation above the SAL is

$$P_n(f) = 1 - (1-f)^n \ . \qquad (4.1)$$

Thus, n must be chosen so that $P_n(f) \geq P_{min}(f)$ for all f.

In application, P_{min} is specified for one or two representative values of f rather than for the whole range between 0 and 1. These values are selected as above on the

basis of the expected heterogeneity of the site (which, in general, increases as the size of the site increases, among other factors) and the toxicity of the potential contaminants. (These assumptions should always be spelled out and are highly appropriate subjects for discussion among stakeholders.) Look-up tables, nomograms, or graphs can be used in place of Equation 4.1 to determine the required number of samples n. The n samples are then allocated in a randomized or biased fashion, depending on the investigators' confidence in available criteria for biasing. Negative results are summarized by confidence statements; the hypothesis that contamination affects more than a given fraction of the site can be rejected with a certain level of statistical confidence if none of the n observations exceeds the SAL. A single positive observation results in accepting the hypothesis that contamination is present at the site under this simple decision rule; that is, no attempt is made to control "false positives" under the binomial sampling strategy and no statistical confidence is computed for a positive result. Under rather weak conditions, measurement error increases the probability of falsely accepting the hypothesis that contamination is present but does not increase the probability of false negatives. However, analytical measurements that are biased downward can create problems, so this possibility should be minimized by quality assurance sampling.

Example

An area next to the loading dock of a machine shop has been identified as a PRS because waste oils were formerly stored there before being shipped to a permanent disposal or recycling facility. The area is about 200 ft^2, unpaved, and unvegetated. Waste oils could have been contaminated with low levels of natural or depleted uranium or beryllium. There is no record of leakage from drums stored at the site. No field surveys or sampling have ever been performed at the site.

In view of the lack of quantitative information, the decision to be made was formulated as follows:

> Determine whether soil contamination is present above SALs. If so, perform a baseline risk assessment for the site, which may involve collecting additional information to determine the average contaminant levels. If not, propose NFA.

New environmental data, specifically, soil contaminant levels at the site, are required to make this decision. The decision domain includes surface soils (0-6 in.) in the area on which drums may have been stored. The data for each contaminant (selected metals and hydrocarbons) are summarized by the observed sample maximum and are compared with the corresponding SAL. The constituents of interest are not extremely toxic. It was decided that if contamination is above SALs over more than 20% of the domain, the probability of observing it should exceed 0.85 [that is, $P_{min}(0.8) = 0.85$]; if more than 40%, the probability should rise to 0.95 [$P_{min}(0.6) = 0.95$]. Judgmental sampling based on visual inspection and a radioactivity survey will be used to bias the samples.

Table H-1 shows that eight samples ensure that at least one will fall in the most contaminated fifth of the domain with probability 0.85 or greater while providing probability of 0.98 of observing contamination that affects 60% of the site. If it can be assumed that contaminants, if present, are associated with oil stains or with above-background field radiation measurements, these probabilities can be increased or fewer samples can be taken to attain the same level of assurance. However, it is impossible to quantify the improvement in detection probabilities that

TABLE H-1

NUMBER OF INDEPENDENT OBSERVATIONS REQUIRED TO DETECT CONTAMINATION WITH SPECIFIED PROBABILITY

		Fraction of the Site That Is Contaminated									
		0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05
	0.75	2	3	3	4	4	5	7	9	14	28
	0.76	3	3	3	4	5	5	7	9	14	28
	0.77	3	3	3	4	5	6	7	10	14	29
	0.78	3	3	3	4	5	6	7	10	15	30
Probability	0.79	3	3	4	4	5	6	7	10	15	31
of Detecting	0.80	3	3	4	4	5	6	8	10	16	32
Contamination	0.81	3	3	4	4	5	6	8	11	16	33
in at Least	0.82	3	3	4	4	5	6	8	11	17	34
One Sample	0.83	3	3	4	5	5	7	8	11	17	35
	0.84	3	4	4	5	6	7	9	12	18	36
	0.85	3	4	4	5	6	7	9	12	19	37
	0.86	3	4	4	5	6	7	9	13	19	39
	0.87	3	4	4	5	6	8	10	13	20	40
	0.88	4	4	5	5	6	8	10	14	21	42
	0.89	4	4	5	6	7	8	10	14	21	44
	0.90	4	4	5	6	7	9	11	15	22	45
	0.91	4	5	5	6	7	9	11	15	23	47
	0.92	4	5	5	6	8	9	12	16	24	50
	0.93	4	5	6	7	8	10	12	17	26	52
	0.94	5	5	6	7	8	10	13	18	27	55
	0.95	5	6	6	7	9	11	14	19	29	59
	0.96	5	6	7	8	10	12	15	20	31	63
	0.97	6	6	7	9	10	13	16	22	34	69
	0.98	6	7	8	10	11	14	18	25	38	77
	0.99	7	8	10	11	13	17	21	29	44	90

could result from using these field indicators. A stratified sampling plan (Section 5.2.3) that assigns some samples to areas with positive field indications and others to areas with none could be used to provide information for quantifying this improvement.◊

Example

A 2-acre area was used for temporary storage of new and used materials, including bulk metals and waste solvents in drums. Vehicle tracks and devegetation suggest which areas were most used, although no records are available and the site is no longer used. In this case, because the site is fairly large and potentially heterogeneous, it is desirable to detect contamination if it affects as little as 5% of the site with probability 0.85. Table H-1 shows that, in the absence of useful field information, 37 samples are required. Visual evidence of usage might be used to bias sampling.◊

4.3 A Bayesian Statistical Approach

Bayesian statistical methods elicit information from both decision makers and technical experts, which is used to model expectations about the distribution of

contamination at the site. The result of a Bayesian analysis of screening assessment is a direct probability statement about the chances that contaminants occur at a site at a level that exceeds SALs rather than a confidence statement that is only indirectly related to this probability.

A Bayesian approach to screening assessment requires specification of a *prior* probability distribution that models the proportion of the site, f, that is actually expected to be contaminated above SALs. The prior distribution can be determined by obtaining answers to the following types of questions:

> Before seeing any data, what is the probability that the next observation will produce an observation with concentrations less than SALs?
>
> After seeing an (hypothetical) observation with concentrations below SALs, what is the probability that the next observation will produce an observation with concentrations lower than SALs?

More generally, these questions can be asked based on a hypothetical sequence of observed concentrations. (A minimum of three such questions must be answered to complete the specification of the prior distribution. However, overspecification is encouraged to validate the inputs.)

The design specification $P_{min}(f)$ used in Section 4.2 is replaced by a loss function that specifies the costs associated with making incorrect decisions. These costs do not have to be stated in dollar terms, but they do need to reflect the relative consequences of making a false negative decision—such as proposing NFA when the site does contain areas of contamination above SALs—and of making a false positive decision—such as proposing further action when the site does not contain areas of contamination above SALs.

Sample sizes are selected to minimize the expected loss associated with each decision, as measured by the loss function adjusted by the probability of each hypothesis. After measurements have been made, the prior probability distribution is updated by the new data. For the screening assessment decision, as more observations at concentrations below SALs are recorded (assuming no observations at concentrations greater than SALs), the expected loss under the NFA decision decreases. At the point at which the expected loss under the NFA decision becomes less than the expected loss under the "further action" decision, sufficient samples have been taken to justify a proposal of NFA. As in Section 4.2, if any observation should result in a concentration greater than the SAL, further action could be required.

The probabilistic prior model for the distribution of concentrations and the loss function representing the consequences of false decisions can be obtained through consultation with all interested parties, including the operable unit (OU) teams and the regulatory stakeholders. If little is known about the site, this lack of knowledge can be reflected by choosing a relatively flat or "uninformative" prior probability model. The resulting number of samples is a consequence of these choices. In general, the less informative the prior probability model, the more samples are required.

4.4 Statistical Methods for Background Comparisons

During screening assessment, the levels of some constitutents must be compared with natural background values, as shown in Figure 4-2. If this comparison indicates that the sample values for a particular constituent are not different from background values, no further evaluation of that constituent is necessary, even if these natural background values exceed the SALs (which is the case for the elements arsenic, beryllium, and thorium.) Background comparisons may also be reported for constituents whose background range is below the SAL. Finally, the methods described below can be applied in comparing observations from a specific PRS with observations obtained from nearby areas unaffected by that PRS (such as OU-specific background data) in order to determine whether elevated levels are related to the PRS in question or are part of a more widespread release.

Concentrations that are above background will be compared with SALs. No adjustment for nonzero background concentrations is performed during such a screening assessment. However, background values may be taken into account in performing risk assessments for carcinogens and radionuclides to determine whether incremental amounts of these constituents pose an unacceptable risk. For noncarcinogens, only the total concentration values are considered in the risk analysis (Appendix K).

Comparisons of sample values with background distributions may be performed using a series of three tests described by Gilbert and Simpson (1990, 0972). The use of three different tests is recommended to allow detection of different types of deviations from the background distribution. The proposed tests are nonparametric, that is, they do not require specification of a specific functional form for the distribution of a particular constituent. They can also accommodate observations that are below detection limits.

The Wilcoxon rank sum test [also called the Mann-Whitney test (Conover 1980, 1050)] is used to assess whether two distributions are significantly different. This test is especially effective for detecting elevated concentrations throughout the site, even when the shift above background is small. The first step in performing the Wilcoxon rank sum test is to construct an ordered list from smallest to largest of the data set obtained by combining the background measurements and the sample values. The values are ranked starting with 1 for the smallest value. The sum of the ranks corresponding to the sample values is then compared with tabled values [e.g., Table A7 (Conover 1980, 1050)] to determine whether the sample values are likely to have come from the same population as the that of the background measurements.

The quantile test (Johnson et al. 1987, 0973) also tests for differences between two distributions. The quantile test is designed to detect differences in the upper tails of the distributions, which could occur if the data represented a site of which only a small part was contaminated. The first step in the quantile test is the same as that for the Wilcoxon rank sum test: ranks are assigned to the combined background and sample values, assigning the rank 1 to the smallest value. Then, from the largest r values from the combined data set, a count, k, is determined of the number of values that come from the sample values rather than from the background values. The value of k is compared with tabled values. If k is sufficiently large, the sample values are determined to be above background.

To protect against individual extreme values that may not be flagged by either the Wilcoxon rank sum test or the quantile test, Gilbert and Simpson (1992, 0974) also recommend a "hot-measurement" test. This test simply flags individual measurements that will be subjected to further evaluation, even if the other tests do not reveal significant distributional differences. The critical level used in this test may be based on a variety of criteria, including professional judgment, regulatory limits, SALs, and extreme quantiles of the background distribution.

The series of three tests described above is designed to detect differences in sample values from a reference background distribution without assuming a specific functional form of the background distribution. For some situations, sufficient information may exist to characterize the distributions of the sample values and the reference background distribution as members of a specific family of probability distributions (e.g., the log normal family). Use of this information to construct a parametric test can result in a test that is more powerful, i.e., a test that is more likely to detect a difference in the two distributions if they are actually different; however, this advantage is lost if the parametric assumptions are incorrect.

Distribution-dependent techniques that may be useful for normally distributed data include the two-sample t-test and normal tolerance limits. The two-sample t-test is used to detect a difference in the means of two populations. Normal tolerance limits are used to specify an upper limit so that a given proportion of the observations in a random sample from the reference population lie below that level with specified confidence. EPA guidance (1989, 0794) discusses the use of these and similar methods for environmental sampling decisions. Odeh and Owen (1980, 0975) provide extensive tables for computing normal tolerance limits.

Data for background comparisons may be derived from a variety of sources. Results of background studies conducted under the auspices of the ER Program are summarized in Appendix F. These studies analyzed background soil and tuff samples for many constituents that are expected to have nonzero concentration levels, even in the absence of releases attributable to Laboratory operations. Data from earlier studies [Ferenbaugh et al. (1990, 0099) and Purtymun et al. (1987, 0211)] provide additional background information. National background data may also be useful when regional values are unavailable; Shacklette and Boerngen (1984, 0418) provide information on background levels of several elements using data collected across the United States. At selected sites, site-specific background values may be available from locations where a release is unlikely to have occurred. OU background data may be used to determine whether elevated values at a PRS are caused by a localized release or by more general OU-wide contamination (e.g., from airborne stack releases). Gilbert and Simpson (1990, 0794) and a DOE report (DOE 1992, 0976) point out that reference areas for background data must be selected with care. Determining appropriate background data may involve historical information, data availability, information on soil types, other site-specific information, and professional judgment.

5.0 RISK-BASED DECISIONS

The presence of contaminant concentrations above SALs may not in itself warrant corrective action for any of a number of reasons. SALs are purposely set at very low levels, levels at which human health effects are unlikely even under worst-case exposure assumptions. The actual extent and overall level of contamination may preclude negative impacts under any realistic exposure scenario, or the available remediation alternatives may be far more destructive of the ecosystem than any

historical release. Thus, in general, further evaluation of the site, which may include further sampling to characterize not only contamination but also other environmental parameters, is required to determine whether corrective action is desirable. In general, this decision is risk-based, although non-risk-based criteria may be more appropriate for certain sites.

Sampling to support decisions beyond the screening decision must be guided by well-specified decision statements. Decision criteria can then be derived, based, for example, on the need to estimate the risk associated with existing contamination or on the need to determine the volume of soil to be removed. Risk-based decisions take into consideration not only contamination levels at the site but also the mechanisms by which organisms (human or other) might be exposed to this contamination, either by their activities at the site or as a result of migration of contaminants away from the site. Thus, specifications for a sampling and analysis plan to support such a decision include a detailed description of the scenario to be used for risk assessment.

5.1 Data Quality Objectives for Risk-Based Decisions

The risk associated with contamination depends on the actual dose to the assumed receptors, which, in turn, is proportional to the intake of contaminants integrated over both the spatial domain and temporal duration of exposure under the assumed exposure scenario. Sampling must therefore be designed to ensure that data are adequate to support decisions at the exposure unit scale. As described in Appendix K, both current and future uses of the site need to be considered during Step 4 of the DQO process in order to select the appropriate exposure unit, which, in turn, determines the spatial and sometimes also the temporal scale of the investigation. Current EPA guidance (EPA 1989, 0305) recommends using an upper 95% confidence limit for the mean concentration of contaminants at a site or portion thereof (that is, within an exposure unit). This guidance suggests that a false negative decision error rate on the order of 5% can be tolerated if the true risk is equal to the target risk level. Among sampling plans that achieve this decision error rate at the target risk level, further optimization is possible to ensure even smaller error rates when the true risk significantly exceeds the target risk level and also to decrease the rate of false positive decisions when the true risk is less than the target risk level. If the recommended statistic is used, these error rates depend on the precision of the estimate of the mean, which, in turn, is a function of the sample size. Specifications for desired decision error rates are elicited during the DQO process and depend on many nonenvironmental considerations.

Completing the design of a sampling plan to collect data for estimating the mean concentration in exposure units requires further knowledge or assumptions. In particular, the magnitudes of significant components of error—population variability, sampling error, and analytical error—must be known or estimated to calculate the number of samples required to achieve the specified decision error rates. This information may be available from the initial site investigation or from other sources (Section 6.1 of this appendix), or quality assurance sampling may be designed to test the assumptions (Section 7 of this appendix).

5.2 Sampling Strategies for Risk-Based Decisions

Because sampling to estimate means is the usual goal of classical survey sampling, many well-developed strategies are discussed in statistical literature. Strategies that

are particularly useful for environmental work are discussed in the following subsections and also by Gilbert (1987, 0506).

The Los Alamos ER Program is currently developing additional sample allocation schemes for risk assessment in both the classical and Bayesian statistical frameworks. Developments in both areas build on the classical work by including existing information about distributions of contaminants of concern and evaluation of the consequences of making incorrect decisions as more explicit factors in the design. As for screening assessment, some distinctions arise between the classical and Bayesian approaches to statistical inference. For example, in the Bayesian approach, the results of the data analyses are presented as probabilities that the hypotheses obtain, while, in the classical approach, they are presented as confidence levels for accepting or rejecting a null hypothesis (Berger 1985, 0977).

5.2.1 Simple Random Sampling

Simple random sampling is easy to conceptualize in the case of finite populations, where the population units available for sampling can be enumerated and a randomization mechanism can be used to select n units in such a way that each possible set of n units has an equal chance of being chosen (the "simple" aspect of this design). In practice, simple random sampling is only approximated in most environmental work. Common modifications are restriction of potential sampling locations to the nodes of a grid and spatial stratification to ensure covering the site. Most discussions of statistical sampling, environmental or otherwise, recommend using some kind of randomization in selecting samples for both theoretical and practical reasons. The practical argument for randomization is that it should result in a more "representative" sample of the whole population, unbiased either consciously or unconsciously by the judgment of the investigator. Extrapolation of results from a small but randomly allocated sample to the whole population is a more satisfactory procedure than it would be if the sampling locations were selected at the whim of the investigator, no matter how objective he/she might be.

The reasons for not using randomization in the field also appear to be practical—sites chosen at random often turn out to be unsuitable for sampling for one reason or another (too rocky, underneath a concrete pad, next to a beehive, etc.), and it is more time-consuming to survey in random locations than to survey a regular grid. EPA has many practical techniques for overcoming these objections (EPA 1989, 0794, Chapter 5). One of the simplest randomization schemes is to use a regular grid, randomizing only the starting point and the orientation. Additional randomization, rather than the judgment or convenience of the field team, should be used to replace a grid point that turns out to be unsuitable for sampling. Simple methods are also available for randomizing each sampling location, starting from a surveyed grid that can be applied on the spot by a field team equipped with nothing more elegant than a pair of dice (or a similarly low-tech method for generating random numbers), a compass, and a tape measure.

When the observations are based on a simple random sample, the standard estimator for the mean of the sampled population is the sample mean,

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \ , \tag{5.1}$$

where x_i is the measurement of the outcome variable on the ith sample. Again, assuming statistical independence of the observations, this estimator has variance

$$\frac{\sigma^2 + \theta^2}{n}, \tag{5.2}$$

where σ^2 is the between-sample variance and θ^2 is the variance of the analytical error. If the observations are correlated, Equation 5.2 does not hold; however, if the between-sample correlations can be estimated [based, for example, on an estimated spatial covariance function (Section 5.4)], this expression can be modified. As Equation 5.2 shows, the precision with which a population mean can be estimated depends not only on the sample size but also on the population variance (about which there is often no information), as well as on analytical error variance, which may or may not be reliably provided by the laboratory or by the instrument manufacturer. Therefore, determining an appropriate sample size involves making some reasonable assumptions about the variances of the measured outcome variables. Frequently, analytical error is insignificant compared with the population variance, σ^2; however, if not, one way to reduce θ^2 is to make multiple measurements on each sample.

Sampling for the purpose of estimating a mean differs from screening investigations in some important respects. For one thing, biased sampling of the target population results in biased estimates of the mean, which increases the false positive decision error rate. For some sites, this drawback may be considered an acceptable price to pay to avoid revisiting the site. However, it becomes even more critical to test the assumption that the principles used to bias the sample do in fact bias the results upward by appropriate quality assurance sampling. Such sampling is likely to take the form of including a few samples from areas thought to be less contaminated; therefore, as an alternative to biased sampling, the investigator might consider a stratified sampling design (Section 5.2.3, below).

Example

Screening investigation of the example of the former drum storage area described in Section 4.2 began with a site inspection and a radiological survey, whose results were to be used to bias subsequent sampling. If there are no positive results from these surveys, the investigator could select samples at random from the surface soil of the PRS and might anticipate performing a baseline risk assessment using the mean values of the contaminants of concern identified by the screening assessment, if any. How precise will the estimates of these means be if based on the screening assessment sample of size 11?

The fact that there were no positive field indications might be used to bound the concentration of some of the contaminants at the site and their variability as well. For example, if the radiological survey instrument should be able to detect uranium concentrations above 20 pCi/gm in surface soil, it may be concluded that the average concentration at the site is below that level, and the standard deviation is unlikely to exceed half of this amount. (Distributions with coefficients of variation as large as 0.5 are very rare, although they could occur at sites with small but highly contaminated hot spots.) Thus, the standard deviation of the mean of the proposed 11 samples should be less than $10\sqrt{11}$ or about 3 pCi/gm (assuming that the analytical error is negligible by comparison with 10 pCi/gm), which would allow estimating the mean with a 95% confidence interval not larger than ±6 pCi/gm (and probably a great deal smaller because the sample standard deviation is likely to turn out to be quite a bit less than 3 pCi/gm).◊

5.2.2 Composite Sampling

As a general rule, the larger the population variance, the more samples are needed to estimate a mean with given precision. This subsection and the following two subsections present sampling strategies that, correctly applied, can increase precision without increasing the number of laboratory analyses required.

One way to reduce sampling variability is to form composite samples. A composite sample is generally made up in the field. Grab samples [called "increments" in the statistical literature on composite sampling (Elder et al. 1980, 0795)] are collected as usual following the appropriate procedures, except that less material may be required in each grab sample than if each were to be analyzed separately. The material from several grab samples is combined and homogenized to form a composite sample from which subsamples (seldom more than two) are removed and packaged as usual for laboratory analysis. Clearly, this brief description passes over some significant practical details. In particular, it is desirable that each grab sample contribute an equal amount to the composite and to the subsamples, which suggests that any sieving to remove rocks and other debris should be done before the increments are composited. Homogenization should be as thorough as possible. If volatile contaminants are of concern, compositing should not be used.

In order to estimate the population mean from composite samples, the following assumptions are made:

- The estimate is computed as the average of $n = r \times s$ subsamples, that is, Equation 5.1 is used with the measurements on s subsamples from each of r composites. (Equation 5.3, below, can be modified if not all composites have the same number of subsamples.)

- The volume of each composite is equal to that of s subsamples. (If $s = 1$, that is, if the entire composite is analyzed to produce one measurement per composite, the last term in Equation 5.3 should be ignored.)

- Each composite is formed from $m \geq 1$ grab samples. Equation 5.3 assumes that each grab sample is homogeneous; however, modifications can be made if this is not the case.

- σ^2 is the between-grab sample variability, usually more significant than any inhomogeneity within grab samples.

- τ^2 is the variance of the contribution of the individual grab samples to the measured subsamples. Ideally, each subsample has a contribution from each increment that went into its parent composite that is 1/n of the volume of the total subsample so that τ^2 is zero and, again, the last term of Equation 5.3 vanishes.

- θ^2 is the analytical error variance.

With these assumptions, the variance of the estimate of the mean is given by

$$\frac{\sigma^2}{nm}+\frac{\theta^2}{rs}+\frac{m}{rs}\frac{S-s}{S-1}\sigma^2\tau^2 \ . \tag{5.3}$$

Thus, when the variability among grab samples is the major component of variance (that is, when σ^2 is much larger than either θ^2 or τ^2), its effect on the estimate of the mean of a population can be reduced by compositing.

When collecting data for a risk-based decision, sampling designs that include physical averaging do not adversely affect the estimation of averages at the exposure unit scale, provided that the compositing design does not composite grab samples from different exposure units. Composite sampling also has advantages for screening assessment (Boswell and Patil 1990, 0978). For example, if 18 increments are taken from a site and are used to create 3 composite samples and 2 subsamples are taken from each composite, 6 laboratory analyses are required. If all 6 composite subsamples indicate concentrations below SAL-related levels, the site can be proposed for NFA. For composite sampling, SALs must be modified to account for the averaging effect of compositing. If 6 increments go into one composite but only one is above the SAL, their mean may be below the SAL; however, assuming increments of equal weights, their mean cannot be below 1/6 of the SAL, so 1/6 of the SAL can be used for screening assessments based on composites of 6 increments.

When the constituents of interest do not have short holding times and when adequate storage space is available, a fraction of each grab sample can be retained for individual analysis in cases where the composite sample produces a large measurement. Designs that exploit this possibility to improve spatial resolution or to characterize the upper tail of the contaminant distribution have been proposed in recent literature (Bloom 1992, 0979; Gore and Patil 1993, 0980). Continuing the previous example, if 1 composite indicates contamination above SAL-related levels, 6 more chemical analyses could be performed to determine the maximum concentration, which still results in a saving compared with performing 18 discrete analyses. The appropriate number of increments used to form a composite can be optimized according to prior expectations of contaminant concentrations with respect to SALs. Many other design considerations can be incorporated in the selection of grab samples to be composited, e.g., spatial resolution can be maintained by compositing neighboring samples or samples from comparable depths or soil types instead of compositing at random across the site.

5.2.3 Stratified Sampling

A second common method for reducing sampling variability partitions the domain into comparatively homogeneous strata, allocating a certain number of samples to each stratum (generally more samples to more variable strata.) It is assumed that there are J such strata, and n_j samples are allocated to the jth stratum. If the jth stratum accounts for a fraction F_j of the domain, then the appropriate estimator for the population mean is

$$\bar{x}_s = \sum_{j=1}^{J} F_j \bar{x}_j \ , \tag{5.4}$$

where $\bar{x}_j$ is the mean outcome for the samples in the jth stratum (computed as in Equation 5.1). Denoting the within-stratum variances by σ_j^2, this estimator has variance

$$\sum_{j=1}^{J} \frac{F_j^2 \sigma_j^2}{n_j} \tag{5.5}$$

(ignoring analytical error), which can be substantially smaller than the variance of the ordinary, unstratified mean if the σ_j^2 are small compared with the variability between strata. Often, of course, it is necessary to estimate the Fj from the data, which adds another, possibly significant component of variance to Equation 5.5.

In a sense, a biased screening investigation sample could be considered a stratified sample; however, if one stratum (e.g., the stratum with no positive field indications) is not sampled at all, the corresponding estimate of the mean (but not the sample maximum) has infinite variance, from Equation 5.5.

Example

In the past, debris from several firing sites was burned in trenches about 10 ft deep that had been excavated in the alluvium in a flat canyon bottom. The last of the trenches has now been backfilled, and the entire area, less than 1 acre, has been leveled and reseeded. Although the bulk of the material brought to this site consisted of plywood and similar combustibles, this material may have been contaminated with small amounts of high explosive (HE), HE residuals, depleted uranium, and other heavy metals used at the firing sites. The screening assessment identified depleted uranium as the only contaminant of concern; depleted uranium was observed in the thin layer of ash at the bottom of one trench.

The next step, therefore, is a baseline risk assessment. Step 1 of the DQO process identifies as the most significant onsite exposure scenario exposure of individuals who are making recreational use of the area to material eroded from the trenches. Using this scenario, the mean contamination contained in the disturbed volume is estimated and used to calculate risk.

The conceptual model for the site envisions a layer of ash and debris at the bottom of the excavated trench, which is covered by fill that might be slightly contaminated and is underlain by undisturbed alluvium into which contaminants may have leached. The area is to be investigated by drilling to a depth of a few feet below the bottom of the pits. Contaminant levels in the ash and debris layer could be both significantly higher than in the other two strata and significantly more variable. Therefore, even though the ash and debris are probably only a small fraction of the total volume, the investigator allocates more samples to those strata than to the fill and alluvium.
In this example, it is also necessary to estimate F_j for each stratum. The fractions of each stratum in each drill hole through the trenches (which can be observed independently of the selection of samples for laboratory analysis) can be used for this purpose:

$$\hat{F}_j = \sum_{h=1}^{H} t_{hj} \Big/ \sum_{h=1}^{H} d_h \,, \tag{5.6}$$

where t_{hj} is the number of linear feet of core through the jth stratum in the hth hole and d_h is the total length of core from the hth hole. If the thicknesses of the ash and debris strata are very variable, the variance given by Equation 5.5 will be significantly inflated.◊

Example

Risk-based sampling (Seiler 1987, 0564) is a stratified sampling strategy that deserves mention because it is designed to estimate not the mean contaminant level for the population but rather a weighted mean proportional to risk. It is a form of stratified sampling; the population to be sampled is stratified according to the degree of exposure associated with each unit. Thus, for a site at which dermal contact with soil is the main exposure route, those parts of the site that are currently exposed constitute one stratum, those imminently subject to exposure by erosion another, and more deeply buried areas are assigned to other strata. If these strata are then sampled in proportion to their contribution to receptor exposure potential, the (equally weighted) sample average of the observed contamination levels is proportional to the total risk posed by this contaminant distribution.◊

5.2.4 Double Sampling

Double sampling, together with ratio or regression estimation of the population mean, is a third method for reducing the variance of the estimate without significantly increasing the number of expensive laboratory analyses required. The assumption is that there is one or more relatively inexpensive "fallible" measurement that is correlated (generally imperfectly) with more expensive "accurate" measurement(s) of the outcome variable of interest. If the fallible measurements are made on a large number, n^*, of samples from the population, and the accurate measurements are made only on a small subsample of size n, it may be possible to obtain a more precise estimate of the overall population mean by using both sets of measurements than by using the n accurate measurements alone. This estimate is calculated as

$$\bar{x}_R = \bar{x}_a + \hat{\beta}\left(\bar{x}_f^* - \bar{x}_f\right) \quad , \tag{5.7}$$

where $\bar{x}_a$ is the mean of the n accurate measurements, $\bar{x}_f$ is the mean of the fallible measurements on the same subsample of size n, $\bar{x}_f^*$ is the mean of all n* fallible measurements, and $\hat{\beta}$ is the slope of the estimated linear regression of accurate on fallible values, based on the subsample. Equation 5.7 is called a "regression" estimator for the population mean. Gilbert (1987, 0506) gives the formula for its variance in his Equation 9.2, which depends not only on the variability of the accurate and fallible measurements but also on the goodness of their correlation. Gilbert also provides an extensive discussion of the conditions under which use of double sampling is cost-effective.

Theory or the empirical evidence of the linear regression may suggest that the linear regression actually passes through zero, that is, the accurate measurement is zero if, and only if, the fallible measurement is zero, in which case a slight modification of Equation 5.7, called a "ratio" estimator, is appropriate. Equation 5.7 can also be extended to the case in which a combination of two or more fallible measurements is available on the large sample.

Example

Following each shot at a former firing site, debris was bulldozed into a nearby arroyo to prepare the firing pad for the next shot. Use of the site had been discontinued by 1960, but a mound of unconsolidated debris, soil, and rock, several feet thick, remains on the side of the arroyo. One of three soil samples from the base of the mound at the edge of the arroyo channel, collected during a screening investigation, showed elevated levels of depleted uranium and some other metals.

Given that depleted uranium is expected to be the only radionuclide present, field radioactivity measurements could be used to supplement analytical measurements of depleted uranium and other metals to improve the estimate of the mean contamination in this disposal area. Debris as well as fill material will be sampled, and regression estimators will be developed independently for each of these strata. For depleted uranium, a ratio estimator can be used. Concentrations of other metals may not be exactly proportional to radioactivity; therefore, the more general regression estimator should be used. For these other metals, the correlation may not be good enough to improve the estimate of the mean over the estimate provided by the usual sample mean; however, because depleted uranium is the principal contaminant of concern, sample sizes may still be determined based on the ratio estimator for depleted uranium.

6.0 OTHER SAMPLING AND ESTIMATION STRATEGIES

Although screening assessments and risk-based decisions are the most common types of decisions in the RFI stage of the RCRA process, other types of decisions occur both in the RFI stage and in subsequent stages. The decisions and decision criteria become much more variable, and the sampling strategies used need to make as much use as possible of information gathered in earlier phases. This section outlines some considerations and strategies that may be used.

6.1 Variance Estimation

Several of the formulas in the preceding sections indicate that the precision of the computed statistic, and hence the probability of error in testing a hypothesis and in making the resulting decision, depends not only on the sample size, which can be controlled by the investigator, but also on natural variability and measurement error. The effects of natural variability can be partially controlled by using statistical techniques, such as stratification, compositing, and replicate measurements, and by choosing appropriate sampling and analysis methods. However, natural variability is to some extent beyond the control of the investigator. Worse, there is often, at least initially, no basis for predicting the magnitude of natural variability. Therefore, one goal of the initial RFI site characterization is to collect enough data to estimate the important variance components. Accurate variance estimates are particularly important in designing a monitoring plan to meet regulatory requirements for site closure, conditional remedies, and deferred action.

6.1.1 Variance Components

Some of the specific components of variance that have appeared in the formulas above include

- the overall population variance,
- within-stratum population variances,
- subsample and between-aliquot variance, and
- error in analytical measurement.

Designing a preliminary study to estimate the magnitudes of these errors is similar to designing laboratory experiments. Balancing the design with respect to the factors of interest, avoiding a design in which two important effects are confounded, and including sufficient replication to distinguish measurement error and local heterogeneity from other variance components are important considerations. Field duplicates, splits, and other sample types that are built into a sampling plan for quality control purposes can be especially useful—field blanks and spiked samples provide a measure of analytical error; splits provide a measure of the sum of analytical error and the variance between subsamples or aliquots; and field duplicates provide a measure of the sum of analytical error, aliquot variance, and variance caused by local heterogeneities in the sampled medium. The use of quality assurance sampling is discussed further in Section 7 of this appendix.

6.1.2 Spatial and Temporal Covariance

Many of the variables of interest in site remediation—contaminant concentrations, hydrogeologic variables such as permeability and mineralization, and population densities of biota—can be expected to be spatially correlated, at least over short distances. Some variables, such as climate parameters, also have significant temporal correlations. For some forms of estimation, this correlation is not a drawback that invalidates the common expressions for variance but is an advantage that enables the investigator to predict with improved accuracy the spatial or temporal distribution of an outcome variable at unobserved points (Section 6.2).

Although an estimate of spatial or temporal correlation can be formed given almost any reasonably well-distributed sample from the population, a good estimate demands a little extra care. The optimal type of design for estimating spatial covariance is probably a radial grid with spokes (Flatman and Yfantis 1984, 0504) because this design provides collinear observations along four different axes and the opportunity to evaluate directional anisotropies as well as correlation as a function of separation. However, reasonable covariance estimates can be based on more uniformly distributed samples, provided care is taken to obtain a little extra information for estimating the correlation on a scale that is small compared with the average sampling density. This small-scale variability is critical for estimating predictability.

Spatial or temporal continuity is modeled statistically using a spatial or temporal covariance function or variogram. Important features to quantify are

- the ratio of local (microscale) variability to global variability. Both field duplicates and samples that are closer together than average are essential for estimating this ratio.
- the correlation distance, defined so that observations separated by more than this distance in space or time appear to be uncorrelated. For the purpose of calculating this estimate, the

data should contain several pairs of observations with approximately the same spacing for each of a number of different spacings.

- the overall (global) variability. Estimating global variability should not be difficult, provided that the whole domain is reasonably well represented in the sample.

Another important spatial consideration for environmental sampling is the relationship between the volume of the sample (or the support of a field observation) and the result. Often the sample volume is dictated by the analytical technique used. However, studies in which the sample volume was varied have shown, first, that smaller samples are generally much more variable and, second, that it can be very difficult to correlate measurements made on samples of different sizes. It is important to consider these relationships both in selecting analytical techniques and in making field decisions about the volume of soil to homogenize when sampling.

6.2 Prediction Approach to Sampling and Estimating

One alternative to the classical sampling methods described in Sections 4 and 5 views the problem as one of predicting the outcome variables for unsampled locations by using the observations to construct a statistical model for the outcome variables. This approach goes by various names in the statistical sampling literature—"model-based sampling," "prediction approach"—but is philosophically distinct from the more widely accepted design-based approaches that have been implicit in almost all of the discussion so far. In classical sampling, the probabilistic structure that relates the observations to the population was introduced by modeling the sampling process itself, and randomization of that process (Section 5.2) is a key concept. In model-based approaches, the probabilistic framework is introduced by means of a statistical model for the population. Of course, introducing a statistical model does not preclude randomizing the sampling plan. In application, model-based sampling must be concerned with the ability of the procedures to withstand deviations from the postulated models and can use the ideas of design-based sampling, including randomization, as safeguards against such departures (Little 1983, 0509).

Models used in the prediction approach usually incorporate *auxiliary variables* that are known or are easily measured for the entire population of interest. [Stratification is another way to use auxiliary variables: the population is partitioned into substrata based on the values of auxiliary variables such as the medium type (soil, sediment, tuff, decaying vegetation) or provenance (ash, debris, or fill, in the burning pit example).] One type of auxiliary variable that is always available in environmental work is location, given by two or three spatial coordinates and possibly a time coordinate as well. The first law of geography, cited at the beginning of Section 6.1.2, suggests that these spatial and temporal variables should not be ignored in environmental work, and some prediction approaches to sampling and estimation (such as, in particular, kriging) are explicitly designed to exploit them (Cressie 1991, 0793).

Models used for prediction approaches to sampling and estimation combine "fixed effects" and "random effects." The fixed effects represent trends in the outcome variable with respect to the auxiliary variables and also provide a mechanism for including other aspects of the process generating the observations, such as

integration over some volume by compositing or by field instrumentation. This part of the model usually includes unknown parameters (at least a population mean), whose estimation is one goal of data analysis. The random effects are modeled only by their estimated covariance.

The idea of the prediction approach, then, is (1) to use sample observations to estimate the parameters of both the covariance model and the trend component, (2) to use the resulting model to predict the unobserved outcome variables, and finally (3) to estimate population parameters of interest using these predictions when observations are not available. Ideally, estimation of the covariance structure is based on data from a preliminary survey, as discussed briefly in Section 6.1.2, because this information is needed to design an appropriate follow-up sampling and analysis plan. In practice, the same data are often used for both Steps 1 and 2.

The advantage of model-based estimation is that estimators for functionals of the population other than the global mean are easily constructed. In particular, the use of model-based procedures is almost essential for estimating the means of many small subpopulations, such as averages over many small exposure units. The design-based alternatives require a large number of samples, enough observations in each subpopulation to estimate its mean independently of the rest of the data.

Example

This example is a simplified version of the Bayo Canyon firing site, discussed in much more detail in the RFI Work Plan for OU 1079 (LANL 1992, 0783).

A large canyon-bottom area included several firing points in which shots containing small amounts of radioactive materials were fired. During the 1960s, the site was sampled and remediated under the DOE's Formerly Utilized Sites Remedial Action Program (Mayfield et al. 1979, 0818). As a result of this work, there is a good data base for residual radioactive contamination but not for other possible contaminants, particularly metals. The site is potentially suitable for residential development.

A baseline risk assessment that uses a residential exposure scenario is planned for this site, which implies that it is necessary to estimate average contamination levels over rather small exposure units (each less than 1/5 acre in size, of which several hundred are within range of the former firing points) and to make decisions about whether to clean up or to investigate further on a unit-by-unit basis. New environmental data (for metals, HE, and by-products) are needed to supplement existing radionuclide data.

Large false negative error rates cannot be tolerated for this public area. Fortunately, both the conceptual model and the existing data suggest a fairly continuous distribution of contaminants around the firing points, which can be exploited in the design of a sampling plan. Because the site is so large, the proposed approach is to use kriging to predict contaminant levels by exposure units, which requires fewer than one observation per exposure unit if the contaminant distributions are as continuous as suggested by the existing data (LANL 1992, 0783). A design-based approach to this problem would require a minimum of one composite sample per exposure unit.◊

6.3 "Hot-Spot" Sampling

At some point during the RCRA process, it may be necessary to define the problem as one of locating small but highly contaminated areas or volumes. The only known approaches to this problem are very resource-intensive unless inexpensive yet effective field survey methods are available.

Sampling designs for this "hot-spot" detection problem are usually based on regular grids (typically rectangular or triangular; the latter are somewhat more efficient). The grid spacing is determined by specifying the desired probability for detecting a contaminated area as a function of its size. Gilbert (1987, 0506, Chapter 10) discusses the determination of grid spacing, including several nomograms for determining the probabilities of detection and one graph that can be used for cost/benefit analysis.

Grid spacings must be comparable to (within about a factor of two) the radius of a contaminated area in order to have a reasonably high probability of detecting that area, and, therefore, very fine grids are required if small hot spots are of potential concern. The necessity of very fine grids limits the appropriateness of hot-spot sampling for RFI work. However, the technique may have more utility during CMS and CMI, when the area under consideration has been better delineated and it becomes important to minimize the amount of unnecessary remedial work.

6.4 Determining What Fraction of a Site Is Contaminated

The binomial sampling strategy described in Section 4.2 is the simplest form of a nonparametric approach to the problem of estimating the proportion of a site that exceeds an action or cleanup standard. In later phases of the RCRA process, particularly in verifying the attainment of cleanup standards, more data may be collected, and more efficient tests—in particular, tests that control the probability of false positives as well as false negatives—can be devised. Several such tests, including sequential versions that could be applied during site cleanup, are discussed in EPA guidance (EPA 1989 0794, Chapters 7 and 8).

An approach that is similar to binomial sampling consists of coding each observation as a 1 or a 0, depending on whether the observation exceeds the specified standard. The test statistic is then the sum of these codes, which is just the number of "exceedances" of the standard in the total sample of size n. If the proportion of zeros is sufficiently large, the site can be considered acceptably clean, even if there are some ones in the sample. This approach typically requires 30 to 100 observations (EPA 1989, 0794, Tables A.7, A.8, and A.9), depending on acceptable bounds of error.

The second approach, which requires making an assumption about the form of the probability distribution of the outcome variable (e.g., normal, log-normal), is to estimate a confidence interval for a percentile of this distribution. For the tail percentiles that are usually of interest (often the 90th or above), the correctness of the assumption is critical; thus, use of this method must be preceded by a test of the assumption, something that also requires a substantial number of observations (several tens, at least.)

7.0 STATISTICAL DATA QUALITY ASSESSMENT

Any process for assessing data adequacy must start by carefully defining what is meant by adequacy. Ideally, criteria for determining data adequacy will have been developed before designing a data collection program. Use of the DQO process ensures that a full set of design specifications is developed, including the level of uncertainty acceptable in the decision to be made. These limits on uncertainty define data adequacy (sufficiency) for decision making.

Statistical data quality assessment as described here and as developed by the EPA (van Ee 1990, 1052; Clayton 1992, 1059; Michael 1991 et al., 1051) can greatly increase the level of confidence decision makers have in deciding whether a data set is sufficient to support their decisions and whether a design should be reused for a similar application. The formal data quality assessment process described below should be applied whenever the outcome of a study is not immediately clear. If data reveal an obvious problem or nonproblem, a partial check on the design assumptions may suffice. In all other circumstances, a data quality assessment should be carried out after data have been collected but before the results are delivered to the decision maker.

Figure H-2 illustrates the three major inputs of the data quality assessment process described in this appendix: the project DQOs, the statistical assumptions made to develop a design, and an estimate of the total error associated with the data upon which a decision will be made. If an input is missing or incomplete, the process requires the assessor to develop that input before analyzing the data. For example, if the statement that defines data adequacy is missing, the process suggests that this input be elicited by working with the data users.

The data quality assessment process as presented here consists of six sequential steps (Figure H-3) that lead to a determination of whether the data in question are sufficient for decision making. The description that follows focuses on *what* occurs during the data quality assessment process. Each step of the process is discussed to provide the reader with a clear picture of what each step accomplishes and why each step is important. It is beyond the scope of this appendix to explain *how the* statistical operations that are required at each step are carried out.

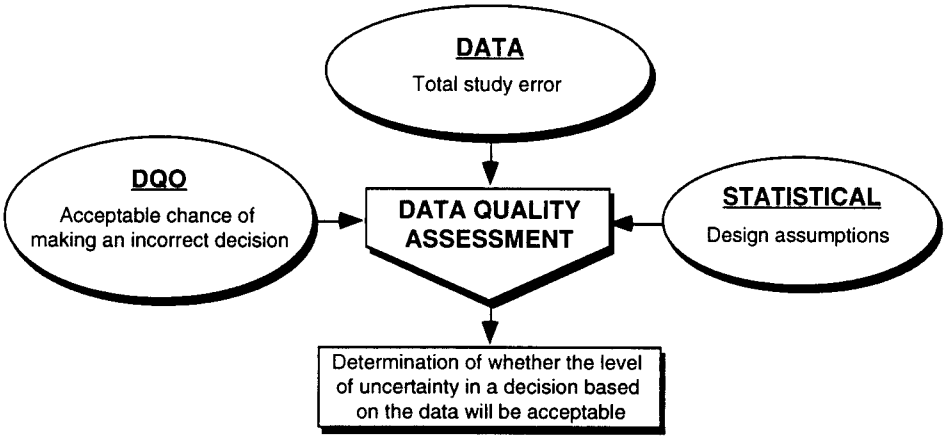

Figure H-2 Data Quality Assessment Process Flow

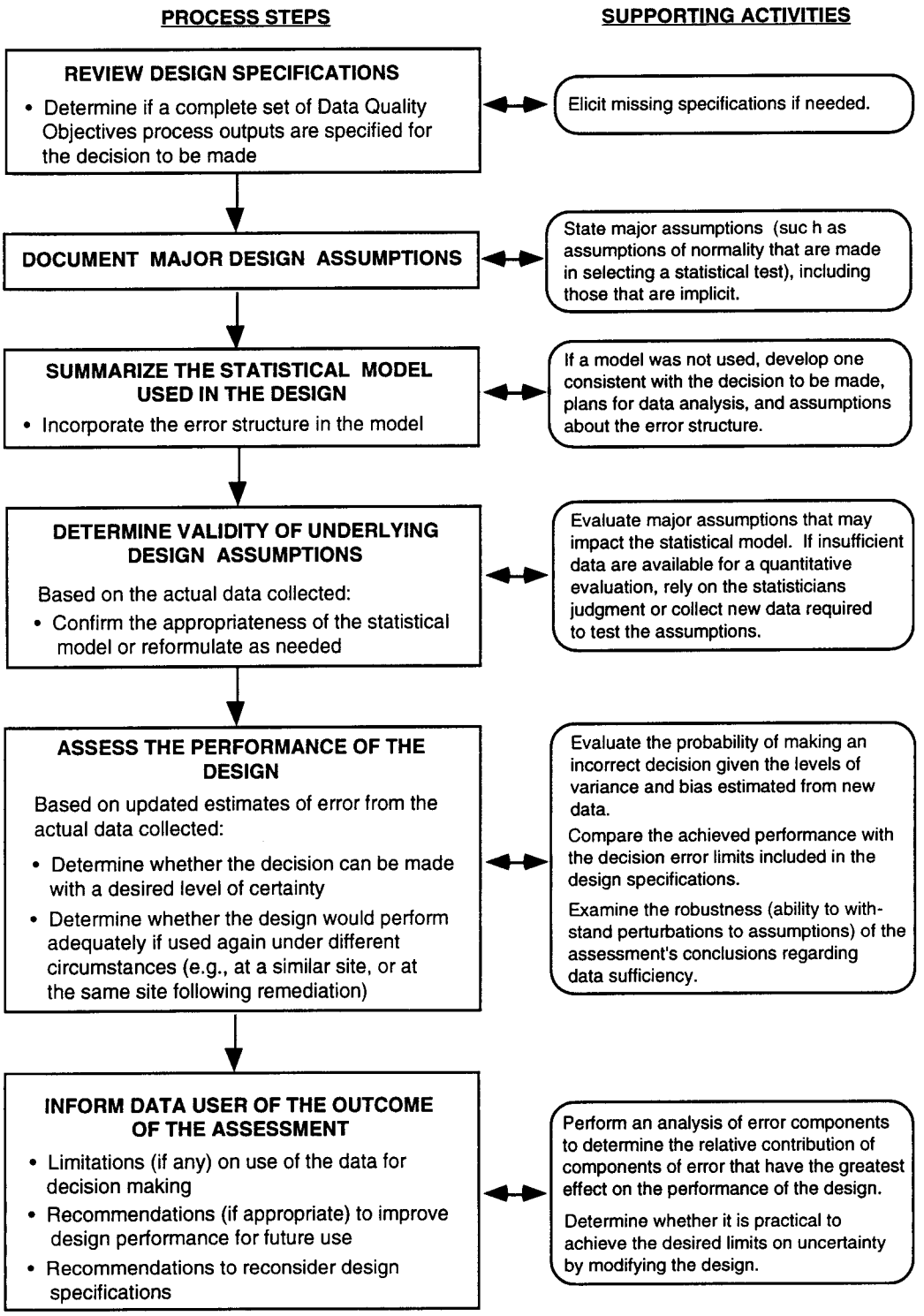

Figure H-3. Process flow in a statistical data quality assessment.

7.1 Step 1: Review Design Specifications

The first step is to ensure that the purpose for which the data were collected is clearly understood so that the measures of data quality that are most critical for this purpose are evaluated. This step involves a comprehensive review of planning and design documents such as DQO documentation, statistical design documents, work plans, sampling and analysis plans, and quality assurance project plans. Understanding the basis for the design requires either a complete set of DQOs, as described in EPA guidance (EPA 1992, 0981) and Section 3 of this appendix, or the equivalent information about what data are needed, how they will be used, and how good the results need to be to support the intended use.

Two outputs of the DQO process are critical inputs for performing a data quality assessment: the decision rule and the limits on uncertainty. A decision rule provides a complete description of how data (inputs) will be combined (in a summary statistic or result) and compared with some action level (decision criterion) to make the decision for each subpopulation or area defined (the boundaries) in the DQO process. Limits on uncertainty specify the probability that the data user is willing to accept of making an incorrect decision. Limits are expressed for both false positive and false negative decision errors as a function of the magnitude of various error scenarios considered to be within the realm of possibility.

If the review of design specifications indicates that critical specifications are incomplete, a retrospective elicitation of these specifications is needed. In specifying the decision rule, a statistician should work with the data users to determine how they think data should be used. The statistician can suggest different approaches (use of means, medians, etc.), and the implications of the choices can be discussed. Limits on uncertainty should reflect the decision makers' evaluation of the consequences associated with each type of decision error. The DQO process guidance (EPA 1992, 0981) describes a step-by-step process for eliciting limits on uncertainty. It is preferable to elicit acceptable error rates before discussing the error rates actually achieved or the results of any statistical analysis on the data.

7.2 Step 2: Document Major Design Assumptions

Translating the decision rule and accompanying limits on uncertainty into a statistical design requires a number of additional assumptions. To the extent that these assumptions fail, the performance of that design may be affected. All assumptions explicit and implicit to the formulation of the problem should be clearly stated. Many of these assumptions will then be evaluated based on the field data and corresponding quality control data collected.

Some or all of the following common assumptions are used in designing a sampling plan to collect the data:

- The total study error is of a given magnitude.
- Observations are unbiased (or all data are corrected for bias).
- The distribution of the outcome variable is known (e.g., the measured variable is normally distributed).

- The observations are independent of one another.
- The sample design is randomized.

Additional assumptions might be made about homogeneity of variance among areas of interest (decision units), the degree of homogenization achievable through compositing, the structure and relationships among error components, or parameters of a nonstatistical model that might be used as part of the decision rule.

7.3 Step 3: Summarize the Statistical Model used in the Design

After formulating the decision rule and specifying the underlying assumptions, a detailed statistical model is formulated to describe the statistical test that will be used to analyze the data. The components of this model are the statistical test to be used (e.g., a one sided t-test of the equality of two means) and the parameters that will influence the outcome of the test (e.g., the variance component of total study error and the sample size). The model should also break out the major sources of variability that contribute to the total variance term used in the statistical test, including the assumed error structure and an algorithm capable of calculating this total.
Ideally, this statistical model should be developed during the design phase so that it can be used to estimate the expected performance of alternative designs. If such a model was developed before the data were collected, the goal of Step 3 is to summarize the model used in such a manner that it can be easily exercised with the actual data generated. If no model was developed during the design phase, or if the developed model is incomplete or overly simplified, then one will need to be developed during Step 3.

Documenting the statistical model is a key step both in optimizing sampling and analysis plans and in evaluating data adequacy. The model may take the form of a simple algorithm, or it may involve a complex computer simulation, depending on the complexity of the situation, the scale of the project, and the desire to test the effect of departures from the assumed conditions through sensitivity analysis. In particular, information from sensitivity analysis can be used in designing the quality control program to focus on those components of total study error that are of the greatest relative importance.

7.4 Step 4: Determine the Validity of Underlying Design Assumptions

If the outputs of the previous three steps are readily available, as should be the case for studies that used the DQO planning process to develop a statistical design, this step is where the post-data collection data quality assessment process actually begins. Each major assumption on which the statistical design model hinges is evaluated in this step. Assuming that adequate supporting data are available, quantitative analyses are performed to test the assumptions.

If a parametric statistical model has been used to develop and evaluate the design, the assumptions that should be evaluated first are those related to the assumed error structure, the assumed zero bias, and the assumed distribution of the parameter of interest. For example, if a t-test of means is to be conducted, then, at a minimum, the statistical model assumes zero bias. It also assumes that random errors contributing to the total study variance are additive, uncorrelated, and normally

distributed with homogeneous variance. To determine the validity of each underlying assumption, a series of analyses is performed. To the degree that data can support graphical analyses, plots are often useful tools for assessing assumptions. Simple histograms of the data can reveal gross departures from a symmetric, normal distribution. For models with many error terms, plots of the standard deviations for the error terms versus the group mean concentrations are useful for determining whether errors appear to be additive (the standard deviation would not appear to be correlated with concentration).

If assumptions underlying the original model (e.g., a parametric test) are found to be invalid, the data quality assessment process may nevertheless continue. Data transformations and other alterations of the statistical model may be considered to make the assumptions more reasonable. For example, nonparametric analogs that do not make distributional assumptions can be considered. However, whenever a different model is to be applied, care should be taken to document and test the validity of whatever new set of assumptions needs to be made and to consult the data user to ensure that the proposed model still addresses the environmental problem.

The amount of effort expended in verifying assumptions varies. For example, if the results reveal concentrations orders of magnitude higher than a threshold of interest, assumptions about analytical recovery do not need to be tested. However, it might be appropriate to investigate the assumption that samples have not been contaminated by analyzing blank quality control samples. If, on the other hand, concentrations are close to the threshold of interest, more attention to the validity of assumptions regarding bias is called for. If a computer simulation has been conducted to evaluate performance of the design, then the same program can, and probably should, be used to test the effect of invalid assumptions. The data quality assessment effort can then be focused on testing those assumptions to which the simulation outcome is most sensitive.

In some cases, the available data will be inadequate to perform meaningful statistical tests of assumptions. For example, if the degrees of freedom associated with a specific test are very small and the investigator is attempting to test the null hypothesis that an assumption is true (e.g., samples are independent), a very strong correlation would need to exist to reject the null. In cases where supporting data are not available, it may be necessary to rely on the judgment of the statistician or the project team, coupled with the results of a sensitivity analysis of the model in use. As a last resort, additional data can be collected specifically to test an assumption believed to be critical to the outcome of the study.

7.5 Step 5: Assess the Performance of the Design

Provided the underlying assumptions of the initial model are reasonable or the model can be reformulated to be consistent with the observed conditions, the next step of the data quality assessment process entails assessing the performance of the design. In this step, data generated as part of the study are used to obtain estimates of total study error. These estimates then become inputs to the statistical model and are used to perform the statistical test upon which the decision will be based. They are also used to evaluate the general performance of the design. After the achieved design performance has been evaluated, one or both of the following questions can be answered:

- Can the data be used to make the decision (for each area of interest) with the desired level of confidence?

- Does the design perform adequately over the entire range of interest specified in the DQOs for the study?

The answers to both questions are directly affected by the total study error and by the number of independent observations included in the summary statistic.

For models involving a simple hypothesis test, data are used to perform the test at a significance level consistent with limits on uncertainty expressed in the project DQOs. One of two outcomes is possible: the null hypothesis is accepted or rejected. A test might result in acceptance of the null hypothesis either because the data are too variable to disprove the conditions established as the null or because data are clearly consistent with the null. In either case, the null hypothesis is accepted. The data quality assessment evaluates the probability that accepting the null hypothesis is the wrong decision by calculating the statistical power that the test had for rejecting the null hypothesis, given the estimate of total study error and the number of independent samples taken. If a test results in the rejection of the null hypothesis at the desired significance level, the data are usually sufficient to support that decision because false positives are controlled directly through the significance level specified for the test.

Figure H-4 illustrates the expected performance of a design relative to the acceptable level of uncertainty as expressed in a discomfort curve. In this case, the data user has specified that a mean concentration value will be generated for each area of interest and will be compared with a risk-derived target concentration level to determine whether to take action. The acceptable false positive and false negative error rates (the "discomfort curves") are determined by the decision maker's requirements as a function of a number of hypothetical "true" conditions (mean concentrations of specific compounds that might be present in the area). As this hypothetical mean value increases above the target level, the discomfort curve indicates that a higher and higher probability of data leading to a decision to take action was desired. Stated another way, the probability of deciding not to take action when action should be taken should get smaller and smaller as a function of the severity of the hypothetical problem.

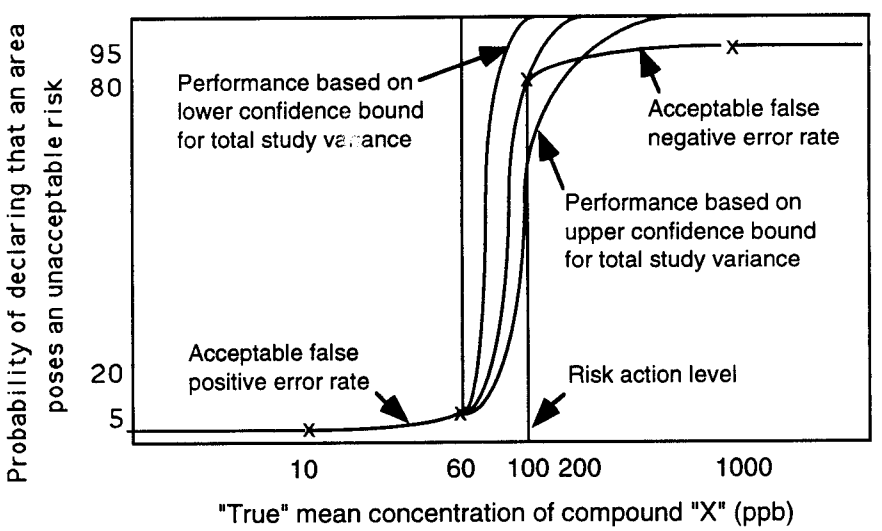

Figure H-4. Expected performance of a design: power curves and acceptable error rates.

To address the question of the adequacy of design performance, the expected design performance must be evaluated across the full range of conditions depicted on the X-axis of the discomfort curve. In the example shown in Figure H-4, when the point estimate of the total study variance is used to estimate the design performance, the design appears optimal in that it achieves or exceeds the desired control of false negative errors over the full range of values considered. However, when an upper-confidence-bound estimate of the total study variance is used, the design appears to fail over a small set of values ranging from approximately 100-200 ppb. Here, the probability of a false negative decision is greater than desired. Therefore, before arriving at a final decision that data are sufficient, the sensitivity of that conclusion to error in the estimate of total study error must be considered.

The fact that a design is expected to fail over some range of potential values does not necessarily mean that the data are inadequate to make a decision. For example, if the outcome of the study considered in Figure H-3 is a mean value in excess of 300 ppb or less than 100 ppb, the design achieves the desired control of decision errors. In other words, situations exist in which the answer to the first question is that data are adequate to make the decision, and the answer to the second is that the design may be inadequate under circumstances different from those observed.

If bias is detected and no correction in the data has been made, the impact of bias on design performance should also be considered. In general, uncorrected bias in the data shift the power curves in one direction or the other. The robustness of the conclusions of the data quality assessment can be determined by reassessing the design performance under a range of possible conditions (levels of total study variance and bias). If the conclusions are extremely sensitive to some error component and the confidence in that estimate is fairly low, the data quality assessment process may indicate the need to gather additional data in order to gain the desired level of confidence.

7.6 Step 6: Inform Data User of the Outcome of the Assessment

After the analytical aspects of statistical data quality assessment have been completed, the results of the assessment must be documented and communicated to the data user. A full explanation of any conclusions reached based on the assessment should be transmitted. As depicted in the example presented in Figure H-4, the answer to the question of whether the data are sufficient for decision making may not be a simple yes or no. The level of confidence in the outcome should be discussed. Any and all limitations on the intended use of the data should be included. In cases where the design may be used again, either at the same site after some cleanup has taken place (e.g., to verify cleanup) or at a similar site, the report should include recommendations for improving the design. For example, more samples may be recommended or a more efficient sample allocation strategy may be used. If the data quality assessment reveals that the data are insufficient and if information is available to permit a diagnosis of why the study failed, the outcome of these analyses should be included to help the data user understand which assumptions were faulty and where excessive error entered the data.

In some cases, the probabilities of incurring a decision error are only slightly higher than desired. In other cases, a careful assessment of the design reveals that, to achieve the desired control on decision errors, sample sizes would need to be so much larger that it would be impractical to gather the data. In either of these cases, the report may suggest relaxing the DQOs and living with more uncertainty.

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■ APPENDIX I

Decision Strategies for Environmental Restoration

1.0 INTRODUCTION

As described in Chapter 1 of this Installation Work Plan (IWP) for Environmental Restoration (ER), the Hazardous and Solid Waste Amendments (HSWA) Module of the Los Alamos National Laboratory's (Laboratory's) permit to operate as a treatment and storage facility (EPA 1990, 0306) specifies a three-step corrective action process: the Resource Conservation and Recovery Act (RCRA) facility investigation (RFI), the corrective measures study (CMS), and corrective measures implementation (CMI). At each step, there are a number of alternatives for action at a potential release site (PRS) or for gathering more information about contamination at a site. Choices among the alternatives are difficult because of uncertainty from many sources and because of the existence of multiple stakeholders, multiple goals, and strict regulatory requirements.

This appendix discusses the overall decision process, together with formal procedures that can aid the selection of strategies in this complex situation. In particular, this appendix describes decision analysis as a supporting and integrating tool. Decision analysis is a philosophy, a theory, and a set of practical procedures for decision making. It provides a systematic method grounded in a set of widely accepted, formal axioms for quantifying sources of uncertainty, defining scales for measuring outcomes, quantifying the value of different decision strategies, and identifying optimal decisions based on multiple objectives.

1.1 Overview

Four factors contribute to the difficulties that arise while structuring and evaluating RCRA corrective decisions in the ER Program at the Laboratory. One factor is the number and diversity of stakeholders in the cleanup process, including regulatory agencies, Laboratory employees, and the public. A second factor is the significant uncertainties that result from incomplete information about historical activities at the site, changing physical characteristics of the site, incomplete understanding of the health impacts of contaminants, inexact forecasts of future uses of sites, and other influences. Even with the best mathematical and computer models to forecast the current state and long-term fate of contaminants, these uncertainties cannot be eliminated completely. A third factor is the existence of multiple objectives for the cleanup effort. Public and worker health and safety must be protected, ecological systems must be preserved, costs must be held at a responsible level, facility operations must be maintained, and socioeconomic impact must be minimized. Finally, the decision process must be structured to meet RCRA regulatory criteria.

The RCRA permit regulates not only the physical waste site but also the process of making decisions regarding the waste site. The RCRA permit for the Laboratory states that "The Permittee shall prepare a plan to ensure that all information, data, and resulting decisions are technically sound, statistically valid, and properly documented." According to the RCRA permit, the process of identifying corrective actions must consider "site-specific objectives for the corrective action...based on public health, the environment, information from RFI, EPA (Environmental Protection Agency) Guidance and the Federal statutes" and must review "a workable number of options that each appear to adequately address all site problems and objectives." The RCRA permit further states that the program must describe the "alternatives and tradeoffs among the evaluation criteria."

In summary, the decision process must be logically sound and consistent. It must support the generation, evaluation, and recommendation of alternatives in light of program objectives, as well as account for multiple stakeholders, multiple evaluation criteria, uncertainty, and risk. This appendix reviews the decision tools available to help the ER Program at the Laboratory meet these requirements.

1.2 The Corrective Action Decision Process at the Laboratory

Figure I-1, a diagram of the RCRA corrective action process, illustrates the general decision flow and the decision alternatives for the RFI/CMS/CMI process, including the possibilities for action and for gathering and evaluating information throughout the decision-making process. Each rounded rectangle in this diagram describes an information-gathering or PRS treatment action in the decision process. Each diamond represents an information evaluation point. The arrow to each action is labeled by a description of the information evaluation result that leads to that action.

