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Date: August 31, 2000
Refer to: ER2000-0469

Mr. John Kieling
NMED-HWB
P.O. Box 26610
Santa Fe, NM 87502

SUBJECT: DRAFT OF MESA-TOP MDAs IMPLEMENTATION PLAN

Dear Mr. Kieling:

Enclosed is a copy of the draft Mesa-Top MDAs Implementation Plan, which was scheduled for development and review by the MDA's High Performing Team (HPT) in the third quarter of this calendar year. The draft is substantially complete in it's description of the technical approach for streamlined corrective actions for mesa-top MDAs, which has been discussed in several meetings of the HPT. Chapter 7, Containment Alternatives and Chapter 8, Long-term Monitoring and Stewardship are not complete in technical details. We expect that the details will be developed by the HPT once the technical approach presented in Chapters 1 through 6 is formally accepted by the HPT.

We are submitting this draft with the expectation that all members of the HPT will review it in its entirety in time for a fruitful discussion and decision regarding the technical approach at our scheduled September 8, 2000 meeting.

Sincerely,

Julie A. Canepa, Program Manager
Los Alamos National Laboratory
Environmental Restoration

Sincerely,

Theodore J. Taylor, Program Manager
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DH/JAC/TT/eim

Enclosure: Draft Mesa-Top MDAs Implementation Plan

ASWA LANL 9/11/2000

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DRAFT

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

DRAFT 1

AUGUST 28, 2000

NMED, DOE, AND LANL

HIGH PERFORMING TEAM

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TABLE OF CONTENTS

1.0. INTRODUCTION 1-1
- 1.1. Background 1-1
- 1.2. Purpose and Scope 1-1
- 1.3. Underlying Concepts 1-2
- 1.4. Organization of Document 1-3

2.0. TECHNICAL APPROACH 2-1
- 2.1. Plug-in Process 2-1
- 2.2. Regulatory Process 2-2
- 2.3. Presumptive Remedy -- Containment by Capping 2-4
- 2.4. Monitored Natural Attenuation 2-6
- 2.5. Risk-Based Corrective Action 2-8
- 2.6. Assessment Constraints 2-13
  - 2.6.1. Risk Thresholds 2-13
  - 2.6.2. Media Compliance Points 2-14
  - 2.6.3. Assessment Period 2-15
  - 2.6.4. Probabilistic Risk Assessment 2-15
  - 2.6.5. Institutional Controls 2-16
  - 2.6.6. Future Land Use 2-16
  - 2.6.7. Receptors 2-16

3.0. CANDIDATE SITES 3-1
- 3.1. Grouping Criteria 3-1
- 3.2. Decision Logic 3-1
- 3.3. Relevant Characteristics of Identified Mesa-Top MDA Sites 3-6
  - 3.3.1. MDA A (TA-21) 3-7
  - 3.3.2. MDA B (TA-21) 3-8
  - 3.3.3. MDA C (TA-50) 3-8
  - 3.3.4. MDA G (TA-54) 3-8
  - 3.3.5. MDA H (TA-54) 3-9
  - 3.3.6. MDA L (TA-54) 3-9
  - 3.3.7. MDA T (TA-21) 3-9
  - 3.3.8. MDA U (TA-21) 3-9
  - 3.3.9. MDA V (TA-21) 3-9
  - 3.3.10. MDA AB (TA-49) 3-10
- 3.4. Process for Sites That Are Not Candidates 3-10

4.0. CONCEPTUAL SITE MODELS FOR MDAS 4-1
- 4.1. Overview 4-1
- 4.2. Mesa-Top MDA Features, Events, and Processes 4-2
  - 4.2.1. FEP Screening 4-3
  - 4.2.2. Base-Case and Alternate Conceptual Models 4-3
- 4.3. Interaction Matrix 4-3
  - 4.3.1. Identification of Rare Events 4-4
- 4.4. Pictorial MDA Conceptual Model 4-5
  - 4.4.1. Site Features 4-5
  - 4.4.2. Contaminant Release Processes 4-7
  - 4.4.3. Contaminant Transport Processes 4-7
  - 4.4.4. Exposure Pathways 4-7

5.0 LEAD SITE SELECTION AND EVALUATION 5-1
5.1. Lead Site Selection 5-1
5.2. Role of Lead Site 5-1
5.3. Primary Lead Site: TA-54 Area G 5-1
5.4. Supplemental Lead Site for Vapor Phase Transport: TA-54 MDA L 5-3
5.5. Evaluation of Containment Alternatives for Lead Sites 5-4

6.0 RISK-BASED ASSESSMENT 6-1
6.1. Assessment Goals 6-1
6.2. Implementation of Process Models 6-1
6.3. Systems Modeling 6-2
6.4. Logic Trees 6-4
6.5. Assessment of Remedial Alternatives for Lead Sites 6-5
6.6. Remedy Profiles 6-7
6.7. Site Specific Assessment of Remedy Profiles 6-7

7.0. CONTAINMENT ALTERNATIVES 7-1
7.1. Capping Technologies Appropriate for Semiarid Environments 7-2
7.1.1. LANL Demonstration Plots 7-2
7.1.2. SNL Demonstration Plots 7-2
7.1.3. Experience and Uncertainties 7-2
7.2. Passive Venting Methods 7-2
7.3. Design Models 7-2
7.4. Risk Management Considerations 7-2
7.5. Decision Support Tools 7-2

8.0 LONG-TERM MONITORING AND STEWARDSHIP 8-1
8.1. Institutional Control 8-1
8.2. Monitoring Goals 8-1
8.2.1. Risk Based 8-1
8.2.2. Performance Based 8-1
8.2.3. Compliance Based 8-1
8.3. Surface Monitoring 8-1
8.3.1. Strategy and Goals 8-1
8.3.2. Techniques 8-1
8.4. Subsurface Monitoring 8-1
8.4.1. Strategy and Goals 8-1
8.4.2. Techniques 8-1
8.5. Groundwater Monitoring 8-2
8.5.1. Strategy and Goals 8-2
8.5.2. Techniques 8-2

9.0 REFERENCES 9-1

List of Appendices

APPENDIX A PLUG-IN APPROACH
APPENDIX B PRESUMPTIVE REMEDY
APPENDIX C MDA DESCRIPTIONS
APPENDIX D FEP LIST AND DESCRIPTIONS
APPENDIX E RARE EVENTS
APPENDIX F EXPERT ELICITATION
APPENDIX G SPECIAL STUDIES RELATED TO MDA PERFORMANCE
APPENDIX H SUMMARY FOR MDA G
APPENDIX I SUMMARY FOR MDA L
APPENDIX J MODELS
APPENDIX K COVER TECHNOLOGIES
APPENDIX L MONITORING TECHNOLOGIES

List of Figures

Figure 2-1. Plug-in Process Diagram 2-3
Figure 2-2. Example MDA Cover System. 2-7
Figure 2-3. Risk-Based Corrective Action Assessment Scheme 2-12
Figure 3-1 Decision Logic for Selection of Landfill-Like Mesa-Top MDAs for the Plug-in Group..... 3-4
Figure 4-1. Limited interaction matrix 4-4
Figure 4-2. Typical MDA Conceptual Model Diagram 4-6
Figure 4-3. Generic Interaction Matrix for Candidate MDAs 4-9
Figure 6-1. Risk Time Histories. 6-3
Figure 6-2. Cumulative distributions of the maximum risk. 6-4
Figure 6-3 Schematic Illustration of the effects of Uncertainties on Corrective Action Decisions..... 6-5
Figure 6-4. A simple logic tree with 2 characteristics. 6-6
Figure 6-5. An abbreviated logic tree with 3 characteristics..... 6-6

List of Tables

Table 3-1 Description of Laboratory MDAs and Anticipated Cleanup Plans..... 3-2
Table 3-2 Results of Applying Mesa-Top MDA Decision Logic..... 3-5
Table 3-3 Relevant Characteristics of Mesa-Top Plug-in Group Candidate Sites 3-7

Ch. 1
TOC

1.0. INTRODUCTION

This plan describes the approach for selecting corrective actions for a category of waste disposal sites, mesa-top material disposal areas (mesa-top MDAs), at the Los Alamos National Laboratory (Laboratory). This document tiers from the Environmental Restoration (ER) Project Installation Work Plan (IWP), and gives a streamlined approach for the corrective-measures study/corrective measure implementation (CMS/CMI) process for this category of sites (LANL 1998a, Section 3.1.3.3). A team of representatives from the ER Project, the Department of Energy (DOE), and the New Mexico Environment Division (NMED) developed this plan to enhance efficiency in the corrective-action process. The preparation of this plan represents the proactive and cooperative planning efforts of the three organizations.

Upon approval by NMED, the process described in this plan will be applied to MDAs A, B, C, G, H, L, T, U, V and AB. These sites are the mesa-top MDAs that are within the organizational purview of the ER Project's MDA Focus Area. These are all landfill-like sites where radioactive and hazardous wastes and materials were placed in subsurface disposal units such as pits, shafts, seepage pits, or absorption beds. The similarities among the sites in terms of disposal unit types, waste types, and disposal environment are essential to the application of the approach described herein. The specific sites to which the process will be applied have been identified as part of the process (described in Section 3, Candidate Sites).

1.1. Background

The impetus for preparing an implementation plan for this set of sites, when a general CMS process is already in place in the IWP (LANL 1998a, Section 3.1.3.3), comes from three factors. First, the similarities of the site types, the waste types, and the disposal environments have become evident as the RCRA Facility Investigations (RFI) have progressed. Second, such similarities offer the prospect for employing streamlining approaches, such as the "presumptive remedy" concept and the "plug-in" approach, developed by EPA and DOE to reduce the time, effort and expense of the corrective action process. Third, significant progress has been made in evaluating two major material disposal areas, MDAs G and L, resulting in evaluation techniques and technical findings that are directly applicable to similar sites. A portion of this plan is focused on conveying information supporting these three factors.

1.2. Purpose and Scope

The purpose of this plan is to document the process for selecting corrective actions for the mesa-top MDAs, to provide information supporting the proposed approach, and to identify constraints on the technical evaluations as agreed to by the NMED, DOE and Laboratory team. The details of the technical evaluations are reserved for appendices and separate topical documents. The described process provides documentation for regulatory evaluation, public input, and regulatory approval of each proposed corrective action.

This implementation plan employs current approaches to corrective action. It is consistent with EPA's Subpart S corrective action guidance (EPA 1996a), it draws on EPA's presumptive remedy policy (EPA 1993a), the DOE/EPA plug-in approach (DOE 1999a, EPA 1993b), and the use of risk-based corrective action as described by DOE, EPA, and NMED (EPA 1999c, **DOE XXX4,** EPA 1990a, EPA 1996a, NMED 2000a). The application of these policies and approaches reduces costs and shortens schedules for applying final corrective actions to the target group of sites.

The scope of this plan has two constraints:

- It applies only to a portion of the overall RCRA corrective action process. The RCRA Facility Investigation (RFI) will be completed as usual for each site to define the characteristics of the site, as needed to complete the plug-in process. The process in this document follows the RFI, it takes up at the point where the normal RCRA Corrective Measures Study (CMS) would begin. It continues through selection and approval of the final remedy. In this context, the process in this plan replaces the usual site-specific CMS process as described in the IWP at Section 3.1.3.3, Requirements for Corrective Measures Study (LANL 1998a).

- It applies to a limited, target group of sites. This plan applies to those mesa-top MDAs which are within the organizational purview of the ER Project's MDA Focus Area: MDAs A, B, C, G, H, L, T, U, V, AB and portions of G and L.

1.3. Underlying Concepts

Some important concepts underlie the rationale, technical information, and process presented in this plan. These concepts are identified, substantiated and elaborated as they occur in the document. However, because of their importance as a theme, or thread, throughout this plan they are presented explicitly here, in brief.

- *Risk-based corrective action.* The extent of remedial action needed at each MDA is determined by the potential for unacceptable human health or ecological risks from contaminant releases.

- *Presumptive remedy and focused evaluation of alternatives.* The presumptive remedy for a material disposal area is containment, and the preferred containment type is capping. The details of the cap applied at each disposal unit will depend on site-specific conditions.

- *Sufficient and focused RFI, emphasis on stabilization actions prior to final remedy.* Past experience and recent RFI investigations have shown that, generally, contaminants in MDAs are well contained. Current risks at MDAs come from any existing contamination present in the accessible environment. These risks are mitigated by on-going voluntary corrective actions, maintenance, and monitoring.

- *Conceptual model development and evaluation, risk-based assessments.* Estimates of future risks are developed from site-specific models of contaminant release processes, and projections of future releases to the environment, including the effects of natural attenuation. Assessments done for MDA G indicate that future risks are dominated by releases of contaminants to the surface from disruption of disposal unit covers. Subsurface processes, such as water-borne releases of contaminants to groundwater, appear to be negligible for mesa-top waste disposal sites.

- *A lead site can represent a group of similar sites.* MDAs G and L (the largest, best-characterized, and most intensively assessed MDAs) are characteristic of the other mesa-top MDAs in terms of disposal unit types, waste types, and disposal environment. Together MDAs G and L are bounding and conservatively representative of the others.

- *Plug-in remedy selection: similar remedies for similar sites.* The risk assessments, evaluations of capping requirements, cap designs, and long term monitoring programs prepared on the basis of information from MDAs G and L can be extended with minor changes to other, sufficiently similar, mesa-top MDAs. Appropriate consideration must be given to site-specific differences identified from the RFI or other information sources.

- *Public involvement.* Early public involvement with the mesa-top MDA remedy selection process for the containment and capping alternatives will provide NMED, as well as the Laboratory and DOE, with input important to the regulatory process.

It is expected that some mesa-top MDAs are so small and contain such limited contaminant inventories that the results of the risk-based assessment will indicate no remedial action is necessary. Nonetheless, the Laboratory plans to install a containment cap at each MDA as the minimal corrective action. This approach is a good faith response to public and regulatory concerns about these kinds of sites in general, and will eliminate the need for any additional evaluations that might be required to justify a "no further action" (NFA) recommendation. In addition, the Laboratory intends to provide maintenance and long-term monitoring for each MDA, commensurate with projected risks.

Although the Laboratory's mesa-top MDAs are regulated by NMED under the RCRA Corrective Action program, this plan draws freely from EPA guidance for both the RCRA Corrective Action program and the CERCLA Superfund program. It is EPA's intent that there be consistency, coordination, and integration between the two programs as described in *Coordination Between RCRA Corrective Action and Closure and CERCLA Site Activities* (EPA 1996b). In addition, remedial actions at the radioactively contaminated mesa-top MDAs are also subject to compliance with DOE Orders (**DOE XXX6**).

1.4. Organization of Document

This first chapter provides an introduction to the purpose and approach of the mesa-top MDAs implementation plan. Chapter 2 focuses on the major concepts employed in the technical evaluation of the MDA corrective actions. In Chapter 3, information is presented on all MDAs at the Laboratory and a group of similar sites is identified as the mesa-top MDAs for the application of the plug-in approach. Chapter 4 presents the conceptual site model for MDAs, and describes its role in assessing similarities and differences between sites. Chapter 5 describes the basis on which the lead sites (MDAs G and L) have been selected for the plug-in approach, and summarizes the information available for them. In Chapter 6 the modeling concepts and modeling approach for the long term risk assessments are introduced. Chapters 7 and 8 provide information on cover alternatives and monitoring technology, respectively. References are consolidated in Chapter 9, and numerous appendices are included to support the main text.

Next Chapter: Chapter 2

Top of this Chapter

Table of Contents

Ch. 2
TOC

2.0. TECHNICAL APPROACH

The "plug-in approach" mentioned in Chapter 1 provides the structure for the process of selecting corrective actions for mesa-top MDAs. This chapter describes the plug-in process and provides information on the technical approach for implementing it. A brief description is given of the regulatory process to be used for approving both this new approach and the corrective action proposals that will result from it. In addition to the plug-in approach, three concepts used in the assessment process are described: presumptive remedies, monitored natural attenuation, and risk-based corrective action. This chapter concludes by presenting several assumptions agreed to by the NMED, DOE, and Laboratory team as risk and compliance constraints on the assessments.

2.1. Plug-in Process

General description. EPA's presumptive remedy policy (EPA 1993a), described in Section 2.2, acknowledges that similar problems at similar sites are usually addressed by a limited set of likely response actions[1]: "Presumptive remedies are preferred technologies for common categories of sites..." (EPA 1992a, p. 1). The process described by DOE and EPA as the plug-in approach (DOE 1999a, EPA 1993b) builds on the EPA presumptive remedy policy "to expand the use of presumptive remedies and generic approaches as mechanisms to streamline waste site remediation." (DOE 1999a, p. 1). DOE guidance gives the following descriptions (DOE 1999a, p. 1):

> "Generic approaches are remedial strategies which use the knowledge gained from previous experience at a waste site(s) to serve as the basis and justification for subsequent responses at similar sites."
>
> "... the underlying premise is that similarities between sites can be used to better focus data collection, risk evaluations, and alternative analyses while reducing repetitive documentation and enhancing decision-making consistency."
>
> "This concept of utilizing similarities between sites to streamline response planning and implementation is embodied in EPA's presumptive remedy policy..."
>
> "In situations where there appears to be a recurrent problem... select a "lead site" (i.e., a site considered to most likely represent expected site conditions for a group of sites) to be evaluated first and serve as the basis for determining appropriate response actions. The implicit assumption being that similar waste management practices and site characteristics will have resulted in similar problems and therefore require similar remedial measures."

An EPA record of decision (ROD) for a Superfund site where the plug-in approach was applied states (EPA 1993b):

> "The Plug-in Approach allows multiple, similar, but separate subsites (facilities or areas within the larger site) to make use of the same remedy at different times. Under this

---

[1] The terms "remedial action", "remedy", "remedial alternative" (CERCLA terms); "corrective action", "corrective measure" (RCRA terms); and "response", "response action" (plug-in approach terms) are used in different regulatory settings and may have specific connotations in those settings. In this document, the term "corrective action" is primarily used because the Laboratory's ER Project is regulated under the RCRA corrective action process. Some of the concepts used in this plan were originally expressed in the other terms, however, and these terms are occasionally used herein, as well. If a specific regulatory connotation is intended, it will be made clear.

> approach, EPA selects a standard remedy that applies to a given set of conditions rather than to a specific subsite. At the same time, EPA selects a process and a set of criteria for determining where those conditions exist. Subsites are then fully characterized... EPA then makes subsite-specific determinations to "plug-in" subsites to the remedy."
>
> "EPA believes these approaches are consistent with CERCLA, the NCP, and the mandate to protect human health and the environment."

The more similar the sites and the "recurring problems", the more likely it is that they can be addressed by the same or very similar corrective actions. DOE and EPA guidance, example applications of the plug-in approach, and the specific approach selected for the Laboratory's mesa-top MDAs are discussed in Appendix A, Plug-in Approach.

Application of plug-in approach to mesa-top MDA corrective action. A diagram of the Laboratory's implementation of the plug-in process is shown in Figure 2-1, and described in the following bullets.

- The process begins with the identification of a group of similar sites (mesa-top MDAs). The normal RFI site characterization is completed for all of the sites, including actions to cleanup contamination that presents a current day human health or environmental risk.
- Two "lead sites" are selected to represent the group (MDAs G and L).
- The process relies on the evaluation of potential corrective actions for the "lead sites" to identify a set of remedies applicable to the group. "Remedy profiles" are developed to describe when each corrective action is applicable, based on the evaluations done for the lead sites. This step is to be documented as an "Assessment of Alternatives for Mesa-Top MDAs".
- Each site in the group is compared to the remedy profiles. If the site fits one or more profiles, the site can be "plugged-in" to those remedies, based on the evaluations developed for the lead sites. This step is to be documented as a "Plug-in Remedy Selection for MDA xxx".
- The sites in the group, although similar, will have differences that may push them just outside the bounds of a remedy profile. In this case, the process provides for additional site-specific data collection, or assessment of the remedy to see if it can be modified to account for the conditions of the site. If needed this step will be documented in the "Plug-in Remedy Selection for MDA xxx" as an additional "Site-Specific Evaluation" component.
- If one of the lead site remedies cannot be modified to account for site-specific differences, then the site was not sufficiently similar to be included in the initial plug-in group and must be addressed by a site-specific CMS (or may be included in another, yet to be defined group of sites).
- The plug-in comparisons and selection of the corrective action for the site are documented, submitted to the regulatory approval process, and implemented upon approval.

The plug-in approach reduces the time and cost for evaluation of corrective actions for similar sites. In some cases, site characterization efforts also can be reduced by focusing investigations on confirming that site conditions fit within a remedy profile.

2.2. Regulatory Process

The plug-in approach for the mesa-top MDAs differs from the corrective measures process identified in the IWP (LANL 1998a) and in the HSWA portion of the Laboratory's RCRA operating permit, Module VIII

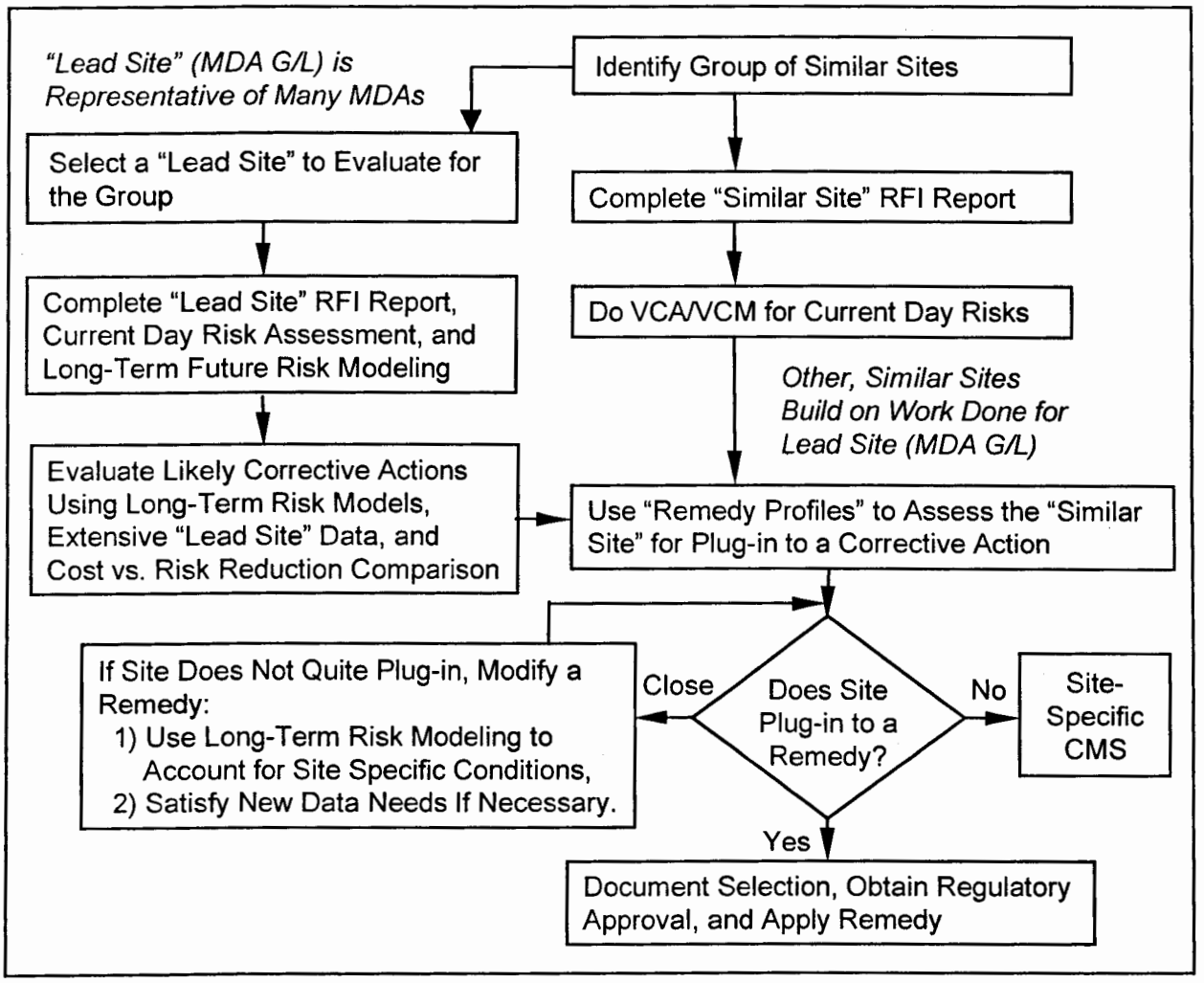


Figure 2-1. Plug-in Process Diagram

(**NMED 1981a???**), which applies to ER Project sites. For mesa-top MDAs, that process will be replaced by the process described in this plan. As a result, corrective measures study plans and reports will not be done, and the decision on the final corrective action will be made based on the documentation resulting from the plug-in process. The documentation will consist of: 1) the evaluation of alternatives based on the lead sites, 2) the comparison of RFI data from a particular mesa-top MDA to the resulting remedy profiles, and 3) the results of any site-specific assessments made to confirm the applicability of a remedy. The first item will stand alone (Assessment of Alternatives for Mesa-Top MDAs), while the second two will be combined into a single document for each site (Plug-in Remedy Selection for MDA xxx).

To ensure public acceptance of the plug-in process, two process-related regulatory approvals will be sought, along with a site-specific regulatory approval for each site. These are:

- Regulatory approval of this plan (Implementation Plan for Mesa-Top MDAs),
- Regulatory approval, with public comment, of the alternatives assessment based on the lead sites (Assessment of Alternatives for Mesa-Top MDAs), and

- Regulatory approval, with public comment, of the selection of the final corrective action for each site, including the comparison to the remedy profiles and any site specific assessments needed (Plug-in Remedy Selection for MDA xxx).

2.3. Presumptive Remedy -- Containment by Capping

General description. EPA policy defining the use of presumptive remedies in hazardous waste site remediation is described in *Presumptive Remedies: Policies and Procedures* (EPA 1993a) and elaborated in several other publications (EPA 1992a, EPA 1993c, EPA 1993d, EPA 1993e, EPA 1995a). The presumptive remedy concept resulted from the observation that a limited and common set of remedies consistently were chosen for certain types of sites. This observation indicated that extensive assessment of a wide range of potential alternative remedial technologies at each new site was not productive or cost-effective. EPA acknowledged this by suggesting that for some types of sites a particular remedy could be presumed, barring site-specific indications to the contrary.

> "Presumptive remedies are preferred technologies for common categories of sites..." (EPA 1993a, p 1.)

> "The objective of the presumptive remedies initiative is to use clean-up techniques shown to be effective in the past at similar sites in the future. The use of presumptive remedies will streamline removal actions, site studies, and clean-up actions, thereby improving consistency, reducing costs, and increasing the speed with which hazardous waste sites are remediated." (EPA 1992a, p. 1).

One category of sites for which a presumptive remedy was proposed was municipal landfills addressed under CERCLA. Such sites contained hazardous as well as municipal wastes, and EPA's experience was that the volume and heterogeneity of the waste generally made treatment options impracticable:

> "Because treatment is usually impracticable, EPA generally considers containment to be the appropriate response action, or the 'presumptive remedy,' for the source areas of municipal landfills."

> "The presumptive remedy for CERCLA municipal landfill sites relates primarily to containment of the landfill mass and collection and/or treatment of landfill gas. In addition, measures to control landfill leachate, affected ground water at the perimeter of the landfill, and/or upgradient ground-water that is causing saturation of the landfill mass may be implemented as part of the presumptive remedy." (EPA 1993d, p. 2).

The specified components of the presumptive remedy may include any or all of the following, depending on the conditions and needs at the specific site (EPA 1993d, p. 2):

- Landfill cap,
- Landfill gas collection and treatment,
- Source area groundwater control to contain plume,
- Leachate collection and treatment
- Institutional controls to supplement engineering controls.

Application of containment presumptive remedy to mesa-top MDA corrective action. CERCLA municipal landfills differ in some important ways from the Laboratory's hazardous and radioactive waste landfills; most obviously in the nature of the wastes. A detailed review is given in Appendix B, Presumptive Remedy, of the containment presumptive remedy, including application to non-municipal landfills sites and precedents for using containment as a presumptive remedy for low-level radioactive waste landfills. The review concludes that containment by capping is the applicable presumptive remedy for the Laboratory's mesa-top MDAs. For two ER Project sites, MDA J and the Airport Landfill, capping has been selected as the final remedy.

A similar situation was addressed by EPA with regard to landfills at military installations in *Application of the CERCLA Municipal Landfill Presumptive Remedy to Military Landfills* (EPA 1996c). See Appendix B, Presumptive Remedy, for a more detailed review of this guidance. With regard to landfill contents, EPA noted:

> The proportion and distribution of hazardous wastes in a landfill are important considerations. Generally, the municipal landfills produce low-level threats with occasional hot spots. Similarly, most military landfills present only low-level threats with pockets of some high hazard waste. However, some military facilities have a high level of industrial activity compared to overall site activities. In these cases, there may be a higher proportion and wider distribution of industrial (i.e., potentially hazardous) wastes than at other less industrialized facilities." (EPA 1996c).

EPA's focus on using the presumptive remedy unless clear indications to the contrary are found is demonstrated in their expectations for use of the guidance:

> "EPA anticipates that the containment presumptive remedy will be applicable to a significant number of landfills found at military facilities. Although waste types may differ between municipal and military landfills, these differences do not preclude use of source containment as the primary remedy at appropriate military landfills."
>
> "Additionally, EPA continues to seek greater consistency among cleanup programs, especially in the process of selecting response actions for sites regulated under CERCLA and corrective measures for facilities regulated under the Resource Conservation and Recovery Act (RCRA). In general, even though the Agency's presumptive remedy guidances were developed for CERCLA sites, they should also be used at RCRA Corrective Action sites to focus the RCRA Facility Investigation, simplify evaluation of remedial alternatives in the Corrective Measures Study, and influence remedy selection..." (EPA 1996c).

An element of the EPA process for determining a presumptive remedy is the presence of a history of sites of a specific type for which remedial evaluations have been made, and for which the proposed presumptive remedy is often chosen as the final remedy. DOE Guidance specifies a focus on shallow land burial with containment by capping as the preferred disposal option (**DOE XXX7**). NRC and State low-level radioactive waste compact experience provides another group of sites which serves as a precedent supporting the selection of containment by capping as the presumptive remedy for radioactive waste landfills (**NRC XXX9**, **OTHER XX10**). Appendix B, Presumptive Remedy, gives a review of the guidance and experience represented by DOE, NRC and State waste disposal compacts as precedence for the containment by capping presumptive remedy.

For the Laboratory's mesa-top MDAs, the main factors that figured in the CERCLA municipal landfill and military landfill presumptive remedy determinations are relevant to the MDAs: large volumes of

heterogeneous wastes, infeasible excavation and treatment options, and availability of a sufficiently protective and cost-effective alternative -- containment.

Site-specific knowledge at the Laboratory's mesa-top MDAs (see Chapter 3, Candidate Sites), including detailed assessments for MDAs G and L (see Chapter 5, Lead Site Selection and Evaluation), indicates that a landfill cap and institutional controls are the primary containment actions needed. Occasionally consideration may need to be given to subsurface gases in the vadose zone, but neither groundwater nor leachate controls are needed for this type of disposal unit in this particular disposal environment.

Accepting containment by capping as the presumptive remedy for the Laboratory's mesa-top MDAs is a critical part of the process described in this plan. The presumptive remedy allows an immediate focus on the most likely type of remedy for these sites. The assessments included in the plug-in process will identify any sites for which the presumptive remedy is not suitable, leading to a reassessment of those sites for other remedial alternatives.

Identifying containment by capping as the presumptive remedy does not completely specify the nature of the remedial action to be applied. As found in the assessments of MDA G that have already been done, differing cap designs which may include infiltration barriers, or plant and animal intrusion barriers, or other discrete layers may be required to maintain containment. The components of one potential capping system are shown in Figure 2-1. While containment by capping will be the general remedy, alternative cap designs will be evaluated for different conditions (see Chapter 7, Containment Alternatives). This evaluation is the "Assessment of Alternatives for Mesa-Top MDAs" described as part of the plug-in approach (Section 2.1).

2.4. Monitored Natural Attenuation

General description. Natural attenuation refers to naturally-occurring processes that "act without human intervention to reduce the mass, toxicity, mobility, volume, or concentration of contaminants in soil or groundwater" (EPA 1999a, p. 3). In other words, it is the use of natural processes to reduce the amount or toxicity of contamination in soil or water. The natural attenuation processes listed by EPA "include biodegradation; dispersion; dilution; sorption; volatilization; radioactive decay; and chemical or biological stabilization, transformation, or destruction of contaminants." (EPA 1999a, p. 3). Natural attenuation of contaminants can reduce risk from a contaminated site in three ways (EPA 1999a, p. 4):

- Transformation of contaminants to a less toxic form through destructive processes such as biodegradation or abiotic transformations,
- Reduction of contaminant concentrations in soil or water, which can reduce potential exposure levels,
- Reduction of contaminant mobility or bioavailability through sorption onto the soil or rock matrix.