In general, the corrective action process moves from the actions in the upper left-hand corner to those in the lower right-hand corner. The starting point of the general decision diagram is the archival information node. After reviewing the archival information, the decision maker(s) may decide to proceed immediately to one of the final actions, that is, to take no further action (NFA) under the ER Program, to defer action, or to remediate based on available information. The criteria for NFA and deferred action are explained in more detail in Section 4.1 of this appendix. Voluntary corrective action (VCA) (remediation without conducting a formal CMS) is appropriate when the site may pose a hazard, when the corrective measure is obvious, and when it is less expensive to remediate than to undertake a complete site characterization.

Archival information is usually not sufficient to select one of the alternatives listed on the right-hand side of Figure I-1, and the decision maker most often proceeds with further characterization of the site. RFI site characterization usually proceeds in several phases and, once the site is sufficiently well understood, leads to a baseline risk assessment. The RFI site characterization and risk assessment then lead to one of the options for action already considered or to a formal CMS to select and design the most appropriate and effective corrective action. Site characterization may continue into the CMS and CMI phases of the RCRA process, although the later data collection activities focus on site characteristics that affect particular corrective measures.

In summary, each information evaluation during the RFI has the potential of leading to a treatment action (NFA, deferred action, or remediation), of jumping ahead to a later stage of information gathering, or returning to an earlier stage of information gathering. This decision-making approach permits economy in gathering information and flexibility in the response to new information.

2.0 DECISION SUPPORT TOOLS FOR THE ER PROGRAM

The Laboratory's streamlined approach for environmental restoration consists of the coordinated use of a set of decision tools, including data quality objectives (DQOs), risk analysis, and decision analysis, to implement the observational approach described in Appendix G. DQOs and risk analysis are described in detail in Appendices I and K, respectively. They are reviewed briefly in this section in order

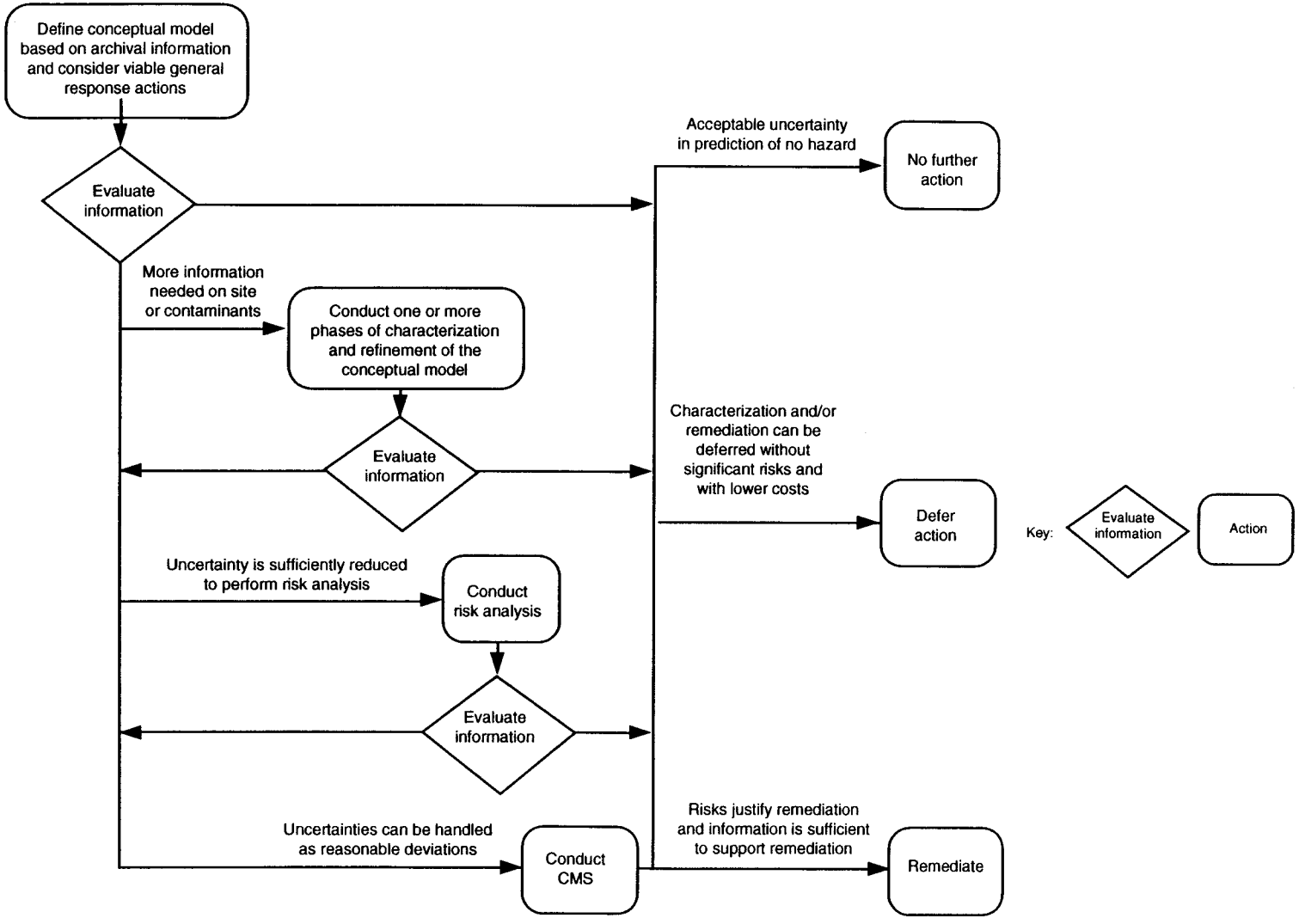


Figure I-1. General decision flow and decision alternatives for the corrective action process.

to discuss their integrated use and how decision analysis supports their use. Decision analysis and its applications are then described in more detail in Section 3.

The observational approach, which provides the rationale for the streamlined approach to environmental restoration, recognizes the uncertainties inherent in the many decisions that must be made during the process of environmental remediation and the impossibility of completely eliminating uncertainty. It emphasizes that complete information is an unreasonable goal; information should be gathered only to the extent necessary to make a specific decision and to move forward in the remediation process. In particular, the observational approach advocates the phased collection of information, not only during the RFI but also during the CMS and CMI. Phased collection of data helps ensure that unnecessary data are not collected and that the level of detail specified for each data collection activity is appropriate for the current stage of the RCRA process. It promotes decision making that is neither premature nor delayed and demands efficient, adaptive decision making.

The DQO process is a series of steps leading from the definition of a contamination problem and a set of decision alternatives through the formulation of an appropriate hypothesis about the site to the design of a sampling and analysis plan that provides data to test the hypothesis. Using this approach, the investigator bases intermediate sampling decisions (e.g., the number of observations and analytical precision required) on explicit definitions of "acceptable" uncertainties for each decision. Because the DQO process links sampling decisions to a specific remediation decision and develops the most cost-effective sampling plan to resolve a problem satisfactorily, the process is a useful tool for implementing the observational approach.

Risk assessment is the determination of the human health and environmental risks imposed by contamination. Risk assessment considers (1) pathways through the environment that contaminants might follow to reach potential receptor populations, (2) possible land uses and receptor activities at the exposure points, (3) exposure routes (e.g., ingestion, inhalation), (4) the toxic properties of materials, and (5) the health and environmental impacts of contaminants. The outcome of a risk assessment is both an evaluation of the risks posed by a contaminated site and an understanding of the physical factors that create those risks. Risk assessments help to implement the observational approach by allowing decisions to consider the impact of contamination at a site as well as the level of contamination.

Decision analysis is a formal, quantitative process for structuring, analyzing, and communicating decisions in complex, uncertain environments. Decision analysis breaks the decision into components and structures the components in a decision model. The decision model logically integrates what one can do (decision alternatives), what one knows and does not know (uncertainties), and what one wants (values). Once created, the decision model can be exercised to provide insights and directions for action.

Decision analysis directly supports the observational approach by calculating the value of progressively reducing uncertainty when evaluating alternatives. To do this, decision analysis first defines a single measure of value based on multiple decision criteria, including health and safety, environmental impacts, managerial concerns related to operations and compliance, public concern, and cost. This value measure can be used not only to evaluate the decision alternatives but also to determine the value of additional information, taking into consideration the losses caused by making a bad decision, the current likelihood of choosing the best decision, and the improvement in that likelihood that may be obtained by gathering more information.

Decision analysis supports the DQO process by developing definitions of the value of additional information and accuracy. The value of information provides a basis for determining the appropriateness of different "discomfort curves" and "acceptable" errors used by DQOs in sampling design.

Decision analysis supports risk assessment by helping to integrate health and safety risks with other measures of benefits and costs. Decision analysis can also provide tools for developing estimates of uncertainties relevant to risk assessments and for calculating risks in complex situations.

3.0 OVERVIEW OF DECISION ANALYSIS

Decision analysis is a widely accepted approach for analyzing major public policy issues, which has been used by government agencies, including DOE, EPA, and the Department of Defense, and by many individual DOE facilities to address a great variety of problems. In the ER Program, it offers a framework for a consistent and efficient installation-wide RFI/CMS/CMI process, as well as tools for addressing problems in individual operable units (OUs). It provides a set of procedures for assessing and analyzing decision alternatives that takes into account the experience, knowledge, and objectives of the decision maker(s) and the risks present in the decision. Basic references on decision analysis include Making Hard Decisions: an Introduction to Decision Analysis (Clemen 1991, 0808) and Decision Analysis (Raiffa 1968, 0812).

Figure I-2 is an illustration of a very simple decision model. The decision alternatives, shown on the left side of the diagram, are to remediate or not remediate the site. There is one uncertainty: whether the site is contaminated or not contaminated. As shown in Figure I-2, the best information currently available has led to the belief that the probability of contamination is only 0.01 (a probability of 0.99 that the site is not contaminated). Values are listed at the far right. In the following sections, the process for constructing and using such a model is discussed.

3.1 The Decision Analysis Process

The cycle for developing and using the decision analysis model consists of five basic steps. (The process is referred to as a cycle because frequently the result of one pass through the steps outlined below is a decision to gather more information or to create a new alternative and then reanalyze the problem.)

1. Problem Formulation

   In the problem formulation step, the decision maker (or decision team) defines the decision problem and lists the decision alternatives, reviews the uncertainties that complicate decision making, and describes the objectives guiding the decision (objectives are quantified through values later in the cycle). The result of this step is a conceptual (i.e., not yet quantitative) version of the decision model. The conceptual decision model behind the tree in Figure I-2 has the following components:

   - decision problem: should the site be remediated?
   - decision alternatives: remediate or do not remediate the site;

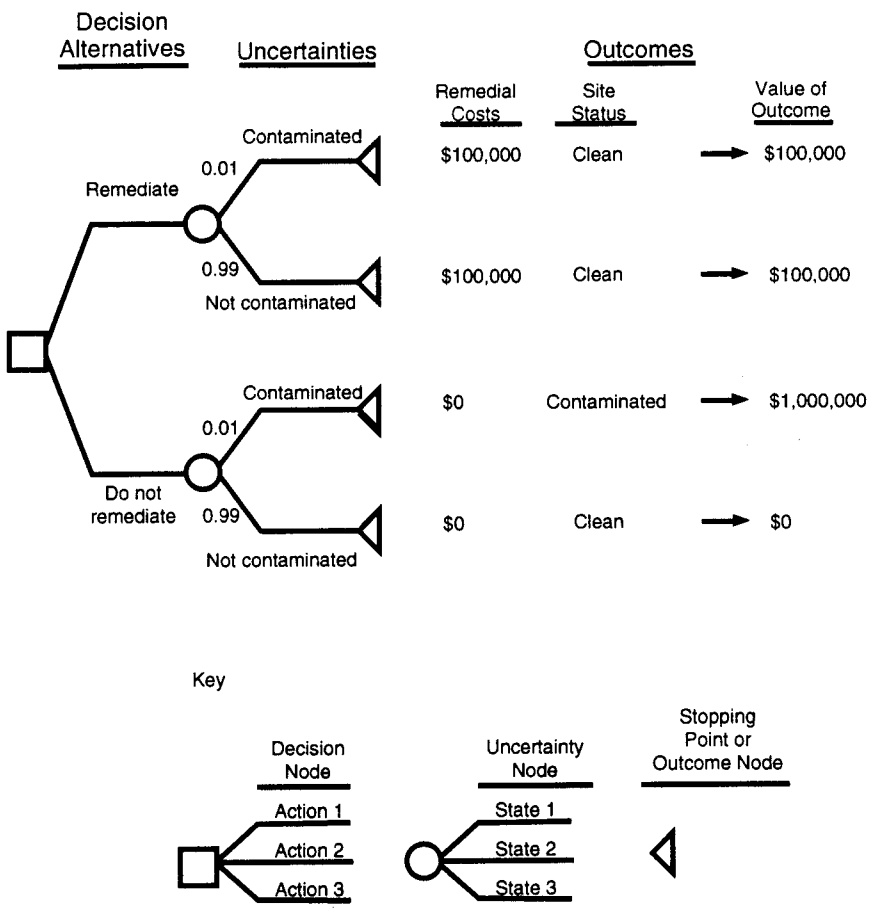


Figure I-2. Simple decision tree.

- uncertainties: whether the site is contaminated;
- objectives: minimize health risk and minimize costs.

More general decision alternatives that arise in the course of the RCRA process are enumerated in Section 3.2 below. Programmatic objectives are discussed in Section 3.3. Section 3.4 presents a generic conceptual decision model that could be applied in the ER Program.

2. Deterministic Modeling

The deterministic model computes a single value for each combination of decision alternatives and uncertainty states (a state is a particular resolution of an uncertainty). Figure I-2 shows four such combinations, each corresponding to one state of the uncertainty (whether the site is contaminated) and one decision alternative (remediate or do not remediate). The deterministic model can be further broken down into structural models that may determine multiple final outcomes and value models that determine a single value for each combination of final outcomes.

A structural model calculates an outcome that follows from the selection of each of the alternatives, given the states of the uncertainties. For example, in a financial analysis, the structural model might include statements such as "profits equal revenues minus costs." For the example in Figure I-2, the structural models are contained in the following four statements:

- Remediating the site costs $100,000.
- Not remediating the site costs $0.
- Contaminated sites that are not remediated have high human health effects.
- Uncontaminated sites and contaminated sites that are remediated have low health effects.

In the ER Program, structural models needed for corrective action decisions include, at a minimum, a cost model and a risk assessment model; that is, there are at least two types of final outcomes—dollar costs and human health effects—that must be modeled. There may also be structural models for environmental impacts or other final outcomes of importance.

The value model provides a single measure of value for any set of final outcomes. In ER Program decisions, the value model is particularly important because of the many disparate final outcomes of concern, such as dollar costs and human health effects. Multiattribute utility analysis (Keeney and Raiffa 1976, 0809) is the technique used by decision analysis to construct value models that can balance in a logical, defensible way the multiple final outcomes of concern to the ER Program. Tools used by multiattribute utility analysis to support value modeling are objectives hierarchies. These hierarchies link top-level, general objectives to more detailed and concrete objectives and scales, which are detailed descriptions of uncertainties or final outcomes.

The objectives hierarchy for the example in Figure I-2 consists of two objectives: minimize health risk and minimize costs. One simple, defined value scale appears in the example. It describes the final health risk outcomes and has two states: low and high health effects. In an actual study, value scales would be defined in much more detail.

The value model in the example is straightforward. The model assigns a value of one unit to each dollar spent, zero unit to low health effects, and one million units to high health effects. The single value (actually a "cost" in this example, which is something to be minimized, not maximized) associated with each set of final outcomes is shown in the right-hand column of Figure I-2. The tools for value modeling are discussed further in Section 3.3.

Deterministic models are often used for "what if" analyses, in which uncertainties are set to a wide range of states so that their impact on the final outcomes can be examined. When final outcomes are minimally affected by a particular uncertainty, that uncertainty may be fixed at a single state and thus may be given less attention in later stages of the analysis.

3. Probabilistic Modeling

In the probabilistic modeling step, the descriptions of important uncertainties in the decision model are expanded to probability distributions over their possible states. When historical or experimental data are available, they can be used to help specify appropriate distributions. In other cases, probabilistic descriptions rely on the opinions of unbiased experts. Decision analysis offers both formal and informal procedures for eliciting these probabilities from experts (Merkhofer 1987, 0811), and a number of computer programs have been developed for recording, combining, and analyzing the probability information gathered in this step.

The one uncertainty in the example is whether the site is contaminated. The probabilistic model assigns probabilities of 0.01 that the site is contaminated and 0.99 that the site is not contaminated.

4. Value-of-Information and Other Analyses

In this step, a number of analyses can be performed by exercising the fully quantified (probabilistic) decision model. These analyses include

- determining the best decision based on current information,
- estimating the probable value of gathering more information,
- describing a "risk profile" that indicates the probability of occurrence of each possible final outcome,
- analyzing the sensitivity of the optimal policy to uncertainties in the model, and
- determining the value of controlling an uncertain variable.

In the example, the expected value of each decision can be calculated and used as a guide to decision making. Expected value is calculated by multiplying the value associated with each set of final outcomes by the probability of that set and summing the weighted values for each alternative. The calculations are as follows:

For "remediate site": (0.01 x 100,000) + (0.99 x 100,000) = 100,000.

For "do not remediate site": (0.01 x 1,000,000) + (0.99 x 0) = 10,000.

According to this analysis, the probability and value (cost) of high health effects are too low to justify cleaning the site.

The value of perfect information on site contamination can also be calculated in the decision model. If it is known that the site is contaminated, the site should be cleaned, with a resulting value (cost) of 100,000. If it is known that the site is not contaminated, the site is not to be cleaned, with a resulting value (cost) of 0. The expected cost with perfect information is the sums of the costs of responding to each state times the probabilities that each state will occur:

Expected value (cost) with perfect information: (0.01 x 100,000) + (0.99 x 0) = 1,000.

The value of perfect information is the difference in the expected values with and without perfect information:

Value of perfect information: 10,000 - 1,000 = 9,000.

The value of perfect information is the maximum that should be paid for information gathering. In this case, if the value (cost) units can be interpreted as dollars, the cost is no more than $9,000.

5. Decision

The final step of the decision analysis cycle is to make and communicate a decision. It is especially important to present the results and insights gained from the analysis clearly in order to back up the recommended action. Decision analysis uses graphical devices such as influence diagrams, decision trees, sensitivity charts, and risk profiles to facilitate communication of the decision.

3.2 Decision Alternatives in the ER Program

This section provides a list of the decision alternatives in each step of the ER Program.

3.2.1 RFI Decision Alternatives

The RFI step of the corrective action process is defined to include decisions made when planning the RFI, decisions made at the conclusion of the RFI regarding future action at the site, and the intermediate decisions on sampling or action at the site.

After archival review, five main alternatives exist for the RFI work plan:

- based on archival information, propose NFA;
- propose deferred action;
- propose VCA, with or without a very limited RFI investigation;
- proceed with a CMS;
- propose a Phase I investigation.

If NFA or deferred action is chosen, few additional decisions need to be made at this point. The alternatives, CMS and VCA, are described in Chapter 4. In the event that a Phase I investigation is chosen, a number of additional sampling decisions must be made, which include

- whether the objective of Phase I is to determine

- presence or absence of contamination (e.g., in support of a proposal for NFA),
- extent of contamination (e.g., in support of possible VCA or eventual CMS),
- average level of contamination (e.g., in support of eventual baseline risk assessment), or
- offsite migration (e.g., in support of a proposal for deferred action);

- whether site-specific hydrogeologic or other properties of the environment need to be measured at this time (e.g., to characterize environmental transport pathways for assessment of risks to offsite receptors);
- what media to sample;
- what sampling techniques to use;
- what parameters to measure;
- what analytic methods to use;
- how many samples are needed; and
- where samples should be placed.

Phase I investigation is followed by evaluation of all information to select, if possible, one of the action alternatives (NFA, deferred action, VCA) or to select an information-gathering alternative (further characterization, risk analysis, or CMS). Frequently, several phases of site characterization occur during the RFI. The RFI ends when an action alternative (NFA, deferred action, VCA, CMS) is chosen and the extent of contamination is sufficiently understood to support baseline risk assessment and/or CMS, as required.

3.2.2 CMS Decision Alternatives

It is expected that less than 5% of PRSs will require a CMS/CMI. The CMS step of the corrective action process includes both the decisions made in planning the CMS and the decisions concerning the selection of a corrective measure for implementation.

The CMS plan must propose ways of evaluating corrective action alternatives for the site. The following categories of decisions are among those that need to be addressed when planning the CMS:

- whether additional site or contaminant characterization is needed to select and design an appropriate corrective action,
- which corrective methods and land uses should be considered in feasibility studies,

- what level of detail is appropriate for the feasibility studies,
- which corrective actions should be evaluated by bench- and pilot-scale tests,
- which corrective actions should be addressed by detailed engineering evaluations,
- for which potential deviations from probable site conditions should contingency modifications of the selected corrective action be developed, and
- what the schedule will be for conducting the CMS.

During the CMS, many corrective measures alternatives are available, including various combinations of monitoring, containment, in-situ treatment, removing contaminants (with treatment and disposal options), and land use restrictions (Chapter 4). The CMS concludes with formal definition of cleanup standards and the selection and design of a corrective measure to attain these standards, together with contingency plans that can be implemented if deviations from expected site conditions materialize.

3.2.3 CMI Decision Alternatives

This step implements the selected corrective measures. However, given the uncertainties that may still exist, several decisions will remain to be made, including

- whether an observed deviation from expected site conditions is sufficient to warrant implementation of one of the contingencies to the planned corrective action;
- when implementation of the selected corrective measure is complete, i.e., whether the planned cleanup levels have been attained;
- whether all dangerously contaminated material has been removed;
- whether containment barriers have been sufficiently extended; and
- whether the long-term effectiveness of the implemented corrective measure meets expectations.

3.3 RCRA Evaluation Criteria

The values of the decision maker are incorporated in the decision process through an objectives hierarchy and scales that allow measuring a state or the level of a final outcome. A suggested objectives hierarchy for the Laboratory is shown in Figure I-3. The top level of the hierarchy is a list of key concerns for evaluating alternative corrective measures (Chapter 4). Lower-level objectives identify the specific aspects of the higher-level objectives. The future performance of corrective

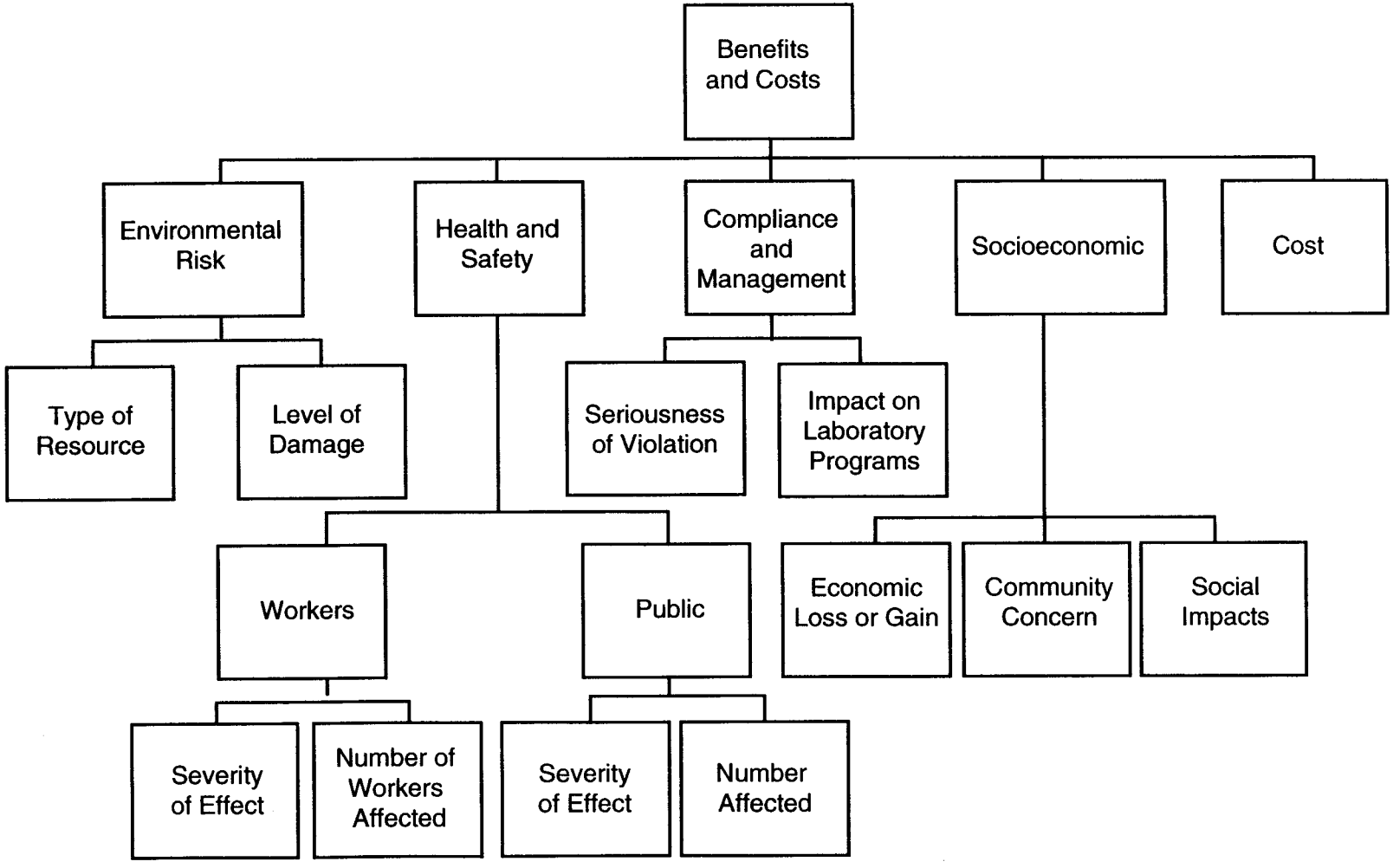


Figure I-3. Objectives hierarchy.

measures alternatives under consideration can be evaluated using scales that reflect the lowest-level, most concrete objectives.

The hierarchy shown in Figure I-3 is based on hierarchies developed to support the Laboratory's response to the Department of Energy's (DOE) Tiger Team findings (LANL 1992, 0810) and the prioritization of ER Program activities. Personnel throughout the Laboratory were interviewed individually and collectively over several months to develop these hierarchies. The hierarchies were reviewed by the Environment, Safety, and Health Council, other Laboratory managers, the ER Program manager, a set of OU project leaders (OUPLs), ER Program technical team leaders, and other ER Program personnel. The objectives reflect the major concerns identified in the RCRA operating permit, the IWP, and relevant federal regulations, as well as issues important to Laboratory operations.

To be able to use the objectives hierarchy in evaluating outcomes, scales must be developed that allow decision makers to clearly describe final outcomes. In some cases, natural scales exist. For example, dollars is a natural scale for communicating outcomes involving costs. In other cases, natural scales do not exist and artificial scales must be created. As an example, the following scale for measuring community concern might be used.

Level 1 The waste unit generates no public concern for the following reasons:

- People are not aware of the waste unit or of any problem that includes the waste unit other than the Laboratory as a whole.
- People are aware of a distinct problem but do not have any special concern beyond their concern about the Laboratory as a whole.

Level 2 The contaminated unit generates some public concern for any of the following reasons:

- There are occasional (several per year) news stories about the problem in the media serving the Los Alamos area, and the problem is discussed at community meetings.
- Claimed economic impacts on the community or on the Laboratory are less than $100,000 total or $10,000 annually.

Level 3 The contaminated unit generates moderately high public concern for any of the following reasons:

- There are monthly news stories about the problem in the media serving the Los Alamos area and occasional news stories in national media.
- The problem is frequently discussed at community and local government meetings.

- Claimed economic impacts on the community are less than $100,000 total or $10,000 annually.

Level 4 The contaminated unit generates very high public concern for any of the following reasons:

- There is frequent (more frequent than monthly) negative national news coverage about the problem and there have been large-scale protests.
- Claimed economic impacts on the community total on the order of $1,000,000 or more or $100,000 annually.

The NFA and deferred action criteria presented in Section 4.1 of this appendix illustrate a practical application of scales.

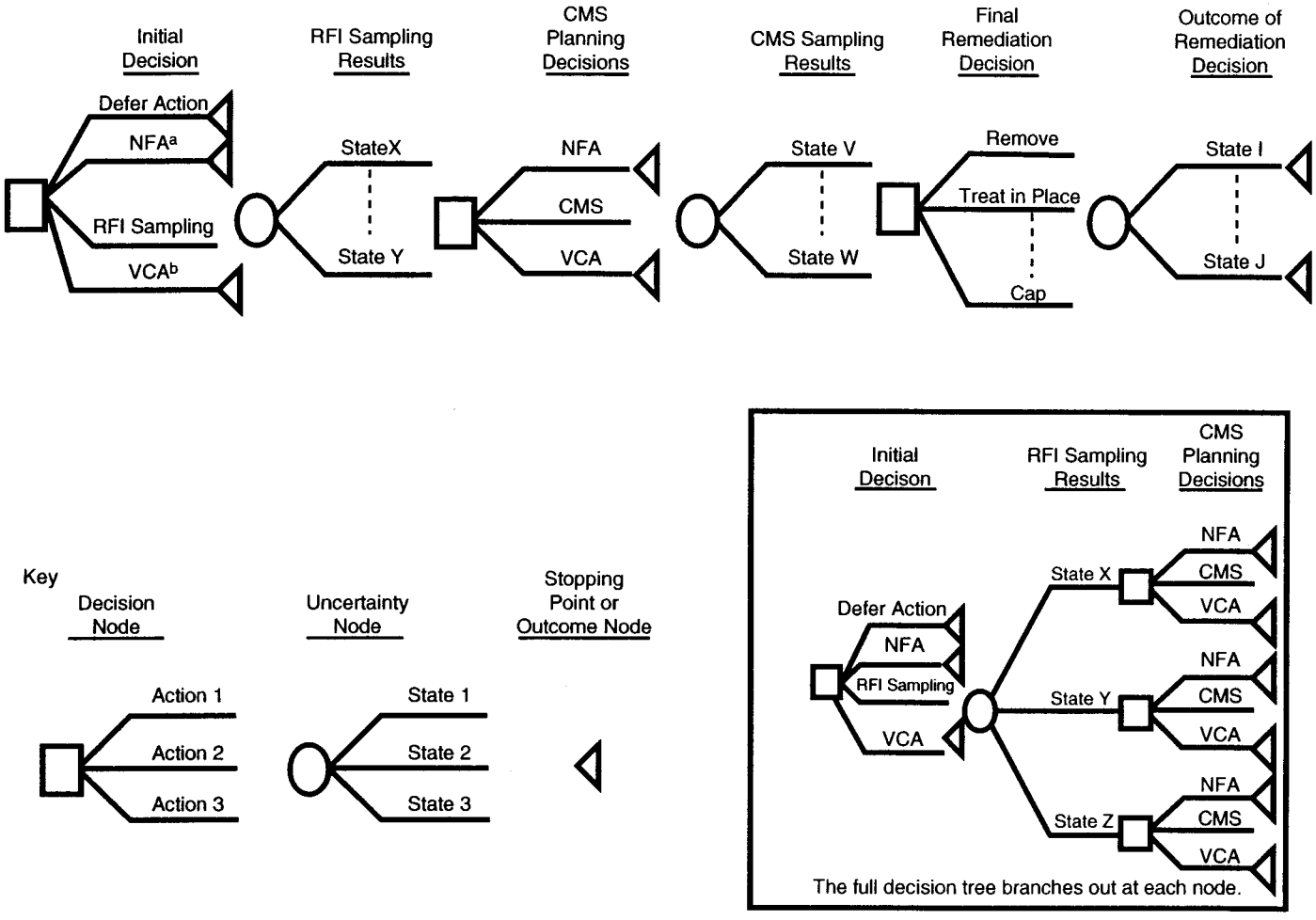
3.4 Application of Decision Analysis in the ER Program

This section describes a decision analysis model that could be used by the ER Program.

Figure I-4 shows a simplified decision tree that corresponds to the RCRA corrective action strategies process diagram shown in Figure I-1. Each branch of a decision node represents one alternative open to the decision maker. Each branch of an uncertainty node represents one possible state of the uncertainty described by that node and is associated with the probability of that state. Thus, uncertainty nodes are described in this tree by discrete probability distributions. Each outcome node describes a final outcome and is associated with the value of that outcome. The full diagram for a decision tree branches out to the right, as illustrated in the inset. Each branch that does not end in an outcome node is connected either to a decision node or to an uncertainty node, together with all of its branches. A path through the tree represents one unique set of decision alternatives and uncertainty states.

Figure I-4 greatly simplifies the RCRA decision process. As described in Section 3.2, there can be many RFI, CMS, and CMI alternatives. Figure I-4 lists only one or a few of each. Likewise, to fully represent the uncertainties during the RFI, CMS, and CMI, a number of uncertainty nodes, each with numerous branches, would be needed. Finally, Figure I-4 presents only one phase each of RFI, CMS and CMI sampling, when, in practice, each may have several phases.

To implement the decision analysis process, the decision maker defines alternatives for each branch of the decision nodes, determines the probabilities associated with each branch of the uncertainty nodes, and assigns values to each final outcome node. Then the investigator can compute an expected value for each path through the decision tree by multiplying probabilities and values, selecting at each decision the alternative on the path that has the highest expected value. (This process is called "rolling back the tree," and decision analysis software packages exist that perform these calculations.) At the end of this calculation, the initial alternative with the highest expected value can be distinguished.



a. No further action.
b. Voluntary correction action.

Figure I-4. General decision tree in summary form.

3.4.1 Decisions at the Initial Decision Node

At the first decision node of the tree, the decision alternatives are NFA, deferred action, RFI sampling, or VCA. The decision is based on the likelihood of contamination as estimated from archival information, programmatic guidance, and personal assessment. Because at this stage there is usually little or no quantitative information about the site, RFI sampling is the most common decision.

Sampling alternatives for RFI are described in Section 3.2. Often at this stage, the key future decision for the PRS is whether remediation is required at all, and the key uncertainty is whether contamination is significant. In these cases, Phase I sampling is likely to focus on the presence or average concentration of contaminants in the PRS. Guided by the DQO process, a cost-effective sampling and analysis plan is designed to provide data to confirm or reject, within acceptable levels of error, the hypothesis that contamination exists above a level of concern at the site.

At sites where archival information indicates higher probability that significant contamination is present, the decision on whether remediation is required may depend on the results of a baseline risk assessment. In these cases, Phase I investigations are designed to refine the conceptual exposure model on which this baseline risk assessment is based.

3.4.2 Decisions During Phase I and Phase II Investigations

Sometimes RFIs are conducted in multiple phases. At the initiation of each phase, the decision maker must consider the action alternatives (NFA and VCA) and the alternatives for further investigation (site characterization, risk assessment, or CMS). If characterization is chosen, the decision maker must address the alternatives for sampling. After each phase of characterization, the probability distributions are updated before reconsidering these decisions.

As shown in Figure I-1, if the results of Phase I sampling suggest the presence of constituents at levels of possible concern but provide little specific information, additional sampling to support a baseline risk assessment may be recommended. This follow-up sampling generally focuses on determining the extent of contamination near the PRS and on identifying potential pathways for public exposure. If the Phase I sampling results suggest low levels of constituent concentrations or no credible pathways, a decision for NFA is likely. If the initial results suggest a potential health or environmental hazard and provide enough detail about the extent of existing contaminants, a decision to proceed with a VCA will be taken if an effective remediation alternative is obvious; otherwise, a decision to proceed with a CMS will be taken.

Once knowledge of the site is sufficient to support baseline risk assessment, the major decisions on NFA, VCA, CMS, or continued characterization still remain. If neither NFA nor VCA is chosen at this stage, it is likely that the site will proceed through CMS and CMI. The major future decisions will be on the alternatives for corrective actions, and, therefore, further characterization, if required, will focus on the uncertainties that affect the costs and benefits of remediation alternatives.

As more quantitative information becomes available, more formal application of decision analysis also becomes possible. For example, the decision between NFA

and further action can be evaluated in two ways. First, it can be determined whether NFA meets EPA requirements at an acceptable level of uncertainty or if further action is required. (If further action is required, it can be determined whether VCA or a formal CMS to evaluate alternatives has the lowest expected cost to meet EPA requirements.) Alternatively, however, it can be determined whether NFA or further action is the best course of action based on maximization of the total value, which includes factors in addition to the value placed on compliance. In this latter mode of analysis, instances may be identified in which further action that remediates the site beyond EPA requirements still has positive value. (This approach is similar to the as low as reasonably achievable approach to remediation.) This second form of analysis may also indicate instances in which further action and eventual cleanup to meet EPA requirements have negative total benefits, a result that could occur because of expected environmental impacts of feasible corrective measures, risks to cleanup workers, social disruption, direct dollar costs, or other negative effects of remediation. In these cases, the ER Program may wish to impose conditional remedies (Chapter 4).

3.4.3 Decisions Regarding CMS and CMI

Decision alternatives for CMS and CMI are described in Section 3.2. The CMS may include several phases: feasibility studies, bench or pilot tests of corrective studies, and final engineering studies. Selection of a corrective action for implementation is based on the probabilities and values associated with the long-term outcomes.

During the CMI, new information about the effectiveness of corrective actions and site conditions may be obtained. This information may result in decisions to alter the engineering design of the corrective action.

The final uncertainty node is the outcome of the implemented corrective action. This one uncertainty node is a representation of all of the individual residual uncertainties that exist at a site and how they will affect workers and the public in the future. This true state of the site will only be revealed over time. The final decision on corrective action must be made with recognition of these unresolvable uncertainties.

4.0 EXAMPLE APPLICATIONS OF DECISION ANALYSIS

This section steps through two applications of decision analysis in the ER Program.

4.1 Proposed No Further Action and Deferred Action after Archival and Field Reconnaissance Investigations

In the first stages of investigating a site, little quantitative information may be available. In this case, an NFA or a deferred action decision, if taken, must be based on a subjective evaluation of the site. The NFA or deferred action criteria described below can be used to guide this subjective evaluation. The criteria illustrate the use of scales to support such evaluations, but, in this case, only one level of each scale is described—specifically, the most favorable or lowest-risk level. Thus, at this early stage, the recommendation for NFA is only made if the PRS meets the strictest standards.

According to proposed Subpart S to 40 CFR 264 (EPA 1990, 0432), a PRS can be recommended for NFA if it can be demonstrated that the PRS poses no threat to

human health or the environment. This section describes a four-step procedure for determining, based on archival information, whether a PRS meets this requirement or meets other conditions that would allow the PRS to be recommended for NFA or a delay in characterization. This process is illustrated in Figure I-5.

Step 1: In the first step, the OUPL ensures the accuracy of the PRS data base maintained by the ER Program's Facility for Information Management and Display (FIMAD). Specifically, he/she checks the following:

- The PRS has not been closed.
- The PRS is correctly numbered.
- The PRS is correctly located.
- The PRS data base is otherwise accurate.

If the PRS data base is not correct, the OUPL needs to provide up-to-date information to the FIMAD. If in correcting the data base it is determined that the PRS is already properly closed or never existed, the PRS should be recommended for NFA and delisting. Otherwise, the evaluation moves to the second step based on the corrected data base.

Step 2: In the second step, the OUPL determines whether the site should be addressed by another program and excluded from the ER Program. Any of the following conditions could exclude a PRS from the ER Program and lead to a recommendation for NFA and delisting from the HSWA Module.

- The PRS began operation after November 1988. The ER Program will evaluate each site and determine, on a case-by-case basis, whether it falls under the ER Program.
- The PRS involves a discharge to surface waters and has always operated under a Part B, National Pollution Discharge Elimination System permit or began operation after 1972.
- The PRS is a satellite that has been used as a storage area for less than 90 days and is not a historical release site.

Step 3: At PRSs that are not recommended for NFA, characterization may be delayed beyond the current RFI if any of the following pertains to the site:

- The PRS is operating under a RCRA permit [RCRA Section 3004 (a)] or interim status.
- The PRS is an active site from which no credible pathways lead off the site.
- The PRS is an inactive site that cannot be characterized or remediated without disrupting activities at an active site and from which no credible contaminant pathways lead off the site.
- VCA or institutional control is already planned for the PRS. In the latter case, no credible pathways lead from the PRS off the site.

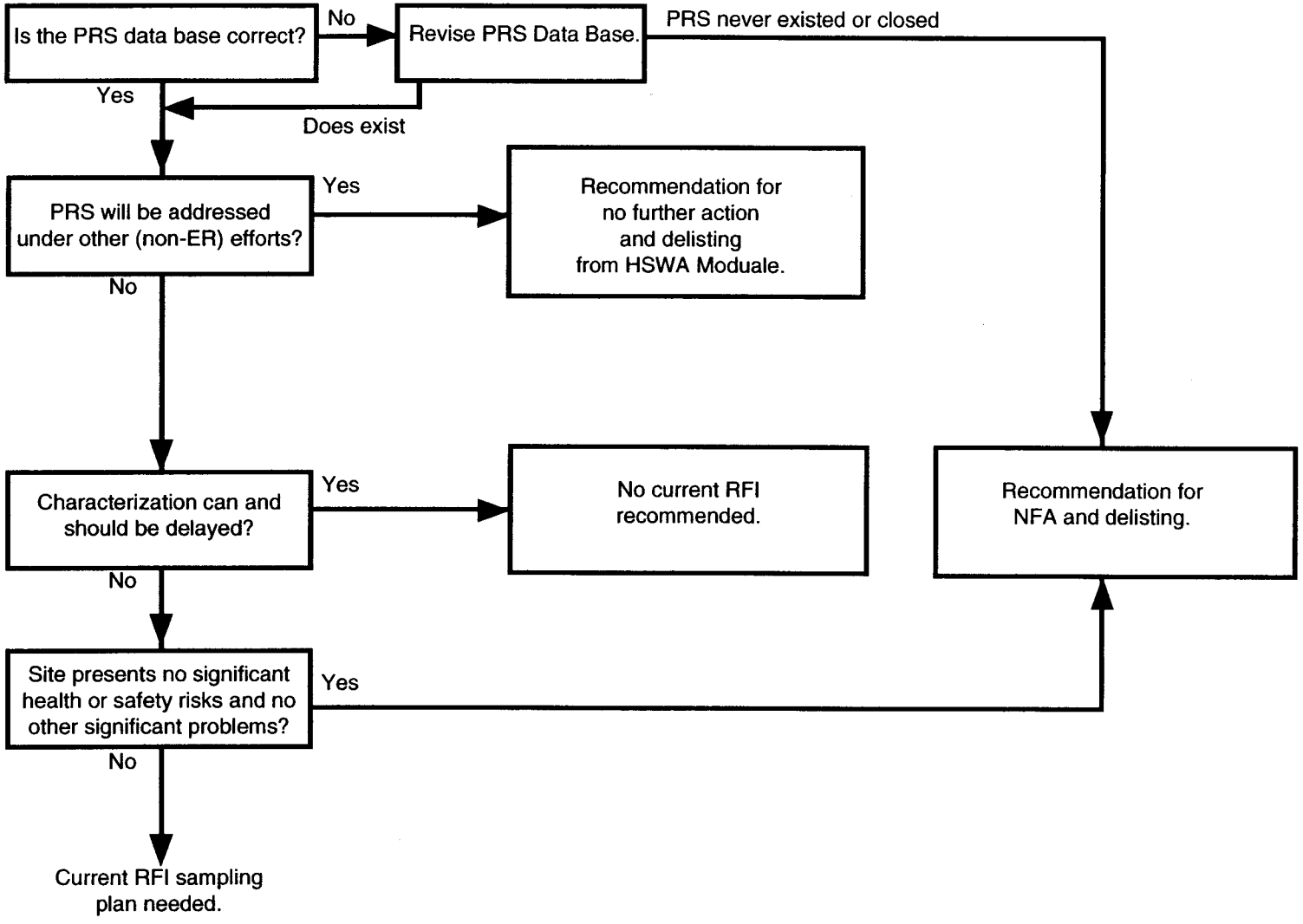


Figure I-5. Decisions for delayed investigation.

In cases of active sites, inactive sites associated with active sites, and sites for which institutional control is planned, characterization takes place in conjunction with future remediation. This remediation will be coordinated with decontamination and decommissioning. In the case where VCA is planned, characterization takes place in conjunction with the VCA. For all other scenarios, the process proceeds to a detailed review of health, safety, and other problems at the PRS.

Step 4: This last step is to review health, safety, and other problems. In this step, the remediation needs of the PRS are examined with respect to several factors. If any of the conditions of this review are not met, the site is not recommended for NFA and needs a current RFI sampling plan. The review is summarized in Figure I-6 and includes a review of the following:

- health and safety risks, based on archival information, which are assessed for
    - site workers (who are performing routine site operations rather than characterization and remediation activities) to determine that potential risk agent(s) are far enough below screening action levels (SALs) or that the lack of credible exposure scenarios ensures that they pose no danger to site workers for any foreseeable activity (excavation, removing or moving fill, drilling, etc.).
    - offsite workers to determine that the potential risk agent(s) have not migrated to new locations or evolved into new forms in such a way that they are near SALs or in any way pose a danger to offsite workers for any foreseeable activity.
    - onsite and offsite members of the public to determine that the potential risk agent(s), together with containment and local use patterns, do not now nor will they in the foreseeable future pose a danger to the public either on or off the site.
- risk to the environment
    - The nature and current status of the constituents and environmental pathways preclude impact on environmental resources, including those resources listed in Table I-1.
    - The nature and current status of the constituents and environmental pathways are such that the likely scenarios for exposing sensitive environmental resources will not result in any damage.
- regulatory compliance, i.e., applicable regulatory requirements do not mandate characterization because of the contaminant(s), the location, the migration pathways, or other factors.

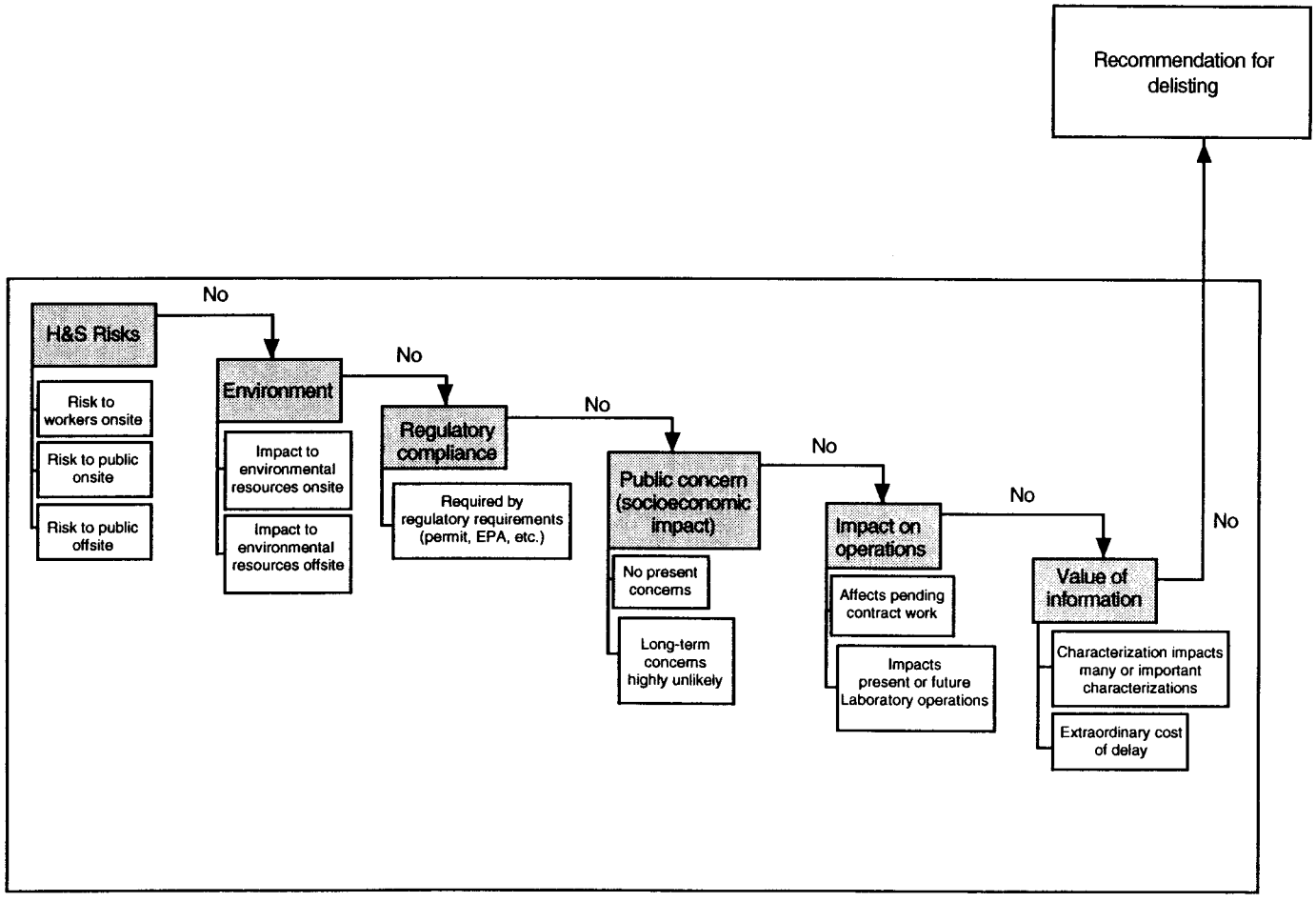


Figure I-6. Review for health, safety, and other problems.

TABLE I-1

ENVIRONMENTAL RESOURCES IN THE LOS ALAMOS AREA

Federally endangered species	Concern for habitat of peregrine falcon and bald eagle
State endangered species	Jemez Mountain salamander Gramma grass cactus Wood lily
Candidate for the federal register	Northern goshawk
Federally protected resources	Wetlands; habitat supporting threatened and endangered species
Other resources	State-designated natural areas, wildlife management areas, scenic areas, to protect unique biotic communities
	Federal wild and scenic river (Jemez River)
	Federal wilderness area (Bandelier National Monument)
	National Park and National Forest (Bandelier National Monument and Santa Fe National Forest)

- public concern (workers and area residents have no immediate or long-term concerns about or interest in the characterization of the PRS).
- impact on Laboratory programs and operations
  - Failure to characterize the PRS poses no immediate threat or long-term danger of causing an adverse impact on Laboratory programs, such as temporarily shutting down a Laboratory facility, reducing the size or number of existing programs, or influencing future programs.
  - There is no danger that failure to characterize the PRS will cause an adverse impact on Laboratory operations (such as contamination of or other harm to critical equipment or that drainage will contaminate other operations).
  - There will be no regulatory curtailment of other operations or programs because of failure to characterize this PRS.

- value of Information (characterization of the PRS does not contribute to the effectiveness or value, nor does it reduce the expense of other characterizations, and, if not done, will not result in extraordinary costs, risks, or socioeconomic impacts should characterization be required at a later date).

There is no reasonable basis for characterizing the PRS if the site satisfies all the conditions described above. Thus, the PRS is recommended for NFA and delisting.

4.2 Case Study Showing Application of Decision Analysis

This case study is intended to illustrate how decision analysis can be applied to planning and implementing characterization and remediation of material disposal areas and landfills at the Laboratory.

4.2.1 Landfill Description

The hypothetical industrial landfill examined in this case example was identified as a possible remediation site during the RCRA field assessment. The landfill was used mainly for disposing of residues resulting from burning materials contaminated with high explosives but also contains construction debris such as large pieces of timber, concrete rubble, and pipes. In addition, it contains miscellaneous, nonconstruction debris, such as flasks, bottles, and other items used in manufacturing and testing high explosives (HE). The landfill contains an estimated 13,000 yd^3 of waste.

The landfill, which is located in a saddle of a short mesa and occupies approximately 2 acres, extends down the slope of the canyon to form a shelf over the original slope of the canyon. Although the landfill does not reach the canyon bottom, a few large items have fallen to the bottom. An intermittent stream runs through the canyon below and eventually into the Rio Grande. Past testing has shown that barium is present in the landfill over EP toxic levels. Other contaminants of concern are unburnt HE.

The potential mechanisms by which existing contamination could cause onsite exposure or lead to transport off the site are leaching to the tuff below and eventually into the groundwater, storm water run-off, mass wasting, erosion, and excavation of the landfill for remediation purposes.

4.2.2 Formulating Decision Analysis

A decision analysis team was formed to review background material on the landfill. The team interviewed experts to formulate the problem, using an influence diagram to depict the decisions, uncertainties, and values in the problem and the relationships between them. The formulation was further revised through additional consultation with experts.

A two-stage analysis was performed for this problem. First, the team determined the remediation approach that would be taken if the approach had to be chosen immediately. Second, the team examined possible characterization activities to determine what activities have the potential to improve this preliminary decision at reasonable cost.

A simple influence diagram for this problem is shown in Figure I-7. In this diagram, the rectangle contains the decision about the remediation alternatives. Ovals indicate uncertainties, including all of the uncertain current conditions of the landfill, such as the type and amount of contamination, the stability of the slope, the extent and pathways of migration, and the uncertainties regarding costs such as the costs of material disposal and the costs of safety precautions. The values noted in the rounded rectangle are the same as those adopted for the ER Program as a whole. Finally, arrows indicate influences; an arrow from an uncertainty to a value indicates that the value depends on the state of the uncertainty.

The analysis team identified the feasible corrective action alternatives available for the landfill. The alternatives considered were (1) full removal and (2) treating in place, capping, and monitoring.

In the second alternative, the barium in the landfill is treated by mixing it with sodium sulfate to form barium sulfate. Then a cap is placed over the landfill, and a monitoring system is set up to measure potential offsite migration of contaminants. The uncertainties at the site include

- quantity of contamination in the landfill,
- toxicity of the contaminants,
- pathways of migration to the tuff and offsite and the extent to which migration has occurred,
- stability of the slope,
- impact of HE as the result of an explosion during remediation,
- environmental impacts of contamination,

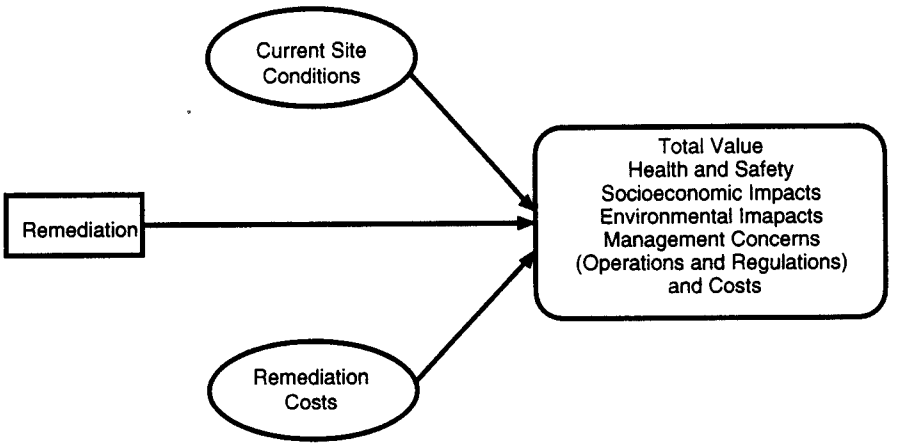


Figure I-7. High-level influence diagram.

- environmental impact of the remediation alternatives,
- extent of exposure of the public to contaminants,
- extent of exposure of workers to contaminants, and
- costs of remediation.

As the analysis proceeded and more information was gathered, some of these uncertainties became known quantities, and others were found to be irrelevant.

The initial list of values used by the analysis team are the ER Program values: health and safety, socioeconomic impacts, environmental impacts, Laboratory operations, and costs. Health and safety concerns include the health and safety of both the public and workers. Potential impacts on workers include exposure through remediation and the impacts of HE explosions. Socioeconomic impacts result from public concern and impacts on the local economy. Environmental impacts include impacts on flora and fauna on and off the site. Laboratory operations are of concern because they could be disrupted by remediation. In addition, regulatory issues are of concern because of their effect on Laboratory operations. The final value, costs, includes the costs of characterization and remediation. It was assumed that the cost of disposal at an approved site would cover all future costs of management.

4.2.3 Deterministic Analysis

A deterministic model is constructed to calculate a measure of total value for each alternative. A graphical representation of the structural model used in this analysis is shown in Figure I-8.

In a typical decision analysis, in order to calculate the total value, a measurement scale for each final outcome is developed. Then each final outcome is scored on its own scale, and the scores are aggregated in a total value through a multiattribute utility function. However, in this simplified analysis, the only value taken into account in the model is costs. It is assumed that each of the remediation alternatives is adequate to remove all health and safety concerns and has only minor, if any, impacts on the environment. Moreover, it has been determined that neither of the alternatives would impact Laboratory operations and that both would be approved by EPA and state regulators. Neither alternative is seen as having significant socioeconomic impacts. Therefore, costs become the only criterion against which the outcomes need to be evaluated.

The structural model shown in Figure I-8 calculates the costs of each alternative. Arrows indicate the inputs that are needed to calculate each value in the diagram. Three aspects of the model should be noted. First, it is assumed that if removal is chosen, not all disposal area materials will be classified as hazardous wastes. Only the fraction of the materials that is contaminated will be disposed in a hazardous waste landfill. Uncontaminated materials will be disposed at much lower cost in a standard landfill. Second, it is assumed that the expenditure for worker safety will be determined by the level of unburnt HE in the landfill, and it is assumed that the impact of safety costs will be much higher for removing the HE and stabilizing the slope than for capping. Third, it is assumed that if the cap proves ineffective at the end of 5 years, the material in the landfill will be removed and the cost of removal will be incurred at that time.

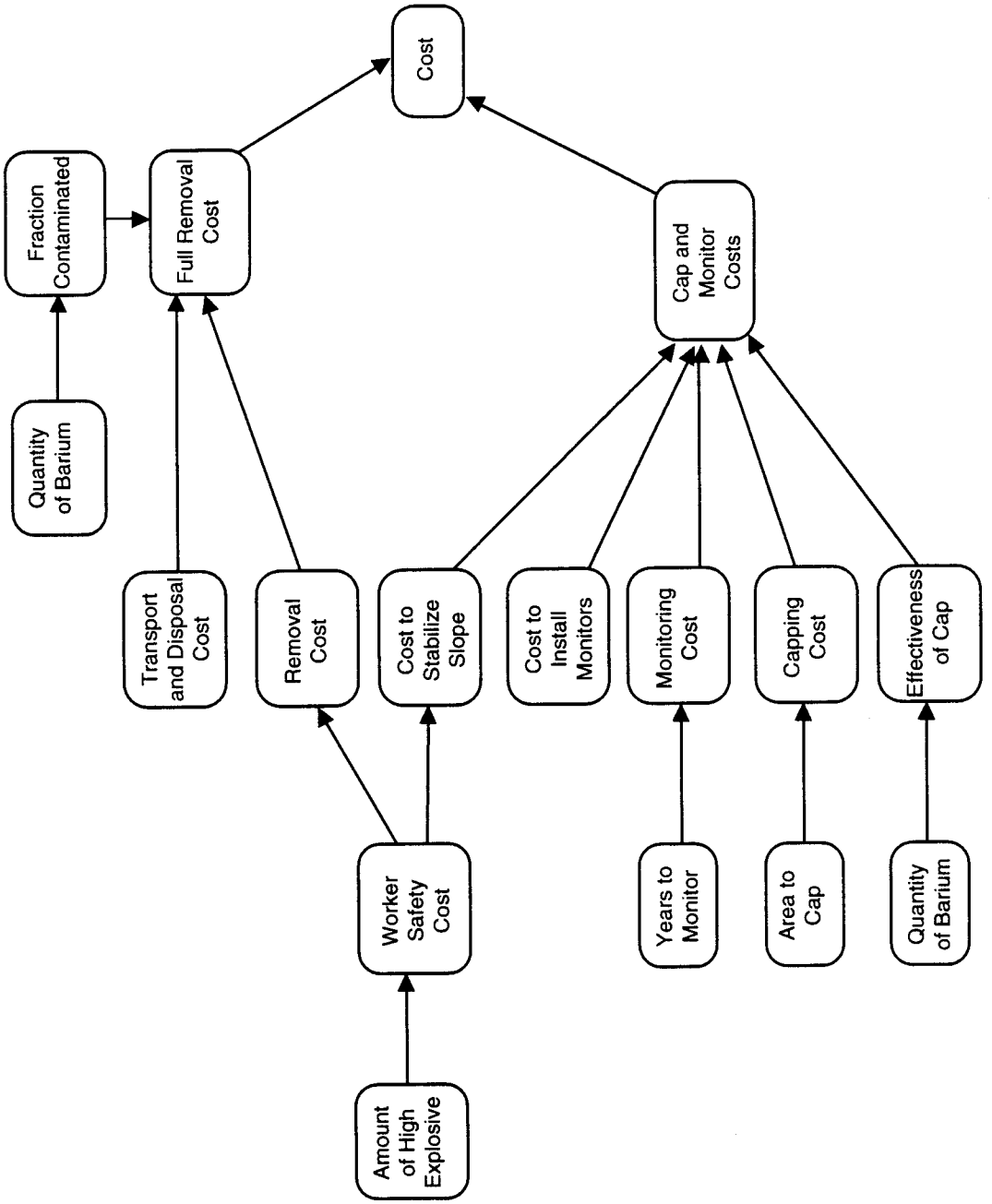


Figure I-8. Structural model.

The investigators use this model to find a nominal solution and to perform a sensitivity analysis to identify important uncertainties. Table I-2 lists the nominal states of the uncertainties and the worst and best extremes. The nominal analysis suggests that the capping and monitoring option is the preferred solution. The discounted total costs for capping and monitoring are $2.3 million and for removal are $3.4 million.

The sensitivity analysis indicates that the decision to remove or to cap and monitor is not sensitive to two uncertainties: the cost of stabilizing the slope and the quantity of HE. The range of slope stabilization costs is too small compared with other costs

TABLE I-2

VALUES FOR NOMINAL-CASE AND SENSITIVITY ANALYSIS

Uncertainty	Worst	Nominal	Best
Quantity of barium	High	Nominal	Low
Fraction of volume contaminated (%)	65	55	15
Cost to stabilize slope	$1,000,000	$750,000	$500,000
Quantity of HE (worker safety multiplier)	5	1	—
Effectiveness of capping	Ineffective	Effective	Effective

to have much impact on the final solution. The HE-related safety costs for each alternative are too similar to have much impact. Therefore, these uncertainties are set at their nominal state in the model.

The outcomes are deemed to be sensitive to the other three uncertainties. If the fraction of the disposal area contaminated is very low, disposal costs are cut dramatically, and full removal becomes a better solution than capping and monitoring. If the cap is ineffective, removal is superior to capping now and still incurring removal costs in the future. Finally, although the standard sensitivity analysis shows that the quantity of barium does not affect the decision, it is decided to continue to treat the quantity of barium as an uncertainty because there is concern that the impacts of the quantity of barium on the two important uncertainties, fraction contaminated and effectiveness of capping, are not adequately captured in the sensitivity analysis.

4.2.4 Probabilistic Analysis

The next step in the decision analysis cycle is to construct the probabilistic model of the problem (Figure I-9). From left to right, the decisions and uncertainties in the model are the corrective action decision, quantity of barium, fraction of the disposal area contaminated, and effectiveness of the cap; the structure of the tree is identical for the removal branch. The probabilities and states of uncertainties used in this model are gathered from experts designated by the OUPL. Because the sensitivity analysis indicates that the corrective action decision is not sensitive to two uncertainties and that these uncertainties can be set at their nominal states, the need for data collection in this step is minimized.