EPA expresses a preference for processes that degrade or destroy contaminants, but accepts use of other processes which dilute, disperse, sorb or stabilize the contaminants (EPA 1999a, p. 3). Natural attenuation is expected to be only one component of a total remedy, to be used in addition to or as a follow-up to active remedial measures such as treatment, containment, or engineering controls (EPA 1999a, p. 11). EPA does not recommend natural attenuation as the sole remedy for a contaminated site (EPA 1999a, p. 2); nor does the ER Project in this plug-in approach.

EPA expects source control and long-term performance monitoring to be fundamental components of any remedy that includes natural attenuation (EPA 1999a, p. 3). It is the emphasis on long-term monitoring of the performance of the natural attenuation process that gives the concept its name, Monitored Natural

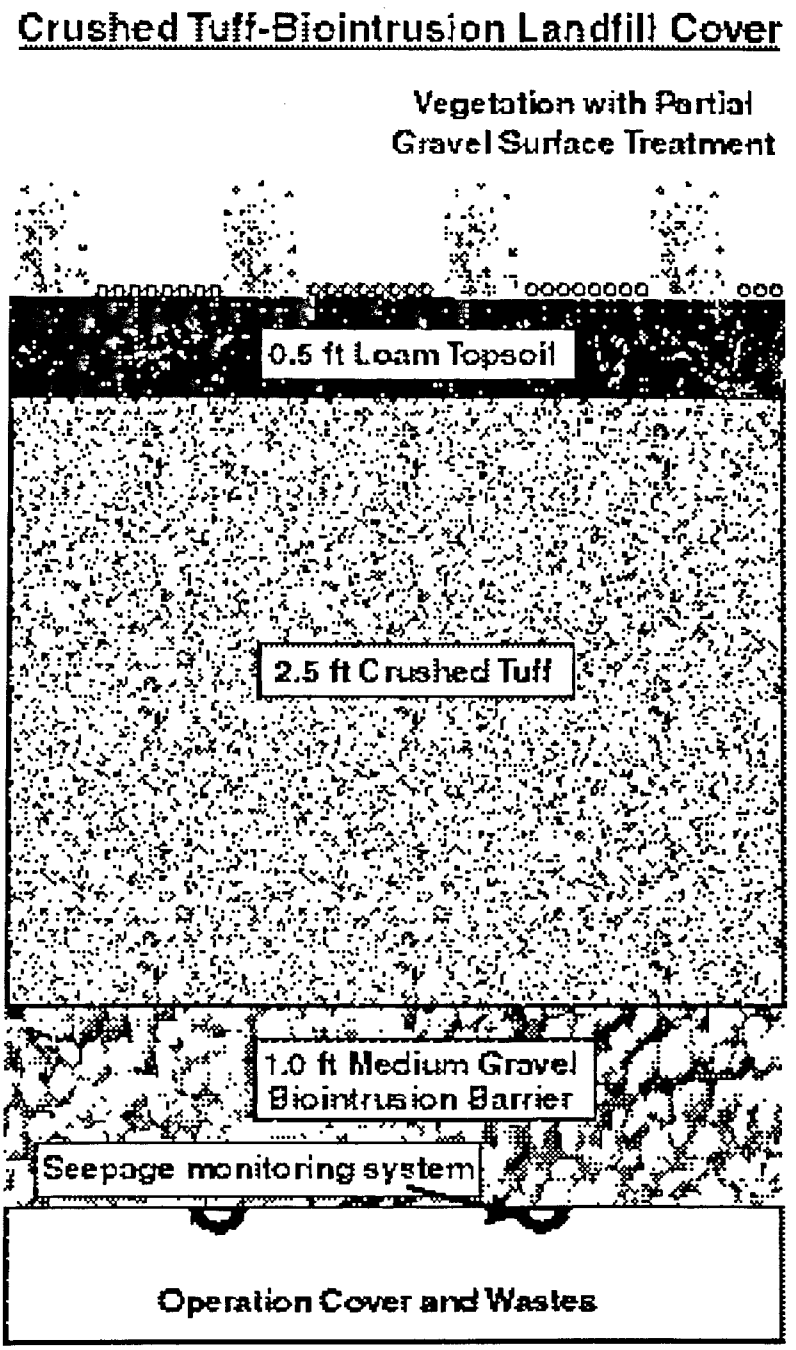


Figure 2-2. Example MDA Cover System.

Attenuation (MNA). EPA clearly states that MNA does not represent a "no action" remedy or the "walking away" from the responsibility to ensure that the remedy for a site is protective of human health and the environment. Specific use of long-term monitoring, institutional controls to ensure the continued efficacy of the attenuation, and contingency actions to be taken at certain trigger levels are suggested (EPA 1999a, p. 13).

Application of monitored natural attenuation to mesa-top MDA corrective action. Monitored natural attenuation is proposed as one component of the corrective measures regime for mesa-top MDAs at the Laboratory. Although, much of the EPA MNA policy is described in relation to reducing contaminants already present in a groundwater plume, for mesa-top MDAs MNA represents a second line of protectiveness against contaminant releases (secondary to the source control provided by capping). EPA expects the decision to use natural attenuation as a component of the remedial action to be based on suitable site-specific information and scientifically sound assessment of the specific attenuation processes. EPA suggests this usually requires a comprehensive conceptual site model, and analytical or numerical simulation (computer modeling) of the fate, transport, and attenuation processes (EPA 1999a, pp. 13-16).

Three components of natural attenuation are explicitly included in the conceptual model for MDAs (see Chapter 4, Conceptual Site Models for MDAs) and in the computer models used to represent and simulate the conceptual model (see Chapter 6, Risk-Based Assessments):

- Sorption: Although the potential for liquid releases of contaminants in the subsurface is greatly reduced by containment caps, studies of the attenuation effects of sorption of released contaminants within the geologic profile of the Bandelier tuff have shown this to be a significant secondary barrier to contaminant transport to groundwater (**Ref Sorption Discussion**).

- Dispersal: The only identified contaminant plumes associated with the mesa-top MDAs are volatile organic compounds (VOCs) and tritiated water vapor in the vadose zone. Studies of the VOC plumes at MDA L show it remains in the shallow vadose zone and slowly disperses to the atmosphere at low concentrations (below risk-based levels of concern) (**Ref VOC Plume Discussion**).

- Radioactive Decay: Radioactive contaminants decay with time. For some, the consequent decrease in concentration is an important aspect of the risk reduction afforded by containment in the waste disposal unit. Tritium in particular, although highly mobile in the environment , is significantly reduced (by half every twelve years) by its rapid radioactive decay. (**Ref Rad Risk Discussion**)

Consistent with EPA expectations for the use of MNA, long-term monitoring of the MDAs for contaminant releases after application of the final remedy is an integral part of the containment presumptive remedy, as discussed in Chapter 8, Long Term Monitoring and Stewardship.

2.5. Risk-Based Corrective Action

General description. A risk-based corrective action is one that is taken to reduce to an acceptable level an actual or projected health risk, considering human health and the environment. The concept of risk-based corrective action was put forward by EPA in 1990 in a proposed 40 CFR 264 Subpart S (EPA 1990a). It was supplemented in 1996 by an update to the proposed Subpart S (EPA 1996a), and has been elaborated over the years by numerous EPA guidance documents. Although Subpart S was never promulgated as a formal regulation, EPA "...has found in practice that the current regulations, supplemented by current and planned guidance, provide us an adequate foundation to authorize State programs, and that additional regulations are not necessary at this time." (EPA 1999b, p. 54606). NMED has been authorized by EPA to manage RCRA corrective actions in New Mexico under the Subpart S guidance. NMED expects to use guidance prepared by EPA Region 6 in *Risk Management Strategy* (EPA 1998a), when it is finalized, and states (NMED 2000a):

> "The Strategy establishes a non-traditional, tiered (and iterative) risk-based approach (RBA). The RBA allows for more flexibility as long as established performance standards are met."

To implement risk-based corrective actions it was necessary for Subpart S guidance to define:

- the levels of health risk that would require a corrective action be taken, and that would be acceptable after a remedial action was completed (see paragraph *Risk Levels*, below),
- the methods for determining the level of health risk associated with a site (see paragraph *RFI Site Characterization, Risk Assessment, and Voluntary Corrective Action*, below), and
- methods for demonstrating that a remedial technology applied to a site could be expected to achieve or maintain a risk reduction to acceptable levels (see paragraph *Long Term Risk Assessment*, below).

Application of risk-based corrective action to mesa-top MDAs.

Risk Levels. Under Subpart S, the need for corrective action at a site is determined by the presence of contaminant releases to the environment, and contaminant concentrations in soil, air, groundwater, or surface water at levels that represent an unacceptable risk to human health or the environment.

> "EPA's goal in RCRA corrective action is, to the extent practicable, to eliminate significant releases from solid waste management units that pose threats to human health and the environment, and to clean up contaminated media to a level consistent with reasonably expected, as well as current, uses." (EPA 1990a, Section V.B.)

> "...EPA's risk reduction goal is to reduce the threat from carcinogenic contaminants such that, for any medium, the excess risk of cancer to an individual exposed over a lifetime generally falls within a range from 10^{-6}. . . to 10^{-4}. For non-carcinogens, the hazard index should generally not exceed one (1). Available risk-based media cleanup standards are considered protective if they achieve a level of risk which falls within the 10^{-6} and 10^{-4} risk range." (EPA 1996a, pp. 19449-50).

The risk levels cited above provide the guidance for this implementation plan for evaluating corrective actions at mesa-top MDAs. Specific details on the application of these basic risk levels are given in Section 2.6.1, Risk Thresholds.

RFI Site Characterization, Risk Assessment, and Voluntary Corrective Action. Under the plug-in approach (Section 2.1, Plug-in Process and Figure 2-1), the RFI will be completed for each mesa-top MDA to support the development of the conceptual site model, define the nature and extent of contaminant releases, assess current-day risks, and identify any stabilization actions needed to mitigate the current-day risks. For the Laboratory's ER Project, all sites -- including the mesa-top MDAs -- are characterized using the RFI process as defined in the IWP (LANL 1998a) and detailed in ER Project guidance documents.

Conceptual Site Model. A conceptual site model (EPA 1996a, p. 19444) is a textual, graphical and/or pictorial description of site conditions that conveys what is known about sources, releases, migration, exposures, and risks. It is based on the information available at a given time, and evolves and is updated as new information becomes available. NMED refers to this as the site conceptual exposure model (SCEM) (NMED 2000a). A major component of the MDA conceptual site model is a list of "features, events and processes" (FEPs) relevant to the risk assessment of the sites. The conceptual model is not a mathematical model or computer model, although it may be represented by these and they are helpful in predicting future conditions. Considerable work has been done already in the development of a detailed conceptual site model for MDAs. The current conceptual site model and the process for developing and updating it is presented in Chapter 4, Conceptual Site Models for MDAs.

Site characterization. Site characterization through the RFI process identifies the nature of the contaminants and the extent of their distribution; the direction, rate, movement and concentration of contaminant releases; and levels of contamination in environmental media (EPA 1996a, pp. 19444). The conceptual site model is used to focus the characterization efforts and to test an emerging understanding of the important release and transport pathways for a site. Detailed site characterization guidance has been developed for the ER Project based on the IWP (LANL 1998a). The site characterization phase has been initiated, and in many cases completed, for most of the mesa-top MDAs (see Chapter 3, Candidate Sites).

Risk Assessment. As part of the RFI, a current-day risk assessment evaluates human health (and ecological) risks for a site, based on contaminant levels in accessible environmental media, contaminant toxicity information, exposure routes to human or ecological receptors, and a calculation of health impacts. Fate and transport modeling may be used to estimate media concentrations. Current and future land uses are factored into scenarios for exposure to determine if existing contaminant levels are unacceptable, by comparison to the risk levels given above, and to determine site-specific media cleanup levels. For the mesa-top MDAs, current-day risk assessments are included within the RFI process as defined in the IWP (LANL 1998a) and detailed in ER Project guidance documents. Current day risk assessment results are documented in site-specific RFI Reports (see Chapter 3, Candidate Sites).

Stabilization. In this implementation of the plug-in approach for mesa-top MDAs, any unacceptable current-day risks are addressed by voluntary corrective actions (Section 2.1, Plug-in Process and Figure 2-1). The use of risk-based voluntary corrective actions (also called voluntary corrective measures, interim actions, interim measures, or stabilization) is addressed within the RFI process in the IWP (LANL 1998a) and detailed in ER Project guidance documents. Such actions are used to stabilize a site pending a final remedy, and must be consistent with expected final remedies such as the containment presumptive remedy.

> "One of EPA's overriding goals... is to expedite risk reduction by emphasizing early implementation of interim actions to control or minimize ongoing threats to human health or the environment. ...Generally, interim actions should be compatible with, or a component of, the final remedy." (EPA 1996a, pp. 19446-47)

The risk reduction achieved by a voluntary corrective action is evaluated based on the conceptual site model, using the same current-day risk assessment process, accounting for the reductions in contaminant concentrations or availability achieved by the action.

RFI results from mesa-top MDAs have generally shown minimal releases of contaminants, if any. Identified releases usually appear to have been associated with the period of site operations, rather than with any subsequent mobilization and transport of contaminants after the cessation of operations. The current-day risk assessments generally have not identified health risks above the $1x10^{-6}$ level, and the need for voluntary corrective actions to address current-day risks has been minimal (see Chapter 3, Candidate Sites). In the absence of identifiable releases and a lack of the demonstrable potential for health risks, additional corrective actions such as capping to control the contaminant source normally would not be required within the RCRA corrective action framework.

Long Term Risk Assessment. In the preceding paragraphs, the RFI portion of the risk-based corrective action process was described in brief. In the following paragraphs, the corrective measures portion of the process -- specific to this implementation of the plug-in approach -- is introduced. The remainder of this implementation plan elaborates the following few paragraphs. As noted previously, the plug-in process outlined here replaces the formal CMS process described in the IWP (LANL 1998a, Section 3.1.3.3). The term "long term risk assessment" is used here to mean projections of future releases from a site, ensuing

migration and contamination of environmental media, and exposures and future health risks resulting from processes that occur over long periods of time. The term is used to distinguish it from the current-day risk assessment, which is based on existing conditions of environmental contamination, as described above.

Applications of long-term risk assessment. Long-term risk assessment is used in the plug-in approach for mesa-top MDAs in three contexts (see also Figure 2-1).

- First, as part of the evaluation of the lead sites, a long-term risk assessment is used to identify the future risks associated with the site under its current condition. This is a "no action" assessment of future risks associated with the lead site. This step has been completed. It is documented in the *Performance Assessment and Composite Analysis for Los Alamos National Laboratory Material Disposal Area G* (LANL 1997a), and in the *RFI Report for Material Disposal Areas G, H, and L at Technical Area 54* (LANL 2000a). It is summarized here in Chapter 5, Lead Site Selection and Evaluation.

- Second, long-term risk assessments are used to project the reduction in future risks achieved by corrective actions applied to the lead site, specifically, various capping options under the containment presumptive remedy. This step, when completed, will provide the "Assessment of Alternatives for Mesa-Top MDAs", one of the critical products for implementing the plug-in approach (see Section 2.1, Plug-in Process and Section 2.2, Regulatory Process). The assessment of the capping options allows preparation of "remedy profiles" against which RFI data from each of the other mesa-top MDAs may be compared to select a final remedy. The comparison of individual sites to the remedy profiles will be documented in the "Plug-in Remedy Selection for MDA xxx", the critical document for presenting the site-specific decisions of the plug-in approach (see Section 2.1, Plug-in Process and Section 2.2, Regulatory Process). More details are presented in **Section ???, XXX XXX**.

- Third, if necessary, long-term risk assessments may be used to evaluate variations in the original capping options to respond to site-specific differences between the lead sites and other sites in the mesa-top MDA group. Such site-specific assessments will be used when conditions at a particular site do not quite match the conditions specified by a remedy profile. Three assessment options are available; first, to see if the remedy profile can be expanded or optimized without compromising the protectiveness of the remedy, or second, to collect additional site data to address uncertainties or data gaps, and third, to modify the remedy itself to accommodate the exceptional conditions. Assessments of this nature will be documented as an additional component of the site-specific "Plug-in Remedy Selection for MDA xxx" (see Section 2.1, Plug-in Process and Section 2.2, Regulatory Process). More details are presented in **Section ???, XXX XXX**.

Use of computer models. Computer models are used to do the projections of contaminant release and migration for the long-term risk assessments. The calculation of projected contaminant concentrations in environmental media, exposures of human and ecological receptors, and calculation of health risks are also included. Figure 2-3 presents a high-level view of the role of computer models in the risk-based assessment of corrective actions. The three boxes across the top of the figure represent three major categories of information needed for the modeling of future risks.

- *Site Specific Data.* This category includes information about the disposal unit, waste characteristics, and environmental processes specific to a particular site. In this implementation plan, a high degree of similarity between sites is expected so the plug-in approach can be applied. Site specific information is summarized in Chapter 3, Candidate Sites, and Chapter 5, Lead Site Selection and Evaluation. The identification of important site-specific processes and information is addressed in Chapter 4, Conceptual Site Models for MDAs.

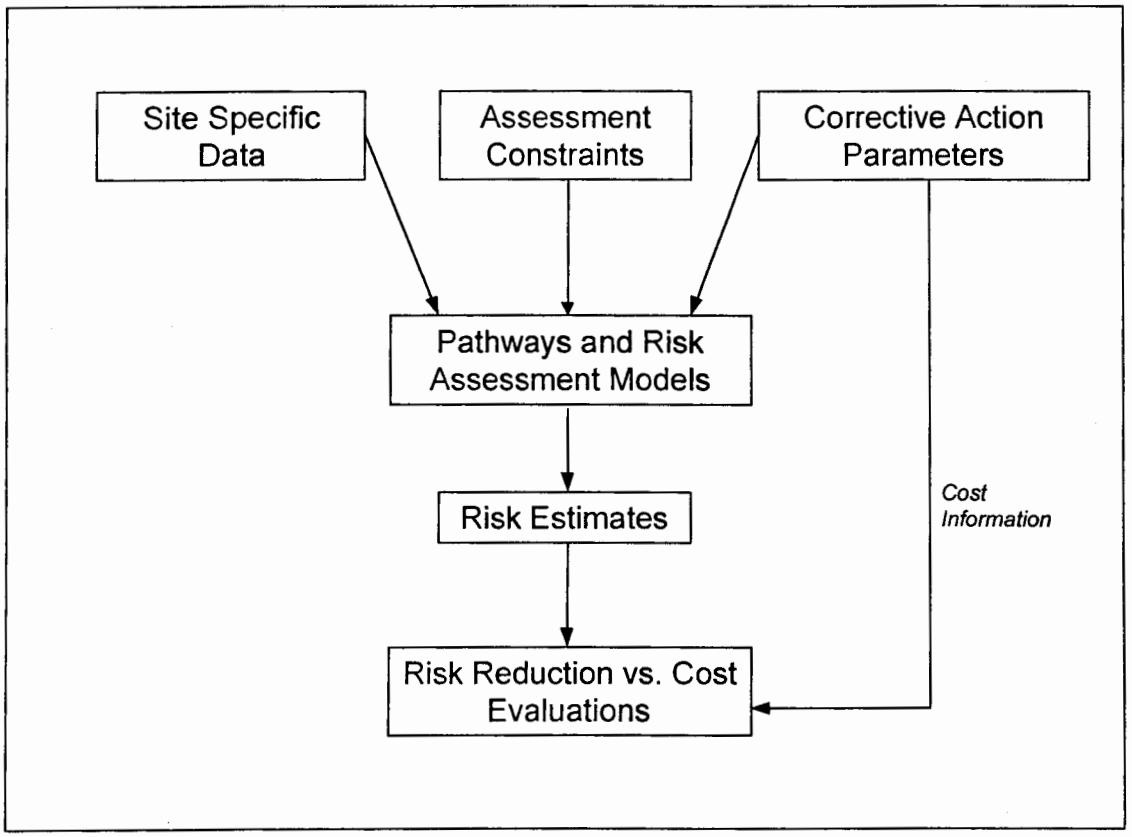


Figure 2-3. Risk-Based Corrective Action Assessment Scheme

- *Assessment Constraints.* This category represents information that bounds the assessment, or constrains it to certain regulatory requirements. Examples of this kind of information are: acceptable health risk levels, particular media concentration limits, the time period over which risks from a site must be projected and a corrective action must be protective, the locations at which media concentrations are to be projected or receptor exposures calculated, the exposure scenarios to be used for calculating human or ecological receptor exposures, period of institutional control, future land use, and risk assessment assumptions. Agreement by NMED, DOE, and the Laboratory on the assessment constraints is necessary, and is addressed in Section 2.6, Assessment Constraints.

- *Corrective Action Parameters.* This category provides information describing the changes in site conditions resulting from a corrective action. For example, different types of caps provide different barriers and thicknesses that must be modeled. This category also includes information on the costs, longevity, institutional control needs, maintenance, and monitoring components of the remedy. These elements factor into remedy comparisons such as cost versus risk reduction. More details are given in **Section ???, xxx xxx**.

The three categories of information above provide input to the computer models, represented by the central box, *Pathways and Risk Assessment Models,* in Figure 2-3. The model's outputs are *Risk Estimates* (projections) for human health and the environment for particular contaminants, migration pathways and exposure routes. The risk projections are used to compare the performance of different capping systems in terms of controlling releases, reducing health risks via different pathways, and cost (**Section ???, xxx xxx**).

The computer modeling tools use both analytical and numerical calculations, and both process- and systems-level models are employed. Descriptions of the modeling techniques are given in Chapter 6, Risk-Based Assessment. To address the effects of uncertainties in our knowledge of environmental processes and changes in conditions over time, uncertainty analyses are conducted using point estimates and probabilistic risk assessment (PRA) from stochastic models, bounding calculations on deterministic models, and logic-tree analyses to include the effects of unlikely FEPs.

Computer models implement the conceptual site model. The environmental processes included in the computer models are based on the detailed conceptual site model for the mesa-top MDAs (Chapter 4, Conceptual Site Models for MDAs). The conceptual model helps ensure that processes that are important in long-term release and migration scenarios are not over looked, such as aspects of natural attenuation that may supplement the benefits of a containment cap. It is used to compare different sites at a conceptual level, to identify those that are similar and can be grouped for the plug-in approach. The exposure calculations for human and ecological receptors, and the estimation of health risks, use the same methods as for the current-day risk assessments, although land use assumptions, exposure scenarios, and receptor locations may vary.

In conjunction with computer simulations, the processes identified in the MDA conceptual site model can be evaluated for their relative contributions to the future risk associated with a site. The important, versus insignificant, contributors to future risk can be identified so the models can be simplified and risk assessments and corrective actions can be focused on important components. The risk-reduction benefits of capping a mesa-top MDA are evaluated using the same long term risk assessment, with changes to the conceptual model to include the effects of the cap on release and transport processes.

2.6. Assessment Constraints

The assumptions discussed in the following sections are used to constrain aspects of the long term risk assessments for the mesa-top MDAs. These constraints impose conditions on the assessment, to comply with regulatory interests. They specify the locations where risk will be estimated, the risk thresholds to be met at those locations, the time period over which risk estimates are to be made, the land uses to be assumed for the MDA properties, the scenarios for exposures to future residents, and the nature and duration of institutional controls that can monitor for and mitigate future contaminant releases.

2.6.1. Risk Thresholds

The risk thresholds for the mesa-top MDAs are based on EPA Subpart S guidance, as noted previously:

> "...EPA's risk reduction goal is to reduce the threat from carcinogenic contaminants such that, for any medium, the excess risk of cancer to an individual exposed over a lifetime generally falls within a range from 10^{-6}. . . to 10^{-4}. For non-carcinogens, the hazard index should generally not exceed one (1)... Available risk-based media cleanup standards are considered protective if they achieve a level of risk which falls within the 10^{-6} and 10^{-4} risk range." (EPA 1996a, pp. 19449-50).

These are all-pathway limits for the receptor locations, exposure scenarios, and other constraints given in the following sections.

Carcinogenic Chemicals. The EPA target risk range for increased excess fatal cancers of 10^{-6} and 10^{-4} will be applied to cancer-causing chemicals in the MDA inventories.

Noncarcinogenic chemicals. Toxicity thresholds (including the Hazard Index and Hazard Quotient) identified in the IWP will be applied to non-cancer causing chemicals in the MDA inventory.

Radioactive contaminants. For radioactive contaminants, which are carcinogens, the guidance provided by EPA for CERCLA sites has been adopted. This guidance uses a radioactivity effective dose equivalent (EDE) of 15 mrem/yr, and equates that dose to a lifetime excess cancer risk estimate of $3x10^{-4}$, for an all pathways assessment (EPA 1997a, 58693). In addition, radioactive contaminants via any groundwater pathway are limited to a 4 mrem/yr (EDE) contribution to the 15 mrem/yr (EDE) all pathways dose.

The cancer risk levels are interpreted as described by EPA: contaminant concentrations leading to risk estimates of less than $1x10^{-6}$ are of no concern; risk estimates in the range of $1x10^{-4}$ to $1x10^{-6}$ are indicative of the need for assessment; and levels above $1x10^{-4}$ may need remedial action. EPA is also clear that there is no firm line at a risk level of $1x10^{-4}$ that demands remedial action. The EPA document *Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination* (EPA 1997a, pp. 4 - 5, 58693) states:

> "Cleanup should generally achieve a level of risk within the 10^{-4} to 10^{-6} carcinogenic risk range based on the reasonable maximum exposure for an individual. The cleanup levels to be specified include exposures from all potential pathways, and through all media (e.g., soil, ground water, surface water, sediment, air, structures, biota). As noted in previous policy, "the upper boundary of the risk range is not a discrete line at 1×10^{-4}, although EPA generally uses 1×10^{-4} in making risk management decisions. A specific risk estimate around 10^{-4} may be considered acceptable if justified based on site-specific conditions.""
>
> "If a dose assessment is conducted at the site then 15 millirem per year (mrem/yr) effective dose equivalent (EDE) should generally be the maximum dose limit for humans. This level equates to approximately 3×10^{-4} increased lifetime risk and is consistent with levels generally considered protective in other governmental actions, particularly regulations and guidance developed by EPA in other radiation control programs."

The goal of a 10^{-4} to 10^{-6} risk range is consistent with the EPA's Clean Water Act, which limits of the dose from intake of radioactivity in drinking water to 4 mrem/yr (~ $1x10^{-4}$ risk) (40 CFR 141), and EPA's national emissions standards for hazardous air pollutants (NESHAPS) radionuclide regulations, which limit the dose from radioactivity in the air to 10 mrem/yr (~ $2x10^{-4}$ risk) (40 CFR 61).

Risk-based thresholds, rather than dose-based, are used in this document because MDAs containing hazardous, radioactive, or mixed waste can more easily be assessed and compared using risk as the common framework.

2.6.2. Media Compliance Points

Media compliance points are the locations at which estimates of contaminant concentrations will be projected for air, surface water, soil, sediment, and groundwater. The media compliance points remain fixed for the duration of the assessment period, based on the closest release points or points of maximum concentrations. The descriptions given below are based on the lead-site for the plug-in assessment, MDA G. To the degree site-specific conditions differ, additional assessments may be needed. These points differ from the "receptor locations", described below, which change with land use assumptions over time. These points also differ from actual monitoring locations that may be established as part of the

long-term monitoring program for the corrective action (see Chapter 8, Long-Term Monitoring and Stewardship).

- Groundwater. The media compliance point for projected groundwater concentrations is the surface of the regional aquifer directly beneath the disposal unit.
- Air. The media compliance point for projected contaminant concentrations in air is the location of the maximum projected airborne concentrations, generally expected to be in an adjacent canyon to the north of the disposal unit.
- Soil. The soil media compliance point is the soil surface at any point on or around the disposal unit.
- Sediment. For sediments, the media compliance point is the base of the adjacent canyon.
- Surface Water. The media compliance point for surface water is the point where runoff from the mesa top joins the alluvial sediments of the adjacent canyon floor.

2.6.3. Assessment Period

The performance of the containment presumptive remedy (capping) for mesa-top MDAs will be evaluated for a period of 1000 years. (Based on assumptions made for the *Performance Assessment and Composite Analysis for Los Alamos National Laboratory Material Disposal Area G* (LANL 1997a), the assessment period ends in 3046.) This period is based on DOE radioactive low-level radioactive waste disposal site performance objectives (**DOE Order 435.1**), and is consistent with EPA and NRC guidance for similar purposes (**EPA REF**, **NRC 10 CFR 61**).

A corrective action will be acceptable if the projected risks and media concentrations do not exceed the risk range given above during the 1000-year period. If projected risk levels are increasing at 1000 years, projections will be made to a maximum of 10,000 years to estimate the time of maximum risk and the maximum media concentrations. This information will allow informed decision making. If the time of the maximum is far in the future, and the maximum levels are not excessive, this condition will not disqualify an otherwise acceptable remedy. The projections into the future are intentionally overestimated and become more highly uncertain for longer times.

As discussed in Chapter 6, Risk-Based Assessments, an uncertainty analysis and stochastic modeling are used identify the major contributors to uncertainty in the risk projections, and to estimate the uncertainty bounds on the risk projections. Assessments of unlikely but potentially significant FEPs (**Ref Rare Events discussion**) are also considered to determine if such events may have such serious consequences that additional effort should be taken to mitigate against them.

2.6.4. Probabilistic Risk Assessment

Long-term risk assessments are inherently uncertain because of the difficulty in predicting future site conditions. To assess and incorporate this uncertainty into the decision-making process, we use probabilistic risk assessment (PRA). Probabilistic risk assessment is a risk assessment that produces a probability distribution for risk. Thus our assessment does not produce a single risk estimate to be compared to the risk thresholds, but instead produces a variety of risk estimates corresponding to different levels of confidence, and to some extent to the variation of risk among the exposed population.

Risk-based corrective action in a probabilistic framework becomes a task in multiple-objective decision-making. We propose a set of criteria to minimize the number of quantitative risk objectives that must be

considered while still capturing the important characteristics of the risk distribution and variability. Specifically, we propose that the principal requirement is the reasonable maximum exposure (RME) risk should fall below the risk target thresholds (10^{-4} excess cancer risk and hazard index of 1) with a confidence level of 90% or more. Auxiliary criteria that are not evaluated in relation to thresholds but can assist in the discrimination between remedy alternatives are described in detail in Chapter 6, Risk-Based Assessments.

2.6.5. Institutional Controls

In the *Performance Assessment and Composite Analysis for Los Alamos National Laboratory Material Disposal Area G* (LANL 1997a), the institutional control period was assumed to commence following final site closure for MDA G, planned to occur in 2046, and to continue for 100 years (between 2047 and 2146). During the institutional control period, site access is controlled, environmental monitoring is performed, and containment caps are maintained (see Chapter 8, Long Term Monitoring and Stewardship).

All MDAs in the mesa-top group, other than MDA G, already have ceased waste disposal operations. They will enter institutional control upon completion of the selected corrective action. For consistency, institutional control is assumed to continue for all mesa-top MDAs until 2146.

2.6.6. Future Land Use

The Laboratory's Site Development Plan reflects the current future land use assumptions. For MDA G, the site is identified for future industrial use on DOE property. Access to the site will be limited to workers and general facility surveillance will be continued. Future land use is identified for two periods following corrective action.

During the 100 year institutional control period (through 2146), access is controlled within the current MDA fence lines, public access is assumed to be allowed for recreational or industrial land use outside the fence, and residential land uses may occur as close as 1.3 miles from the MDA fence.

For the remaining 900 years of the assessment period (through 3146), recreational uses are assumed to be possible on the MDA site proper, but sufficient site control is maintained that industrial uses occur only outside the area of the current MDA fence and residential uses are no closer than 0.25 miles.

2.6.7. Receptors

The assessment of long-term future risk will be carried out in a manner consistent with the concepts of

- Reasonable Maximum Exposure (RME), defined by EPA as "the highest exposure that is reasonably expected to occur at a site" (EPA 1989a), and
- Central Tendency Exposure (CTE), defined by the EPA as the risk "representing the average or typical individual in a population, usually considered to be the mean or median of the distribution" (EPA 1999c).

The receptor locations for the RME and CTE risk assessments will be the locations of the maximum media-specific contaminant locations for each exposure pathway. Exposure scenarios will be consistent with the land use and media of interest in each exposure pathway, and will be consistent with the scenarios identified in the IWP.

3.0. CANDIDATE SITES

Information on each of the 26 MDAs at the Laboratory is given in Appendix C, MDA Descriptions. A brief summary for each MDA is presented in Table 3-1, below.

3.1. Grouping Criteria

Two major criteria can be used to identify a group of similar MDAs to which the plug-in approach can be applied. The first criterion is administrative: the plug-in group must all be within the organizational purview of the ER Project's Material Disposal Area Focus Area. For logistical reasons, not all MDAs fall within the purview of the MDA Focus Area. Those that do are identified in Table 3-1 in the third column where the PRS numbers and responsible focus area are listed.

The second criterion is technical: the plug-in group of MDAs must be similar in terms of waste disposal units, waste types, and disposal environment. The impetus to use the plug-in approach is that such similarities were observed during the RFI process. General types of similarities are:

- Many MDAs are subsurface disposal units such as pits, trenches, absorption beds, seepage pits, and vertical shafts. The similarities include limited surface expression of contaminated materials, and excellent present-day containment of disposed wastes in the subsurface units.
- Most MDAs received solid or liquid wastes from similar sources: radioactive and nuclear weapons related research laboratories.
- The wastes received at most MDAs are primarily contaminated with radionuclides, metals, and some organic compounds – usually organic solvents.
- Many MDAs received only solid wastes, and conditions at the MDAs which received liquid wastes are now similar to the solid waste disposal areas: radioactive and hazardous wastes dispersed in a dry soil and rock matrix.
- Many MDAs were constructed in the Bandelier tuff on the tops of the mesas of the Pajarito Plateau. This disposal environment is dry and well isolated from underlying groundwater.

For comparison, there are also MDAs on the land surface, in the alluvial sediments of canyon floors, and which contain some different contaminants such as high concentrations of explosive compounds. These may not be similar enough to be included in this plug-in group. Finally, from a regulatory perspective, MDAs that fall under RCRA Closure, or have active RCRA-permitted operations, are subject to a regulatory process that is outside of the ER Project.

3.2. Decision Logic

The plug-in group is targeted at mesa-top, landfill-like MDAs. To identify this group, the decision logic shown in Figure 3-1 was developed. The results of applying the decision logic to the Laboratory's 26 MDAs are given in Table 3-2. The identified candidate mesa-top plug-in sites are:

- TA-21: MDAs A, B, T, U, and V.
- TA-49: MDA AB.
- TA-50: MDA C.
- TA 54: MDAs G, H, and L.

Table 3-1 Description of Laboratory MDAs and Anticipated Cleanup Plans

MDA	TA	PRS and ER Focus Area	Description	Current Status	Anticipated Path to Completion
A	21	21-014 MDA Focus Area	1.8-acre site containing two 50,000-gal. underground tanks and 3 pits	Phase I RFI surface investigation complete, RFI report to be written	Containment (capping)
B	21	21-015 MDA Focus Area	6-acre site used primarily for solid waste disposal; small section used for chemical waste disposal	Phase I RFI field work complete, RFI report in draft	Containment (capping)
C	50	50-009 MDA Focus Area	7 pits and 108 shafts within 11.8-acre site	Phase I RFI field work complete, RFI report to be written	Containment (capping)
D	33	33-003(a–b) RA Focus Area	Two underground concrete chambers, experiments conducted in 1948 containing high explosives, beryllium	Performed Phase I and II RFI in 1994 and 1996	No further action (NFA) recommended in RFI Report
E	33	33-001(a–e) RA Focus Area	Underground chamber plus 6 waste disposal pits, spent projectiles, uranium, beryllium	Performed Phase I investigation in 1996	Voluntary corrective measure (VCM) to include evaluation of containment (capping)
F	6	6-007(a) RA Focus Area	Classified trash was interred here during the late 1940s	Geophysics studies have been completed but not documented in a report	Containment (capping) versus removal
G	54	54-013(b), 54-014(b, c, d), 54-017, 54-018, 54-019, 54-020 MDA Focus Area	34 disposal pits, 174 disposal shafts, and 4 transuranic waste trenches within a 65-acre site	RFI report 2000	Containment (capping)
H	54	54-004 MDA Focus Area	9 vertical shafts within a 0.3-acre site	RFI report 2000	Containment (capping)
J	54	54-005 MDA Focus Area	4 disposal pits and 2 disposal shafts within a 2.65-acre site	Closure under NMED Solid Waste Regulations In 1999	Site closure by the facility, ER is assuming NFA
K	33	33-002(a–e) RA Focus Area	Septic tank, sump, roof drain, and outfall associated with main site, contaminants include tritium from TA-33 processing facility.	Septic tank, Potential Release Site (PRS) 33-002(a), is plugged and is scheduled for decontamination and decommissioning (D&D) and is therefore deferred. Remaining PRSs are proposed for NFA	Sampling following D&D for PRS 33-002(a), NFA proposed for remaining PRSs
L	54	54-001(a–e), 54-002, 54-015(g), 54-008, 54-012(b), 54-009, 54-014(a), 54-015(l) MDA Focus Area	1 chemical waste disposal pit, 34 disposal shafts and 3 chemical waste disposal impoundments within a 2.5-acre site	RFI Report 2000	Containment (capping)
M	9	9-013 ?? Focus Area	Surface trash disposal site	Expedited cleanup completed in Fiscal Year 1996	Eco and applicable or relevant and appropriate requirements (ARARs) assessment must be completed before close out
N	15	15-007(a) ?? Focus Area	Construction and office debris reported to be buried in shallow trenches <1 acre in size	RFI investigation could not definitively locate this MDA.	Phase II required to find and characterize
P	16	16-018 ?? Focus Area	HE burn ground residues disposed of here	Phase I of clean closure in progress	RCRA clean closure
Q	8	8-006(a–b) ?? Focus Area	Naval guns and other metallic trash was buried here during the late 1940s	Limited Phase I sampling and geophysics complete. No report written	Voluntary corrective action
R	16	16-019 ?? Focus Area	World War II era HE burn ground and associated HE residues and trash on surface	Geophysics study completed, limited sampling suggest high levels of contamination	VCM surface cleanup

Table 3-1 (Continued) Description of Laboratory MDAs and Anticipated Cleanup Plans

MDA	TA	PRS and ER Focus Area	Description	Current Status	Anticipated Path to Completion
S	11	11-009 ?? Focus Area	HE degradation experiment in progress	Approved for deferred action in OU 1082 work plan	Complete
T	21	21-016(a–c) MDA Focus Area	3.5-acre site consisting of 4 liquid waste absorption beds, a waste storage area, and a series of disposal shafts to dispose of wastes mixed with cement	Phase I RFI field work complete, RFI report to be written	Containment (capping)
U	21	21-017(a–c) MDA Focus Area	1.3-acre site containing 2 absorption beds and associated sump	Phase I RFI field work complete, RFI report to be written	Containment (capping)
V	21	21-018(a–b) MDA Focus Area	1-acre site containing 3 liquid absorption beds designed to dispose the outflow from a radioactive laundry facility	RFI Phase I completed and report submitted to NMED 8/96	Containment (capping)
W	35	35-001 ?? Focus Area	Two 4-in diameter, 125 ft long stainless steel tubes suspended vertically inside 8-in diameter carbon-steel-cased wells; each tube is backfilled under pressure with nitrogen and is sealed, it contains 150 l of liquid sodium reactor coolant contaminated with plutomiun-239 and associated fission products	Proposed for NFA in OU1129 work plan, May 1992 (NFA Rationale: institutional controls preclude release to the environment)	If NFA proposal is accepted this site is completed (not HSWA)
X	35	35-002 ?? Focus Area	Site of the Los Alamos Power Reactor Experiment No. 2 (LAPRE II) reactor, which was buried in place after it was decommissioned in 1959; the site was remediated in 1991 as an ER interim action	Proposed for NFA in OU1129 Work Plan, May 1992 (NFA Rationale: recommended for NFA because all reactor-related equipment and "contaminated soils were removed").	If NFA proposal is accepted this site is completed Note: This PRS is still in the permit
Y	39	39-001(a and b) ?? Focus Area	Construction, office, and firing site debris buried in 5 shallow trenches.	RFI report complete with RSI.	CMS/CMI to evaluate containment (capping) versus removal
Z	15	15-007(b) ?? Focus Area	Approximately 2000 yd of construction debris and other debris from firing site activities. uranium present.	RFI report complete.	VCM proposed
AA	36	36-001 ?? Focus Area	Firing site debris (burned and unburned) place in trenches approximately 13 ft deep, and covered 2–3 ft of soil	Phase I RFI report denied by NMED, additional sampling required	VCM to evaluate containment (capping) and other cleanup options
AB	49	49-001(a–g) MDA Focus Area	Multiple shafts and chambers at depths between 60 ft and 80 ft (18 m and 24 m), used for hydronuclear safety experiments from late 1959 to 1961, total volume of contaminated tuff estimated at about 1,000,000 ft^3 (30,000 m^3), radiological inventory estimated as 0.2 Ci uranium-235 and 2450 Ci plutonium-239, solid lead used as shielding for experiments contained in the experiment chambers as well as beryllium	Phase I RFI field work for Area 2 complete; RFI report to be written; interim measures (IM) and best management practices for Area 2 completed 10/99; IM report in progress	Containment (capping)

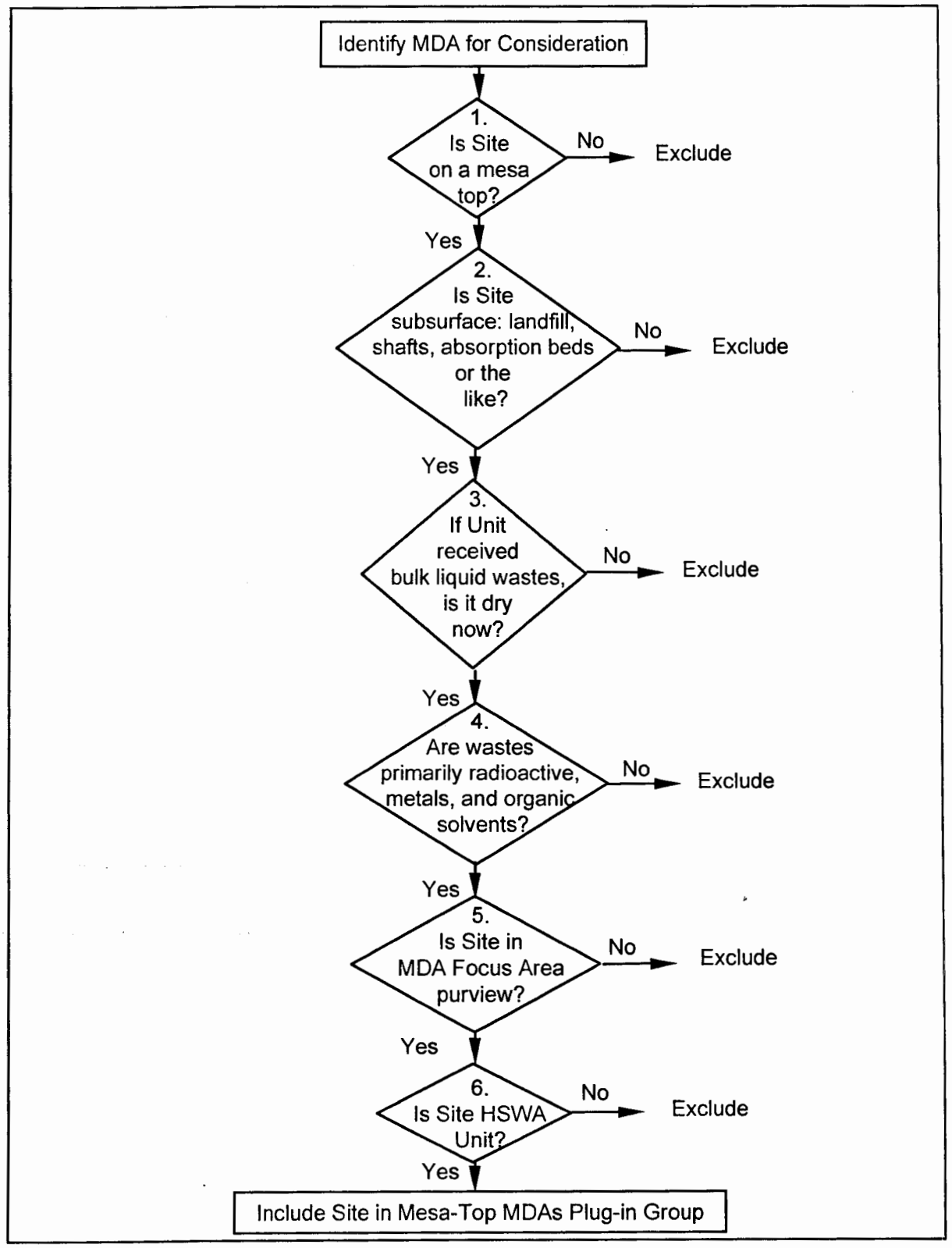


Figure 3-1 Decision Logic for Selection of Landfill-Like Mesa-Top MDAs for the Plug-in Group

Table 3-2 Results of Applying Mesa-Top MDA Decision Logic

MDA	TA		1. On mesa top?	2. Units are subsurface?	3. Liquid waste units dry now?	4. Wastes rad, metals, organics?	5. Site in MDA Focus Area?	6. HSWA unit?	Plug-in candidates are shaded
A	21	DP Mesa, solid waste pits	Y	Y	N/A	Y	Y	Y	
B	21	DP Mesa, solid waste pits	Y	Y	N/A	Y	Y	Y	
C	50	Mesita del Buey, solid waste pits and shafts, limited liquids	Y	Y	Y	Y	Y	Y	
D	33	Solid waste chambers	Y	Y	N/A	Y	N	Y	
E	33	Solid waste pits, 1 solid waste chamber	Y	Y	N/A	Y	N	Y	
F	6	Solid waste pits and chambers	Y	Y	N/A	Y	N	Y	
G	54	Mesita del Buey, solid waste pits and shafts, HSWA units	Y	Y	N/A	Y	Y	Y	
G	54	Mesita del Buey, solid waste pits and shafts, RCRA Reg. Units	Y	Y	N/A	Y	Y	N	
H	54	Mesita del Buey, solid waste pits and shafts,	Y	Y	N/A	Y	Y	Y	
J	54	Mesita del Buey, solid waste pits, RCRA Reg. Units	Y	Y	N/A	Y	Y	N	
K	33	Liquid waste septic system, sumps, siphon tank, drain field	Y	N	?	Y	N	Y	
L	54	Mesita del Buey, liquid waste pits, solid and liquid shafts, HSWA	Y	Y	Y	Y	Y	Y	
L	54	Mesita del Buey, mixed waste storage, RCRA Reg. Units	Y	N	N/A	Y	Y	N	
M	9	Solid waste landfill	Y	N	N/A	Y	N	Y	
N	15	Solid and liquid waste pit	Y	Y	?	Y	N	Y	
P	16	Solid waste landfill, RCRA Reg. Unit	N	Y	N/A	Y	N	N	
Q	8	Solid waste burial ground	Y	Y	N/A	Y	N	Y	
R	16	Solid and liquid waste burial ground	Y	Y	?	Y	N	Y	
S	11	Solid waste experimental plot	N	N	N/A	Y	N	Y	
T	21	DP Mesa, liquid waste pits, solid waste shafts	Y	Y	Y	Y	Y	Y	
U	21	DP Mesa, liquid waste pits	Y	Y	Y	Y	Y	Y	
V	21	DP Mesa, liquid waste pits	Y	Y	Y	Y	Y	Y	
W	35	Liquid storage tanks	Y	Y	N	Y	N	N	
X	35	Buried decommissioned reactor - removed	Y	Y	N/A	Y	N	Y	
Y	39	Solid and liquid waste pit	Y	Y	?	Y	N	Y	
Z	15	Solid waste landfill	Y	N	N/A	Y	N	Y	
AA	36	Solid waste trenches	Y	Y	N/A	Y	N	Y	
AB	49	Frijoles Mesa, deep test shafts – solid wastes	Y	Y	N/A	Y	Y	Y	

3.3. Relevant Characteristics of Identified Mesa-Top MDA Sites

The ten identified mesa-top MDAs are radioactive and chemical waste disposal units where wastes were deposited in subsurface excavations on the mesa tops. Table 3-2 summarizes some important information for these sites. A brief summary for each of the identified mesa-top MDAs follows these introductory paragraphs. More detailed descriptions are included in Appendix C, MDA Descriptions.

At the solid waste disposal areas, the dumped wastes were covered with the crushed Bandelier tuff excavated from the pits. Most of these MDAs were used primarily for disposal of solid radioactive wastes, but many also received some radioactive or chemical liquid wastes: MDAs A, B, C, H, and G. These MDAs were managed like the sanitary or municipal landfills of that time, where large pits or trenches were dug and waste was dumped, backfilled, and covered with crushed tuff.

The liquid waste disposal areas used pits excavated into the mesa-top. Some of these were backfilled with graded rock and gravel as absorption beds, intended to "absorb" the major contaminants on to the bed materials and allow water to seep into the underlying tuff. Others were open impoundments where liquids were allowed to seep or evaporate. Only two of the ten MDAs received exclusively liquid wastes, MDAs U and V, both designed as absorption beds. Two other MDAs were primarily liquid waste MDAs, but also received significant quantities of solid wastes placed in disposal shafts, MDAs T and L. At MDA L the wastes placed into the shafts included significant quantities of containerized (drummed) liquid wastes.

One MDA was used for safety tests of nuclear weapons components. Detonations, without fission yield, were conducted in the bottom of deep shafts (60 to 80 ft typ.).

Investigations conducted at these MDAs indicate that the contamination in the disposal units is well-contained and inaccessible under present conditions. RFI data show that low levels of surface contamination are present at some MDAs (**list them**), and historical records identify that contaminant releases have occurred during the operational periods for some of the MDAs (list these too). The releases include windblown dust (**list**), smoke and fumes from fires (**list**), and liquid waste overflows (**and list again**). It is believed that the surface contamination observed at these sites is associated with the releases from the operational period, rather than loss of containment or contaminant transport occurring after the operations ceased.

Some subsurface releases have been observed at several sites. Most of these releases involve vapor-phase contaminants (typically volatile organic compounds and tritium) in the pore-space of the vadose zone (MDAs L and G). These are the only releases identified at the Laboratory's mesa-top MDAs that constitute a contaminant "plume" (contaminants actively being transported by an environmental medium – pore gas). Although easily measured, the plumes have a relatively small scale, are slowly dispersing to the atmosphere, and do not threaten groundwater.

The evidence of some liquid-phase transport of contaminants has been identified beneath most of the liquid waste seepage pits and absorption beds (MDAs L, T, U, and V). In all cases, the contaminants are now immobile, sorbed in a dry tuff matrix. The known history of liquid waste operations, and the dry conditions currently found beneath all of the liquid waste disposal units, combine to indicate these contaminants were released by saturated or unsaturated flow during waste disposal operations and were deposited onto the tuff matrix. In the absence of a mobilizing environmental medium -- water, these sorbed contaminants will remain fixed in the tuff as the residual from the liquid waste operations.

Table 3-3 Relevant Characteristics of Mesa-Top Plug-in Group Candidate Sites

MDA	TA	Phase I RFI Completed?	RFI Report Drafted Initiated?	Current Day Risks Identified?	VCA/VCM Expected	Total Area Within Fence (acre)	Number of Solid Waste Pits	Number of Liquid Waste Pits	Depth (typ.) (ft)	Volume (Total) (cy)	Crushed tuff cover thickness (typ) (ft)	Number of Disposal Shafts	Depth (typ.) (ft)	Volume (Total) (cy)	Concrete caps?	Distance to Mesa Edge <100 ft?	Upper Stratigraphic Unit	Adjacent Canyon Floor >100 ft Below?	Ecological Unit (PP or PJ)	Watershed Aggregate
A	21	N	N	N	N	1.25	3		13-30	8230	5					N	Qbt3	Y	PJ	LA
B	21	Y	Y	?	N	6.03	U	U	18.5	27781	3-6.5					N	Qbt3	Y	PJ-PP	LA
C	50	Y	N	N	N	12.3	7		20	?	>6	108	16	?	N	N	Qbt3	Y	PP	Mort
G	54	Y	Y	Y	N	65	34		60	?	3	174	60	?	Y	Y	Qbt2	Y	PJ	Mort
H	54	Y	Y	Y	N	0.3						9	60	570	Y	N	Qbt2	Y	PJ	Paja
L	54	Y	Y	Y	N	2.58	?			U	U	34	65	U	A	Y	Qbt2	Y	PJ	Mort
T	21	Y	N	N	N	2.21		4	U	U	?	62	60	47775	N	N	Qbt3	Y	PP	LA
U	21	Y	N	N	N	0.2		2	?	702	2					N	Qbt3	Y	PJ-PP	LA
V	21	Y	Y	Y	N	0.88		3	10	5556	?					Y	Qbt3	Y	PJ	LA
AB	49	?	?	?	N	?						?	60-80	39000	T	N	Qbt4	Y	PJ-PP	Ancho

PJ = Pinon Juniper, PP = Ponderosa Pine, PJ-PP = transition zone

LA = Los Alamos Canyon, Mort = Mortandad Canyon, Paja = Pajarito Canyon, Ancho = Ancho Canyon

U = Unknown

A = Site is asphalt paved

T = Crushed tuff cap

3.3.1. MDA A (TA-21)

MDA A occupies a 1.25-acre (0.5-ha) site in the eastern portion of DP Mesa. This site was used for waste disposal during two periods, 1945-1949 and 1969-1977. Between 1944 and 1947, two shallow pits approximately 4 m (13 ft) deep received about 1020 m^3 (36,000 ft^3) of "solid wastes with alpha contamination accompanied by small amounts of beta and gamma" (LANL 1977a, 0216). During this period, two underground storage tanks (the General's Tanks) were installed to store a total of 49,000 gal. (186,200 l) of a sodium hydroxide solution which contained 334 g (0.7 lb.) of plutonium-239 at the time of emplacement (circa 1947). The liquid from these tanks was recovered, treated, and solidified in cement in 1975. The contaminated cement remained buried at MDA A for several years, but was retrieved in the late 1980s and moved to Pit 29 at MDA G. In 1969, a 9-m- (30-ft-) deep pit was excavated at MDA A for

the disposal of building debris contaminated by uranium-235, plutonium-238, and plutonium-239 from demolition work at TA-21.

3.3.2. MDA B (TA-21)

MDA B is a 6-acre (2.4-ha) inactive disposal site located on DP Mesa just west of the TA-21 fenced boundary and south of commercial businesses on DP Road. MDA B operated from 1945 through 1948. MDA B consists of an unknown number of waste trenches, however the TA-21 work plan estimates the volume of the trenches to be 21,240 m^3 (27,612 yd^3) (**LANL 1991**, 7529). A geophysical survey conducted as part of the 1998 RFI found the disposal trenches to be approximately 15 ft (4.5 m) wide by 300 ft (90 m) long by 12 ft (3.6 m) deep and unlined.

The radiological inventory includes "plutonium, polonium, uranium, americium, curium, lanthanum, (and) actinium." (LANL 1977a, 0216) The disposal capacity of the pits is estimated to be about 21,000 m^3 (760,000 ft^3). The entire pit area is estimated to contain no more than 100 g (6.13 Ci) of plutonium-239.

3.3.3. MDA C (TA-50)

MDA C was established in May 1948 as replacement for MDA B at TA-21. MDA C is an 11.8-acre (4.7-ha) site enclosed by a fence. Radioactive and hazardous waste was disposed in seven pits and 108 shafts at MDA C between 1948 and 1965. The pits were filled between 1948 and 1959, and the shafts were filled between 1958 and 1965. The average depth of the MDA C disposal pits was 20 ft (6 m), and the average depth of shafts was about 16 ft (4.8 m). The total radiological inventory estimates of MDA C are 196 Ci in pits and 49,483 Ci in shafts (LANL 1977a, 0216). This estimate includes 28 Ci of uranium (uranium-233, -234, -235, -236, and -238); 49,136 Ci of cesium-137; 31 Ci of strontium-90; 26 Ci of plutonium-239; 149 Ci of americium-241; 50 Ci of mixed fission products; and 200 Ci of mixed activation products.

3.3.4. MDA G (TA-54)

MDA G is the low-level waste (LLW) disposal area for the Laboratory and has been in use since 1957. MDA G also is used to store low-level mixed, transuranic (TRU), and mixed-TRU waste and will continue to store such wastes for the foreseeable future.

MDA G is a 65-ac (26-ha) site containing several waste storage domes, a liquid-waste sump, a septic tank leach field, a solid waste compactor, four TRU-waste storage pads, 34 disposal pits, 174 shafts, and 4 subsurface TRU-waste trenches (LANL 1997a, 55873, p. 3). In earlier years the site received a variety of waste types including some liquid hazardous and mixed wastes. Until 1971, no attempt was made to segregate waste by pits (LANL 1977a, 5707; LANL 1977b, 5708, p. G-10). Pits vary in size but, in general, are 200 ft by 60 ft (60 m by 18 m) and approximately 60 ft (18 m) deep. Three pits currently receive LLW, and one is receiving asbestos wastes; the remainder of the pits have been closed and capped with a layer of crushed tuff, and are not visible on the surface. Shafts are typically 6 ft (1.8 m) in diameter and 60 ft (18 m) deep and receive wastes that require special packaging (for example, tritium), special handling (for example, highly activated metals), or segregation (for example, PCB-contaminated waste). Many shafts currently receive waste. The TRU-waste trenches are between 200 ft and 300 ft (60 m and 90 m) long, 13 ft (4 m) wide, and 6 ft (1.8 m) deep. All these trenches have been closed and are covered with crushed tuff.

3.3.5. MDA H (TA-54)

MDA H is a 0.3-acre (0.12-ha) inactive site containing nine shafts where classified waste was deposited from 1960 until 1986. The shafts are 6 ft (1.8 m) in diameter and 60 ft (18 m) deep. Disposed waste materials common to all nine shafts include weapon components, classified documents and paper, aluminum, plastic, stainless steel, rubber, graphite, weapon mock-ups (models), DU scraps, classified shapes, film, prints and slides, classified objects contaminated with HE, and graphite nuclear reactor fuel elements.

Eight of the nine shafts at MDA H are sealed; one shaft received waste as late as 1986, but no additional waste disposal at MDA H is planned. Shaft 9 is the only unit at MDA H that intentionally received hazardous waste after 1980, making it subject to RCRA interim status closure provisions and New Mexico State jurisdiction. The original closure plan for Shaft 9 was submitted in November 1986. The eight sealed shafts collectively contain approximately 13,600 ft^3 (408 m^3) of classified waste; Shaft 9 received approximately 990 ft^3 (30 m^3) of waste by the time disposal ceased in 1986 (LANL 1992, 7669).

3.3.6. MDA L (TA-54)

MDA L, a 2.5-ac (1-ha) facility, includes 4 covered chemical waste disposal pits, 34 covered shafts, and surface storage facilities for chemical-mixed, hazardous, and PCB wastes. The site currently is used for surface hazardous waste storage and treatment but was used for subsurface disposal of liquid hazardous wastes between the late 1950s and 1985.

3.3.7. MDA T (TA-21)

MDA T includes 4 absorption beds and 62 shafts that received radioactively contaminated liquid from the plutonium processing laboratories at TA-21 between 1945 and 1952. In 1952, a liquid waste treatment plant was installed to remove plutonium and other radionuclides from process wastewater. Thereafter, the absorption beds received relatively small quantities of LLW until 1967, when a new liquid waste treatment process was initiated. Between 1968 and 1975, treated liquid waste was mixed with cement pumped into shafts at MDA T for disposal. After 1975, the cement paste was poured into corrugated metal pipes, and retrievably placed at MDA T in 62 vertical shafts.

3.3.8. MDA U (TA-21)

MDA U is an inactive disposal site located near the eastern end of DP Mesa. MDA U is a fence-enclosed area of approximately 0.2-acres (0.08-ha) and contains two absorption beds and a distribution box. The absorption beds, with an estimated volume of about 18,000 ft^3 (540 m^3), were used for subsurface disposal of radioactively contaminated liquid wastes from 1948 to 1968 (LANL 1991, 7529). The distribution box and distribution lines to the beds were removed in 1985.

3.3.9. MDA V (TA-21)

MDA V is a 0.88-acre (0.35-ha) site located southwest of the TA-21 fenced boundary. MDA V consists of three absorption beds that occupy a volume of 4250 m^3 (5525 yd^3). The absorption beds were used between 1945 and 1961 for liquid waste disposal from a laundry facility at TA-21-20. The laundry facility mainly washed clothing from uranium and plutonium refinement operations.

3.3.10. MDA AB (TA-49)

MDA AB, situated on Frijoles Mesa, was the location of the hydronuclear and related experiments performed from late 1959 to mid-1961. Experiments designed to assess the safety of storage and transportation of nuclear weapons components were conducted at four different areas in multiple shafts and chambers at depths between 60 ft and 80 ft (18 m to 24 m). The total volume of contaminated tuff has been estimated at about 1,000,000 ft^3 (30,000 m^3). The radiological inventory has been estimated as 0.2 Ci uranium-235 and 2,450 Ci plutonium-239, with some fission and activation products also likely to be present. Solid lead used as shielding as well as small amounts of beryllium are also contained in the experiment chambers.

In 1961, the surface over the shafts in Area 2 was covered with a clay/gravel layer overlain with asphalt to stabilize residual surface contamination. This pavement was removed in 1999 as part of an interim measure (IM) of the RFI to protect the site from subsurface moisture that results from surface water ponding, run-on, and inhibited evapotranspiration. The IM was completed by installing a clean, crushed-tuff cap containing a wire-mesh layer to inhibit burrowing animals. It was covered with native grasses to promote transpiration of moisture and inhibit erosion, and gravel also to inhibit erosion.

3.4. Process for Sites That Are Not Candidates

The MDAs listed in Table 3-2 that were not selected for inclusion in the mesa-top MDAs plug-in group, and any sites selected for the group that may be dropped from it later, will be considered for inclusion in other yet to be defined plug-in groups, other streamlined assessment and corrective action approaches, and traditional CMS/CMI as needed.

Next Chapter: Chapter 4

Top of this Chapter

Table of Contents

4.0. CONCEPTUAL SITE MODELS FOR MDAs

The mesa-top MDAs under the purview of the MDA Focus Area (A, B, C, G, H, J, L, T, U, V, and AB) exhibit important similarities. This section identifies common features of the mesa-top MDAs and addresses important characteristics related to contaminant migration and transport that are inherently present in the MDA mesa-top setting. These elements serve as the basis for the development of a generic conceptual model for the mesa-top MDAs. We use the term "conceptual model" in the following sense: a conceptual model is a set of assumptions concerning the features, events and processes (FEPs) relevant to the risk assessment of a site. This is a broader definition of the term compared to some usages, e.g. (EPA 1996a, p. 19444), where the conceptual model is defined as a three-dimensional picture of the site. However, our definition is consistent with the purpose of the conceptual model as stated in (EPA 1996a, p. 19444), in which a conceptual site model

> "... conveys what is known or suspected about the sources, releases and release mechanisms, contaminant fate and transport, exposure pathways and potential receptors, and risk. The conceptual site model is based on the information available at any given time and will evolve as more information becomes available."

NMED refers to this as the site conceptual exposure model (SCEM) (NMED 2000a). Although the conceptual model is not a mathematical model or computer model, it may be represented by these and they are helpful in predicting future conditions. A detailed mesa-top MDA conceptual model helps ensure that the processes important for long-term contaminant release and migration scenarios are not overlooked, such as aspects of natural attenuation that may supplement the benefits of a containment cap. The conceptual model can be used to compare different sites at a conceptual level, and to identify those that are similar for the plug-in approach.

4.1. Overview

Conceptual site models were developed for each MDA during preparation of RFI work plans and sampling and analysis plans (SAPs), and have been updated as needed as new became available. These previously developed conceptual site models took a number of forms and were developed at differing levels of detail. Currently the ER Project uses a number of modeling tools in the development, verification, and presentation of the conceptual site model.

- **Comprehensive FEP list**. A comprehensive list of all site features, events and processes (FEPs) is used to identify the FEPs to be considered during the development of the conceptual model, and to organize all available and relevant data and information about the FEPs and the site (Section 4.2).

- **FEP screening**. The comprehensive FEP list is screened to identify the important factors affecting disposal site containment performance. The screening is based on ratings of probability and consequence, using a hazard identification procedure (Section 4.2.1). Since ratings of probability and consequence are dependent on the choice of risk measure and the time of the evaluation, and are relative to target risk thresholds, the conceptual model should also include at this point the risk measures of concern and the temporal boundaries of the model.

- **Base-case and alternate conceptual models**. The base-case conceptual model includes all relevant FEPs considered to be likely (highly probable). A number of alternate conceptual models may be constructed to account for unlikely FEPs that have a potential for significant consequences, i.e. contributions to the risk measures (Section 4.2.2 and Section 4.3.1). The base-case and alternate conceptual models are graphically represented using a logic tree (see Section 6.4).

- **Interaction matrices**. Interaction matrices are used to identify the relationships, or interactions, between site features, and the events and processes affecting contaminant containment (Section 4.3). Interaction matrices are also used for graphically representing the pathways of contaminant transport in a conceptual model, and as an aid in the development and verification of the corresponding mathematical model.

- **Pictorial description**. A generalized view of the conceptual model can be presented pictorially as an aid in intuitive understanding (Section 4.4).

4.2. Mesa-Top MDA Features, Events, and Processes

"Features" are the conditions of the system within the spatial boundaries of the model (such as inventory and geology) as well as external conditions (such as climate) that may influence the system. "Events and processes" are influences that may induce changes in the system conditions. Events are sudden or episodic (such as drought or seismic events), while processes produce gradual and continuing changes (such as erosion or radioactive decay). Events and processes that affect external features are not included in the FEP list, but may need to be considered to determine correlations between external influences.

The initial mesa-top MDA FEP list has been constructed and is presented in Appendix D, FEP List and Descriptions. The FEPs in this list will be screened to determine which are likely to affect release, transport and exposure processes applicable to the mesa-top MDAs (Section 4.2.1). Based on the importance (probability and consequence) of the FEPs determined as likely to affect site performance, they may be included in or excluded from a refined, "screened" mesa-top MDA FEP list (Section 4.2.2).