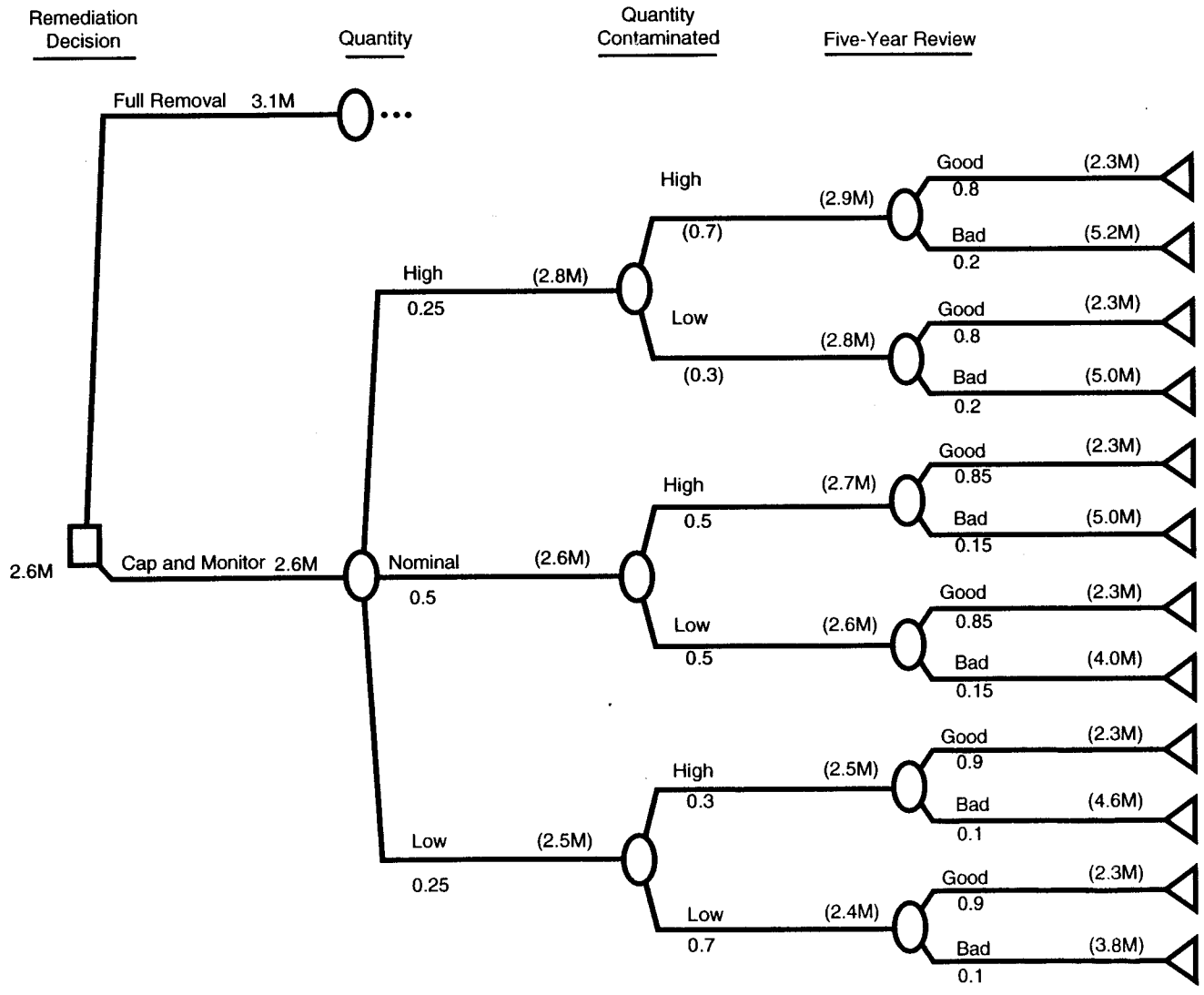


Figure I-9. Decision tree for corrective action.

4.2.5 Evaluation: Determining the Optimal Decision and Value of Information

If it were necessary to make the decision immediately, the decision analysis would point to capping and monitoring as the least costly alternative; however, this alternative does pose somewhat higher extreme risks. The expected cost of the capping and monitoring alternative is $2.63 million, and the expected cost of the removal alternative is $3.13 million. These results are illustrated in Figure I-10, which shows the cumulative distributions on costs for both alternatives. The cumulative distribution indicates the probability that the actual cost will be lower than a value chosen on the horizontal access. Although the capping and monitoring alternative has lower expected costs, removal has a higher probability of avoiding very high costs because of the small chance that the cap may prove ineffective. For removal, it is almost certain that costs will be less than $4.5 million, but, for capping and monitoring, the probability that costs are less than $4.5 million is only 0.9.

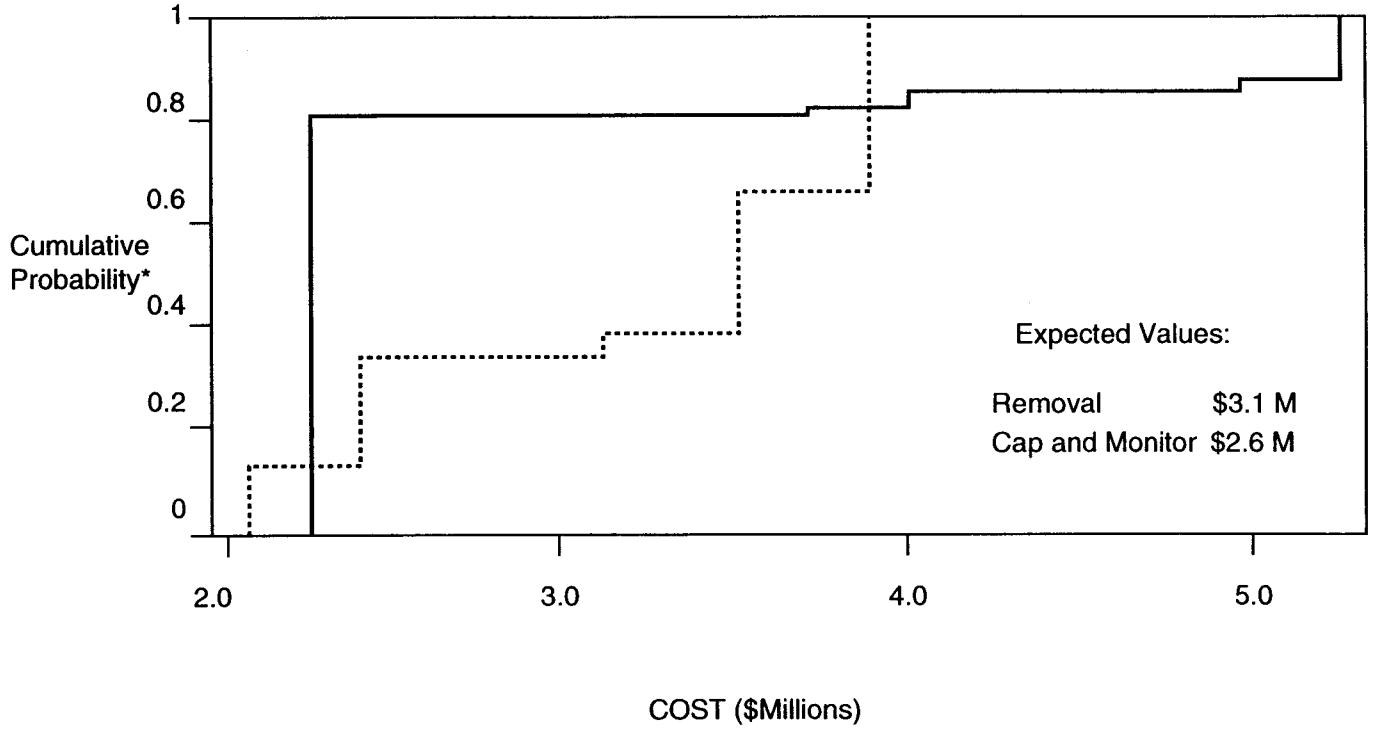
At this time in the RCRA process, decisions regarding site characterization are perhaps more important than decisions on the final method of remediation. In a second stage of the decision analysis, characterization decisions can be analyzed with a minor expansion of the model. Characterization alternatives that might be considered are

- develop more detailed costs estimates,
- drill deep holes to accurately determine the quantity of barium and the fraction of the disposal area contaminated, and
- take less accurate, shallow samples to determine the quantity of barium and the fraction of the disposal area contaminated.

The first consideration is the value of obtaining perfect information on the quantity of barium and fraction contaminated. The value of perfect information provides an upper bound on how much to spend on characterization activities to resolve these uncertainties. The expanded decision tree for the analysis of the value of perfect information is shown in Figure I-11. The difference between this expanded tree and the tree shown in Figure I-9 is that two uncertainty nodes have been moved before the corrective action decision node, indicating that these two uncertainties are known at the time of the decision.

The analysis shows that the value of perfect information is approximately $70,000. Because the minimum cost of digging deep holes for taking samples in the disposal area is higher than this value, this characterization activity was not considered further. A program using less accurate, shallow samples is estimated to cost $50,000. However, the expected value of the additional information gained is only $35,000. Therefore, neither of these characterization activities can be recommended. The decision analysis indicated that either new characterization activities be formulated or that the capping and monitoring strategy be adopted without further characterization.

This example illustrates the application of decision analysis to both characterization and remediation problems. It shows how decision analysis can provide a valuable tool for intelligently using the full range of expertise and data available at the Laboratory to make decisions throughout the RCRA process.



*The cumulative probability is the probability that the actual cost is less than or equal to the Cost on the horizontal axis.

Key
Removal
Cap and Monitor

Figure I-10. Results of corrective action analysis.

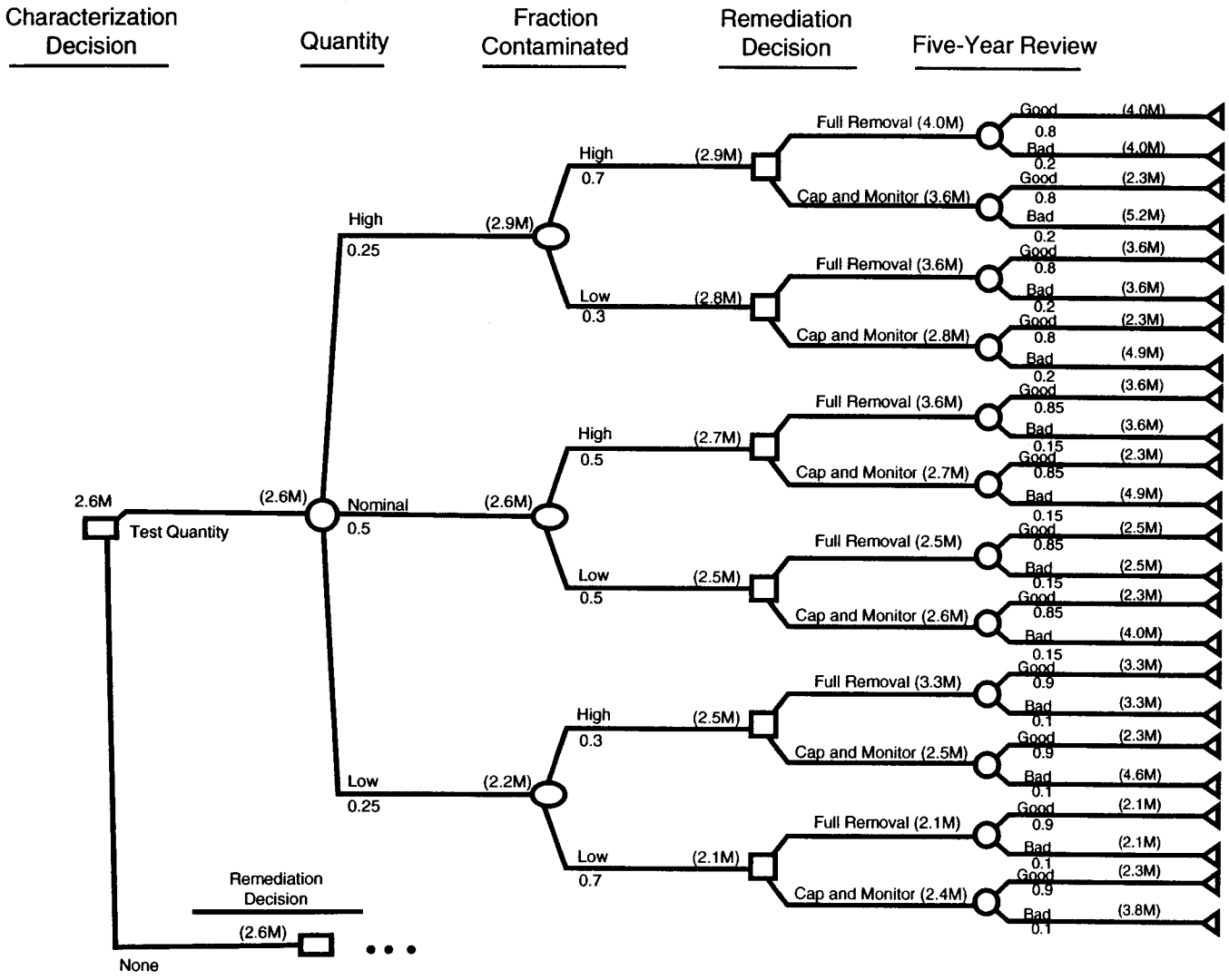


Figure I-11. Decision tree for perfect information.

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■ APPENDIX J

Screening Assessment Methodology

1.0 INTRODUCTION

Screening assessments are performed at Los Alamos National Laboratory (the Laboratory) to identify the presence of contaminants of concern at potential release sites (PRSs). Contaminants of concern are constituents whose concentration levels in one or more environmental medium are above a level of concern defined by medium-specific screening action levels (SALs). The screening assessment begins with the identification of potential constituents and environmental media of concern based on knowledge of the history and processes that occurred at a PRS. Existing or new environmental data collected during the Resource Conservation and Recovery Act (RCRA) field investigation (RFI) are then compared with SALs for the constituents identified.

The principal test carried out during screening assessments is the comparison of sampling data with SALs. If SALs are not exceeded, the PRS may be recommended for no further action (NFA). If SALs are exceeded, further evaluation, either statistical or by sampling, is required at the PRS. However, some additional screening may be necessary if two or more constituents are present to determine the potential for combined effects. When SALs are lower than background concentrations, constituent concentrations are compared with background distributions as an additional step in screening assessment. Table J-1* presents a summary of SALs for nonradiological potential chemicals of concern. The SALs for radionuclides are presented in Table J-2.

SALs will be used only for screening assessments and are not to be used as cleanup criteria in a corrective measures study or corrective measures implementation. If the results of the screening assessment show that chemical-specific levels are exceeded, more site-specific data and analysis may be needed.

2.0 SCREENING ACTION LEVELS FOR NONRADIOLOGICAL CONSTITUENTS

The Environmental Restoration (ER) Program at the Laboratory takes its primary direction from EPA guidance (EPA 1989, 0088). Subsequent guidance, Corrective Action for Solid Waste Management Units (Subpart S) (EPA 1990, 0432), a proposed regulation under RCRA, presents a methodology for calculating action levels to determine the need for further evaluation of contamination in various environmental media (i.e., groundwater, surface water, air, and soil). The action levels are calculated using chemical-specific toxicity values and default exposure parameters. In order to comply with the Hazardous and Solid Waste Amendments (HSWA) Module for the Laboratory, SALs have been developed that follow the Subpart S methodology for exposure parameter defaults but that incorporate more recent toxicity values available from the Environmental Protection Agency's (EPA's) Integrated Risk Information System (IRIS) data base (EPA 1993, 1062) and Health Effects Assessment Summary Tables (HEAST) (EPA 1992, 0833), which are updated periodically.

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*In this appendix, the tables are located after the text.

2.1 Assumptions

A summary of the nonradiological SAL values is presented in Table J-1. These values are based on the methodology presented under proposed Subpart S (EPA 1990, 0432) and on toxicity values [i.e., reference doses (RfDs) and carcinogenic slope factors] from the IRIS data base (EPA 1993, 1062) or the HEAST (EPA 1992, 0833). Table J-3 contains the toxicological information used for establishing nonradiological SALs. The constituents included in Tables J-1 and J-3 are those on the EPA's Target Analyte List (EPA 1991, 0814), Target Compound List (EPA 1991, XXXX), and potential high-explosive compounds used at the Laboratory. Other constituents may need to be added as the results of site characterization become available. Tables J-1 and J-3 will be updated annually to reflect any modified toxicity values.

SAL derivations are based on the following assumptions and equations contained in proposed Subpart S:

1. To take the most conservative approach in deriving soil SALs that consider systemic (i.e., noncarcinogenic) effects, the model assumes that a 16-kg child ingests soil at a rate of 200 mg/day. For carcinogenic constituents in soil, the long-term exposure of an adult is modeled. For this calculation, it is assumed that a 70-kg adult ingests soil at a rate of 100 mg/day over a 70-yr exposure duration.

2. A modification of the Subpart S methodology has been introduced to account for exposure to organic compounds volatilizing from soil. The modification is applied to account for potential inhalation exposure, as presented in more recent EPA guidance for calculating preliminary remediation goals (EPA 1991, 0302). The Laboratory's Environmental Restoration (ER) Program has selected this approach because SALs for volatile substances calculated using this modified approach are lower (i.e., more conservative) than those calculated using the unmodified Subpart S method. For the purpose of calculating SALs, volatile constituents are defined as those with a molecular weight less than 200 and a Henry's Law Constant greater than 1×10^{-5} atm/m^3-mole (EPA 1991, 0302).

   The equation for calculating SALs for volatile constituents has been expanded to account for potential inhalation exposure (equations are given in Section 2.2, below). The soil-to-air volatilization factor was calculated based on an equation given by EPA (1991, 0302) and chemical-specific parameters (Strenge and Peterson 1989, 0837; EPA 1988, 0747). The default particulate emission factor was used in SAL calculations for volatile constituents to maintain consistency with the equation given in EPA guidance (EPA 1991, 0302), although this factor is so low that it does not affect the calculated SALs. To calculate SALs for volatile constituents that have systemic effects, the investigators use a model in which a 16-kg child ingests soil at a rate of 200 mg/day and inhales 20 m^3/day of air. The SAL calculation for carcinogenic volatile

constituents models exposure of a 70-kg adult over a 70-yr exposure duration, with a soil ingestion rate of 100 mg/day and an inhalation rate of 20 m^3/day.

3. In deriving SALs for constituents in water, it is assumed that a 70-kg adult ingests water at a rate of 2 L/day over a 70-yr exposure duration. These SALs apply to constituents in both groundwater and surface water.

4. In deriving SALs for constituents in air, it is assumed that a 70-kg adult inhales air at the rate of 20 m^3/day, 70-yr exposure duration.

5. Proposed Subpart S specifies the use of maximum contaminant levels (MCLs) promulgated under the Safe Drinking Water Act as action levels for groundwater constituents. Subpart S also indicates that state water quality standards established pursuant to the Clean Water Act, Section 303c, will be used as action levels for surface water constituents when these standards have been established for the surface water body in question. When numeric water quality standards have not been established by the state, Subpart S specifies that MCLs will be used as action levels if the state designates the surface water as a drinking water source.

In keeping with Subpart S, when the MCL value or state groundwater standard is not available, the value calculated using the specified exposure assumptions for water (No. 3 above) will be used as the SAL. Although not specifically stated, it is consistent with Subpart S to use the same SAL criteria for both groundwater and surface water constituents. For surface water constituents, these criteria may be more stringent than required because New Mexico has not designated surface waters to be evaluated as drinking water sources.

2.2 Equations

2.2.1 General Equations for Calculating SALs

2.2.1.1 Systemic Toxicants

$$SAL = \frac{THI \times RfD \times BW \times CF}{I \times A} \qquad (2.1)$$

where,

SAL	=	mg/kg for soil, µg/L for water, µg/m^3 for air ;
THI	=	target hazard index: 1;
RfD	=	chronic reference dose (mg/kg-day): oral RfD used for soil and water SALs, inhalation RfD used for air SALs;
BW	=	body weight: 16 kg for child (for soil SALs), 70 kg for adult (for water and air SALs);
CF	=	conversion factor: 10^6 mg/kg for soil SALs, 10^3 µg/mg for water and air SALs;
I	=	intake rate: 200 mg/day for soil SALs, 2 L/day for water SALs, 20 m^3/day for air SALs;
A	=	absorption factor: 1.

2.2.1.2 Carcinogenic Constituents

$$SAL = \frac{R \times BW \times LT \times CF}{SF \times I \times A \times ED} \quad (2.2)$$

where,

SAL	=	mg/kg for soil, µg/L for water µg/m^3 for air ;
R	=	target risk: 10^{-6} for Class A and B carcinogens, 10^{-5} for Class C carcinogens;
BW	=	body weight: 70 kg;
LT	=	assumed lifetime: 70 yr;
CF	=	conversion factor: 10^6 mg/kg for soil SALs, 10^3 µg/mg for water and air SALs;
SF	=	slope factor (mg/kg-day)$^{-1}$: oral SF used for soil and water SALs; inhalation SF used for air SAL;
I	=	intake rate: 100 mg/day for soil SALs, 2 L/day for water SALs, 20 m^3/day for air SALs;
A	=	absorption factor: 1;
ED	=	exposure duration: 70 yr.

2.2.2 Equations for Calculating Soil SALs for Volatile Constituents

2.2.2.1 Systemic Toxicants

$$SAL = \frac{THI \times BW}{\left\{[1/RfD_O \times CF\ ING] + [1/RfD_i \times INH \times (1/VF + 1/PEF)]\right\}} \quad (2.3)$$

where,

SAL	=	mg/kg for soil, µg/L for water, µg/m^3 for air ;
THI	=	target hazard Index: 1;
BW	=	body weight: 16 kg;
RfD_O	=	chronic oral reference dose: mg/kg-day;
CF	=	conversion factor: 10^{-6} kg/mg;
ING	=	soil ingestion rate: 200 mg/day;
RfD_i	=	chronic inhalation reference dose: mg/kg-day;
INH	=	inhalation rate: 20 m^3/day;
VF	=	soil-to-air volatilization factor (chemical-specific): m^3/kg, calculated using equation given by EPA (1991, 0302) and chemical-specific parameters (Strenge and Peterson 1989, 0837; EPA 1988, 0747);
PEF	=	particulate emission factor: 4.63 x 10^9 m^3/kg (EPA 1991, 0302).

2.2.2.2 Carcinogenic Constituents

$$SAL = \frac{R \times BW \times LT}{ED \times \left\{[SFo \times CF \times ING] + [SF_i \times INH \times (1/VF + 1/PEF)]\right\}} \quad (2.4)$$

where,

SAL = mg/kg for soil, µg/L for water, µg/m^3 for air;

R = target risk: 10^{-6} for Class A and B carcinogens, 10^{-5} for Class C carcinogens;

BW = body weight: 70 kg;

LT = assumed lifetime: 70 yr;

ED = exposure duration: 70 yr;

SF_O = oral slope factor (mg/kg-day)$^{-1}$;

CF = conversion factor: 10^{-6} kg/mg;

ING = soil ingestion rate: 100 mg/day;

SF_i = inhalation slope factor (mg/kg-day)$^{-1}$;

INH = inhalation rate: 20 m^3/day;

VF and PEF as defined above.

2.3 Derivation of SALs When Chronic Toxicological Data Are Lacking

When SALs are needed for evaluating and comparing specific noncarcinogenic contaminants and adequate chronic toxicological information for the compound of interest does not exist, an interim conservative estimated value is derived by extrapolating from acute toxicological data.

2.4 Derivation of SALs for Other Media and Substances

Values analogous to SALs may be needed for evaluating substances that involve unique exposure considerations (e.g., substances found on structural surfaces and debris, shrapnel, high explosives, asbestos). The methods that will be used to evaluate these substances are discussed in the following paragraphs.

2.4.1 Structural Surfaces and Debris

Proposed Subpart S does not provide guidance on the derivation of SALs for potentially contaminated structural surfaces or debris (e.g., concrete, wood). These values may be needed for evaluating currently unused buildings. The structural surfaces of unused buildings may contain removable nonradiological constituents because these surfaces have not been subjected to weathering. SALs for these structural surfaces may be derived using wipe test data and appropriate assumptions on dust resuspension rates, inhalation and ingestion rates, and exposure period. These SALs for structural surfaces will be derived on an as-needed basis when characterization data become available.

Plausible exposure routes for structural materials (i.e., demolition debris), either buried or at the land surface, are through human contact with the surrounding media (soil, water, air) because some constituents may already have been released into the surrounding media as the result of weathering. Therefore, nonradiological contamination from exposed and buried structural debris can be evaluated by comparing SALs with constituent levels in surrounding media.

2.4.2 High Explosives and Asbestos

Shrapnel and unexploded high explosives present in some operable units need special consideration. The primary health hazard associated with these materials is injury by explosion. The toxicity of chemicals that might be released from these materials will be evaluated for individual constituents using appropriate SALs for soil, water, air, and structural surfaces. SALs for some high explosives and constituents of high explosives known to have been used at the Laboratory and for which toxicity data exist are presented in Tables J-1 and J-3. The SALs for high explosives were developed using Subpart S methodology. The work plans for individual operable units address characterization of sites with respect to shrapnel and high explosives, as needed.

Another special substance that needs criteria for screening decisions is asbestos. The SAL approach developed for evaluating most other constituents is not appropriate for asbestos; the Laboratory is seeking criteria consistent with federal and state guidance so that asbestos-contaminated soils can be evaluated.

3.0 SCREENING ACTION LEVELS FOR RADIOACTIVE CONSTITUENTS

As described above, SALs for many RCRA-regulated nonradioactive constituents have been recommended in, or derived using, proposed Subpart S regulations. However, radioactive compounds are not regulated under RCRA, and Subpart S regulations do not address radioactive constituents. To ensure that radioactive and nonradioactive compounds are addressed similarly and to simplify integrating RCRA, DOE, and CERCLA requirements for radioactive compounds, SALs for radioactive compounds have been derived in a manner similar to that used for deriving action levels in proposed Subpart S.

Section 3.1 presents the rationale for developing SALs for radioactive constituents in soil. Sections 3.2 and 3.3 discuss the methodology and assumptions used to derive SALs for radioactive constituents in soil and water, respectively.

3.1 Rationale for Deriving SALs for Radioactive Constituents in Soils

In developing SALs for radioactive constituents, it is necessary to consider all relevant and applicable standards for protecting human health. For radionuclides in the environment, guidance assumes that the protection standards that govern human health generally protect other biotic species (NCRP 1991, 0986; International Atomic Energy Agency 1992, 0983). The limits of radiation exposure to humans are governed by listing an upper bound of a radiation dose established in the radiation protection standards that corresponds to an acceptable health risk. The upper-bounded radiation dose limit may not be exceeded but may be reduced by using health physics principles and DOE's as low as reasonably achievable (ALARA) guidance (DOE 1990, 0779).

Because current radiation protection standards [e.g., NESHAPS (EPA 1992, 1061) and MCLs (EPA 1993, 1071) are based on radiation dose limits rather than on corresponding cancer slope factors or risk levels as are nonradioactive compounds enumerated in Subpart S, SALs for radioactive compounds are based on radiation dose levels considered to be "acceptable" to individuals in the general public. The national and international radiation communities and DOE (NCRP 1988, 0778; DOE 1990, 0080) have set a limit of 100 mrem/yr as a maximum acceptable radiation dose to individuals in the general public from all contaminant pathways, radionuclides, and exposure sources. Radiation dose to the public is further limited to 25 mrem/yr from individual facilities or sources (e.g., DOE 1988, 0266; EPA 1977, 1064). The radiation dose limits to the general public apply to cumulative exposure from multiple radioactive constituents through multiple pathways, whereas action levels for nonradioactive compounds in Subpart S have been derived for a single contaminant via a single exposure pathway.

The Laboratory has proposed SALs for radionuclides in soils at an annual dose limit of 10 mrem/yr (above background levels) from a single radioactive constituent via all pathways for radionuclides for which media-specific concentration limits are not specified in other regulations (e.g., MCLs). The proposed conservative dose limit of 10 mrem/yr was chosen as a SAL based on the following criteria (discussed in full in Chapter 4, Section 4.2.2.2):

- fraction of 100 mrem/yr and 25 mrem/yr regulatory standards,
- specified in DOE Order 5400.5 (DOE 1990, 0080) as a reporting level,
- generally within detection limits for current field instruments, and
- discernible from background radiation levels in the US (Table J-4).

Even if radionuclide levels exceed a SAL, consideration of ALARA may lead to further investigation or cleanup.

3.2 SALs for Radioactive Constituents in Soil

Preliminary SALs have been derived for several radionuclides that may be encountered in contaminated soils at the Laboratory (Table J-2). The following methodology and assumptions were used in deriving these SALs:

- The RESRAD computer code (Gilbert et al. 1989, 0754), Version 4.6, was used to derive the SALs. This code is DOE's choice of methodology required by DOE Order 5400.5 to be used in the derivation of cleanup criteria for radionuclides in soils at DOE sites.
- A residential scenario, which included exposure to the following sources through the following pathways, was used to derive a SAL for each radionuclide: (1) external exposure from gamma emitters in soil, (2) inhalation of contaminated dust and

radon gas, (3) ingestion of contaminated soil and plants grown on the site, and (4) consumption of municipal water (which probably is not contaminated because of the great depth to the main aquifer in Los Alamos).

- The input data used in the RESRAD calculations typify the range of soil properties encountered on Laboratory mesa tops (Dorries 1992, 1066; 1992, 1067; 1992, 1068; 1993, 1069). The volume of contaminated soil is assumed to extend down 3 m from the surface and cover an area of 500 m^2. When site-specific data were not available, default values in the model were used. These default values were derived from averaged soil data obtained from both the Laboratory and the general literature (Gilbert et al. 1989, 0754).

3.3 SALs for Radioactive Constituents in Water

SALs for radionuclides in water are based on regulations given in 40 CFR 141.16 (EPA 1992, 1072) and the proposed national primary drinking water regulations for radionuclides (EPA 1991, 0887), which govern MCLs in community drinking water supplies. For alpha-emitting radionuclides, the proposed standards state that

- the maximum contaminant level for ^{226}Ra and ^{228}Ra is 20 pCi/L and
- the maximum contaminant level for gross alpha activity (excluding ^{226}Ra, radon, and uranium) is 15 pCi/L.

For beta- and gamma-emitting radionuclides, the proposed standards state that

- the maximum contaminant level for ^{228}Ra is 20 pCi/L and
- average annual concentrations of beta particle and gamma radioactivity (excluding ^{228}Ra) in drinking water shall not produce an effective dose equivalent greater than 4 mrem/yr. The proposed regulations also apply the 4-mrem/yr effective dose equivalent limit to tritium and ^{90}Sr. However 40 CFR 141.16 lists specific MCLs for these beta emitters. The MCLs are 20,000 pCi/L for tritium and 8 pCi/L for ^{90}Sr.

The EPA's Federal Guidance Report No. 11 (EPA 1988, 0982) tabulates dose conversion factors for intakes of radionuclides. Federal Guidance Report No. 11 is currently used to derive the SALs for radionuclides in water at the Laboratory. The effective dose equivalent factors contained in this document are consistent with the dose conversion factors published by DOE (DOE 1988, 0266) and EPA (EPA 1988, 0982). The following calculations are used to derive concentration limits of radionuclides that may be present in water at the Laboratory. Limits for other radionuclides may be derived using the methodology discussed below.

For beta- and gamma-emitting radionuclides, the yearly dose limit of 4 mrem/yr is converted to a SAL by dividing the annual dose limit by the water intake rate and effective dose equivalent factor, as shown below:

$$\mathrm{SAL} = \frac{DL \times CF}{IR \times DCF_{b-g}} \quad , \tag{2.5}$$

where,

SAL	=	screening action level for beta-gamma emitters in picocuries per liter,
DL	=	annual dose limit of 4 mrem/yr,
CF	=	conversion factor, 10^6 pCi/μCi,
IR	=	water intake rate of 2 L/day or 730 L/yr,
DCF_{b-g}	=	ingestion effective dose equivalent factor for beta-gamma emitters, millirems per microcurie (dose conversion factors for ingestion are listed in Table 2.2 of Federal Guidance Report 11 in units of *Sv/Bq*. To convert to millirem per microcurie, these values were divided by 3.7×10^9).

Alpha-emitting radionuclides have a 15-pCi/L limit that excludes ^{226}Ra, uranium, and radon. Limits for uranium isotopes and other alpha emitters can be derived based on the 4-mrem/yr method used for beta-gamma emitters. Derived water SALs for radionuclide constituents are presented in Table J-2.

The method for applying the water SALs parallels the one proposed by the EPA to apply MCLs to drinking water (EPA 1991, 0887). For alpha emitters, ^{226}Ra, and uranium, the SALs would be applied by

- counting samples for gross alpha. If the gross alpha measurement is less than 15 pCi/L, the SALs for gross alpha, ^{226}Ra, and uranium are not exceeded.

- If the gross alpha measurement is greater than or equal to 15 pCi/L, the activity of ^{226}Ra and/or uranium in the sample is compared with the SALS. The "adjusted" gross alpha (less ^{226}Ra and/or uranium) is then computed. If this value is less than 15 pCi/L, the adjusted SAL for gross alpha is not exceeded.

- If multiple alpha-emitting radionuclides are present, they will be addressed as described in Section 4.

For beta-gamma emitters, the SALs will be applied by

- analyzing the samples for individual beta-gamma emitters and comparing the results with the SALs.

- addressing multiple beta-gamma-emitting radionuclides, if present, as described in Section 4.

4.0 ADDRESSING MULTIPLE CONSTITUENTS

Proposed Subpart S does not address how to evaluate several constituents with concentrations close to but below SALs in a single environmental medium. If multiple constituents do not exceed but are near their SALS, it is possible that in combination they could prove deleterious to human health. It is difficult to determine the interaction a mixture of chemicals will have on an organism. For example, a mixture of chemicals may produce an additive response that is simply the sum of their individual responses. However, more complicated interactions can include synergism, potentiation, and antagonism. Without research on a given combination of chemicals, predicting a possible toxic response from a mixture is highly uncertain.

As the first step in determining multiple effects, a simple additive equation based on concentration data normalized by SALs will be used. This approach assumes that there are no chemical interactions. Constituents are first grouped according to the environmental medium (soil, water, air) and toxicological effects (systemic toxicants, carcinogens, radionuclides). Then, SALs for all constituents are normalized to 1 so that concentration data can be treated as proportions of the respective SALs. If the sum of proportions for the different potential contaminants of concern is greater than 1, the effect of the multiple constituents is considered adverse and further action may be taken (i.e., baseline risk assessment); otherwise, NFA is proposed. The equation for calculating the appropriate normalized sum is

$$M = \max_{samples} \left\{ \sum_{\text{PCOCs}} C_i / SAL_i \right\} , \qquad (2.6)$$

where,

M	=	maximum sum of proportions,
C_i	=	concentration of the ith chemical for a given sample, and
SAL_i	=	chemical-specific SAL for the ith chemical.

The maximum is taken over all samples such that the normalized sum of concentrations represents concentration data from within a single sample. The decision rule is restated in terms of a comparison of the maximum normalized sum of concentrations (M) with one.

The choice of potential contaminants of concern to include in the calculation also needs to be addressed. If all potential contaminants of concern are included, exceedance is very likely. However, the ER Program proposes not to include those potential contaminants of concern for which observed concentrations are within background levels when making this calculation.

TABLE J-1

SUMMARY OF SCREENING ACTION LEVELS FOR POTENTIAL CHEMICALS OF CONCERN IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
Inorganics				
Aluminum[d], 7429-90-5				40, 200
Antimony, 7440-36-0	32	6[h]		12, 60[e]
Arsenic, 7440-38-2	0.40	50[i]	0.00023	2, 10[e]
Barium, 7440-39-3	5,600	2,000[h]	0.49	40, 200
Beryllium, 7440-41-7	0.16	4[h]	0.00042	1, 5[e]
Cadmium, 7440-43-9	80	5[h]	0.00056	1, 5
Calcium[d], 7440-70-2				1000, 5000
Chromium III, 16065-83-1	80,000	~~50~~		2, 10
Chromium VI, 7440-47-3	400	~~50~~	0.000083	2, 10
Chromium (Total)		100[h]		10, 50
Cobalt[d], 7440-48-4				10, 50
Copper, 7440-50-8	3,000	1,300		5, 25
Cyanide, 57-12-5	1,600	200[i]		2, 10
Iron[d], 1543-83-10				20, 100
Lead, 7439-92-1	500[f]	50[j]		0.6, 3
Magnesium[d], 7786-30-3				1000, 5000
Manganese, 7439-96-5	8,000	3,500	0.39	3, 15
Mercury, 7439-97-6	24	2[h]	0.30	0.04, 0.2
Nickel, 7440-02-0	1,600	100[h]	0.0042	8, 40
Nitrate	130,000	10,000[h]		
Nitrite, 14797-65-0	8,000	1,000[h]		
Potassium[d], 7447-40-7				1000, 5000
Selenium, 7782-49-2	400	50[h]		1, 5
Silver, 7440-22-4	400	170		2, 10
Sodium[d], 7647-14-5				1000, 5000
Thallium, 7440-28-0	6.4	2[h]		2, 10[e]
Vanadium, 7440-62-2	560	240		10, 50
Zinc, 7440-66-6	24,000	10,000		4, 20

TABLE J-1

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Chemicals[b]	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m3	CRQL[c] mg/kg and µg/l
High Explosives				
2-amino-2,6-DNT (aminodinitrotoluene)[d]				
4-amino-2,6-DNT (aminodinitrotoluene)[d], 19406-51-0				
Ammonium nitrate[d], 6484-52-2				
Barium nitrate (soluble barium)	5,600	2,000[h]		40, 200
CEF (tri(b-chloroethyl)-phosphate)[d], 115-96-8				
1,3-DNB (dinitrobenzene), 99-65-0	8	3.5		
2,4-DNT (dinitrotoluene), 121-14-2	1	0.05		0.33, 10[e]
2,6-DNT (dinitrotoluene), 606-20-2	1	0.05		0.33, 10[e]
DPA (diphenylyamine), 122-39-4	2,000	880		
HMX (cyclotetramethylenetetranitramine), 2691-41-0	4,000	1,800		
Nitrocellulose (non-toxic)[d], 9004-70-0				
Nitromethane[d], 75-52-5				
NP (bis(2,2-dinitropropyl) acetal/formal)[d], 5917-61-3				
PETN (pentaerythritolletranitrate), 78-11-5	1,600	700		
RDX (trimethylenetrinitramine), 121-82-4	64	3.2		
TATB (triaminotrinitrobenzene)[d], 3058-38-6				
Tetryl (N-methyl-N,2,4,6-tetranitrobenzeneamine), 479-45-8	800	350		
1,3,5-TNB (trinitrobenzene), 99-35-4	4	1.8		
2,4,6-TNT (trinitrotoluene), 118-96-7	40	12		

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Chemicals[b]	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
Organics				
Volatile Organic Compounds				
Acetone, 67-64-1	8,000	3,500		0.01, 10
Benzene, 71-43-2	0.67	5[h]	0.12	0.01, 10[e]
Benzoic Acid, 65-85-0	320,000	140,000		100, —
Bromodichloromethane, 75-27-4	11	0.56		0.01, 10[e]
Bromoform, 75-25-2	89	4.4	0.90	0.01, 10[e]
Bromomethane, 74-83-9	0.43	49	4.9	0.01, 10
2-Butanone (Methyl ethyl ketone), 78-93-3	4,000	1,700	1,000	0.01, 10
Carbon disulfide, 75-15-0	7.4	3,500	10	0.01, 10
Carbon tetrachloride, 56-23-5	0.21	5[h]	0.066	0.01, 10[e]
Chlorobenzene, 108-90-7	67	100[h]	20	0.01, 10
Chloroethane, 75-00-3	3,300		10,000	0.01, 10
Chloroform, 67-66-3	0.21	100[h]	0.043	0.01, 10[e]
Chloromethane, 74-87-3	6.4	27	5.6	0.01, 10
Dibromochloromethane, 124-48-1	83	4.2		0.01, 10[e]
1,1-Dichloroethane, 75-34-3	410	3500	500	0.01, 10
1,1-Dichloroethene, 75-35-4	0.59	7[h]	0.29	0.01, 10[e]
1,2-Dichloroethane, 107-06-2	0.20	5[h]	0.038	0.01, 10[e]
cis-1,2-Dichloroethene, 156-59-2	800	70[h]		0.01, 10
trans-1,2-Dichloroethene, 156-60-5	1600	100[h]		0.01, 10
1,2-Dichloropropane, 78-87-5	6.5	5[h]	4.0	0.01, 10
cis-1,3-Dichloropropene, 10061-01-5	0.17	0.19	0.027	0.01, 10[e]
trans-1,3-Dichloropropene, 10061-02-6	0.17	0.19	0.027	0.01, 10[e]
Ethyl benzene, 100-41-4	3,100	700[h]	1000	0.01, 10
n-Hexane, 110-54-3	4,800	2,100		
2-Hexanone[d], 591-78-6				0.01, 10
Methanol, 67-56-1	40,000	18,000		

TABLE J-1

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Chemicals[b]	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
4-Methyl-2-pentanone (MIK), 108-10-1	510	1,700	80	0.01, 10
Methylene Chloride, 75-09-2	5.6	5[h]	2.2	0.01, 10[e]
Styrene, 100-42-5	16,000	100[h]		0.01, 10[e]
1,1,2,2-Tetrachloroethane, 79-34-5	3.9	1.8	0.18	0.01, 10[e]
Tetrachloroethene, 127-18-4	5.9	5[h]	1.8	0.01, 10[e]
Toluene, 108-88-3	890	1000[h]	380	0.01, 10
1,1,1-Trichloroethane, 71-55-6	1,000	200[h]	1,000	0.01, 10
1,1,2-Trichloroethane, 79-00-5	6.3	5[h]	0.63	0.01, 10[e]
Trichloroethene, 79-01-6	3.2	5[h]	0.58	0.01, 10[e]
Vinyl Chloride, 75-01-4	0.013	2[h]	0.012	0.01, 10[e]
Xylene (Total), 1330-20-7	160,000	10,000[h]		0.01, 10
Semi-Volatile Organic Compounds				
Acenaphthene, 83-32-9	4,800	2,100		0.33, 10
Acenaphthylene[d], 208-96-8				0.33, 10
Anthracene, 120-12-7	24,000	10,000		0.33, 10
Benzo[a]anthracene, 56-55-3	0.64	0.1[i]		0.33, 10
Benzo[b]fluoranthene,205-99-2	0.7	0.2[i]		0.33, 10
Benzo[k]fluoranthene,207-08-9	1.5	0.2[i]		0.33, 10
Benzo[ghi]perylene[d], 191-24-2	44			0.33, 10
Benzo[a]pyrene, 50-32-8	0.10	0.2[h]	0.00057	0.33, 10[e]
alpha-BHC, 319-84-6	0.1	0.0056		
beta-BHC, 319-85-7	4	0.19		
Bis-(2-chloroethoxy)methane[d], 111-91-1				0.33, 10
Bis-(2-chloroethyl)ether, 111-44-4	0.13	0.032	0.0032	0.33, 10[e]
Bis-(2-ethylhexyl)phthalate, 117-81-7	50	4[i]		0.33, 10[e]
4-Bromophenyl-phenylether[d], 101-55-3				0.33, 10
Butyl benzyl phthalate, 85-68-7	16,000	100[i]		0.33, 10

63 50
38
27

TABLE J-1

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Chemicals[b]	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m³	CRQL[c] mg/kg and µg/l
Carbazole, 86-74-8	35	1.8		0.33, 10
Chlordane, 57-74-9	0.54	0.2[h]		0.017, 0.05
4-Chloroaniline, 106-47-8	320	140		0.33, 10
4-Chloro-3-methylphenol[g] (p-chloro-m-cresol), 59-50-7	16,000	7,000		0.33, 10
2-Chloronaphthalene, 91-58-7	6,400	2,800		0.33, 10
2-Chlorophenol, 95-57-8	400	170		0.33, 10
4-Chlorophenyl phenyl ether[d], 7005-72-3				0.33, 10
Chrysene, 218-01-9	22	0.2[i]		0.33, 10
DDD, 72-54-8	2.9	0.15		0.03, 0.1
DDT, 50-29-3	2.1	0.1		0.03, 0.1
Dibenzo[a,h]anthracene, 53-70-3	0.086	0.3[i]		0.33, 10
Dibenzofuran[d], 132-64-9				0.33, 10
Di-n-butylphthalate, 84-74-2	8,000	3,500		0.33, 10
1,2-Dichlorobenzene, 95-50-1	1,600	600[h]	200	0.33, 10
1,3-Dichlorobenzene, 541-73-1	7,200	600[h]		0.33, 10
1,4-Dichlorobenzene, 106-46-7	290	75[h]	700	0.33, 10
3,3'-Dichlorobenzidine, 91-94-1	1.6	0.078		0.33, 10[e]
2,4-Dichlorophenol, 120-83-2	240	100		0.33, 10
Diethylphthalate, 84-66-2	64,000	5,000[i]		0.33, 10
Dimethylformamide, 68-12-2	8,000	3,500		
2,4-Dimethylphenol, 105-67-9	1,600	700		0.33, 10
Dimethyl phthalate, 131-11-3	80,000	35,000		0.33, 10
4,6-Dinitro-2-methylphenol[d] (4,6-dinitro-o-cresol), 534-52-1				0.8, 25
2,4-Dinitrophenol, 51-28-5	160	70		0.8, 25
Di-n-octyl phthalate, 117-84-0	1,600	700		0.33, 10
Endosulfan, 115-29-7	4	1.8		
Ethyl acetate, 141-78-6	72,000	32,000		
Ethylene glycol, 107-21-1	160,000	70,000		

TABLE J-1

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Chemicals[b]	Soil Screening Action Level mg/kg	Water Screening Action Level µg/l	Air Screening Action Level µg/m^3	CRQL[c] mg/kg and µg/l
Fluoranthene, 206-44-0	3,200	1,400		0.33, 10
Fluorene, 86-73-7	3,200	1,400		0.33, 10
Hexachlorobenzene, 118-74-1	0.44	1[h]	0.0022	0.33, 10[e]
Hexachlorobutadiene, 87-68-3	90	4.5	0.45	0.33, 10[e]
Hexachlorocyclopentadiene, 77-47-4	560	50[h]	0.07	0.33, 10
Hexachloroethane, 67-72-1	80	25	2.5	0.33, 10
Indeno[1,2,3-cd]pyrene, 193-39-5	0.41	0.4[i]		0.33, 10
Isophorone, 78-59-1	7,400	370		0.33, 10
2-Methylnaphthalene[d], 91-57-6				0.33, 10
2-Methylphenol (o-cresol), 95-48-7	4,000	1,700		0.33, 10
4-Methylphenol (p-cresol), 106-44-5	4,000	1,700		0.33, 10
Naphthalene, 91-20-3	3,200	1400		0.33, 10
2-Nitroaniline, (o-nitroaniline) 88-74-4	4.8	2.1	0.20	0.8, 25[e]
3-Nitroaniline(m-nitroaniline)[d], 99-09-2				0.8, 25
4-Nitroaniline(p-nitroaniline)[d], 100-01-6				0.8, 25
Nitrobenzene, 98-95-3	5.3	18	2.0	0.33, 10
2-Nitrophenol[d], 88-75-5				0.33, 10
4-Nitrophenol[d], 100-02-7				0.8, 25
N-Nitrosodiphenylamine, 86-30-6	140	7.1		0.33. 10[e]
N-Nitrosodi-N-propylamine, 621-64-7	0.10	0.0050		0.33, 10[e]
2,2-Oxybis(1-chloropropane) (bis[2-chloroisopropyl]ether), 108-60-1	100	0.50	1.0	0.33, 10
PCB (Aroclors), 1336-36-3	0.09	0.50[h]		0.033, 1
Pentachlorophenol, 87-86-5	5.8	1[h]		0.8, 25[e]
Phenanthrene[d], 85-01-8				0.33, 10
Phenol, 108-95-2	48,000	21,000		0.33, 10
Pyrene, 129-00-0	2,400	1,000		0.33, 10
1,2,4-Trichlorobenzene, 120-82-1	160	70[h]	9.0	0.33, 10
2,4,5-Trichlorophenol, 95-95-4	8,000	3,500		0.8, 25
2,4,6-Trichlorophenol, 88-06-2	64	3.2	0.32	0.33, 10[e]

a. SALs based on methodologies given by EPA 1990 (0432) and EPA (1991, 0302). SALs are rounded to two significant figures. Water SALs are used for both groundwater and surface water.
b. Target Analyte List (TAL), Target Compound List (TCL), High-Explosive List, with associated Chemical Abstractt Services numbers, as given by EPA (1991, 0814; ~~0779~~ **TBD)** (DOE 1991, 0779)
c. Contract Laboratory Program (CLP) and Contract-Required Quantitation Limits (CRQLs) for soil (mg/kg) and water (µg/l), respectively. CRQLs are provided as an indicator of the analytical method detection limit, and are not to be viewed in an absolute sense as a standard of performance for a given sample representing a given matrix and a given analyte. CRQLs are not available for air.
d. Toxicity data (e.g., RfDs and/or slope factors) were not available; therefore, SALs were not calculated.
e. The SAL is less than the CRQL; therefore, special analytical services may be required.
f. Soil SAL based on EPA guidance on establishing lead cleanup levels (EPA 1989, 0987).
g. Based on subchronic RfD divided by 10; chronic RfD not available.
h. Safe drinking water regulations (EPA 1993, 1071) MCL water SALs were not calculated for compounds with MCLs in accordance with proposed EPA guidance (EPA 1990, 0432)
i. MCL is not final. Number presented is a draft or proposed MCL from EPA (1993, 1071)
j. No MCL or toxicity information appropriate for SAL derivation is available for lead. The SAL presented is based on Federal ambient water quality criteria for the protection of human health based on water and fish consumption (EPA 1993, 0830).

TABLE J-2

SUMMARY OF SCREENING ACTION LEVELS FOR RADIONUCLIDES IN SOIL AND WATER FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY

Radionuclides	Soil Screening Action Level (pCi/g dry soil)[a]	Water Screening Action Level pCi/l[b]
Americium-241	22.0	15[e]
Carbon-14	4.7×10^5	2,600[f]
Cesium-134	1.90	75[f]
Cesium-137	4.0	110[f]
Cobalt-57	40.0	4,600[f]
Cobalt-60	0.90	200[f]
Gross Alpha Particle Activity	NA	15[g]
Iodine-129	41.0	20[f]
Manganese-54	3.40	2,000[f]
Plutonium-238	27.0	15[e]
Plutonium-239	24.0	15[e]
Radium-226	0.73[c]	20[g]
Radium-228	1.6[c]	20[g]
Ruthenium-106	15.0	200[f]
Sodium-22	1.30	480[f]
Strontium-90	8.90	8[h]
Thorium-230	10.0[c]	15[e]
Thorium-232	0.88[c]	15[e]
Tritium	1.5×10^7[d]	2×10^4[h]
Uranium-233	86.0	19[f,i]
Uranium-234	86.0	19[f,i]
Uranium-235	18.0	21[f,i]
Uranium-238	59.0	6.7[i]
Depleted Uranium	59.0[j]	NA[i]
Natural Uranium	66.0[j]	NA[i]

a. Based on 10 mrem/yr (above background) dose limit. Input data are representative of mesa top environment at the Laboratory.

b. Water SALs are used for both groundwater and surface water.

c. Generic limits for ^{226}Ra, ^{228}Ra, ^{230}Th, and ^{232}Th are set in DOE Order 5400.5 **(DOE 1990, 0080)** at 5 pCi/g averaged over the first 15 cm of soil and 15 pCi/g averaged over each additional 15-cm interval. The more conservative derived SALs are to be used for screening purposes only.

d. The SAL for tritium in soil is 1.5×10^7 pCi/g dry soil. If soil tritium concentrations are reported in pCi/mL soil moisture, the values must be converted to a dry soil basis by multiplying by $M/[\rho_W(1-M)]$, where M is the moisture fraction of the sample (g water/g total sample)and ρ_W is the soil moisture density ≈1g/mL). E.g., a soil with 10% moisture fraction containing 10^6 pCi of tritium per milliliter of soil moisture contains $10^6 \times 0.1 / (1 \times 0.9) = 1.1 \times 10^5$ pCi/g dry soil.

e. The total of all alpha emitters, less ^{226}Ra, ^{222}Rn, and uranium, will not exceed 15 pCi/L in accordance with EPA's proposed rule ***(EPA 1991, 0887***, pp. 33050-33127).

f. Calculated based on 4-mrem/yr dose limit using Federal Guidance Report No. 11 **(EPA 1988, 0982).** The total of all beta and photon emitters, less ^{228}Ra, will not exceed 4 mrem/yr in accordance with EPA's proposed rule ***(EPA 1991, 0887).***

g. MCL listed in EPA's proposed rule ***(EPA 1991, 0887).***

h. MCL from Table A, Average Annual Concentrations Assumed to Produce a Total Body or Organ Dose of 4 mrem/yr, in 40 CFR 141 **(EPA 1991, 0887).**

i. The MCL for total uranium concentration is 20 µg/L or 30 pCi/L in accordance with EPA's proposed rule **(EPA 1991, 0887).** In the proposed rule, the EPA states that the activity ratio of ^{234}U to ^{238}U in rock (1:1) is not appropriate for drinking water. EPA has found ratios ranging from 0.7:1 to 32:1, with a geometric mean of 2.7:1. Using the geometric mean, an "overall mass to activity ratio" (specific activity) of 1.3 pCi/µg was calculated for uranium as it appears in drinking water. The specific activity of natural uranium in rock is 0.68 pCi/µg. Therefore, no value is listed for "natural" or "depleted" uranium in the water SAL column because it appears that the isotopic mix can change in water. The MCL for total uranium (20 µg/L) was set based on toxicity to the kidney. However, for ^{233}U, ^{234}U, and ^{235}U, the SALs were set based on cancer mortality risk because radiation dose, not kidney toxicity, was the limiting factor.

j. Calculated assuming the following isotopic abundances:

	Natural Uranium (%)	Depleted Uranium (%)
^{234}U	0.0057	0.0005
^{235}U	0.7204	0.2500
^{238}U	99.2739	99.7500

TABLE J-3

TOXICOLOGICAL INFORMATION FOR ESTABLISHING SCREENING ACTION LEVELS FOR POTENTIAL CHEMICALS OF CONCERN IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[d] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l[e]	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[f] mg/kg and µg/l
Inorganics												
Aluminum[g], 7429-90-5												40, 200
Antimony, 7440-36-0	0.0004					32						12, 60[h]
Arsenic, 7440-38-2	0.0003	1.75, A		15, A		24	0.40				0.00023	2, 10[h]
Barium, 7440-39-3	0.07	ND, D	0.00014[i]	ND, D		5,600				0.49		40, 200
Beryllium, 7440-41-7	0.005	4.3, B2		8.4, B2		400	0.16				0.00042	1, 5[h]
Cadmium, 7440-43-9	0.001[j]			6.3, B1		80					0.00056	1, 5
Calcium[g], 7440-70-2												1000, 5000
Chromium III, 16065-83-1	1.0					80,000						2, 10
Chromium VI, 7440-47-3	0.005			42, A		400					0.000083	2, 10
Cobalt[g], 7440-48-4												10, 50
Copper, 7440-50-8	0.037[j]					3,000		1,300				5, 25
Cyanide, 57-12-5	0.02	ND, D		ND, D	8.2e+03	1,600						2, 10
Iron[g], 1543-83-10												20, 100
Lead[g], 7439-92-1		ND, B2		ND, B2								0.6, 3
Magnesium[g], 7786-30-3												1000, 5000

TABLE J-3

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Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[d] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l[e]	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[f] mg/kg and µg/l
Manganese, 7439-96-5	0.1	ND, D	0.00011	ND, D		8,000		3,500		0.39		3, 15
Mercury, 7439-97-6	0.0003[i]	ND, D	8.6e-5[i]	ND, D		24				0.30		0.04, 0.2
Nickel, 7440-02-0	0.02			0.84, A		1,600					0.0042	8, 40
Nitrate	1.6[k]					130,000						
Nitrite, 14797-65-0	0.1					8,000						
Potassium9, 7447-40-7												1000, 5000
Selenium, 7782-49-2	0.005	ND, D		ND, D		400						1, 5
Silver, 7440-22-4	0.005					400		170				2, 10
Sodium9, 7647-14-5												1000, 5000
Thallium, 7440-28-0	0.00008 l					6.4						2, 10[h]
Vanadium, 7440-62-2	0.007[i]					560		240				10, 50
Zinc, 7440-66-6	0.3	ND, D		ND, D		24,000		10,000				4, 20

TABLE J-3

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Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[d] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l[e]	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[f] mg/kg and µg/l
Volatile Organic Compounds												
Acetone, 67-64-1	0.1				1.4e+04	8,000		3,500				0.01, 10
Benzene, 71-43-2		0.029, A		0.029, A	5.7e+03		0.67[m]				0.12	0.01, 10[h]
Benzoic acid, 65-85-0	4	ND,D		ND,D		320,000		140,000				100, —
Bromodichloromethane, 75-27-4	0.02	0.062, B2		ND, B2	8.0e+02	1,600	11	700	0.56			0.01, 10[h]
Bromoform, 75-25-2	0.02	0.0079, B2		0.0039, B2		1,600	89	700	4.4		0.90	0.01, 10[h]
Bromomethane, 74-83-9	0.0014	ND, D	0.0014	ND, D	3.9e+02	0.43[m]		49		4.9		0.01, 10
2-Butanone (Methyl ethyl ketone), 78-93-3	0.6	ND, D	0.29	ND, D	1.9e+04	4,000[m]		1,700		1,000		0.01, 10
Carbon disulfide, 75-15-0	0.1		0.0029[i]		3.2e+03	7.4[m]		3,500		10		0.01, 10
Carbon tetrachloride, 56-23-5	0.0007	0.13, B2		0.053, B2	3.3e+03	56	0.21[m]				0.066	0.01, 10[h]
Chlorobenzene, 108-90-7	0.02	ND, D	0.0057[i]	ND, D	1.5e+04	67[m]				20		0.01, 10
Chloroethane, 75-00-3			2.9		1.4e+03	3,300[m]				10,000		0.01, 10
Chloroform, 67-66-3	0.01	0.0061, B2		0.081, B2	4.8e+03	800	0.21[m]	0			0.043	0.01, 10[h]
Chloromethane, 74-87-3		0.013, C[i]		0.0063, C[i]	1.2e+03		6.4[m]		27		5.6	0.01, 10

TABLE J-3

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Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[d] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l[e]	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[f] mg/kg and µg/l
Dibromochloromethane, 124-48-1	0.02	0.084, C		ND, C		1,600	83	700	4.2			0.01, 10[h]
1,1-Dichloroethane, 75-34-3	0.1[i]	ND, C	0.14[i]	ND, C	3.8e+03	410[m]		3,500		500		0.01, 10
1,1-Dichloroethene, 75-35-4	0.009	0.6, C		0.12, C	2.1e+03	720	0.59[m]				0.29	0.01, 10[h]
1,2-Dichloroethane, 107-06-2		0.091, B2		0.091, B2	5.5e+03		0.20[m]				0.038	0.01, 10[h]
cis-1,2-Dichloroethene, 156-59-2	0.01				4.6e+03	800						0.01, 10
trans-1,2-Dichloroethene, 156-60-5	0.02					1600						0.01, 10
1,2-Dichloropropane, 78-87-5		0.068, B2[i]	0.0011	ND, B2[i]	7.1+03	6.5[m]	10			4.0		0.01, 10[h]
cis-1,3-Dichloropropene, 10061-01-5	0.0003	0.18, B2[i]	0.0057	0.13, B2[i]	6.8+03	14[m]	0.17[m]	11	0.19	20	0.027	0.01, 10[h]
trans-1,3-Dichloropropene, 10061-02-6	0.0003	0.18, B2[i]	0.0057	0.13, B2[i]	6.8+3	14[m]	0.17[m]	11	0.19	20	0.027	0.01, 10[h]
Ethyl benzene, 100-41-4	0.1	ND, D	0.29	ND, D	2.2e+04	3,100[m]				1000		0.01, 10
n-Hexane, 110-54-3	0.06[i]			0.057		4,800		2,100				
2-Hexanone9, 591-78-6					5.5e+04							0.01, 10
Methanol, 67-56-1	0.5					40,000		18,000				
4-Methyl-2-pentanone (MIK), 108-10-1	0.05[i]		0.023[i]		3.2e+04	510[m]		1,700		80		0.01, 10

TABLE J-3

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Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[d] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l[e]	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[f] mg/kg and µg/l
Methylene Chloride, 75-09-2	0.06	0.0075, B2	0.86[i]	0.0016, B2	2.9e+03	1,400[m]	5.6[m]			3000	2.2	0.01, 10[h]
Styrene, 100-42-5	0.2		0.29		1.8e+04	16,000						0.01, 10[h]
1,1,2,2-Tetrachloroethane, 79-34-5		0.2, C		0.2, C	2.9e+04		3.9[m]		1.8		0.18	0.01, 10[h]
Tetrachloroethene, 127-18-4	0.01	0.052, B-C[n]		0.002, B-C[n]	6.0e+03	800	5.9[m]				1.8	0.01, 10[h]
Toluene, 108-88-3	0.2	ND, D	0.40	ND, D	1.1e+04	890[m]				380		0.01, 10
1,1,1-Trichloroethane, 71-55-6	0.09[i]	ND, D	0.29[i]	ND, D	5.1e+03	1,000[m]				1,000		0.01, 10
1,1,2-Trichloroethane, 79-00-5	0.004	0.057, C		0.056, C	1.1e+04	320	6.3[m]				0.63	0.01, 10[h]
Trichloroethene, 79-01-6		0.011, B-C[n]		0.006, B-C[n]	5.8e+03		3.2[m]				0.58	0.01, 10[h]
Vinyl Chloride, 75-01-4		1.9, A[i]		0.294, A[i]	1.1e+03		0.013[m]				0.012	0.01, 10[h]
Xylene (Total), 1330-20-7	2				9.6e+03	160,000						0.01, 10

TABLE J-3

TOXICOLOGICAL INFORMATION FOR ESTABLISHING SCREENING ACTION LEVELS FOR POTENTIAL CHEMICALS OF CONCERN IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[d] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l[e]	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[f] mg/kg and µg/l
Semi-Volatile Organic Compounds												
Acenaphthene, 83-32-9	0.06				3.4e+05	4,800		2,100				0.33, 10
Acenaphthylene[g], 208-96-8					6.1e+04							0.33, 10
Anthracene, 120-12-7	0.3	ND, D		ND, D	1.8e+05	24,000		10,000				0.33, 10
Benzo[a]anthracene, 56-55-3		1.1[o], B2		NA, B2			0.64					0.33, 10
Benzo[b]fluoranthene, 205-99-2		1.1[o], B2		ND, B2			0.7					0.33, 10
Benzo[k]fluoranthene, 207-08-9		0.48[o], B2		ND, B2			1.5					0.33, 10
Benzo[ghi]perylene, 191-24-2		0.16[o], D		ND, D			44					0.33, 10
Benzo[a]pyrene, 50-32-8		7.3, B2		6.1, B2[i]			0.10				0.00057	0.33, 10[h]
alpha-BHC, 319-84-6		6.3, B2		6.3, B2			0.1		0.0056			
beta-BHC, 319-85-7		1.8, C		1.9, C			4		0.19			
Bis(2chloroethoxy)methane[g] 111-91-1		ND, D		ND, D								0.33, 10
Bis-(2-chloroethyl)ether, 111-44-4		1.1, B2		1.1, B2	4.9e+04		0.13[m]		0.032		0.0032	0.33, 10[h]