Information used to construct the FEP list is obtained from ER Project reference documents (e.g., the installation work plan (LANL 1998a), RFI work plans and SAPs, environmental surveillance reports, biological assessments, threatened and endangered species habitat management plans, and the preliminary hydrogeologic atlas for Los Alamos National Laboratory (LANL 1999a), generic FEP lists for geological waste repositories, from scientific publications, and subject matter expert elicitation (Appendix D, FEP List and Descriptions).

A hazard identification elicitation was initiated in July 2000. As a result of that elicitation, the comprehensive FEP list is being expanded and this is partially reflected in the FEP list in Appendix D, FEP List and Descriptions. The next steps in the elicitation are as follows: the expanded FEP list will be circulated to the hazard identification panel for review and revision. A series of meetings will follow to conduct the screening of these FEPs for probability and consequence.

The FEP list for MDAs (Appendix D, FEP List and Descriptions) shows the organizational structure of the list at a high categorical level and presently considers FEPs applicable in the present day setting and over a long-term assessment (e.g., >1000 years). The FEP list is divided at the highest level into natural FEPs, waste and repository FEPs, and human-induced FEPs. Additional subdivisions are introduced by technical discipline. Each entry in the FEP list will be annotated in tabular form with information useful in the development of the mathematical model, including screening information and reference information. Appendix D, FEP List and Descriptions also presents descriptions of FEPs based on present day understanding of concepts and theory; these descriptions will be expanded and refined as needed to incorporate newly-identified supporting information.

The list is not final, rather it is dynamic in the sense that it can be expanded with additional information obtained from scientific literature or subject matter expert elicitation to refine understanding of the FEPs and reduce uncertainties associated with the prediction of interactions over long assessment periods.

4.2.1. FEP Screening

Each entry in the comprehensive FEP list is assessed as to whether it is included or excluded from the conceptual model, and the reasons for the decision are documented. Some valid reasons for exclusion include low probability and low consequence, or regulatory exclusion. A variety of temporal ranges is considered, from 100 years to 1000 years. A hazard identification procedure is used to identify likely FEPs, and unlikely FEPs that have a potential for significant consequences. These FEPs are "included" in the conceptual model, the remaining FEPs are considered "excluded".

FEPs are screened for probability based on modeling and expert elicitation. The probability for an alternate conceptual model that contains several unlikely FEPs is usually very low, except when the FEPs are strongly correlated. A hazard reduction analysis (Kessler 1998) is used to assist in the estimation of consequences. Unlikely FEPs are screened for consequence based on their potential disrupting the most effective components of the containment system (see Chapter 6, Risk-Based Assessment).

4.2.2. Base-Case and Alternate Conceptual Models

The base-case conceptual model consists of the list of likely FEPs and the associated textual descriptions, including the justification for exclusions and probability/consequence ratings. An alternate conceptual model is similar to the base-case conceptual model, but also includes one or more FEPs that are rated unlikely but have a potential for significant consequences. The relationships between the base-case and the alternate conceptual models are represented by a logic tree, (Section 6.4, Logic Trees). The conceptual site model is actually a set of conceptual models, including a base-case conceptual model and the alternate conceptual models assumed to have low probability.

4.3. Interaction Matrix

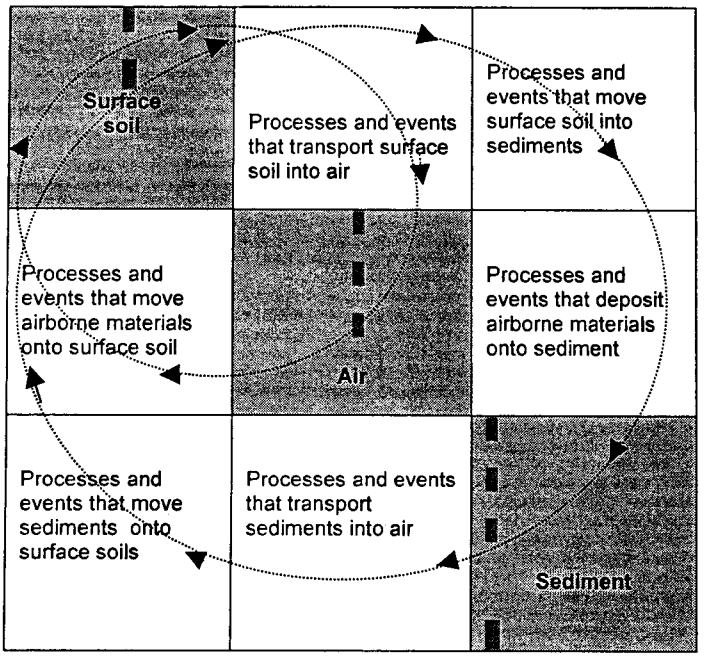
An interaction matrix is used to represent the conceptual model of a site in terms of a matrix of significant FEPs. Features included in the interaction matrix are aspects of the environmental system, generally the site geology, hydrology, and other components of the environment. For the MDA evaluation, the scale of modeling will include the disposal unit mesas and the adjacent canyon systems, which essentially incorporates the watershed aggregate within which an MDA is located (ref IWP).

For the MDA interaction matrix, "features" are used as environmental "compartments" or "media", that may become "reservoirs" or "carriers" for contaminants: soil, air, surface water, groundwater, rock matrix, plants, and so on. The "features" included in the interaction matrix are actually collections of features from the FEP list.

The "events" and "processes" of the interaction matrix refer to more-or-less episodic events, and more-or-less continuous processes, which may move contaminants and other materials through the environment. "Events" and "processes" move material (including contaminants) between the media and reservoir "features" of the environment.

For the mesa-top MDA interaction matrix, most of the contaminant release and transport processes discussed in Section 4.4 are considered to be more-or-less continuous "processes", because they may be treated that way over the long period of time involved in a long-term risk assessment. The term "event", for the mesa-top MDA interaction matrix, is reserved for processes that still appear more-or-less episodic on a time scale of a 1000 years. As discussed below (Section 4.3.1), a category of "rare events" is also defined for the mesa-top MDA interaction matrix.

In an interaction matrix, the "features" of a site are represented in the blocks on the main diagonal of the matrix. Events and processes link the features, and are placed into the remaining blocks of the matrix, following a clockwise convention. A chain of interactions through the matrix identifies a pathway. Figure 4-1 shows an example of a small interaction matrix (modified from Watkins et al. 1999, 63523, p. 359).



F3.2-3 / IWP / 031700 / PTM

Figure 4-1. Limited interaction matrix

Analogous to the comprehensive FEP list, the ER Project has developed a *comprehensive* interaction matrix that includes all the FEPs for an entire watershed. (LANL 2000b, no ER ID, p. 3-18). The comprehensive matrix will be screened to incorporate only those probable and consequential FEPs for a given corrective-action site, resulting a *site-specific* interaction matrix to document the subset of contaminant release, transport and exposure pathways that will be included in the conceptual model for a specific site. More than one site-specific interaction matrix may be constructed to illustrate alternate conceptual site exposure models based on the probability and consequence screening (Section 4.2.2).

4.3.1. Identification of Rare Events

A subset of "events" identified as "rare" describes events (e.g., earthquakes, volcanism) that are potentially severe in nature and impact, but have a very low probability of occurrence in the 1000 year time frame of the long-term risk assessment. "Rare events" may enhance or change the interactions among the base-case FEPs, possibly requiring that they be described by different mathematical models.

Rare events are deviations from current environmental conditions that may significantly change the processes defined in the MDA interaction matrix. Such events include local climatic changes (potentially related to global climatic changes), seismic events, volcanism, fire, flooding, and unpredictable future human activities that have the potential to drastically alter present contaminant release, migration, and exposure scenarios. Evaluation of such events increases the complexity of the assessment because of the modified importance of specific processes participating in the event. Despite this, inclusion of these

events in the evaluation is important for developing a better understanding of the system and for the prediction of its future behavior.

A sample rare event has been screened against the MDA interaction matrix to illustrate the identification of processes likely to be enhanced (Appendix E, Rare Events). Each identified rare event will be evaluated in a similar manner to identify important processes participating in the event, to assess potential consequences, and to allow an assignment of probability of occurrence.

4.4. Pictorial MDA Conceptual Model

Data available for MDAs A, B, C, G, H, L, T, U, V, and AB (see Chapter 3, Candidate Sites) indicate that a single pictorial representation is adequate to depict, conceptually, the principal site features and environmental events and processes that may affect long-term containment of contaminants in the subsurface. The major differences among the mesa-top MDAs are the nature and extent of contamination at each site, although there are also differences in disposal environment to be considered. A general MDA conceptual model is shown pictorially in Figure 4-2 (LANL 2000a, p. 3-17). The figure illustrates features of the site environment, contaminant release processes, and contaminant transport to locations where human and ecological exposures may occur. (Please note that this pictorial representation has not been updated to be consistent with the results of the latest hazard identification elicitation and FEP list, as that elicitation is not complete.)

4.4.1. Site Features

The important features of the mesa-top environment for contaminant containment in a subsurface disposal unit, as shown in Figure 4-2, include:

- The mesa-canyon topography; which has important effects on air, surface water, and subsurface contaminant transport, as well as on potential contaminant receptors.
- The geology, consisting of subsurface layers of various volcanic depositions (e.g., Units 2, 1vu, 1vc, and 1vg of the Tshirege Member of the Bandelier Tuff; the Otowi Member of the Bandelier Tuff; and the Cerros del Rio Basalts), which has variable physical and chemical features that affect subsurface contaminant transport.
- The hydrology, incorporating intermittent surface streams in adjacent canyons, liquid- and vapor-phase water moving through the subsurface within the rock matrix, within fractures in the rock, and along interfaces between layers, and transpiration, all of which affect surface and subsurface transport of contaminants.

The solid arrows emanating from the mesa surface and vegetation (Figure 4-2) represent the movement of water as a liquid (straight arrows) and as a vapor (serpentine arrows).

- Liquid water generally moves down into the mesa (i.e., infiltrates),
- Water vapor generally moves up through the mesa surface and out the mesa sides (i.e., evaporates), or up through vegetation (i.e., transpires).

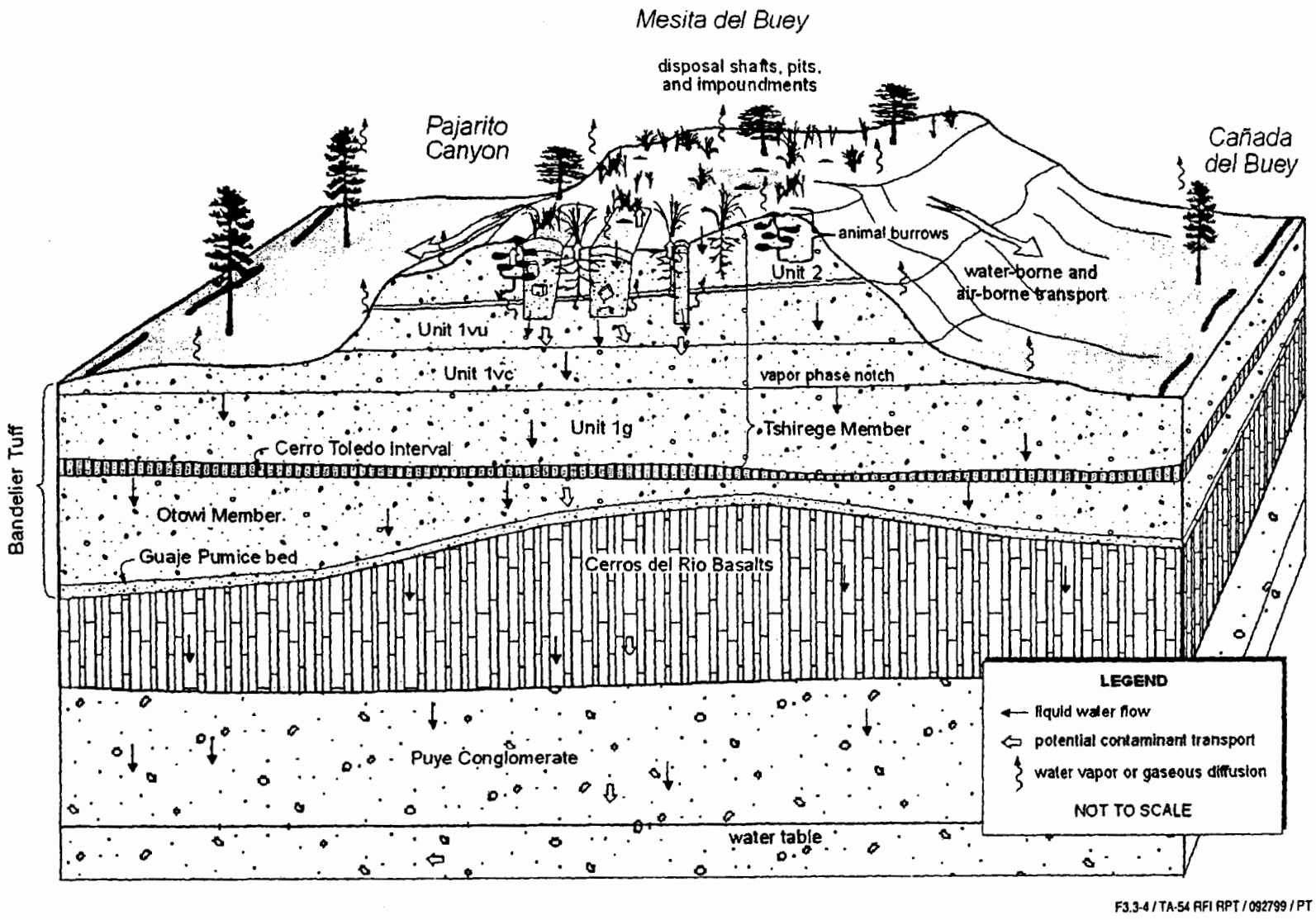


Figure 4-2. Typical MDA Conceptual Model Diagram

4.4.2. Contaminant Release Processes

The contaminant inventories at the mesa-top MDAs include radioactive and hazardous liquids and solids disposed of in pits, trenches, and shafts. Contamination is present in the subsurface soil and rock into which liquid wastes were released or test shots were detonated, as well as in solid waste such as laboratory trash (paper, plastic and equipment), metals, semi-solid sludge and cement. Some solid wastes were packaged in plastic bags and cardboard or metal containers prior to disposal, while others were not.

Radionuclides and hazardous chemicals may be released from the subsurface containment of the pits, trenches and shafts through five primary processes listed below. The straight open-arrows in Figure 4-2 illustrate these contaminant release pathways.

- Diffusion of vapor-phase contaminants.
- Biotic intrusion by plants and animals.
- Erosion of the site cover, or cliff retreat.
- Leaching by liquids originating within the waste, or infiltrating from the surface.
- Human intrusion.

4.4.3. Contaminant Transport Processes

Contaminants originally present in surface soils and sediments around the MDAs, as well as any additional contaminants released over time from the disposed waste, may be redistributed within and beyond the site by a number of transport pathways as listed below. The serpentine open-arrows in Figure 4-2 identify the contaminant transport processes.

- Diffusion of gas-phase contaminants from the ground surface (including mesa sides).
- Airborne transport of gases, and of particulates entrained from surface soils.
- Surface water erosion and transport of contaminated surface soils into adjacent canyons.
- Biotic uptake and redistribution of contamination.
- Water infiltration and water-borne contaminant transport to the regional aquifer.

4.4.4. Exposure Pathways

Exposure pathways combine a contaminant release with air or water transport to locations where the contaminant may be available to human or ecological receptors. Exposure pathways can combine one or more contaminant release processes and transport mechanisms. For example, contaminants in water (either below ground or on the surface) can be assimilated by plants; resuspended contaminants in air can be deposited on plants; and contaminated surface soils can be splashed onto plants. Exposures result as the plants may then be consumed by animals or humans.

Next Chapter: Chapter 5
Top of this Chapter
Table of Contents

Figure 4-3. Generic Interaction Matrix for Candidate MDAs

1.1 **Air**	1.2 Deposition Gas exchange Precipitation	1.3	1.4	1.5 Deposition Gas exchange Precipitation	1.6 Deposition Gas exchange Precipitation	1.7 Deposition Gas exchange Precipitation	1.8	1.9	1.10	1.11	1.12	1.13	1.14 Condensation Deposition Respiration Precipitation	1.15 Condensation Deposition Inhalation Precipitation
2.1 Entrainment Gas exchange	2.2 **Mesa Top Soil**	2.3 Subsidence	2.4	2.5 Mass wasting	2.6 Weathering Run-off Erosion Suspension Desorption Advection Diffusion	2.7 Weathering Run-off Erosion Suspension Desorption Advection Diffusion	2.8	2.9	2.10	2.11	2.12	2.13	2.14 Root uptake External contact	2.15 Ingestion External contact
3.1 Gas exchange	3.2 Gas exchange Erosion Excavation	3.3 Shallow (Mesa Top) Vadose Zone	3.4 Percolation Unsaturated flow Gas exchange	3.5 Mass wasting	3.6 Gas exchange Erosion	3.7 Gas exchange Erosion	3.8	3.9	3.10	3.11	3.12	3.13	3.14 Root uptake External contact	3.15 Ingestion External contact
4.1 Gas exchange	4.2	4.3 Capillary rise Adsorption Gas exchange	4.4 **Perched Groundwater Within Mesas**	4.5	4.6	4.7 Discharge Desorption Advection Diffusion Gas exchange	4.8 Discharge Infiltration Percolation Advection Diffusion Adsorption Gas exchange	4.9	4.10 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	4.11	4.12	4.13	4.14 Deep root uptake External contact	4.15
5.1 Entrainment Gas exchange	5.2	5.3	5.4	5.5 **Slope and Canyon Sediment and Soil**	5.6 Flooding Erosion Suspension Desorption Advection Diffusion	5.7 Erosion Suspension Desorption Advection Diffusion	5.8	5.9	5.10	5.11	5.12	5.13	5.14 Root uptake External contact	5.15 Ingestion External contact
6.1 Gas exchange	6.2 Infiltration Deposition Adsorption	6.3 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.4 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.5 Infiltration Deposition Adsorption	6.6 **Stormwater**	6.7 Mixing	6.8 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.9 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.10 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.11	6.12 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.13	6.14 Root uptake External contact	6.15 Ingestion External contact
7.1 Gas exchange	7.2 Infiltration Deposition Adsorption	7.3	7.4	7.5 Infiltration Deposition Adsorption	7.6 Mixing	7.7 **Surface Water**	7.8 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.9 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.10 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.11	7.12 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.13	7.14 Root uptake External contact	7.15 Ingestion External contact
8.1 Gas exchange	8.2	8.3	8.4	8.5 Gas exchange	8.6 Gas exchange Erosion	8.7 Gas exchange Erosion	8.8 **Alluvial Vadose Zone**	8.9 Percolation Unsaturated flow Gas exchange	8.10	8.11	8.12	8.13	8.14 Root uptake	8.15 Bioturbation Ingestion External contact
9.1 Gas exchange	9.2	9.3	9.4	9.5	9.6	9.7 Discharge Mixing Desorption Advection Diffusion Gas exchange	9.8 Capillary rise Adsorption Gas exchange	9.9 **Alluvial Groundwater**	9.10 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	9.11	9.12 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	9.13	9.14 Root uptake External contact	9.15
10.1 Gas exchange	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	10.10 **Intermediate Vadose Zone**	10.11 Percolation Unsaturated flow Gas exchange	10.12	10.13	10.14	10.15
11.1 Gas exchange	11.2	11.3	11.4	11.5	11.6	11.7 Desorption Advection Diffusion Gas exchange Discharge	11.8	11.9	11.10 Capillary rise Adsorption Gas exchange	11.11 **Intermediate Groundwater**	11.12 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	11.13	11.14	11.15
12.1 Gas exchange	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	12.10	12.11	12.12 **Deep (Regional) Vadose Zone**	12.13 Percolation Unsaturated flow Gas exchange	12.14	12.15
13.1 Gas exchange	13.2	13.3	13.4	13.5	13.6	13.7 Desorption Advection Diffusion Gas exchange Discharge	13.8	13.9	13.10	13.11	13.12 Capillary rise Adsorption Gas exchange	13.13 **Regional Groundwater**	13.14	13.15
14.1 Respiration Biomass	14.2 Biomass	14.3 Biomass	14.4	14.5 Biomass	14.6 Biomass	14.7 Biomass	14.8 Biomass	14.9	14.10 Biomass	14.11	14.12 Biomass	14.13	14.14 **Flora**	14.15 Ingestion External contact
15.1 Exhalation Biogas exchange	15.2 Bioturbation Biomass	15.3 Bioturbation Biomass	15.4	15.5 Bioturbation Biomass	15.6 Biomass	15.7 Bioturbation Biomass	15.8 Bioturbation Biomass	15.9	15.10 Bioturbation Biomass	15.11	15.12 Bioturbation Biomass	15.13	15.14 Biomass External contact	15.15 **Fauna**

Ch. 5 TOC

5.0. LEAD SITE SELECTION AND EVALUATION

The lead site for the mesa-top MDAs plug-in group could be any of the ten identified sites: MDAs A, B, C, G, H, L, T, U, V, or AB. The selection of a lead site takes into consideration that the site be characteristic of the group, and that it is a site on which additional resources will be expended to ensure a good understanding of its environmental issues.

5.1. Lead Site Selection

It is clear from the summaries presented in Chapter 3, Candidate MDAs, that within the Laboratory's ER Project MDA G stands out as an obvious choice for a lead site. It is the most extensively assessed and studied of the MDAs. Its large size, large volume of waste, large contaminant inventory, and low position in the geologic profile (shorter distance to groundwater) gives it perhaps the greatest potential for long-term risk. For most long-term risk issues, MDA G is characteristic of the group and is probably a bounding case in almost all aspects. These facts imply that a corrective action selected for MDA G has a high probability of being effective for the other sites as well.

MDA G is not the best choice as a bounding lead site for two aspects: liquid waste disposal, and vapor-phase contamination of the vadose zone. For these aspects, the neighboring MDA L is a better lead site. Because of this, and because MDAs L and G are closely neighboring sites, a combined lead site consisting of MDAs G and L is used in this plan.

A negative aspect of choosing MDAs G and L as the lead site is that both are combined HSWA inactive (RCRA corrective action) and RCRA-permitted operating facilities. The remedies that are identified and evaluated based on characteristics of the lead site will not likely be first demonstrated on the lead site. Final corrective actions are not planned at MDAs G and L before they are likely to be applied to the other sites. However, this situation does not inhibit use of the understanding and experience gained from extensive investigations and assessments at MDAs G and for expediting corrective measures at other sites through the plug-in approach.

5.2. Role of Lead Site

The plug-in approach relies on the judgment that similar waste-management practices and site characteristics have resulted in similar "recurring problems" at the mesa-top MDAs, and therefore similar response actions will be needed. The recurring problems for MDAs are captured in the conceptual model (Chapter 3, Conceptual Site Models for MDAs). The role of the lead site is to represent these conditions for site-specific evaluation, and to provide sufficient information that competent long-term containment (capping) remedies can be clearly assessed. The remainder of this chapter summarizes the extent of the site-specific knowledge and prior assessment available for the combined lead site. Detailed discussion of the studies contributing general environmental knowledge (that would be applicable to any site selected as the lead site) is given in Appendix G, Special Studies Related to MDA Performance. Detailed discussions of studies and assessments for MDAs G and L are given in Appendix H, Summary for MDA G, and Appendix I, Summary for MDA L.

4.2 Primary Lead Site: TA-54 Area G

Studies of MDA G have been conducted in support of the performance assessment and composite analysis for MDA G, and the RCRA Facilities Investigation (RFI) for MDAs G, H and L. The performance assessment and composite analysis were prepared for the DOE as part of the design basis for operating portions of that facility, while the RFI was conducted for the NMED (under agreement with the EPA) as

part of the remediation basis for formerly-used portions. Together, these three separate analyses comprise the most comprehensive investigation of any MDA at the Laboratory:

- The performance assessment addresses the quantity and potential impacts of radioactive waste disposed of from 1988 through the projected operational lifetime of the facility (2044)
- The composite analysis addresses the quantity and potential impacts of radioactive waste disposed of over the entire projected facility lifecycle
- The RFI addresses the quantity and potential impacts of both hazardous and radioactive waste disposed of before 1988 (there are no hazardous wastes disposed of after 1988).

The performance assessment was conducted to demonstrate that there is reasonable expectation that performance objectives established to ensure long-term protection of human health and the environment will not be exceeded as LLW is disposed of at the facility in the future. The composite analysis supplements the performance assessment by accounting for releases from past, present, and future disposals (at MDA G and other MDAs) that may contribute to the cumulative long-term radiological dose. The requirement for a composite analysis in addition to a performance assessment was implemented by the DOE to assist in the planning and integration of corrective actions at DOE installations that manage both operational and formerly-used disposal sites. In keeping with its purpose, the composite analysis was extensively used to complete the RFI for MDA G. The inventory estimate and the framework for investigating the fate, transport and potential biological impacts of hazardous and radioactive constituents in the inventory that have already been released or that may be released in the future was taken directly from the composite analysis (which considers only radioactive constituents) and applied to hazardous constituents in the inventory.

Several field experiments that have been performed to characterize surface and subsurface processes under disturbed conditions (i.e., in the presence of MDAs) provide important information that supports a better understanding of contaminant transport and matrix hydrogeologic characteristics in a mesa top (vadose zone) setting. The results of the special studies, some of which were performed directly in support of the development of the MDA G performance assessment, illuminate the following key observations regarding contaminant transport:

- Aqueous-phase transport of contaminants is minimal under normal unsaturated conditions.
- Diffusion of volatile contaminants is significant under normal saturation conditions.
- Both aqueous- and vapor-phase transport are controlled by high air permeability zones (fractured units and surge beds) within the mesa.
- Hydrologic characteristics of the unsaturated tuff can retain or arrest the movement of water-soluble contaminants.
- Unsaturated matrix flow accompanied by sorption is the dominant transport mechanism in normal unsaturated conditions.
- Fracture transport of contaminants is not sustained in normal unsaturated conditions
- Vertical (downward) flux of water or leachate in the tuff is very slow.
- Groundwater travel times are very long.
- The natural system is effective in controlling (if not eliminating) potential exposures via groundwater.

The conclusions of all three analyses (i.e., performance assessment, composite analysis, RFI risk assessment) conducted for MDA G are entirely consistent. All three indicate that the future risk associated with the contaminant inventory can be maintained below risk-based thresholds if the cover over specific disposal locations is perpetually maintained against the effects of erosion and intrusion by deep-rooting plants and deep-burrowing animals, and is maintained to ensure that passive venting of vapor-phase contaminants remains effective. The disposal locations requiring active, long-term institutional maintenance are identified on the basis of specific contaminant concentrations. Disposal locations with lesser concentrations of these specific contaminants require less active controls.

The largest uncertainties in the conceptual model of groundwater pathway analysis were in the following:

- total inventory of non-sorbing, long-lived radionuclides
- infiltration rate through the disposal units
- percolation rate of leachate through the vadose zone
- factors affecting dilution in the regional aquifer

The largest uncertainties in the air pathway analysis were associated with the following parameters:

- animal burrow depth
- total actinide inventory and concentration
- extent of channeling of winds into Cañada del Buey.

The primary uncertainties in the surface water pathway analysis are associated with the following parameters:

- animal burrow depth
- total actinide inventory and concentration
- amount of sediment transported in stormwater.

A summary of the setting, historical operations, the RFI investigation, and a discussion of special studies related to MDA G performance is presented in Appendix G.

5.3. Supplemental Lead Site for Vapor Phase Transport: TA-54 MDA L

Early disposal activities at MDA L resulted in a subsurface volatile organic vapor plume that extends beyond the MDA boundary. The major differences in waste management operations and release potential between MDA G and MDA L include the large amount of *free* liquids disposed of at MDA L (which subsequently percolated into the subsurface) and the absence of substantial residual and buried contaminant inventories at MDA L. Because of the difference in disposal activities and the magnitude of the resultant release, MDA L presents a more appropriate model for defining bounding conditions related to VOC transport.

Studies of MDA L have been conducted in support of the RFI for MDAs G, H and L. A pore-gas monitoring network has provided quarterly data since 1985. in addition, the ER Project has developed a numerical model calibrated to the pore-gas data and site conditions to provide an understanding of

current and future plume behavior. These analyses provide the following observations as related to VOC transport in the subsurface:

- Diffusion of volatile contaminants is significant under normal saturation conditions.
- A diffusion model (concentration-driven movement) appropriately characterizes the behavior of the plume.
- Atmospheric flux is effectively mitigating plume growth.
- Upon source depletion, the plume will begin to shrink as a result of continued atmospheric influence (natural attenuation).

A summary of the setting, historical operations, the RFI investigation, and a discussion of special studies and modeling efforts related to VOC transport at MDA L is presented in Appendix H.

5.4. Evaluation of Containment Alternatives for Lead Sites

As stated in the ER Project Installation (Site-wide) Work Plan, remedies are selected on the basis of the EPA threshold and balancing criteria. All remedies must meet these four threshold criteria:

- protect human health and the environment;
- attain (risk-based) media cleanup standards;
- control the source(s) of releases so as to reduce or eliminate, to the extent practicable, further releases; and
- comply with applicable standards for waste management.

Remedies that meet the threshold criteria are then evaluated on the basis of five balancing criteria to determine the remedy that poses the best relative combination of attributes:

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

Capping and long-term monitoring and maintenance meets the threshold criteria and at least three of the five balancing criteria, namely, short-term effectiveness, implementability and cost. It is difficult to assert long-term reliability and effectiveness over periods of thousands of years. While the mobility of the waste is effectively reduced by maintenance and waste volume is nil, toxicity is not reduced through capping and long-term maintenance. However, toxicity is not a relevant factor when exposure pathways are incomplete, which may be an assumed condition of long-term maintenance.

Alternatives to the remedy of active long-term site maintenance and monitoring that would also meet the EPA threshold criteria include removing some or all of the material within an MDA and disposing the inventory elsewhere, and/or stabilizing some or all of the inventory.

Excavation and off-site disposal may be a practical alternative for MDAs that contain a relatively small, shallow, homogeneous and well-characterized inventory. Excavation and offsite disposal is not a practicable alternative for MDAs that contain large volumes of deeply buried heterogeneous materials contaminated with a variety of constituents. For these MDAs, excavation would be extremely difficult and inordinately hazardous, and off-site disposal is unlikely or virtually impossible. That is, this alternative would not provide the best combination of EPA threshold and balancing criteria.

Depending on the particular method, stabilization may or may not provide the best combination of EPA threshold and balancing criteria. It is possible that more robust stabilization technologies than capping would be appropriate for certain well-constrained disposal systems or portions thereof.

Next Chapter: Chapter 6

Top of this Chapter

Table of Contents

Ch. 6
TOC

6.0. RISK-BASED ASSESSMENT

In this chapter, we described the process for assessing the risk-related decision objectives for site-specific remedy selection. Our focus is on the principal objective: the reasonable maximum exposure (RME) risk should fall below the risk target thresholds (10^{-4} excess cancer risk and hazard index of 1) with a confidence level of 90% or more. The assessment of auxiliary objectives follows a similar process, and differences are noted where applicable. The process proceeds by the steps outlined below, in roughly linear order.

- **Statement of the assessment goals.** The specifics of the risk-related decision objectives influence the implementation of the risk assessment. Therefore it is important to have these objectives finalized early in the process.
- **Implementation of process models.** To better understand the processes and events contributing to the risk at the sites, detailed process models are used to simulate current and future conditions of portions of the sites.
- **Development of systems models.** To integrate all significant processes and events contributing to the risk at the sites, systems models are used.
- **Development of logic trees.** A quantitative implementation of a logic tree is used to account for alternate conceptual models. Low probability scenarios and conditions the have the potential to contribute to the risk are simulated independently, and their contributions to the total risk are assessed.
- **Assessment of remedial alternatives for lead sites.** The remedial alternatives are fully evaluated for the lead sites, chosen to be representative and bounding examples of the plug-in group. Probabilistic risk assessment (PRA) is used for the lead site assessment of alternatives.
- **Development of remedy profiles.** The risk-based components of the remedy profile are developed using the methods of scaling and back-calculation from point estimates and from probabilistic risk assessment (PRA).
- **Site-specific assessment of remedy profiles.** The resulting remedy profiles will be applied in a systematic fashion. The most effective and least general approach, scaling, is attempted first. If the requirements for this approach are not met, a more widely-applicable approach is then attempted (point estimates). As a last resort, PRA of the site is considered.

6.1. Assessment Goals

The goal of the risk assessment is to provide quantitative assessments of the risk-related decision objectives for each MDA site in the MDA mesa-top group selected for the plug-in approach. The principal objective is the reasonable maximum exposure (RME) risk should fall below the risk target thresholds (10^{-4} excess cancer risk and hazard index of 1) with a confidence level of 90% or more. Auxiliary objectives include the mean RME risk, and the 90% UCL and mean central tendency exposure (CTE) risk. CTE risk is the risk experience by an average or typical individual in the population.

6.2. Implementation of Process Models

A *process model* is a detailed mechanistic model of an environmental process occurring at a site. In order to resolve all relevant aspects of the process, high spatial and temporal resolution is usually

required. For some of the processes active at mesa-top MDAs, process models are available that have been validated by extensive review and comparison to data. Examples are hydrologic models such as FEHM, UnSat H and HELP. Such validated models provide reliable and accurate performance estimates that are risk-neutral.

Process models will be used in the development and refinement of the conceptual and mathematical systems models, the development of input variable distributions, and the performance-based technical design of remedial alternatives.

Process models require large amounts of computational resources and are prohibitively expensive to run for long time periods, or for the many realizations needed for stochastic uncertainty analysis, or for many different process related-scenarios. Thus for the long-term risk assessment, we must use systems models as described in the next section.

6.3. Systems Modeling

Systems models integrate the information and uncertainties about all relevant processes and events in order to assess the risk of a site. These models typically have low spatial resolution and a small number of variables. Most variables in systems models are composites; for example, total quantities and average property values over large regions are used. The results are not expected to accurately reproduce the precise or detailed behavior of the actual system. However, the approximations introduced into systems models are required to be conservative, that is, to over-estimate the risk from the site. Systems models for assessing RME risk also use conservative scenarios for the exposure of individuals.

Stochastic systems models are used because of the uncertainties in both the current site characterization and the prediction of long-term future risk. However, not all variables in the model are treated stochastically; only those variables whose uncertainty contributes strongly to the uncertainty of the risk are represented by probability distributions. The details of the development of the stochastic model are contained in Appendix J, Models.

Small stochastic models are suitable for probabilistic risk assessments (PRA), in which determining the probability distribution of risk is the purpose of the estimate (Morgan 1990). However, deterministic point estimates of an upper bound on risk will be obtained before attempting the computationally intensive task of PRA. A point estimate of risk is a single deterministic computation using the model, in which all stochastic input variables are replace by the value of, say, their 90% upper confidence limit (UCL). The risk value produced by a 90% UCL point estimate is an upper bound on the 90% UCL of the full risk distribution, provided certain requirements on the stochastic model are satisfied, as described in Appendix J, Models.

Point estimates are valuable even if more rigorous, probabilistic simulations are planned. Point estimates are easy to obtain and provide a starting point to further analysis. Point estimates may be used for screening purposes before probabilistic risk assessment (PRA). In cases where point estimates produce risks well below target values, PRA may be deemed unnecessary. Point estimates may also be used for verification of PRA. The risk estimates for a given confidence level from PRA should always be less than the results from point estimates for the same confidence level.

A high-risk result from a point estimate indicates the potential for a high-level of risk to be present. However, if the point estimate is expected to be over-conservative, PRA is warranted to confirm a high-risk result. A PRA may also be performed to evaluate the conservatism of a point estimate. When employing risk estimates for decision making, it should be kept in mind that the risk estimates from both point estimates and PRA are conservative, and are thus upper bounds on the actual risk.

Figures 6.1 through 6.3 are schematic plots of the results of systems model computations. These are for illustrative purposes, and are not actual risk estimates for mesa-top MDAs. Figure 6.1 shows an estimate of risk versus time. A 3-layer model hierarchy is shown. For each model, the 90% UCL of risk is shown as a function of time. Figure 6.2 shows cumulative distributions of maximum risk. The risk calculated by point estimate will always dominate (bound) the risk calculated by PRA, which in turn dominates the actual risk. Figure 6.3 shows the effects of uncertainties on corrective action decisions.

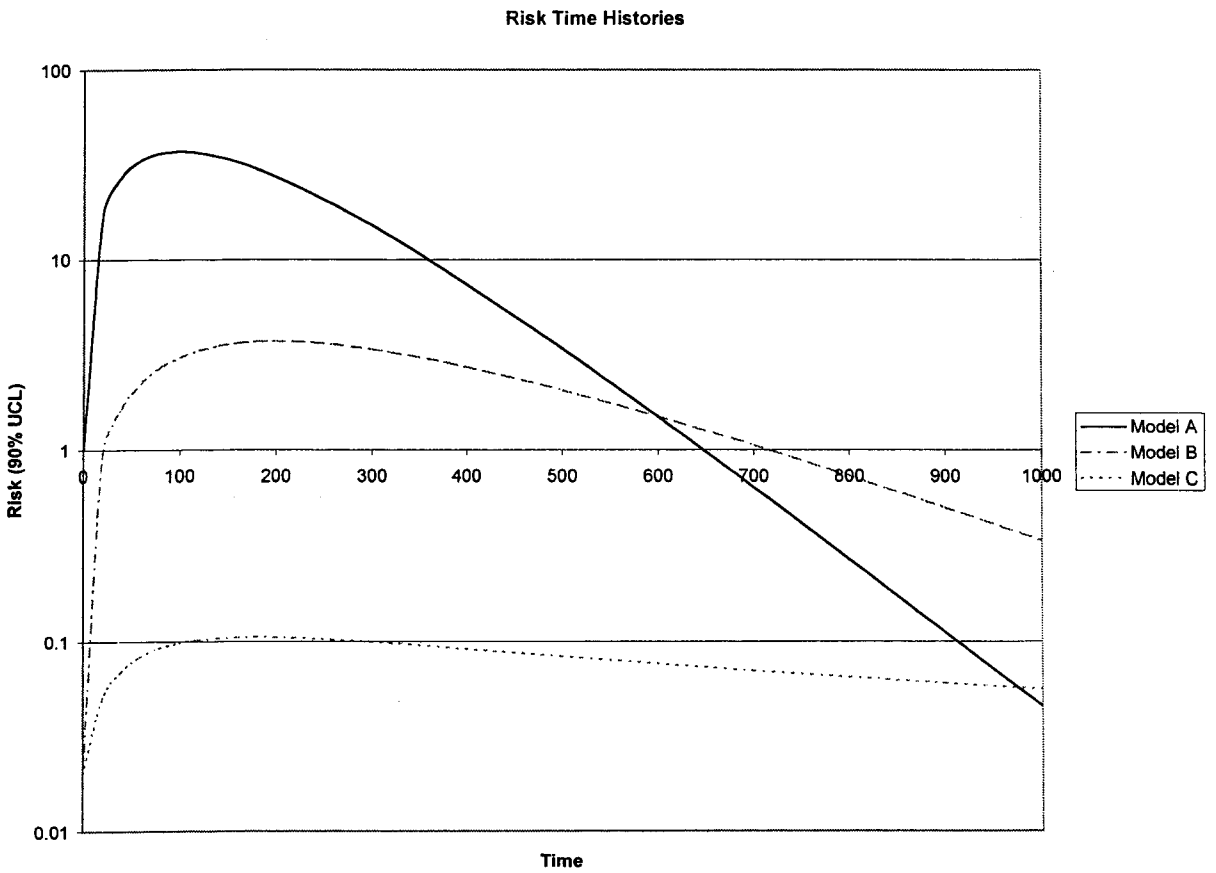


Figure 6-1. Risk Time Histories.

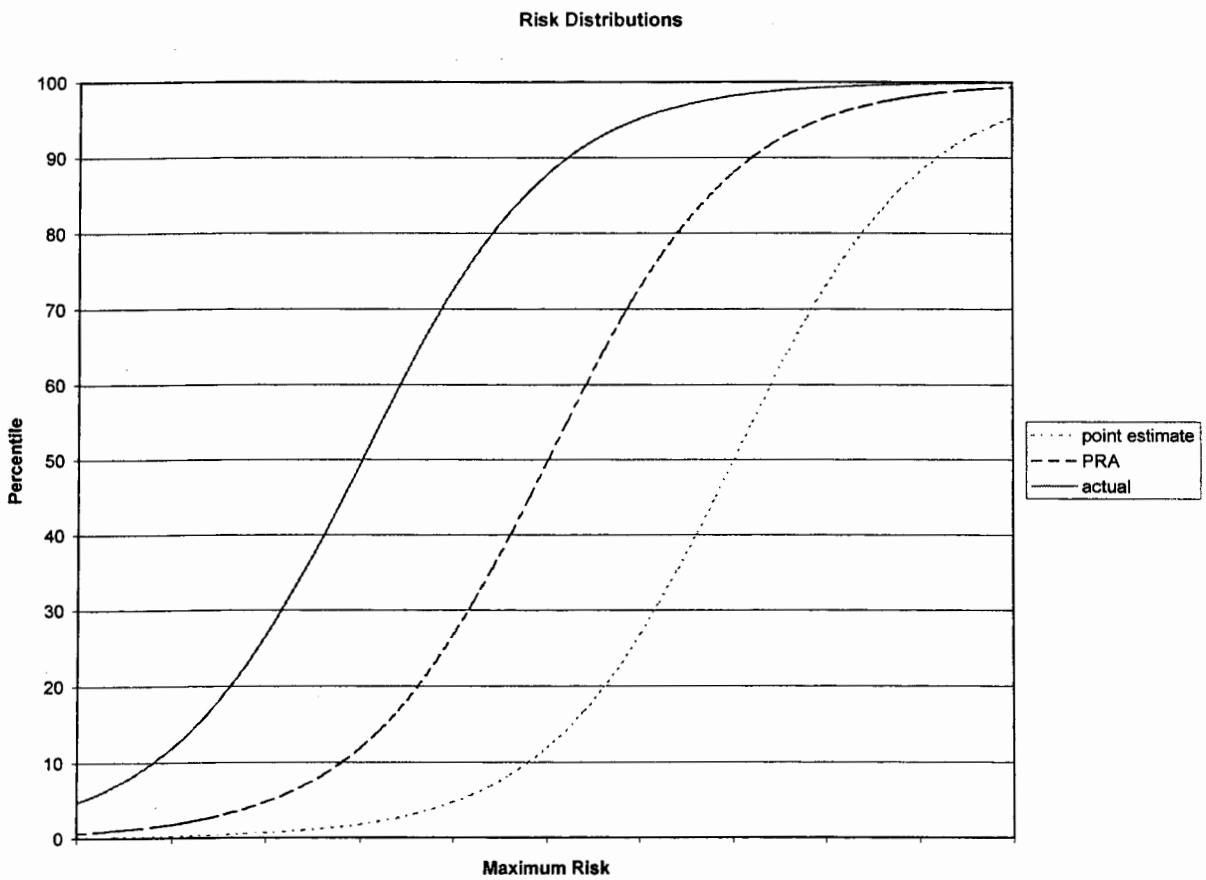


Figure 6-2. Cumulative distributions of the maximum risk.

6.4. Logic Trees

A logic tree (Kessler 1999) is a graphical modeling approach used to account for alternate conceptual models. The logic tree structure is constructed during the development of the conceptual model. Quantitative risk assessment from the logic tree is performed at the systems modeling stage of the assessment.

We illustrate the logic tree approach with a simple example. Suppose the base-case model assumes current climate conditions and no seismic activity. There is a set of three alternate conceptual models associated with these characteristics. In each conceptual model, the various propositions of the base-case model are either true or false. Figure 6-4 shows the logic tree for this example. Each final node is a conceptual model, one of them being the base-case model. In some cases, we may abbreviate the logic tree as shown in Figure 6-5. In this case, a conceptual model is a collection of propositions, one from each characteristic: climate, vulcanism and seismicity.

The alternative propositions to the base-case assumptions arise from the consideration of unlikely (but possible) features/events/processes (FEPs). Only those unlikely FEPs that have a potential for significant

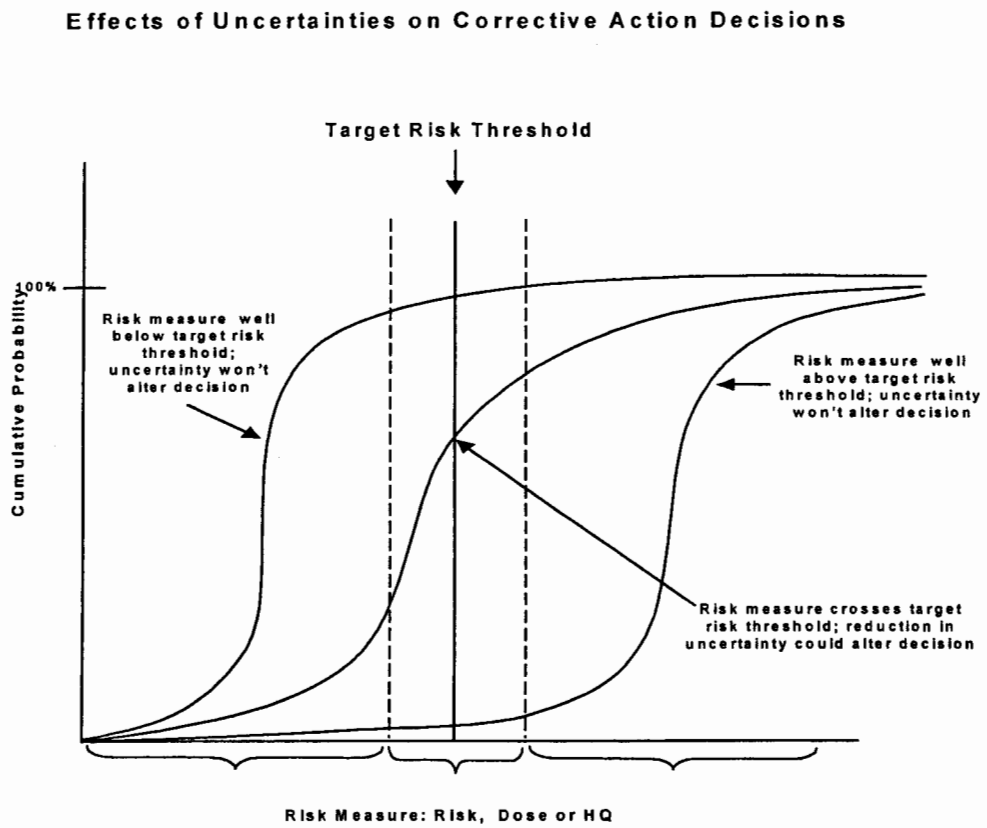


Figure 6-3 Schematic Illustration of the effects of Uncertainties on Corrective Action Decisions.

consequences are modeled in detail. The resulting alternate conceptual models are simulated outside of the base-case model in order to obtain accurate simulation of low-probability cases.

We use a hazard identification procedure to identify unlikely FEPs that have a potential for significant consequences. FEPs are screened for probability based on modeling and expert elicitation. The probability of an alternate conceptual model with several unlikely FEPs is usually very low, except when the FEPs are strongly correlated. A hazard reduction analysis (Kessler 1998) is used to assist in the estimation of consequences. FEPs are screened for consequence based on their potential for influencing protective systems with a high hazard reduction magnitude.

The risk distribution associated with a particular conceptual model is called its conditional risk distribution. The risk contribution of a conceptual model is the product of its conditional risk distribution times its probability. The total risk distribution is the sum of these contributions over all conceptual models, including the base-case model.

6.5. Assessment of Remedial Alternatives for Lead Sites

The risk assessment approach described in the previous section will be implemented in full detail for the lead sites MDA G and MDA L identified in Chapter 5, Lead Site Selection and Evaluation.

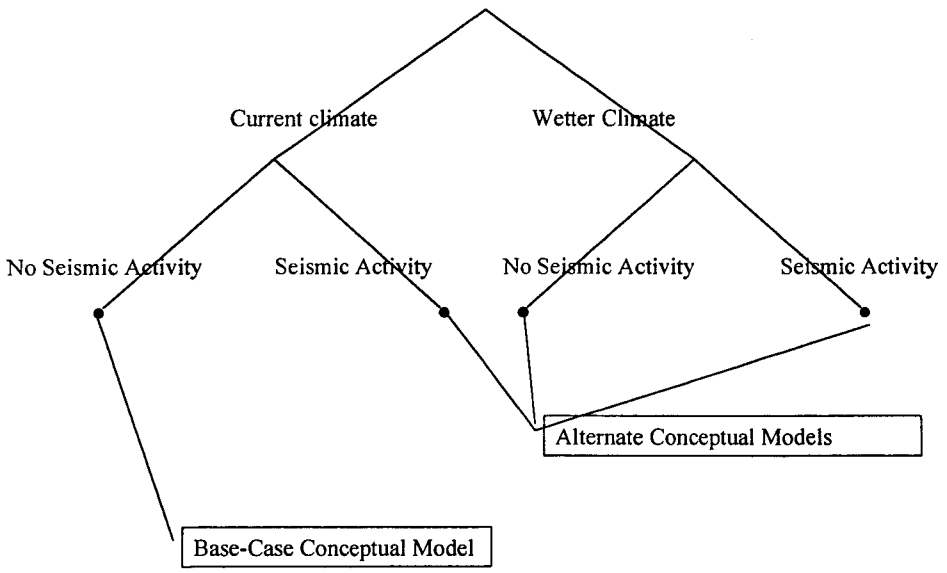


Figure 6-4. A simple logic tree with 2 characteristics.

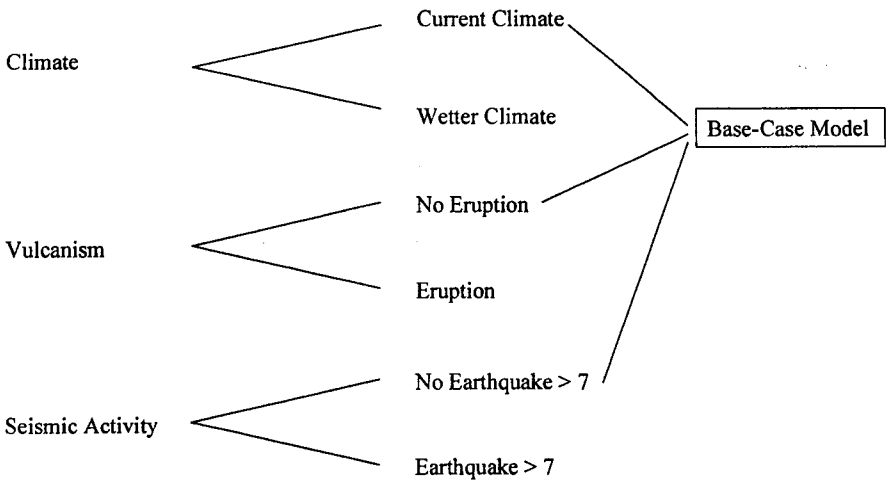


Figure 6-5. An abbreviated logic tree with 3 characteristics.

The goals of the assessment of remedial alternatives for lead sites are:

1. validation and verification of the risk computations;

2. identification of issues concerning performance and risk-reduction by the remedial alternatives;

3. to establish bounding risk estimates for sites sufficiently similar to the lead site but with equal or less inventory.

A large amount of characterization data is available for the lead sites. Additional information will be obtained as needed by expert elicitation. The approach for deriving input variable distributions for the risk-assessment systems model is described in Section 6.3, Systems Modeling.

Risk computations performed for the lead sites will include hazard reduction assessment (a method for assessing the contributions to risk reduction of the various protective systems, natural or engineered, of the site), point estimates of risk and full PRA for all viable remedial alternatives. The systems models used to obtain these risk estimates are described in Section 6.3, Systems Modeling and Section 6.4, Logic Trees.

6.6. Remedy Profiles

DOE guidance for the plug-in approach (DOE 1999a) describes the use of a remedy profile:

> "The remedy profile defines those conditions which must or must not be present for the alternative to be effective. This profile may be composed of technical factors (e.g., technology can only address certain constituents), as well as administrative factors (e.g., land use requirements) that have the potential to impact the effectiveness or implementability of a response action."

Remedy profiles may be used to expedite clean-up when similarities between sites allow information and experience from one site to be applied at other sites.

The remedy profile may contain some technical requirements that pertain to performance-based goals of the remedy. Other technical components of the remedy profile are related to the risk-based goals of the remedy. Several different methods of obtaining and applying remedy profiles are available to us. These methods differ with respect to their range of applicability, degree of conservatism and the amount of site-specific information needed.

We will develop the remedy profiles by several methods, as described in Appendix J, Models. The methods used are scaling and back-calculation from point estimates and from PRA. The resulting remedy profiles will be applied in a systematic fashion as described in the next section.

6.7. Site Specific Assessment of Remedy Profiles

Scaling is the first approach attempted. If the site is determined to be sufficiently similar to the lead site, the inventory probability distributions will be compared for stochastic dominance (as defined in Appendix J, Models) and the effectiveness of the remedial alternatives is determined. Scaling may also be applied with respect to variables other than inventory that enter linearly in the risk model. This approach is especially effective because scaling applies to the entire risk distribution of the site. Thus mean values of risk are obtained as well as percentiles. If the sites are not sufficiently similar or scaling is not feasible

because of the analytic form of the risk model, remedy profiles based on point estimates will be considered.

To apply constraints based on point estimates, it is sufficient to know an upper bound on the appropriate UCL (90%) of the stochastic variables. If sufficient information is available to apply the point-estimate remedy profile, the remedy is determined to be effective if all constraints are satisfied. If one or more constraints are not satisfied, the remedy profile based on PRA will be considered.

For remedy profile constraints based on PRA, an upper bound (based on stochastic dominance) of the probability distribution of the variable is required. If sufficient information is available to apply the PRA remedy profile, the remedy is determined to be effective if all constraints are satisfied. If one or more constraints are not satisfied, a full PRA simulation of the site may be considered.

In some cases, the site may not be sufficiently characterized to apply a remedy profile for a particular remedy. In this case, a decision must be made as to whether there exists a potential cost-savings of sufficient size to justify collecting the additional information. Such decisions may be assisted by the assessment of expected value of information, described further in Appendix J, Models.

Next Chapter: Chapter 7

Top of this Chapter

Table of Contents

Ch. 7 TOC

7.0. CONTAINMENT ALTERNATIVES

This section discusses, in a general way, the technical issues that the ER Project will address in the alternatives assessment for the lead sites (i.e., MDA G and MDA L). These issues include caps and surface vents over MDAs that provide a high probability that risk thresholds are not exceeded under RME and/or CTE conditions, over a period of 1000 years.

Our current understanding of the lead site for solid-form waste (MDA G; see Chapter 5, Lead Site Selection and Evaluation) indicates that the most risk-significant inventory release processes are bioturbation and erosion. Therefore, alternative cap designs for this lead site will focus on minimizing biointrusion and erosion. Similarly, the alternatives assessment for our lead VOC site (MDA L; Chapter 5) will focus on the risk-significant releases identified for that site, namely, diffusion of vapors into the atmosphere.

Dissolution of contaminants and transport in water infiltrating covers and percolating through waste and the vadose zone has not been demonstrated the MDAs considered in this document. Still, cap failure modes that lead to large volumes water in MDAs are considered in cap designs, since such a failure mode (thought unlikely) would be of potentially high consequence (groundwater contamination).

In summary, the high-level objectives for the alternatives assessment for the lead MDAs are:

- Cap materials, thickness, density, and surface expression that minimize the probability of erosion to depths of risk-significant contaminant concentrations, taking into consideration uncertainties in MDA inventory, contaminant concentrations, and erosion processes and rates over a period of 1000 years.

- Biobarriers that minimize the probability of animal intrusion and root penetration at depths where risk-significant contaminant concentrations are present, taking into consideration uncertainties in MDA inventory, contaminant concentrations, and ecological succession over a period of 1000 years.

- Surface vents that are sufficient in size, number and location to minimize the probability of releases of risk-significant concentrations of volatile contaminants into air, taking into consideration uncertainties in MDA inventory.

7.1. Capping Technologies Appropriate for Semiarid Environments

An Integrated Risk-Based Approach For Landfill Cover Design (shown in Figure 7.1-1) is proposed to develop conceptual landfill cover designs. The Laboratory's Environmental Science Group has supported the ER Project in several studies related to landfill cover design in semi-arid environments, and this section summarizes more detailed information presented by Springer (LANL 1999x, LANDFILL COVER AND POST-CLOSURE MONITORING DESIGNS FOR BASELINE PLANNING). Based on previous risk assessment studies of MDAs (Gallegos et al., 1975; Gallegos and Johnson, 1976; Hanson and Rodgers, 1983; Walker et al., 1981; Wheeler et al., 1977) and the Performance Assessment and Composite Analysis for Los Alamos National Laboratory Material Disposal Area G (Hollis et al., 1997), three primary risk pathways of concern for covers are considered: biointrusion, erosion, and seepage, in order of significance. A recommended approach in cover design for mitigating each risk pathway is presented.

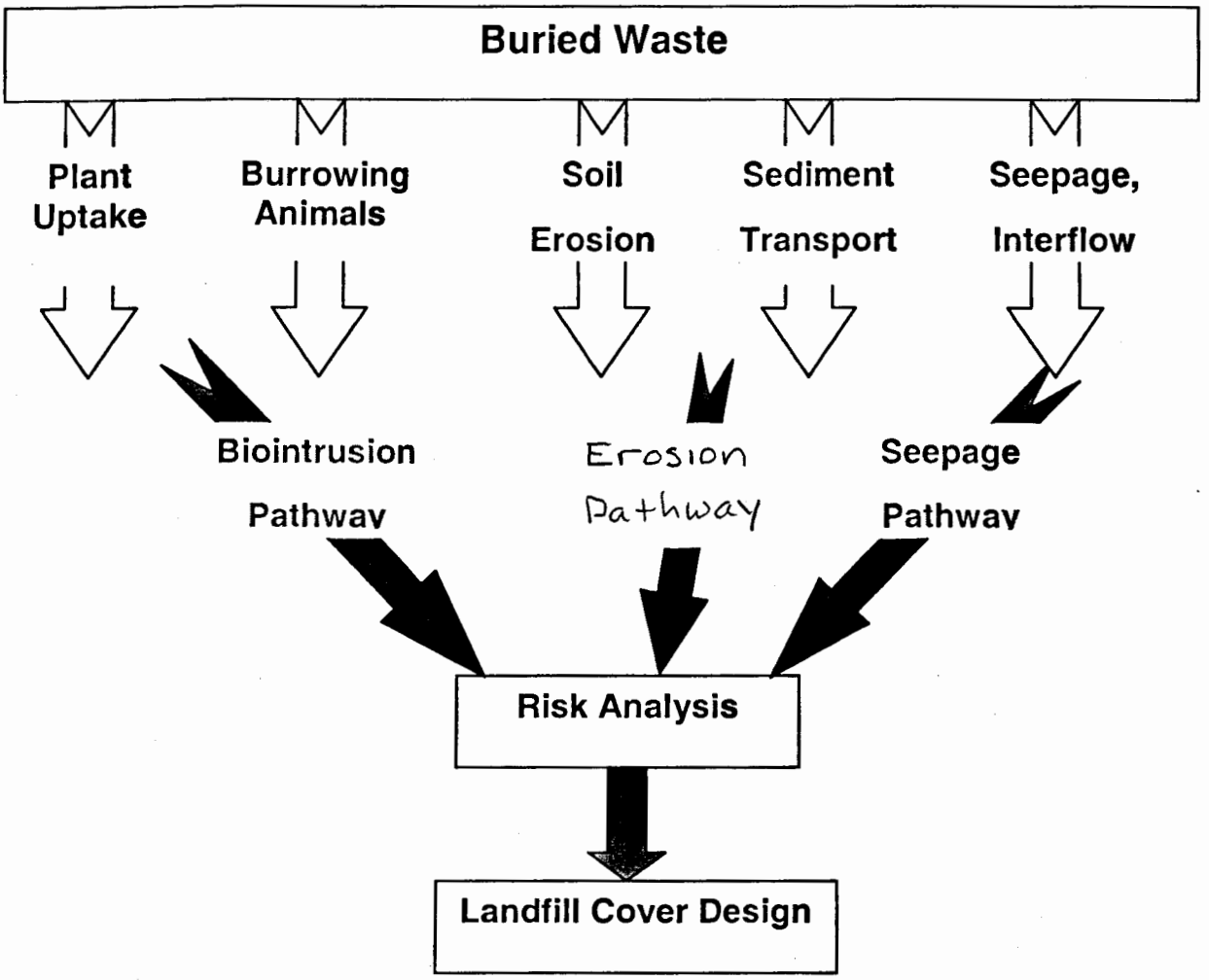


Figure 7.1-1. Integrated Risk-Based Approach For Landfill Cover Design.

Since the ER Project has not completed site characterization, modeling, and risk assessment at each MDA, important assumptions made in generating these conceptual landfill cover designs are given.

The conceptual designs discussed below are based on the best available data at this time. Assumptions made in developing the conceptual designs are given below. As more detailed site characterization occurs at the MDAs, and as our understanding of surface processes improves, the assumptions and/or conceptual designs may need to be revised. If an MDA does not match the assumptions below, it will need to be reassessed:

- The proposed cover designs herein are placed directly on the waste. Covers may currently be in place on some MDAs, and this may affect final cover design for a given MDA. However, this will need to be assessed on a case by case basis.

- Institutional controls (or ultimate transfer to the institutional surveillance program) will maintain the covers, as they will be employed. This means a grass-gravel mulch cover will be maintained on the landfill, and that growth of woody vegetation and any succession changes will be prevented.
- The time frame over which the cover or monitoring equipment must last is 1000 years. Natural materials are used in the landfill cover design to maximize the cover's design life.

Table 7.1-1 represents an attempt to analyze a few of the risk-pathway factors by examining the waste management options to reduce risks associated with biointrusion, erosion and seepage and the problems associated with these management options. For example, small slopes would have a tendency to favor low erosion, but would favor seepage (Table 4). We also tried to bring out a point made by Hakonson (1988) that biointrusion barriers have not been field-tested using larger life forms such as shrubs and trees.

However, we do know that gravel biointrusion barriers are effective in reducing biointrusion and that they can enhance deep evaporation in landfill covers consisting of overlying layers of soil and crushed tuff as well as helping to divert infiltrating snowmelt horizontally. Thus, such a configuration could be used on an MDA in a relatively dry climate where only a small amount of seepage might be generated and the engineered barrier (in this case, the gravel layer) used did not have to be as efficient as either a hydraulic barrier or a capillary barrier in reducing seepage through the landfill cover. In contrast, this approach would not work for a wetter MDA site, where increased seepage and interflow would be a larger problem.

We also know from many studies that partial gravel layers can reduce soil loss by over an order of magnitude, so that this will be a good recommendation at all MDA sites. Any effects related to increased infiltration and reduced evaporation will be offset by increased plant biomass with time (Nyhan et al., 1998), which will augment the erosion control provided by the initial partial gravel cover.

We are proposing that at least two alternative landfill covers be evaluated in the MDA alternatives assessment. The Crushed Tuff-Biointrusion Landfill Cover (Figure 7.1-2) is proposed for use for disposal units where the relative importance of risks is: biointrusion > erosion > seepage/interflow. An example of a site where this landfill cover could be used might be MDA-G. The Capillary-Biointrusion Landfill Cover (Figure 7.1-3) is proposed for disposal units that have higher potential human and ecological risk, where the relative importance of risks is: biointrusion ≥ seepage/interflow > erosion.

Field performance data are available for NMED, EPA, and DOE to support the performance of both of these landfill cover designs from several sources: the Protective Barrier Landfill Cover Demonstration plots, field studies of engineered covers tested at the pilot scale and on actual waste sites, and natural analog studies in Ponderosa Pine forests and Pinyon-Juniper woodlands.

The ER Project is also considering non-traditional capping techniques that will result in a return of an MDA to its natural state. This would involve dynamic compaction of existing covers and MDA contents, resulting in a much more stable configuration of material below the natural grade. The final cover would then be emplaced over the compacted inventory and interim cover materials. Materials that provide capillary and biointrusion barriers would still be constructed, but they would be below the natural grade of the mesa. The attempt would be to leave the mesa as close to its natural state as possible. In this way, we could rely on our understanding of mesa erosion, which is better than our understanding of cover erosion.