TABLE J-3

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Bis(2-ethylhexyl)phthalate, 117-81-7	0.02	0.014, B2		ND, B2		1,600	50					0.33, 10[h]
4-Bromophenyl-phenylether[g], 101-55-3												0.33, 10
Butyl benzyl phthalate, 85-68-7	0.2	ND, C		ND, C		16,000						0.33, 10
Carbazole, 86-74-8		0.02, B2[l]		ND, B2[f]			35		1.8			0.33, 10
Chlordane, 57-74-9	0.00006	1.3, B2		1.3, B2		4.8	0.54					0.017, 0.05
4-Chloroaniline, 106-47-8	0.004					320		140				0.33, 10
4-Chloro-3-methylphenol (p-chloro-m-cresol), 59-50-7	2[i,p]					16,000		7,000				0.33, 10
2-Chloronaphthalene, 91-58-7	0.08				1.4e+05	6,400		2,800				0.33, 10
2-Chlorophenol, 95-57-8	0.005					400		170				0.33, 10
4-Chlorophenyl phenylether[g], 7005-72-3												0.33, 10
Chrysene, 218-01-9		0.032[o],B2		ND, B2			22					0.33, 10
DDD, 72-54-8		0.24, B2					2.9		0.15			0.03, 0.1
DDT, 50-29-3	0.0005	0.34, B2				40	2.1	18	0.1			0.03, 0.1
Dibenzo[a,h]anthracene, 53-70-3	0.09[k]	8.1[o], B2		ND, B2			0.086					0.33, 10
Dibenzofuran[g] 132-64-9												0.33, 10

TABLE J-3

TOXICOLOGICAL INFORMATION FOR ESTABLISHING SCREENING ACTION LEVELS FOR POTENTIAL CHEMICALS OF CONCERN IN SOIL, WATER, AND AIR FOR ENVIRONMENTAL CHARACTERIZATION OF LOS ALAMOS NATIONAL LABORATORY[a]

Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[d] mg/kg and µg/l
Di-n-butylphthalate, 84-74-2	0.1	ND, D		ND, D		8,000		3,500				0.33, 10
1,2-Dichlorobenzene, 95-50-1	0.09		0.057[i]		4.5e+04	1,600[m]				200		0.33, 10
1,3-Dichlorobenzene, 541-73-1	0.09[k]				3.3e+04	7,200						0.33, 10
1,4-Dichlorobenzene, 106-46-7		0.024, C[l]	0.2[i]	ND, C	3.6e+04	5,800[m]	290			700		0.33, 10
3,3'-Dichlorobenzidine, 91-94-1		0.45, B2		ND, B2			1.6		0.078			0.33, 10[h]
2,4-Dichlorophenol, 120-83-2	0.003					240		100				0.33, 10
Diethylphthalate, 84-66-2	0.8	ND, D		ND, D		64,000						0.33, 10
Dimethylformamide, 68-12-2	0.1[i]		0.0086			8,000		3,500				
2,4-Dimethylphenol, 105-67-9	0.02			ND, D	1.1e+05	1,600		700				0.33, 10
Dimethyl phthalate, 131-11-3	1[v]	ND, D		ND, D		80,000		35,000				0.33, 10
4,6-Dinitro-2-methylphenol[9] (4,6-dinitro-o-cresol), 534-52-1												0.8, 25
2,4-Dinitrophenol, 51-28-5	0.002					160		70				0.8, 25
Di-n-octyl phthalate, 117-84-0	0.02[i]					1,600		700				0.33, 10
Endosulfan, 115-29-7	0.00005 i, q					4		1.8				
Ethyl acetate, 141-78-6	0.9					72,000		32,000				
Ethylene glycol, 107-21-1	2					160,000		70,000				

TABLE J-3

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Fluoranthene, 206-44-0	0.04	ND, D		ND, D		3,200		1,400				0.33, 10
Fluorene, 86-73-7	0.04				5.1e+05	3,200		1,400				0.33, 10
Hexachlorobenzene, 118-74-1	0.0008	1.6, B2		1.6, B2		64	0.44				0.0022	0.33, 10[h]
Hexachlorobutadiene, 87-68-3	0.002[r]	0.078, C		0.077, C		160	90	70	4.5		0.45	0.33, 10[h]
Hexachlorocyclopentadiene, 77-47-4	0.007		0.00002[l]			560				0.07		0.33, 10
Hexachloroethane, 67-72-1	0.001	0.014, C		0.014, C		80	500	35	25		2.5	0.33, 10
Indeno[1,2,3-cd]pyrene, 193-39-5		1.7[o], B2		ND, B2			0.41					0.33, 10
Isophorone, 78-59-1	0.2	0.00095, C		ND, C		16,000	7,400	7,000	370			0.33, 10
2-Methylnaphthalene[g], 91-57-6					1.9e+05							0.33, 10
2-Methylphenol (o-cresol), 95-48-7	0.05	ND, C		ND, C		4,000		1,700				0.33, 10
4-Methylphenol (p-cresol), 106-44-5	0.05[f]	ND, C		ND, C		4,000		1,700				0.33, 10
Naphthalene, 91-20-3	0.04[f]				6.8e+04	3,200		1,400				0.33, 10
2-Nitroaniline, (o-nitroaniline) 88-74-4	6.0e-05[f]		5.7e-05[l]			4.8		2.1		0.20		
3-Nitroaniline(m-nitroaniline)[g], 99-09-2												0.8, 25
4-Nitroaniline(p-nitroaniline)[g], 100-01-6												0.8, 25

TABLE J-3

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Nitrobenzene, 98-95-3	0.0005	ND, D	0.00057[l]	ND, D	1.3e+04	5.3[m]		18		2.0		0.33, 10
2-Nitrophenol[g], 88-75-5												0.33, 10
4-Nitrophenol[g], 100-02-7					1.9e+04							0.8, 25
N-Nitrosodiphenylamine, 86-30-6		0.0049, B2		ND, B2			140		7.1			0.33. 10[h]
N-Nitrosodi-N-propylamine, 621-64-7		7, B2		ND, B2			0.10		0.0050			0.33, 10[h]
2,2-Oxybis(1-chloropropane) (bis[2-chloroisopropyl]ether), 108-60-1	0.04	0.07, C[l]		0.035, C[l]		3,200	100	1,400	0.50		1.0	0.33, 10
PCB (aroclors), 1336-36-3		7.7, B2					0.09					0.033, 1
Pentachlorophenol, 87-86-5	0.03	0.12, B2		ND, B2		2,400	5.8					0.8, 25[h]
Phenanthrene[g], 85-01-8		ND, D		ND, D	4.4e+05							0.33, 10
Phenol, 108-95-2	0.6					48,000		21,000				0.33, 10
Pyrene, 129-00-0	0.03	ND, D		ND, D		2,400		1,000				0.33, 10
1,2,4-Trichlorobenzene, 120-82-1	0.01	ND, D	0.0026[l]	ND, D	9.5e+04	160[m]				9.0		0.33, 10
2,4,5-Trichlorophenol, 95-95-4	0.10					8,000		3,500				0.8, 25
2,4,6-Trichlorophenol, 88-06-2		0.011, B2		0.011, B2			64		3.2		0.32	0.33, 10[h]

TABLE J-3

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Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor (mg/kg-d)$^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor (mg/ kg-d)$^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l	Air Screening Action Level Systemic Toxicant µg/m^3	Air Screening Action Level Carcinogen µg/m^3	CRQL[d] mg/kg and µg/l
High Explosives												
2-amino-2,6-DNT (aminodinitrotoluene)[g]												
4-amino-2,6-DNT (amino-dinitrotoluene)[g], 19406-51-0												
Ammonium nitrate[g], 6484-52-2												
Barium nitrate (soluble barium)	0.07	ND, D	0.00014[f]	ND, D		5,600				0.49		40,200
CEF (tri(b-chloroethyl)-phosphate)[g], 115-96-8												
1,3-DNB (dinitrobenzene), 99-65-0	0.0001	ND, D		ND, D		8		3.5				
2,4-DNT (dinitrotoluene), 121-14-2	0.002	0.68, B2[i]		ND, B2		160	1	70	0.05			0.33,10[h]
2,6-DNT (dinitrotoluene), 606-20-2	0.001[k]	0.68, B2[i]		ND, B2		80	1	35	0.05			0.33,10[h]
DPA (diphenylyamine), 122-39-4	0.025					2,000		880				
HMX (cyclotetramethylenete-tranitramine), 2691-41-0	0.05			ND, D		4,000		1800				

TABLE J-3

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Chemicals[b]	Chronic Oral RfD mg/kg-day	Oral Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	Chronic Inhalation RfD mg/kg-d	Inhalation Carcinogenic Slope Factor $(mg/kg\text{-}d)^{-1}$ and Group[c]	VF[k] m^3/kg	Soil Screening Action Level Systemic Toxicant mg/kg	Soil Screening Action Level Carcinogen mg/kg	Water Screening Action Level Systemic Toxicant µg/l	Water Screening Action Level Carcinogen µg/l	Air Screening Action Level Systemic Toxicant $\mu g/m^3$	Air Screening Action Level Carcinogen $\mu g/m^3$	CRQL[d] mg/kg and µg/l
Nitrocellulose (non-toxic)[g/k], 9004-70-0												
Nitromethane[g], 75-52-5												
NP (bis(2,2-dinitropropyl) acetal/formal)[g], 5917-61-3												
PETN (pentaerythritolletra-nitrate), 78-11-5	0.02[s]					1,600		700				
RDX (trimethylenetri-nitramine), 121-82-4	0.003	0.11, C		ND, C		240	64	110	3.2			
TATB (triaminotrinitro-benzene)[g] 3058-38-6												
Tetryl (N-methyl-N,2,4,6-tetranitrobenzeneamine), 479-45-8	0.01					800		350				
1,3,5-TNB (trinitrobenzene), 99-35-4	0.00005					4		1.8				
2,4,6-TNT (trinitrotoluene), 118-96-7	0.0005	0.03, C		ND, C		40	230	18	12			

a. SALs based on methodologies given by EPA (1990, 0432; EPA 1991, 0302). Reference dose (RfD) and carcinogenic slope factor data obtained from EPA (1993, 1062), unless otherwise noted. SALs are rounded to two significant figures. Water SALs are used for both groundwater and surface water. ND = not determined.
b. Target Analyte List (TAL), Target Compound List (TCL), High Explosive List, with associated Chemical Abstract Service numbers, as given by EPA (1991, 0814; 1991, ~~0779~~ TBD).
c. Carcinogens grouped as follows: Group A—human carcinogen; Group—B probable human carcinogen; Group C—possible human carcinogen; Group D—not classifiable as to human carcinogenicity.
d. Soil-to-air volatilization factor; calculated based on equation given by EPA (1991, 0302) and chemical-specific parameters given by Strenge and Peterson (1989, 0837) and EPA (1988, 0747). The volatilization factor (VF) is given only for substances with molecular weight less than 200 and Henry's Law constant greater than 10^{-5}atm/m^3-mole.
e. Water SALs not calculated for compounds with MCLs (Table J-1, Chemical-Specific MCLs).
f. Contract Laboratory Program, Contract-Required Quantitation Limits (CRQLs) for soil (mg/kg) and water (µg/l), respectively. CRQLs are provided as an indicator of the analytical method detection limit and are not to be viewed in an absolute sense as a standard of performance for a given sample. CRQLs are not available for air.
g. Toxicity data (e.g., RfDs and/or slope factors) were not available; therefore, SALs were not calculated.
h. The SAL is less than the CRQL; therefore, special analytical services may be required.
i. Toxicity data obtained from EPA (1992, 0833).
j. Oral RfD for cadmium in food/solids.
k. EPA 1993, 1071.
l. Oral RfD for thallium (I) sulfate.
m. Soil SAL incorporates inhalation pathway (only for substances with both an inhalation RfD or slope factor and a VF listed). The equation is given below.
n. Values obtained from the Superfund Health Risk Technical Support Center (1992, 1070).
o. Carcinogenic oral slope factor calculated based on relative potency estimates for polycyclic aromatic hydrocarbons (ICF-Clement 1988, 1063).
p. Based on subchronic RfD divided by 10; chronic RfD for 4-chloro-3-methylphenol not available.
q. Oral RfD was withdrawn on December 1, 1992, until further review (EPA 1993, 1062).
r. Oral RfD was withdrawn on May 1, 1993 until further review (EPA 1993, 1062).
s. Acceptable dose rate for oral route of exposure (Layton et al. 1987, 1060), p. 5.

General Equations for Calculating SALS

Systemic Toxicants

SAL = (THI x RfD x BW x CF)/(I x A), where

SAL = soil screening action level (mg/kg for soil SALs; µg/L for water SALs; µg/m^3 for air SALs).
THI = target hazard index; 1.
RfD = chronic reference dose (mg/kg/day): oral RfD used for soil and water SALs; inhalation RfD used for air SAL.
BW = body weight; 16 kg for child (used for soil SAL): 70 kg for adult (used for water and air SALs).
CF = conversion factor: 10^6 mg/kg for soil SAL; 1,000 ug/mg for water and air SALs.
I = intake assumption: 200 mg/day for soil SAL (child); 2 L/day for water SAL; 20 m^3/day for air SAL.
A = absorption factor: 1.

Carcinogenic Constituents

SAL = (R x BW x LT x CF)/(SF x I x A x ED), where

R = target risk: 10^{-6} for Class A and B carcinogens; 10^{-5} for Class C carcinogens.
BW = body weight: 70 kg.
LT = assumed lifetime: 70 yr.
CF = conversion factor: 10^6 mg/kg for soil SAL; 1000 µg/mg for water and air SALs.
SF = slope factor (mg/kg/day)$^{-1}$: oral SF used for soil and water SALs; inhalation SF used for air SALs.
I = intake assumption: 100 mg/day for soil SAL; 2 L/day for water SAL; 20 m^3/day for air SAL.
A = absorption factor: 1.
ED = exposure duration: 70 yr.

Equations for Calculating Soil SALs for Volatile Contaminants

Systemic Toxicants

SAL = (THI x BW)/((1/RfD$_O$ x 10^{-6} kg/mg x ING) + (1/RfD$_I$ x INH x (1/VF + 1/PEF)), where

THI = target hazard index: 1.
BW = body weight: 16 kg.
RfD$_O$ = chronic oral reference dose (mg/kg/day).
RfD$_I$ = chronic inhalation reference dose (mg/kg/day).
ING = ingestion intake assumption: 200 mg/day.

VF = soil-to-air volatilization factor (m^3/kg; chemical-specific).
INH = inhalation intake assumption: 20 m^3/day.
PEF = particulate emission factor (4.63×10^9 m^3/kg;) (EPA 1991, 0302).

Carcinogens

SAL = $(R \times BW \times LT)/ED \times [(SF_O \times 10^{-6}\ kg/mg \times ING) + (SF_i \times INH \times (1/VF + 1/PEF))]$, where

R = target risk: 10^{-6} for Class A and B carcinogens; 10^{-5} for Class C carcinogens.
BW = body weight: 70 kg.
LT = assumed lifetime: 70 yr.
ED = exposure duration: 70 yr.
SF_O = oral slope factor $(mg/kg/day)^{-1}$.
ING = ingestion intake assumption: 100 mg/day.
SF_i =inhalation slope factor $(mg/kg/day)^{-1}$.
INH = inhalation intake assumption: 20 m^3/day.
VF and PEF as defined above.

TABLE J-4

PUBLISHED US AVERAGE EFFECTIVE DOSE EQUIVALENT RATES[a] AND ESTIMATES FOR THE LOS ALAMOS AREA FROM NATURAL BACKGROUND RADIATION[b]

RADIATION SOURCE	US AVERAGE (mrem/yr)	LOS ALAMOS (mrem/yr)
Cosmic Rays	27	58
Cosmogenic Radiation	1	1
External Terrestrial	28	39
Radionuclides in Body	40	40
Inhaled Radionuclides	200	200
Rounded Total	300	340

a. The US average data are from Table 9.7 (NCRP 1990, 0985, p. 148)

b. With the exception of the cosmogenic source, the Los Alamos data come from "Environmental Surveillance at Los Alamos during 1990" (Environmental Protection Group 1992, 0740). The cosmic and external terrestrial components were based on measurements; the balance of the values in the report were obtained from the National Council on Radiation Protection (NCRP 1990, 0985).

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■ APPENDIX K

Human Health Risk Assessment Methodology

1.0 INTRODUCTION

The purpose of this appendix is to present the fundamental risk assessment methodology to be used to evaluate potential risks to human health associated with exposure to contaminants at, or released from, potential release sites (PRSs) at Los Alamos National Laboratory (the Laboratory). This methodology has been developed to establish the scope of the baseline risk assessment as an integral part of the Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) process and to establish a consistent risk assessment approach to be applied at all operable units (OUs).

Risk-based decisions are used to support an RFI decision that no further action (NFA) is needed or to provide a point of comparison relative to which the benefits of a proposed corrective action can be evaluated. Risk assessments address both long-term risks that remain after a proposed remedial alternative has been implemented and short-term risks to workers and the public during and after the proposed alternatives have been implemented.

The major elements of the risk assessment process addressed in this appendix are

- developing a set of chemical and radiological data for risk assessments. Contaminants of concern are identified by means of the screening process described in Appendix J. Once contaminants of concern have been identified, a set of chemical data for use in the risk assessment is developed.

- exposure assessment. The exposure assessment process identifies appropriate land use scenarios, receptors, contaminant transport pathways, exposure pathways, and intake parameters so that concentrations of contaminants in environmental media can be converted to chemical intake and radiological dose levels for human receptors.

- toxicity assessment. The toxicity assessment identifies significant toxic effects and endpoints so that appropriate toxicity values may be selected to quantify potential toxic effects.

- risk characterization. The final step of the process integrates the results of the exposure assessment and toxicity assessment so that the investigator can estimate excess cancer risks and noncarcinogenic toxicological impacts.

Each of the components of the risk assessment, as it will be applied at the Laboratory, is described in detail in the following sections.

2.0 DEVELOPING A SET OF CHEMICAL AND RADIOLOGICAL DATA AND INFORMATION FOR USE IN THE RISK ASSESSMENT PROCESS

Evaluation of environmental data at the Laboratory begins with the screening assessment process, which involves comparing measured concentrations of potential contaminants of concern with screening action levels (SALs) and, when necessary, background concentration distributions. SALs are media-specific concentration levels for potential contaminants that are derived using conservative risk-based

criteria. SALs for nonradiological contaminants are based on the methodology presented in proposed Subpart S of 40 CFR 264 (EPA 1990, 0432) to calculate action levels. Radiological SALs are based on a 10-mrem/yr dose using a residential exposure scenario. Environmental sampling and analysis during the screening assessment process are designed to determine whether potential contaminants of concern are present at concentrations above SALs or background concentration distributions. For the purposes of performing risk assessment at the Laboratory, any contaminant present above a SAL or background distribution is considered a contaminant of concern, which, in contrast to NFA, warrants further evaluation. A detailed description of the screening assessment process and the derivation of SALs is presented in Appendix J.

Environmental data from screening assessments or more detailed environmental investigations conducted during the RFI process at the Laboratory are used as input to risk assessments.

A set of site-specific chemical and radiological data that has undergone extensive quality assurance evaluations for use in risk assessment is critical to the success of evaluating the potential impacts on human health. Approaches to data evaluation are document in Appendix H of this Installation Work Plan (IWP). The Environmental Restoration (ER) Program will follow Environmental Protection Agency (EPA) guidance (1989, 0305) to focus the data set that will be carried through each step of the risk assessment.

Distributions of background constituents are evaluated in a different manner from that used for a screening assessment, depending on whether the constituent is presumed to have a nonthreshold (carcinogenic) or threshold (noncarcinogenic) response. Therefore, chemical and radioactive carcinogens are evaluated both for incremental risks (risk above that associated with background concentrations) and total risk (which includes background contributions), and noncarcinogens are evaluated only for total risk.

3.0 EXPOSURE ASSESSMENT

3.1 Introduction

Exposure assessment requires the framework of a conceptual site model, which identifies contaminant sources, potential current and future receptors, and exposure pathways that link the sources and receptors. Conceptual site models are used to examine the completeness of potential human exposure pathways. Any exposure pathway considered in quantitative human health risk assessment must have each element present, i.e., a contaminant source and mechanism for release, a potential for human contact with the exposure medium, and a route of human exposure from that medium.

At the Laboratory, contaminants were originally deposited in either surface or subsurface soils, as shown in the conceptual site model (Figure 3-1) and Table 3-1. Through release mechanism pathways, contaminants were or could have been distributed in potentially contaminated media of concern, which include soil, air, edible plants, and water (Section 3.2.2). Receptors are exposed through contact with a contaminated medium by means of exposure routes (i.e., ingestion, inhalation, dermal contact). Land use and receptor-specific characteristics must be considered when identifying significant exposure routes for quantitative dose estimates. Section

3.2.3 identifies the most likely receptors for evaluation in ER Program risk assessments. This conceptual framework for the receptors is used to identify appropriate receptor-specific exposure routes (Section 3.2.4) for evaluation using quantitative risk assessment; these routes are indicated by bullets in Figure 3-1.

Baseline risk assessments are conducted during the RFI to evaluate the potential threat to human health that a site may pose in the absence of any remedial action. Baseline risk assessments are risk assessments used to evaluate corrective actions that are conducted during the corrective measures study (CMS) or voluntary corrective action. In assessing exposure of current receptors, the investigator considers currently existing restrictions to areas of contamination (e.g., fencing, cover materials). Under the EPA's risk assessment guidance for evaluating potential future receptors, the investigator must assume that current access restrictions, such as fencing, are no longer in place and that disturbance of subsurface contamination may occur (EPA 1989, 0305). The ER Program generally applies this EPA guidance in developing risk assessment methodology.

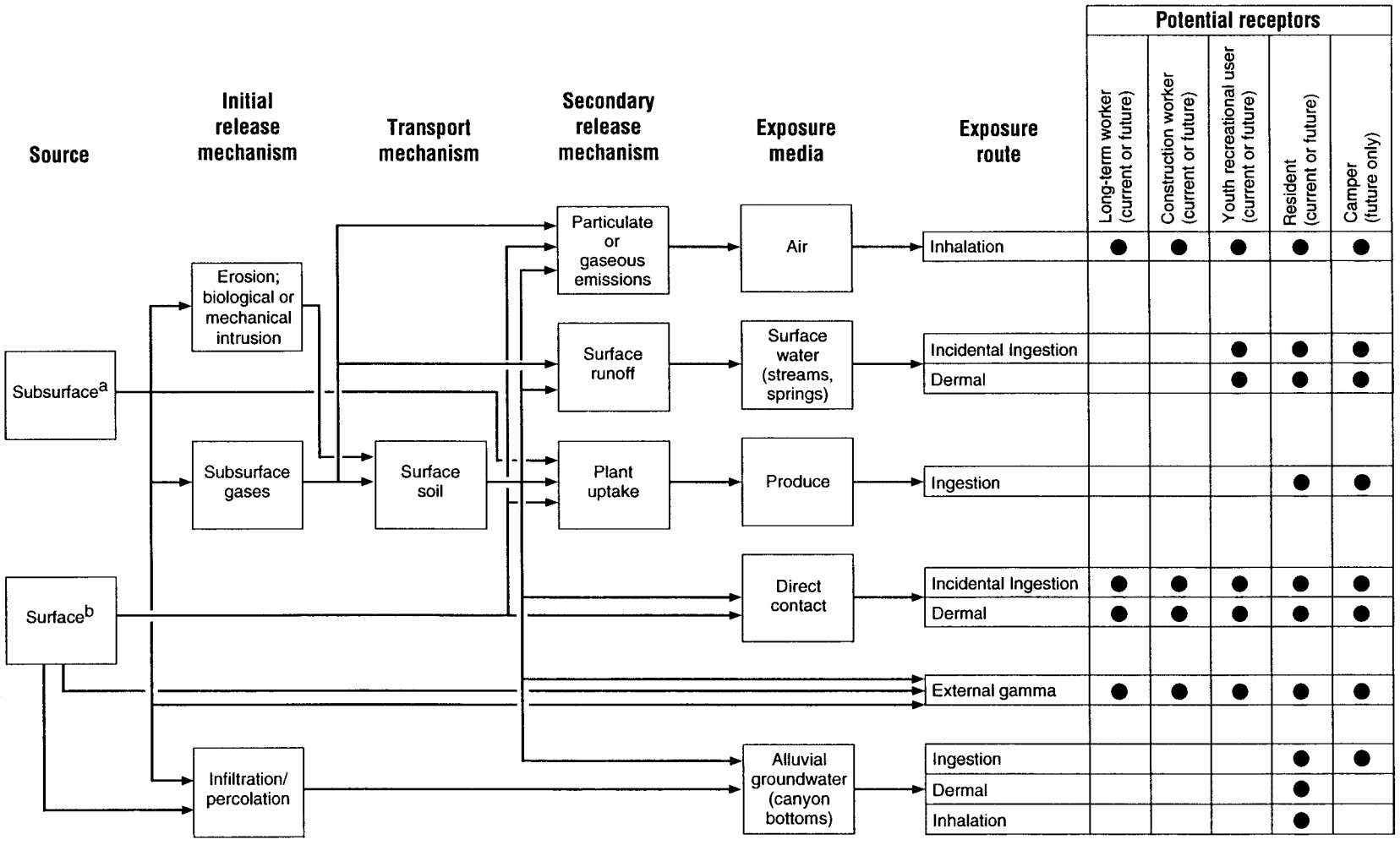
PRSs at the Laboratory consist of the solid waste management units (areas in which solid wastes have been routinely and systematically released, including chemically contaminated wastes) identified in Module VIII of the Laboratory's permit to operate under RCRA [the Hazardous and Solid Waste Amendments (HSWA) Module] and other areas of concern (sites that potentially contain hazardous substances, such as radionuclides, but no hazardous constituents defined by RCRA) designated by the Laboratory's ER Program. For baseline risk assessment, PRSs have been grouped in two categories: those located inside the Laboratory's current boundaries (Laboratory PRSs) and those located outside of the Laboratory's present boundaries (extra-Laboratory PRSs). The scope of this appendix is limited to exposures occurring within a given PRS or OU for both Laboratory and extra-Laboratory PRSs. If Phase I and/or Phase II data from RFIs indicate contaminant migration past OU or Laboratory boundaries, additional methods for evaluating effects upon distant receptors will be developed.

Each of the elements of the conceptual site model for the Laboratory is discussed in detail in this section, and detailed information is provided on estimating chemical intake and radiological dose for receptors likely to incur the "reasonable maximum exposure (RME)" (EPA 1989, 0305) to site contaminants under both current and future exposure conditions. In general, these receptors are those persons who potentially spend the most time near an area of contamination; in some instances, the receptor is selected because of substantial physical contact with a contaminated medium (e.g., construction workers). Schematic representations of the conceptual site model for Laboratory and extra-Laboratory PRSs are presented in Figure 3-1.

3.2 Exposure Scenarios

3.2.1 Sources of Contamination

Potential sources of environmental contamination at the Laboratory are leaking tanks and other subsurface structures, spills, surface disposal, etc. Contaminants released during past operations could be transported from the medium in which a spill occurred to other media (e.g., surface soil contaminated by an operational release could provide a source of contamination for sediments in drainages). In some cases, the source itself may be the exposure point. Information is being



[a]Examples of subsurface sources include landfills (buried wastes and structures), MDAs, USTs, dry wells, and septic systems.

[b]Examples of surface sources include firing site and drop tower experiments, surface disposal and burn areas, outfalls, cooling tower releases, buildings, spills, and overflows.

KEY: ● Identifies exposure routes for evaluation using quantitative risk assessment

Figure 3-1. Conceptual site model for Laboratory and extra-Laboratory PRSs.

TABLE 3-1

SUMMARY OF CONCEPTUAL MODEL ELEMENTS

PATHWAYS/MECHANISM	CONCEPT/HYPOTHESES
HISTORICAL SOURCES	• Operations/processes that contributed to the creation of the PRS (i.e., storage area, etc.).
INITIAL RELEASE MECHANISM	• Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, leaching, dumping, or disposing into the environment.
TRANSPORT MECHANISMS	
Atmospheric Dispersion	• Entrainment is limited to chemicals in surface soils.
Particulate Dispersion	• Entrainment and deposition are controlled by soil properties, surface roughness, vegetative cover and terrain, as well as atmospheric conditions.
Volatilization	• Volatilization of volatile organic compounds occurs in surface soils, subsurface soils, and surface water.
Surface Water Run-Off	• Surface water run-off is directed by natural topographic features or manmade diversions and flows toward the canyons. A topographic low can cause the water to pond on the mesa top; however, in most cases, the water flows into the canyon.
Surface Water	• Chemical transport by surface run-off can occur in solution, sorbed to suspended sediments, or as the result of mass movement of heavier bed sediments. • Surface run-off may carry chemicals beyond the OU boundary. • Contaminated surface run-off may infiltrate the canyon-bottom alluvium.
Sediments	• Surface soil erosion and sediment transport are functions of run-off intensity and soil properties. • Chemicals dispersed on the soil surface can be collected by surface water run-off and concentrated in sedimentation areas in drainages. • Erosion of drainage channels can extend the area of contaminant dispersal in the drainage.
Alluvial aquifers	• Surface run-off discharged to the canyons may infiltrate into sediments of channel alluvium.
Infiltration	• Infiltration into surface soils depends on the rate of precipitation or snowmelt, prior soil water status, depth of soil, and hydraulic properties of the soil. • Infiltration into the tuff depends on the unsaturated flow properties of the tuff. • Joints and fractures in the tuff may provide additional pathways for infiltration to enter the subsurface regime.
SECONDARY RELEASE MECHANISM	
Leaching	• Storm water/snowmelt can dissolve chemicals from soil or other solid media, making them available for contact. • Water solubility of chemicals and their relative affinity for soil or other solid media affect the ability of leaching to cause a release. • Leaching and subsequent resorption can extend the area of contamination.
Soil erosion	• The erosion of surface soils is dependent on soil properties, vegetative cover, slope and aspect, exposure to the force of the wind, and precipitation intensity and frequency. • Depositional areas, as well as erosional areas exist, and erosive loss of soil may not occur in all locations. • Storm water run-off can mobilize soils/sediments, making them available for contact. • Storm intensity/frequency, physical properties of soils, topography, and ground cover determine the effectiveness of erosion as a release mechanism. • Erosion may also enlarge the contaminated area.

PATHWAYS/MECHANISM	CONCEPT/HYPOTHESES
POTENTIAL RELEASE MECHANISM (continued)	
Mass Wasting	• The loss of rock from the canyon walls is a discontinuous, observable process. • The rate of the process is extremely slow.
Resuspension (wind suspension)	• Wind suspension of contaminated soil/sediment as dust makes chemicals available for contact via inhalation/ingestion. • Physical properties of soil (e.g., silt content, moisture content), wind speed, and size of exposed ground surface determine effectiveness of wind suspension as a release mechanism. • Wind suspension can enlarge the area of contamination and create additional exposure pathways, such as deposition on plants followed by plant consumption by humans/animals.
Excavation	• Manual or mechanical movement of contaminated soil during construction, remediation, or other activities makes contaminated soil available for dermal contact, ingestion, and inhalation as dust. • The method of excavation (i.e., type of equipment), physical properties of soil, weather conditions, and magnitude of excavation activity (i.e., depth and total area of excavation) influence the effectiveness of excavation as a release mechanism. • Excavation can increase or decrease the size of the contaminated area, depending on how the excavated material is handled.
EXPOSURE ROUTE	
Inhalation	• Vapors, aerosols, and particulates (including dust) can be inhaled and absorbed by the lungs and mucous membranes. • Physical and chemical properties of airborne chemicals influence the degree of retention in the body after being inhaled.
Ingestion	• Ingestion of soil, water, food, and dust can lead to chemical intake via absorption in the gastrointestinal tract.
Direct Contact	• Some hazardous chemical constituents absorb through the skin when in contact with contaminated surfaces of soil, tuff, or rubble. • Physical and chemical properties of chemicals influence the degree of dermal absorption. • Factors such as skin moisture and temperature affect the degree of dermal absorption.
External Penetrating Radiation	• External, or whole body radiation, can occur through exposure to gamma-ray-emitting radionuclides that may be present in soil either directly through the soil or re-entrained dusts. • Exposure to penetrating radiation can also occur through inhalation or ingestion when radionuclide-contaminated soil or tuff surfaces erode and/or dusts become re-entrained.

gathered during the RFIs to identify possible sources of contamination and release mechanisms for each PRS at the Laboratory.

The original release sources at the Laboratory include but are not limited to

- subsurface sources: buried wastes [landfills, materials disposal areas (MDAs)], septic systems (tanks and drainlines), sanitary waste treatment facilities, sumps, underground storage tanks, and storm sewers.

- surface sources: firing-site experiments (including firing pads and chambers), blowdown from cooling towers, surface disposal units (e.g., burn areas), drop tower experiments, spills, storage areas, buildings, outfalls, debris, and fallout from stack emissions.

Many of the constituents found in the environment are naturally occurring (e.g., metals and polycyclic aromatic hydrocarbons); however, past Laboratory operations may have contributed to the release of several classes of compounds at levels that exceed background levels. The following paragraphs describe sources that may have contributed to environmental contamination.

Many types of volatile organic compounds (VOCs) have been used in Laboratory experiments and maintenance operations. Nonhalogenated VOCs were used as solvents and scintillation cocktails (e.g., acetone, toluene, and benzene) and may have been present in paints, paint thinners, and fuels. Halogenated VOCs were also used as solvents and degreasing agents (e.g., 1,1,1-trichloroethane and trichloroethene) and may have been present in research chemicals. These types of compounds may be found in buried waste, sumps, drainlines, underground storage tanks, septic systems, sanitary waste treatment facilities, spills, storage areas, buildings, and outfalls.

Semivolatile organic compounds (SVOCs) include a variety of chemical groups [e.g., polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), pesticides, herbicides, and others that may have been used in research applications]. Because PCBs have been used widely as coolants and lubricants in transformers, capacitors, and other electrical equipment, it is expected that transformers, MDAs, storage areas, and landfills contain PCBs. PAHs are typically generated as products of incomplete combustion or detonation of fuels and/or fuel oil. Thus, PAHs are most likely to be found in buried wastes, firing sites, burn areas, drop tower experiments, waste oils, spills, storage areas, buildings, outfalls, and debris. Sources of possible pesticide and herbicide contamination include maintenance and chemical storage areas (such as magazines) and any surface soil at locations where pesticides and/or herbicides were used regularly to control pests and vegetation. Other SVOCs may be found at source areas such as buried waste sites, sumps, drainlines, spills, storage areas, buildings, outfalls, and debris.

Metals and related compounds were used for a variety of purposes in past Laboratory operations, and their presence is likely to be confirmed at many source areas. Metals are typically associated with plating activities (chromium and nickel), blowdown from cooling towers (chromates and molybdenates), photoprocessing operations (silver and cyanide), machining operations, electroprocessing operations (nickel, lead, silver), and activities associated with machining, testing, and disposing of explosives (beryllium and lead).

Some PRSs may contain high explosives (HE) used in formulations (e.g., TNT, RDX and HMX), their environmental degradation products (e.g., DNT and TNB), impurities of commercial HE, inert components (e.g., cyanuric acid), residual HE, and binders (e.g., nitrocellulose). Several types of explosives and their degradation products may be present in the soils and/or sediments at sites where explosives were or are currently processed, assembled, machined, stored, tested, or disposed. PRSs that contain sites of past HE activities are likely to include buried waste, sumps, drainlines, firing sites, surface disposal units, drop tower experiments, storage areas, burn areas, buildings, outfalls, and debris.

Radionuclides have been used in a variety of Laboratory studies and operations, including medical research (iodine, tritium); animal studies (lanthanum, ^{90}Sr, cobalt, cesium); reaction (iodine, tritium); detonation of test assemblies (^{140}La, depleted uranium); radiographic facilities for examination of HE charges (radium, ^{90}Sr, cobalt); weapons research and testing (plutonium, uranium, americium, tritium); and other research (fission and activation products). Sources that contain radionuclides are widespread across the Laboratory; these sources include septic tanks, dry wells, drainlines and drain fields, outfalls, storage areas, surface disposal areas, MDAs, landfills, stack emissions, and firing sites.

3.2.2 Exposure Pathways

Exposure pathways describe the courses that contamination takes from its source to a receptor. Exposure pathway analysis at the Laboratory links sources, locations, and types of environmental releases with locations and activity patterns of receptors to determine the significant pathways of exposure (Figure 3-1). Exposure generally involves three elements: (1) a source and mechanism for contaminant release, (2) a pathway consisting of a retention or transport medium and a location of potential human contact with the contaminated medium (often referred to as the exposure point), and (3) a receptor who may receive a dose of a contaminant via ingestion, inhalation, or dermal contact at the exposure point. A medium contaminated as a result of a past release can be a contaminant source for other media, e.g., soil contamination can be a source for groundwater or surface water contamination. In some cases, the source itself is the exposure point, without any release to other media.

3.2.2.1 Contaminant Release Scenarios

Possible release mechanisms and potentially impacted environmental media are described in Table 3-1. Under current conditions, the releases mechanisms considered most likely to lead to human exposures to contaminants from PRSs are (1) dispersion of airborne particulates or gases from contaminated soil into the air, (2) surface water run-off, which would redistribute soil contaminants into drainage pathways, (3) release of external gamma radiation, (4) generation of radon gas from a few PRSs that contain high concentrations of radon-generating contaminants (i.e., radium and thorium), and (5) volatilization for a few PRSs that contain high concentrations of tritium or volatile organic compounds.

The potential for contaminants to migrate from surface and subsurface soil areas to the main aquifer is considered low because of the nature of the tuff underlying the Laboratory, the high rate of evapotranspiration relative to precipitation in northern New Mexico, and the great depth to the main aquifer (600 ft or more). However, the Laboratory is continuing to investigate the possibility of more rapid contaminant transport along fractures in the tuff and the extent of perched groundwater. Alluvial aquifers in some canyon bottoms contain significant quantities of contaminants, but

these aquifers do not appear to provide enough water to support domestic or recreational use. When groundwater may be a reasonable source of human exposure, ER Program risk assessments evaluate potential exposure to perched and alluvial groundwater on a PRS-specific basis.

3.2.2.2 Contaminant Fate and Transport

A variety of site-specific and chemical-specific factors influence the fate and transport of environmental contaminants at the Laboratory. Once a contaminant has been released to the receiving medium, it may be

- transported (e.g., carried downstream in water or transported through air),
- physically transformed (e.g., by volatilization),
- chemically transformed (e.g., by hydrolysis or oxidation),
- biologically transformed (e.g., by biodegradation), and/or
- accumulated in one or more medium, including the receiving medium.

To determine the fate of contaminants at a particular PRS, information on the contaminants' physical and chemical properties is required. Representative physical and chemical properties of contaminants of concern at the Laboratory include K_{OC} (the organic-carbon-partitioning coefficient), K_{OW} (the octanol/water-partitioning coefficient, Henry's Law Constant, solubility, vapor pressure, bioconcentration factor, and medium-specific half-life. Site-specific characteristics that may influence fate and transport must also be considered. Examples of site-specific characteristics include soil properties, such as moisture content, organic content, grain size, and cation exchange capacity.

In performing risk assessments, the ER Program uses applicable chemical and site-specific information to evaluate transport within and between media and retention or accumulation within a single medium. Data from environmental sampling will be used to identify media that are contaminated now. Fate and transport modeling may be required to identify media that may be contaminated now (for media not sampled) or in the future.

3.2.3 Characterization of Potentially Exposed Populations

3.2.3.1 Demographic Data

Los Alamos County includes the two residential areas that border the Laboratory—the towns of Los Alamos and White Rock. The Los Alamos townsite, at the northern border of the Laboratory, had an estimated population of 12,000 in 1990; the town of White Rock immediately to the east of the main Laboratory site had an estimated population of 7,200 in 1990. The percent of the Los Alamos County population under age 18 is approximately 26%; about 9% of the population is 65 years of age or older (Environmental Protection Group 1990, 0497).

Large tracts of land to the south, southeast, and west of the Laboratory are managed by the National Park Service (Bandelier National Monument) and the Forest Service (Santa Fe National Forest). Bandelier National Monument is used exclusively for recreation (e.g., hiking and camping), whereas, on Santa Fe National Forest lands, grazing, logging, and other uses, in addition to recreational use, are allowed. The Rio Grande forms the southeastern boundary of the Laboratory; the land on the opposite bank belongs to the Santa Fe National Forest. The San Ildefonso Pueblo borders the Laboratory to the northeast.

3.2.3.2 Land Use

Ideally, estimation of risks to human health and the environment at the Laboratory will be based on reasonable and site-specific land use and exposure assumptions that reflect stakeholder input. However, until this input has been provided and incorporated, current and future land use at all OUs is assumed be residential.

An approach that will be proposed to stakeholders involves a number of scenarios for two categories of PRS: those located inside and those located outside Laboratory boundaries; therefore, these two categories are discussed separately. The land use scenarios discussed in this appendix are generalized scenarios that are likely to apply to many of the OUs under evaluation. However, OU-specific differences in current and potential future land uses should be considered in individual risk assessments. This OU-specific information should be used to identify appropriate receptors for evaluation.

3.2.3.2.1 Current Land Use Scenarios

3.2.3.2.1.1 Extra-Laboratory OUs

Three OUs—1071, 1078, and 1079—address areas located outside current boundaries of the Laboratory. Two of the extra-Laboratory PRSs are located in the town of Los Alamos; the third contains many sites located on canyon sides or in canyon bottom areas to the north, south, and east of the town. Some PRSs comprising these OUs continue are still managed and used by the Laboratory; others are considered to have been remediated by past decontamination and decommissioning (D&D) projects and have been released for unrestricted use. Changes in regulatory standards and guidance since past remediation activities have led to listing some of the released areas as solid waste management units in the HSWA Module. Current land use categories for extra-Laboratory PRSs can be classified as (1) commercial/ industrial, (2) recreational, and (3) residential.

3.2.3.2.1.2 Laboratory OUs

The most prevalent current land use for OUs and PRSs located within the Laboratory's current boundaries is Laboratory operations, which encompasses potential exposure of employees. Risk assessments for these OUs will evaluate exposure of current employees to residual contaminants from past operations using data collected under the ER Program. Risks from current operations (i.e., occupational exposures) are monitored by the operator groups and are not included in ER

Program risk assessments.

Large portions of Laboratory property are currently undeveloped. Many of these properties are located in canyons; a few are located on mesa tops. Much of the undeveloped land controlled by the Laboratory is used as a buffer zone to provide security for Laboratory facilities and as a reserve for future construction (Chapter 2). The public is allowed limited access to some Laboratory areas (e.g., parts of Ancho, Mortandad, and Pueblo canyons, and an archaeological site near the White Rock Y). Some of the currently undeveloped areas of the Laboratory were used for operations or waste disposal in the past, and contaminants may have migrated to other areas (e.g., surface run-off may have carried contaminants into canyons). Current use of undeveloped areas is limited to occasional recreational use (e.g., hiking or biking) by Laboratory employees, the public (for the few areas listed above), and trespassers.

3.2.3.2.2 Future Land Use Scenarios

3.2.3.2.2.1 Extra-Laboratory OUs

Future land use for most extra-Laboratory PRSs (including canyon bottom areas) is presumed to be residential because this use is generally the most restrictive. Physical restrictions for some extra-Laboratory areas preclude residential use (e.g., steep canyon sides, narrow bottoms); an appropriate future land use assumption for those areas is likely to be recreational.

3.2.3.2.2.2 Laboratory OUs

Future land use assumptions for OUs located on Laboratory property include (1) continued Laboratory operations and (2) recreational use (hiking, biking, and camping). Future residential land use for most Laboratory OUs is implausible because they are likely to be managed by DOE over the long term. Proposed RCRA Subpart S supports the use of plausible assumptions on future patterns of use, assuming that institutional controls such as deed restrictions are used as necessary to guide those future uses (EPA 1990, 0432). Most Laboratory land would involve a transfer of ownership to the neighboring National Park Service or National Forest Service, whose functions include managing recreational lands. Generally, future recreational land use is the most appropriate assumption for those canyon bottom areas unlikely to be used for Laboratory operations. For mesa tops, continued Laboratory operations is generally the appropriate future land use assumption.

Notwithstanding the general assumption that future residential use of Laboratory OUs is implausible, it is acknowledged that limited areas released for recreational use might actually be used for residential purposes such as ranger housing. The Laboratory may need to re-evaluate these limited areas at the time a change in land use is proposed, using assumptions for a residential exposure scenario.

3.2.3.3 Potential Receptors

The appropriate current and future receptors likely to come into contact with contaminated media are being assessed (Figure 3-1). The characteristics of these generalized receptors are summarized below. Receptor-specific assumptions may

need to be modified, or additional alternate receptors may be needed based on OU-specific data; however, it is expected that the generalized receptor scenarios discussed below will be applicable for most ER Program risk assessments.

3.2.3.3.1 Receptors under Current Land Use Scenarios

Currently, the receptors that may be evaluated in risk assessments are long-term workers, construction workers, youth (i.e., age 10-18) recreational users, and residents. Only current residents of extra-Laboratory PRSs will be evaluated. The worker scenarios are appropriate for any properties currently used for commercial/ industrial activities (e.g., commercial areas in extra-Laboratory OUs) or for continued Laboratory operations (Laboratory OUs). Exposure parameters for long-term workers should generally reflect the RME conditions, which include periods of outdoor work (discussed further in Section 3.4.2.1). PRS-specific data are used to determine whether a construction worker scenario, which evaluates subsurface contamination, should be assessed.

The youth recreational scenario is used to evaluate current use of canyonside and bottom areas at extra-Laboratory sites and for trespassing on Laboratory-controlled PRSs. This receptor is assumed to hike or bike frequently in the area encompassing a given PRS.

It is assumed that long-term institutional controls are imposed on the MDAs at the Laboratory to prevent contact with subsurface contamination. These areas have been or are currently used for subsurface disposal of radioactive and nonradioactive waste, and it can be assumed that these areas would present a significant risk if excavation were to occur. For these MDAs, only current and future exposure of long-term workers to surface contamination will be assessed.

3.2.3.3.2 Receptors under Future Land-Use Scenarios

For most extra-Laboratory OUs, the future receptor evaluated will be a resident, regardless of current land use. In a limited number of extra-Laboratory areas (e.g., canyon sides) in which physical restrictions preclude residential use, a youth recreational user will be assessed.

For both mesa top and canyon bottom OUs whose past, current, or likely future use is Laboratory operations, the RME receptor is likely to be the long-term worker or the construction worker, both of which will be assessed as current receptors. However, the receptor most often assumed for canyon bottoms on Laboratory land will be a future camper (because most canyon bottom areas have not been used for Laboratory operations).

In general, it is not expected that canyonside areas will have subsurface contamination (i.e., greater than 2 ft in depth). Because of erosion, the soil in these areas generally does not extend to depths of greater than 2 ft. Accordingly, no current or future exposure to subsurface contamination on canyon sides needs to be considered. Also, the most plausible land use identified for canyonside areas is recreational use, which does not involve exposure to subsurface contamination. Therefore, the receptor evaluated for both current and future land use of canyonside areas will be the recreational youth user (i.e., hiker or biker). Exceptions can be addressed in PRS-specific risk assessments, as necessary.

To facilitate evaluation of changed land use (particularly loss of institutional control) and to account for possible redistribution of subsurface contaminants to the surface, future receptors may be evaluated by assuming exposure to subsurface contamination that has been redistributed to the soil surface. Use of subsurface contamination levels estimates the RME for future receptors when subsurface contamination levels are higher than those at the surface. Appropriate use of surface or subsurface contaminant levels to assess future receptors will need to be determined on a PRS-specific basis.

3.2.3.3.3 Application of Current and Future Scenarios in Risk Assessments

In some instances, it may be sufficient to evaluate only one receptor for a given PRS; this receptor represents the maximally exposed individual under both current and future conditions. An example would be a PRS currently used residentially and at which no subsurface contamination exists. Conversely, depending on PRS-specific contaminants of concern, depths of contamination, and other factors, it may be necessary to evaluate up to three receptors for a single PRS. An example is an operating Laboratory PRS at which both surface and subsurface contamination are present and at which subsurface contamination levels are higher than surface levels. For this example, a "current" long-term worker is assessed for the current exposure scenario (using surface contamination data), a construction worker is used to assess possible current exposure to subsurface contamination if excavation should take place, and a "future" long-term worker, who is assumed to be exposed to former subsurface contaminants that have been redistributed to the surface, is assessed for the future land use scenario.

The risk associated with contamination of environmental media depends on the actual dose to receptors engaged in the activities that occur on the selected land use scenario. This dose is proportional to both the temporal frequency and duration of exposure and to the integral of the contaminant concentration over a spatial exposure unit within which these activities take place. For example, under the camping scenario, exposure may occur annually over several years for a period of 2 to 4 weeks each year (the exposure frequency and duration), during which time the receptor can be expected to roam over an area of one-half to several acres (the exposure unit). Exposure units for the land use scenarios used by the ER Program are defined below in Section 3.3.2

3.2.4 Summary of Receptor-Specific Exposure Routes

Exposure routes evaluated for all potential receptors are inhalation of particulate and/or gaseous emissions from soils or structural surfaces, direct contact with soil or dust from structural surfaces (ingestion and dermal contact), and external gamma irradiation from soils or structural surfaces (Figure 3-1).

Potential contact with perennial surface water in canyon streams is most likely for the future camper and the youth recreational user. Contact with perennial surface waters may also be an exposure route for future residential scenarios in a limited number of extra-Laboratory canyon bottom PRSs. Dermal uptake from surface water and incidental ingestion of surface water while wading are appropriate exposure routes for quantitative assessment. Inhalation does not need to be assessed because volatile contaminants are present in surface waters for only short periods before being dissipated to the air. The appropriateness of the surface water pathway should be determined on a PRS-specific basis; surface water may not be

present in quantities large enough to warrant evaluation of this pathway. For most PRSs, it is unlikely that worker contact with surface water will be a significant exposure route because infiltration occurs rapidly after storm events and areas of Laboratory operations are distant from perennial canyon streams.

The need for assessment of exposure to temporary standing water after storm events will be assessed on a PRS-specific basis. However, surface water pools created by storm events are generally present only for short periods (e.g., about 2 h) before infiltration occurs, and storm events capable of generating these pools occur approximately 3 to 11 times per year. Therefore, potential for contact with this standing water is limited.

If field investigations reveal the presence of measurable gaseous emissions directly to air (i.e., via subsurface vapor migration from MDAs), exposure to these emissions will be evaluated. Based on OU data available to date, the location of emissions is assumed to be distant from work and residential areas, which indicate that the receptor evaluated will be the youth recreational user or the future camper; inhalation will be the exposure route assessed.

The ingestion exposure route may be evaluated for current and future residents who ingest homegrown produce and possibly for future campers who ingest wild edible plants (e.g., berries and nuts). PRS-specific information is needed to determine whether quantitative assessment of this pathway is appropriate. For example, extra-Laboratory PRSs currently used for residences may have a concrete cover over the contaminated area, ruling out gardening. In this instance, evaluation of ingestion for the current resident would not be appropriate, although the pathway would be evaluated for a future resident to address the possibility that the concrete cover is removed. Similarly, ingestion of wild foods by future campers should be assessed only if edible species are identified in the vicinity of the PRS.

Although ingestion of game animals such as elk is a possible current or future exposure route, the large territory over which these animals graze in semiarid climates makes the probability of significant uptake of contaminants from a single PRS small. Similarly, although grazing livestock on Laboratory lands may be allowed in the future, these animals would not be expected to have significant uptake of contaminants from any single PRS. Because the overall uptake from multiple PRSs may result in significant bioaccumulation of contaminants in game animals, the risks from ingestion of contaminated meat may be evaluated on a Laboratory-wide basis. Therefore, evaluation of the game and/or livestock ingestion pathway is outside the scope of an OU-specific risk assessment. Similarly, although contaminants from the Laboratory may have reached the Rio Grande River via canyon streams, the potential for contaminant intake as the result of ingesting fish will be evaluated (if needed) on a Laboratory-wide basis.

For Laboratory OUs with associated alluvial aquifers in canyon bottoms, it is hypothesized that a well is drilled in the future to support recreational use of the areas. It is assumed that water supply to these wells is adequate to provide drinking water for future campers but not to provide bathing facilities. Therefore, ingestion is the only significant exposure pathway associated with groundwater to be evaluated for future campers. For extra-Laboratory OUs, there is a possibility that canyon bottoms will be used residentially and that a domestic well will be drilled to access alluvial groundwater, although this source may be limited. If necessary, ingestion of and dermal contact with contaminants in alluvial groundwater may be assumed for future residents in extra-Laboratory canyon bottom OUs (only when contaminants

of concern have been identified in alluvial groundwater). Volatile contaminants are not likely to be present in alluvial groundwater because the most likely mechanism of contamination, run-off from contaminated surface soil, results in volatilization. However, should any volatiles be identified, inhalation of these contaminants during household use (e.g., showering) should be evaluated.

3.3 Estimation of Exposure Concentrations

The media-specific concentration of a contaminant at the location of exposure (i.e., the exposure concentration) must be estimated in order to evaluate the amount of human exposure that might be associated with a contaminant source. This section provides guidelines for estimating exposure concentrations for all contaminants of concern in soil, air, produce, on structural surfaces, and in surface water and alluvial aquifers.

Exposure concentrations can be estimated directly by using media-specific environmental sampling and analysis data or by using a combination of sampling data and environmental fate and transport calculations and models. For most risk assessments performed under the ER Program, some combination of sampling data and fate and transport modeling will be required to estimate exposure concentrations.

3.3.1 Methods

3.3.1.1 Direct Estimation

Insofar as possible, sampling data will be used to directly estimate exposure concentrations for ER Program risk assessments. Direct use of sampling data is particularly applicable when exposure involves direct contact with the environmental medium of concern (e.g., direct contact with contaminated soils) and in cases where monitoring has occurred directly at an exposure point (e.g., a drinking water well). For these example exposure scenarios, sampling data provide the best estimate of current exposure concentrations. The data quality objectives (DQO) process applied to the design of sampling plans during the phases of the RFI will result in the collection of environmental data appropriate for use in the risk assessment.

3.3.1.2 Modeling Approaches

In some instances, it may not be appropriate to use direct sampling data alone to estimate exposure concentrations, and some form of environmental fate and transport calculations or computer modeling applications will be required. Instances in which fate and transport calculations or modeling may be required include the following:

- Fate and transport calculations for contaminants will be required when exposure points are remote from contaminant sources and when release mechanisms exist to transport contaminants to an exposure point (e.g., transport of contaminants in groundwater to a receptor).

- Modeling will be required when temporal distribution of contaminants is needed and monitoring data are lacking. Typi-

cally, environmental sampling data give an indication of current conditions. Although there are situations in which it is reasonable to assume that contaminant concentrations will remain constant over time, in many cases, the time span over which data are taken during one-time sampling are not adequate to predict future exposure concentrations.

- When direct measurements of contaminant concentrations in air are unavailable, fate and transport modeling will be needed to determine air concentrations based on contaminated soil concentrations.

The level of effort required to estimate exposure concentrations depends on the type and quantity of data available, the level of detail required in the assessment, and the expected level of risk to human health and the environment. In general, estimating exposure concentrations involves analyzing direct sampling data and applying simple environmental fate and transport calculations.

For those efforts requiring a complicated modeling approach, a wide variety of EPA-approved contaminant fate and transport models is available for use in exposure assessments. Contaminant fate and transport models are applied in ER Program risk assessments on a PRS-specific basis. The procedure to conduct complicated contaminant fate and transport modeling includes

- identifying and bounding the modeling problem and approach,
- selecting qualified experts to identify the appropriate models to be applied. This step may also include developing models to account for unique conditions at the Laboratory.
- communicating with regulatory agencies to obtain approval of the modeling approach before conducting the modeling exercise.

3.3.1.3 Uncertainty in Exposure Concentration Estimates

Evaluating uncertainty is a very important component of the exposure assessment. EPA (1989, 0305) specifies that a qualitative discussion of uncertainty in the exposure analysis should include (1) a tabular presentation of the ranges of estimates of exposure concentrations and exposure parameters consistent with the data, the point values used in calculating the RME dose or intake, and a brief description of the rationale used in selecting the point value and (2) a summary of major sources of uncertainty in the risk assessment that specifically address monitoring data, the models used to estimate exposure concentrations, and the values selected for intake variables.

The same EPA guidance document suggests using an "upper 95% confidence limit on the arithmetic average [that is, the mean or expected value] concentration of contaminants at a site (or portion thereof) [that is, within an exposure unit]" as the appropriate statistic for representing an RME. The words in brackets above interpret the phrases used in the EPA regulatory guidance in terms that are used in the Los Alamos ER Program. The arithmetic mean of the observations from an exposure unit is not the only reasonable estimator for the mean concentration in that exposure unit. Depending on observed distributional shapes, there may be substantially better

estimators. The selection of an appropriate estimator of the mean is tailored to each situation.

The EPA guidance assumes a classical approach to statistical data analysis. If a Bayesian approach is taken instead, constructs such as confidence bounds can be replaced by probability intervals, and significance levels can be replaced by probabilities that hypotheses are true. Although the basic idea of estimating an RME with an upper bound for a mean concentration may remain, the Bayesian construction of such an estimate is quite different from the classical construction espoused in the current guidance. A Bayesian analysis demands construction of an exposure concentration distribution from which pertinent statistics (such as means, probability bounds, quantiles) may be calculated directly.

A recent Science Advisory Board review (EPA 1993, 1013) of the *Human Health Evaluation Manual* recommended that EPA move toward a distributional approach for calculating RMEs. This approach requires that the EPA develop distributions for the variables needed to calculate individual exposures; these distributions, together with Monte Carlo simulation methods, are used to determine distributions of exposure, and an appropriate quantile of the distribution (e.g., the 90th or the 95th percentile) could be used as the RME (e.g., the 90th percentile of the exposure distribution corresponds to an exposure concentration for which there is a 90% probability that an individual is exposed at no greater level). The ER Program at Los Alamos endorses this distributional approach to exposure and risk assessment, and, where possible, distributions for environmental data and parameters used in calculating dose/intake should be developed and presented. However, at present, EPA's policy is to use distributional approaches only as a means of assessing uncertainty.

In the following subsections, simple methods are described by which to estimate exposure concentrations for the exposure routes of inhalation of particulates and gas, ingestion of contaminated plants, and external gamma radiation, on the basis of concentrations of contaminants in surface and subsurface soil. More sophisticated modeling approaches than those presented may be required, based on PRS-specific needs.

3.3.2 Exposure Concentrations for Various Exposure Pathways

3.3.2.1 Exposure Concentrations for Soil-Related Exposure Pathways

Soil data can be used to estimate exposure concentrations for the following pathways: incidental soil ingestion, dermal contact with soil, inhalation of particulates and gases, ingestion of contaminated plants, external gamma exposure, and inhalation of radon and its decay products. These pathways are addressed in the following subsections. Using measured air or food concentrations, gamma exposure rates, and radon concentrations (when available) is preferable to the use of soil data for the following pathways: inhalation of particulates and gases, ingestion of contaminated produce, external gamma exposure, and inhalation of radon.
Under the Laboratory's ER Program, surface soil samples are generally considered to include any data obtained within the top 6 in. of soil, although some surface samples may be obtained from up to 2 ft of soil (EPA 1989, 0088). In assessing the risk from incidental soil ingestion, dermal contact, and particulate inhalation, it is preferable to use soil samples taken from shallow depths (2 in.) because receptors are most likely to be exposed to near-surface soils. However, in instances in which contaminant levels in the upper 2 ft of soil are homogeneous or in which levels in the 0.5- to 2-ft horizon exceed those in the 0- to 0.5-ft horizon, use of data from the lower

horizon will provide equal or higher estimates of dose or intake. Use of data from the 0.5- to 2-ft horizon also takes into account possible limited soil intrusion by receptors. Therefore, use of data from the 0.5- to 2-ft horizon to derive surface exposure concentrations is acceptable and should be used as necessary on a PRS-specific basis.

For the purposes of ER Program risk assessments, subsurface soil is considered to extend to a depth of 12 ft (EPA 1989, 0088). This depth is assumed under RCRA guidance because 12 ft is considered the maximum depth to which a basement is excavated and therefore direct exposure to contaminants in soils deeper than 12 ft does not need to be assessed. (Contamination of soil or tuff found at depths of greater than 12 ft may be assessed by modeling potential for transport to groundwater.) For many mesa tops in the vicinity of the Laboratory, consolidated tuff is reached at depths of less than 12 ft. It is also uncommon for house foundations to be placed in the tuff in the Los Alamos area . Therefore, the total depth used to derive subsurface exposure concentrations may be adjusted on a PRS-specific basis.

An exposure unit is defined as the surface area over which a given receptor is assumed to receive a daily average exposure. Ideally, when data are collected for risk assessment, sampling plans are designed so that the samples collected represent the area over which they will be averaged. The statistic used to describe the contaminant distribution (the RME) for the exposure unit of concern are used to calculate the dose to a receptor (e.g., current EPA guidance suggests using a 95% upper-confidence bound of the arithmetic average). For example, a resident could be assumed to be randomly exposed to an area of soil equal to the average size of a residential property [about 1/8 acre (500 m^2) (EPA 1989, 0305)].

Precedent for using the exposure unit concept is given in EPA risk assessment guidance (EPA 1989, 0305). This EPA document states that "the area over which the [receptor] activity is expected to occur should be considered when averaging the monitoring data.... For example, averaging soil data over an area the size of a residential backyard (e.g., 1/8 acre) may be most appropriate for evaluating residential soil pathways."

The land use scenario assumed for the PRS directly leads to the definition of the area over which a receptor receives a daily exposure. Thus, for ER Program risk assessments, each land use assumed (Section 3.2.2) has an associated exposure unit. Assumptions of appropriate exposure unit areas are made using site-specific information on land use patterns and likely activities for receptors being evaluated (EPA 1989, 0305). For ER Program risk assessments, assumed exposure unit areas are needed for four receptors: current and future residents, long-term workers, construction workers, and current and future recreational users. Assumed exposure unit areas for these receptors are presented in Table 3-2 and are discussed below. In general, PRSs on extra-Laboratory OUs are treated as residential and have an exposure unit of 500 m^2.