Table 7.1-1. Summary of Waste Management Options for Waste Sites

Biointrusion Options	Associated Problems	Erosion Options	Associated Problems	Seepage-interflow Options	Associated Problems
Fencing	Keeps out gophers, not plants	Low (5%) landfill cover slope	Limited erosion control	Mid-high landfill cover slope	Conflicts with low slopes for erosion
Gravel layer	Unknown performance with shrubs and trees	Partial gravel cover	Allows infiltration, reduces evaporation, not permanent	Rock biointrusion layer	Limited seepage control, unknown hydrologic effects with plant roots
Geotextile layer	Limited biointrusion	High plant cover	Increased biointrusion, not permanent	Capillary Barrier	Unknown hydrologic effects with plant roots
Soil compaction and thickness	Limited biointrusion			Hydraulic barrier	Unknown hydrologic effects with plant roots
				Interflow trench	May be no interflow

Crushed Tuff-Biointrusion Landfill Cover

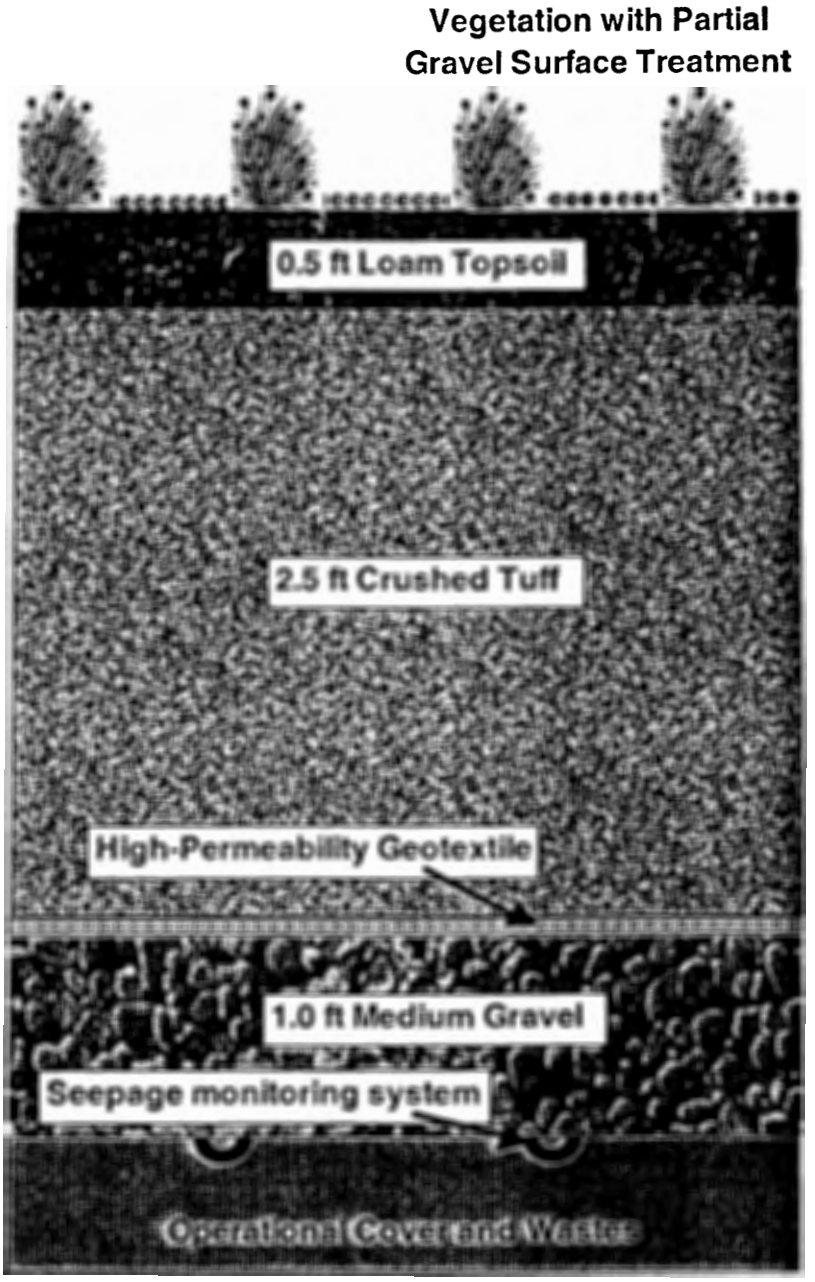


Figure 7.1-2. Crushed Tuff-Biointrusion Landfill Cover (5% slope).

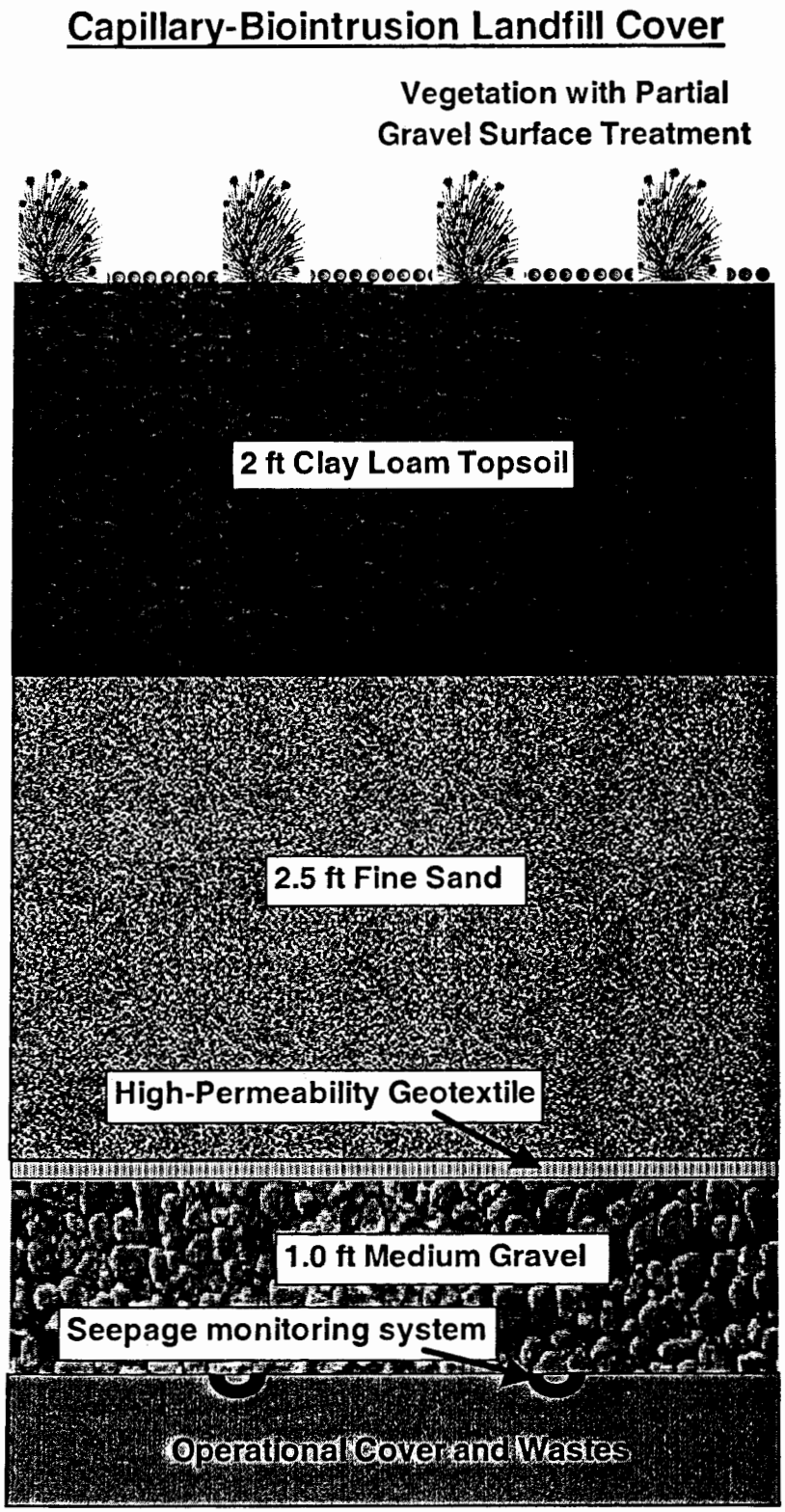


Figure 7.1-3. Capillary-Biointrusion Landfill Cover

7.3. Passive Venting Methods

(This section will discuss the current thinking of passive venting for MDA L, including some pilot studies that have been performed to optimize the venting.)

7.4. Design Models

(This section will discuss the computational models that will be used to support cover designs and passive venting designs.)

7.5. Risk Management Considerations

The ER Project recognizes that a comprehensive decision-making process regarding LANL's MDAs cannot be made on the basis of risk-assessment and design-basis model results alone. While such models are valuable for analyzing one key factor in final remedy selection, they must be balanced with objective methods of assessing other factors in risk management, such as installation and long-term maintenance costs and stakeholder concerns. The alternatives assessment of lead MDAs will apply standard cost-benefit analyses to provide risk managers with information to evaluate alternatives in a relatively objective manner.

7.6. Decision Support Tools

Decision analysis tools have been applied to various remediation problems to objectively compare remediation alternatives in terms of a probability and cost of failure for each alternative (Russell 19xx, Freeze 19xx, Jennings 19xx). In structuring a decision analyses model, logic trees (as described in Chapter 6 of this plan) will be used to organize the probabilistic outcomes for each alternative, including cap failure modes and associated repair and (potential) cleanup costs, and cap performance and long-term operation and maintenance. Probabilities of cap failure modes will computed using stochastic process or system models (also discussed in Chapter 6, Risk-Based Assessment). Costs associated with cleanup after failure and long-term operation and maintenance will require considerable subjectivity; however, the ER Project will develop a way to systematically account for failure costs and associated uncertainties.

Next Chapter: Chapter 8

Top of this Chapter

Table of Contents

Ch. 8 TOC

8.0. LONG-TERM MONITORING AND STEWARDSHIP

The DOE Center for Risk Excellence is responsible for a program for addressing the risk management requirements of long-term stewardship. To assist in defining the scope and objectives of this program, the National Academies of Science (NAS) National Research Council prepared a report for the DOE (NAS 2000). That report discusses many known and potential problems with the DOE's stewardship program as implemented to date. Many of the MDAs to which the approach described in this plan will be applied are the very sites for which long-term stewardship will be required. For this reason, the ER Project intends to use this plan to engage the issues brought to light in the NAS report. Indeed, the probabilistic risk assessment allows the ER Project and our DOE counterparts to address the NAS recommendation that the DOE "develop its stewardship plans under the assumption that contaminant isolation eventually will fail."

8.1. Institutional Control

8.2. Monitoring Goals

8.2.1. Risk Based

8.2.2. Performance Based

8.2.3. Compliance Based

8.3. Surface Monitoring

8.3.1. Strategy and Goals

8.3.2. Techniques

8.4. Subsurface Monitoring

8.4.1. Strategy and Goals

8.4.2. Techniques

8.5. Groundwater Monitoring

8.5.1. Strategy and Goals

8.5.2. Techniques

Next Chapter: Chapter 9

Top of this Chapter

Table of Contents

Ch. 9
TOC

9.0. REFERENCES

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Top of this Chapter

Table of Contents

APPENDIX A

PLUG-IN APROACH

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

8/27/00 1:07 PM

TABLE OF CONTENTS

A.1. INTRODUCTION **1-2**

A.2. DOE GUIDANCE **2-2**

A.3. EXAMPLE APPLICATIONS **3-4**

A.3.1. Indian Bend Wash. 3-4

A.3.2. Hanford Example 3-4

A.4. GUIDANCE AND EXAMPLES SUMMARY **4-5**

List of Figures

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List of Tables

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APPENDIX A

PLUG-IN APPROACH

A.1. INTRODUCTION

In 1992, EPA acknowledged that a consistent set of remedies were being selected for particular classes of sites, and began to define "presumptive remedies" for certain site types where there was a documented history that evaluations of remedial alternatives always concluded that one remedy (or a small set of remedies) was the appropriate solution.

In 1993 an EPA Superfund project at Indian Bend Wash, Arizona, needed to address 70 sites which all had VOC contamination of the vadose zone. This project created the concept of doing a single Feasibility Study (FS) to evaluate remedial alternatives that could be applied to any of the 70 sites. This was called the "plug-in" approach because any of the 70 sites, based on site-specific characteristics, could be plugged in to one of the pre-evaluated remedial alternatives from the initial FS.

In 1995, the plug-in approach was used, and extended, in the Focused Feasibility Study for the Hanford 100 Area Source Operable Unit. In this implementation of the plug-in approach, a general FS was done to pre-evaluate a large number of potential remedial alternatives that might be applicable to one kind of site or another at Hanford. In conjunction, the high priority sites in the 100 Area Source Operable Unit were evaluated and grouped into nine site type categories based on contaminants, the process which created the contamination, and the type of contaminated media at the site. Finally, the specific conditions at each site were matched against the "remedy profile" and the site was "plugged in" to one of the pre-evaluated remedial actions.

The documents listed in the reference section were reviewed in order to understand the use of the "plug-in" approach advocated by DOE and EPA for streamlining the process of selecting a remedial alternative for contaminated sites. DOE promoted the plug-in approach in a series of information releases in 1999 (DOE 1999a-c). These built on earlier DOE promotion of approaches for expediting cleanup in 1997 (DOE 1997a,b) and EPA promotion of the "presumptive remedy" approach in the early 1990s (EPA 1992a,b, 1993a-d). In addition to these publications which described the concepts of the streamlining approaches, one application of the plug-in approach cited by DOE as an example (DOE 1999b) has been examined in detail: the focused feasibility study for the Hanford 100 Area source operable unit (DOE 1995a,b). A second example application cited by DOE (DOE 1999b), documented by EPA Region IX for the Indian Bend Wash Superfund Site, was summarized in the Hanford 100 Area reports (DOE 1995a) at a level sufficient for these comments, and was not acquired for detailed review. The purpose of the reviews and comments is to provide insight into the form that the application of the plug-in approach to LANL ER sites might take.

A.2. DOE GUIDANCE

The DOE publication identifying the plug-in approach as a generic strategy for expediting remedial action (DOE 1999b), indicates the intent is to use knowledge gained from one or more waste sites to serve as the basis for subsequent responses at similar sites. Steps in the process are identified as:

1. **Identify A Recurring Site Problem.**

   This may be based on:

   - Process similarities

- Contaminant similarities
- Contaminated media similarities
- Waste disposal unit similarities

2. Identify Likely Response Actions.

Evaluate the potential to use the selected remedy and associated decision basis from a previously completed waste site, or if no previous site has been addressed, select a representative "lead site" to be evaluated first and serve as the basis for determining appropriate response actions.

3. Develop Remedy Profiles.

For each likely remedial action, identify the range of conditions the remedy can effectively address; that is, the conditions that must or must not be present for the alternative to be effective. Elements of the remedy profile may include (among others):

- Depth of effectiveness
- Concentration limits
- Land use restrictions
- Cost considerations for too large or too small volumes
- Implementation logistics

4. Define the Plug-in Decision Process.

Two sets of decisions are identified:

- A site being evaluated warrants remedial action (response criteria)
- A site being evaluated does or does not fall within the bounds of effectiveness for remedial alternative (remedy profile).

Decision rules for both decisions need to be developed.

5. Evaluate the Subsequent Waste Sites.

Use information on site-specific conditions to determine if remedial action is needed, and if the site fits the remedy profile and can be plugged in to the pre-selected and pre-evaluated remedy(ies). These possible outcomes are anticipated:

- Waste site characteristics fall within the bounds of the remedy profile, and the response criteria indicate remedial action is needed. Apply the plug-in remedy.

- A response action is needed (based on response criteria), but the waste site characteristics fall just outside the bounds of the remedy profile. Evaluate remedy enhancements to increase the range of conditions for the plug-in remedy profile.

- A response action is needed, but the waste site characteristics fall outside the remedy profile, and the site cannot be plugged in. Evaluate additional remedial alternatives on a site-by-site basis.

- A response action is not needed. Document the case for no required remedial action.

A.3. EXAMPLE APPLICATIONS

In both of the example applications of the plug-in approach (Hanford 100 Area, Indian Bend Wash), the presence of numerous similar sites in similar environmental settings was identified early in the process. In the Indian Bend Wash example, there were numerous (70) occurrences of a single type of site (VOC contamination of vadose zone soil). In the Hanford 100 Area example, there were numerous occurrences of each of several well-defined different types of sites (retention basins, buried pipelines, process effluent trenches, decontamination cribs and french drains, pluto cribs, seal pit cribs, burial grounds, D&D facilities).

In both examples, after identifying the presence of the recurring site problems, an identification and evaluation of potential remedial alternatives was conducted. This step was consistent with standard RCRA/CERCLA guidance for evaluating alternative remedial actions. Although the range of alternatives considered was limited to probable actions, the alternatives were developed in sufficient detail to allow comparison of protectiveness, implementability, and cost on the basis of CERCLA comparison criteria.

A.3.1. Indian Bend Wash.

For the Indian Bend Wash example, the result was a full evaluation of remedial alternatives for the first, or lead, site. The savings and streamlining became apparent for subsequent sites where, if they were judged to be sufficiently similar, a pre-evaluated remedial action was available for the site to be plugged in to.

A.3.2. Hanford Example

For the Hanford 100 Area example, a wide range of remedial alternatives potentially applicable to a variety of different types of wastes and sites were developed in detail in an extensive development and evaluation of remedial alternatives. As a second step, each of the waste site groups was assessed to determine the subset of remedial alternatives that would apply to that type of waste site. The third step was to evaluate the subset of remedial alternatives to rank them for protectiveness, implementability, and cost for each type of waste site (again on the basis of CERCLA comparison criteria). The savings and streamlining became apparent as each individual site could be compared to the remedy profiles pre-selected and ranked for sites of its site type. If the individual site fits the profile for one or more of the pre-evaluated remedial alternatives, no further evaluation was needed.

The role of pathways modeling and risk assessment for the Hanford 100 area is described below, but a similar level of information for the Indian Bend Wash example was not obtained.

For Hanford, risk-based contaminant levels were calculated using pathway models and a set of standard exposure scenarios, and are expressed as preliminary remediation goals (PRGs). Three sets of PRGs are calculated for each of the exposure scenarios: one for material that is or may become exposed on the surface; one for material in the vadose zone below the depth that may be exposed at the surface; and one for the vadose zone material under conditions of reduced infiltration (as a result of installation of a "Hanford barrier" cover system).

The surface materials PRG is nominally for a 0-3 ft depth; however, for consideration of ecological risk, these PRGs are actually applied to a 10 ft depth. At Hanford, it was concluded that human

health PRGs are conservative for ecological receptors, but since ecological receptors (burrowing animals) are exposed in burrows to a depth of 10 ft, the surface materials PRGs would have to be applied to that depth rather than to 3 ft.

The two sets of subsurface PRGs, for protection of groundwater pathways thus apply to the vadose zone from 10 ft depth to the water table, both without and with a "Hanford barrier" cover.

Application of the PRGs is straightforward:

- If contaminant concentrations at 0 to 10 ft are less than the surface PRGs, and at greater than 10 ft are less than the subsurface PRGs, no action is taken.
- If surface PRGs or subsurface PRGs are exceeded (in the appropriate depth range), remedial action must be taken (and can be selected using the plug-in process).
- If either surface or subsurface contamination exceeds the "reduced infiltration" PRGs, the offending material must be removed (using one of the removal/disposal options in the set of plug-in alternatives).

In the assessment of any particular site within the site type groups defined for the Hanford 100 Area, no specific risk assessment is needed beyond comparing contaminant concentrations to PRGs.

{An interesting note on the PRGs: they appear to be based on one-tenth the health effects limits we are accustomed to (10^{-7} rather than 10^{-6} cancer risk; 0.1 rather than 1.0 HI, for example) to account for the possible presence of multiple contaminants (rather than the sum of ratios approach we use); and radionuclide PRGs include a decay correction to 2018 AD, the date for the end of institutional control assumed for Hanford.}

A.4. GUIDANCE AND EXAMPLES SUMMARY

In summary, the guidance for the plug-in approach and the example reviewed show the approach to focus on plugging new sites in to one or more potential remedial alternatives that have been evaluated for protectiveness, implementability, and cost (among other CERCLA evaluation criteria), and have been determined to be suitable for "lead" sites representative of the specific site type. No reduction in the standard RCRA or CERCLA process is attained for the lead site, but can be realized for subsequent sites of the type evaluated. It appears to be important to the process that a "complete" evaluation of remedial alternatives be done for the lead site.

Neither the guidance nor the examples indicate that only evaluation of one or a few "preferred alternatives" for the lead site would be in-consistent with the process. This observation is consistent with EPA's description of the presumptive remedy process, where a standard remedy or set of remedies consistently emerges after evaluation of probable remedies for a particular site type. The ones that come to the top of the list most consistently become the "presumptive remedy".

In the Hanford example, site characterization was also minimized by carefully defining very explicit site types. For example, three types of disposal trenches were defined based on the process originating the waste. Knowing that the trench received a particular kind of effluent set bounds on the contaminants and concentrations that could be present and reduced not only the characterization work needed, but in some cases the potential remedial alternatives as well.

The Hanford documents expressed a clear preference for removal options over containment with long-term surface access restrictions and groundwater monitoring.

APPENDIX B

PRESUMPTIVE REMEDY

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

8/27/00 1:09 PM

TABLE OF CONTENTS

B.1. PRESUMPTIVE REMEDY -- CONTAINMENT BY CAPPING 1-1
B.1.1. EPA Military Landfills Presumptive Remedy. 1-2
B.1.2. Application of DOE Low-Level Radioactive Waste Disposal Experience. 1-4
B.1.3. Application of NRC and State Low-Level Radioactive Waste Compact Experience. 1-4
B.1.4. Application to mesa-top MDA corrective action. 1-4

List of Figures

Figure 1-1 EPA Decision Logic for Use of Containment Presumptive Remedy for Military Landfills..... 1-3
Figure 1-2 Example MDA Cover System. ..... **Error! Bookmark not defined.**

List of Tables

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APPENDIX B

PRESUMPTIVE REMEDY

B.1. PRESUMPTIVE REMEDY -- CONTAINMENT BY CAPPING

EPA policy defining the use of presumptive remedies in hazardous waste site remediation is described in *Presumptive Remedies: Policies and Procedures* (EPA 1993a) and elaborated in several other publications (EPA 1992a, EPA 1993c, EPA 1993d, EPA 1993e, EPA 1995a). The presumptive remedy concept resulted from the observation that a limited and common set of remedies consistently were chosen for certain types of sites. This observation indicated that extensive assessment of a wide range of potential alternative remedial technologies at each new site was not productive or cost-effective. EPA acknowledged this by suggesting that for some types of sites a particular remedy could be presumed, barring site-specific indications to the contrary.

> "Presumptive remedies are preferred technologies for common categories of sites..." (EPA 1993a, p 1.)

> "The objective of the presumptive remedies initiative is to use clean-up techniques shown to be effective in the past at similar sites in the future. The use of presumptive remedies will streamline removal actions, site studies, and clean-up actions, thereby improving consistency, reducing costs, and increasing the speed with which hazardous waste sites are remediated." (EPA 1992a, p. 1).

One category of sites for which a presumptive remedy was proposed was municipal landfills addressed under CERCLA. Such sites contained hazardous as well as municipal wastes, and EPA's experience was that the volume and heterogeneity of the waste generally made treatment options impracticable.

> "Because treatment is usually impracticable, EPA generally considers containment to be the appropriate response action, or the 'presumptive remedy,' for the source areas of municipal landfills."

> "The presumptive remedy for CERCLA municipal landfill sites relates primarily to containment of the landfill mass and collection and/or treatment of landfill gas. In addition, measures to control landfill leachate, affected ground water at the perimeter of the landfill, and/or upgradient ground-water that is causing saturation of the landfill mass may be implemented as part of the presumptive remedy." (EPA 1993d, p. 2).

The specified components of the presumptive remedy may include any or all of the following, depending on the conditions and needs at the specific site (EPA 1993d, p. 2):

- Landfill cap,
- Landfill gas collection and treatment,
- Source area groundwater control to contain plume,
- Leachate collection and treatment
- Institutional controls to supplement engineering controls.

B.1.1. EPA Military Landfills Presumptive Remedy.

CERCLA municipal landfills differ in some important ways from the Laboratory's hazardous and radioactive waste landfills; most obviously in the nature of the wastes. A similar situation was addressed by EPA with regard to landfills at military installations in *Application of the CERCLA Municipal Landfill Presumptive Remedy to Military Landfills* (EPA 1996c). With regard to landfill contents, EPA noted:

> The proportion and distribution of hazardous wastes in a landfill are important considerations. Generally, the municipal landfills produce low-level threats with occasional hot spots. Similarly, most military landfills present only low-level threats with pockets of some high hazard waste. However, some military facilities have a high level of industrial activity compared to overall site activities. In these cases, there may be a higher proportion and wider distribution of industrial (i.e., potentially hazardous) wastes than at other less industrialized facilities." (EPA 1996c).

As part of the military's low-hazard wastes, "generally ... no more hazardous than some wastes found in municipal landfills" (EPA 1996c, Highlight 3), EPA noted the presence of low-level radioactive wastes, among other constituents. The presence of high-hazard military wastes within the landfills was also recognized and addressed by EPA:

> "Military wastes, especially high-hazard military wastes may possess unique safety, risk, and toxicity characteristics.... If...these wastes may have been disposed at the site, special consideration should be given to their handling and remediation. Caution is warranted because site investigation or attempted treatment of these contaminants may pose safety issues for site workers and the community. Some high-hazard military-specific wastes could be considered to present low-level risk, depending on the location, volume, and concentration of these materials relative to environmental receptors." (EPA 1996c, Decision Framework, item 4).

A major factor in determining the applicability of the presumptive remedy to military landfills, was the factor that figured prominently for municipal landfills: the impracticability of excavation and treatment as an alternative:

> "The volume of landfill contents, types of wastes, hydrogeology, and safety must be considered when assessing the practicality of excavation and consolidation or treatment of wastes. ...If military wastes are present, especially high-hazard military wastes..., safety considerations may be very important in determining the practicality of excavation." (EPA 1996c, Decision Framework, item 5).

EPA's focus on using the presumptive remedy unless clear indications to the contrary are found is demonstrated in the decision diagram accompanying the guidance, shown here in Figure 2-2, and in their expectations for use of the guidance:

> "EPA anticipates that the containment presumptive remedy will be applicable to a significant number of landfills found at military facilities. Although waste types may differ between municipal and military landfills, these differences do not preclude use of source containment as the primary remedy at appropriate military landfills."
>
> "Additionally, EPA continues to seek greater consistency among cleanup programs, especially in the process of selecting response actions for sites regulated under CERCLA

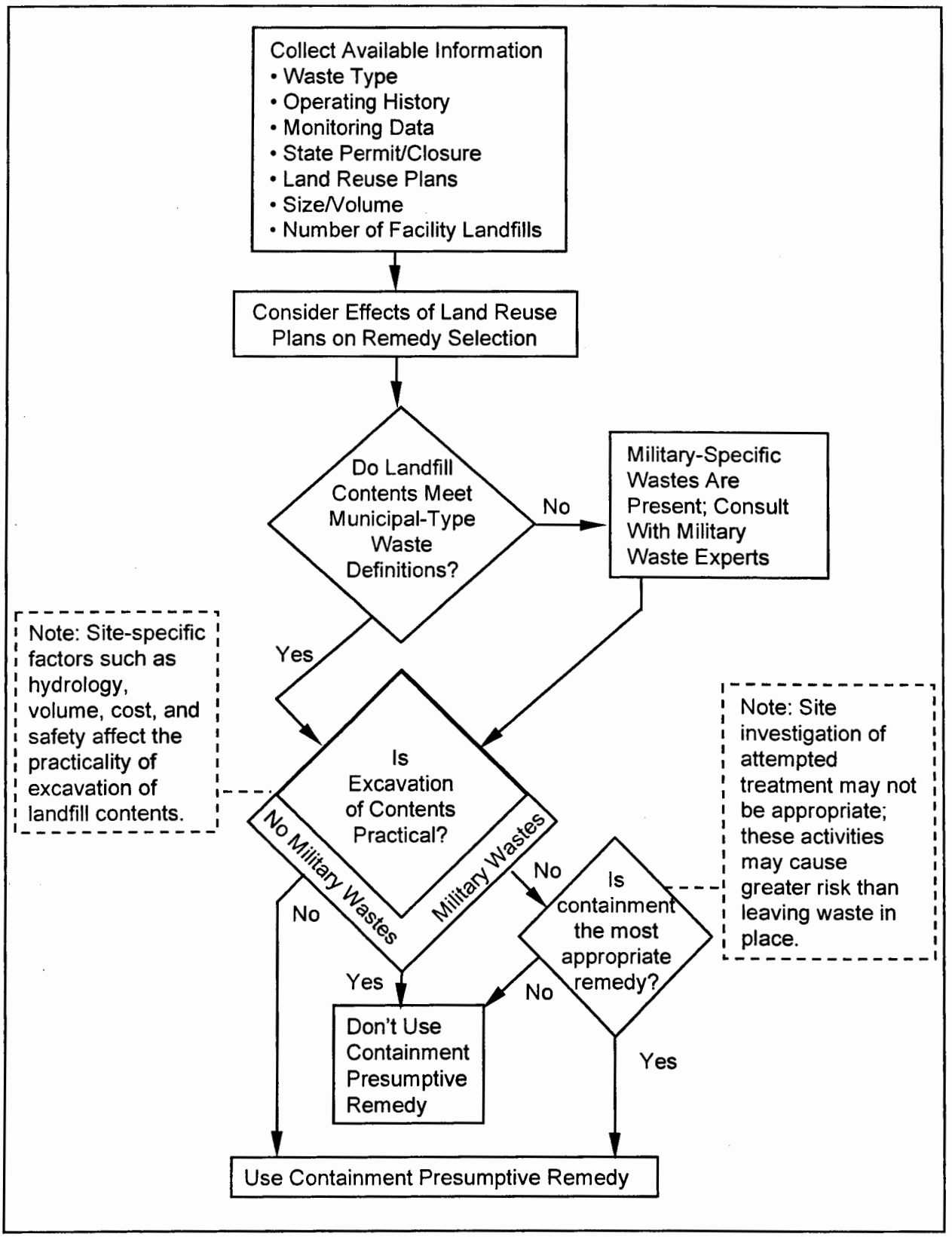

Figure 1-1 EPA Decision Logic for Use of Containment Presumptive Remedy for Military Landfills

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APPENDIX C

MDA DESCRIPTIONS

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

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APPENDIX C

MDA DESCRIPTIONS

C.1. INTRODUCTION

This section presents our knowledge of the Los Alamos National Laboratory's (the Laboratory's) material disposal areas (MDAs). Each MDA is briefly described and has a complete fact sheet included in Attachment A. The detail of information available for an MDA reflects its status in the corrective action process. ~~MDA G which is the Laboratory's operating disposal facility for low-level radioactive solid waste (LLW) is an important exception as it has been extensively assessed through environmental restoration (ER) and waste management activities~~. An operational summary of all the MDAs is presented in Table 2.1-1.

There are 26 MDAs at the Laboratory. They are designated with single letters from A to Z (except I and O, which were not used) then double letters AA and AB. Several of the MDAs are located within a single technical area (TA). For convenience, these MDAs are grouped together for discussion first, then the remaining MDAs are discussed in alphabetical order.

C.2. MDAS A, B, T, U, AND V AT TA-21

TA-21, also known as DP Site, centers on DP Mesa immediately east-southeast of the Los Alamos townsite at an elevation of 7140 ft (2142 m). The TA spans the boundary of the DP Canyon and the Los Alamos Canyon watersheds. Groundwater lies at a approximately 1150 ft (345 m) deep. TA-21 has been used for both chemical research and plutonium and uranium metal production from 1945 to 1978. The major industrial activity was related to uranium and plutonium refinement, which produced the greatest volume of waste at the TA-21 MDAs (Figure 2.1-1).

The TA-21 operable unit (OU) Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) work plan (LANL 1991, 7529) describes the original approach to investigations into contaminant nature, extent, and risk characterization. More recently, a revised project plan was developed for potential release sites (PRSs) (including MDAs) at TA-21, primarily because portions of the site are being considered for transfer to either Los Alamos County or San Ildefonso Pueblo pursuant to Public Law 105-119.

C.2.1. MDA A

MDA A (PRS 21-014) occupies a 1.25-acre (0.5-ha) site in the eastern portion of TA-21. Surface water run-off from this site enters DP Canyon, which is located within the Los Alamos Canyon watershed. This site was used for waste disposal during two periods, 1945-1949 and 1969-1977. Between 1944 and 1947, two shallow pits approximately 4 m (13 ft) deep received about 1020 m^3 (36,000 ft^3) of "solid wastes with alpha contamination accompanied by small amounts of beta and gamma." (Rogers 1977, 0216) During this period, two underground storage tanks (the General's Tanks) were installed to store a total of 49,000 gal. (186,200 l) of a sodium hydroxide solution which contained 334 g (0.7 lb.) of plutonium-239 at the time of emplacement (circa 1947). The liquid from these tanks was recovered, treated, and solidified in cement in 1975. The contaminated cement remained buried at MDA A for several years, but was retrieved in the late 1980s and moved to Pit 29 at MDA G. In 1969, a 9-m- (30-ft-) deep pit was excavated at MDA A for the disposal of building debris contaminated by uranium-235, plutonium-238, and plutonium-239 from demolition work at TA-21.