Recreational land use scenarios have exposure units equal to 1/2 acre (2,000 m^2). A 1/2-acre area is a reasonable estimate of the area covered by a child playing, a youth recreating, an adult exercising, or a family camping in the lands surrounding Laboratory work sites. The exposure unit concept for recreational users assumes that receptors locate a "preferred area" in which to spend the predominant portion of their recreational time and that this area encompasses the PRS being evaluated. The half-acre exposure unit is not necessarily assumed to be square but can be fit to the site-specific landscape of the PRS (e.g., a long rectangle for an outfall). A variable exposure unit shape for the recreational scenario is an appropriate assump-

TABLE 3-2

RISK ASSESSMENT FOR LOS ALAMOS NATIONAL LABORATORY
SUGGESTED VALUES FOR SCENARIO PARAMETERS

Parameter	Unit	Long-Term Worker[a]	Construction Worker[b]	Youth Recreational User[c]	Resident[d]	Future Camper[e]
General Exposure Parameters						
Total Exposure Time (ET)	h/d	8	8	2	20	24
Exposure Time Outdoors (ET_o)	h/d	0-8	8	2	2	24
Exposure Frequency (EF)	d/yr	250	90	170	350	28
Exposure Duration[f] (ED)	yr	25	1	9	30	20
Area of Exposure Unit[g] (A_{EU})	m^2	500	Area of Contamination	2000	500	2000
Body weight[h] (BW)	kg	70	70	50	70 Adult 15 Child	70 Adult 15 Child
Indoor Shielding Factor for External Gamma (SF)	%	70	NA[i]	NA	70	NA
Pathway-Specific Exposure Parameters						
Inhalation Pathway						
Inhalation Rate[j] (IR_a)	m^3/h	0.83 Indoors 1.7 Outdoors	1.7	3.2	0.83 Indoors 1.7 Outdoors	1.3
Particulate Concentration in Air[k] (PC)	mg/m3	0.09	15	PRS-specific	0.09	0.09
Amount of Outdoor Dust Present Indoors[l]	%	40	NA	NA	40	NA
Ingestion Pathways						
Soil Ingestion Rate[m] (IR_s)	mg/d	50 or 100	480	100	100-Adult 200-Child	100 Adult 200 Child
Groundwater Ingestion Rate[n] (IR_{gw})	L/d	1	1	NA	2	2
Surface Water Ingestion Rate[n] (IR_{sw})	L/d	1	1	0.05	0.05	0.05
Exposure Frequency for Surface Water Ingestion[o] (EF_{sw})	d/yr	NA	NA	40	40	28
Produce or Berry Ingestion Rate[p] (IR_p)	g/d	NA	NA	NA	340	140
Fraction Ingested Produce Grown on Contaminated Area[p] (F_{HG})	%	NA	NA	NA	30	100
Soil Dermal Contact Pathway						
Exposure Frequency - Soil Dermal Contact[q] (EF_d)	events/yr	NA	90	170	170	28
Skin Surface Area Available for Soil Contact[r] (SA_s)	cm^2/event	NA	3200 (arms & hands)	5000	5000	5000

Soil-to-Skin Adherence Factor[r] (ADF)	mg/ cm^2	NA	1	1	1	1
Groundwater Dermal Contact Pathway						
Dermal Contact Exposure Time for Groundwater (ET_{gw})	hr/ event	NA	NA	NA	0.25	NA
Skin Surface Area Available for Groundwater Contact[r] (SA_{gw})	cm^2/ event	NA	NA	NA	20000	NA
Surface Water Dermal Contact Pathway						
Dermal Contact Exposure Time for Surface Water (ET_{sw})	hr/ event	NA	NA	1	1	1
Exposure Frequency for Surface Water Dermal Contact[o] (EF_{sw})	d/yr	NA	NA	40	40	28
Skin Surface Area Available for Surface Water Contact[r] (SA_{sw})	cm^2/ event	NA	NA	5000	5000	5000

TABLE 3-2 (Continued)

a. Current and future long-term workers; usually will assume 4 hr/day working outdoors (represents reasonable maximum exposure). Primarily for mesa top areas, but may be used for canyon bottoms, as appropriate.

b. Construction worker; for evaluation of exposure to areas of surface and subsurface contamination, as appropriate. Evaluation limited to contaminants in soils at depths of 12 ft or less.

c. Youth recreational user of canyon sides and bottoms. Receptor is a youth age 10 to 18 using canyon sides and bottoms for hiking or biking. This is the only land use scenario applicable for areas of contamination on canyon sides. Although unlikely as a current use scenario because of institutional controls on Laboratory property, it is possible that limited trespassing occurs.

d. Current or future resident is a resident of extra-Laboratory areas (may include some canyon bottom areas in the future). This scenario does not apply to Laboratory property, for which future land use will be controlled by DOE.

e. Future camper on Laboratory mesa top or canyon bottom areas assuming the site is released for recreational use (e.g., released to National Park Service).

f. Exposure duration for occupational and residential scenarios (i.e., 25 and 30 yr) recommended by the EPA (1991, 0746). For youth recreational user, 9 yr is the age-range duration and is also the median time at one residence (EPA 1989, 0305). Construction worker exposure duration is chosen based on the assumption that projects will be of limited scope. Future recreational users assumed to use site as long-term vacation area.

g. Area of residential exposure unit based on EPA guidance (EPA 1989, 0305). Other areas are based on assumptions on likely scenario-specific activity patterns.

h. Body weights: 70 kg for adult scenarios (EPA 1991, 0746); 50 kg for youth scenarios (12 to <15 years old (EPA 1989, 0304) ; and 15 kg for child 1-6 years old (EPA 1991, 0746).

i. Not applicable.

j. Inhalation rates: standard default value of 0.83 m^3/hr used for indoor residential and indoor long-term worker exposures (EPA 1991, 0746). Inhalation rates accounting for resting, light, moderate, and heavy activity (EPA 1989, 1011) calculated for other scenarios as follows:

   Long-term or Construction Worker, Resident—Outdoor inhalation rate of 1.7 m^3/hr equal to 0.5 exposure time at light activity + 0.5 exposure time at moderate activity, adult male inhalation rate.

   Youth Recreational User—inhalation rate of 3.2 m^3/hr equal to entire exposure time at moderate activity, inhalation rate for 10-year-olds.

   Future Camper—inhalation rate of 1.3 m^3/hr equal to 8 hr/day resting, 12 hr/day light activity, 2 hr/day moderate activity and 2 hr/day heavy activity, adult male inhalation rate.

   Definitions—resting, reading, sleeping, watching television; light activity: domestic work, personal care, conducting minor indoor repairs, and home improvements; moderate activity: heavy indoor cleanup, major indoor repairs, climbing stairs; heavy activity: vigorous physical exercise, climbing stairs carrying a load (EPA 1989, 1011) .

k. Reference for 0.09 mg/m^3 particulate concentration in air is Environmental Protection Group 1990, 0497. Value of 15 mg/m^3 considered maximum for construction worker scenarios (OSHA 1991, 0610).

l. Based on value given by Alzona et al. (1979, 0944). Only applies for inhalation pathways and for soil ingestion pathway when entire exposure occurs indoors.

m. Standard default soil ingestion rates recommended by EPA (1991, 0746)). For the resident and future camper scenarios, the soil ingestion pathway assumes an ingestion rate of 200 mg/day and body weight of 15 kg for 6 yr exposure as a child and an ingestion rate of 100 mg/d and body weight of 70 kg for 24 yr and 14 yr, respectively, for exposure as an adult. Long-term worker rates of 50 or 100 mg/day are rates recommended for commercial/industrial scenarios by EPA (1991, 0305). Rate of 480 mg/day for the future construction worker is based on EPA guidance (1991, 0746) to account for substantial soil contact and potential ingestion of inhaled material that is not retained in the lungs.

n. For groundwater, standard default water ingestion rate recommended by EPA (1991, 0746). For surface water ingestion, 0.05 L/day based on EPA recommended ingestion level of 50 ml/hr for the 1-hr exposure time (EPA 1989, 0305).

o. Exposure frequency for surface water ingestion and dermal exposure equal to total exposure frequency (28 days/yr) for the future camper; equal to 40 days/yr for the youth recreational user and future residents (based on best professional judgment of likely wading frequency).

p. Produce ingestion rate and fraction of produce grown on or collected from the contaminated area: 340 g/day, 30% for residential scenario includes ingestion of vegetables and fruits; 140 g/day, 100% for future recreational user for fruits only (EPA 1991, 0746).

q. Number of soil dermal contact events equal to exposure frequency, except for residential scenario. For residents, it is assumed that dermal contact occurs seasonally (e.g., during gardening), about 5 days/wk for 8 mo/yr.

r. Skin surface area available for contact and soil-to-skin adherence factor assumptions as recommended in (EPA 1992, 0833)

tion because potentiallycontaminated areas are formed over easily accessible land, where receptors tend to be exposed.

As part of the continued-Laboratory-operations land use scenario, commercial/ industrial exposure scenarios have variable exposure unit sizes, depending on the type of PRS. PRSs modeled with a continued-Laboratory-operations scenario are generally on mesa tops and either have subsurface contamination or surface contamination only. For PRSs with a subsurface component for which a construction worker scenario is being evaluated, the exposure unit area equals the surface area of the contamination (i.e., it is assumed that the construction worker spends the entire exposure duration in the contaminated area and that no dilution from exposure to uncontaminated areas occurs). Construction worker receptors are likely to be exposed to a small area of contamination for a short time only. For PRSs with surface contamination, the appropriate receptors for the commercial/industrial exposure scenario are the long-term workers at a site. Under the long-term worker scenario, the exposure unit chosen equals 500 m^2, which is a reasonable estimate for a typical site worker who works indoors, taking lunch and breaks outdoors or spending up to 4r h outdoors.

When data have been collected without the appropriate exposure unit as a basis for averaging, an adjustment for the correct exposure unit must be incorporated before dose from soil sources can be calculated. Adjustment is made only for areas of contamination that are smaller than the exposure unit because areas that are larger consider multiple exposure units (Appendix H describes proper methodology). For PRSs that are smaller than the exposure unit, a correction factor can be applied to the dose or intake estimates to adjust them downward, accounting for the likelihood that, on average, the receptor will only be exposed to the contaminated area for a fraction of the daily exposure time. Corrections for exposure unit size can be made with the "fraction from contaminated source" parameter (Section 3.4.2.8).

3.3.2.1.1 Exposure Concentrations for Incidental Soil Ingestion

To evaluate exposures to current receptors (e.g., long-term worker, youth recreational user, resident at extra-Laboratory PRS), contaminant concentrations in surface soils are used to calculate incidental soil ingestion intakes. An appropriate statistic is used as the RME for the incidental soil ingestion pathway (e.g., current EPA guidance suggests using the 95% upper confidence of the arithmetic average). Assessment of potential exposure to subsurface soil contaminants is needed for evaluating the construction worker scenario and future exposure scenarios. For the construction worker, an appropriate statistic is used as the RME for the incidental soil ingestion pathway (e.g., current EPA guidance suggests using the 95% upper confidence of the arithmetic average).

Subsurface soil exposure concentrations can be used to evaluate exposures of future receptors exposed over the long term (i.e., workers, recreational users, residents of extra-Laboratory properties). To estimate exposures for these future receptors, it is assumed that subsurface soil contaminants have been redistributed to the soil surface before these receptors can be exposed. PRS-specific data, such as soil depth, volume of contaminated soil, likely future land use, and likely size of structure to be built on the property, are needed to determine the surface area over which the contaminated soil will be distributed. Assuming an appropriate soil thickness (e.g., 6 in.), area and depth of excavation corresponding to the likely type of structure to be built, and the appropriate exposure unit for the future receptor of interest, "derived" surface soil exposure concentrations for the future receptor can

be estimated. This method is similar to one described by Reynolds et al. (1990, 1009) for estimating potential surface contaminant concentrations on the basis of measured subsurface levels. To distinguish these derived surface concentrations from measured surface concentrations in this text, the derived surface concentrations are termed "subsurface exposure concentrations."

In instances where receptor-specific exposure concentrations from surface soil data exceed exposure concentrations calculated from subsurface soil data, the risk assessor may decide to use surface soil data to assess risks to future receptors in order to ensure that risks are not underestimated. This decision is based on the likelihood of future excavation and should consider site-specific data and probable future land uses.

3.3.2.1.2 Exposure Concentrations for Dermal Contact with Soils

With few exceptions, the dermal absorption exposure route does not apply for most radionuclide contaminants in soil because the skin provides an effective barrier to the absorption of most radionuclides. Even absorption of tritium from soil water is likely to be much lower than absorption from immersion in a body of water, given equal concentrations of tritium. In the Los Alamos area, where soil moisture is generally low, dermal uptake of tritium from soil is assumed to be negligible.

It is possible that the presence of radioactively tagged organic contaminants will result in a dermal exposure route for radionuclides. The significance, if any, of this exposure route for radionuclides should be evaluated on a PRS-specific basis.

For chemicals, the significance of dermal absorption from soils is highly dependent on the identity of contaminants of concern for specific PRSs. In general, organic contaminants are more easily absorbed through the skin than are inorganic contaminants. Chemical-specific data for the PRS-specific contaminants of concern should be used to determine whether evaluation of this pathway is appropriate. When evaluation is necessary, exposure concentrations are the same as those for the soil ingestion pathway (i.e., surface exposure concentrations for current receptors and subsurface exposure concentrations for future receptors, both in units of milligrams per kilogram).

3.3.2.1.3 Exposure Concentrations for the Inhalation of Soil-Derived Particulates and Gases

3.3.2.1.3.1 Particulates

The inhalation-of-soil-derived-particulates exposure route includes the inhalation of contaminants adhering to dust particles that become airborne as the result of wind erosion and mechanical disturbances of contaminated soil. Exposure concentrations of airborne contaminants depend to some extent on the exposure scenario being assessed. For example, the concentrations of particulates inhaled by an indoor office worker are expected to be significantly lower than the concentration of particulates inhaled by an outdoor construction worker because particulate levels are higher in construction zones. The concentrations of airborne contaminants may be obtained by direct measurement or by modeling the emission and dispersion from the source (i.e., soil).

Generally, measured air concentrations of particulate-associated radionuclide and

chemical contaminants will not be available for use in ER Program risk assessments. Emissions resulting from suspension of soils by wind erosion or vehicular disturbance can be estimated using site-specific input parameters and any of a number of models (e.g., models described in EPA's *Superfund Exposure Assessment Manual* (EPA 1988, 0747) or models from the Air Superfund National Technical Guidance Series (EPA 1989, 1011). When necessary, models can also be used to estimate dispersion from the source to downwind receptor locations. The need for air emission and dispersion modeling is determined on an OU- or PRS-specific basis.

In some instances, it is sufficient to estimate emissions from the contaminant source simply by obtaining a site-specific value for mass loading of particulates to air, and assuming that radionuclide and chemical contaminant levels in these particulates are equal to those measured in soils. Average particulate level values can be used for most exposure scenarios and may be obtained from the meteorologic station nearest the site. An average value for the Los Alamos area has been estimated as 0.09 mg/m^3 (Environmental Protection Group 1990, 0497). However, for the construction worker scenario, the assumed particulate level is higher because of receptor activities that disturb the soil. If data for construction sites at the Laboratory are not available, a particulate level of 15 mg/m^3, which is the Occupational Safety and Health Administration's limit for nuisance dust (OSHA 1991, 0610), can be assumed for construction worker scenarios. It may also be necessary to assume a particulate level higher than the average level for some recreational users (e.g., bikers), depending on whether their activities are expected to generate dusts. Appropriate assumptions based on PRS-specific particulate levels are made in individual ER Program risk assessments.

Not all particulate matter is respirable by humans; therefore, an adjustment is needed to account for the respirable portion of the particulates. Paustenbach (1989, 1007) gives a range of 30% to 50% as the respirable fraction of suspended particulates. Unless site-specific data on levels of respirable particulates are available, it is recommended that 50% of air particulate matter be assumed to be respirable. Air exposure concentrations for particulate-associated contaminants can be estimated as follows:

$$Air\ EC = Soil\ EC \times PC \times CF \times RF, \qquad (3.1)$$

where

Air EC = exposure concentration in air (picocuries per cubic meter for radionuclides, milli grams per cubic meter for chemicals),

Soil EC = appropriate surface or subsurface soil exposure concentration, (picocuries per gram for radionuclides, milligrams per kilogram for chemicals),

PC = particulate concentration (milligrams per cubic meter),

CF = conversion factor: 10^{-3} g/mg for radionuclides, 10^{-6} kg/mg for chemicals, and

RF = respirable fraction: 0.5.

3.3.2.1.3.2 Gases

Inhalation of volatile contaminants from soils is not a pathway of concern for most receptors because these contaminants volatilize quickly from surface soils; therefore, exposure is relatively short-term. EPA guidance (EPA 1991, 0302) does suggest evaluating this pathway for workers exposed to subsurface contaminants [e.g., construction worker scenarios for ER Program risk assessments (EPA 1991, 0302)]. The only volatile radiological contaminants of concern are radon and tritium. Radon is addressed separately (Section 3.3.2.1.6). The concentration for tritium in air will be evaluated on a PRS-specific basis. Air exposure concentrations for volatile chemicals can be estimated as follows:

$$Air\ EC = Soil\ EC \times (1/VF), \tag{3.2}$$

where

Air EC = exposure concentration of volatile contaminant in air (milligrams per cubic meter);

Soil EC = appropriate subsurface soil exposure concentration (mil ligrams per kilogram);

VF = soil-to-air volatilization factor, chemical-specific (cubic meters per kilogram).

Available soil-to-air volatilization factors for potential chemicals of concern are given in Appendix J. The equation for deriving volatilization factors is given in EPA guidance (EPA 1991, 0302).

3.3.2.1.4 Exposure Concentrations for Ingestion of Contaminated Foods

The ingestion of edible plants grown in contaminated soils presents a potential exposure route for current and future residents at extra-Laboratory PRSs and recreational users. When available, an appropriate statistic will be used as the RME for ingestion of edible vegetation (e.g., current EPA guidance suggests using the 95% upper-confidence bound of the arithmetic average). Alternatively, concentrations in foods can be modeled from soil concentrations; food contamination resulting from root uptake is modeled separately from that resulting from foliar deposition.

3.3.2.1.4.1 Root Uptake

Root uptake will be the primary contributor to contaminant levels for nonleafy food species such as potatoes, carrots, and berries. Soil data can be used to predict contaminant concentrations resulting from root uptake in edible plants; however, considerable uncertainty is involved. Contaminant-specific data relating concentra-

tions in edible produce to soil concentrations are generally unavailable, especially for chemical contaminants. Soil-to-plant transfer factors available in the literature are derived from data used for evaluating radiological exposure from weapons testing fallout and may not be appropriate for evaluating chemical toxicity. Additionally, the transfer of contaminants of concern from soil to edible plants depends on many factors, such as plant species, pH of the soil, and chemical form of the contaminant (Gough et al. 1979, 0998). For some substances, a certain soil level is toxic to some plant species and, beyond that level, growth does not occur.

Nonetheless, a general method for predicting contaminant concentrations in edible plants from soil concentrations is provided here for use in deriving baseline risk estimates. This method may result in overestimating concentrations in foods. If the resulting calculated risks are high, a more thorough assessment may be required, based on PRS-specific contaminants of concern and data on soil types, growing conditions, and types of edible plants likely to grow in the Los Alamos area.

Although not entirely applicable for every species of edible plant, soil-to-plant transfer factors have been assigned to many radioactive and inorganic substances (Yu et al. 1993, 1014; Ng et al. 1968; 1016; 1982, 1006). Plant uptake of organic compounds may be estimated using the procedure described by Briggs et al. (1982, 0995). Alternatively, soil-to-plant transfer factors for organic substances have also been compiled (Strenge and Peterson 1989, 0837) .

Exposure concentrations in edible plants may be calculated as follows:

$$\text{Produce EC} = Soil\ EC \times TF \times RDP, \tag{3.3}$$

where

Produce EC	=	exposure concentration in edible portion of plant (picocuries per gram for radionuclides, milli grams per kilogram for chemicals);
Soil EC	=	exposure concentration in soil (picocuries per gram for radionuclides, milligrams per kilogram for chemicals;
TF	=	soil-to-plant transfer factor, radionuclide- and chemical-specific, (unitless);
RDP	=	root depth parameter, PRS-specific (unitless).

The root depth parameter is used to assess the fraction of root length that is in contact with contaminated soil, which essentially provides a dilution factor for root uptake. For example, if contamination is found only in the top 15 cm of soil and the active root depth is 100 cm, the root depth parameter is 0.15 (i.e., the fraction of contaminant in soil transferred to the plant is estimated to be 15% of the amount that would be transferred to a plant with a root depth of 15 cm or less). Site-specific values of root depths for local edible plants should be used when available. If site-specific values for the species of concern are not available, generic values can be used (e.g., Zipparo et al. 1993, 1015). This root-depth dilution factor method is recommended for the produce ingestion pathway if only surface soil [the top 6 in. (15 cm)] is contaminated.

Another approach for estimating the exposure concentration in edible plants resulting from root uptake is to use the effective soil exposure concentration over the soil depth equivalent to the root length and to assume that the root depth parameter in Equation 3.3 is equal to 1. In cases where subsurface soil is contaminated, this weighted average method is recommended.

3.3.2.1.4.2 Foliar Deposition

Foliar deposition may be a significant contributor to contaminant levels for leafy edible species such as lettuce and spinach. A method has been developed that uses contaminant-independent "mass-loading" transfer factors from soil to air to edible portions of plants in estimating foliar deposition (Kennedy and Strenge 1993, 1002). These mass-loading transfer factors are recommended for a variety of plant types and are added to contaminant-specific root uptake transfer factors to obtain total soil-to-plant transfer factors. (Both factors must be based on dry plant weight). The factors are then multiplied by dry-plant-weight to wet-plant-weight conversion factors. Finally, multiplication by the soil concentration yields the contaminant concentration in edible portions of the plant. The equation for this calculation is

$$\text{Produce EC} = CF \times [(Soil\ EC_{eff} \times TF_{RT}) + (Soil\ EC_{surf} \times TF_{FD})] \times W \quad , \qquad (3.4)$$

where

Produce EC	=	concentration in edible portions of plant (picocuries per kilogram or milligrams per kilo gram),
CF	=	unit conversion factor (radionuclides only) (1,000 g/kg),
Soil EC_{eff}	=	effective soil exposure concentration over length of roots (picocuries per gram or milligrams per kilogram),
Soil EC_{surf}	=	surface soil exposure concentration (picocuries per gram or milligrams per kilogram),
TF_{RT}	=	soil-to-plant transfer factor from root uptake [picocuries (or milligram) per kilogram dry plant per picocurie (or milligram) per kilogram soil],
TF_{FD}	=	soil-to-plant transfer factor from foliar depo sition [picocuries (or milligrams) per kilo gram dry plant per [picocurie (or milligram) per kilogram soil], and
W	=	dry-plant-weight to wet-plant-weight con version factor (kilograms dry weight per kilogram wet weight).

The above methodology, although inherently simple, is based on fixed assumptions of airborne dust, crop yields, removal rates, etc. These assumptions should be evaluated for applicability to conditions at the Laboratory before using this model.

3.3.2.1.5 Exposure Concentrations for External Gamma Exposure

When possible, direct measurement of external gamma exposure rates should be used to estimate external gamma exposure concentrations. Exposure to gamma radiation in air is measured by the quantity of ion pairs (ionization) formed per unit mass of air by gamma rays emitted from contaminated air, soil, and structural materials. For onsite assessments, the contribution from gamma emitters in air is generally negligible compared with the other two sources. Exposure to external radiation may be estimated from the concentrations of emitters in the source, taking into account attenuation and source/receptor geometries. However, directly measuring exposure via the air pathway at the receptor location (in units of milliroentgens per hour) results in a faster, more accurate assessment of dose than measuring the concentrations in the source medium.

When direct measurement of gamma exposure rates is not practical (e.g., for use in assessing future exposure from contaminated subsurface soil), soil concentrations of specific radionuclide contaminants of concern can be used to estimate gamma exposure rates (external gamma irradiation from structural surfaces is addressed in Section 3.3.2.3). Other minor exposure routes, such as external radiation from immersion in contaminated dust and water, do not contribute significantly to the external gamma exposure of any of the postulated receptors. Therefore, exposure concentrations in air and water are not needed to assess the risk to receptors from the external exposure route.

To assess external gamma irradiation from soils, soil exposure concentrations for the appropriate soil depths should be used. For current receptors, surface soil data (i.e., samples collected within 2 ft of the surface) should be used as the exposure concentrations. For future receptors, subsurface soil data will be needed to assess the risk both during activities involving soil excavation and after subsurface soil contaminants are redistributed to the surface.

If the receptor is postulated to be indoors a significant portion of the time (i.e., long-term worker or resident) and the source of contamination is soil, shielding by uncontaminated structural materials should be taken into account to more realistically assess receptor exposure. The recommended shielding factor is 0.7 (Yu et al. 1993, 1014). Also, the presence of any uncontaminated cover material should be accounted for in calculating the exposure rates. To conservatively assess the risks from the external exposure route, the receptor is assumed to be located at the center of the contaminated area.

3.3.2.1.6 Exposure Concentrations for the Inhalation of Radon

The presence of ^{226}Ra (and other members of the natural uranium chain) or ^{228}Th (and other members of the natural thorium decay chain) in soil or structural materials results in the generation of ^{222}Rn or ^{220}Rn gas, respectively. Exposure concentrations in air of either radon isotope may be estimated from the concentrations of radium or thorium in soil by using an appropriate model such as RESRAD (Attachment 1 to this appendix) or by measuring them directly. Modeling is recommended

if radon precursors are detected and measurements of airborne radon are not available. Modeling is also required when estimating the dose in a future use scenario that involves indoor occupancy of buildings that do not currently exist (Section 3.4.3.6). In such cases, surface or subsurface soil concentrations for the appropriate radium or thorium isotope are used as exposure concentrations.

When radon measurements are available, they should be used in calculating exposure concentrations. Radon measurements are usually reported in units of picocurie per liter. To calculate the radon dose, however, these concentrations must be corrected for the ingrowth of radon decay products, which contribute most of the dose. The radon concentration unit that accounts for this contribution is defined as the working level (WL), which is equal to the concentration of short-lived decay products that release 1.3×10^5 MeV of potential alpha energy per liter of air. The concentrations of decay products in air are seldom in equilibrium with radon. To convert concentrations of radon from picocuries per liter to concentration of daughters in working levels, the degree of equilibrium between the former and the latter must first be estimated. Equilibrium factors depend on factors such as radionuclide half-lives, radon emanation and ventilation rates, fraction of decay products attached to particulates, plateout of decay products, and particulate deposition rates. The following equation is used to convert the radon concentrations to decay product working levels (i.e., the exposure concentrations):

$$C_{WL} = C_{pCi/l} \times CF \times EF \quad , \tag{3.5}$$

where

C_{WL}	=	concentration of radon decay products (working level),
$C_{pCi/L}$	=	radon concentration (picocuries per liter),
CF	=	conversion factor (working level per picocuries per liter), and
EF	=	equilibrium factor (unitless).

The conversion factors for ^{222}Rn and ^{220}Rn are 0.01 and 0.13 WL per picocurie per liter, respectively (ICRP 1981, 1000). In the absence of site-specific data, an equilibrium factor of 0.5 is recommended (National Research Council 1991, 1005).

3.3.2.2 Exposure Concentrations for Water Pathways

3.3.2.2.1 Ingestion of Groundwater or Surface Water

When contaminants of concern are identified in potable alluvial groundwater, it is appropriate to assess ingestion of groundwater in canyon bottoms. Water is considered potable if there is sufficient yield to support the assumed use (e.g., domestic or recreational use) and adequate quality (e.g., the water is low in total dissolved solids). The receptor to be evaluated for this pathway depends on the location of the PRS; a future resident is evaluated for extra-Laboratory PRSs, and a future camper is evaluated for Laboratory PRSs. No actual current use of alluvial groundwater is known.

When sufficient numbers of samples exist, an appropriate statistic is used to represent the RME in alluvial groundwater. For example, current EPA guidance

suggests using the 95% upper-confidence bound of the arithmetic average. However, it is expected that data for alluvial groundwater will be limited to one or two rounds of sampling from only a few monitoring wells for most OUs. Given such limited data, it may be necessary to use the maximum level of each contaminant of concern in any monitoring well as the exposure concentration. The units are picocuries per liter for radionuclides and milligrams per liter for chemicals.

Perennial surface water bodies are generally limited to streams in a few canyon bottoms. Assessment of potential exposure to contaminants in these surface waters includes an assumption of limited ingestion during recreational use (e.g., wading) by the youth recreational user, future camper, or future resident. The exposure concentrations are an appropriate statistic to represent the RME in alluvial groundwater. The units are picocuries per liter for radionuclides and milligrams per liter for chemicals.

3.3.2.2.2 Dermal Absorption from Groundwater or Surface Water

Dermal absorption of most radionuclides from water is negligible compared with other exposure pathways and is not assessed. However, absorption of tritium from water may be significant (Pinson and Langham 1957, 1008). The tritium exposure concentration used to evaluate dermal absorption from the water pathway is simply the concentration of tritium in water in units of picocuries per liter.

After chemical contaminants of concern have been identified for a PRS, their potential for dermal absorption from water should first be evaluated qualitatively. If a significant potential for dermal absorption exists, either an appropriate statistic is used to represent the RME in water, or the maximum contaminant levels detected are used as exposure concentrations, depending on the numbers of samples available. The units are milligrams per liter.

3.3.2.2.3 Inhalation from Household Use of Groundwater

In general, this pathway is unlikely to be applicable for ER Program assessments. The most likely mechanism for contamination of alluvial groundwater in canyon bottoms is via run-off from Laboratory operations on mesa tops. This mechanism would lead to volatilization rather than to leaching of volatile contaminants to groundwater. However, because there may be some sources of volatile contaminants in canyon bottoms, this pathway cannot be completely ruled out.

If volatile contaminants are detected in alluvial groundwater, inhalation exposure to volatiles will only be a potentially significant pathway for extra-Laboratory areas in which future residential use is possible (future campers in canyon bottoms would not use the groundwater for bathing or showering). For future residents, showering is likely to be the most significant exposure source during household use. Because of the limited application of this pathway, equations for the derivation of air exposure concentrations and dose/intake while showering are not presented. The need for evaluating this pathway should be determined on a PRS-specific basis. If needed, methods for evaluating exposure while showering are available [e.g., Byard (1989, 0996)].

3.3.2.3 Exposure to Contaminated Building Surfaces

3.3.2.3.1 Radiological Contaminants

Building surfaces that have been contaminated as a result of past Laboratory operations may result in worker exposures to these contaminants. It is assumed that these buildings will remain in use for industrial/commercial purposes in the future. Therefore, only the long-term-worker scenarios need to be considered. Demolishing and renovating contaminated buildings may result in higher short-term exposures to construction personnel; however, health impacts are likely to be lower than exposures from long-term building use. Worker exposure to radiological contaminants in buildings may occur from one or more of the following pathways (Kennedy and Strenge 1993, 1002) :

- dermal exposure to and inhalation of gamma radiation emitted from building surfaces,
- ingestion of dust from contaminated building surfaces, and
- inhalation of air contaminated by the entrainment of radionu clides from building surfaces.

For the external exposure route, actual measurement of exposure rates at locations where individuals are likely to work provide the most precise estimate of worker doses. Alternatively, surface or volumetric concentrations of total radioactivity (loose plus fixed) in disintegrations per minute per 100 cm^2 or picocuries per gram may be used in conjunction with shielding models or external dose rate factors to estimate exposure rates at receptor locations.

For ingestion of radionuclides, the exposure concentration is the measured concentration of loose surface contamination in disintegrations per minute per 100 cm^2.

The exposure concentration for the inhalation pathway resulting from the building occupancy scenario may be obtained by direct measurement of airborne contaminants (picocuries per cubic meter for radionuclides). When no measurements are available, the exposure concentration may be obtained by modeling the resuspension of contaminants from building surfaces (Kennedy and Strenge 1993, 1002).

3.3.2.3.2 Chemical Contaminants

Exposure to chemical contaminants on indoor surfaces may occur via ingestion, dermal contact, and inhalation. Ingestion and dermal contact are possible only when surfaces are accessible for direct contact. Potential for inhalation depends on the extent of dust resuspension. For ER Program risk assessments, volatile contaminants are presumed to have dissipated.

A recent review of the literature found no correlation between chemical contaminant concentrations in surface wipe samples (for which methods are specified under the Occupational Safety and Health Act) and air concentrations of those chemicals (Caplan 1993, 0997). Caplan attributed the lack of correlation to the dependence of resuspension on several factors, including properties of dusts (e.g., adhesiveness, particle size distribution, and density); properties of surfaces (e.g., macro- and microstructure, adhesive properties, porosity); and variable activities in buildings (e.g., foot traffic, vehicle traffic, vibrations, air exchange). Because an accurate resuspension factor for chemicals from surfaces to air is not available, monitoring

data will likely be needed for estimating air exposure concentrations caused by surface contamination. Wipe samples will be used to identify contaminants that might be present in air.

Estimates of potential ingestion and/or dermal contact exposure via contaminated indoor surfaces can be made using wipe sample data and assumptions on extent of contact. The receptor of concern for this exposure pathway in ER Program risk assessments is a long-term worker. The need for assessing this pathway should be evaluated on a PRS-specific basis. Examples of risk calculations for contaminated building surfaces in the literature are scarce, although such an analysis has been conducted for dermal contact with PCBs on contaminated surfaces (Rosenbaum et al. 1990, 1010). For the ingestion pathway, methods used for assessing radiological contamination in buildings (Kennedy and Strenge 1993, 1002) could be adapted to address chemical contamination.

3.4 Estimation of Radiological Dose and Chemical Intake

3.4.1 Methods

3.4.1.1 General Exposure Parameters

Estimates of exposure are based on the contaminant concentrations at exposure locations (Section 3.3) and scenario-specific assumptions and exposure parameters. Scenario-specific assumptions include factors such as frequency and duration of exposure to a contaminated medium by a potential receptor. Exposure parameters are associated with the route of exposure (e.g., ingestion and inhalation). The assumptions and intake factors for the exposure scenarios applicable for ER Program risk assessments are presented in Section 3.4.2. The approach and equations for determining contaminant doses and intakes at the potential exposure locations are given in Sections 3.4.3-3.4.5.

The EPA's risk assessment guidance recommends the quantification of intakes for each route of exposure from an exposure medium (EPA 1989, 0305). Exposure estimates are based on the RME expected to occur under current and future land use conditions (Sections 3.2.2. and 3.2.3). The RME is defined as the highest exposure that can reasonably be expected to occur at a site. Scenario assumptions and intake parameters used to estimate the RME are based, to the extent possible, on values provided in the *Exposure Factors Handbook* (EPA 1989, 0304), *Human Health Evaluation Manual* (EPA 1989, 0305) and in a supplement to that manual (EPA 1989, 1011). Section 3.3 provides further discussion of appropriate methods for estimating the RME.

3.4.1.2 Estimates of Radiological Dose

Internal exposure to radioactive contaminants is expressed in terms of the 50-yr committed effective dose equivalent (CEDE). To calculate the CEDE, the contaminant concentration is multiplied by dose conversion factors (DCFs) and by the environmental transport factors appropriate for each medium and receptor scenario. Dose conversion factors, which are specific to the radionuclide and exposure pathway, are used to determine the CEDE per unit intake of the radionuclide. Derivation of DCFs incorporates the following consideration for each radionuclide:

- the radiosensitivity of each internal organ,

- the type of radiation emitted by the radionuclide (alpha, beta, and gamma), and

- the solubility class or gastrointestinal absorption fraction of the radionuclide following inhalation or ingestion, respectively.

The concept of committed dose applies only to internal dose pathways. For the external dose pathway, there is no long-term residence of radionuclides in the body. In this case, the appropriate measure of radiological exposure is the effective dose equivalent (EDE). Dose conversion factors for external exposure from contaminated soil are based on continuous occupancy and a contaminated area of infinite extent and depth. The calculation of EDE at the receptor point must therefore be corrected for appropriate occupancy factors, and shielding and geometry for each exposure scenario (Sections 3.4.2-3.4.5).

The sum of the CEDE (internal dose pathways) and the EDE (external dose pathway) is termed the total effective dose equivalent. For purposes of simplification, both CEDE and EDE are referred to as dose (expressed as millirem) in the following sections.

Separate DCFs are available for the various exposure routes (i.e., external gamma, inhalation, ingestion) for the radionuclides potentially present at the Laboratory. When several inhalation or ingestion DCFs are available for each radionuclide, the DCF resulting in the highest dose estimate will be applied. DCFs are available from a DOE (1988, 0266) report for internal dose and from (Yu et al. 1993, 1014) for external dose. The dose contributions from short-lived decay products (having half-lives of less than 6 mo) are incorporated in the DCF for the parent radionuclide. For example, the dose contributions from ^{90}Y and ^{137}Ba are included in the DCFs for ^{90}Sr and ^{137}Cs, respectively.

Radiation doses can be calculated with RESRAD, a computer program used to estimate doses to onsite receptors at radioactively contaminated sites (Yu et al. 1993, 1014). The code incorporates the DCFs discussed above and allows the user to enter values for site- and scenario-specific parameters (contaminant concentrations, area and thickness of the contamination at the PRS, exposure pathways, occupancy factors, intake rates, etc.). Use of the RESRAD code to calculate radiological doses is discussed in Attachment 1.

3.4.1.3 Estimates of Chemical Intake

Exposure to chemical contaminants is expressed in terms of intake, which is the amount of contaminant taken into the body per unit body weight per unit time (generally expressed as milligrams per kilogram per day).

3.4.2 Scenario-Specific Assumptions and Exposure Parameters

The assumptions used to estimate radiological doses and chemical intakes for the receptors described in Section 3.2.3 are discussed in Sections 3.4.2.1 through 3.4.2.8 and are summarized in Table 3-2.

Some exposure parameters depend on the age of the receptor (e.g., ingestion and inhalation rates, body weight, skin surface areas). For long-term receptors for whom some portion of exposure occurs during childhood (e.g., residents and future campers), variable exposure parameters may be appropriate for the portions of

exposure that occur during childhood and those portions that occur during adulthood. However, use of variable exposure parameters generally does not alter calculated intake significantly because, for example, decreased body weight corresponds with decreased ingestion and inhalation rates. The only pathway for which incorporation of both child and adult intake parameters alters calculated intake substantially is the soil ingestion pathway, because children have higher ingestion rates than adults (and lower body weights). Under EPA guidance, variable exposure parameters should be assumed for the soil ingestion pathway but are not necessary for inhalation and dermal contact pathways (EPA 1991, 0746; EPA 1992, 1012).

3.4.2.1 Exposure Time, Frequency, and Duration

Exposure time, frequency, and duration together define the total amount of time a receptor may be in contact with a given distribution of contaminants in the exposure unit. The exposure time is the number of hours per day that a receptor is present at a specific exposure point, the exposure frequency is the number of days per year that exposure occurs, and the exposure duration is the total number of years over which exposure occurs. For each scenario, the exposure time is further divided into time spent indoors and time spent outdoors.

Long-term workers at the Laboratory are assumed to be onsite 8 h/day for 250 days/yr over 25 yr. EPA risk assessment guidance recommends these exposure time, frequency, and duration values for workers (EPA 1991, 0746). In general for ER Program risk assessments, assumptions of increased worker time spent outdoors result in higher intake and dose estimates than assumptions of no or little time spent outdoors. These results occur because intake from particulate inhalation and dose from external gamma irradiation are greater for outdoor exposures, and the assumed soil ingestion rate is also higher for outdoor workers. Therefore, an assumption of a substantial fraction of the day spent outdoors (e.g., 4 h) generally represents the RME for a long-term worker. An exception to this assumption occurs when radon is the contaminant of concern; radon build-up inside buildings might lead to a higher calculated risk for workers who spend most of their time indoors. Specific exposure assumptions for long-term workers in ER Program risk assessments should be made on a PRS-specific basis, depending on the contaminants of concern and the likelihood of outdoor work.

Youth recreational users of canyon sides and bottoms (e.g., hikers and bikers) are assumed to spend 2 h/day outdoors in canyon areas for 170 days/yr (e.g., about 5 days/wk for 8 mo/yr, which are reasonable estimates, considering the climate in the Los Alamos area). The exposure duration is estimated as 9 yr, which is the median time spent at one residence (EPA 1989, 0088) and is also consistent with the age range assumed for this receptor (10-18 years). Although the youth recreational user is more likely to be a concern in the future, the current use scenario is included to address potential trespassers.

The current and future residents of PRS areas in the townsite are assumed to have an exposure frequency of 350 days/yr and an exposure duration of 30 yr, as recommended in EPA guidance (EPA 1991, 0746). The exposure time assumes 20 h/day, allowing for 4 h/day spent away from the property. Two hours per day are assumed to be spent outdoors on the residential property.

Construction workers are assumed to be onsite 8 h/day 90 days/yr. An exposure duration of 1 yr is used, assuming the time spent at any single PRS is limited.

Cumulative exposures from several PRSs for construction workers are discussed in Section 5. These workers' activities are assumed to occur outdoors only. In general, construction is currently not allowed in PRS areas. However, because schedules for required construction work cannot be predicted, the construction worker scenario is considered possible for both the present and the future.

For PRS areas where future recreational use is assumed (i.e., canyon bottoms), camper receptors are assumed to be onsite 24 h/day, 28 days/yr over 20 yr. The future camper is assumed to spend the entire 24 h outdoors.

For the dermal-absorption-from-soil-pathway, all the scenarios except the residential scenario assume the number of soil contact events is equal to the exposure frequency (days per year). For residents, it is assumed that dermal contact occurs seasonally (e.g., during gardening), approximately 5 days/wk for 8 mo/yr over 30 yr. For the youth recreational user, future camper, and future resident scenarios, dermal exposure to compounds in surface water (e.g., during wading) is assumed to occur during daily 1-h exposure events. The future camper is assumed to wade in surface water daily while present at the PRS (i.e., 28 days/yr), whereas the youth recreational user and the future resident are assumed to wade 40 days/yr (it is assumed that these receptors are unlikely to wade daily). For the future resident in canyon bottoms, dermal exposure to compounds in groundwater (e.g., during bathing) is assumed to occur for 15 min/day, 350 days/yr over 30 yr.

3.4.2.2 Body Weight

The standard assumption for adult body weight is 70 kg (EPA 1989, 0305). Therefore, a body weight of 70 kg is used for long-term worker, construction worker, resident, and future camper scenarios and for that portion of the current or future resident and future camper scenarios for which an adult is assessed (applicable to soil ingestion pathway only). A body weight of 50 kg for youths of ages 10 to 18 (EPA 1989, 0305) is considered representative for the youth recreational user. A body weight of 15 kg for children of ages 1 to 6 (EPA 1991, 0746) is assumed for both the child portion of the future camper scenario and for the child portion of the current and future resident scenarios for evaluation of the soil ingestion pathway.

3.4.2.3 Inhalation Rates

EPA recommends the use of an inhalation rate of 0.83 m^3/h (20 m^3/day) for the assessment of resident adult scenarios (EPA 1989, 1011). This inhalation rate (which is based on the average inhalation rate over an entire day, including periods of rest, and light, moderate, and heavy activity) should be used for indoor exposures for the current and future resident scenarios. It is also appropriate for the long-term worker scenario for indoor activities, which are assumed to involve light office, laboratory, or maintenance work. [EPA (1989, 0304) defines activity levels as follows: resting includes watching television, reading, and sleeping; light activity includes most domestic work, hobbies, and conducting minor home repairs; moderate activity includes heavy indoor cleanup, conducting major home repairs, and climbing stairs; and heavy activity includes vigorous physical exercise and climbing stairs carrying a load.]

The inhalation rate for other scenarios is adjusted to account for greater exertion while working outdoors or engaging in recreational activities. The outdoor inhalation rate assumed for worker and resident scenarios is 1.7 m^3/h, assuming that half of the

exposure time is spent at moderate activity and half at light activity. For the youth recreational user, an inhalation rate of 3.2 m^3/h is used; this rate is based on a moderate activity level for a 10-yr-old child (EPA 1989, 0304). The inhalation rate of 1.3 m^3/h for a future camper is based on adult exposures of 8 h/day resting, 12 h/day light activity, 2 h/day moderate activity, and 2 h/day heavy activity.

3.4.2.4 Ingestion Rates for Soil and Dust

Soil ingestion rates are based on EPA guidance (EPA 1991, 0746) to account for incidental ingestion of soil and dust. For most scenarios, the recommended soil ingestion rate of 100 mg/day for adults and youths more than 6 yr of age is appropriate. The assumed soil and dust ingestion rate for youth recreational users is 100 mg /day (EPA 1991, 0746).

The soil ingestion rate recommended for workers spending most of their work day indoors is 50 mg/day (EPA 1991, 0746); this rate should be used for long-term workers who are assumed to perform little or none of their work outdoors. For workers assumed to spend their entire exposure duration (i.e., 8 hr/day) indoors, a factor of 0.4 (Alzona et al. 1979, 0994) is applied to the ingestion rate to account for the fact that not all indoor dust is composed of contaminated soil (i.e., smoking and other indoor activities). Long-term workers who spend some portion of their workday outdoors (e.g., 1 hr or more) are assumed to have a higher ingestion rate of 100 mg /day [which is also consistent with EPA guidance to assume 100 mg/day soil ingestion for adults; (EPA 1991, 0746)].

Based on a study by Hawley (1985, 0999), EPA recommends 480 mg/day as a default soil ingestion rate for short-term, outdoor activities in a commercial/industrial setting. Therefore, for the construction worker scenario, an ingestion rate of 480 mg/day is assumed to account for extended daily exposure to contaminated material and ingestion of inhaled material that is not retained in the lungs.
EPA guidance recommends considering both early childhood (i.e., ages 1 to 6, when intake is greater) and adult exposures when evaluating soil ingestion for a residential scenario. For ER Program risk assessments, this approach is used for evaluating both current and future resident and future camper scenarios. Therefore, for the soil ingestion pathway, exposure for these receptors is evaluated assuming 6 yr of exposure as a young child, with an ingestion rate of 200 mg/day, and either 24 yr of exposure (resident scenario) or 14 yr exposure (future camper scenario) at the lower ingestion rate of 100 mg/day.

3.4.2.5 Ingestion Rate for Water

Future residents in canyon bottoms and future campers are the only receptors for which the pathway of groundwater ingestion is evaluated. For this scenario, the standard default value of 2 L/d, recommended by EPA (1991, 0746) for adult residents, is assumed to be the water ingestion rate. It is also assumed that incidental ingestion of surface water might occur during wading for the youth recreational user, future camper, and future resident scenarios. The surface water ingestion rate of 0.05 L/d is based on EPA's (1989, 0088) recommended incidental ingestion level of 50 mL/h for a 1-h exposure time.

3.4.2.6 Produce Ingestion Rate and Fraction Ingested Produce Grown on Contaminated Area

Current and future residents and future campers are the receptors for which the

ingestion of contaminated produce and wild plants is evaluated. EPA (1989, 0304; 1991, 0746) presents figures for "typical" consumption of fruit and vegetables as 140 g/d and 200 g/d, respectively. The reasonable worst-case proportion of ingested produce that is considered to be homegrown (i.e., grown on the contaminated area) ranges from 30% to 40% for fruits and vegetables. Therefore, for the resident scenario, the produce ingestion rate is assumed to be 340 g/d, of which the fraction of ingested produce grown on the contaminated area is estimated to be 40%. The future camper is assumed to ingest wild plants at a rate of 140 g/d, of which 100% is assumed to grow on the contaminated site. Data specific to the Los Alamos area should be used to determine the fractions of produce assumed to be leafy and nonleafy (Section 3.3.2.1.4).

3.4.2.7 Skin Surface Area (Soil and Water Pathways)

Assumptions for total body surface area and the surface area of component body parts are both scenario- and age-dependent (EPA 1992, 1012). For ER Program risk assessments, dermal exposure is evaluated only for adult receptors. This simplification is warranted because dermal exposure is proportional to surface area; thus, intakes calculated for adult and child receptors are similar.

For the showering/bathing scenarios for future residents using canyon bottom groundwater, the mean total adult body surface area is approximately 20,000 cm^2, which is in EPA's recommended default range. For soil contact and wading in surface water scenarios, dermal exposure is expected to occur on roughly 25% of the total surface area (i.e., hands, lower legs, forearms, neck, and head). Twenty-five percent of the mean total body surface area is 5,000 cm^2 for adults. The soil contact surface area for the youth recreational user is increased to 5,000 cm^2 (i.e., adult value) based on the potential dust-generating nature of the recreational activity. For long-term workers who perform some of their work outdoors and future construction workers, protective clothing probably limits the exposure to hands, forearms, neck and head; therefore, the mean surface area for these upper extremities of adults is 3,200 cm^2.

3.4.2.8 Fraction from Contaminated Source

Sampling plans are generally designed so that samples collected for use in a risk assessment represent an exposure unit area. The statistic used to describe the contaminant distribution, the RME, within an exposure unit area is used to calculate receptor dose. An adjustment is recommended in cases for which the area of the PRS is smaller than the appropriate exposure unit area and for which data have not been obtained outside the PRS. This adjustment can be made by prorating the values obtained in the PRS according to the fraction of the exposure unit area corresponding to the PRS. This fraction is termed the "fraction from contaminated source" (FI), and is set to 1 if the PRS is not smaller than the exposure unit.

In effect, the FI parameter adjusts the concentration parameters used in the equations presented in the following sections. This adjustment is equivalent to an assumption that the area outside the PRS but inside the exposure unit is free of contamination. However, considering that the potential impact of nonzero contamination in this area is likely to be small, averaging with an assumption that this area is free of contamination is unlikely to cause gross decision-making errors. Other assumptions can be made about the area outside the PRS; however, if other assumptions are made, the adjustment becomes more complex.

3.4.3 Equations for Exposure to Soil

This section describes the methodology for estimating chemical intakes and radiological doses for exposures based on concentrations in soil. Equations for estimating human intakes are presented for the following exposure routes: incidental soil ingestion, dermal contact with soil, inhalation of particulates, ingestion of contaminated produce, external gamma exposure, and inhalation of radon. With the exception of the external gamma exposure and radon inhalation pathways, the equations presented are based on equations given in EPA's H*uman Health Evaluation Manual* (EPA 1989, 0305); analogous equations are used for the external gamma exposure and radon inhalation pathways.

3.4.3.1 Incidental Soil Ingestion

For both radiological dose and chemical intake estimates, scenario-specific assumptions on exposure time, frequency, and duration, and the assumed ingestion rates for the various receptors are given in Table 3-2. The intake for a long-term worker whose work is exclusively indoors is multiplied by a factor of 0.4 to account for the fact that all exposure occurs indoors, where not all ingested dust originates from contaminated soil (Section 3.4.2.4).

3.4.3.1.1 Radiological Dose

The basic equation used to calculate radiation doses from ingesting contaminated soil is

$$D_{is} = R_{is} \times IR_s \times CF \times EF \times FI \times DCF_i(Ing) \times ED \quad , \tag{3.6}$$

where

D_{is}	=	dose from ingestion of radionuclide, i, in soil (millirem),
R_{is}	=	soil exposure concentration of radionuclide, i, in soil (picocuries per gram) (Section 3.3.2.1.1),
IR_s	=	soil ingestion rate (milligrams per day),
CF	=	conversion factor (10^{-3} g/mg),
EF	=	exposure frequency (days per year),
FI	=	fraction from contaminated source, calculated using scenario-specific exposure units (Section 3.4.2.8) (nitless),
$DCF_i(Ing)$	=	dose conversion factor for ingestion of radionuclide, i (millirems per picocurie), and
ED	=	exposure duration (years).

To account for increased soil intake rates during childhood years, the ingestion rate can be calculated as the time-weighted average over the exposure duration

$$IR_s = \frac{(IR_{sc} \times ED_c) + (IR_{sa} \times ED_a)}{ED_c + ED_a} \quad , \qquad (3.7)$$

where

IR_{sc}	=	child soil ingestion rate (milligrams per day),
IR_{sa}	=	adult soil ingestion rate (milligrams per day),
ED_c	=	child exposure duration (6 yr), and
ED_a	=	adult exposure duration [24 yr or 14 yr (scenario-specific)].

The soil ingestion dose may be calculated with the RESRAD code using the methodology in Attachment 1.

3.4.3.1.2 Chemical Intake

The basic equation used to calculate chemical intake via ingestion is

$$Intake\ (mg/kg\text{-}d) = \frac{C_i \times IR_s \times CF \times FI \times EF \times ED}{BW \times AF \times AD} \quad , \qquad (3.8)$$

where

C_i	=	soil exposure concentration of chemical, i (milligrams per kilogram) (Section 3.3.2.1.1),
IR_s	=	soil ingestion rate (milligrams per day),
CF	=	conversion factor (10^{-6} kg/mg),
FI	=	fraction from contaminated source, calculated using scenario-specific exposure units (Section 3.4.2.8) (unitless),
EF	=	exposure frequency (days per year),
ED	=	exposure duration (years),
BW	=	body weight (kilograms),
AF	=	averaging frequency (365 days/yr), and
AD	=	averaging duration [years (equal to ED for noncarcinogens and 70 yr for carcinogens)].

A modified equation is used to model 6 yr of childhood exposure and 24 yr of adult exposure for the resident scenario and 6 yr of childhood exposure and 14 yr of adult exposure for the future camper scenario. The modified equation is

$$Intake\,(mg/kg\text{-}d) = \frac{C_i \times IR_{sc} \times CF \times FI \times EF \times ED_c}{BW_c \times AF \times AD} + \frac{C_i \times IR_{sa} \times CF \times FI \times EF \times ED_a}{BW_a \times AF \times AD} \quad , \quad (3.9)$$

where

C_i	=	soil exposure concentration of chemical, i (milligram per kilogram) (Section 3.3.2.1.1),
IR_{sc}	=	child soil ingestion rate (milligrams per day),
IR_{sa}	=	adult soil ingestion rate (milligrams per day),
CF	=	conversion factor (10^{-6} kg/mg),
FI	=	fraction from contaminated source, calculated using scenario-specific exposure units (Section 3.4.2.8) (unitless),
EF	=	exposure frequency (days per year),
ED_c	=	child exposure duration (6 yr),
ED_a	=	adult exposure duration [24 yr or 14 yr (scenario-specific)],
BW_c	=	child body weight (15 kg),
BW_a	=	adult body weight (70 kg),
AF	=	averaging frequency (365 days/yr); and
AD	=	averaging duration [years (equal to ED for noncarcinogens and 70 yr for carcinogens)].

Because chemical intakes for carcinogenic risk calculations are averaged over a lifetime of 70 yr, the intakes calculated for use in carcinogenic risk estimates differ somewhat from those calculated for noncarcinogenic endpoint estimations.

3.4.3.2 Dermal Contact with Soil

Dose estimates and chemical intakes for the dermal exposure pathway are calculated using the exposure concentrations in soil (Section 3.3.2.1.1). Scenario-specific assumptions on the dermal exposure factors (exposure time, frequency, duration, skin area, and soil adherence) are given in Table 3-2.

3.4.3.2.1 Radiological Dose

The dermal absorption of radionuclides depends on the chemical compound in which the radioactive element is incorporated. Most radionuclides found in the environment have relatively low dermal absorption fractions, and the contribution to dose from dermal absorption is typically much smaller than the dose from soil ingestion. In addition, dose conversion factors have not been developed for the dermal absorption pathway for most radionuclides (tritium is an exception). If the dermal absorption pathway results in a significant radiation dose because of the high dermal absorption potential of the chemical compound, the dose must be calculated on a case-by-case basis and requires the derivation of dose conversion factors for dermal absorption.

3.4.3.2.2 Chemical Intake

The following equation is used to estimate the dermal absorption of chemicals from soil:

$$Intake\,(mg/kg\text{-}day) = \frac{C_i \times CF \times FI \times ADF \times ABS \times EF_d \times ED \times SA_s}{BW \times AF \times AD}\ , \quad (3.10)$$

where

C_i = soil exposure concentration of chemical, i (milligrams per kilogram) (Section 3.3.2.1.1),

CF = conversion factor (10^{-6} kg/mg),

FI = fraction from contaminated source, calculated us ing scenario-specific exposure units (Section 3.4.2.8) (unitless),

ADF = adherence factor of soil to skin (milligrams per square centimeter per event),

ABS = absorption fraction (unitless, chemical-specific),

EF_d = exposure frequency for soil dermal contact (events per year),

ED = exposure duration (years),

SA_s = skin surface area available for soil contact (square centimeter),

BW = body weight (kilograms),

AF = averaging frequency (365 days/yr), and

AD = averaging duration [years (equal to ED for noncarcinogens and 70 yr for carcinogens)].

Estimation of the dermal absorbed dose for compounds in soil requires identification of appropriate chemical-specific absorption fractions. Although the use of soil permeability coefficients may be preferable, EPA currently recommends the use of

absorption fractions until this issue is investigated further. In estimating absorption fractions, preference is given to experimentally derived values; otherwise, predictive models must be used. Some theoretical approaches to determining an appropriate absorption fraction are discussed in EPA guidance for assessing dermal exposure (EPA 1992, 1012); that document also lists absorption fractions for several compounds.

An EPA review (1992, 1012) of experimental data on soil adherence indicates a conservative range of values from 0.2 mg/cm^2 to 1.5 mg/cm^2 per event. Although the uncertainties in the studies make it difficult to recommend a default value, EPA suggests that 1 mg/cm^2 is a reasonable upper value. Therefore, 1 mg/cm^2 should be used as the soil-to-skin adherence factor for all applicable scenarios (Table 3-2).

3.4.3.3 Inhalation of Particulates

Scenario-specific assumptions on exposure time, frequency, and duration, and assumed inhalation rates for use in calculating dose and intake from the inhalation pathway are given in Table 3.2.

3.4.3.3.1 Radiological Dose

The following equation is used to calculate radiation doses from the inhalation of contaminated dust when all exposure is outdoors:

$$D_{ia} = R_{ia} \times IR_a \times ET \times EF \times FI \times DCF_i(Inh) \times ED \quad , \qquad (3.11)$$

where

D_{ia}	=	dose from inhalation of radionuclide, i, in air (millirem),
R_{ia}	=	concentration of radionuclide, i, in (picocuries per cubic meter), based on soil exposure concentration (Section 3.3.2.1.3),
IR_a	=	inhalation rate (cubic meters per hour),
ET	=	exposure time (hours per day),
EF	=	exposure frequency (days per year),
FI	=	fraction from contaminated source, calculated using scenario-specific exposure units (Section 3.4.2.8) (unitless),
$DCF_i(Inh)$	=	dose conversion factor for inhalation of radionuclide, i (millirems per picocurie), and
ED	=	exposure duration (years).

For receptors assumed to spend some portion (or all) of the exposure time indoors

(i.e., long-term workers and current and future residents), the concentration of particulates indoors is assumed to be reduced by 60% (Alzona et al. 1979, 0994). To account for this assumption, the product of inhalation rate and exposure time in the above equation may be substituted by the following expression:

$$IR_a \times ET = (IR_o \times ET_o) + (0.4 \times IR_i \times ET_i) \quad , \qquad (3.12)$$

where

IR_o	=	outdoor inhalation rate (cubic meters per hour),
IR_i	=	iindoor inhalation rate (cubic meters per hour),
ET_o	=	exposure time outdoors (hours per day),
ET_i	=	exposure time indoors (hours per day).

The dust inhalation dose may be calculated with the RESRAD code using the methodology in Attachment 1.

3.4.3.3.2 Chemical Intake

The following equation is used for calculating chemical intake via inhalation when all exposure is outdoors

$$Intake\ (mg/kg\text{-}day) = \frac{C_i \times IR_a \times FI \times ET \times EF \times ED}{BW \times AF \times AD} \quad , \qquad (3.13)$$

where

C_i	=	concentration of chemical, i, in air (milli grams per cubic meter), based onsoil ex posure concentration (Section 3.3.2.1.3),
IR_a	=	inhalation rate (cubic meters per hour),
FI	=	fraction from contaminated source, calcu lated using scenario-specific exposure units (Section 3.4.2.8) (unitless),
ET	=	exposure time (hours per day),
EF	=	exposure frequency (days per year),
ED	=	exposure duration (years),
BW	=	body weight (kilograms),
AF	=	averaging frequency (365 days/yr), and
AD	=	averaging duration [years (equal to ED for

noncarcinogens and 70 yr for carcinogens)].

For receptors assumed to spend some portion (or all) of the exposure time indoors (i.e., long-term workers and current and future residents), the concentration of particulates indoors is assumed to be reduced by 60%. The above equation is modified to account for this assumption, as follows:

$$Intake\ (mg/kg\text{-}day) = \frac{C_i \times IR_o \times FI \times ET_o \times EF \times ED}{BW \times AF \times AD} + \frac{C_i \times IR_i \times FI \times ET_i \times 0.4 \times EF \times ED}{BW \times AF \times AD} \quad , \quad (3.14)$$

where

C_i	=	concentration of chemical, i, in air (milli grams per cubic meter), based on soil exposure concentration (Section 3.3.2.1.3),
IR_o	=	outdoor inhalation rate (cubic meters per hour),
IR_i	=	indoor inhalation rate (cubic meters per hour),
FI	=	fraction from contaminated source, calcu lated using scenario-specific exposure units (Section 3.4.2.8) (unitless),
ET_o	=	exposure time outdoors(hours per day),
ET_i	=	exposure time indoors(hours per day),
EF	=	exposure frequency (days/year),
ED	=	exposure duration (years),
BW	=	body weight (kilograms),
AF	=	averaging frequency (365 days/yr), and
AD	=	averaging duration [years (equal to ED for noncarcinogens and 70 yr for carcinogens)].

3.4.3.4 Ingestion of Contaminated Produce

3.4.3.4.1 Radiological Dose

The following equation is used to calculate the radiation doses from the ingestion of contaminated produce:

$$D_{ip} = R_{ip} \times IR_p \times F_{HG} \times EF \times DCF_i(Ing) \times ED \quad , \quad (3.15)$$

where

D_{ip} = dose from ingestion of radionuclide, i, in produce (millirems),

R_{ip} = concentration of radionuclide i in produce(picocuries per kilogram), based on soil exposure concentration (Section 3.3.2.1.4),

IR_p = produce ingestion rate (kilograms per day),

F_{HG} = fraction of ingested produce that is grown on or collected from the contaminated area (Section 3.4.2.6) (unitless),

EF = exposure frequency (days per year),

$DCF_i(Ing)$ = dose conversion factor for ingestion of radionuclide, i (millirems per picocurie), and

ED = exposure duration (years).

The produce ingestion dose may be calculated with the RESRAD code using the methodology in Attachment 1.

3.4.3.4.2 Chemical Intake

The following equation is used for calculating chemical intake via ingestion of contaminated produce:

$$Intake\ (mg/kg\text{-}day) = \frac{C_i \times IR_p \times F_{HG} \times EF \times ED}{BW \times AF \times AD}\ , \qquad (3.16)$$

where

C_i = concentration of chemical i in produce (milligrams per kilogram), based on soil exposure concentration (Section 3.3.2.1.4),

IR_p = produce ingestion rate (kilograms per day),

FI_{HG} = fraction ingested produce that is grown on or collected from the contaminated area (Section 3.4.2.6) (unitless),

EF = exposure frequency (days per year),

ED = exposure duration (years),

BW = body weight (kilograms),

AF = averaging frequency (365 days/yr), and

AD = averaging duration [years (equal to ED for noncarcinogens and 70 yr for carcinogens)].

This equation is used for the current and future resident and future camper scenarios.

3.4.3.5 External Gamma Exposure

If direct measurements of the external radiation exposure levels from contaminated soil are available, the dose to current receptors may be estimated as follows:

$$D_x = EL \times CF \times [(ET_i \times SF) + ET_o] \times EF \times ED, \tag{3.17}$$

where

D_x= dose from external gamma radiation (millirems),

EL = outdoor exposure level at 1 m above ground averaged over the exposure unit (milliroentgens per hour),

CF = conversion factor (a function of the average gamma-ray energy) (millirems per hour per milliroentgens per hour),

ET = exposure time, ET_i, for indoor occupancy, ET_o for outdoor occupancy (hours per day)

SF = shielding factor for indoor occupancy: 0.7,

EF = exposure frequency (days/year), and

ED = exposure duration (years).

The RESRAD computer code (Attachment 1) may be used to calculate the external gamma dose if direct measurements are not available.

3.4.3.6 Inhalation of Radon

The working-level month (WLM) is the unit of exposure used to calculate doses from direct measurement of radon (Section 3.3.2.1.6). It is defined as the exposure to 1 WL for 170 hr (2,000 working hours per year). The WLM was used historically to report exposures to uranium miners. An exposure to 1 WLM of ^{222}Rn and ^{220}Rn decay products is equal to a committed effective dose equivalent of 1,000 mrem and 350 mrem, respectively (ICRP 1981, 1000). The ratio of inhalation rates for various scenarios (e.g., long-term worker or resident versus uranium miner) must be applied to correct for the implicit assumptions upon which the WLM is based.

The equation used to calculate dose from directly measured radon is

$$WLM = \frac{C_{Rn} \times IR \times ET \times EF \times ED}{CF}, \tag{3.18}$$

where

WLM	=	working-level month,
C_{Rn}	=	indoor or outdoor air concentration of ^{222}Rn and ^{220}Rn decay products (WL),
IR	=	inhalation rate (cubic meters per hour),
ET	=	exposure time (hours per day),
EF	=	exposure frequency (days per year),
ED	=	exposure duration (years), and
CF	=	conversion factor [204 m^3/mo (CF is the product of the inhalation rate assumed for uranium miners (1.2 m^3/h) and the number of working hours in 1 mo (170 h/mo)]

To estimate the dose from radon and radon decay products based on soil contaminant levels, the RESRAD code can be used (Attachment 1).

3.4.4 Equations for Exposure to Groundwater or Surface Water

This section describes the methodology for estimating chemical intakes and radiological doses for exposures based on concentrations in water. The following exposure routes are addressed: ingestion of groundwater or surface water, dermal absorption from groundwater or surface water, and inhalation from household use of groundwater. The equations presented are based on equations given in EPA's *Human Health Evaluation Manual* (EPA 1989, 0305).

3.4.4.1 Groundwater or Surface Water Ingestion

Radionuclide doses and chemical intakes from ingestion of alluvial groundwater and surface water are calculated based on exposure concentrations in groundwater and surface water (Section 3.3.2.2.1). The youth recreational user, future camper, and the future resident in a canyon bottom are considered the relevant scenarios for this exposure pathway (however, the youth recreational user would not ingest groundwater). Scenario-specific assumptions on exposure time, frequency, and duration, and the assumed ingestion rate are given in Table 3-2.

3.4.4.1.1 Radiological Dose

The dose associated with intake of radioactive contaminants resulting from ingestion of groundwater or surface water can be calculated as follows:

$$D_{iw} = R_{iw} \times (IR_{gw} \text{ or } IR_{sw}) \times (EF \text{ or } EF_{sw}) \times ED \times DCF_i(Ing), \quad (3.19)$$

where

D_{iw}	=	dose from ingestion of radionuclide i in water (millirem),
R_{iw}	=	exposure concentration of radionuclide in groundwater or surface water (picocuries per liter) (Section 3.3.2.2.1),

IR_{gw}	=	groundwater ingestion rate (liters per day),
IR_{sw}	=	surface water ingestion rate (liters per day),
EF	=	exposure frequency (for groundwater in gestion) (days per year),
EF_{sw}	=	exposure frequency (for surface water in gestion) (days per year),
ED	=	exposure duration (years), and
DCF_i(Ing)	=	dose conversion factor for ingestion of adionuclide i (millirems per picocurie).

3.4.4.1.2 Chemical Intake

The following equation is used for calculating chemical intake via ingestion of groundwater or surface water:

$$Intake\ (mg/kg\text{-}day) = \frac{C_i \times (IR_{gw}\ or\ IR_{sw}) \times (EF \times EF_{sw}) \times ED}{BW \times AF \times AD}\ , \quad (3.20)$$

where

C_i	=	exposure concentration of chemical in groundwater or surface water, (milligram per liter) (Section 3.3.2.2.1),
IR_{gw}	=	groundwater ingestion rate (liters per day),
IR_{sw}	=	surface water ingestion rate (liters per day),
EF	=	exposure frequency (for groundwater ingestion) (days per year),
EF_{sw}	=	exposure frequency (for surface water in gestion) (days per year),
ED	=	exposure duration (years),
BW	=	body weight (kilograms),
AF	=	averaging frequency (365 d/yr), and
AD	=	averaging duration [years (equal to ED for noncarcinogens and 70 yr for carcinogens)].

Because chemical intakes for carcinogenic risk calculations are averaged over a lifetime of 70 years, the intakes calculated for use in carcinogenic risk estimates differ

somewhat from those calculated for noncarcinogenic endpoint estimations.

3.4.4.2 Dermal Absorption from Groundwater or Surface Water

Dose estimates and chemical intakes for the dermal exposure pathway are calculated using the exposure concentrations in groundwater or surface water (Section 3.3.2.1.2). Scenario-specific assumptions on the dermal exposure factors (exposure time, frequency, duration, and skin surface area) are given in Table 3-2.

3.4.4.2.1 Radiological Dose

Only dermal absorption of tritium is evaluated (Section 3.3.2.1.2). Dermal absorption of tritium has been investigated for both air and water immersion. According to (Pinson and Langham 1957, 1008), the absorption rate of water vapor by skin is approximately 0.014 L/h (24°C, 100% humidity). Dermal absorption when skin is immersed in water that is the same temperature as the skin is estimated to be 2.5 times faster (0.035 L/h). These estimates are based on a total skin surface area of 1.9 m^2 and should be reduced in cases where only partial contact with the skin occurs (e.g., wading). The tritium uptake rate is simply the concentration of tritium per liter of water times the water absorption rate, as shown in the following equation:

$$D_{H-3} = C_{H-3} \times U \times (SA_{gw} \text{ or } SA_{sw}) \times (ET \text{ or } ET_{sw}) \times (EF \text{ or } EF_{sw}) \times ED \times DCF_{H-3}, \quad (3.21)$$

where

D_{H-3}	=	dose from dermal absorption of tritium (millirems),
C_{H-3}	=	exposure concentration of tritium in water (picocuries per kilogram),
U	=	dermal absorption rate from submersion in water (1.8×10^{-6} L/h-cm^2),
SA_{gw}	=	skin surface area available for groundwater contact (square centimeters),
SA_{sw}	=	skin surface area available for surface water contact (square centimeters),
ET	=	exposure time (for groundwater contact) (hours per day),
ET_{sw}	=	exposure time (for surface water contact) (hours per day),
EF	=	exposure frequency (for groundwater con tact) (days per year),
EF_{sw}	=	exposure frequency (for surface water contact) (days per year),

ED	=	exposure duration (years), and
DCF_{H-3}	=	dose conversion factor for tritium uptake (6.3×10^{-8} mrem/pCi).

3.4.4.2.2 Chemical Intake

The following equation is used to estimate the dermal absorption of inorganic chemicals from groundwater or surface water:

$$Intake\,(mg/kg\text{-}day) = \frac{C_i \times CF \times K_p \times (ET_{gw}\ or\ ET_{sw}) \times EV \times (EF \times EF_{sw}) \times ED \times (SA_{gw}\ or\ SA_{sw})}{BW \times AF \times AD}, \quad (3.22)$$

where

C_i	=	exposure concentration of chemical, i, in water (milligrams per liter),
CF	=	conversion factor: 10^{-3} L/cm^3,
K_p	=	permeability coefficient, chemical-specific (centimeters per hour),
ET_{gw}	=	dermal contact time for exposure to ground water (hours per event),
ET_{sw}	=	dermal contact time for exposure to surface water (hours per event),
EV	=	event frequency [events per day (equal to 1 event/day for youth recreational user, future resident, and future camper scenarios),
EF	=	exposure frequency (days per year),
EF_{sw}	=	exposure frequency (for surface water contact) (days per year),
ED	=	exposure duration (years),
SA_{gw}	=	skin surface area available for contact with groundwater (square centimeters),
SA_{sw}	=	skin surface area available for contact with surface water, (square centimeters),
BW	=	body weight (kilograms),
AF	=	averaging frequency: 365 d/yr, and
AD	=	averaging duration [years (equal to ED for noncarcinogens and 70 yr for carcinogens)].

The above equation applies to the youth recreational user, future camper, and future canyon bottom resident scenarios and assumes an absorbed dose that occurs during water contact events (i.e., wading and bathing). This equation is recommended for evaluating inorganic contaminants using the traditional steady-state approach for estimating the dermally absorbed dose from water. Chemical-specific permeability coefficients for selected inorganics are summarized by EPA (1992, 1012); for other inorganics, the default assumption of 10^{-3} cm/h is used.

For organics, EPA is cautiously recommending a newer, non-steady-state approach EPA (1992, 1012). The agency feels that the model more accurately reflects normal human exposure conditions and that it accounts for the dose that may occur after the actual exposure event resulting from absorption of contaminants in skin lipids. However, it appears that the model may be overly conservative, and it is difficult to validate because data are lacking. Alternatively, the steady-state equation (3.23) may be used for organics by using permeability coefficients obtained from EPA (1992, 1012) in which experimentally measured or calculated values (i.e., based on octanol/water partition coefficients) are summarized for over 150 common organic compounds.

3.4.4.3 Inhalation from Household Use of Groundwater

Section 3.3.2.3 provides a discussion of this pathway.

3.4.5 Assessment of Exposure to Contaminated Building Surfaces

Radiation doses to current and future long-term workers resulting from contaminated building surfaces may be estimated using National Research Council methodology for dose assessments from residual radioactive contamination from decommissioning (Kennedy and Strenge 1993, 1002). That document provides detailed equations for estimating the dose to workers from external gamma radiation from contaminated surfaces, from inhalation of suspended surface contamination, and from inadvertent ingestion of surface contamination.

Section 3.3.2.3 provides a discussion of the evaluation of building surfaces contaminated with chemical substances.

4.0 TOXICITY ASSESSMENT

The toxicity assessment involves gathering information on potential health effects and/or toxicological properties of the chemicals of concern for subsequent comparison with estimated intake levels. Both noncarcinogenic and carcinogenic effects are considered in the toxicity assessment.

4.1 Types of Toxicological Information Considered in the Toxicity Assessment

In collecting toxicity information (much of this information will have been collected in the screening assessment phase but may need to be updated), the hierarchy established by Superfund guidance for the appropriate sources of toxicity values will be followed. The first choice for information is the Integrated Risk Information System (IRIS) (EPA 1993, 1062), which is a data base maintained by the EPA that contains the most up-to-date toxicity information and regulatory values for a number

of chemicals. If the chemical of potential concern is not in IRIS, the Health Effects Assessment Summary Tables (HEAST) (EPA 1992, 0833) will be consulted. These tables are not as current as IRIS; however, unlike IRIS, they contain interim as well as verified health-based values. If values are not available in IRIS or HEAST, toxicity values will be derived from alternate sources such as regulatory levels (e.g., MCL in drinking water or comparative potency factors for PAHs). The basis and confidence for all toxicity values will be provided.

The outcome of this analysis will be a table of toxicity values for the chemicals of potential concern. Available toxicity information will be reviewed and summarized for each chemical of potential concern. This information will focus on health effects (both noncarcinogenic and carcinogenic) from chronic and/or subchronic exposure because these time spans are typically the exposure durations of concern when estimating human health risk. However, acute toxicity will also be considered. A chronic toxicity table will follow the table of toxicity values in the text to summarize critical effects and target organs associated with each chemical.

4.2 Toxicity Assessment for Noncarcinogenic Effects

The goal of this step is to identify reference doses (RfDs) for the various compounds. The RfDs, established by the EPA, are estimates of the daily exposure to the human population below which exposure is not likely to incur appreciable risk of noncarcinogenic deleterious effects during a lifetime. Reference concentrations are analogous to RfDs and are typically used to evaluate toxicity resulting from exposure via inhalation. These values are converted to a daily inhalation dose, an inhalation RfD. The RfD and/or reference concentration are used to evaluate the potential for noncarcinogenic health effects from a particular chemical.

4.3 Toxicity Assessment for Carcinogenic Effects

4.3.1 Nonradiological Contaminants

The cancer slope factor is an upper-bound estimate of cancer risk associated with exposure to a particular chemical and is used to estimate the lifetime excess cancer risk associated with the estimated chemical intake for that chemical. The EPA 's weight-of-evidence classification will be provided to indicate the confidence in the evidence used to classify a chemical as a carcinogen. The EPA classifies chemicals in Groups A, B1, B2, C, D, and E. Group A chemicals are those chemicals considered to be human carcinogens because sufficient evidence has been obtained to demonstrate carcinogenicity in humans. Group B chemicals are probable human carcinogens. A classification of B1 indicates limited evidence of carcinogenicity in humans, and B2 indicates demonstrated evidence of carcinogenicity in animals with inadequate or lack of evidence in humans. Group C suggests only the possibility of human carcinogenicity because evidence of carcinogenicity in animals is limited and data on humans are inadequate or lacking. Group D compounds are not classifiable as to human carcinogenicity because of inadequate or no evidence, and Group E chemicals show evidence of noncarcinogenicity. The cancer slope factors are used to estimate the excess cancer risk associated with exposure to potential carcinogens.

4.3.2 Radiological Contaminants

The toxic effects of radiological contaminants are distinctly different from those of nonradiological contaminants. Therefore, a separate section will be included in the analysis to discuss the chronic toxicity of radionuclides. It is recognized that

exposure to radionuclides can have several health effects, such as teratogenesis and mutagenisis; however, carcinogenecity will be the focus of toxicity assessment and risk characterization because it is the principal adverse biological effect following chronic exposure and is well documented.

4.4 Identifying Appropriate Toxicity Values for Risk Assessment

RfDs and cancer slope factors are EPA's preferred toxicity values; therefore, when available, they will be used for the quantitative portion of the toxicity assessment. Alternate sources will be used (also when available) for those compounds that do not have published toxicity values, and toxicity values will be derived from these data, if possible. Additional information may include controlled epidemiologic investigations, clinical studies, and experimental animal studies. A toxicologist will review this information and, if it is determined that the information is adequate to establish a valid toxicity value, the toxicologist will derive a toxicity value.

4.5 Uncertainties Related to Toxicity Information

For those compounds that have established RfDs, the confidence in the RfD and the data base of toxicological information will be provided. The weight of evidence for the carcinogenic potential of compounds will also be discussed. Uncertainty is increased when alternate means are used to derive toxicity values. The uncertainty generated from the various methods used to estimate toxicity values will be examined. When no toxicity information is available, the limitations and impact inherent to excluding contaminants of concern can be great. The cumulative consequences of uncertainty from the different sources of toxicity information (or lack thereof) will be described and quantified to the extent possible.

5.0 RISK CHARACTERIZATION

5.1 Quantifying Risks

Risk characterization involves integrating the exposure and toxicity assessments in quantitative and qualitative expressions of potential health risk. The data from the initial tasks are reviewed, and the carcinogenic and noncarcinogenic risks are quantified for individual and multiple chemicals.

To characterize potential noncarcinogenic effects, chemical intakes and toxicity values are compared. The hazard quotient is the ratio of a chemical exposure level over a specified amount of time to an RfD for that chemical. The hazard quotient is not a statistical probability that a noncarcinogenic effect will occur but is rather a comparison of the exposure level and the appropriate toxicity value. The hazard quotients for several chemicals are summed for a particular pathway to yield a hazard index for that pathway. All hazard indices in an exposure scenario will be totaled. Hazard indices are not mathematical probabilities of the incidence or severity of an adverse health effect but a numerical index of a recommended safety threshold. A hazard index or hazard quotient greater than 1 indicates a potential health risk. If a hazard index exceeds 1, the hazard index is segregated by target organ on a chemical-by-chemical basis. A hazard index of less than 1 suggests that site-related contaminants are not likely to present a health risk under the given exposure scenario.

Carcinogenic risk is characterized by estimating the probability that an individual will develop cancer over a lifetime as a result of exposure to a potential carcinogen. The

probability of developing cancer is estimated by multiplying the cancer slope factor by the calculated intake. The carcinogenic risk estimate is generally an upper-bound estimate of risk, which means that the "true risk" probably does not exceed the risk estimates generated for the assessment and is likely to be less than the predicted risk. Again, risk is summed by chemical and pathway to determine the scenario cancer risk.

Exposure to radiological contaminants of concern are calculated by using the RESRAD computer code, which generates annual doses for potential receptors. The dose estimates are compared with the DOE's dose limit of 25 mrem/yr, which is based on exposure to an individual from a single site. This dose estimate is not combined with nonradiological risk. The contribution to adverse carcinogenic health effects from exposure to radionuclides will be discussed in the risk assessment in conjunction with carcinogenic risk from nonradiological constituents.

5.2 Combining Risk Across Exposure Pathways

The resulting carcinogenic and noncarcinogenic risks are added across exposure pathways in an exposure scenario. Additionally, combined impacts from multiple exposure scenarios are assessed if exposure to more than one scenario is possible (e.g., a child exposed in both recreational and residential scenarios).

5.3 Assessing and Presenting Uncertainty

The risk assessment will also discuss the uncertainties inherently associated with all components of the risk assessment process. The uncertainty analysis will highlight the areas in which assumptions were incorporated because sufficient data were not available to accurately characterize the risks associated with a particular exposure. The implication of these uncertainties on the overall risk results will be discussed fully. Whenever possible, uncertainty analysis will include a quantitative evaluation. The general approach, when it is necessary to make assumptions about the frequency or magnitude of exposures, will be to use conservative assumptions that are likely to overestimate risk.

5.4 Summarizing and Presenting the Results of Baseline Risk Characterization

Once the carcinogenic and noncarcinogenic risks have been assessed for a site, a determination will be made of which contaminants, media, and pathways present the greatest risks for each scenario. The conclusions will be summarized in the text, and the risk values will be in tabular form.

ATTACHMENT 1

Methods for Using RESRAD in ER Program Risk Assessments

DOE Order 5400.5 (DOE 1988, 0266) requires that the methodology incorporated in the RESRAD computer code (Gilbert 1987, 0312; Yu et al. 1993, 1014) be used to establish soil cleanup guidelines for radionuclide contamination at DOE sites. With some minor modifications of input data and output results, which are outlined in this attachment, the RESRAD code can also be used in implementing the proposed risk assessment methodology for soil contaminated with radionuclides. The use of a computer code, such as RESRAD, carries the additional advantage of minimizing data input and calculational errors.

RESRAD is a pathway analysis code that calculates radiation doses to an onsite individual from chronic exposure to soil contaminated with radionuclides. The RESRAD code allows the user to define up to nine pathways and three exposure routes: external gamma dose from radionuclides in soil; inhalation dose from contaminated dust and radon gas; and ingestion dose from intake of contaminated plants, meat, milk, aquatic foods, water, and soil. A variety of scenarios, including residential, industrial, and recreational, can be modeled by adding or suppressing pathways and entering appropriate values for occupancy and consumption rates.

The following exposure pathways will be considered:

- external exposure from gamma-emitting radionuclides in soil,
- inhalation of airborne particulates originating from contaminated soil,
- inhalation of radon progeny caused by radon emanations from soil contaminated with radon precursors,
- ingestion of contaminated soil, and
- ingestion of produce grown on contaminated soil.

In the discussion that follows, it is assumed that the reader is familiar with the operation of the RESRAD code (i.e., is experienced in entering data, running the code, and obtaining results) or has access to the user's guide.

To provide conservative results that are compatible with the calculations performed for chemicals, leaching of radionuclides from the contaminated zone is neglected for all pathways, which also has the effect of suppressing the water-dependent pathways. To set the leach rate to 0, the distribution coefficients for the radionuclides in the contaminated zone should all be set to a very large number (e.g., 106). This way, only the radioactive decay is taken into consideration. Also, the erosion rate of the contaminated zone should be set to 0.

The RESRAD code calculates doses on an annual basis. The maximum dose from most radionuclides occurs at time 0. However, for some radionuclides, the ingrowth of decay products may result in higher dose rates at a later time. To obtain a conservative total dose estimate, the maximum annual dose calculated for each radionuclide should be multiplied by the exposure duration (in years). However, for radionuclides such as ^{60}Co whose half-lives are short relative to the exposure duration, the user may choose to have the code calculate doses at regular intervals

throughout the period of exposure. For example, if the exposure duration is 30 yr, the user could have the code calculate doses at 3-yr intervals (t=0, 3, 6, ..., 27 yr). The resulting annual doses are then summed and multiplied by 3 to obtain the total dose received during the exposure period.

With the exception of the external exposure pathway and the plant ingestion pathway, the concentrations entered in the code should cover the entire exposure unit area. The appropriate depth of the contamination should be entered as input to the code (e.g., 0.15 m for surface soil contamination). When exposure to future receptors from subsurface contamination is evaluated, a zone of surface contamination is created by assuming that the contaminated subsurface soil is excavated and distributed over the exposure unit area. The average depth of the contaminated layer to be entered in the code is calculated by dividing the volume of the excavated soil by the exposure unit area. If this thickness exceeds 0.15 m, the latter should be entered.

For external exposure and plant ingestion pathways, the contaminant concentrations entered in the code should be derived from measurements taken over the area of contamination rather than the exposure unit area.

The RESRAD code calculates area factors that are used to take into account uncontaminated areas when the contaminated zone is small relative to the size of the exposure unit. However, RESRAD does not allow the user to change the size of the exposure unit parameter. For all pathways except external exposure, it is recommended that the area of the contaminated zone be set to the RESRAD default of 10,000 m^2, which results in an area factor of 1 calculated by the code. Because the concentrations entered in the code are averaged over the exposure unit area, no further adjustment may be needed for certain pathways.

Exposure to External Radiation

The RESRAD computer code allows the user to estimate the exposure from gamma-emitting radionuclides in soil. A conservative assumption made in the RESRAD code is that the receptor is located roughly at the center of a homogeneously contaminated area. Because the dose contributions from external gamma exposure are not a linear function of area size, the exposure unit area concept is not valid for this pathway. The RESRAD code adjusts the dose automatically as a function of area size. Therefore, the user should enter the concentrations of contaminants that are present in the area of contamination rather than dilute the concentrations over the receptor-specific exposure unit.

The following parameters are important in calculating the external dose:

- area, thickness, and bulk density of soil in the contaminated zone;
- thickness and soil density of the cover (for subsurface contamination);
- fraction of time during the year that the receptor spends outdoors, indoors, and away from the contaminated area; and
- shielding from external gamma radiation afforded by buildings during indoor occupancy.

Adjusting the dose to reflect the shape of the contaminated zone is recommended only when the contaminated area is less than 1,200 m^2 and when the shape deviates considerably from that of a circular area. Appendix A of the RESRAD manual provides instructions on how to calculate the shape factor for a noncircular contaminated area.

In the case of subsurface contamination, two cases may be run. To assess current exposures, the exposure scenario is modeled by entering the thickness and density of the material covering the subsurface contamination. For future exposures, the contaminated soil is assumed to be redistributed over an area encompassing the exposure unit. In this case, no cover is assumed to be present, and the average thickness of the contaminated zone covering the exposure unit area will be equal to the excavated volume divided by the exposure unit area or 15 cm, whichever is smaller.

The fraction of time spent indoors or outdoors entered in the RESRAD code is calculated based on annual averages. These fractions can be calculated as follows:

$$f_i = \frac{ET_i \times EF}{8766}$$

$$f_o = \frac{ET_o \times EF}{8766}$$

where

f_i	=	fraction of year spent indoors (dimension less),
f_o	=	fraction of year spent outdoors (dimen sionless)
ET_i	=	exposure time indoors (hours per day),
ET_o	=	exposure time outdoors (hours per day),
EF	=	exposure frequency (days per year), and
8,766	=	number of hours in a year (hours per year).

The RESRAD default value for the shielding factor during indoor occupancy is 0.7 (i.e., indoor exposure levels are 30% lower than outdoor levels).

Inhalation of Contaminated Dust

The RESRAD code uses a mass-loading model to estimate the concentration of contaminants in air resulting from resuspension of contaminated soil. The mass-loading model assumes that the contaminant concentration in airborne dust is the same as the concentration in soil adjusted for the presence of a ground cover (e.g., grass, pavement), depth of the contaminated soil, and area size.
The following parameters are important in calculating the dust inhalation dose:

- inhalation rate;
- mass loading of respirable particulates;
- fraction of time during the year that the receptor spends outdoors, indoors, and away from the contaminated area;
- reduction in outdoor dust levels afforded by buildings during indoor occupancy;
- thickness of soil in the contaminated zone; and
- thickness of the cover (for subsurface contamination).

Inhalation rates entered in RESRAD must be converted to units of cubic meters per year. If separate inhalation rates are given for outdoor and indoor activities, a time-weighted average inhalation rate should be entered. (Time spent away from the contaminated area should not be included in the time-weighted average.) In obtaining this average, any reductions in the dust levels during indoor occupancy must also be considered. The following equation should be used to derive the time-weighted indoor/outdoor inhalation rate:

$$IR = EF_x \frac{(0.4 \times ETi \times IR_i) + (ET_o \times IR_o)}{(0.4 \times ET_i) + ET_o}$$

where

IR	=	weighted average annual inhalation rate (cubic meters per year),
EF	=	exposure frequency (days per year),
0.4	=	reduction factor for indoor dust that is of outdoor origin (dimensionless),
ET_i	=	exposure time indoors (hours per day),
IR_i	=	indoor inhalation rate (cubic meters per hour),
ET_o	=	exposure time outdoors (hours per day),
IR_o	=	outdoor inhalation rate (cubic meters per hour).

Time fractions spent indoors and outdoors are calculated in the same way as that for the external exposure pathway.

A cover and depth factor calculated by RESRAD accounts for mixing of contaminated soil that may occur with underlying or overlying uncontaminated soil. If no cover is present and the contaminated layer is thicker than the mixing depth (set to 1 cm for the inhalation pathway, assuming no gardening), the cover and depth factor calculated by the code is 1 (i.e., no dilution). This will be the case for most surface contamination scenarios. If subsurface contamination is present and is assumed to be redistributed over the exposure unit area, RESRAD calculates a cover and depth factor less than 1 if the thickness of contaminated soil, averaged over the entire

exposure unit area, is less than 1 cm.

In RESRAD, the area of the contaminated site and a dilution length are used to calculate an area factor that accounts for dilution from uncontaminated sources. This area factor is calculated as

$$FA = A^{1/2}/(A^{1/2} + DL)$$

where

FA	=	area factor for inhalation pathway,
A	=	area of contaminated zone (square meters), and
DL	=	dilution length (meters).

Conservative results that neglect dilution with uncontaminated dust from outside the exposure unit can be obtained by forcing the area factor to equal 1, which is accomplished by setting the value of DL to 0.

Inhalation of Radon

The RESRAD code allows the user to estimate the dose to an onsite receptor resulting from inhalation of ^{222}Rn and ^{220}Rn (and their short-lived progeny) emanating from soil contaminated with radionuclides in the natural uranium and thorium decay series. Except for the mass-loading factor and the dust reduction factor for indoor occupancy, the same parameters that are important in the dust inhalation pathway are also important in the radon inhalation pathway. In addition, the following parameters are also important.

- density and porosity of cover and contaminated soil;
- density, thickness, and porosity of building foundation;
- diffusion coefficient or volumetric water content in cover, contaminated soil and foundation;
- building height and air exchange rate;
- average annual wind speed; and
- radon emanation fraction.

In the absence of site-specific data for the above parameters, the RESRAD defaults may be used because they are representative of national average values.
For combinations of indoor and outdoor occupancy, the time-weighted average inhalation rate is calculated in the same way as for the dust inhalation pathway, except that the dust reduction factor for indoor occupancy is set to 1 rather than to 0.4 (i.e., no reduction).

The maximum radon dose may not occur at time 0 unless only the immediate precursors are present in the soil. Instead, the radon dose may increase over time as the result of ingrowth of radionuclides in the uranium or thorium decay series.

Ingestion of Contaminated Soil

Doses from soil ingestion can be calculated using the RESRAD code. In the RESRAD model, the cover and depth factor derived for the inhalation models also

applies to the soil ingestion model. However, RESRAD uses an area factor that is set to 1 if the contaminated area is greater than or equal to 1,000 m^2; otherwise it is the area divided by 1,000 m^2. Because the concentrations used in the RESRAD input will have already been adjusted for the appropriate exposure unit, an area of 1,000 m^2 or greater should be entered. Other important parameters include the soil ingestion rate and the fraction of time during the year that the receptor spends outdoors, indoors, and away from the contaminated area.

Because RESRAD allows the input of a single soil ingestion rate, an age-weighted average value is required to account for increased intakes during childhood years:

$$IR = 10^{-3} \times EF \times \frac{(IRc \times ED_c) + (IR_a \times ED_a)}{ED_c + ED_a}$$

where

IR	=	age-weighted average soil ingestion rate (grams per year),
10^{-3}	=	conversion factor (grams per year),
EF	=	exposure frequency (days per year),
IR_c	=	child soil intake rate (milligrams per year),
IR_a	=	adult soil intake rate (milligrams per year),
ED_c	=	child exposure duration (years), and
ED_a	=	adult exposure duration (years).

Because the intake rate calculated above already factors in the exposure frequency, no correction is required for time spent inside, outdoors, or offsite. To prevent RESRAD from further correcting the soil intake rate, the parameter for time fraction outdoors onsite should be set to 1 (the time fraction indoors should be set to 0).

For workers that spend all their time indoors, the intake rate in milligrams per day should be multiplied by the exposure frequency in days per year and converted to grams per year. The RESRAD code automatically reduces the result by a factor of 0.4 (using the shielding factor for inhalation) to account for the fraction of soil ingested that originates outdoors. In this case, the fraction of time spent indoors should be set to 1 (the time fraction spent outdoors should be set to 0).
For a combination of outdoor and indoor activities, the time fractions are calculated as

$$f_i = \frac{ET_i}{ET_i \times ET_o}, \text{ and}$$

$$fo = 1 - f_i,$$

where the above parameters have been previously defined.

Ingestion of Contaminated Produce

The RESRAD code can be used to estimate the radiation dose from ingestion of produce grown on contaminated soil. The model used in RESRAD accounts for the transfer of radionuclides in plants resulting from root uptake and foliar deposition. The contribution from contaminated irrigation water is set to 0, explicitly by setting the irrigation rate to 0 or implicitly by setting the radionuclide distribution coefficients in soil to a very large number (thus suppressing groundwater transport).

Because a relatively small area is required to grow produce for personal consumption, the exposure unit concept does not apply to the plant ingestion pathway. Concentrations entered in the code should be derived from the actual area of contamination. To prevent the RESRAD code from applying an area correction factor for small areas, the area of contamination should be entered as 1,000 m^2 or larger.

Other parameters in RESRAD important in calculating doses from ingestion of produce are

- produce consumption rates (leafy vegetables and other vegetables, fruit, and grain);
- soil-to-plant contaminant transfer factors (for root uptake);
- depth of plant roots;
- soil mixing layer; and
- mass loading of dust in air (for foliar deposition).

The ingestion rates entered in the code should be the annual average consumption of produce assumed to be grown or picked onsite and should not include any imported produce. Although it does not make a difference in the calculations which category of produce is selected (leafy vegetables or other vegetables, fruits, and grains), it is recommended that the consumption rate of leafy vegetables be set to 0.

The RESRAD code uses a mass-loading parameter for foliar deposition of resuspended contaminants that is not consistent with the approach presented in Section 3.3.2.1.4. This parameter should be set to 0 in the code input. To account for the differential transfer of contaminants through root uptake or foliar deposition, the transfer factor libraries should be modified using the following procedure.
In Section 3.3.2.1.4, a methodology is developed to account for the presence of surface and/or subsurface zones of contamination, each with potentially different concentrations of contaminants. Contaminants transferred to plants through foliar deposition originate from the surface layer of soil, whereas the contaminants transferred to plants through root uptake may originate from surface as well as from subsurface layers, depending on root depth.

Two separate runs are required to calculate the transfer of contaminants from soil to roots and from soil to leaves. In each run, the concentrations entered in the code are as follows:

- for root uptake, the concentrations may be entered either as the weighted average concentrations over the length of the roots (setting the thickness of the contaminated zone equal to the root depth) or as the surface concentrations if no subsurface contamination is present (setting the thickness of the contaminated zone to 15 cm) and

- for foliar deposition, the concentrations in the topmost 15 cm of soil should be entered.

For root uptake, the RESRAD default parameters for root uptake transfer factors may be used, or they may be changed to site-specific values if such data are available. For foliar deposition, values for a mass-loading transfer factor may be obtained for different types of vegetation from NUREG/CR-5512; these are not contaminant-specific but differ according to plant type. Before using them in RESRAD, these mass-loading transfer factors must be converted from a dry-plant- weight basis to a wet-weight basis using conversion factors provided in NUREG/CR-5512.

The dose contributions from the root uptake and foliar deposition runs are summed to obtain the total dose from ingestion of produce. However, RESRAD automatically assumes that only half of the produce ingested is grown onsite. Therefore, this total dose must be multiplied by a factor of 2.

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■ APPENDIX L

Ecological Risk Assessment and Natural Resource Damage Assessment

1.0 INTRODUCTION

This appendix outlines the integrated approach to ecological risk assessment and natural resource damage assessment (NRDA) used by the Environmental Restoration (ER) Program at Los Alamos National Laboratory (the Laboratory). This approach is under development, and more specific guidance will appear in the 1994 Installation Work Plan (IWP).

Ecological risk assessment quantifies the risk posed to nonhuman biological systems by releases of hazardous materials and remedial alternatives used to mitigate these releases (DOE 1979, 0051). An ecological risk assessment may be performed as a part of the baseline risk assessment in the Resource Conservation and Recovery Act (RCRA) field investigation (RFI) and may also be considered when comparing remedial alternatives during corrective measures studies (CMS). NRDA is a requirement of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and its purpose is to determine whether natural resources have been injured by the release of hazardous materials, and, if so, to quantify the associated economic loss resulting from those injuries (Department of the Interior 1991, 1018). NRDA is the responsibility of natural resource trustees (usually a federal agency such as the National Park Service or Fish and Wildlife Service). The Department of Energy (DOE) is the primary federal trustee for the Laboratory. Under NRDA regulations, DOE is responsible for coordinating a preassessment screening to determine whether natural resources have been damaged. Although the ER Program is operating under RCRA, not CERCLA regulations, DOE has opted to maintain consistency with CERCLA, and the ER Program at the Laboratory will provide information and resources to support NRDA preassessment screening.

It is important to stress that NRDA and ecological risk assessment are separate regulatory requirements. However, the integrated approach being developed by the ER Program is designed to facilitate the efficient use of resources while maintaining the desired confidence in the results of site characterization and the selection of remedial alternatives. Both ecological risk assessment and NRDA will take on increasing importance to decision making as the corrective action process approaches the remediation stage. The ER Program plans to integrate the data needs of NRDA preassessment screening with data collection for ecological risk assessment. Some natural resources (e.g., minerals) that are not related to biota will have to be handled separately if measurable damages to these resources could occur. The ER Program has started a biological monitoring program that will assist in developing ecological risk models and provide reference data for NRDA. These data will supplement the biological data collected to fulfill other regulatory requirements, which include the National Environmental Policy Act (NEPA), the Endangered Species Act, and the New Mexico Wildlife Conservation Act.

1.1 Integration of the Regulatory Framework under CERCLA, RCRA, and NRDA Regulations

RCRA addresses releases of specific "hazardous wastes" and "hazardous waste constituents" (as defined in RCRA Section 3001 and 40 CFR 261.3), which, by definition, are also defined as "hazardous substances" under CERCLA (Section 101[14]). However, many of the substances addressed under CERCLA are not regulated under RCRA. Because human health and environmental concerns for materials regulated by CERCLA and RCRA cannot be separated, the ER Program

at the Laboratory has developed an approach that addresses releases of hazardous substances not regulated under RCRA in the corrective action program required by the Hazardous and Solid Waste Amendments (HSWA) Module of the Laboratory's permit to operate under RCRA (Chapter 1). It is the stated policy of DOE and the ER Program (Annex I, Section 1.2) that all corrective measures implemented at the Laboratory comply specifically with RCRA regulations and the HSWA Module and also with CERCLA, as appropriate.

CERCLA contains a requirement to perform a baseline risk assessment as part of the remedial investigation/feasibility study (RI/FS) process. The purpose of this baseline assessment is to characterize current and potential adverse impacts to human health and the environment in the absence of any remedial action. The National Oil and Hazardous Substances Pollution Contingency Plan (NCP)(Section 300.430) (EPA 1990, 0559) specifically states that the baseline risk assessment must evaluate current and future threats to human health and the environment that may arise from contaminants migrating in groundwater or surface water, releasing to the air, leaching through or remaining in soil, and bioaccumulating in the food chain.

The Environmental Protection Agency (EPA) (EPA 1989, 0988) has identified the need to perform an ecological assessment as part of the baseline risk assessment to evaluate actual and potential impact to ecological resources and has issued a number of guidance documents for conducting and integrating ecological risk assessments in the RI/FS process (EPA 1988, 0087; EPA 1989, 0988; EPA 1989, 0303). The EPA (EPA 1989, 0988) defines an ecological risk assessment as

> "...a qualitative and/or quantitative appraisal of the actual or potential effects of a hazardous waste site on plants and animals other than people and domesticated species."

Guidance for implementing RCRA [40 CFR 264.93 and 264.94, as interpreted by DOE (1979, 0051)] also identifies the need to conduct an ecological risk assessment, and EPA's RCRA guidance (EPA 1989, 0088) requires detailed environmental assessments to be performed, including biological and ecological resource monitoring.

Data collected and evaluated during an ecological risk assessment are similar to the data required in the NRDA process. Thus, the ecological assessment may be useful in performing portions of the NRDA process. Guidance on implementing NRDA (43 CFR 11.23[f][4]) allows the use of an ecological assessment as part of the preassessment screen. Specifically, the NRDA regulations state that

> "If the natural resource trustee already has a process similar to the preassessment screen, and the requirements of the preassessment screen can be satisfied by that process, the processes may be combined to avoid duplication."

DOE guidance also advocates that CERCLA or RCRA ecological risk assessment be part of the preassessment screen performed to comply with the NRDA regulations to avoid duplication (DOE 1991, 0560).

2.0 NATURAL RESOURCE DAMAGE ASSESSMENT

2.1 Natural Resource Trustees

Executive Order (EO) 12580 as interpreted by DOE (DOE 1992, 0964), CERCLA (Section 107[f]), and Sections 300.600 and 300.615 of the NCP (EPA 1990, 0559) designate the Secretary of Energy as the primary federal natural resource trustee for natural resources that occur on, over, or under land administered by DOE. A trustee is any federal natural resource management agency so designated in the NCP (Section 300.600), any state agency designated by the governor (as allowed under CERCLA Section 107[f][2][B]), or any native American nation or tribe (NCP Section 300.610). DOE's Albuquerque Operations Office, with DOE Headquarters' oversight, will most likely carry out the responsibilities of trustee.

In addition to DOE, other authorities may serve as cotrustees for natural resources at the Laboratory, and some trustee other than DOE may have the primary stewardship for a particular resource. For example, DOE, the lead trustee, shares stewardship with the Department of Interior for any federally listed endangered species that may occur at the Laboratory.

The ER Program will identify all trustees of resources that occur within the boundaries of the Laboratory or who may be affected by releases from the Laboratory. Table L-1 provides a list of potential natural resource trustees who may become involved with the NRDA process at the Laboratory.

TABLE L-1

POTENTIAL NATURAL RESOURCE TRUSTEES

Trustee	Natural Resource
Department of the Interior	
Fish and Wildlife Service	Federally listed threatened and endangered species Federally designated critical habitats Migratory birds
National Park Service	Bandelier National Monument Archaeological resources Mineral resources
Department of Agriculture	
Forest Service	Santa Fe National Forest
Department of Defense	
Army Corps of Engineers	Cochiti Reservoir
State of New Mexico	State-listed biota and habitats Groundwater, surface water, and drinking water supplies Fish and game
Native American Tribes	Game and nongame fish and wildlife Groundwater, surface water, and drinking water supplies Archaeological sites Ancestral religious sites

The responsibilities of a natural resource trustee include assessing damages or injury to, destruction of, or loss of natural resources. Natural resources are defined by CERCLA (Section 101[16]) and the NCP (Section 300.5) as

> "... land, fish, wildlife, biota, air, water, groundwater, drinking water supplies, and other such resources belonging to, managed by, held in trust by, appertaining to, or otherwise controlled by the United States ... , any state or local government, any foreign government, any Indian Tribe, or, if such resources are subject to a trust restriction on alienation, any member of an Indian tribe."

Natural resources may also include the "supporting ecosystems" of biotic resources (NCP Section 300.600[b]).

2.2.1 Trustee Coordination

When a resource falls under the jurisdiction of more than one trustee, the NCP (Section 300.615[a]) directs the trustees to coordinate and cooperate in carrying out their responsibilities. Each trustee must designate a lead official. The NRDA regulations (43 CFR 11.14[w]) define the lead official as

> "...a Federal or State official authorized to act on behalf of all affected Federal or State agencies acting as trustees where there are multiple agencies, or an official designated by multiple tribes where there are multiple tribes, affected because of coexisting or contiguous natural resources or concurrent jurisdiction."

The lead official is responsible for presiding over and/or coordinating meetings and other communications among the multiple trustees. The lead official is designated by mutual agreement of all the natural resource trustees (43 CFR 11.32[a][1][ii][A]). After all natural resource trustees have been identified for the Laboratory, DOE will coordinate a trustees' meeting specifically to identify the lead authorized official for the Laboratory. In the event that the trustees cannot reach consensus regarding the designation of the lead authorized official, DOE's Albuquerque Operations Office/ Los Alamos Area Office will assume that role as permitted under NRDA regulations (43 CFR 11.32[a][1][ii][B]). The Secretaries of Commerce and Interior will be designated as trustees as indicated by their management or protection responsibilities.

2.3 The Natural Resource Damage Assessment Process

Under the provisions of CERCLA (§107[a][4][C]), DOE, as the party responsible for releases of hazardous materials from the Laboratory, may be liable for damages involving the injury, destruction, or loss of natural resources, including the costs of assessing such injury, destruction, or loss. Because the DOE is the responsible party, monetary claims (damages) may be brought against DOE by the other natural resource trustees. "Damage" is the amount of money sought by the natural resource trustee as compensation for injury to the natural resource.

An injury is defined (43 CFR 11.14[v]) as

> "...a measurable adverse change, either long- or short-term, in the chemical or physical quality or the viability of a natural resource resulting either directly or indirectly from exposure to a discharge of oil or release of a hazardous substance, or exposure to a product of reactions resulting from the discharge of oil or release of a hazardous substance. As used...injury encompasses the phrases 'injury,' 'destruction,' and 'loss.'"

Natural resource trustees use the NRDA process to evaluate injuries to natural resources and to determine the amount that may be sought in a natural resource damage claim. The NRDA process consists of three phases:

- the preassessment phase,
- the damage assessment phase, and
- the postassessment phase.

The preassessment phase includes notification of natural resource trustees of potential injuries to natural resources and requires coordination of all assessments, investigations, and planning to determine whether a NRDA should be performed.

A formal NRDA is performed only if the preassessment screen determines that a NRDA is necessary. The damage assessment phase identifies and quantifies injuries to natural resources. The dollar amount of any damage is also determined as part of the damage assessment phase. The final phase of the NRDA process, the postassessment phase, documents the results of the assessment and states how the damage claim will be paid. The formal NRDA process determines damages only for "residual injuries," which are those injuries that will not or cannot be addressed by response actions. Response actions include all environmental restoration activities conducted under CERCLA and RCRA.

In the event that preassessment screening indicates the need for a formal damage assessment, such an assessment will be performed not by the ER Program or DOE but by the other trustees. The ER Program and the lead trustee will cooperate with other appropriate trustees by providing information as requested.

2.4 Implementation of the NRDA Preassessment Screening Process

The ER Program is currently identifying its responsibilities in the NRDA preassessment process and is developing procedures for implementing the process at the Laboratory. The following sections provide an overview of preassessment screening and the ER Program's integrated approach. Future revisions of the IWP will describe the plans for implementing this process in greater detail.

2.4.1 The Preassessment Screen

The preassessment screen is used to determine whether to proceed with or to discontinue the NRDA process. This determination is made by evaluating the information collected for the preassessment screen against five decision criteria (43 CFR 11.23[e]):

- a release of a hazardous substance has occurred;
- natural resources for which a federal or state agency or native American tribe may assert trusteeship under CERCLA have been or are likely to have been adversely affected by the release;
- the quantity and concentration of the released hazardous substance is sufficient to potentially cause injury to those natural resources;
- sufficient data are available, or are likely to be obtained at reasonable cost, to pursue an assessment; and
- response actions, if any, carried out or planned do not or will not sufficiently remedy the injury to natural resources without further action.

TABLE L-2

COMPARISON OF THE ECOLOGICAL RISK ASSESSMENT PROCESS AND THE NRDA PREASSESSMENT SCREEN

Ecological Risk Assessment	NRDA Preassessment Screen
The ecological risk assessment provides a qualitative and/or quantitative appraisal of the actual or potential effects of a hazardous waste site on plants or animals other than people and domesticated species. The ecological risk assessment includes	The preassessment screen provides a rapid review of readily available information and allows for the determination of whether a natural resource has been adversely affected and whether to initiate a full NRDA. The preassessment screen includes
1. Identification of potential contaminants of concern, including the nature and extent of contamination and toxicological effects of contaminants.	1. A determination that a release of a hazardous substance has occurred. (Requires identification of potential contaminants of concern.)
2. Identification of exposure pathways. Baseline characterization of the physiochemical and biotic environments and identification of potentially exposed biotic receptors.	2. A determination that natural resources under the jurisdiction of a natural resource trusteeship have been or are likely to have been adversely affected by the release. (Requires identification of biotic and other natural resource receptors and of exposure pathways.)
3. Determination of contaminant fate and transport and identification of biotic receptors potentially affected by exposure to the contaminants of concern.	3. A determination that the quality and concentration of the released hazardous substance is sufficient to potentially cause injury to natural resources. (Requires identification of contaminant fate and transport, exposure pathways, and toxicological effects.)
4. The results of the ecological risk assessment will be used in the CMS to • evaluate corrective action alternatives • assess potential impacts to the environment from the construction implementation, and operation of corrective action alternatives.	4. A determination that corrective actions, if any, carried out or planned do not or will not sufficiently remedy the injury to the natural resource without further action. (Requires identification of baseline conditions and an evaluation of corrective action alternatives.)

Determination of injury is likely to be the most demanding criterion to evaluate. It is the intent of the ER Program to provide ecological risk assessment data to support evaluation of injury to biological resources. Table L-2 compares the general scope and outcome of ecological risk assessment with those of the NRDA preassessment screen.

After evaluating the five decision criteria against existing information and proposed remedial actions identified through the RCRA corrective action process at the Laboratory, the trustees will either terminate the NRDA process or will continue to a formal NRDA. If the preassessment screen indicates that one or more of the decision criteria is not met, the NRDA process will be terminated. If all five decision criteria are met, the NRDA process will move to the next phase, and a formal damage assessment will be initiated by the trustees (other than DOE) whose resources are affected. DOE as the lead trustee will notify the other trustees of the outcome of the preassessment screen. The ER Program will document the outcome of the preassessment screen in its administrative record.

2.4.2 Data Needs

The NRDA regulations (43 CFR 11.24) identify specific information and data needs that the ER Program will need to provide to support the trustees performing the preassessment screen. This information includes

- the time, quantity, duration, and frequency of releases;
- the names of the substances, as provided in the implementing regulations for RCRA and CERCLA;
- the history of the current and past use of the site identified as the source of the release;
- relevant operations occurring at or near the site; and
- additional hazardous substances potentially released from the site.

Some of this information is found in previously prepared documents, such as the Comprehensive Environmental Assessment and Response Program's Phase I report (DOE 1987, 0264), the RCRA facility assessment prepared by EPA Region 6 (EPA 1987, 0816), the 1988 and 1990 SWMU reports (International Technology Corporation 1988, 0329; LANL 1990, 0143), and the RFI work plans that are being prepared for each of the OUs at the Laboratory. Additional information will be provided in RFI phase reports as data are collected and evaluated.

2.4.3 Preliminary Identification of Potentially Affected Natural Resources

To identify the natural resources potentially affected by releases, the NRDA regulations (43 CFR 11.25) require a preliminary identification and evaluation of four factors:

- potential exposure pathways,
- areas where exposure or effects may have occurred or are likely to occur,

- areas of groundwater or surface water that may be or have been exposed, and
- estimates of hazardous substance concentrations in areas of potential exposure.

The ER Program will provide this information to the trustees. Information for identifying exposure pathways will include, at a minimum, the circumstances of the release; the characteristics of the receiving terrain or water body; weather conditions; and the known physical, chemical, and toxicological properties of the hazardous substances. The pathways to be considered may include direct contact, surface water, groundwater, air, and food chains.

To estimate areas where exposure or effects may have occurred or are likely to occur, areas in which hazardous materials have or are likely to spread through pathways will be identified. Estimates of exposure areas should also identify areas of indirect effects. These areas are areas that have not directly received hazardous materials as a result of a release at the Laboratory but that may be inhabited by biota that have inmigrated through contaminated areas.

2.3.4 Scope of a NRDA Preassessment

The Laboratory uses the operable unit (OU) approach for organizing and managing the various potential release sites (PRSs) identified at the Laboratory. OUs are aggregates of PRSs that will be addressed together during the corrective action process outlined in the HSWA Module. RFI work plans, as required by the Laboratory's permit to operate under RCRA, are being prepared for 24 OUs. Data collection, site characterization, ecological screening assessment, and other activities associated with the RCRA corrective action process are being developed and conducted independently for each OU. Chapter 1 of the IWP presents a more detailed discussion of OUs and the corrective action process at the Laboratory. Although the RCRA corrective action process addresses each OU individually, injuries to natural resources may occur as a result of past releases from multiple PRSs and OUs or from the entire Laboratory, and the natural resource trustees will focus on the resource, regardless of OU boundaries. Thus, the preassessment screen will be based on the spatial scale appropriate for the particular resource of interest. For example, possible impacts on an elk resource would encompass several OUs and lands outside Laboratory boundaries. Additional information on the integration of OU assessments, preassessment screens, and ecological risk assessments will be provided in future revisions of the IWP

3.0 ECOLOGICAL RISK ASSESSMENT

The ecological risk assessment process will follow the guidance provided in the "Risk Assessment Guidance for Superfund, Volume II, Environmental Evaluation Manual: Interim Final" (EPA 1989, 0988) and "Framework for Ecological Risk Assessment" (EPA 1992, 0989). The purpose of the ecological risk assessment is to estimate the environmental effects of releases of hazardous substances and to evaluate the consequences of potential remedial alternatives to biota. EPA (1992, 0989) gives three major steps for ecological risk assessment: problem formulation, analysis, and risk characterization.

Current ER Program efforts are focused on the problem formulation stage, and tools are being developed for the analysis and risk characterization steps. Two kinds of ecological risk assessments are planned: the first is based on a streamlined screening model, and the second is based on a dynamic ecological risk assessment model. The three steps specified by EPA will be applied to both types of ecological risk assessment.

3.1 SCREENING MODEL FOR ECOLOGICAL RISK

The screening model will be applied to effects of stressors on PRSs and OUs (e.g., effects of releases of hazardous materials and physical disturbance of the site during remediation). The purpose of the screening model is to identify the data needs for developing a dynamic ecological risk assessment model or to propose no further action (NFA). NFA can be proposed if the effect of each stressor on each key species (endpoint) is low. If NFA is proposed for all OUs, a dynamic ecological risk assessment model is not necessary. Otherwise, the results of the screening assessment will be used to focus additional data collection and risk assessment on stressors, species, and sites at which risk is not low.
To be credible, a screening model must have a low probability of eliminating a scenario, component, or process that may, in fact, be important. Moreover, screening models are not useful if they retain all scenarios at all sites as potentially important. Thus, some false positives can be tolerated, but almost no false negative errors can be tolerated. The ER Program will develop guidelines for acceptable error rates in screening models.

3.2 Dynamic Model for Ecological Risk Assessment

The purpose of the dynamic model is to evaluate the risk stressors pose to endpoints. This risk reflects species, community, and ecosystem responses. The response is integrated over spatial and temporal scales that make sense ecologically. For example, the response of an elk population is integrated over its foraging range, which potentially encompasses several OUs and offsite habitat.

3.3 Formulating the Problem for Ecological Risk Assessment

The purpose of problem formulation is to determine whether an ecological risk is occurring or is likely to occur. The factors used in this determination include the existence of stressors, an ecosystem potentially at risk from these stressors, and the potential of each stressor to impact the endpoint. If an ecological risk is likely, the output of the problem formulation step is a list of stressors and endpoints that best characterize the risk. A conceptual model is developed based on the selected stressors and endpoints.

3.3.1 Identifying Stressors

Stressors include contaminants of concern and disturbances of the physical environment. The contaminants of concern at the Laboratory include radioactive materials, metals, and organic chemicals. Physical disturbance (e.g., collecting samples or excavating soil near a goshawk nest) during site characterization and implementation of an interim corrective action may be a stressor for some species.

3.3.2 Determining Whether an Ecosystem Is at Risk

An ecosystem is at risk if there is a possible exposure pathway from the stressor to the endpoint. At some PRSs (firing sites, decommissioned structures, outfalls), ecological receptors may come in direct contact with the source of contamination. For other PRSs, there may be no current exposure pathways (constituents are buried or are enclosed by a structure), and the question is whether any species could be exposed in the future.

3.3.3 Selecting an Endpoint

Two types of endpoints are used in ecological risk assessment. Assessment endpoints are expressions of the environmental value to be protected. A measurement endpoint is an observable response to a stressor, which is associated with the assessment endpoint (e.g., abundance of earthworms). Assessment and measurement endpoints should address ecological effects on receptors at all scales from individuals to ecosystems. The following criteria are used to determine endpoints (Suter et al. 1993, 0991, p. 22):

- societal relevance of receptor (e.g., cultural, aesthetic, economic);
- biological relevance of receptor (e.g., key predator species);
- a clear definition that is widely accepted by the scientificcommunity (e.g., quantification of nutrient cycling by using the production:respiration ratio);
- accessibility of endpoint for purposes of predicting and measuring effects created by stressor; and
- susceptibility of the receptor to hazardous agents.

The most important requirement is that a measurable change in the endpoint be detected before catastrophic changes occur in the environment. Endpoints should be the equivalent of "canaries in the coal mine," so that proactive management can prevent or mitigate degradation of the environment.

The ER Program's current approach is to group the endpoints—primary species, secondary species, and ecosystem process—in three tiers (Table L-3). Each tier reflects habitat diversity at the Laboratory. Habitats include ponderosa pine forest, old fields in secondary succession, piñon-juniper woodlands, and riparian areas (Table L-4). The model for screening ecological risk will be based on the primary (key species) endpoints. The dynamic ecological risk model will include endpoints from each tier.

3.3.4 Elements of the Conceptual Model

Spatial and temporal activity patterns of animals and spatial patterns of plants are an important component of the conceptual model. The proposed list of endpoints encompasses a range of spatial and temporal scales (Table L-3). Some endpoints (e.g., an individual of a threatened or endangered rodent species) could be continuously exposed to potential contaminants of concern in a PRS. Clearly, a

TABLE L-3

EXAMPLES OF ECOLOGICAL RISK ASSESSMENT ENDPOINTS

	Primary-Level Species	Secondary-Level Species	System Level
Possible Assessment Endpoints	Survival Population levels Risk to humans Sustained harvest	Survival risk to humans Stability	Sustainability of ecosystem
Possible Measurement Endpoints	Tissue concentration Life span Population density Biomass Harvestable numbers	Tissue concentration Biomass Population density Species diversity	Decomposition rates Soil fertility Erosion rates Taxonomic diversity Structural diversity Primary productivity Water relationship
Possible Receptors	Economic species Food Fur/fiber Recreation Endangered or threatened species	Dominant species Keystone species Resource used by primary species Consumers of primary species	Soil/soil microbes Fauna/flora Wetlands Rivers/streams Special habitats
Model Resolution	Individual and population	Community	Ecosystem
Time Scale	Months to years	Years	Decades to centuries
Spatial Scale	10^{-1} to $>10^6 m^2$	10^{-1} to $>10^6 m^2$	10^4 to $>10^6 m^2$
Processes	Ingestion Inhalation Elimination Factors affecting economic or recreational value Mortality Reproduction germination establishment Dispersal	Ingestion Inhalation Elimination Factors affecting economic or recreational value Mortality Reproduction germination establishment Migration interspecific interactions	Erosion Decomposition Nutrient cycling: gains and losses Primary production Response/frequency/extent of natural disturbances

sensible ecological risk assessment can be performed for some species in a PRS or OU (e.g., small mammals and plants). For other species or endpoints (e.g., deer or elk), the ecological risk assessment must include land outside of the Laboratory. Selecting a spatial scale for ecological risk assessment is based on ecological knowledge of the endpoint, and similar knowledge is being used to select the spatial scale of the NRDA. The difference is that the NRDA is based on the spatial scale of the resource, rather than on ecological endpoints.

Bioconcentration, bioaccumulation, and bioavailability must be considered when building the conceptual model because these factors affect the dose received by endpoints. For example, two sites with the same elemental concentration of a metal will demonstrate different toxicological effects if the chemical form of a metal differs at each site. Likewise, two predators feeding on a contaminated prey species may receive different doses if each predator consumes different portions of the prey.

TABLE L-4

A POSSIBLE GENERAL FOOD WEB OF THE COMMON BIOLOGICAL RESOURCES OF THE LOS ALAMOS COUNTY REGION*

Group	Juniper/ Grassland	Piñon/ Juniper	Riparian (in Canyons)	Ponderosa Pine	Mixed Conifer
Producers	Juniper Saltbush Ponderosa pine Prickly pear Feathergrass Dropseed Three-awn	Piñon pine Juniper Rabbitbrush Apache plume Mountain mahogany Blue grama	Cottonwood Currant Hoptree Box elder Sedge Bluegrass Little bluestem	Ponderosa pine Gambel oak Skunkbush Mountain muhly	Douglas fir Ponderosa pine Aspen White fir
Consumers	Deer mouse Piñon mouse Cottontail Woodrat	Deer mouse Piñon mouse Cottontail Woodrat Mule deer	Harvest mouse Meadow vole Cottontail Chipmunk Mule deer Elk	Deer mouse Chipmunk Squirrel Woodrat Mule deer Elk	Pocket gopher Montane vole Chipmunk Woodrat Mule deer Elk Bluebird Junco
Secondary Consumers	Coyote Gray fox Bobcat Scrub jay Piñon jay Rattlesnake Turkey vulture	Coyote Gray fox Bobcat Steller's jay Piñon jay Spiny lizard Red-tailed hawk Turkey vulture	Coyote Raccoon Bobcat Steller's jay Common raven Kestrel Golden eagle Gopher snake Turkey vulture	Mountain lion Black bear Bobcat Common flicker Pygmy nuthatch Common raven Turkey vulture	Mountain lion Black bear Green-tailed towhee Clark's nutcracker Hairy woodpecker Turkey vulture

*DOE 1979, 0051

3.4 Conducting the Analysis

The analysis phase of ecological risk assessment quantifies the risk posed by stressors through an exposure analysis and ecological response analysis. The exposure analysis relies on the distribution of the stressor in the environment and produces an exposure profile. The ecological response analysis is usually based on controlled experiments that produce a stressor/response profile.

3.4.1 Summarizing Existing Data on Stressor Distribution and Response

All pertinent ecological data available for the site are collected, summarized, and statistically analyzed. These data include species lists of plants and animals for the OU and population estimates of key species (endpoints). Species-specific bioaccumulation and bioconcentration factors are usually not available for the Laboratory, and these data are obtained by conducting a literature survey. Although information from the literature is not usually species-specific, it may provide an acceptable estimate. Use of non-site-specific data increases the uncertainty of the models; therefore, data collected at the site are preferred if they are available or can be reasonably collected. These ecological data and the list of potential contaminants of concern are important to developing ecological response models and constructing an exposure analysis.

3.4.2 Performing Exposure Analysis

3.4.2.1 Evaluating Exposure Probabilities

The exposure analysis indicates whether a stressor can potentially impact an endpoint. This evaluation is performed using the conceptual model for the exposure scenario and knowledge of the distribution of the stressor in the environment. For example, the conceptual exposure model for an elk population may include ingestion of contaminated forage and inhalation and ingestion of dust.

To define an acceptable exposure, the investigator must define what constitutes an insignificant impact on the endpoint. One way to define an insignificant impact is to use a fraction (e.g., 10%) of the "natural" temporal or spatial variation in the endpoint. The ecological baseline studies will help define natural variation.

3.4.3 Analyzing Ecological Response

3.4.3.1 Evaluating Effect of Stressor Relative to Background Concentrations

This step requires that the baseline condition for the endpoints be established, which is the main objective of ecological baseline studies (Section 4). Baseline conditions include all disturbance of the physical environment at the Laboratory, exclusive of the stressor (release of a contaminant of concern or physical disturbance during sampling or remediation). Some contaminants of concern (e.g., metals and radionuclides) have nonzero background concentrations, which is related to world-wide fallout or local geologic characteristics. A major problem in ecological risk assessment is separation of anthropic contamination from the ecological effects of background levels of the contaminant of concern and other stressors. The effect of background concentrations on endpoints could be the basis for deciding that the effect of the potential contaminants of concern is low.

3.4.3.2 Developing Dynamic Pathway Models

Dynamic pathway models are quantitative extensions of the conceptual models and provide the basic method for evaluating ecological effects of stressors. The dynamic pathway model is based on both process knowledge and statistical analysis of exposure response and fate and transport data. These models represent Laboratory investigators' current biological, chemical, physical, and mathematical knowledge of how species and ecological processes respond to natural and human-induced environmental variations.

3.4.3.3 Conducting Pathway Analyses

Pathway analyses are estimates of the ecological effects of contaminants of concern on endpoints, based on the movement of the contaminant of concern from point of origin (in the contaminated ecosystem) to point of maximum concentration, as defined by dynamic pathway models. If these analyses indicate that the probability of adverse effects is low for an endpoint, that contaminant of concern does not contribute to an ecological risk.

3.4.4 Conducting Analytical Procedures

3.4.4.1 Evaluating Adequacy of Data and Models

The basis for determining acceptable uncertainty in data or model predictions is the effect of this uncertainty on decision making (Chapter 4). Each data set collected before or during the ecological risk assessment and each quantitative model will be evaluated. If a data set fails to meet data quality objectives (DQOs), the decision maker may reconsider some of the uncertainty tolerances or may collect additional data. If a model does not meet the DQOs, the model should be re-evaluated and modified. Any necessary modifications should be based on additional data collection, additional information from the literature, or revisions in the model structure that can be justified on the basis of current scientific knowledge.

3.4.4.2 Formulating Modified Sampling and Analysis Requirements

Experimental designs, data collection and sampling techniques, and data analysis methodologies must be clearly stated and must conform to scientifically accepted and defensible procedures. These requirements will be formulated during the project formulation stage of the ecological risk assessment. It is often the case during complex ecological studies, such as an ecological risk assessment, that unexpected problems or unforeseen data requirements occur. Therefore, there is a high probability that additions to, or modifications of, the original sampling and analysis requirements will be necessary during the ecological risk assessment. If and when these additions or modifications occur, they must be clearly stated and fully justified.

3.5 Characterizing Risk

The purpose of the ecological risk assessment is to characterize the current and potential ecological risks associated with the presence of one or more stressors at a site. This characterization will describe which species and ecological processes are impacted by stressors, and the temporal and spatial scale of these impacts. The scale establishes a context for the predicted impacts (e.g., a 10% population reduction in elk over 100 acres for 10 years). Each risk assessed to be significant (i.e., each key species, ecological process, and the overall ecosystem) will be characterized.

3.5.1 Predicting Risk and Defining Ecological Consequences

Risk prediction is a statement of the probability that characterized risk will occur, which includes estimates of uncertainty and sensitivity of this probability. Each specific risk must have an associated risk prediction statement.

A detailed statement of estimated potential ecological consequences of the risks must also be presented. These estimates will be based on the model predictions obtained in the ecological risk assessment and on the interpretations of these results by the scientists involved in developing the ecological risk assessment. The statement must include clear descriptions of specific consequences, estimates of the probability that these consequences will actually occur, and documentation of how these estimates of potential consequences were achieved. The basis of the

probability estimates will be an uncertainty and sensitivity analysis of the dynamic pathway models. This uncertainty in the decision based on the ecological risk assessment (e.g., propose NFA) will be communicated to the decision maker.

3.5.2 Documenting the Process

The entire ecological risk assessment process will be formally documented. This documentation will include methods used, results achieved, and discussion of these results. The documentation will also include a list of persons involved in the ecological risk assessment, along with their duties and responsibilities.