Table C.2-1 Operational Summary of the MDAs at the Laboratory

MDA	Date From	Date To	Disposal Units	Inventory	Volume (yd^3)	Area (acre)
A	1945	1977	2 underground tanks, 3 pits	Unclassified; solid, liquid; radioactive (LLW, TRU[a])	8230	1.25
B	1945	12/48	2 underground pits	Unclassified; solid, liquid; radioactive (LLW, TRU)	27,781	6.03
C	1948	1974	7 pits, 108 shafts	Classified[b]; solid, liquid; mixed[c]	190,837	12.3
D	1948	1952	2 underground concrete chambers	Unclassified; solid; hazardous	310	0.03
E	1948	1952	1 Underground chamber, 6 pits	Classified; solid; mixed, TSCA[d]	U[e]	1.4
F	1/46	12/52	Several pits and chambers	Classified; solid; radioactive (LLW)	U	1.4
G	1/57	Open	Numerous pits, shafts, trenches	Classified; solid, liquid; mixed, TSCA	420,000	65
H	1/60	1968	9 shafts	Classified; solid; mixed, TSCA	U	0.3
J	1/61	Open	—	Unclassified; solid; hazardous	95,000	2.65
K	1955	12/90	Septic system, sumps, siphon tank, drain field	Unclassified; liquid; mixed	16,133	1.0
L	1959	12/85	4 pits, 34 shafts	Unclassified; solid, liquid; mixed, TSCA	U	2.58
M	1948	1965	Landfill	Unclassified; solid	2408	3
N	1/62	1/65	Pit	Unclassified; solid, liquid; mixed	U	0.28
P	1950	1984	Landfill	Unclassified; solid; hazardous	13,000	1.4
Q	1/45	1/46	Burial ground	Unclassified; solid; hazardous	U	0.2
R	6/45	12/51	Shallow burial ground	Unclassified; solid, liquid; mixed, TSCA	U	11.5
S	1965	Open	Experimental plot	Unclassified; solid; hazardous	40	0.0023
T	1945	1967	4 absorption beds, several shafts	Unclassified; solid, liquid; radioactive (LLW, TRU)	U	2.21
U	1/45	12/68	2 absorption beds	Unclassified; liquid, radioactive	667	0.2
V	1945	1961	3 absorption beds	Unclassified; liquid; mixed	5556	0.88
W	1964	1974	4 underground tanks	Unclassified; liquid; mixed	0.4	<0.001
X	1959	1959	Buried decommissioned reactor	Unclassified; solid; mixed	U	0.05
Y	1973	1976?	1 pit	Unclassified; solid, liquid; mixed, TSCA	4000	0.2
Z	1/65	12/81	Landfill	Unclassified; Solid	U	0.4
AA	1965	1989	2–4 trenches	Unclassified; solid; mixed	U	1.4
AB	1959	1961	Numerous shafts and cavities	Unclassified; solid, liquid; mixed	37	.45

[a] TRU = transuranic waste.
[b] MDAs containing classified inventory also contain unclassified inventory.
[c] MDAs containing mixed inventory may include mixed LLW, mixed TRU, or both.
[d] TSCA = Toxic Substances Control Act.
[e] U = unknown.

There is some discrepancy in the records about the number of pits on the east end of the site. An early engineering drawing (LASL 1970, 24374) depicts four; however, a later drawing (LASL 1945, 24448), along with several reports and memos, refer to the existence of only two pits. A recent geophysical survey of MDA A (Gerety et al. 1989, 6893) suggests the presence of only two pits on the east end of the site.

Additional information about the sequence of events and data that pertain to MDA A can be found in Table 16.8-1 of the TA-21 work plan (LANL 1991, 7529). MDA A is a Hazardous and Solid Waste Amendments (HSWA) solid waste management unit (SWMU) listed in Module VIII of the Laboratory's RCRA permit. RFI activities completed at MDA A include a Phase I surface investigation completed in accordance with the RFI work plan (LANL 1991, 7529). The data from these investigations will be evaluated in accordance with the methodology described in this document. Activities completed at

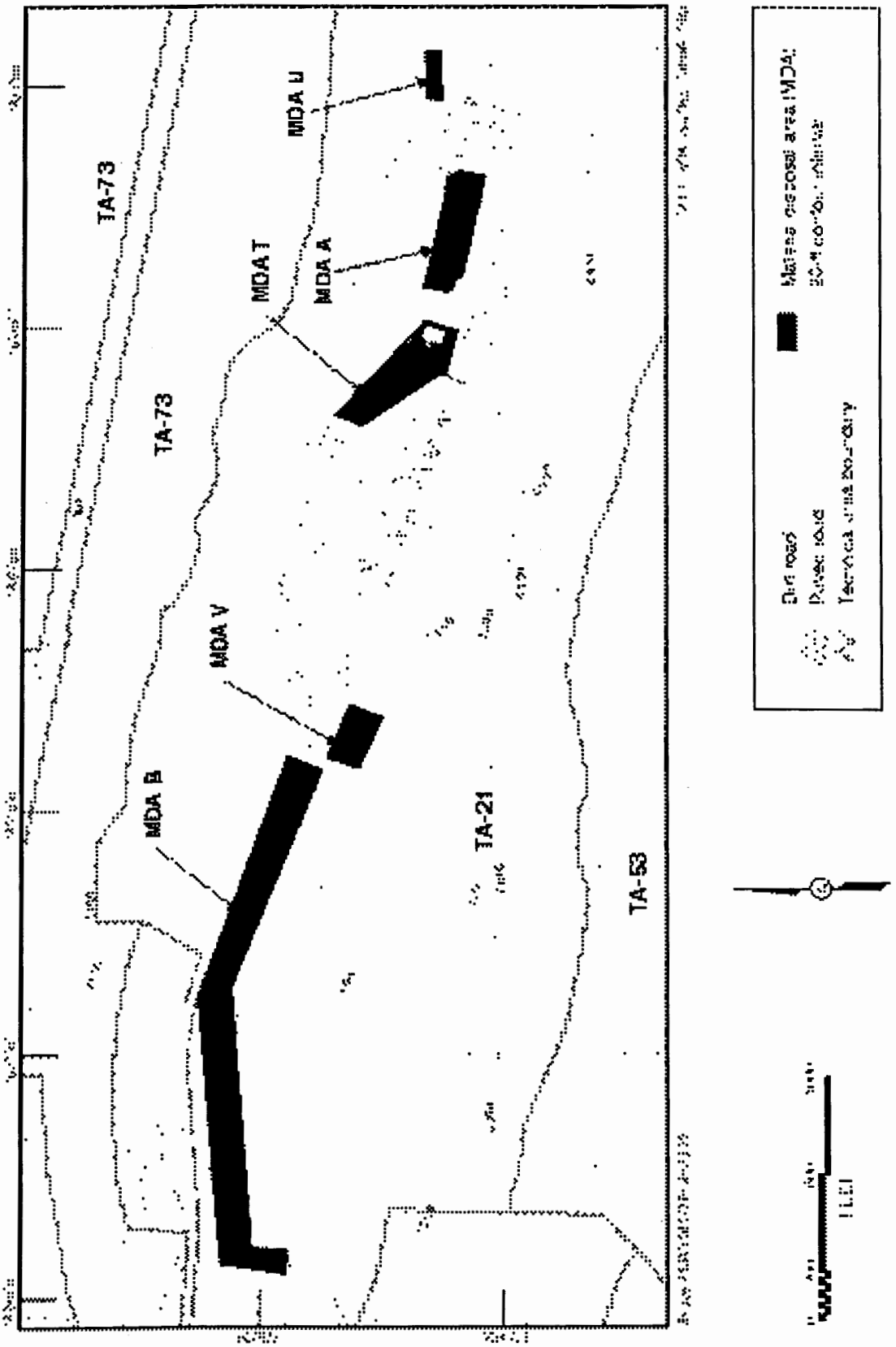

Figure 2.1-1. Locations of MDAs at TA-21 (A,B,T,U,V)

Figure C.2-1. Location of MDAs at TA-21 (A, B, T, U, V)

MDA A are referenced in a field summary report completed in 1994 and weekly status reports completed in 1997

C.2.2. MDA B

MDA B (PRS 21-015) is an inactive disposal site located on DP Mesa just west of the TA-21 fenced boundary and south of commercial businesses on DP Road. Run-off from this site enters the Los Alamos Canyon watershed. The approximate area of the MDA is 6 acres (2.4 ha) and it was operated from 1945 through 1948. The TA-21 work plan (LANL 1991, 7529). states that buried waste pits occupy about 4650 m^2 (5580 yd^2) with an estimated volume of 21,240 m^3 (27,612 yd^3) (LANL 1991, 7529). MDA B consists of an unpaved, fenced, eastern area and a paved, fenced, western area, neither of which contains any surface structures. The number of trenches comprising MDA B is unknown. A geophysical survey conducted as part of the 1998 RFI to delineate the dimensions of the trenches found the disposal trenches to be approximately 15 ft (4.5 m) wide by 300 ft (90 m) long by 12 ft (3.6 m) deep and unlined.

The radiological inventory includes "plutonium, polonium, uranium, americium, curium, lanthanum, (and) actinium." (Rogers 1977, 0216) The disposal capacity of the pits is estimated to be about 21,000 m^3 (760,000 ft^3). The entire pit area is estimated to contain no more than 100 g (6.13 Ci) of plutonium-239.

In 1984, the unpaved portion of MDA B was resurfaced with a variety of cover systems as a pilot study conducted in support of the Department of Energy (DOE) National Low Level Waste Management Program. The present cover incorporates several variations of a nominal 3-ft-(1 m) thick crushed-tuff cover, which is placed over the original crushed-tuff cover. Variations include cobble and gravel biological barriers between the old and new covers, as well as shrub, grass, and gravel/mulch surface treatments. The total cover of this portion of MDA B is nominally 6.5-ft-(2 m) thick.

This PRS is a SWMU listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit (EPA 1990, 1585). RFI activities completed at MDA B include the following:

- Phase I surface investigation was conducted at MDA B and associated drainages completed in accordance with the TA-21 OU RFI work plan (LANL 1991, 7529).
- Phase I subsurface sampling and analysis plan (SAP) RFI work plan revision was submitted to the New Mexico Environment Department (NMED) in September 1998 (Environmental Restoration Project 1998, 59506).
- Request for supplemental information (RSI) for Phase I subsurface SAP was issued by NMED.
- Response to RSI was submitted to NMED in February 1999 (Environmental Restoration Project 1999, 62885.2).
- Phase I subsurface investigation is on-going during 1999.

C.2.3. MDA T

MDA T (PRS 21-016) includes 4 absorption beds and 62 shafts that received radioactively contaminated liquid from the plutonium processing laboratories at TA-21 between 1945 and 1952. Run-off from this site enters DP Canyon, which is located within the Los Alamos Canyon watershed. In 1952, a liquid waste treatment plant was installed to remove plutonium and other radionuclides from process wastewater. Thereafter, the absorption beds received relatively small quantities of LLW until 1967, when a new liquid waste treatment process was initiated. Between 1968 and 1975, treated liquid waste was mixed with cement pumped into shafts at MDA T for disposal. After 1975, the cement paste was poured into corrugated metal pipes, and retrievably placed at MDA T in 62 vertical shafts.

Approximately 18,300,000 gal. (69,540,000 l) of liquid waste was discharged to the MDA T absorption beds between 1945 and 1967. "As of January 1973, the absorption beds contained . . .10 Ci of plutonium-239. . . As of July 1976, the disposal shafts contained 7 Ci of uranium-233, 47 Ci of plutonium-238, 3,761 Ci of americium-241, and 3 Ci of mixed fission products." (Rogers 1977, 0216) The total volume of cement paste permanently disposed in shafts at MDA T was 122,500 ft^3 (36,750 m^3).

MDA T is a SWMU listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA T include the following:

- Phase I surface investigation conducted at MDA T and associated drainages was completed in accordance with the TA-21 OU RFI work plan (LANL 1991, 7529).
- Phase I subsurface investigation SAP was submitted to NMED in the SAP for Group 21-016 (Environmental Restoration Project 1996, 54127).
- Phase I subsurface investigation completed.
- RSI on Phase I subsurface SAP issued by NMED July 29, 1997 (NMED 1997, 56498).
- Response to RSI.

C.2.4. MDA U

MDA U [PRSs 21-017 (a, b, and c)] is an inactive disposal site located north of TAs-21-152 and -153 near the eastern end of TA-21. MDA U is a fence-enclosed area of approximately 0.2 acres (0.08 ha) and contains two absorption beds [PRSs 21-017(a) and (b)] and a distribution box [PRS 21-017(c)]. Run-off from this site enters DP Canyon, which is located within the Los Alamos Canyon watershed. The absorption beds, with a surface area of approximately 1800 ft^2 (162 m^2) and an estimated volume of about 18,000 ft^3 (540 m^3), were used for subsurface disposal of radioactively contaminated liquid wastes from 1948 to 1968 (LANL 1991, 7529). The distribution box [PRS 21-017(c)] and distribution lines in PRSs 21-017 (a and b) were removed in 1985.

This PRS is a SWMU listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA U include the following:

- Phase I surface investigation was conducted in 1994 in accordance with the TA-21 OU RFI work plan (LANL 1991, 7529).
- Additional Phase I surface investigation SAP was submitted to NMED in 1998.
- Phase I subsurface SAP was submitted to NMED in the SAP for PRSs 21-017(a,b, and c) (LANL 1998, 62549).
- Phase I subsurface RFI is ongoing at risk, 1999.

C.2.5. MDA V

MDA V [PRS 21-018(a)] is an 0.88-acre (0.35-ha) site located southwest of the TA-21 fenced boundary. MDA V consists of three absorption beds that occupy 15,000 ft^2 and have a volume of 4250 m^3 (5525 yd^3). Surface water run-off from this site enters the Los Alamos Canyon watershed. The absorption beds were used from 1945 through 1961 for liquid waste disposal from a laundry facility at TA-21-20. The laundry facility mainly washed clothing from uranium and plutonium refinement operations.

This PRS is a SWMU listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA V include the following:

- Phase I surface and subsurface investigation was conducted at MDA V and its associated drainages in 1994 and 1996 in accordance with the TA-21 OU RFI work plan (LANL 1991, 7529).

- RFI report recommending no further action (NFA) was submitted to NMED in 1996 (Environmental Restoration Project 1996, 54969).
- Notice of Deficiency (NOD) on Phase I surface and subsurface RFI report issued by NMED. Response to NOD. Both are reported in (LANL 1997, 63530).

Recently, a nontraditional in situ vitrification cold test was performed near MDA V in early in 1999 to plan to vitrify a portion of one of the absorption beds (Environmental Restoration Project 1999, 63096).

The data from investigations at MDA V will be evaluated in accordance with the methodology described in this document.

C.3. MDAS G, H, J, AND L AT TA-54

TA-54 is located on Mesita del Buey and spans the boundary of the Cañada del Buey and Pajarito Canyon watersheds. The elevation at TA-54 ranges from 6700 ft to 6800 ft (2010 m to 2040 m). The depth to groundwater below TA-54 ranges from 900 ft to 980 ft (270 m to 294 m). The major industrial activity at TA-54 has been waste storage and disposal. The 45 SWMUs at TA-54 are organized within four MDAs (G, H, J, and L) and within three facilities located in the western part of TA-54 including TA-54 West, former radiation exposure and animal holding facilities.

The location and approximate dimensions of MDAs G, H, J, and L at TA-54 are shown in Figure 2.2-1.

C.3.1. MDA G

MDA G is a 100-acre (40-ha) site that has served as the Laboratory's principal radioactive solid waste storage and disposal site since the Laboratory's routine operations began there in 1959. The majority of stormwater run-off from MDA G enters the Pajarito Canyon watershed and a much smaller portion drains into Cañada del Buey, which is located within the Mortandad Canyon watershed. MDA G will continue operating in its current capacity for the foreseeable future. Disposal units (pits and shafts) containing waste disposed before 1988 comprise HSWA SWMU [PRS 54-013(b)-99] and are subject to corrective action under the purview of the ER Project.

From 1959 to 1970 nearly all of the Laboratory's solid radioactive waste was disposed at MDA G. It was interred into pits and into lined and unlined shafts dug into the mesa. The depth of these pits and shafts is approximately 60 ft (18 m). Layers of waste in pits have been backfilled with clean excavated materials (crushed tuff), and filled pits have been covered with at least 1 m (3 ft) of crushed tuff and about 5 in. (12 cm) of topsoil, which has been re-vegetated with native grasses. Filled shafts have been capped with crushed tuff, concrete, or both.

In 1971, the Laboratory began segregating radioactive waste into two categories differentiated by the concentration of transuranic radioisotopes present in the waste. Since that time, TRU has been retrievably stored at MDA G, and only LLW has been permanently disposed. Since the implementation of RCRA in 1986, mixed LLW (i.e., LLW that also meets the definition of a RCRA listed or characteristic hazardous waste) has been segregated from the LLW and stored above ground at MDA G. Thus, the inventory of PRS 54-013(b)-99 includes (in descending order of relative volume) LLW, solid TRU, solid mixed TRU, and LLW.

As a HSWA SWMU, MDA G has undergone extensive investigation. a permitted RCRA storage facility, and an authorized DOE LLW disposal facility. There are known to be subsurface vapor-phase plumes of volatile organic compounds (VOCs) and tritium, but no other releases have been found in the subsurface.

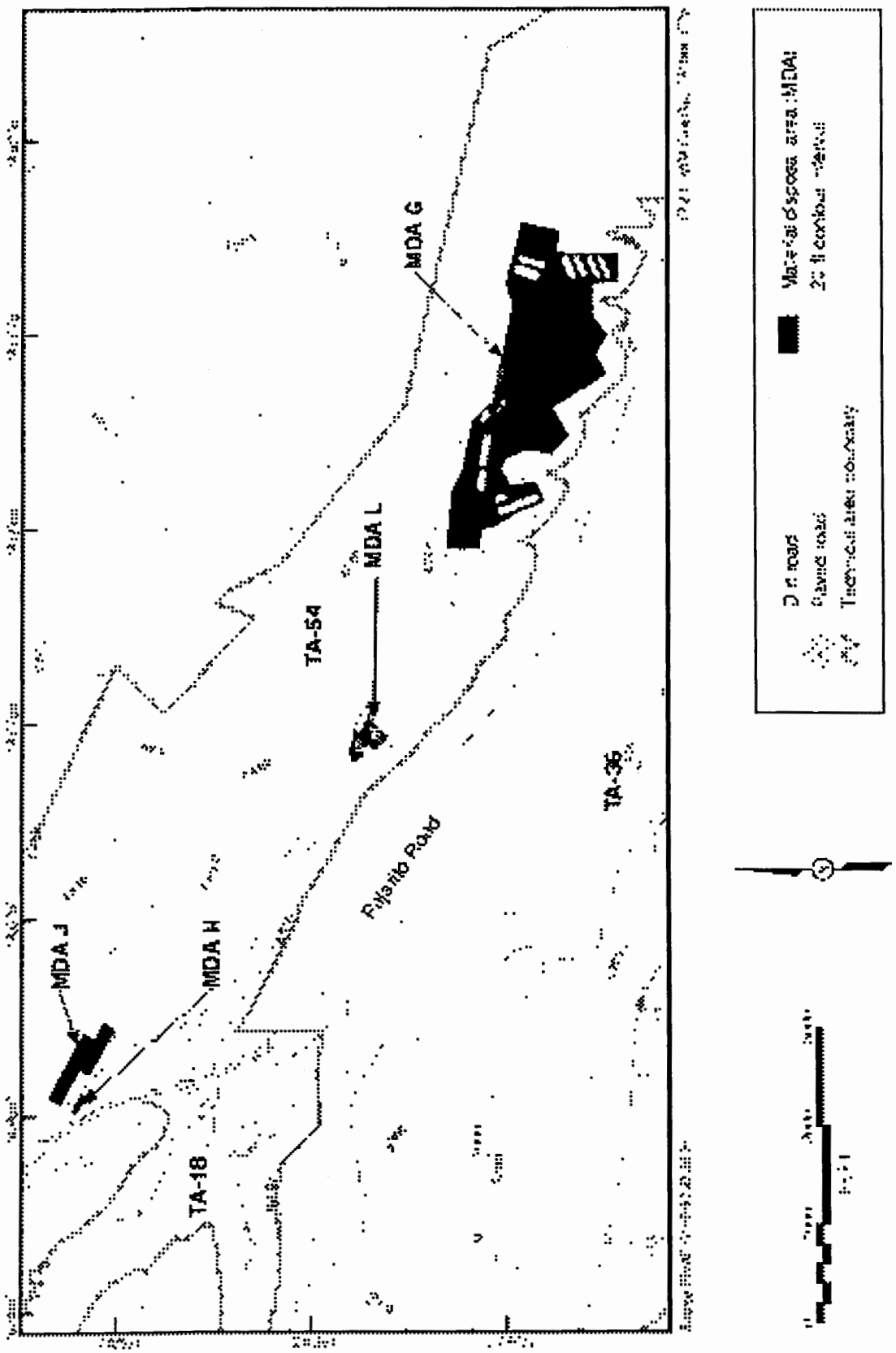

Figure 2.2-1. Locations of MDAs at TA-54 (G,H,J,L)

Figure C.3-1..Location of MDAs at TA-54 (G, H, J, L)

In 1997, the performance assessment and composite analysis of LANL MDA G (Hollis et al. 1997, 63131) was published to authorize continued LLW disposal pursuant to DOE requirements. An RFI report for MDA G is scheduled to be submitted to NMED in Fiscal Year (FY) 1999. The risk assessment performed for the MDA G RFI builds on the performance assessment and composite analysis, and is the basis of the technical approach for risk assessments performed during the RFI and corrective measures study process for all of the Laboratory's MDAs.

C.3.2. MDA H

MDA H (PRS 54-004) is a fenced 0.3-acre (0.12-ha) rectangular area measuring 200 ft by 70 ft (60 m by 21 m) just inside the western boundary of TA-54. Stormwater run-off from this site enters the Pajarito Canyon watershed. Nine shafts were used for the disposal of classified wastes from 1960 to 1986. Eight of the nine shafts are capped by a 3-ft (1-m) layer of concrete and a 3-ft (1-m) layer of soil. Shaft 9 has a locked steel plate as a cover. This shaft potentially contains a volume of 990 ft^3 (30 m^3) of hazardous waste. The other eight shafts were 6 ft (1.8 m) in diameter and approximately 60 ft (18 m) in depth for a total disposal capacity of approximately 13,565 ft^3 (407 m^3).

Waste disposal logs show that nearly every shaft received the following materials: weapons components, classified documents and paper, aluminum, plastic, stainless steel, rubber, graphite shapes, weapon mockups, depleted uranium scraps and classified shapes, film, prints and slides, classified shapes contaminated with high explosives (HE), and graphite reactor fuel rods. In addition, RCRA hazardous metals were disposed in many of the shafts.

This PRS is a SWMU listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA H include a Phase I investigation conducted in accordance with RFI work plan for OU 1148 (LANL 1992, 7669).

Phase I investigation data will be evaluated in accordance with the methodology described in this document, which will be included in the RFI report for MDA H to be completed in FY 1999.

C.3.3. MDA J

Administratively controlled waste was disposed at MDA J (PRS 54-005) in a 2.65-acre (1.1-ha) site from 1961 through 1998. Run-off from this site enters Cañada del Buey, which is located within the Mortandad Canyon watershed. The MDA consists of four pits and two shafts with an approximate waste capacity of 2.6 million ft^3 (78,000 m^3). Examples of administratively controlled waste are classified items such as safes with secured locks, objects with classified shapes, scrap equipment, sand from barium sand treatment operations at MDA L, and empty containers. Historically, MDA J received waste that was potentially contaminated with trace quantities of nonreactive HE residues. Other wastes included asbestos and residual amounts of hazardous waste. Land farming also occurs at this site to bioremediate petroleum-contaminated soils from other Laboratory sites.

MDA J is scheduled to be closed in FY 1999 as a special waste landfill in accordance with the New Mexico solid waste regulations. Afterwards, we will propose that MDA J be removed from the HSWA module of the Laboratory's RCRA operating permit, under which the ER Project operates.

C.3.4. MDA L

MDA L (PRS 54-006) is a 2.58-acre (1.03-ha) site for disposing hazardous materials and liquid wastes and the storage of gas cylinders. Run-off from this site enters Cañada del Buey, which is located within

the Mortandad Canyon watershed. Since the implementation of RCRA in 1986, MDA L has been used in its present capacity for storage of RCRA waste, PCB waste, and some mixed waste (such as lead contaminated with radiation). Early operations between about 1959 and 1985 included disposing chemical wastes within unlined pits and shafts dug into the mesa. In 1986, much of the previously used surface area was covered with asphalt to support surface structures.

PRS 54-006 is a SWMU listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA L include the following:

- Installing multiple boreholes into the subsurface around and beneath the disposal units, and
- Monitoring of a plume of VOCs, in accordance with a plan submitted to the Environmental Protection Agency (EPA) (LANL 1993, 22430).

The data from these investigations will be evaluated in accordance with the methodology described in this document, as the basis of the RFI report for MDA L completed in FY 1999 (in process).

C.4. MDAS D, E, AND K AT TA-33

TA-33, also known as Hot Point (HP) Site, is located near the southeast boundary of the Laboratory and spans the boundary of the Chaquehui Canyon and Ancho Canyon watersheds. Within TA-33, elevation ranges from 5300 ft to 6300 ft (1590 m to 1890 m) and depth to groundwater ranges from 760 to 910 ft (228 m to 273 m). In 1947 TA-33 was a test site for weapons using conventional HE, uranium, and beryllium. The experiments were performed in underground chambers, on surface firing pads, and at firing sites equipped with large guns that fired projectiles into catcher berms. The weapons experiments ceased in 1972. A high-pressure tritium facility was operated at TA-33 from 1955 until late 1990.

The location and approximate dimensions of MDAs D, E, and K at TA-33 are shown in Figure 2.3-1.

C.4.1. MDA D

MDA D [PRSs 33-003(a and b)] is located at approximately 6500-ft (1950 m) elevation on a mesa formed by Ancho Canyon and White Rock Canyon. The depth to groundwater beneath MDA D is approximately 910 ft (273 m). Run-off from this site may either drain to the Ancho Canyon watershed or directly into White Rock Canyon. MDA D consists of two underground chambers, TA-33-4 and TA-33-6 [PRSs 33-003(a and b), respectively], used to test explosive devices. The chambers were constructed in 1948 and were used for initiator tests involving polonium-210, milligram quantities of beryllium, and large amounts of HE. Chamber TA-33-4 was used once in 1948 with no apparent rupture; Chamber TA-33-6 was used twice, once in December 1948 and again in April 1952. The second test destroyed the chamber. Debris from the detonation was ejected through the elevator shaft and spread over the mesa. A 10-ft-deep crater that formed around the chamber was later filled with the ejected debris and covered with uncontaminated soil.

The SWMUs at this MDA are listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA D include the following:

- Phase I investigation was conducted in 1994 in accordance with the RFI work plan for OU 1122 (LANL 1992, 7671).
- Additional investigations were conducted in 1996 in accordance with the revised SAP presented in RFI Report for TA-33, PRSs 33-003(a), 33-004(a), 33-007(c), 33-009, 33-011(d), 33-013, 33-016, 33-017, and Revised SAPs for PRSs 33-003(b), 33-004(k), 33-008(b), C-33-001, C-33-002 (LANL 1995, 50113).

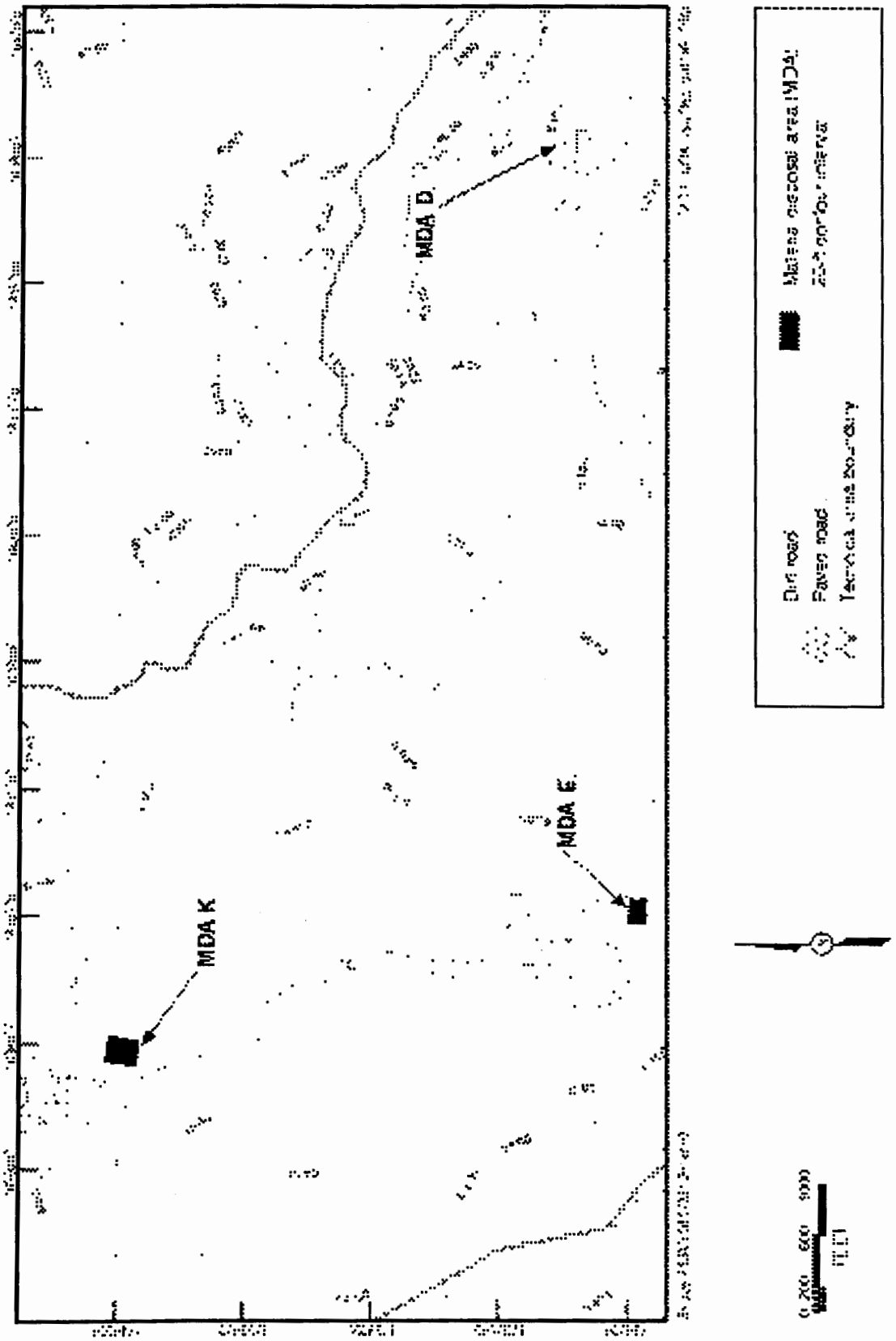

Figure C.4-1. Locations of MDAs at TA-33 (D, E, K)

C.4.2. MDA E

MDA E [PRSs 33-001(a–e)] sits on mesa near a point formed by Chaquehui Canyon and one of its tributaries. MDA E is located at approximately 6500-ft (1950 m) elevation. The depth to groundwater beneath MDA E is approximately 760 ft (228 m). Run-off from this site enters the Chaquehui Canyon watershed. MDA E operated between 1948 and 1955 for disposal of gun-type initiators and debris. Test material contaminated with polonium-210 was carried to the open pits. The first structure was underground chamber No. 3, TA-33-29, which was completed in February 1950 and used for a single experiment in April 1950. The explosive experiment in the chamber did not breach the surface. Beginning in 1951, South Site was used for gun-type and implosion studies. A Los Alamos Scientific Laboratory internal memo (Meyer 1962, 6741) referring to contaminated disposal Area E, TA-33 states that "Area E at TA-33 has been used as a storage area and for burial of low-level radioactive contaminated equipment." A report by the US Geological Survey (Abrahams 1963, 8149) states that the area contains several hundred kilograms of depleted uranium. The curie contents of pits 1 and 2 are reported as 240 Ci and 60 Ci, respectively, and descriptions of the contents of pits 1 and 2 indicate the presence of hazardous waste (Rogers 1977, 0218). No information is available on pits 5 and 6; TA-33 personnel indicate that these trenches were not used and were filled and compacted in 1963.

The SWMUs at this MDA are listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. No RFI activities have been completed at MDA E to date. A focused RFI will be developed for MDA E in accordance with the methodology described in this document.

C.4.3. MDA K

MDA K [PRSs 33-002(a–e)] is a 1.0-acre (0.4-ha) site located within TA-33 on a mesa at an approximate elevation of 6500 ft (1950 m). The depth to groundwater beneath MDA K is approximately 820 ft (246 m). Run-off from this site enters the Chaquehui Canyon watershed. MDA K received liquid effluent from the high-pressure tritium facility (TA-33-86) that operated at from 1955 until 1990. This facility housed equipment used to transfer tritium from large tanks to smaller tanks that were transported to various Laboratory locations Occasionally the building was used for other activities; for example, a uranium fluidized bed assembly was constructed in 1960. After the TA-33-86 tritium facility operations ceased in 1990, all equipment was removed from the building. The building and associated structures are scheduled for decontamination and decommissioning in 1999. MDA K contains consolidated PRSs 33-002(a–e). PRS 33-002(a) is the septic tank and drain field, PRSs 33-002(b and c) are sumps (dry wells), PRS 33-002(d) is a cooling water outfall, and PRS 33-002(e) is a roof drain outfall.

The SWMUs at this MDA are listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA K include the following:

- Phase I investigation conducted at PRSs 33-002(a and b) in 1993 in accordance with the RFI work plan for OU 1122 (LANL 1992, 7671).
- Phase I investigations and Phase II SAPs for PRSs 33-002(a and b) are presented in the RFI report for MDA K, PRSs 33-002(a,b,c,d,e) (Environmental Restoration Project 1995, 50113).
- PRSs 33-002(b and c) were recommended for NFA for human health in the NFA report for PRSs 33-002(b,c), 33-003(b), 33-004(k), 33-006(a), 33-008(a,b), 33-011(d), 33-013, 33-017 (Environmental Restoration Project 1997, 57021).
- PRS 33-002(d and e) were recommended for NFA in the RFI report for MDA K, PRSs 33-002(a,b,c,d,e) (Environmental Restoration Project 1995, 50113).