4.0 ECOLOGICAL BASELINE STUDIES

The ecological baseline studies performed for the ER Program have established baseline (reference) sites as required by 43 CFR Part 11 for determining natural background levels of stressors and biological characteristics. The NRDA process defines an injury as a *measurable* change in a resource, which relies on reference sites to determine whether changes in resources are caused by the release of the hazardous substance or are within the range of normal variation.

Reference sites have been established in a wet canyon (Guaje Canyon), and investigators plan to establish mesa and dry-canyon reference sites in the near future. Five reference sites at differing elevations have been established on Forest Service lands in Guaje Canyon to compare with similar sites in Los Alamos Canyon (and other canyons on Laboratory lands). The mesa reference sites will be located in Bandelier National Monument.

5.0 Summary

The Laboratory's ER Program is developing an integrated approach to NRDA and ecological risk assessment for RFIs and remediation (Table L-2). The integrated approach will use environmental data collected to fulfill other regulatory requirements (e.g., NEPA and the Endangered Species Act). New tools and paradigms are being developed as existing ecological risk assessment approaches are shown to be deficient when applied to RCRA and CERCLA sites.

References for Appendix L

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■ APPENDIX M

List of Standard Operating Procedures for Implementation of Environmental Restoration Program at Los Alamos National Laboratory

LOS ALAMOS NATIONAL LABORATORY
ENVIRONMENTAL RESTORATION PROGRAM
STANDARD OPERATING PROCEDURES

This appendix consists of the table of contents of the Environmental Restoration Program's standard operating procedures (SOP) manual. The SOPs in that document are updated frequently. Although the information in this table of contents is current as of September 1993, the reader is advised to contact the ER Program Office to determine whether the SOPs he/she needs are still current.

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Los Alamos National Laboratory
Environmental Restoration Program

STANDARD OPERATING PROCEDURES

CONTENTS—VOLUME I

General Instructions	dated September 17, 1993
Master Distribution List	dated September 17, 1993
List of Superseded Documents	dated September 17, 1993

PROCEDURE NUMBERS	**TITLE**
1.0	**General Instructions**
LANL-ER-SOP-01.01,R0	General Instructions for Field Investigations
LANL-ER-SOP-01.02,R0	Sample Containers and Preservation
LANL-ER-SOP-01.03,R0	Handling, Packaging, and Shipping of Samples
LANL-ER-SOP- 01.04,R1	Sample Control and Field Documentation
LANL-ER-SOP-01.05,R0	Field Quality Control Samples
LANL-ER-SOP-01.06,R0	Management of RFI-Generated Waste
3.0	**Reconnaissance/Field Surveys**
LANL-ER-SOP-03.02,R1	General Surface Geophysics
LANL-ER-SOP-03.04,R0	Petrography
LANL-ER-SOP-03.05,R0	Determination of Volume Constituents in Thin Sections of Rocks
LANL-ER-SOP-03.06,R0	Fracture Characterization
LANL-ER-SOP-03.07,R0	Characterization of Lithologic Variation Within the Rock Outcrop of a Volcanic Field
LANL-ER-SOP-03.08,R0	Geomorphic Characterization
LANL-ER-SOP-03.09,R0	Geologic Mapping of Bedrock Units
LANL-ER-SOP-03.10,R0	Trenching and Logging

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PROCEDURE NUMBERS	TITLE
4.0	**Drilling, Excavating, Sampling, and Logging**
LANL-ER-SOP-04.01,R0	Drilling Methods and Drill Site Manage ment LANL-ER-SOP-04.04,R0 General Borehole Logging
5.0	**Well Installation/Development and Water Sampling Techniques**
LANL-ER-SOP-05.01,R0	Monitor Well Construction
LANL-ER-SOP-05.02,R0	Well Development
6.0	**Sampling Techniques**
LANL-ER-SOP-06.01,R0	Purging of Wells for Representative Sampling of Groundwater
LANL-ER-SOP-06.02,R0	Field Analytical Measurements of Groundwater Samples
LANL-ER-SOP-06.03,R0	Sampling for Volatile Organics
LANL-ER-SOP-06.04,R0	Sampling Commercial/Municipal/Do mestic Wells
LANL-ER-SOP-06.05,R0	Soil Water Samples
LANL-ER-SOP-06.06.R0	Tensiometer (Soil Suction Monitor) Installation and Measurement
LANL-ER-SOP-06.09,R0	Spade and Scoop Method for Collection of Soil Samples
LANL-ER-SOP-06.10,R0	Hand Auger and Thin-Wall Tube Sam pler
LANL-ER-SOP-06.11,R0	Stainless Steel Surface Soil Sampler
LANL-ER-SOP-06.13,R0	Surface Water Sampling
LANL-ER-SOP-06.14,R0	Sediment Material Collection
LANL-ER-SOP-06.15,R0	Coliwasa Sampler for Liquids and Slur ries
LANL-ER-SOP-06.16,R0	Thief Sampler for Dry Powders or Gran ules
LANL-ER-SOP-06.17,R0	Trier Sampler for Sludges and Moist Powders or Granules
LANL-ER-SOP-06.18,R0	Collection of Sand, Packed Powder, or Granule Samples Using the Hand Auger
LANL-ER-SOP-06.19,R0	Weighted Bottle Sampler for Liquids and Slurries in Tanks
LANL-ER-SOP-06.21,R0	Volatile Organic Sampling Train

PROCEDURE NUMBERS	TITLE
LANL-ER-SOP-06.22,R0	Canister Sampling for Organics, EPA Method T0-14
LANL-ER-SOP-06.23,R0	Measurement of Gamma-Ray Fields Using a Sodium Iodide Detector
LANL-ER-SOP-06.24,R0	Sample Collection from Split-Spoon Samplers and Shelby Tube Samplers
LANL-ER-SOP-06.25,R0	Total Suspended Particulate Air Sam pling
LANL-ER-SOP-06.26,R0	Core Barrel Sampling for Subsurface Earth Materials
LANL-ER-SOP-06.29,R0	Single Stage Sampling for Surface Water Run-Off

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Los Alamos National Laboratory
Environmental Restoration Program

STANDARD OPERATING PROCEDURES

CONTENTS—VOLUME II

General Instructions	dated September 17, 1993
Master Distribution List	dated September 17, 1993
List of Superseded Documents	dated September 17, 1993

PROCEDURE NUMBERS	TITLE
7.0 Charac	**Subsurface Hydrogeological Site terization**
LANL-ER-SOP-07.01,R0	Pressure Transducers
LANL-ER-SOP-07.02,R0	Fluid Level Measurements
LANL-ER-SOP-07.03,R0	Well Slug Tests
LANL-ER-SOP-07.04,R0	Aquifer Pumping Tests
9.0	**Geochemistry**
LANL-ER-SOP-09.01,R0	Thin Section Preparation
LANL-ER-SOP-09.02,R0	Operating the Microprobe
LANL-ER-SOP-09.03,R0	Operation of the Siemens X-Ray Diffractometer
LANL-ER-SOP-09.04,R0	Calibration and Alignment of the Si emens Diffractometers
LANL-ER-SOP-09.05,R0	Clay Mineral Separation for X-Ray Diffrac tion Analysis
LANL-ER-SOP-09.06,R0	Zeolite Purification and Separation
LANL-ER-SOP-09.07,R0	Operating Instructions for ISI Mode DS-130 Scanning Electron Micrscope and Tracor Northern Series II X-Ray Analyzer
LANL-ER-SOP-09.09,R0	Certification of Standards for Electron Microanalysis

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PROCEDURE NUMBERS	TITLE
10.0	**Field Screening Techniques**
LANL-ER-SOP-10.01,R0	Screening of PCBs in Soil
LANL-ER-SOP-10.04,R0	MCA-465/Fidler Instrument System
11.0	**Geotechnical Analysis**
LANL-ER-SOP-11.01,R0	Measurement of Bulk Density, Dry Density, Water Content, and Porosity in Soil
LANL-ER-SOP-11.02,R0	Particle Size Distribution of Soil/Rock Samples
LANL-ER-SOP-11.03,R0	Permeability of Granular Soils
LANL-ER-SOP-11.04,R0	Soil and Core pH
LANL-ER-SOP-11.05,R0	Total Organic Carbon
LANL-ER-SOP-11.06,R0	Cation-Exchange Capacity
12.0	**Curatorial Management Activities**
LANL-ER-SOP-12.01,R0	Field Logging, Handling, and Documentation of Borehole Materials
14.0	**Gross Measurements of Radioactivi ty in Soils**
LANL-ER-SOP-14.01,R0	Berthold Low Alpha and Beta Activity Counter Calibration, Quality Control, Detection Limit, and Use

■ APPENDIX N

Education and Experience of Environmental Restoration Program Staff

Name and Affiliation	Education/Expertise	ER Program Assignment
Ted Taylor	Ph.D. Economics 10 years experience in management of environmental compliance, environmental restoration, and radioactive waste management programs	DOE-LAAO Program Manager
Steve Slaten	B.S. Geology and Petroleum Engineering 10 years experience in environmental engineering, including regulatory waste management enforcement and compliance, and management of investigations of inactive sites	DOE-LAAO Project Manager
Courtland Fesmire	B.S. 9 years experience in environmental engineering, including regulatory enforcement and compliance and management, planning, and execution of environmental field investigations	DOE-LAAO, Project Management
Paul Treat	B.S. Mechanical Engineering M.S. Materials Engineering 4 years experience in reactor design, diffusion, regulatory compliance, and program management	DOE-LAAO, Project Management
Bob Vocke	Ph.D. Water Resources 17 years experience in environmental and hazardous waste site assessment, including waste management, regulatory compliance, and program management	Program Manager (UC)
Lars Soholt	Ph.D. Biology 22 years experience in environmental assessment of energy and waste management systems, including project management experience	Deputy (UC)

Paul Aamodt	B.S. Geology M.A. Management 20 years experience in geosciences, including site characterization, radioactive and hazardous waste management and disposal, and project management	Deputy (UC)
Jim Aldrich*	Ph.D. Geology 24 years experience in geosciences research and project management; environmental sciences, including hazardous waste site assessment, project management planning, and scheduling	Operable Unit Project Leader
Susan Alexander		Technical Team Leader, Health and Safety
Garry Allen	B.S. Electrical Engineering 21 years experience in engineering design, 16 years experience in technical project management, 12 years experience in technical line management	Operable Unit Project Leader
Kathleen Armstrong	B.S. Education, M.A. in Training and Learning Technologies in progress. 2 years experience in intermediate education; 1 year experience in training coordination and development;	Training Coordinator
Betsy Barnett	B.A. Languages 13 years experience writing and editing documents pertaining to the environment and radioactive waste disposal	Technical Team Leader, Document Preparation
Roy Bohn	B.S. Biology/Chemistry 13 years experience in health physics, environmental sampling and regulations, geological sampling and survey.	Field Coordinator

*All personnel from this point on are University of California employees.

Darrell Bultman	B.S. Mechanical Engineering M.S. Mechanical Engineering 8 years experience in engineering design, including 3 years in project management	Technical Team Leader, Mixed-Waste Disposal Facility
David Broxton	M.S. Geology 15 years experience in petrologic and and geochemical studies of volcanic rocks, geologic disposal of high-level nuclear waste, and project management	Principal Investigator, Geology
Kathy Campbell	Ph.D. Mathematics 13 years experience with statistical sampling/presentation/evaluation of geochemical and hazardous waste/ chemistry data	Technical Team Leader, Statistics
Allen Cogbill	Ph.D. Geological Sciences 15 years experience acquiring and analyzing detailed surface and subsurface geophysical data, especially potential field and seismic data	Principal Investigator, Geophysics
John Conaway	Ph.D. Geophysics 20 years experience in borehole and surface geophysical techniques specializing in direct detection of contaminants with nuclear borehole technology	Principal Investigator, Borehole physics
Jean Dewart	M.S. Atmospheric Sciences 15 years experience in dispersion modeling and air quality regulations	Technical Team Leader, Air Quality

Alison Dorries	Ph.D Chemistry, M.P.H. Public Health 7 years experience in toxicology, pulmonary health research, regulation development, and human health risk assessment	Technical Team Leader, Human Health Risk Assessment
Barry Drennon	14 years experience in analytical chemistry, 4 years in records management and archive investigations	Records/ Information Technician
Gary Eller	Ph.D. Chemistry 19 years experience at Los Alamos in transuranic, process, and environmental chemistry research, development, and management and environmental project management	Operable Unit Project Leader
Joan Fisk	24 years experience in analytical chemistry and related management of analytical services, including 10 years of organics and inorganics analyses and 14 years in the development and management of infrastructures for contracted analytical services, including quality assurance and data validation programs.	Technical Team Leader for Environmental Chemistry
Bill Foley	B.S. Mechanical Engineering 36 years experience in facilities engineering	Construction Project Manager, Mixed-Waste Disposal Facility
Teralene Foxx	M.S. Biology 20 years experience in field biology and plant ecology	Technical Team Leader, Biological Resource Evaluations
Bruce Gallaher	M.S. Hydrology 15 years experience in contaminant hydrology and regulatory compliance, including management of waste site characterization studies	Principal Investigator, Hydrology
Jamie Gardner	B.S. Earth Science, Ph.D. Geology 18 years experience in evaluating geologic hazards at nuclear facilities, 14 years in developing and managing large interdisciplinary earth	Technical Team Leader, Earth Sciences; Principal Investigator, Framework

	science programs in a research on the tectonics, magmatism, and geohydrology of the Jemez Mountains and Pajarito Plateau	Studies
Doris Garvey	M.S. Economics 25 years experience in economic and environmental regulatory analysis, in cluding 15 years in environmental assessments and impact analysis, 3 years of environmental regulatory compliance management, and 3 years as manager for the Laboratory's National Environmental Policy Act program.	Technical Team Leader, Environmental Assessment
Tracy Glatzmaier	B.S. Chemical Engineering, M.S. Industrial Engineering (Engineering Management Option) 8 years experience in engineering and project design and management; data acquisition and analysis in atmospheric transport and diffusion; 5 years management experience	Programmatic Project Leader/ Operable Unit Project Leader
Sue Goff	M.S. Geology 17 years experience in geosciences, including designing, organizing, and managing drilling, geophysical logging, and curation management operations	Technical Team Leader, Subsurface Technogies
Robert Gonzales	B.U.S. (Bachelor of University Studies) Environmental Science 16 years experience in regulatory compliance and environmental assessments, including hazardous waste site characterization, waste management, and project management	Project Leader for Engineering Project Review
Gene Gould	B.A. History; additional formal course work in accounting and business law; 20 years experience in program management and development, resource management, and federal grant administration	Operable Unit Project Leader

Wayne Hansen	Ph.D Radiation Biology 23 years experience in environmental assessment, waste management, and environmental monitoring. Certified health physicist.	Technical Team Leader, Ecological Risk
Elizabeth J. Kelly	Ph.D. Biostatistics 25 years experience as an applied statistician and operations research analyst consulting and providing project management for a variety of projects addressing problems in such areas as ecological modeling, optimal sample design, data assessment, decision analysis, reliability, safety, and probability risk assessment.	Programmatic Project Leader, for Environmental Assessments Technical Teams
Beverly Larson	Ph.D Candidate in Anthropology 19 years experience in cultural resource management, 8 years as archaeology team leader at the Laboratory	Principal Investigator, Cultural Resources
Craig Leasure	Ph.D. Analytical Chemistry 6 years experience as manager of chemistry performing analysis for ER Program	Technical Team Leader, Analytical Laboratory Instrumentation
Patricia Leyba	A.A./B.B.A. Business Administration 11 years experience in office/information management systems and 4 years experience in electronic desktop publishing	Electronic Publications Specialist
Pat Longmire	Ph.D. Geochemistry: emphasis in low-temperature aqueous chemistry, 15 years experience in geochemical aspects of radionuclide, inorganic, and organic solute migration	Operable Unit Project Leader; Principal Investigator, Geochemistry
Larry Maassen	M.S. Exploration Geology 12 years experience in exploration geology; 6 years in radioactive waste program quality assurance; 3 years in environmental restoration program management	Programmatic Project Leader

Nancy Marusak		Technical Team Leader, Facility for Information Management, Analysis, and Display
Brad Martin	B.S. Electrical Engineering, M.B.A. 12 years experience in electronic manufacturing; 8 years in facilities, safety, property, and financial management, including experience as health and safety officer and 1 year managing RCRA field investigation process	Operable Unit Project Leader
Caroline Mason	Ph.D. Inorganic Chemistry 18 years experience at Los Alamos in hydrogen energy research and in international scientific developments, including environmental issues abroad.	Operable Unit Project Leader
Dave McInroy	B.S. Biology 10 years experience in waste management activities, including 4 years of project management and three years as a regulatory compliance technical team leader	Programmatic Project Leader,
Roy Michelotti	B.S. Mechanical Engineering, M.B.A. 13 years experience in engineering design and project management, 1 year in facility management and as health and safety officer	Operable Unit Project Leader
John Miglio	Ph.D. Analytical Chemistry 15 years experience in radiochemistry, 5 years experience in analytical chemistry, and 1-1/2 years experience in sample management	Technical Team Leader, Sample Coordination Facility
Carl Newton	Ph.D. Geophysics 30 years experience in geophysics; assignments include section leader at Los Alamos and program manager at DOE Headquarters	Operable Unit Project Leader

Ted Norris	Ph.D. Chemistry 12 years experience in radionuclide migration, 3 years experience in atmospheric pollutant transport, 3 years experience as health and safety officer, and 3 years experience in environmental restoration project management	Programmatic Project Leader
Al Pratt	B.S. Forestry, B.S. Environmental Science, M.B.A. 10 years experience in resource management; 5 years experience in radioactive waste management program, including project management	Operable Unit Project Leader
Mike Ray	B.S. Geology 21 years experience in geosciences, including 9 years experience in waste-related site assessment and information management for technical baseline design documents	Programmatic Project Leader
Alfredo Rey	B.S. Mechanical Engineering, M.B.A. General Management 21 years total experience: 9.5 years in group management, including personnel, financial, and ES&H management; formal training and experience in project management; 19 years in nuclear weapons and special nuclear materials manufacturing, quality control of manufactured parts, and health and safety in manufacturing environments.	D&D Project Leader
Cheryl Rofer	M.S. Organic Chemistry 5 years experience in developing technology for environmental remediations; more than 20 years experience in explosives, uranium, laser, and fossil fuel chemistry	Operable Unit Project Leader
Miguel Salazar	B.S. Civil Engineering 22 years experience in general engineering (air field, oil/gas pipelines, buildings, disposal areas, drainage structures, etc.), 12 years in radioactive waste management, 8 years in decontamination and decommissioning management	Programmatic Project Leader

Marja Shaner	A.A. Arts and Humanities (foreign languages) A.A. Paralegal Studies (emphasis on litigation and environmental law) 3 years experience in law office management, 6.5 years in Laboratory Counsel/General Law Office, with specialty in environmental law, policy and procedure development for General Law Office	Staff Member
Dan Stout	B.S. Engineering Physics 10 years experience in decontamination and decommissioning, remedial action, and project management	Decontamination and Decommissioning Project Leader
Larry Souza	B.A. General Studies 18 years experience in implementing and managing quality assurance and quality control programs; 2 years experience at DOE facilities of which one was spent overseeing waste-handling program in accordance with RCRA	Quality Program Project Leader
Everett Springer	Ph.D. Watershed Science 11 years experience in hydrology, including analysis of surface and subsurface flow and contaminant transport	Operable Unit Project Leader
Ines Triay	Ph.D. Chemistry 7 years experience in environmental science, extensive experience in the study of actinide and fission product migration in the subsurface and design and evaluation of remediation techniques for removing actinides from soils and water	Operable Unit Project Leader
Sandra Wagner	M.S. Organic/Analytical Chemistry; M.S. Environmental Science 9 years experience in implementing and managing assessment and remediation activities for hazardous waste sites	Programmatic Project Leader

■ APPENDIX O

Projected Schedule and Cost for the Environmental Restoration Program at Los Alamos National Laboratory

LOS ALAMOS NATIONAL LABORATORY

ENVIRONMENTAL RESTORATION

FY 1993COST PLAN ($K)

PROJECT NAME: LOS ALAMOS NATIONAL LABORATORY | SUBMITTED BY: R. VOCKE | CONTRACTOR RESPONSIBLE: UNIVERSITY of CALIFORNIA

DATE: 30 September 1993 | REPORTING LEVEL: ADS | CURRENT PERIOD: September 1, 1993 thru September 30, 1993

	TASK	PRIOR FY's TOTAL	PLANNED DOLLARS ($K) CURRENT FISCAL YEAR: 1993 OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL	BUDGET YEAR FY94	FIVE YEAR PLAN WINDOW FY95	FY96	FY97	FY98	FY99	Budget at Completion
1049	Canyons Assessment	672	1	1	1	1	1	25	24	22	24	23	24	23	170	4210	2907	32703	34405	22056	28146	210622
1062	Interim Rem Assessment	1719	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1719
1063	Interim Rem UST's	1340	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1340
1066	NEPA Documentation	240	21	18	20	18	2	3	4	3	1	1	2	1	94	1532	1638	0	0	0	0	3504
1067	RCRA MWSDF	1933	127	109	294	328	328	404	360	329	363	294	157	134	3227	2992	8353	1201	0	0	0	17706
1071	TA-0, 19, 26, 73, 74 Assess	2093	75	64	75	68	68	121	145	156	528	673	496	131	2600	8605	11283	12518	5164	3038	5770	69795
1078	TA-1 Assessment	2104	78	62	335	406	410	508	285	166	190	137	146	324	3047	2574	1996	1664	3185	3157	853	18580
1079	TA-10, 31, 32, 45 Assess	2270	77	71	72	42	33	117	658	196	117	103	135	57	1678	3467	2623	2117	1371	5563	5982	53046
1082	TA-11,13,16,24,25,28,37	1475	282	195	104	107	52	145	59	75	128	168	155	233	1703	3218	6900	16300	23015	10033	11147	318042
1085	TA-12, 14 ,67 Assessment	0	14	12	60	73	52	119	27	17	43	43	50	93	603	589	4095	2264	1763	571	179	10064
1086	TA-15 Assessment	601	23	28	75	74	11	131	57	145	33	32	44	191	844	2787	4331	2970	3202	3053	3180	31684
1091	TA-16 Burning Ground	31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31
1093	TA-18, 27, 65 Assessment	712	10	28	7	31	35	95	86	42	203	180	183	175	1075	2804	2536	3556	3182	1398	0	15263
1098	TA-2, 41 Assessment	523	227	138	24	38	18	49	42	27	39	110	32	38	782	2996	2661	1614	1854	1450	1360	71970
1100	TA-20, 53, 72 Assessment	0	35	30	124	139	90	161	69	57	115	115	104	31	1070	846	5751	3666	1159	3987	1654	47332
1106	TA-21, Assessment	5740	1063	865	601	201	179	249	244	202	281	368	326	166	4745	7173	14500	15622	10309	6493	6378	159725
1111	TA-6, 7, 22,40, 58, 62 Assess	1373	179	144	94	88	107	97	105	67	90	133	123	93	1320	5854	6819	2286	2463	3051	974	28477
1114	TA-3,30,59,60,61,64 Assess	967	188	22	92	20	79	71	33	34	48	61	104	160	912	2156	2667	4507	6395	7358	5720	82161
1122	TA-33, 70 Assessment	1807	54	47	54	41	38	168	242	257	799	416	325	161	2602	2009	597	1658	1984	2386	2096	17903
1127	TA-35, WST OIL PITS CLSR	1111	3	21	13	11	28	11	0	0	0	0	0	0	87	0	0	0	0	0	0	1198
1129	TA-4,5,35,42,48,52,55,63,66	2120	91	118	161	157	138	179	220	277	336	380	341	227	2625	4095	6530	5097	4333	5459	1762	130202
1130	TA-36,68,71 Assessment	462	139	39	48	37	29	40	25	25	48	51	134	307	922	3064	2522	1231	1047	1803	2797	14497
1132	TA-39 Assessment	437	11	16	19	10	25	50	94	68	28	57	321	345	1044	3025	5728	1970	1766	342	2965	44343
1135	TA-40, Scrap Deton. Site Clsr	317	133	47	37	30	7	0	0	0	0	0	0	0	254	0	0	0	0	0	0	571
1136	TA-43, Assessment	0	2	2	20	27	22	95	15	7	17	18	16	29	270	66	709	746	405	571	61	2828
1140	TA-46, Assessment	628	239	204	163	19	31	12	48	22	33	51	62	24	908	3091	5952	4870	570	210	0	16229
1144	TA-49, Assessment	1192	185	141	62	27	27	389	97	130	77	41	35	33	1244	1539	2002	1711	1027	941	1732	16384
1147	TA-50, Assessment	1170	14	31	18	19	19	22	65	111	256	247	265	252	1319	5270	6350	957	4808	3039	1885	49786
1148	TA-51, 54, Assess, MDAL	3386	172	134	138	112	118	543	590	503	348	332	348	332	3670	7269	8212	6610	4972	5770	3441	89705
1150	TA-54 Area L Waste Oil	75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	75
1154	TA-57 Assessment	0	9	8	29	31	20	95	25	18	41	34	33	25	368	501	768	411	792	227	0	3067
1157	TA-8, 9, 23, 69 Assessment	680	179	132	53	39	78	45	56	41	23	21	22	17	706	5133	4879	3055	8317	848	936	39968
2105	Tech Support -- Assessment	16397	770	679	763	698	698	814	1761	700	779	736	771	737	9906	15077	15610	15985	15469	15632	13458	273379
2106	Remediation Management	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2107	Assessment Management	21027	1217	1043	1217	1101	1101	1332	1274	1159	1274	1216	1274	1217	14425	16320	17138	17986	18899	19839	20828	507449
2110	Analytical Chem. Bld Studies	242	565	484	565	558	558	96	39	36	39	38	39	38	3055	3396	1796	1884	1979	2078	2181	35506
2220	TA-53 Lagoon Closure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	SUBTOTAL	74844																				
	PLAN		6183	4933	5338	4551	4402	6186	6749	4892	6301	6079	6067	5594	67275	121658	157853	167159	163835	130353	125485	2384151
	FYTD PLAN		6183	11116	16454	21005	25407	31593	38342	43234	49535	55614	61681	67275	67275							
ESCALATION $															0	0	0	0	0	0	0	0
MANAGEMENT RESERVE $															0	9933	13585	14392	14015	10610	9883	169800
CONTINGENCY $															0	20689	35773	31929	35103	29141	25013	896945
	TOTAL														67275	152280	207211	213480	212953	170104	160381	3450896
	PLAN																					
CARRYOVER $															-5901							
BUDGET AUTHORITY $															61453							

Re-baseline in FY94 will incorporate latest DOE Target Funding into the Cost Plan for Permit Modifications.

Reviewed by:

ALBUQUERQUE OPERATIONS OFFICE
ENVIRONMENTAL RESTORATION PROJECT OFFICE
MILESTONE REPORT

5 5-Nov-93
ORTING PERIOD 01 Sep 93 TO 30 Sep 93

INSTALLATION NAME LOS ALAMOS NATIONAL LABORATORY

WBS #	OU/MILESTONE	BAC	PLAN		ESTIMATE			ACTUAL	
		X $1000	START	STOP	START		STOP	START	STOP
????	1063: INTERIM REMEDIAL MEASURES REMEDIATION								
	CONDUCT INTERIM REM MEASURES RE	1225							
	ADS MANAGEMENT	115							
6.1.01	1049: CANYONS ASSESSMENT								
	RFI WORK PLAN	4894		08/21/95			08/21/95	10/2/89	
	01M010 EPA/NMED DRAFT RFI WP			5/5/95			5/5/95		
	RFI	107645	10/25/95	9/29/15	10/25/95		7/22/99		
	01M090 EPA/NMED DRAFT RFI PH1 RE			2/12/98			2/12/98		
	RFI REPORT	7954		11/28/00	7/28/97		11/28/00		
	01M035 EPA/NMED DRAFT RFI REPORT			8/23/00			8/23/00		
	CMS PLAN	1000		7/19/01	8/24/00		7/19/01		
	01M050 EPA/NMED DRAFT CMS PLAN			3/28/01			3/28/01		
	CMS WORK	8870	10/1/92	9/28/01	10/1/93		9/28/01		
	CMS REPORT	1125		7/30/02	10/1/01		7/30/02		
	01M075 EPA/NMED DRAFT CMS REPORT			4/29/02			4/29/02		
	ADS MANAGEMENT	1438	10/1/92	9/29/00			9/29/00	10/1/92	
	VCA	171	3/1/93	8/13/02			8/13/02	8/2/93	
	1049: CANYONS REMEDIATION								
	ADS MANAGEMENT REMEDIATION	1550	2/10/00	9/28/15	10/2/00		9/28/15		
	CMI	13862	10/1/04	9/28/07	10/1/04		9/28/07		
	VCA REMEDIATION	62115	3/1/02	9/29/15	3/1/02		9/29/15		
6.3.06	1066: NEPA DOCUMENTATION								
	DOE EIS DECISION								
	DOE SELECT EIS CONTRACTOR								
	FINISH DRAFT EIS								
	FINISH FINAL EIS								
	TECHNICAL SUPPORT DOCUMENT	3265		3/16/95			2/9/96	1/4/93	
	COMPLETE TECHNICAL SUPPORT DOC								
	ASSMTN PROG DOC	222							
	ASSMTN ADS MGNT	18							
6.1.04	1071: TA-0, 19, 26, 73, 74 ASSESSMENT								
	RFI WORK PLAN	1602	11/11/92	11/24/92				10/19/90	1/22/93
	06M000 EPA/NMED DRAFT RFI WORK			5/22/92			5/22/92		
	RFI	36460	5/22/92	6/8/99			6/8/99	5/18/92	
	06M070 EPA/NMED DRAFT PH1 RPT/WP MOD			10/24/96			10/24/96		
	RFI REPORT	3889		5/10/99	2/16/94		5/10/99		
	06M025 EPA/NMED DRAFT RFI REPORT			2/8/99			2/8/99		
	CMS PLAN	1968		12/8/99	2/9/99		12/8/99		
	06M040 EPA/NMED DRAFT CMS PLAN			8/12/99			8/12/99		
	CMS WORK	0	2/9/99	12/1/00	2/9/99		12/1/00		
	CMS REPORT	1813		7/27/01	12/9/99		7/27/01		
	06M060 EPA/NMED DRAFT CMS REPORT			4/26/01			4/26/01		
	ADS MANAGEMENT	4094	10/1/92	6/7/01			6/7/01	10/1/92	
	VCA	1996	3/1/93	9/30/98			9/30/98	3/1/93	
	1071: TA-0,19,26,73,74 REMEDIATION								
	REMEDIATION SUPERVISION	172	10/1/98	9/30/03	10/1/98		9/30/03		
	CMI	11480	10/1/02	9/30/03	10/1/02		9/30/03		
	VCA REMEDIATION	6327	10/1/98	9/28/01	10/1/98		9/28/01		
6.1.05	1078: TA-1 ASSESSMENT								
	RFI WORK PLAN	1476	10/1/92	2/16/93				2/1/90	9/30/93

	07M005 EPA/NMED DRAFT RFI WORK			5/22/92			5/22/92					
	RFI	4969	6/1/92	3/15/95			3/15/95		6/1/92			
	07M085 EPA/NMED DRAFT PH1 RPT/W			10/12/93			5/4/94					
	RFI REPORT	1632		7/17/96	10/18/93		7/17/96					
	07M030 EPA/NMED DRAFT RFI REPOR			10/9/97			10/9/97					
	CMS PLAN	805		3/12/97	4/17/96		3/12/97					
	07M045 EPA/NMED DRAFT CMS PLAN			11/12/96			11/12/96					
	CMS WORK	21	10/1/92	3/12/98			3/12/98		10/1/92			
	CMS REPORT	799		1/8/99	3/13/98		1/8/99					
	07M065 EPA/NMED DRAFT CMS REPO			10/1/98			10/1/98					
	ADS MANAGEMENT	1317	10/1/92	1/8/99			1/8/99		10/1/92			
	VCA	1829	10/1/93	9/30/96	10/1/93		9/30/96					
	1078: TA-1 REMEDIATION											
	REMEDIATION SUPERVISION	116	10/1/96	8/16/99	10/1/96		8/16/99					
	CMI	674	1/11/99	8/16/99	1/11/99		8/16/99					
	VCA REMEDIATION	4940	3/3/97	9/30/98	3/3/97		9/30/98					
6.1.06	1079: TA-10, 31, 32, 45 ASSESSMENT											
	RFI WORK PLAN	1937	10/1/92	12/1/92					4/2/90			
	08M005 EPA/NMED RFI WORK PLAN			5/27/92			5/27/92				5/27/92	
	RFI	6064	5/1/92	9/30/04			9/30/04		5/1/92			
	08M105 EPA/NMED DRAFT PH1 RPT/W			3/6/95			5/25/95					
	08M110 EPA/NMED DRAFT PH2 RPT/WP MOD											
	RFI REPORT	1662		6/5/97	12/17/93		7/10/97					
	08M045 EPA/NMED DRAFT RFI REPOR			3/6/97			4/9/97					
	CMS PLAN	961		1/29/98	4/10/97		3/5/98					
	08M060 EPA/NMED DRAFT CMS PLAN			9/30/97			11/4/97					
	CMS WORK	1292	10/1/92	1/29/99			3/5/99		10/1/92			
	CMS REPORT	805		11/23/99	3/8/99		1/3/00					
	08M080 EPA/NMED DRAFT CMS REPO			8/20/99			9/24/99					
	ADS MANAGEMENT	1583	10/1/92	9/30/04			9/30/04		10/1/92			
	VCA	1899	3/2/93	9/30/04			9/30/04		3/2/93			
	1079: TA-10,31,32,45 REMEDIATION											
	REMEDIATION SUPERVISION	283	10/1/97	9/30/04	10/1/97		9/30/04					
	CMI	713	11/24/99	11/22/00	1/4/00		1/2/01					
	VCA REMEDIATION	35845	3/3/98	9/30/04	3/3/98		9/30/04					
6.1.07	1082: TA-11,13,16,24,25,28,37 ASSESSMENT											
	RFI WORK PLAN	6476	10/1/92	12/15/95			12/15/95		10/1/91			
	09M010 EPA/NMED DRAFT RFI WORK PLAN			7/7/95			7/7/95					
	RFI	51399	10/1/93	10/16/98	2/15/94		10/16/98					
	09M090 EPA/NMED DRAFT PH1 RPT/WP MOD			3/27/98			3/27/98					
	RFI REPORT	12846		2/28/00	11/22/96		2/28/00					
	09M030 EPA/NMED DRAFT RFI REPORT			11/19/99			11/19/99					
	CMS PLAN	2177		10/13/00	11/22/99		10/13/00					
	09M045 EPA/NMED DRAFT CMS PLAN			6/21/00			6/21/00					
	CMS WORK	1491	10/1/92	8/28/01			8/28/01		10/1/92			
	CMS REPORT	2119		6/27/02	8/29/01		6/27/02					
	09M065 EPA/NMED DRAFT CMS REPORT			8/29/01			8/29/01					
	ADS MANAGEMENT	2397	10/1/92	6/27/02			6/27/02		10/1/92			
	VCA	256	3/1/93	9/28/18			9/28/19		5/1/93			
	1082: TA-11,13,16,24,25,28,37 REMEDIATION											
	REMEDIATION SUPERVISION	1781	10/1/99	9/28/18	10/1/99		9/28/18					
	CMI	32755	10/3/05	9/30/10	10/3/05		9/30/10					
	VCA REMEDIATION	204342	3/1/00	9/28/18	3/1/00		9/28/18					
6.1.08	1085: TA-12,14,67 ASSESSMENT											
	RFI WORK PLAN	1137		6/13/95			6/13/95		10/1/92			
	10M010 EPA/NMED DRAFT RFI WORK PLAN			2/28/95			2/28/95					
	RFI FIELD WORK	5564	9/8/94	1/23/97	10/13/94		1/23/97					
	10M090 EPA/NMED DRAFT PH1 RPT/WP MOD			7/16/96			7/16/96					
	RFI REPORT	2124		6/4/98	9/7/95		6/4/98					
	10M035 EPA/NMED DRAFT RFI REPORT			2/26/98			2/26/98					
	CMS PLAN	0										
	10M050 EPA/NMED DRAFT CMS PLAN											
	BENCH/PILOT & CMS STUDIES	0	10/1/92	9/30/97			9/30/97		10/1/92			

	CMS REPORT		0										
	10M070 EPA/NMED DRAFT CMS REPORT												
	ADS MANAGEMENT		881	10/1/92	6/4/98			6/4/98		10/1/92			
	VCA		177	10/1/92	9/30/98	10/1/93		9/30/98					
	1085: TA-12,14,67 REMEDIATION												
	REMEDIATION SUPERVISION		43	10/1/98	9/30/99	10/1/98		9/30/99					
	CMI		137	3/2/98	9/30/99	3/2/98		9/30/99					
6.1.09	1086: TA-15 ASSESSMENT												
	RFI WORK PLAN		965		9/14/93			1/24/94		10/1/91			
	11M010 EPA/NMED DRAFT RFI WORK				5/28/93			7/2/93				7/2/93	
	RFI		14901		1/27/00	1/10/94		6/15/00					
	11M030 EPA/NMED DRAFT PH1 RPT/W				1/27/97			2/26/97					
	RFI REPORT		3458		1/27/00	7/1/96		6/15/00					
	11M040 EPA/NMED DRAFT RFI REPOR				10/20/99			3/16/00					
	CMS PLAN		1526		6/14/02	3/17/00		11/4/02					
	11M060 EPA/NMED DRAFT CMS PLAN				5/22/00			10/11/00					
	CMS WORK		209	10/1/92	9/13/01			2/8/02		10/1/92			
	CMS REPORT		1499		7/15/02	2/11/02		12/5/02					
	11M085 EPA/NMED DRAFT CMS REPORT				4/12/02			8/30/02					
	ADS MANAGEMENT		1953	10/1/92	8/28/02			8/28/02		10/1/92			
	VCA		312	3/1/93	9/30/99			9/30/99		10/1/92			
	1086: TA-15 REMEDIATION												
	REMEDIATION SUPERVISION		139	10/1/99	9/30/03	10/1/99		9/30/03					
	CMI		1196	10/1/02	9/30/03	10/1/02		12/5/03					
	VCA REMEDIATION		5525	10/1/99	9/28/01	10/1/99		9/28/01					
6.1.10	1093: TA-18, 27, 65 ASSESSMENT												
	RFI WORK PLAN		736		5/26/93			1/10/94		10/1/91			
	12M020 EPA/NMED DRAFT RFI WORK				2/18/93			5/3/93				5/3/93	
	RFI		3089	5/27/93	2/1/96			6/18/96		5/27/93			
	12M105 EPA/NMED DRAFT PH1 RPT/W				3/30/95			12/1/95					
	RFI REPORT		1932		6/5/97	5/4/95		10/22/97					
	12M040 EPA/NMED DRAFT RFI REPOR				3/6/97			7/22/97					
	CMS PLAN		0										
	12M055 EPA/NMED DRAFT CMS PLAN												
	CMS WORK		0	10/1/92	6/5/97			6/5/97		10/1/92			
	CMS REPORT		0										
	12M075 EPA/NMED DRAFT CMS REPORT												
	ADS MANAGEMENT		702	10/1/92	9/30/98			9/30/98		10/1/92			
	VCA		4586	2/19/93	9/30/98			9/30/98		12/22/92			
	1093: TA-18,27,65 REMEDIATION												
	REMEDIATION SUPERVISION		500	10/1/96	9/30/98	10/1/96		9/30/98					
	CMI		0										
	VCA REMEDIATION		3721	3/3/97	9/30/98	3/3/97		9/30/98					
6.1.11	1098: TA-2, 41 ASSESSMENT												
	RFI WORK PLAN		994		8/10/93			1/24/94		10/1/91			
	13M010 EPA/NMED DRAFT RFI WORK PLAN				4/26/93			5/28/93					
	RFI		4848	8/20/93	12/15/95	1/25/94		12/15/95					
	13M030 EPA/NMED DRAFT PH1 RPT/WP MOD				3/30/95			5/25/95					
	RFI REPORT		1911		4/23/97	11/8/94		4/23/97					
	13M040 EPA/NMED DRAFT RFI REPORT				1/22/97			1/22/97					
	CMS PLAN		1053		12/12/97	1/23/97		12/12/97					
	13M060 EPA/NMED DRAFT CMS PLAN				8/18/97			8/18/97					
	CMS WORK		1407	10/1/92	12/11/98			12/11/98		10/1/92			
	CMS REPORT		902		10/7/99	12/14/98		10/7/99					
	13M085 EPA/NMED DRAFT CMS REPORT				7/8/99			7/8/99					
	ADS MANAGEMENT		1195	10/1/92	9/30/99			9/30/99		10/1/92			
	VCA		639	3/1/93	9/30/97			9/30/97		4/1/93			
	1098: TA-2,41 REMEDIATION												
	REMEDIATION SUPERVISION		299	4/24/97	9/30/04	4/24/97		9/30/04					
	CMI		58479	10/2/00	9/30/04	10/2/00		9/30/04					
	VCA REMEDIATION		244	4/24/97	9/30/99	4/24/97		9/30/99					
6.1.12	1100: TA-20 ASSESSMENT												

	RFI WORK PLAN		1344	10/1/92	9/7/94			2/7/95		10/1/92			
	14M010 EPA/NMED DRAFT RFI WORK PLAN				5/23/94			10/17/94					
	RFI		6551	9/8/94	1/23/97	2/8/95		4/21/97					
	14M090 EPA/NMED DRAFT PH1 RPT/WP MOD				7/16/96			9/25/96					
	RFI REPORT		832		8/18/04	3/18/96		8/18/04					
	14M035 EPA/NMED DRAFT RFI REPORT				2/26/98			5/22/98					
	CMS PLAN		1058		1/21/99	5/26/98		4/19/99					
	14M050 EPA/NMED DRAFT CMS PLAN				9/22/98			12/22/98					
	CMS WORK		1833	10/1/92	1/21/00			4/18/00		10/1/92			
	CMS REPORT		906		11/14/00	4/19/00		2/15/01					
	14M070 EPA/NMED DRAFT CMS REPORT				8/11/00			11/8/00					
	ADS MANAGEMENT		1233	10/1/92	9/30/02			9/30/02		10/1/92			
	VCA		3326	3/1/93	8/11/00	3/1/94		8/14/01					
	1100: TA-20 REMEDIATION												
	REMEDIATION SUPERVISION		1392	10/1/97	8/18/04	10/1/97		8/18/04					
	CMI		27259	10/1/97	8/18/04	10/1/97		8/18/04					
	VCA REMEDIATION		1601	3/2/98	8/11/00	3/2/98		8/14/01					
6.1.13	1106: TA-21 ASSESSMENT												
	RFI WORK PLAN		2170										
	RFI		49878	10/1/92	9/30/11			9/30/11		10/1/92			
	15M004 EPA/NMED DRAFT PH1 RPT/WP MOD				11/20/96			11/20/96					
	RFI REPORT		9029		10/21/99			10/21/99		12/1/92			
	15M010 EPA/NMED DRAFT RFI REPOR				7/21/99			7/21/99					
	CMS PLAN		3495		8/17/00	7/22/99		8/17/00					
	15M020 EPA/NMED DRAFT CMS PLAN				4/26/00			4/26/00					
	CMS WORK		2904	10/1/92	8/13/01			8/13/01		10/1/92			
	CMS REPORT		3680		7/25/02	8/14/01		7/25/02					
	15M045 EPA/NMED DRAFT CMS REPORT				4/24/02			4/24/02					
	ADS MANAGEMENT		6425	10/1/92	8/23/02			8/23/02		10/1/92			
	VCA		360	3/1/93	9/30/99			9/30/99		6/1/93			
	1106: TA-21 REMEDIATION												
	REMEDIATION SUPERVISION		1838	10/1/99	9/30/11	10/1/99		9/30/11					
	CMI		29379	10/1/03	9/30/08	10/1/03		9/30/08					
	VCA REMEDIATION		50567	3/1/00	9/30/11	3/1/00		9/30/11					
6.1.14	1111: TA-6, 7, 22, 40, 58, 62 ASSESSMENT												
	RFI WORK PLAN		1521		10/21/93			2/14/94		10/1/90			
	16M010 EPA/NMED DRAFT RFI WORK				5/12/93			10/22/93					
	RFI		10997	11/30/93	10/1/95	3/22/94		10/20/95					
	16M095 EPA/NMED DRAFT PH1 RPT/W				2/28/95			6/15/95					
	RFI REPORT		2194		1/14/97	12/1/94		1/30/97					
	16M035 EPA/NMED DRAFT RFI REPOR				10/4/96			10/23/96					
	CMS PLAN		1044		8/5/97	10/24/96		9/17/97					
	16M050 EPA/NMED DRAFT CMS PLAN				5/8/97			5/27/97					
	CMS WORK		5014	10/1/92	9/30/98			10/13/98		10/1/92			
	CMS REPORT		791		7/30/99	10/14/98		8/11/99					
	16M070 EPA/NMED DRAFT CMS REPORT				4/29/99			5/11/99					
	ADS MANAGEMENT		1218	10/1/92	7/30/99			7/30/99		10/1/92			
	VCA		179	10/1/92	9/30/96			9/30/96		10/1/92			
	1111: TA-6,7,22,40,58,62 REMEDIATION												
	REMEDIATION SUPERVISION		168	10/1/96	9/28/01	10/1/96		9/28/01					
	CMI		4236	10/1/99	9/28/01	10/1/99		9/28/01					
	VCA REMEDIATION		1114	3/3/97	9/29/99	3/3/97		9/29/99					
6.1.15	1114: TA-3, 30, 59, 60, 61, 64 ASSESSMENT												
	RFI WORK PLAN		4775	10/1/92	12/20/96			12/20/96		10/1/92			
	17M005 EPA/NMED DRAFT RFI WORK				7/12/96			7/12/96					
	RFI		23664	10/1/93	7/25/00	5/11/94		7/25/00					
	17M110 EPA/NMED DRAFT PH1 RPT/W				1/14/00			1/14/00					
	RFI REPORT		12879		11/30/01	7/28/98		11/30/01					
	17M050 EPA/NMED DRAFT RFI REPOR				8/27/01			8/27/01					
	CMS PLAN		0										
	17M065 EPA/NMED DRAFT CMS PLAN												
	CMS WORK		0	10/1/92	9/28/01			9/28/01		10/1/92			
	CMS REPORT		0										

	17M085 EPA/NMED DRAFT CMS REPORT											
	ADS MANAGEMENT	2049	10/1/92	11/30/01			11/30/01		10/1/92			
	VCA	818	3/1/93	9/28/01			9/28/01		11/1/92			
	1114: TA-3,30,59,60,61,64 REMEDIATION											
	REMEDIATION SUPERVISION	857	10/2/00	9/28/12	10/2/00		9/28/12					
	CMI	0										
	VCA REMEDIATION	37122	3/1/01	9/28/12	3/1/01		9/28/12					
6.1.16	1122: TA-33 ASSESSMENT											
	RFI WORK PLAN	1614	10/1/92	1/14/93			10/27/93		10/1/92			
	18M005 EPA/NMED DRAFT RFI WORK			5/22/92			5/22/92				5/22/92	
	RFI	5127	10/1/92	9/20/96			9/20/96		3/22/92			
	18M085 EPA/NMED DRAFT PH1 RPT/W			4/20/95			4/20/95					
	RFI REPORT	2500		2/2/98	4/13/94		2/2/98					
	18M025 EPA/NMED DRAFT RFI REPOR			10/24/97			10/24/97					
	CMS PLAN	881		9/18/98	10/27/97		9/18/98					
	18M040 EPA/NMED DRAFT CMS PLAN			5/28/98			5/28/98					
	CMS WORK	675	10/1/92	9/30/99			9/30/99		10/1/92			
	CMS REPORT	880		7/31/00	10/1/99		7/31/00					
	18M060 EPA/NMED DRAFT CMS REPORT			4/28/00			4/28/00					
	ADS MANAGEMENT	1727	10/1/92	7/31/00			7/31/00		10/1/92			
	VCA	496	3/1/93	9/30/98			9/30/98		7/1/93			
	1122: TA-33 REMEDIATION											
	REMEDIATION SUPERVISION	135	10/1/97	9/30/03	10/1/97		9/30/03					
	CMI	1609	10/1/01	9/30/03	10/1/01		9/30/03					
	VCA REMEDIATION	2263	3/2/98	9/30/03	3/2/98		9/30/03					
6.1.17	1127: TA-35 WASTE OIL STORAGE PIT											
	STRG PIT CLSR REMEDIATION	1164	2/3/93	3/26/93			12/2/93		4/1/93			
	ADS MANAGEMENT	19	10/1/92	3/26/93					10/1/92			
	CLOSURE FIELD WORK	15	10/1/92	2/17/93					10/1/92		4/1/93	
6.1.18	1129: TA-4, 5, 35, 42, 48, 52, 55, 63, 66 ASSESSMENT											
	RFI WORK PLAN	1991	10/1/92	4/23/93			12/3/93		12/1/92			
	20M100 EPA/NMED DRAFT RFI WORK			5/22/92			5/22/92					
	RFI	14018	10/1/92	7/30/97			4/17/98		10/1/92			
	20M180 EPA/NMED DRAFT PH1 REPO			5/8/97			12/15/97					
	RFI REPORT	8530		12/7/98	9/20/94		8/20/99					
	20M125 EPA/NMED DRAFT OF RFI REP			9/1/98			5/20/99					
	CMS PLAN	999		7/28/99	5/21/99		4/14/00					
	20M140 EPA/NMED DRAFT CMS PLAN			4/6/99			12/20/99					
	CMS WORK	1880	10/1/92	7/27/00			4/16/01		10/1/92			
	CMS REPORT	1025		6/11/01	4/17/01		2/28/02					
	20M160 EPA/NMED DRAFT CMS REPO			2/26/01			11/6/01					
	ADS MANAGEMENT	4523	10/1/92	6/11/01			6/11/01		10/1/92			
	VCA	2534	3/1/93	6/8/01			9/28/01		5/10/93			
	1129: TA-4, 5, 35, 42, 48, 52, 55, 63, 66 REMEDIATION											
	REMEDIATION SUPERVISION	870	10/1/01	9/30/13	10/1/01		9/30/13					
	CMI	2453	10/1/02	9/30/04	10/1/02		9/30/04					
	VCA REMEDIATION	91375	3/1/99	9/30/13	3/1/99		9/30/13					
6.1.19	1130: TA-36, 68, 71 ASSESSMENT											
	RFI WORK PLAN	604		7/30/93			1/12/94		10/1/91			
	21M015 EPA/NMED DRAFT RFI WORK			4/15/93			5/21/93					
	RFI	2635	5/23/93	6/27/95	10/1/93		5/28/96					
	21M095 EPA/NMED DRAFT PH1 RPT/W			1/9/95			3/6/95					
	RFI REPORT	1243		10/30/96	7/8/94		9/30/97					
	21M040 EPA/NMED DRAFT RFI REPOR			7/30/96			6/30/97					
	CMS PLAN	1105		6/24/97	7/1/97		5/26/98					
	21M055 EPA/NMED DRAFT CMS PLAN			3/4/97			2/2/98					
	CMS WORK	175	10/1/92	9/30/98			5/25/99		10/1/92			

	CMS REPORT	912		7/30/99	5/26/99		3/24/00					
	21M075 EPA/NMED DRAFT CMS REPORT			4/29/99			12/20/99					
	ADS MANAGEMENT	1447	10/1/92	7/30/99			7/30/99		10/1/92			
	VCA	2504	7/30/93	9/30/98	3/1/94		9/30/98					
	1130: TA-36, 68, 71 REMEDIATION											
	REMEDIATION SUPERVISION	145	10/1/97	9/28/01	10/1/97		9/28/01					
	CMI	598	10/1/97	9/28/01	10/1/97		9/28/01					
	VCA REMEDIATION	3129	3/3/97	9/30/99	3/3/97		5/24/00					
6.1.20	1132: TA-39 ASSESSMENT											
	RFI WORK PLAN	443		7/1/93			1/24/94		10/1/91			
	22M010 EPA/NMED DRAFT RFI WORK			3/18/93			6/15/93					
	RFI	10085	7/2/93	1/18/96			6/11/96		6/1/93			
	22M090 EPA/NMED DRAFT PH1 RPT/W			5/2/95			11/22/95					
	RFI REPORT	2341		5/21/97	5/11/95		10/15/97					
	22M035 EPA/NMED DRAFT RFI REPOR			2/20/97			7/15/97					
	CMS PLAN	128		1/14/98	7/16/97		6/9/98					
	22M050 EPA/NMED DRAFT CMS PLAN			9/16/97			2/17/98					
	CMS WORK	0	10/1/92	9/30/99			9/30/99		10/1/92			
	CMS REPORT	1397		7/31/00	10/1/99		7/31/00					
	22M070 EPA/NMED DRAFT CMS REPORT			4/28/00			4/28/00					
	ADS MANAGEMENT	1608	10/1/92	7/31/00			7/31/00		10/1/92			
	VCA	166	3/19/93	8/11/00			8/11/00		2/15/93			
	1132: TA-39 REMEDIATION											
	REMEDIATION SUPERVISION	529	10/1/98	9/29/06	10/1/98		9/29/06					
	CMI	2063	8/1/00	9/30/02	8/1/00		9/30/02					
	VCA REMEDIATION	25583	3/3/97	9/29/06	3/3/97		9/29/06					
6.1.21	1135: TA-40 DETONATION SITE CLOSURE REMEDIATION											
	CLOSURE PLAN	60										
	CLOSURE IMPLEMENTATION	382	10/1/92	12/9/92	10/1/93		12/9/93					
	23M005 CLOSURE IMPLEMENTATION CMPL			12/9/92			12/9/93					
	CLOSURE CERTIFICATION AND REPORT	94	10/13/92	2/3/93	2/3/94		10/21/92					
	23M015 CLOSURE CERTIFICATION RPT			2/3/93			2/3/94					
	ADS MANAGEMENT	36	10/1/92	2/3/93					10/1/92		2/3/93	
6.1.22	1136: TA-46 ASSESSMENT											
	RFI WORK PLAN	295		9/7/94			10/12/94		10/1/92			
	24M010 EPA/NMED DRAFT RFI WORK PLAN			5/23/94			6/27/94					
	RFI	603	9/8/94	1/23/97	10/13/94		1/23/97					
	24M095 EPA/NMED DRAFT PH1 RPT/WP MOD			7/16/96			7/16/96					
	RFI REPORT	890		5/28/98	1/4/96		5/28/98					
	24M035 EPA/NMED DRAFT RFI REPORT			2/26/98			2/26/98					
	CMS PLAN	0										
	24M050 EPA/NMED DRAFT CMS PLAN											
	CMS WORK	0	10/1/92	9/30/99			9/30/99		10/1/92			
	CMS REPORT	0										
	24M070 EPA/NMED DRAFT CMS REPORT											
	ADS MANAGEMENT	597	10/1/92	5/28/98			5/28/98		10/1/92			
	VCA	177	3/1/93	9/30/99	3/1/94		9/30/99					
	1136: TA- 46 REMEDIATION											
	REMEDIATION SUPERVISION	248	10/1/97	9/30/99	10/1/97		9/30/99					
	CMI	0										
	VCA REMEDIATION	17	3/2/98	9/30/99	3/2/98		9/30/99					
6.1.23	1140: TA-46 ASSESSMENT											
	RFI WORK PLAN	1336		9/21/93			2/1/94		10/2/91			
	25M010 EPA/NMED DRAFT RFI WORK			5/17/93			9/30/93					
	RFI	6410	9/22/93	1/26/96	2/2/94		4/17/96					
	25M090 EPA/NMED DRAFT PH1 RPT/W			7/19/95			9/22/95					
	RFI REPORT	2275		5/30/97	3/6/95		8/20/97					
	25M035 EPA/NMED DRAFT RFI REPOR			2/28/97			5/20/97					
	CMS PLAN	0										
	25M050 EPA/NMED DRAFT CMS PLAN											
	CMS WORK	486	10/1/92	9/30/96	10/1/93		9/30/96					

	CMS REPORT	0										
	25M070 EPA/NMED DRAFT CMS REPORT											
	ADS MANAGEMENT	1024	10/1/92	9/30/97			5/30/97		10/1/92			
	VCA	4488	3/1/94	9/30/97	3/1/94		9/30/97		10/1/91			
	1140: TA-48 REMEDIATION											
	REMEDIATION SUPERVISION	46	10/1/97	9/30/98	10/1/97		9/30/98					
	CMI	0										
	VCA REMEDIATION	163	3/3/97	9/30/98	3/3/97		9/30/98					
6.1.24	1144: TA-49 ASSESSMENT											
	RFI WORK PLAN	1053	10/1/92	1/8/93			12/3/93		7/2/90			
	26M010 EPA/NMED DRAFT RFI WORK			5/22/92			5/22/92					
	RFI	4891	5/22/92	4/29/97			9/3/97		5/22/92			
	26M030 EPA/NMED DRAFT PH1 RPT/W			1/2/96			5/7/96					
	RFI REPORT	1633		3/18/99	1/16/96		7/22/99					
	26M040 EPA/NMED DRAFT RFI REPOR			12/11/98			4/21/99					
	CMS PLAN	1086		10/13/99	4/22/99		2/24/00					
	26M060 EPA/NMED DRAFT CMS PLAN			6/21/99			10/26/99					
	CMS WORK	0	12/14/98	10/13/00	4/22/99		2/26/01					
	CMS REPORT	1150		8/22/01	2/27/01		1/3/02					
	26M085 EPA/NMED DRAFT CMS REPORT			5/22/01			9/26/01					
	ADS MANAGEMENT	3270	10/1/93	9/17/01	11/2/93		10/17/01					
	VCA	282	10/1/92	9/30/98			9/29/99		8/2/93			
	1144: TA-49 REMEDIATION											
	REMEDIATION SUPERVISION	264	10/2/00	9/30/03	10/2/00		9/30/03					
	CMI	858	10/1/02	9/30/03	10/1/02		9/30/03					
	VCA REMEDIATION	1899	10/1/92	9/30/02			9/30/02		10/1/92			
6.1.25	1147: TA-50 ASSESSMENT											
	RFI WORK PLAN	1057	10/1/92	12/15/92			9/21/93		4/6/90			
	27M010 EPA/NMED DRAFT RFI WORK			5/22/92			5/22/92				5/22/92	
	RFI	10170	12/16/92	10/16/95			10/16/95		1/4/93			
	27M090 EPA/NMED DRAFT PH1 RPT/W			6/5/95			6/5/95					
	RFI REPORT	1384		2/25/97	1/16/94		2/25/97					
	27M035 EPA/NMED DRAFT RFI REPOR			11/18/96			11/18/96					
	CMS PLAN	1733		10/10/97	11/19/96		10/10/97					
	27M050 EPA/NMED DRAFT CMS PLAN			6/19/97			6/19/97					
	CMS WORK	0	10/1/92	9/30/98			9/30/98		10/1/92			
	CMS REPORT	799		7/30/99	10/1/98		7/30/99					
	27M070 EPA/NMED DRAFT CMS REPO			4/29/99			4/29/99					
	ADS MANAGEMENT	1255	10/1/92	8/11/00			8/11/00		10/1/92			
	VCA	1931	3/1/93	9/29/00	9/1/93		9/29/00					
	1147: TA-50 REMEDIATION											
	REMEDIATION SUPERVISION	740	10/1/96	9/30/05	10/1/96		9/30/05					
	CMI	23307	8/2/99	9/30/05	8/2/99		9/30/05					
	VCA REMEDIATION	7407	3/1/96	9/29/00	3/1/96		9/29/00					
6.1.26	1148: TA-51, 54 ASSESSMENT											
	RFI WORK PLAN	2891	10/1/92	1/14/93			12/14/93		9/2/89			
	28M015 EPA/NMED DRAFT RFI WORK			5/22/92			5/22/92			5/22/92		
	RFI	16541	10/1/92	4/11/96	11/1/92		4/11/96					
	28M095 EPA/NMED DRAFT PH1 RPT/W			4/8/96			4/8/96					
	RFI REPORT	2050		1/27/98	11/7/95		1/27/98					
	28M040 EPA/NMED DRAFT RFI REPORT			10/20/97			10/20/97					
	CMS PLAN	2643		10/27/98	10/21/97		10/27/98					
	28M055 EPA/NMED DRAFT CMS PLAN			7/6/98			7/6/98					
	CMS WORK	1922	10/1/92	10/27/99			10/27/99		10/1/92			
	CMS REPORT	2356		9/5/00	10/28/99		9/5/05					
	28M075 EPA/NMED DRAFT CMS REPORT			6/5/00			6/5/00					
	ADS MANAGEMENT	2164	10/1/92	9/5/00			9/5/00		10/1/92			
	VCA	11861	10/1/92	6/2/03			3/9/04		10/1/92			
	MDA G PILOT STUDIES	2439										
	1148: TA-51, 54 REMEDIATION											
	REMEDIATION SUPERVISION	549	10/1/98	9/29/06	10/1/98		9/29/06					
	CMI	27707	10/1/01	9/29/06	10/1/01		9/29/06					
	VCA REMEDIATION	19020	10/1/97	9/30/04	10/1/97		9/30/04					

6.1.27	1154: TA-57 FENTON HILL ASSESSMENT												
	RFI WORK PLAN	330		9/7/94			11/9/94		12/30/92				
	30M010 EPA/NMED DRAFT RFI WORK PLAN			5/23/94			7/26/94						
	RFI	371	9/8/94	7/21/95	11/10/94		7/21/95						
	30M090 EPA/NMED DRAFT PH1 RPT/WP MOD												
	RFI REPORT	267		11/25/96	7/24/95		11/25/96						
	30M035 EPA/NMED DRAFT RFI REPORT			8/22/96			8/22/96						
	CMS PLAN	0											
	30M050 EPA/NMED DRAFT CMS PLAN												
	CMS WORK	106	10/1/93	9/30/94	10/1/93		9/30/94						
	CMS REPORT	0											
	30M070 EPA/NMED DRAFT CMS REPORT												
	ADS MANAGEMENT	533	10/1/92	9/30/96			9/30/96		10/1/92				
	VCA	459	5/24/94	9/30/96	7/27/94		9/30/96						
	1154: TA-57 FENTON HILL REMEDIATION												
	REMEDIATION SUPERVISION	487	10/1/96	9/30/98	10/1/96		9/30/98						
	CMI	0											
	VCA REMEDIATION	516	3/3/97	9/30/98	3/3/97		9/30/98						
6.1.28	1157: TA-8, 9, 23, 69 ASSESSMENT												
	RFI WORK PLAN	1059		8/31/93			1/24/94		12/2/91				
	31M015 EPA/NMED DRAFT RFI WORK			5/17/93			9/30/93						
	RFI	8376	3/18/93	6/24/96			6/24/96		3/22/93				
	31M095 EPA/NMED DRAFT PH1 RPT/W			3/13/95			3/13/95						
	RFI REPORT	3155		10/28/97	6/9/94		10/28/97						
	31M040 EPA/NMED DRAFT RFI REPOR			7/28/97			7/28/97						
	CMS PLAN	977		6/22/98	7/29/97		6/22/98						
	31M055 EPA/NMED DRAFT CMS PLAN			3/2/98			3/2/98						
	CMS WORK	0	10/1/92	9/30/99			9/30/99		10/1/92				
	CMS REPORT	844		7/31/00	10/1/99		7/31/00						
	31M075 EPA/NMED DRAFT CMS REPORT			4/28/00			4/28/00						
	ADS MANAGEMENT	1279	10/1/92	7/31/00			7/31/00		10/1/92				
	VCA	3237	10/1/92	9/30/99			9/30/99		10/1/92				
	1157: TA-8, 9, 23, 69 REMEDIATION												
	REMEDIATION SUPERVISION	196	10/1/98	9/30/08	10/30/98		9/30/08						
	CMI	14216	10/1/04	9/30/08	10/1/04		9/30/08						
	VCA REMEDIATION	6626	3/3/97	9/29/00	3/3/97		9/29/00						
6.3.03	2107: ASSESSMENT MANAGEMENT ACTIVITIES												
	EM-13 PROGRAMMATIC	224752	10/1/92	9/28/18			9/28/18		10/1/92				
	MANAGEMENT INFO SYSTEM TEAM	180866		9/28/18			9/28/18		10/1/92				
	ADEE DIRECTORATE SUPPORT	78161	10/1/92	9/28/18			9/28/18		10/1/92				
	EM-13 GROUP MANAGEMENT	23672		9/28/18			9/28/18		10/1/92				
6.3.04	2105: PROGRAMMATIC TECHNICAL SUP												
	DATA QUALITY OBJ & STATISTICS	704											
	FRAMEWORK STUDIES	21948		9/30/05			9/30/05		10/1/92				
	ANALYTICAL CHEM/INSTR DEV'MT	1939											
	ASSESS/REMED TECHNOLOGY DEV'MT	1394	10/1/92	9/30/96			9/30/96		10/1/92				
	ENVIRON ENG PILOT STUDIES	12022		9/30/03			9/30/03		10/1/92				
	FIMAD	91304		9/28/18			9/28/18		10/1/92				
	RECORD MANAGEMENT FACILITY RP	30800		9/28/18			9/28/18		10/1/92				
	DECISION/COST BENEFIT ANALYSIS	9531		9/30/05			9/30/05		10/1/92				
	RISK ASSESSEMENT	4353		9/30/05			9/30/05		10/1/92				
	DRILLING SUPPORT TEAM	37260		9/30/05			9/30/05		10/1/92				
	GEOCHEMISTRY SUPPORT TEAM	4953	10/1/92	9/30/05			9/30/05		10/1/92				
	GEOLOGY SUPPORT TEAM	4010	10/1/92	9/30/05			9/30/05		10/1/92				
	HYDROLOGY SUPPORT TEAM	6577	10/1/92	9/30/05			9/30/05		10/1/92				
	QA/SELF ASSESSMENT	17390		9/13/19			9/13/19		10/1/92				
	ECOLOGICAL BASELINE STUDIES	7466		9/30/05			9/30/05		10/1/92				
	IWP UPDATE	6725		9/13/19			9/13/19		10/1/92				
	32M095 IWP FOR FY-93			11/19/93			11/19/93						
	32M100 IWP FOR FY-94			11/18/94			11/18/94						
	32M105 IWP FOR FY-95			11/17/95			11/17/95						
	32M110 IWP FOR FY-96			11/19/96			11/19/96						

	32M115 IWP FOR FY-97				11/19/97			11/19/97					
	32M120 IWP FOR FY-98				11/19/98			11/19/98					
	SOP REVISIONS	5191	10/1/92		9/28/18			9/28/18		10/1/92			
	RENOVATION & CAPITAL EQUIPMENT	5807			9/28/18			9/28/18		11/2/92			
	SAMPLING STRATEGIES	1481											
	SAMPLE FACILITY	315											
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This glossary is included in this version of the Installation Work Plan (IWP) as a draft. Updated, more complete versions will appear in future editions of the IWP.

ER PROGRAM GLOSSARY
DRAFT

Accuracy Any measure of the bias of a sampling and measurement procedure. Accuracy may be quantified using the difference between the average measurement and the correct measurement. **(Campbell)**

Action description memorandum
Action level
Activity data sheet
Administrative procedure

Administrative record A file established in compliance with the requirements set forth in Section 113(k) of CERCLA, as amended, consisting of information upon which EPA bases its decision on the selection of response actions. The administrative record should be established at or near the facility at issue and made available to the public. **(DOE 1991)**

Adsorption Bonding, frequently ionic, of a substance to soil or other medium. A substance is said to be adsorbed if the concentration in the boundary region of a soil particle is greater than in the interior of the contiguous phase. **(DOE 1991)**

Aliquot A subsample removed from a *sample* (*grab* or *composite*) for *analysis*. **(Campbell)**

Alluvial fan A fan-shaped accumulation of sediment deposited by a stream. **(1122)**

Alluvium Clay, silt, sand, gravel, or other rock materials transported by flowing water and deposited in fairly recent geologic time as sorted or semisorted sediments in riverbeds, estuaries, flood plains, lakes shores, and fans at the base of mountain slopes. **(CDR)**

Alpha radiation Ionizing radiation composed of alpha particles emitted in the radioactive decay of certain nuclides. Alpha particles consist of two protons and two neutrons bound together; an alpha particle is identical to the nucleus of a helium atom. It is the least penetrating of the three common types of radiation—alpha, beta, gamma—and can be blocked by a sheet of paper or outer dead layer of skin. **(CDR; DOE 1991)**

Andesite A gray, fine-grained volcanic rock, chiefly plagioclase and pyroxene. **(1122)**

Applicable, relevant, or appropriate requirement (ARARs) Those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only those state standards that are identified by a state in a timely manner and that are more stringent than federal requirements may be applicable. **(40 CFR 300.5)**

A requirement under other environmental laws (other than CERCLA) may be either "applicable" or relevant and appropriate," but not both. Identification of ARARs must be done on a site-specific basis and involves a two-part analysis: first a determination of whether a given requirement is applicable; then, if it is not applicable, a determination of whether it is nevertheless both relevant and appropriate. **(DOE 1991)**

Those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, or that address problems or situation sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. **(DOE 1991)**

Aquifer An underground geological formation, group of formations, or part of a formation that is capable of yielding a significant amount of water to a well or spring. **[40 CFR 1.1.12(i)]**

An underground rock formation composed of materials such as sand, soil, or gravel that can store and supply ground water to wells and springs. Most aquifers used in the United States are within a thousand feet of the earth's surface. **(DOE 1991)**

Area of concern

Army Corps of Engineers A branch of the US Department of Defense that has specialized equipment and personnel for maintaining navigation channels, for removing navigation obstruction, for accomplishing structural repairs, and for performing maintenance to hydropower electric generating equipment. The Corps can also provide design services, perform construction, and provide contract writing and contract administrative services for other federal agencies, such as EPA for Superfund actions. **(DOE 1991)**

As low as practicable

As low as reasonably achievable (ALARA) An approach to radiation protection to control or manage exposures (both individual and collective to the work force and general public) as lows as social, technical, economic, practical, and public policy considerations permit. As used in this order, ALARA is not a dose limit but a process, which has the objective of dose levels as far below applicable limits of the order as reasonably achievable. **(DOE Order 5480.11)**

An approach to radiation protection to control or manage exposures (both individual and collective to the work force and the general public) and releases of radioactive material to the environment as low as social, technical, economic, practical, and public policy considerations permit. As used in this order, ALARA is not a dose limit but rather it is a process that has as its objective the attainment of dose levels as far below the applicable limits of the order as practicable. **(DOE Order 5400.5) from (DOE 1991)**

Ash flow tuff A tuff deposited by a hot dense current, ash-flow tuff can be either welded or unwelded and often fills in channels, making the thickness of the resulting deposit a function of the underlying topography. **(CDR)**

Atomic Energy Commission

Background levels The distribution of concentrations of naturally occurring or widely distributed anthropogenic constituents in environmental media. **(Campbell)**

Background radiation The radioactivity in the environment, including cosmic rays from space and radiation that exists elsewhere—in the air, in the earth, and in man-made materials. In the US, most people receive 100 to 250 millirems of background radiation per year. **(DOE 1991)**

Barrier Any material or structure that prevents or substantially delays movement of water or radionuclides. **(10 CFR 60.2)**

Basalt A hard, dense, dark volcanic rock composed chiefly of plagioclase, augite, olivine, and magnetite. **(1122)**

Base/neutral/acid

Baseline risk assessment A risk calculation that uses an appropriate, site-specific exposure scenario but that assumes no mitigating or corrective measures beyond those already in place. **(Campbell)**

Bedrock Solid rock that underlies all soil, sand, clay, gravel, and loose material on the earth's surface. **(CDR)**

Bentonite A clay containing the mineral montmorillonite, and variable amounts of magnesium and iron, that formed over time by the alteration of volcanic ash. Bentonite can adsorb large quantities of water and expand to several times its normal volume. **(CDR)**

Bermed area

Beta radiation Emitted from a nucleus during fission. Beta radiation can be stopped by an inch of wood or a thin sheet of aluminum. **(DOE 1991)**

Bias A systematic discrepancy between the actual and correct results of a sampling and analysis procedure. Bias may result from imperfect procedures for sampling (e.g., use of judgment samples), for measurement (e.g., errors in instrument calibration), or both. **(Campbell)**

Biological resource evaluation team

Boneyard

Bound

Breccia Rock consisting of sharp, angular fragments cemented together or embedded in a fine-grained matrix. **(CDR)**

Buffer zone A portion of the disposal site that is controlled by the licensee and that lies under the disposal units and between the disposal units and the boundary of the site. **(10 CFR 61.2)**

Byproduct material (a) Any radioactive material (except special nuclear material) yielded in, or made radioactive by, exposure to the radiation incident or to the process of producing or utilizing special nuclear material. For purposes of determining the applicability of the Resource Conservation and Recovery Act to any radioactive waste, the term "any radioactive material" refers only to the actual radionuclides dispersed or suspended in the waste substance. The nonradioactive hazardous waste component of the waste substance will be subject to regulation under the Resource Conservation and Recovery Act.

(b) The tailings or waste produced by the extraction or concentration of uranium or thorium from any ore processed primarily for its source material content. Ore bodies depleted by uranium solution extraction operations and which remain underground do not constitute "byproduct material."

Caldera A volcanic collapse structure, generally on the order of tens of kilometers in diameter, formed during the eruption of volumetrically large (tens to hundreds of cubic kilometers of dense rock equivalent), ashflow and ash-fall tuff deposits. **(CDR)**

Caliche Gravel, sand, or desert debris cemented by porous calcium carbonate; also the calcium carbonate cement. **(CDR)**

Cambrian The oldest of the periods of the Paleozoic Era, which lasted from 570 to 500 million years ago. **(CDR)**

Chain of custody
Change control
Change order

Characterization Describes the qualities or peculiarities of something; defining **(1122)**

Cinder cone A conical hill formed by the accumulation of cinders and other matter ejected from a volcano. **(1122)**

Cleanup Actions undertaken during a removal or remedial response to physically remove or treat a hazardous substance that poses a threat or potential threat to human health and welfare and the environment and/or real and personal property. Sites are considered cleaned up when EPA removal or remedial programs have no further expectation or intention of returning to the site and threats have been mitigated or do not require further action. **(DOE 1991)**

Cleanup levels Media-specific target concentration levels for contaminants that must be met by a selected corrective action. Cleanup levels are established at the conclusion of the corrective measures study (CMS) using criteria such as protection of human health and the environment; compliance with regulatory requirements; reduction of toxicity, mobility, or volume through treatment; long- and short-term effectiveness; implementability; cost; and public acceptance. **(Campbell)**

Clinoptilolite A zeolite mineral. **(1122)**

Closure

CMS risk assessment A risk calculation that estimates the expected reduction in risk resulting from a proposed corrective measure under an appropriate, site-specific exposure scenario. **(Campbell)**

Cobble A rock fragment larger than a pebble and smaller than a boulder. **(1122)**

Colluvium Rock debris accumulated at the base of a cliff or slope, brought there principally by gravity. **(1122)**

Community relations EPA's program to inform and encourage public participation in the Superfund process and to respond to community concerns. The term "public" includes citizens directly affected by the site, other interested citizens or parties, organized groups, elected officials, and potentially responsible parties.

Community relations plan A plan that is prepared at the start of most Superfund response activities to direct activities that will allow the community affected by the site to be kept informed of EPA, state and potentially responsible party activities. Those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, or that address problems or situation sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. **(DOE 1991)**

Community relations program plan The facility-wide community relations plan developed by the Environmental Restoration Program at Los Alamos National Laboratory and described in the Installation Work Plan **(Barnett)**

Community relations project plan A project-specific community relations plan developed for individual operable units at Los Alamos National Laboratory and described in operable unit work plans. **(Barnett)**

Comparability The relationship between measurements produced by different sampling and analysis procedures, or by the same sampling and analysis procedures applied under different conditions, for the same target population. There are no generally applicable measures of comparability. **(Campbell)**

Completeness Any measure of relationship between the quantity and/or quality of measurements produced by a specified sampling and analysis procedure and the quantity and/or quality needed, planned or anticipated prior to implementation of the procedure. **(Campbell)**

Composite liquid waste sampler

Composite sample A specimen that is formed by combining and homogenizing several grab samples. **(Campbell)**

Comprehensive Environmental Assessment and Response Program

Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) The Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986. **(40 CFR 300.5)**

A federal law passed in 1980 and modified in 1986 by SARA. The acts created a special tax that goes into a trust fund, commonly known as Superfund, to investigate and clean up abandoned or uncontrolled hazardous waste sites. Under the program, EPA can either

(1) pay for site cleanup when parties responsible for the contamination cannot be located or are unwilling or unable to per form the work, or

(2) take legal action to force parties responsible for site contamination to clean up the site or pay back the federal government for the cost of the cleanup. **(DOE 1991)**

Conceptual exposure model A conceptual model whose objects are qualitative or quantitative descriptions of sources of contamination, environmental transport pathways for contamination, and biota that may be impacted by contamination (called receptors) and whose relationships describe qualitatively or quantitatively the release of contamination from the sources, the movement of contamination along the pathways to the exposure points, and the uptake of contaminants by the receptors. **(Campbell)**

Conceptual hydrological (or hydrogeological) model

Conceptual model A mathematical model that represents, by means of symbolic objects and qualitative or quantitative relationships among them, a physical, biological, or social system. **(Campbell)**

Confidence interval

Conglomerate Rock consisting of pebbles and gravel embedded in a loosely cementing material **(1122)**

Constituent Any compound or element present in environmental media, including both naturally occurring and anthropogenic elements. **(Campbell)**

Construction project manager

Contaminant Any constituent present in environmental media or on structural debris at a concentration that may present a risk to human health or the environment. **(Campbell)**

Contaminant of concern Any constituent present in environmental media or on structural debris at a concentration that may present a risk to human health or the environment. **(Campbell)**

Contamination reduction zone

Controlled area Any area to which access is controlled in order to protect individuals from exposure to radiation and radioactive materials.

Control zone
Controlled distribution
Corrective action
Corrective action management unit

Corrective measures study The portion of a RCRA corrective action that is generally equivalent to a feasibility study taken under Superfund. **(DOE 1991)**

Corrective measures implementation

Curie A unit of radioactivity defined as the amount of a radioactive material that has an activity of 3.7 x 10^{10} disintegrations per second. **(CDR)**

Dacite A fine-grained extrusive rock containing plagioclase, quartz, alkali feldspar, pyroxene, hornblende, and biotite **(1122)**

Data quality objectives (DQOs) Qualitative and quantitative statements that are developed before sampling begins to allow EPA to identify the quality of data that must be collected during Superfund actions. **(DOE 1991)**

Specifications for sampling and analysis plans, including but not limited to specifications of the media and areas to be sampled, sampling protocols to be used, variables to be measured, analytical methods to be used, and precision and accuracy requirements for the sampling and analysis procedures. **(Campbell)**

Data quality objectives process A step-by-step procedure to develop appropriate data quality objectives based on a decision model (that is, on a statement of decision alternatives, uncertainties, and values). **(Campbell)**

Decay (1) The process whereby radioactive materials undergo a change from one nuclide, element, or state to another, releasing radiation in the process. this action ultimately results in a decrease in the number of radioactive nuclei present in the sample. (2) The spontaneous transformation of one nuclide into a different nuclide or into a different isotope of the same nuclide. **(CDR)**

Decision analysis

Decision model A conceptual model whose objects are qualitative or quantitative descriptions of options (decision alternatives), knowledge (and uncertainties), and objectives (or values) with respect to a given problem. **(Campbell)**

Decommissioning The permanent removal from service of surface facilities and components necessary for preclosure activities only, after ~~repository~~ **facility** closure, in accordance with regulatory requirements and environmental policies. **(CDR)**

Decontamination The removal of unwanted material (especially radioactive material) from the surface of or from within another material. **(CDR)**

Deferred action Postponement of selection and implementation of corrective measures until a future date, usually following decommissioning of an active site. **(Campbell)**

Deferred investigation Postponement of complete evaluation of a PRS, which may be proposed when investigation would have negative impacts on current Laboratory operations. **(Campbell)**

Deficiency

Department of Energy
Department of Energy acquisition regulation
Derived air concentration

Design-based (probability) sampling A theory of statistical sampling according to which estimation of population parameters should be based on the probability of obtaining the selected sample. Randomization of the sampling plan is essential for the validity of inference based on this approach. **(Campbell)**

Detection level The minimum concentration of a substance that can be measured with a 99% confidence that the analytical concentration is greater than zero. **(DOE 1991)**

Detection limit

Discharge As defined by Section 311 (a)(2) of the Clean Water Act, includes, but is not limited to, any spilling, leaking, pumping, pouring, emitting, emptying, or dumping of oil, but excludes discharges in compliance with a permit under Section 402 of the act, discharges resulting from circumstances identified and reviewed and made part of the public record with respect to a permit issued or modified under Section 402 of the Act and subject to a condition in such permit, or continuous or anticipated intermittent discharges from a point source, identified in a permit or permit application under Section 402 of the act, that are caused by events occurring within the scope of relevant operating or treatment systems. For purposes of the NCP (National Contingency Plan?), discharge also means threat of discharge. **(DOE 1991)**

Discomfort curve Quantification of decision maker's tolerance for making the wrong decision, as a function of the amount by which the true condition of the site is above or below the action level. If the truth is very close to action levels, larger probabilities of error are acceptable than when the truth is much worse than, or much better than, those action levels. There is also a difference between tolerance for Type I and Type II errors. **(1122)**

A function that quantifies a decision maker's values that associates with each possible state of a population parameter (or with a functions of the state such as the associated risk under a specified exposure scenario) an upper bound for the probability of selecting a nonoptimal decision alternative, given that that state is the true one. **(Campbell)**

Disposal Emplacement of waste in a manner that assures isolation from the biosphere for the foreseeable future with no intent of retrieval and that requires deliberate action to regain access to the waste. **(DOE Order 5820.2A)**

The discharge, deposit, injection, dumping, spilling, leaking, or placing of any solid waste or hazardous waste into or on any land or water so that such solid waste or hazardous waste or any constituent thereof may enter the environment or be emitted into the air or discharged into any waters, including ground waters. **(RCRA 1004(3)**

Distribution [(probability) distribution] A function defined on subsets of a set S whose values are real numbers between zero and one, with the properties that its value on the empty set is zero, its value on S is one, and its value on the union of disjoint subsets is the some of its values on each set. **(Campbell)**

Diurnal Having daily cycles. **(CDR)**

DOE environmental checklist
Domain

Dose The quantity of radiation absorbed, per unit of mass, by the body or by any portion of the body. **(CDR)**

Dose equivalent An estimate of the amount of biological damage done by the deposition in tissue of a given unit of absorbed radiation does. The does equivalent is obtained by multiplying the absorbed radiation dose by a qualifying factor. The unit of does equivalent is the rem. **(CDR)**

Drop tower
Dry well
Duplicate
Emergency response planning guideline
Energy Research and Development Administration
Energy Systems Acquisition Advisory Board

Environmental assessment (EA)

Environmental medium Any medium capable of absorbing or transporting constituents released from a PRS, including tuffs, soils and sediments derived from these tuffs, surface water, groundwater, air, structural surfaces, and debris. **(Campbell)**

Environmental impact statement
Environmental Protection Agency

Eolian Pertaining to the wind, especially said of sediment deposition by the wind, of structures such as wind-formed ripple marks, or of erosion accomplished by the wind. **(CDR)**

Ephemeral stream

Exposure unit The bounded area or volume within which a person or other receptor may be exposed to contaminants that have been released to the environment. The size of an exposure unit is determined by the receptor activities as described by the exposure scenario. **(Campbell)**

Escarpment A long, more or less continuous cliff or relatively steep slope that was produced by erosion or faulting and faces in one general direction, breaking the continuity of the land by separating two levels or gently sloping surfaces. **(CDR)**

Estimate The value of an estimator based on the observed sample. **(Campbell)**

Estimator (statistic) Any function of a sample probability distribution, such as the sample maximum. **(Campbell)**

Evapotranspiration Discharge of water from the earth's surface to the atmosphere by evaporation from lakes, streams, and soil surfaces, and by transpiration from plants **(1122)**

Exclusion zone
Executive order

Expected value (mean) of a real random variable The first moment of the probability distribution of a real random variable; symbolically,

$$\int_{x \in S}^{?} x\, dP(x).$$ **(Campbell)**

Facility for Information Management, Analysis, and Display

Fanglomerate A sedimentary rock, originally deposited in an alluvial fan and subsequently cemented into a firm rock **(1122)**

Fault A fracture or zone of fractures along which there has been displacement of the sides relative to one another parallel to the fracture. **(CDR)**

Feasibility study A study undertaken by the lead agency to develop and evaluate options for remedial action. The FS emphasizes data analysis and is generally performed concurrently and in an interactive fashion with the remedial investigation (RI), using data gathered during the RI. The RI data re used to define the objectives of the response action, to develop remedial action alternatives, and to undertaken an initial screening and detailed analysis of the alternatives. The term also refers to a report that describes the results of the study. **(40 CFR 300.5)**

A study undertaken by the lead agency go develop and evaluate options for remedial action. the feasibility study emphasizes data analysis, implementablity of alternatives, and cost analyses, as well as compliance with mandates to protect human health and the environment and attain regulatory standards of other laws. The FS is generally performed concurrently and in an interactive fashion with the RI, using data gathered during the RI. **(DOE 1991)**

Federal acquisition regulation
Field instrument for detection of low-energy radiation
Field sampling plan
Field task leader
Field team

Field team leader Person responsible for implementing the sampling plan the OU's specific QAPjP. **(Wagner memo, EM-13:91-836)**

Field duplicate A second specimen collected as near as possible to one already included in the sample. In channel sediment sampling, field duplicates come from the same sediment catchment as another specimen. **(1122)**

Final safety analysis report (FSAR)
Finding
Firing site
Five-year plan
Flame ionization detector

Flood plain That portion of a river valley that is built of sediments deposited during the present regimen of the stream and is covered with water when the river overflows its banks at flood stages. **(CDR)**

Formerly Utilized Sites Remedial Action Program
Framework studies

Gamma radiation A form of electromagnetic, high-energy radiation emitted from a nucleus. Gamma rays are essentially the same as x-rays and require heavy shieldings, such as concrete or steel, to be stopped.

Gas chromatograph
Geographic Information System

Groundwater Water in a saturated zone or stratum beneath the surface of land or water. **[CERCLA 101(12)]**

Geohydrology
Glove box
Glow discharge mass spectrometry

Grab sample A specimen collected by a single application of a field sampling procedure to a target population, e.g., the surface soil from a single hole collected following the SOP for spade and scoop sampling, or a single air filter left in the field for three months. **(Campbell)**

Graphite furnace atomic absorption
Ground fault circuit interrupter

Half-life The time required for one-half of radioactive atoms initially present in a sample to decay. Each radionuclide has a characteristic half-life ranging from a fraction of a second to thousands of years. **(CDR, DOE 1991)**

Hazard-ranking system The method used by EPA to evaluate the relative potential of hazardous substance releases to cause health or safety problems or ecological or environmental damage. **(40 CFR 300.5)**

A scoring system used to evaluate potential relative risks to public health and the environment from releases or threatened releases of hazardous substances. EPA and states use the HRS to calculate a site score, from 0 to 100, based on the actual or potential release of hazardous substances from a site through air, surface water, or ground water to affect people. This score is the primary factor used to decide if a hazardous waste site should be placed on the National Priorities List. **(DOE 1991)**

Hazardous and Solid Waste Amendments (HSWA) Amendments to the Resource Conservation and Recovery Act that Congress passed in 1984. HSWA added the land disposal restrictions, minimum technology requirements, and expanded corrective action authorities to the RCRA statute. **(DOE 1991)**

Hazardous substance The term "hazardous substance" means (A) any substance designated pursuant to Section 311(b)(2)(A) of the Federal Water Pollution Control Act, (B) any element, compound, mixture, solution, or substance designated pursuant to Section 102 of this act, (c) any hazardous waste having the characteristics identified under or listed pursuant to Section 3001 of the Solid Waste Disposal Act (but not including any waste the regulation of which under the SWDA has been suspended by an act of Congress, (D) any toxic pollutant listed under Section 307(a) of the FWPCA, (E) any hazardous air pollutant listed under Section 112 of the Clean Water Act, and (F) any imminently hazardous chemical substance or mixture with respect to which the Administrator has taken action pursuant to Section of the Toxic Substances Control Act. The term does not include petroleum, including crude oil or any fraction thereof which is not otherwise specifically listed or designated as a hazardous substance under Subparagraphs A through F of this paragraph, and the term does not include natural gas, natural gas liquids, liquefied natural gas, or synthetic gas usable for fuel (or mixtures of natural gas and such synthetic gas). **[CERCLA 101(14)]**

Hazardous Waste A solid waste, or combination of solid waste, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may (1) cause, or significantly contribute to,

an increase in mortality or an increase in serious, irreversible, or incapacitating reversible illness; or (2) pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, or disposed of, or otherwise managed.

Health and safety program plan
Health and safety project leader
Health and safety project plan

Health physics The branch of science concerned with the biological effects of radiation exposure. **(CDR)**

High-efficiency air particulate (filter) /n air filter capable of removing from an air stream at least 99.97% of particulate material as small as 0.3 micron in diameter. **(CDR)**

High-pressure ionization chamber
High-pressure liquid chromatography

Holocene An epoch of the Quaternary Period from the end of the Pleistocene to the present. **(CDR)**

Hornblende A silicate mineral containing magnesium, iron, calcium, sodium, and aluminum **(1122)**

Hydraulic conductivity The volume of water that will move through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow. **(CDR)**

Hydraulic gradient A change in the static pressure of groundwater, expressed in terms of the height of water above a datum, per unit of distance in a given direction. **(CDR)**

Hydrogeology
Immediately dangerous to life and health
Inductively coupled plasma atomic emission spectroscopy
Inductively coupled plasma emission spectroscopy
Inductively coupled plasma mass spectroscopy
Indurated Hardened. **(1122)**

Industrial hygienist Responsible for monitoring industrial hygiene conditions affecting the health and safety of site workers **(Wagner**

Infiltration Water flow into the soil at ground surface. **(CDR)**

Inflow Water movement into a reference location. **(CDR)**

Initiator A nuclear weapons component **(1122)**

Injection well
Installation work plan
Installation work plan

Institutional controls Controls prohibiting or limiting access to contaminated media; may consist of deed restrictions, use restrictions, permitting requirements, etc. **(DOE 1991)**

Institutional interim remedial measures
Instrumental neutron activation analysis
Interim action
Interim remedial measure

Interim remedial measure

Intermittent stream

Intertonguing Interfingering. **(1122)**

Joint A surface of a fracture or parting in a rock, without displacement. **(CDR)**

Judgment sample A sample selected on the basis of professional judgment or convenience. **(Campbell)**

Land disposal restriction A RCRA program that restricts land disposal of RCRA hazardous wastes and requires treatment to promulgated treatment standards. These restrictions may be an important ARAR for Superfund actions. **(DOE 1991)**

Laser-induced breakdown spectroscopy

Latite An extrusive volcanic rock containing plagioclase and alkali feldspars, pyroxene, and/or hornblende **(1122)**

Leachate A contaminated liquid resulting when water percolates or trickles through waste materials and collects components of those wastes. Leaching may occur at landfills and may result in hazardous substances entering soil, surface water, or groundwater. **(DOE 1991)**

Leaching The dissolution of soluble constituents of a solid material by the natural action of percolating water or chemicals. **(CDR)**

Level of concern
Limit of quantification

Lithology The study of rocks. Also the description of a rock on the basis of such characteristics as structure, color, mineral composition, grain size, and arrangement of its component parts. **(CDR)**

Los Alamos Site Characterization Program
Lower exposure limit
Major system acquisition
Management Information System
Manhattan Engineer District

Man-rem A unit used in health physics to compare the effects of different amounts of radiation on groups of people. It is obtained by multiplying the average does equivalent to the whole body or a given organ or tissue (measured in rems) by the number of persons in the selected population. **(CDR)**

Mass spectrometer
Material disposal area

Matrix Relatively fine material in which coarser fragments or crystals are embedded; also called "ground mass." **(CDR)**

Maximum contaminant level Under the Safe Drinking Water Act, the maximum permissible level of a contaminant in water that is delivered to any user of a public water system that serves 15 or more connections and 25 or more people. The standards set as MCs take into account the feasibility and cost of attaining the standard. **(DOE 1991)**

Maximum permissible level

Measure A scale or transformation mapping the states of a variable into real numbers or vectors, in a way which preserves the natural ordering, if any, of the states. **(Campbell)**

Measurement, analysis The result of applying an appropriate measure to the observed states of a target population parameter. **(Campbell)**

Measurement error A discrepancy between a measurement and the true state of the population parameter for the observed sample. Measurement error arises, even in the absence of measurement bias, from imperfect application of the selected measure to the sample. **(Campbell)**

Memorandum of agreement

Memorandum of understanding A statement agreed to by two or more parties that recognizes the interrelationship of their functions and specifies appropriate interactions between or among the parties. **(DOE 1991)**

Migration The movement of oil, gas, or water (including that containing radionuclides) through porous and permeable rock. **(CDR)**

Migration pathway Route (e.g., a stream or river) for potential movement of contaminants to environmental receptors (plants, animals, humans)**(1122)**

Minimum detection limit

Mississippian The fifth of seven periods (320 to 345 million years ago) in which the Paleozoic is divided in the United States. **(CDR)**

Mitigation (1) Avoiding an impact altogether by not taking a certain action or parts of an action. (2) Minimizing impacts by limiting the degree or magnitude of the action and its implementation. (3) Rectifying the impact by repairing, rehabilitating, or restoring the affected environment. (4) Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action. (5) Compensating for the impact by replacing or providing substitute resources or environments. **(CDR)**

Model A mathematical or physical system, obeying certain specified conditions, whose behavior is used to understand a physical, biological, or social system to which it is analogous in some way. **(McGraw-Hill Dictionary of Scientific and Technical Terms)**

Model-based (prediction approach to) sampling A theory of statistical sampling according to which estimation of population parameters should be based on a model for the population, whose formulation may depend on theory, data, or both. Randomization of the sampling plan is not essential for the validity of inference base on this approach, but it is still desirable because it protects the investigator against modeling errors. **(Campbell)**

Model parameter Any *real or vector variable* that characterizes a system being modeled. Examples of parameters used in *conceptual exposure modeling* are rates of release of contamination to the environment, numbers of workers at a site. **(Campbell)**

Mixed activation product
Mixed fission products
Mixed waste
Mixed-oxide semiconductor

Mixed-Waste Storage and Disposal Facility Model

Monitoring wells Special wells drilled at specific locations on or off a hazardous waste site where groundwater can be sampled at selected depths and studied to determine such things as the direction in which groundwater flows and the types and amounts of contaminants present. **(DOE 1991)**

Monthly report
Mortar impact area
Multichannel analyzer
Multiple-energy gamma assay spectrometer

National ambient air quality standards (NAAQS) Standards established under the Clean Air Act that regulate the ambient air quality for six priority pollutants. These standards may be ARARs for Superfund sites. **(DOE 1991)**

National Contingency Plan (found in 40 CFR 300)

National Committee on Radiation Protection

National emission standards for hazardous air pollutants (NESHAPS) Standards set under the Clean Air Act that regulate the release of hazardous substances from specific sources. These standards may be ARARs for Superfund sites.

National Environmental Policy Act
National Environmental Research Park

National Pollutant Discharge Elimination System

National Priorities List (NPL) EPA's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial response using money from the Trust Fund. The list is based primarily on the score a site receives on the Hazard Ranking System. EPA is required to update the NPL at least once a year. **(DOE 1991)**

National wetlands inventory

Neighbor A second specimen collected nearer to another sampling location than the average distance between samples. In channel sediment sampling, a neighbor would be collected from a different sediment catchment than the first specimen. **(1122)**

New Mexico Environmental Division (NMED)

No further action (NFA) A decision that no further investigation or remediation is warranted for a PRS. **(Campbell)**

Notice of deficiency

Nuclear Criticality Safety Committee
Nuclear Regulatory Commission

Null hypothesis Default hypothesis, which will be accepted unless sufficiently conclusive evidence that it is false is obtained **(1122)**

Numerical model A conceptual model, some of whose objects and/or relationships are quantified by algebraic or arithmetic expressions. **(Campbell)**

Occupational exposure limit
Occupational Safety and Health Administration
Off-gas

Office of Emergency and Remedial Response Under the supervision of a director, this office is responsible to the assistant administrator (of EPA) for the emergency and remedial response functions of the Office of Solid Waste and Emergency Response (OSWER). The director is responsible for developing national strategy, programs, technical policies, regulations, and guidelines for the control of abandoned hazardous waste sites and response to and prevention of oil and hazardous substance spills. **(DOE 1991)**

Office of Enforcement and Compliance Monitoring Coordinates (EPA's) civil and criminal enforcement actions with the Department of Justice and provides Superfund enforcement support through the activities of the National Enforcement Investigation Center (NEIC) The NEIC performs special environmental monitoring work, evidence audit control processes to ensure proper chain-of-custody procedures, cleanup of federal facility sites, and nonbinding preliminary allocations of responsibility. **(DOE 1991)**

Office of Solid Waste As part of EPA's Office of Solid Waste and Emergency Response, this office is responsible for managing and implementing the RCRA program. **(DOE 1991)**

Office of Solid Waste and Emergency Response (OSWER) Provides policy, guidance, and direction for EPA's hazardous waste and emergency response programs. The functions of these programs include the development and enforcement of policies, standards and regulations for solid and hazardous waste treatment, storage, and disposal; national management of Superfund; and the development of guidelines for the Emergency Preparedness, "Community Right-to-Know," and Underground Storage Tank programs. **(DOE 1991)**

Office of Waste Programs Enforcement As part of the Office of Solid Waste and Emergency Response, this office provides enforcement policy and support for the Superfund and RCRA programs. **(DOE 1991)**

On-scene control group

Operable unit A discrete action that composes an incremental step toward comprehensively addressing site problems. This discrete portion of a remedial response manages migration or eliminates or mitigates a release, threat of release, or pathway of exposure. the cleanup of a site can be divided into a number of operable units, depending on the complexity of the problems associated with the site. Operable units may address geographical portions of a site, specific site problems, or initial phases of an action, or may consist of any set of actions performed over time or any actions that are concurrent but located in different parts of a site. **(DOE 1991)**

Operable unit project leader (OUPL) The person responsible for RCRA investigations at the operable unit to which he/she has been assigned. **(Wagner memo, EM-13:91-836)**

Organic vapor analyzer
Outfall

Paleozoic The era of geologic time between the Precambrian and Mesozoic eras that consists of the Cambrian, Ordovician, Silurian, Devonian, Carboniferous (Mississippian ;and Pennsylvanian), and Permian periods (about 570 million to 225 million years ago).

Perched groundwater Unconfined groundwater in a zone of saturation separated from an underlying saturated zone by an unsaturated zone. Perched groundwater is supported by a perching bed whose

permeability is so low that water percolating downward through it is not able to bring water in the underlying unsaturated zone above atmospheric pressure. **(CDR)**

Paleogroundwater Ancient groundwater **(1122)**

Percentile of a probability distribution p is a 100 a^{th} percentile of a probability distribution if p/100 is an ath quantile. **(Campbell)**

Percolation The passage of a liquid through a porous substance; e.g., the movement of water, under hydrostatic pressure developed naturally underground, through the interstices and pores of the rock or soil; i.e., the slow seepage of water through soils or porous deposits. **(CDR)**

Permissible exposure limit
Personal protective equipment
Phase I sampling
Phase II sampling
Phase report
Phenocryst A relatively large, conspicuous crystal in a porphyritic rock **(1122)**
Photoionization detector
Pilot study

Plutonium A heavy, radioactive, man-made metallic element. Its most important isotope is fissionable ^{236}Pu, which is produced by the irradiation of ^{236}U. Routine analysis cannot distinguish between the ^{239}Pu and ^{240}Pu isotopes, hence the term $^{239,240}Pu$.

Pollutant Includes, but is not limited to, any element, substance, compound, or mixture, including disease-causing agents, which after release into the environment and upon exposure, ingestion, inhalation, or assimilation into any organism, either directly from the environment or indirectly by ingestion through food chains, will or may reasonably be anticipated to cause death, disease, behavioral abnormalities, cancer, genetic mutation, physiological malfunctions (including malfunctions in reproduction) or physical deformations, in such organisms or their offspring; except that the terms "pollutant or contaminant" shall not include petroleum, including crude oil or any fraction thereof which is not otherwise specifically listed or designated as a hazardous substance under Subparagraphs (A) through (F) of Paragraph (14) and shall not include natural gas, liquefied natural gas, or synthetic gas of pipeline quality (or mixtures of natural gas and such synthetic gas).

Population A set of entities or a continuum in a physical, biological or social system, e.g., the residents of Los Alamos County, or the water in an alluvial aquifer, or the plants in Pajarito Canyon. **(Campbell)**

Population dose The sum of the radiation dose received by the individual members of a population exposed to a particular source of event. It is expressed in units of man-rem. **(CDR)**

Population parameter Any variable that characterizes a population. Examples are number of Los Alamos residents under age 20, tritium concentrations in an alluvial aquifer, or the set of species found in Pajarito Canyon. **(Campbell)**

Population [probability] distribution The distribution of a population parameter. **(Campbell)**

Population mean, variance, quantiles, etc. The mean, variance, quantiles, etc. of a population distribution. **(Campbell)**

Porosity The ratio of the total volume of interstices in rock or soil to its total volume expressed as a percentage or as a fraction.

Porphyritic Said of the texture of an igneous rock in which larger crystals (phenocrysts) are set in a finer ground mass **(1122)**

Potential release site
Potential contact medium

Practical quantitation limit

Precambrian The geologic time that elapsed before the beginning of the Paleozoic era (the Paleozoic began about 570 million years ago). **(CDR)**

Precision Reproducibility of measurements produced by a specified sampling and analysis procedure. Irreproducibility may be the result of both sampling error and measurement error. Precision may be quantified using the standard deviation of a probability distribution describing the measurements, a range, or similar indicators of dispersion. **(Campbell)**

Preliminary assessment The process of collecting and reviewing available information about a known or suspected hazardous waste site or release. The extent of release and degree of threat to human health and the environment are evaluated to determine whether further study is needed and whether the release meets the criteria for a CERCLA-funded removal. **(DOE 1991)**

Preliminary safety analysis report
Principal investigator
Program management plan
Program manager (ER Program)
Programmatic environmental impact statement
Programmatic project leader
Project leader
Project management plan
Project team

Proportional sample A stratified sample in which each subpopulation in a partition of the total population is represented by a number of samples that is proportional to the fraction of the total population that belongs to that subpopulation. (Note: A set is partitioned by a collection of its subsets if each member of the set belongs to one and only one of the subsets.) **(Campbell)**

Quality assurance (QA) All the planned and systematic actions necessary to provide adequate confidence that a structure, system, or component is constructed to plans and specifications and will perform satisfactorily. **(CDR)**

Quality assurance/quality control (QA/QC) A system of procedures, checks, audits, and corrective actions used to ensure that field work and laboratory analysis during the investigation and cleanup of Superfund sites meet established standards. **(DOE 1991)**

Quality assurance management staff (EPA)
Quality assurance program plan

Quality assurance project plan A written document associated with all remedial site sampling activities, which presents in specific terms the organization (where applicable), objectives, functional activities, and specific quality assurance (QA) and quality control (QC) activities designed to achieve the data quality objectives of a specific project(s) or continuing operation(s). The QAPP is prepared for each specific project or continuing operation (or group of similar projects of continuing operations). The QAPjP will be prepared by the responsible program office, regional office, laboratory, contractor, recipient of an assistance agreement, or other organization. For an enforcement action, potentially responsible parties may prepare a QAPjP subject to lead agency approval. **(40 CFR 300.5)**

Quality procedure

Quantile of a probability distribution The ath quantile of the probability distribution for a real random variable x is any real number q such that the probability that x is less than q equals a. **(Campbell)**

Quaternary The second period of the Cenozoic era, following the Tertiary, and the corresponding system of rocks. **(CDR)**

Radiation Refers to the process of emitting energy in the form of rays or particles that are thrown off by disintegrating atoms. The rays or particles emitted may consist of alpha, beta, or gamma radiation. **(DOE 1991)**

Radon A colorless, odorless, naturally occurring, radioactive gaseous element formed by radioactive decay of radium atoms. The chemical symbol is Rn, atomic weight is 222, and the half-life is 3.82 days. **(DOE 1991)**

Radiation protection technician Person responsible for monitoring radiation levels during field investigations. **(Wagner memo, EM-13:91-836)**

Radionuclide of concern

Random variable Conceptual model object described by a set of feasible states together with a probability distribution defined on that set. **(Campbell)**

Randomized sample A sample whose selection makes use of a mechanism for generating random numbers (or a satisfactory analog of such a mechanism) to determine which specimens from a target population are included in a sample. **(Campbell)**

RCRA facility assessment (RFA) The first step in the RCRA corrective action process, generally equivalent to the preliminary assessment/site investigation taken under Superfund. **(DOE 1991)**

RCRA facility investigation (RFI) The second step of a RCRA corrective action, generally equivalent to the RI portion of the Superfund process. **(DOE 1991)**

Real-time aerosol monitor

Real variable A variable whose set of feasible states is a subset of the real numbers. **(Campbell)**

Receipt acknowledgment

Receptor A person, plant, animal, or geographical location that is exposed to a chemical or physical agent released to the environment by human activities **(1122)**

Recharge The process by which water is added to the zone of saturation, either directly into a geologic formation or indirectly by way of another formation or through unconsolidated sediments. **(CDR)**

Recommended exposure limit

Reconnaissance sampling Sampling contaminant concentrations in a *target population* for the purpose of bounding their *population probability distributions*. **(Campbell)**

Record
Records management program plan
Records management project plan

Record of decision A public document that explains which cleanup alternative(s) will be used at NPL sites. The record of decision is based on information and technical analysis generated during the RI/FS and consideration of public comments and community concerns. **(DOE 1991)**

Records-Processing Facility

Regulatory standard, regulatory concentration criteria Media-specific contaminant concentration levels of potential concern that are mandated by federal or state legislation or regulation (e.g., the Safe Drinking Water Act, New Mexico Water Quality Control Commission regulations). (Camp**bell)**

Relative percent difference

Release Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles containing any hazardous substance or pollutant or contaminant), but excludes

(A) any release which results in exposure to persons solely within a workplace, with respect to a claim which such persons may assert against the employer of such persons;

(B) emissions from the engine exhaust of a motor vehicle, rolling, stock, aircraft, vessel, or pipeline pumping station engine;

(C) release of source, byproduct, or special nuclear material from a nuclear incident, as those terms are defined in the Atomic Energy Act, if such release is subject to requirements with respect to financial protection established by the Nuclear Regulatory Commission under Section 170 of such act, or, for the purposes of Section 104 of this title or any other response action, any release of source, byproduct, or special nuclear material from any processing site designated under Section 102(a)(1) or 302(a) of the Uranium Mill Tailings Radiation Control Act of 1978, and

(D) the normal application of fertilizer. **[CERCLA 101(22)]**

Relevant and appropriate requirements Those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. Only those state standards that are identified in a timely manner and are more stringent than federal requirements may be relevant and appropriate. **(DOE 1991)**

Remedial design

Remedial investigation A process undertaken by the lead agency to determine the nature and extent of the problem presented by a release. The remedial investigation emphasizes data collection and site characterization, and is generally performed concurrently and in an interactive fashion with the feasibility study. The RI includes sampling and monitoring, as necessary, and includes the gathering of sufficient information to determine the necessity for remedial action and to support the evaluation of remedial alternatives. **(40 CFR 300.5)**

Remedial investigation/feasibility study (RI/FS) Investigative and analytical studies usually performed at the same time in an interactive, iterative process, and together referred to as the "RI/FS." They are intended to

- gather the data necessary to determine the type and extent of contamination at a Superfund site,
- establish criteria for cleaning up the site,
- identify and screen cleanup alternatives for remedial action, and
- analyze in detail the technology and costs of the alternatives. **(DOE 1991)**

Remedial response A long-term action that stops or substantially reduces a release or threatened release of hazardous substances that is serious but does not pose an immediate threat to public health and/or the environment. **(DOE 1991)**

Remediation

Remedy or remedial action Those actions consistent with permanent remedy taken instead of or in addition to removal actions in the event of a release or threatened release of a hazardous substance into the environment, to prevent or minimize the release of hazardous substances so that they do not migrate to cause substantial danger to present or future public health or welfare or the environment. The term includes, but is not limited to, such actions at the location of the release as storage, confinement, perimeter protection using dikes, trenches, or ditches, clay cover, neutralization, cleanup of released hazardous substances and associated contaminated materials, recycling or reuse, diversion, destruction, segregation of reactive wastes, dredging or excavations, repair or replacement of leaking containers, collection of leachate and run-off, on-site treatment or incineration, provision of alternative water supplies, and any monitoring reasonably required to assure that such actions protect the public health and welfare and the environment. The term includes the costs of permanent relocation of residents and businesses and community facilities where the President determines that, alone or in combination with other measures, such relocation is more cost-effective than and environmentally preferable to the transportation, storage, treatment, destruction, or secure disposition off site of hazardous substances, or may otherwise be necessary to protect the public health or welfare; the term includes off-site transport and off-site storage, treatment, destruction, or secure disposition of hazardous substances and associated contaminated materials. **[CERCLA 101(24)]**

Activities conducted at DOE facilities to reduce potential risks to people and/or harm to the environment from radioactive and/or hazardous substance contamination. **(DOE Order 5820.2A)**

Those actions consistent with permanent remedy taken instead of, or in addition to, removal action in the event of a release or threatened release of a hazardous substance into the environment, to prevent or minimize the release of hazardous substances to that they do not migrate to cause substantial danger to present or future public health or welfare or the environment. **(DOE 5400.5)**

Remove or removal The cleanup or removal of released hazardous substances from the environment, such actions as may be necessary taken in the event of the threat of release of hazardous substances into the environment, such actions as may be necessary to monitor, assess, and evaluate the release or threat of release of hazardous substances, the disposal of removed material, or the taking of such other actions as may be necessary to prevent, minimize, or mitigate damage to the public health or welfare or to the environment, which may otherwise result from a release or threat of release. The term includes, in addition, without being limited to, security fencing or other measures to limit access, provision of alternative water supplies, temporary evacuation and housing of threatened individuals not otherwise provided for, action taken under Section 104(b) of this act, and any emergency assistance which may provided under the Disaster Relief and Emergency Assistance Act. **[CERCLA 101 (23)]**

Removal action An immediate action taken over the short term to address a release or threatened release of hazardous substances. **(DOE 1991)**

Replicate

Reportable quantity For any CERCLA hazardous substance, the quantity established in Table 302.4 and Appendix B of 40 CFR 302, the release of which requires notification unless federally permitted. **(DOE Order 5000.3A)**

~~Representative sample~~ A sample from a target population that may be considered typical of that population in one or more respects. This is an extremely ill-defined concept, and its use should be avoided. Consider using one of the following alternatives: simple random sample, stratified sample, proportional sample, systematic sample, judgmental sample, composite sample, grab sample. **(Campbell)**

Representativeness Similarity between the measurements produced by a specified sampling and analysis procedure and the true target population parameters. There are no generally applicable measures of representativeness. **(Campbell)**

Resin bed

Resource Conservation and Recovery Act A federal law that established a structure to track and regulate hazardous wastes from the time of generation to disposal. The law requires safe and secure procedures to be used in treating, transporting, storing, and disposing of hazardous substances. RCRA is designed to prevent new, uncontrolled hazardous waste sites. The law also regulates the disposal of solid waste that may not be considered hazardous. **(DOE 1991)**

Respond or response As defined by Section 101 (25) of CERCLA, means remove, removal, remedy, or remedial action, including enforcement activities related thereto. **(DOE 1991)**

Response action A CERCLA-authorized action at a Superfund site involving either a short-term removal action or a long-term remedial response that may include, but is not limited to, the following activities.

- Removing hazardous materials from a site to an EPA-approved, licensed hazardous waste facility for treatment, containment, or destruction.
- Containing the waste safely on site to eliminate further problems.
- Destroying or treating the waste on site using incineration or other technologies.
- Identifying and removing the source of groundwater contamination and halting further movement of the contaminants.

Restoration

Restricted Area Any area access to which is controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials. "Restricted area" shall not include areas used as residential quarters, although a separate room or rooms in a residential building may be set apart as a restricted area. **(10 CFR 60.2)**

Retardation The act or process that reduces the rate of movement of a chemical substance in a water stream relative to the average velocity of the water. The movement of the chemical substance in the water can be retarded by sorption and desorption reactions, by precipitation and dissolution reactions, and by diffusion into the pore water of the rock matrix. **(CDR)**

Rhyodacite A group of extrusive porphyritic igneous rocks intermediate in composition between dacite and rhyolite, with quartz, plagioclase, and biotite (or hornblende) as the main phenocryst minerals and a fine-grained to glassy ground mass **(1122)**

Rhyolitic Characteristic of a group of extrusive igneous rocks, generally prophyritic and exhibiting flow texture with crystals of quartz and alkali feldspar in a glassy to cryptocrystalline ground mass (rhyolite). **(CDR)**

Risk A measure of a negative or undesirable impact associated with an event. **(Campbell)**

Risk assessment A risk assessment is generated by collecting, analyzing, and synthesizing scientific data to produce the hazard identification, does response, and exposure assessment portion of the risk assessment and to characterize risk. ***(RCRA/CERCLA Update*, June 1992)**

(For the ER Program) Estimation of the likelihood of human health or environmental risk from contamination of environmental media. Risk assessment includes hazard identification, exposure assessment, and dose response analysis. (Campbell)

Risk assessment, baseline

A risk assessment conducted using one or more scenarios appropriate for the site but assuming no mitigating or corrective measures beyond those already in place. **(Campbell)**

Risk assessment, preliminary

A risk assessment conducted using a simplified and not necessarily appropriate scenario and assuming no mitigating or corrective measures beyond those already in place. **(Campbell)**

Risk characterization Includes disclosure of uncertainties, information on data and methodology, and numerical estimates accompanied by descriptive information. ***(RCRA/CERCLA Update*, June 1992)**

Risk management Risk management is the integration of risk characterization with other nonscientific considerations specified in applicable statutes to make and justify regulatory decisions. ***(RCRA/ CERCLA Update*, June 1992)**

Safety analysis report (SAR) A document that analyzes the facility and its safety-related systems for use in establishing whether or not the facility can be operated with reasonable assurance of no undue risk to the health and safety of the public and with adequate provisions for the protection of property and the environment. **(CDR)**

Sample (a) A statistical sample is a set of specimens taken from the target population, for which various parameters of interest are measured. If the target population consists of discrete items, then a sample consists of a subset of these items. If the target population is an environmental continuum (e.g., surface soil in some well-defined region or channel sediments in a drainage), then specimens must be collected according to a standard operating procedure which specifies how much soil is to be included in each specimen, how to collect and store it, etc.

(b) A field or laboratory sample is an individual specimen taken from a target population, or sometimes the product of a field activity such as the filter from a air monitor or a thermoluminescent dosimeter (TLD), which is submitted for laboratory analysis following a period of exposure at the site. **(1122)**

(1) A set of specimens collected from a target population, as in "a sample of size 3". (2) One of a set of specimens collected from a target population, as in "Three samples were submitted for laboratory analysis." **(Campbell)**

Sample maximum The largest measurement of a variable made for the sample. It is impossible to infer the relationship between the sample maximum and the population maximum, but the sample maximum may be used to make inferences about population percentiles below the 100th percentile. **(Campbell)**

Sample mean, variance, quantiles The mean (expected value), variance, quantiles of a sample probability distribution. **(Campbell)**

Sample [probability] distribution The probability distribution that assigns the value $1/N$ to each measurement of an outcome variable recorded for a sample of size N. **(Campbell)**

Sampling The selection of samples from a target population. **(Campbell)**

Sampling and analysis procedure A combined protocol or rule for sampling a target population and obtaining measurements of one or more population parameters for specimens in the sample. **(Campbell)**

Sampling error A discrepancy between the sample distribution and the target population distribution of a population parameter. Sampling error arises, even in the absence of bias or measurement error, from observing only a subset of the total population. **(Campbell)**

Sampling plan

Saturated zone That part of the earth's crust beneath the regional water table in which all voids, large and small, are ideally filled with water under pressure greater than atmospheric. **(10 CFR 60.2)**

Sanidine A high-temperature mineral of the alkali feldspar group. **(1122)**

Scrap detonation site

Screening action levels Media-specific concentration levels for constituents derived using conservative intake assumptions and used during the RCRA field investigation , primarily to identify contaminants of concern. (Campbell)

Screening assessment **Evaluation of information about a PRS to determine whether hazardous or radioactive constituents are present above** the levels of concern defined by media-specific SALs or regulatory standards. **(Campbell)**

Screening level

Scrubber

Secondary alteration minerals Minerals formed by processes after the original formation of the rock by chemical changes to the original minerals or by deposition along fractures **(1122)**

Seismicity The occurrence of earthquakes or the spatial distribution of earthquake activity; also the phenomenon of earth movement. **(CDR)**

Silurian The third of seven periods (395 to 430 million years ago, before the Devonian and after the Ordovician) of the Paleozoic Era. **(CDR)**

Simple random sample A sample that is randomized in such a manner that whether or not a given member of the target population is included in the sample is completely independent of the inclusion of any other member. **(Campbell)**

Site characterization The program of exploration and research, both in the laboratory and in the field, undertaken to establish the geologic conditions and the ranges of those parameters of a particular site relevant to the procedures under this part. Site characterization includes borings, surface excavations, excavation of exploratory shafts, limited subsurface lateral excavations and borings and geophysical testing needed to decide whether site characterization should be undertaken. **(10 CFR 60.2)**

Site safety officer

Soil gas Those gaseous elements and compounds that occur in the small spaces between particles of the earth or soil. Rock can contain gas also. Such gases can move through or leave the soil or rock, depending on changes in pressure. Radon is a gas that forms in the soil wherever radioactive decay of radium occurs.

Solid waste management unit Means any discernible unit at which solid wastes have been placed at any time, irrespective of whether the nit was intended for the management of solid or hazardous waste. Such units include any area at or around a facility at which solid wastes have been routinely and systematically released. **(HSWA Module)**

Split

Standard deviation of a real random variable The square root of the variance of a real random variable. **(Campbell)**

Standard operating procedure

State Any member of the set of feasible values for a variable. **(Campbell)**

Statistic A function of the sample data, such as the average of the observed values (the sample mean), or the largest observed value (the sample maximum), or the number of observations exceeding a predefined level (the number of exceedances) **(1122)**

Statistical parameter Any real or vector variable that characterizes a probability distribution. Examples are expected values and the correlation between two random variables. **(Campbell)**

Stratification Classification of the target population into two or more non-overlapping and exhaustive categories (strata) on the basis of characteristics which are known *a priori* for the entire population **(1122)**

Stratified sample Statistical sample including specimens from all strata of the target population. If the target population has spatial extent, and characteristics of interest may have important variability from one part to another, care must be taken to ensure that the sample is not concentrated in one area. If the target population has both mesa-top surface soils and soils or sediments in drainage channels, and there is reason to believe that contaminants might move through or sorb on these different types of soil in different manners, then the sample should include specimens of both types. **(1122)**

A sample including one or more specimens from each of several subpopulations of the target population. (Note: If the specimens are selected from within each subpopulation using *simple random sampling*, then the sample is called a stratified random sample.) **(Campbell)**

Stratigraphy The study of rock strata to include age relationships **(1122)**

Superfund Amendments and Reauthorization Act of 1986 In addition too certain free-standing provisions of law, it includes amendments to CERCLA, the SWDA, and the Internal Revenue Code. Among the free-standing provisions of law is Title III of SARA, also known as the "Emergency Planning and Community Right -to-Know Act of 1986" and Title IV of SARA, also known as the "Radon Gas and Indoor Air Quality Research act of 1986." Title V of SARA amending the Internal Revenue Code is also known as the "Superfund Revenue Act of 1986." **(40 CFR 300.5)**

Surveillance

Survey

SWMU aggregate

SWMU group

Systematic sample A sample selected by following a prespecified rule. (Note: A systematic sample may be randomized by selecting a random starting point for applying the rule, but the resulting will not, in general, have all of the desirable properties of a simple or stratified random sample.) **(Campbell)**

Target population A collection of items or an environmental region to be characterized. The target population must be explicitly defined prior to sampling so that a sample which represents important features of this population can be selected. Some target populations mentioned in Chapter 3 are: surface soils within a defined area, channel sediments within defined drainages, projectiles in berms, debris in landfills, and sludge in septic tanks. **(1122)**

A population for which the states of one or more population parameters are to be observed. **(Campbell)**

Technical team

Tertiary The earlier of the two geologic periods that make up the Cenozoic Era, extending from 65 to 1.8 million years ago.

Telephone record

Thermoluminescent dosimeter

Topography The physical features of a place or region. **(1122)**

Townsite

Toxic pollutants The 126 individual priority toxic pollutants contained in 65 toxic compounds or classes of compounds (including organic pollutants and metals) adopted by EPA pursuant to Section 307 (a) (1) of the Clean Water Act. **(DOE 1991)**

Toxic Substances Control Act

Toxicity characteristic leaching procedure

Transmissivity A measure of the amount of water that can be transmitted horizontally by the full saturated thickness of the aquifer under a hydraulic gradient of 1. **(DOE 1991)**

Transport or transportation The movement of a hazardous substance by any mode, including pipeline (as defined in the Pipeline Safety Act), and in the case of hazardous substance which has been accepted for transportation by a common or contract carrier, the term "transport" or "transportation" shall include any stoppage in transit which is temporary, incidental to the transportation movement, and at the ordinary operating convenience of a common or contract carrier, and any such stoppage shall be considered as a continuity of movement and not as the storage of a hazardous substance. **[CERCLA 101(26)]**

Transuranic

Treatment Any method, technique, or process, including neutralization, designed to change the physical, chemical, or biological character or composition of any hazardous waste so as to neutralize such waste or so as to render such waste nonhazardous, safer for transport, amenable for recovery, amenable for storage, or reduced in volume. Such term includes any activity or processing designed to change the physical form or chemical composition of hazardous waste so as to render it nonhazardous. **(DOE 1991)**

Treatment, storage, and disposal facility Any building, structure, or installation where a hazardous substance has been treated, stored, or disposed. TSD facilities are regulated by EPA and states under RCRA. **(DOE 1991)**

Trigger level

Tuff A compacted pyroclastic deposit of volcanic ash and dust that contains rock and mineral fragments incorporated during eruption or transport.

Type I error Incorrectly concluding that the null hypothesis is false. In remedial investigations the usual null hypothesis is that the site is contaminated. It is a Type I error to conclude that a site is not contaminated when it is. In routine monitoring, the null hypothesis may be that the site is not contaminated; it is a Type I error to conclude that the site is contaminated when, in fact, it is not. **(1122)**

Type II error Incorrectly concluding that the null hypothesis is true. In remedial investigations the usual error is concluding that a site is contaminated when it is not. In routine monitoring, it may refer to failure to detect contamination. **(1122)**

Ultimate disposal The final disposal of hazardous substances resulting from a removal action. It does not include temporary storage or other temporary measures of managing the waste from a removal action. **(DOE 1991)**

Unanticipated processes and events Those processes and events affecting the geologic setting that are nudged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration. Unanticipated processes and event s may be either natural processes or events or processes and events initiated by human activities other than those activities licensed under this part. Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that (1) the monuments provided for by this part are sufficiently permanent to serve their intended purpose; (2) the value to future generations of potential resources within the site can be assessed adequately under the applicable provisions of this part; (3) an understanding of the nature of radioactivity, and an appreciation of its hazards, have been retained in some functioning institutions; (4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned; and (5) relevant records are preserved , and remain accessible, for several hundred years after permanent closure. **(10 CFR 60.2)**

Underground storage tank As defined in Section 9001(1) of the Solid Waste Disposal Act, the term "underground storage tank" means any one or combination of tanks (including underground pipes connected thereto) which is used to contain an accumulation of regulated substances, and the volume of which (including the volume of the underground pipes connected thereto) is 10% or more beneath the surface of the ground. Such term does not include any

(A) farm or residential tank of 1,100 gallons or less capacity used for storing motor fuel for noncommercial purposes;

(B) tank used for string heating oil for consumptive use on the premises where stored;

(C) septic tank;

(D) pipeline facility (including gathering lines) regulated under

i) the Natural Gas Pipeline Safety Act of 1968 (49 USC App. 1671 et seq.),
II) the Hazardous Liquid Pipeline Safety Act of 1979 (49 USC App. 2001 et seq.), or
III) which is an intrastate pipeline facility regulated under state laws comparable to the provisions of law referred to in Clause (i) or (II) of this subparagraph;

(E) surface impoundment, pit, pond, or lagoon,
(F) storm water or waste water collection system;
(G) flow-through process tank;
(H) liquid trap or associated gathering lines directly related to oil or gas production and gathering operations; or
(I) storage tank situated in an underground area (such as a basement, cellar, mine working, drift, shaft, or tunnel) if the storage tank is situated upon or above the surface of the floor.

The term UST shall not include any pipes connected to any tank which is described in Subparagraphs A through I. **(DOE 1991)**

United States Geological Survey

Unrestricted area Any area, access to which is not controlled by the licensee for purposes of protection of individuals from exposure to radiation and radioactive materials and any area used for residential quarters. **(10 CFR 60.2)**

Unsaturated zone The zone between the land surface and the regional water table. Generally, fluid pressure in this zone is less than atmospheric pressure, and some of the voids may contain air or other gases at atmospheric pressure. Beneath flooded areas or in perched water bodies the fluid pressure locally may be greater than atmospheric. **(DOE 1991)**

Uranium A naturally radioactive element with the atomic number of 92 (number of protons in nucleus) and an atomic weight of approximately 238. The two principal naturally occurring isotopes are the fissionable ^{235}U (0.7% of natural uranium) and the fertile ^{238}U (99.3% of natural uranium. **(DOE 1991)**

Validation

Value engineering

Variable Component of a conceptual model described by a set of feasible values. **(Campbell)**

Variable, auxiliary A population parameter that is known or can be easily observed for all members of the population, whether or not included in a sample. **(Campbell)**

Variable, outcome A population parameter that can be observed for each specimen that is included in a sample. **(Campbell)**

Variance

Variance of a real random variable The centered second moment of the probability distribution of a real random variable; symbolically,

$\int_{x \in S}^{?} (x-\mu)^2 \, dP(x)$, where m is the expected value of the probability distribution. **(Campbell)**

Vector variable A variable whose set of feasible states is a subset of a finite-dimensional Euclidean space.

Volatile organic compound An organic (carbon-containing) compound that evaporates (volatilizes) readily at room temperature. **(DOE 1991)**

Voluntary corrective action (VCA) Selection and implementation of an obvious and effective corrective action during or following the RFI. **(Campbell)**

Water table That surface in a groundwater body at which the water pressure is atmospheric. **(10 CFR 60.2)**

Work breakdown structure

Working group

Xenocryst A crystal foreign to the igneous rock in which it occurs **(1122)**

Zeolite Any of a group of approximately thirty hydrous aluminum silicate minerals. **(1122)**