C.5. MDAS N AND Z AT TA-15

TA-15 is located on Threemile Mesa at an elevation of approximately 7200 ft (2160 m). The depth to groundwater below TA-15 is approximately 1200 ft (360 m). Threemile Mesa is divided by Potrillo Canyon into two smaller finger mesas: Mesita del Potrillo and PHERMEX mesa, which have served as firing site areas. TA-15 is bound to the north by Threemile Canyon and to the south by Water Canyon.TA-15 principal activities have centered on the development and testing of HE.

The location and approximate dimensions of MDAs N and Z at TA-15 are shown in Figure 2.4-1.

C.5.1. MDA N

MDA N [PRS 15-007(a)] is at approximately 7280-ft (2184-m) elevation. The depth to groundwater beneath MDA N is approximately 1170 ft (351 m). Run-off from MDA N enters Potrillo Canyon, which is located in the Water Canyon watershed. MDA N was opened in 1962. Although no information is available about its closing, a 1965 aerial photograph suggests that it was closed before then. MDA N is described in the 1990 SWMU report as a pit containing the remnants of several structures from R Site, the TA-15 firing site that had been exposed to either explosives or chemical contamination. MDA N also may have contained rubble from buildings TA-15-07, TA-15-1 and others; however, little is known about the materials or activities that may have occurred in these buildings. No other information is available on debris deposited in the MDA. The pit is covered and revegetated. The RFI work plan for OU 1086 (LANL 1993, 20946) identifies mercury, thorium, and photographic solutions as potential contaminants.

The SWMU at this MDA is listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA N include a Phase I investigation conducted in accordance with the RFI work plan for OU 1086 (LANL 1992, 14583), which was not successful in locating this MDA through geophysical or sampling efforts.

MDA N will be evaluated in accordance with the methodology described in this document.

C.5.2. MDA Z

MDA Z [PRS 15-007(b)] is located at TA-15 south of the side road leading to TA-15-233. MDA Z is located at an elevation of approximately 7220 ft (2166 m). The depth to groundwater below MDA Z is approximately 1200 ft (360 m). Run-off from this site enters the Cañon de Valle watershed. MDA Z was used between 1965 and 1981 for the disposal of construction debris, including pieces of cement and rebar of various sizes, used concrete bags, steel blast mats from tests at PHERMEX, and other debris. Pieces of partially burned wood are visible. The landfill is roughly rectangular and measures approximately 200 ft by 50 ft (60 m by 15 m). Waste appears to have been placed in a naturally occurring depression; concrete filled sandbags are visible, which were probably piled as a retaining wall, and other debris was probably filled in behind it. One face grades to native soil, while the other is exposed and stands approximately 15 ft (4.5 m) high. Most of the debris on the exposed face is not covered with soil and is exposed to wind, rain, and snowmelt. Contaminants at the site include metals from wire, blast mats, VOCs and/or semivolatile organic compounds from charred wood, road and construction debris, and radioactive substances (e.g. from the blast mats). Chunks of uranium are visible at this site.

The SWMU at this MDA is listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. There have been no RFI activities completed at MDA Z. MDA Z may be evaluated in accordance with the methodology described in this document.

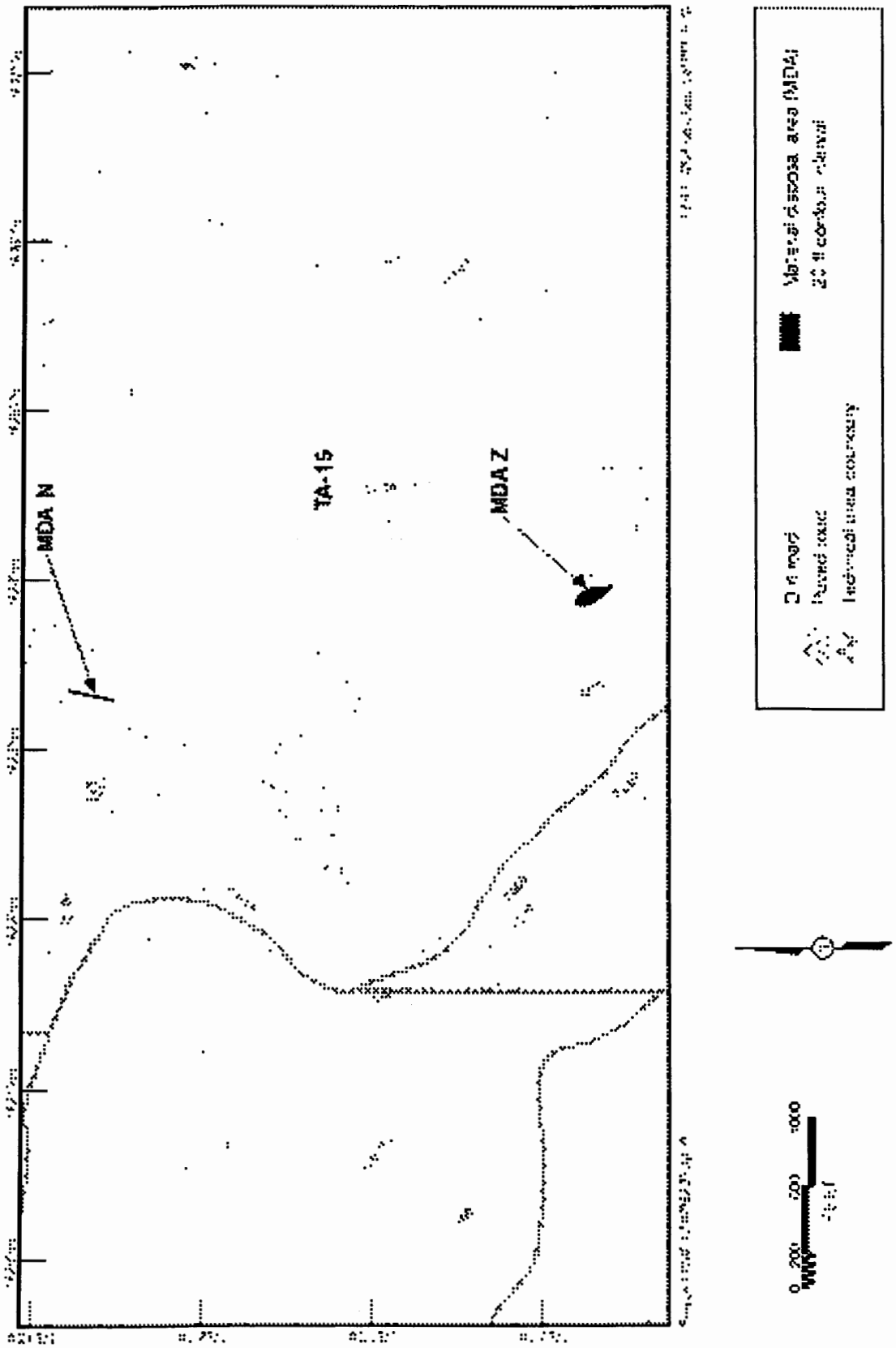

Figure C.5-1 Locations of MDAs at TA-15 (N, Z)

C.6. MDAS P AND R AT TA-16

TA-16, known as S Site, is located within the northwestern portion of the Laboratory at an elevation ranging from 7000 ft to 7500 ft (2100 m to 2250 m). The average depth to groundwater beneath the MDAs is approximately 1200 ft (360 m). TA-16 is located within the Cañon De Valle watershed. Operations at TA-16 focus on the production of HE and include casting, pressing, and machining of HE; assembly of explosive test devices; fabrication of plastic components; development of new materials; and nondestructive examination. TA-16 has been used since the early 1940s and has recently had a high-pressure tritium facility installed.

The location and approximate dimensions of MDAs P and R at TA-16 are shown in Figure 2.5-1.

C.6.1. MDA P

MDA P (PRS 16-018) is a 1.4-acre (0.6-ha) industrial landfill at TA-16 near the south rim of Cañon de Valle. MDA P is located at an elevation of approximately 7500 ft (2250 m). The depth to groundwater beneath MDA P is approximately 1150 ft (345 m). Run-off from MDA P enters the Cañon De Valle watershed. MDA P contains wastes from the synthesis, processing, and testing of HE and residual barium-contaminated sands from HE incineration; from the TA-16 photo development process; from the residues of the burning of HE-contaminated equipment; and from the demolition of the S Site World War II complex. MDA P also contains construction debris such as large timbers, concrete rubble, and pipes, and non-construction debris such as flasks, bottles, morticians' tables, and other items used for the assembly of HE components.

Before the early 1950s when MDA P was designated a disposal area for S Site wastes, the area served as a detonator burning ground. Lead azide and thallium azide detonators were used during this time and are assumed to have been burned at the site. HE disposal activities at MDA P started in the early 1950s and ceased in 1984. Waste disposal was initiated at the western end of the landfill and proceeded eastward. The landfill was used to dispose from burning HE-contaminated materials. Much of the old S Site complex was demolished in the 1960s, and most of the "flashed" residues of these demolition activities were disposed in MDA P.

The MDA P landfill was closed as a RCRA unit in FY 1999; therefore, MDA P will not be evaluated in accordance with the methodology described in this document.

C.6.2. MDA R

MDA R (PRS 16-019) is a historic HE burning ground and associated canyon side disposal area located at TA-16. MDA R is an 11.5-acre (4.6-ha) site located on the mesa's edge on the south side of Cañon de Valle, and runoff from the site enters the Cañon De Valle watershed. MDA R is located at an elevation of approximately 7500 ft (2250 m). The depth to groundwater beneath MDA R is approximately 1240 ft (372 m). MDA R was an active disposal unit from 1945 until 1951, when the modern-day TA-16 burning ground was completed. MDA R occupies an area of 600 ft by 900 ft (180 m by 270 m), although it is likely that the actual contaminated area much smaller.

Likely constituents at MDA R (based on analogy with the modern burning ground and MDA P) are HE, including chunk HE and barium. There are significant amounts of debris along the north side of MDA R. A geophysical survey at MDA R suggests that the depth of waste at MDA R is shallow.

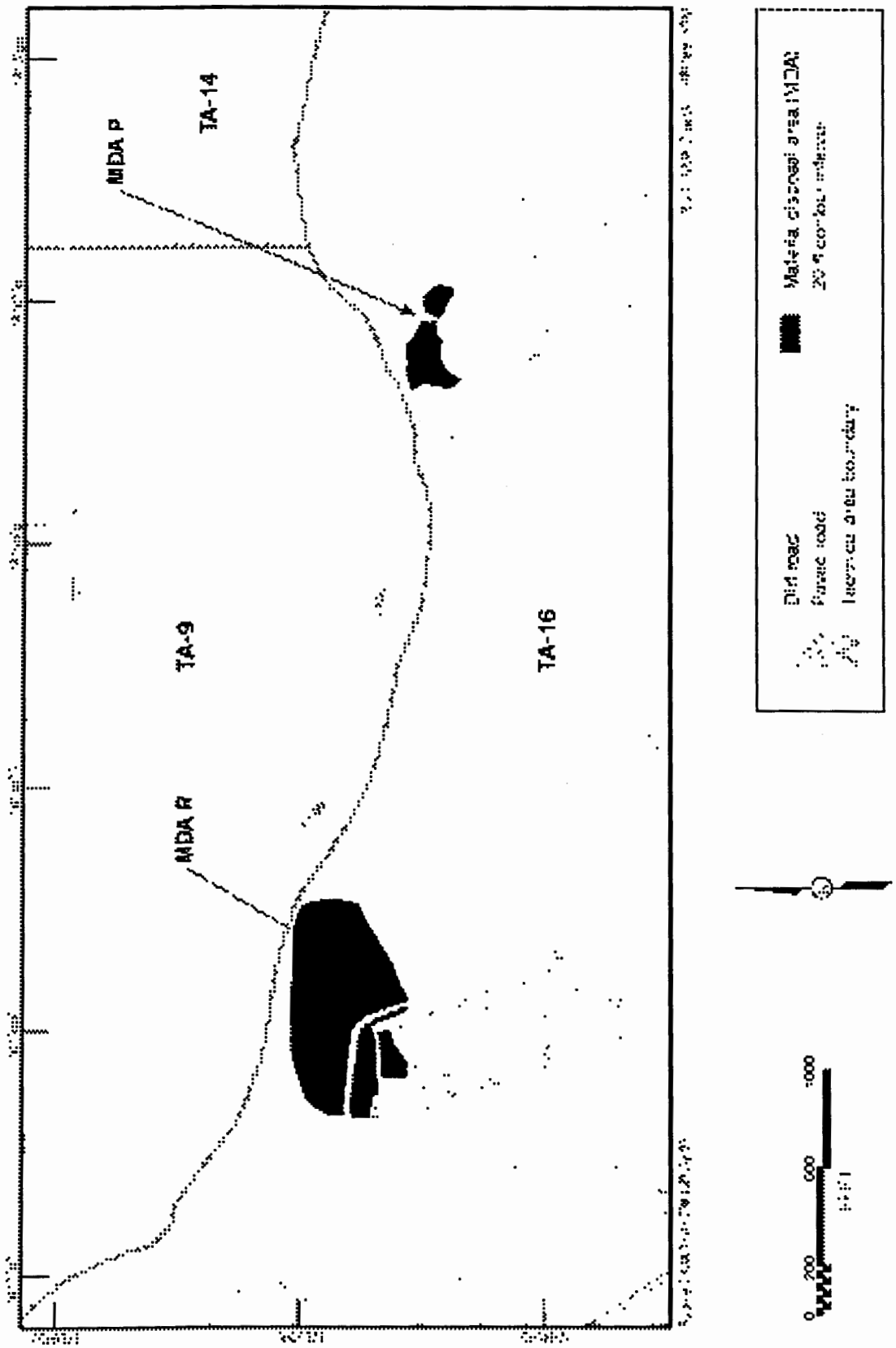

Figure 2.5-1. Locations of MDAs at TA-16 (P,R)

Figure 6-1 Locations of MDAs at TA-16 (P, R)

The SWMU at this MDA is listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA R include the following:

- Phase I investigation was conducted in accordance with the RFI work plan for OU 1082 (LANL 1993, 39940).
- Weekly status reports prepared in 1997.

MDA R may be evaluated in accordance with the methodology described in this document.

C.7. MDAS W AND X AT TA-35

TA-35, which is also known as Ten Site Laboratory, is located at an elevation of approximately 7000 ft (2100 m) on a finger mesa between Mortandad Canyon and Ten Site Canyon, located within the Mortandad Canyon watershed. The depth to groundwater beneath TA-35 is approximately 1200 ft (360 m). TA-35 is currently used for safeguard studies, laser research and development, and other experimental research. At TA-35's MDAs past waste disposal includes source preparation, radionuclide experimentation, and nuclear fission reactor development.

The location and approximate dimensions of MDAs W and X at TA-35 are shown in Figure 2.6-1.

C.7.1. MDA W

MDA W (PRS 35-001) consists of two 4-in.-(10-cm-) diameter, 125-ft (38-m) long stainless steel tubes suspended vertically inside 8-in.-(20-cm-) diameter carbon-steel-cased wells. Each tube, which has been backfilled with nitrogen under pressure and sealed, contains 150 l (39 gal.) of liquid sodium reactor coolant contaminated with plutonium and associated fission products. MDA W is capped with concrete and sits on the southern edge of Ten Site Mesa above Ten Site Canyon. There are no stormwater run-off concerns or any potential for erosion of the cap. Therefore, this site poses no impact on the Ten Site Canyon watershed. The depth to groundwater from the bottom of the carbon-steel-cased wells is around 1000 ft (300 m). MDA W was recommended for NFA in the addendum to the OU 1129 RFI work plan (Pratt 1994, 43475, p. 6-6) on the basis that no evidence of a release exists, the present engineering controls preclude any migration of contaminants to the environment; assessment and remediation options pose a greater threat to human health and the environment than leaving the site as is; and the site will be maintained under perpetual institutional control. There are no administrative controls regarding access to the site.

C.7.2. MDA X

MDA X (PRS 35-002) is the former site of the reactor from the Los Alamos Power Reactor Experiment No. 2 (LAPRE-II), which was buried in place after it was decommissioned in 1959. MDA X was located near the southeast corner of building TA-35-2 on the south side of Ten Site Mesa at an elevation of approximately 7000 ft (2100 m). The depth to groundwater below the former location of MDA X is approximately 1160 ft (348 m). MDA X was remediated in 1991 as an interim action. MDA X was recommended for NFA in the Addendum to the OU 1129 RFI Work Plan (Pratt 1994, 43475, p. 6-7) because all reactor-related equipment and contaminated soils were removed. Afterwards, soil was sampled to confirm the removal of all constituents of concern including radionuclides and hazardous chemicals. There are no administrative controls regarding access to the site.

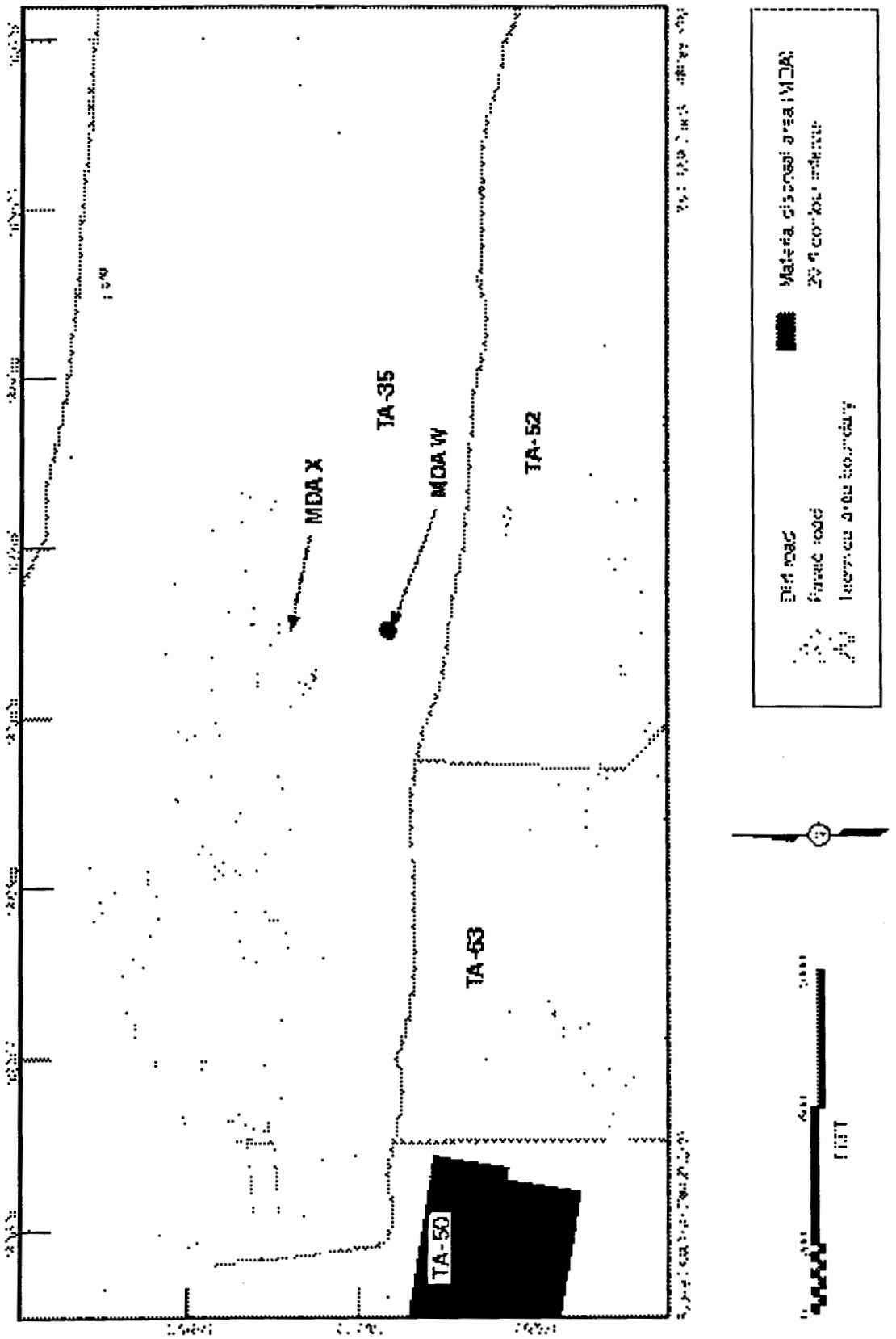

Figure 7-1 Locations of MDAs at TA-35 (W, X)

C.8. MDA C AT TA-50

The MDA C landfill at TA-50 (PRS 50-009) was established in May 1948 as replacement for MDA B at TA-21. MDA C is located at the head of Ten Site Canyon at an elevation of approximately 7200 ft (2667 m). Figure 2.7-1 shows the layout of MDA C at TA-50.

The depth to groundwater below MDA C is approximately 1175 ft (353 m) and run-off from this site enters Ten Site Canyon, which is located in the Mortandad Canyon watershed. MDA C is an 11.8-acre (4.7-ha) site enclosed by a fence. Radioactive and hazardous waste was disposed in seven pits and 108 shafts at MDA C between 1948 and 1965. The average depth of the MDA C disposal pits was 20 ft (6 m), and the average depth of shafts was about 16 ft (4.8 m). The pits were filled between 1948 and 1959, and the shafts were filled between 1958 and 1965. Limited information about waste disposals after 1954 was recorded in log books. The total radiological inventory estimates of MDA C are 196 Ci in pits and 49,483 Ci in shafts (Rogers 1977, 0216). This estimate includes 28 Ci of uranium (uranium-233, -234, -235, -236, and -238); 49,136 Ci of cesium-137; 31 Ci of strontium-90; 26 Ci of plutonium-239; 149 Ci of americium-241; 50 Ci of mixed fission products; and 200 Ci of mixed activation products.

A chronology of the major events pertinent to MDA C is presented in Table 2-9 of the RFI work plan for OU 1147. There is list of interred contaminants taken from site logbooks in Table 2-10 of the RFI work plan for OU 1147 (LANL 1992, 7672).

The SWMU at this MDA is listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA C include the following:

- Phase I surface investigation was conducted in 1993 in accordance with the RFI work plan for OU 1147 (LANL 1992, 7672).
- Phase I subsurface investigation was conducted from 1994 through 1996 in accordance with the RFI work plan for OU 1147 (LANL 1992, 7672).

The data from these investigations will be evaluated in accordance with the methodology described in this document.

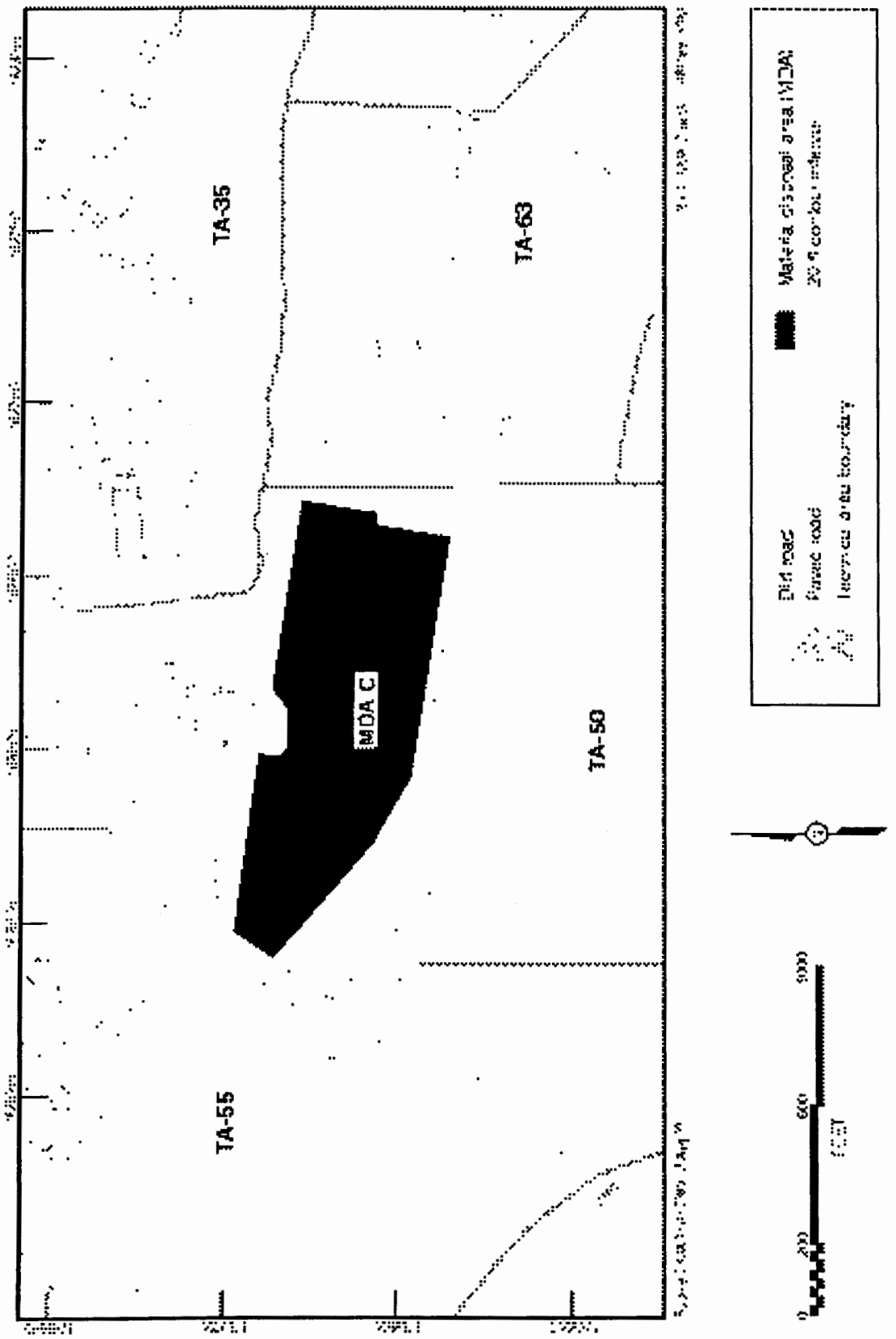

Figure C.8-1 Location of MDA C at TA-50

C.9. MDA F AT TA-6

MDA F [PRS 6-007(a)] consists of two fenced areas located at TA-6 on Twomile Mesa north of Twomile Mesa Road and south of the southwest fork of Twomile Canyon. Figure 2.8-1 shows the layout of MDA F at TA-6.

MDA F sits at an elevation of approximately 7460 ft (2238 m). The depth to groundwater below MDA F is approximately 1275 ft (383 m). Run-off from this site enters the southwest fork of Twomile Canyon, which is located within the Pajarito Canyon watershed. In 1945, defective explosive lenses manufactured for use in the Fat Man implosion weapon were destroyed in this area by detonation. Some of these lenses contained Baratol, which contains barium and trinitrotoluene (TNT). In 1946, a pit was excavated to dispose large classified objects that could not be easily cut. The objects were buried to protect their classification. In 1947, another pit was excavated to dispose other classified material. Two large disturbed areas, which may be these two pits, are visible on 1954 aerial photographs. From 1949 through 1951, work orders were written for three smaller pits to be used for occasional disposal. The locations and contents of these pits are unknown. From 1950 to 1952, three shafts were drilled to dispose spark gaps containing small amounts of cesium-137. None of these disposals correlates with job and work orders in the archives. The three shafts are probably inside of a smaller fence at MDA F. The areas inside the fences at MDA F have been continually monitored for radioactivity since 1981 as part of the Los Alamos environmental surveillance program. No readings above background have been observed.

- RFI Phase I sampling was conducted in July 1994 in accordance with the RFI work plan for OU 1111 (LANL 1993, 26068).
- A voluntary corrective action (VCA) was implemented in August 1995 as described in the VCA completion report for PRS 06-007(f) (Environmental Restoration Project 1996, 54330). This site was restored by recontouring and reseeding with native grasses. A formal request for EPA concurrence to remove PRS 6-007(f) from the HSWA module was presented in the VCA report.

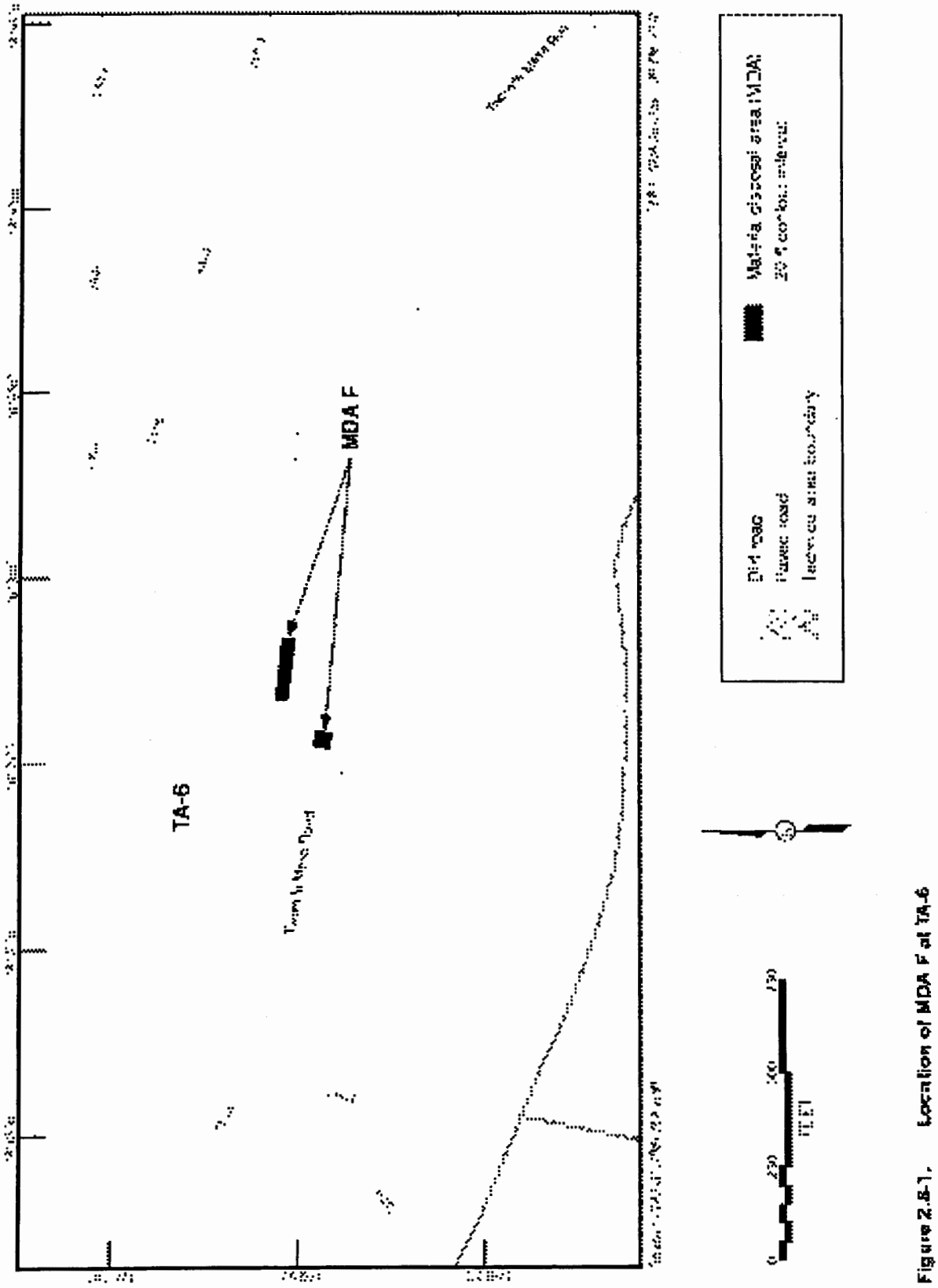

Figure C.9-1 Location of MDA F at TA-6

C.11. MDA Q AT TA-8

MDA Q is located at TA-8 west of Anchor Ranch Road and south of TA-8-21 (Dynamic Experimentation Division Office) in an area known as the TA-8 Gun-Firing site. Figure 2.10-1 shows the layout of MDA Q at TA-8.

MDA Q is a 0.2-acre (0.01-ha) site located at an elevation of 7600 ft (2280 m) on Pajarito Mesa within the Pajarito Canyon watershed. The depth to groundwater below MDA Q is approximately 1200 ft (360 m). The Gun-Firing Site consists of PRS 8-002, an experimental firing site for specially designed naval guns for developing the Little Boy weapon. Two concrete anchor pads for the gun mounts and two target sand butts still remain on the ground surface. A burial ground for the naval guns, called MDA Q, is listed as PRS 8-006(a) and 8-006(b). PRS 8-006(b) was originally thought to be a second waste MDA associated with the firing site, but has since been determined to be the same site as PRS 8-006(a). The Gun-Firing Site was active only during World War II, and the burial at MDA Q was conducted in 1946. MDA Q occupies an irregularly shaped rectangular area with dimensions of approximately 270 ft by 260 ft (81 m by 78 m). We believe that there has not been disposal at MDA Q since 1946.

The SWMUs at this MDA are listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities including radiological and geophysical surveys were conducted at MDA Q in November 1993.

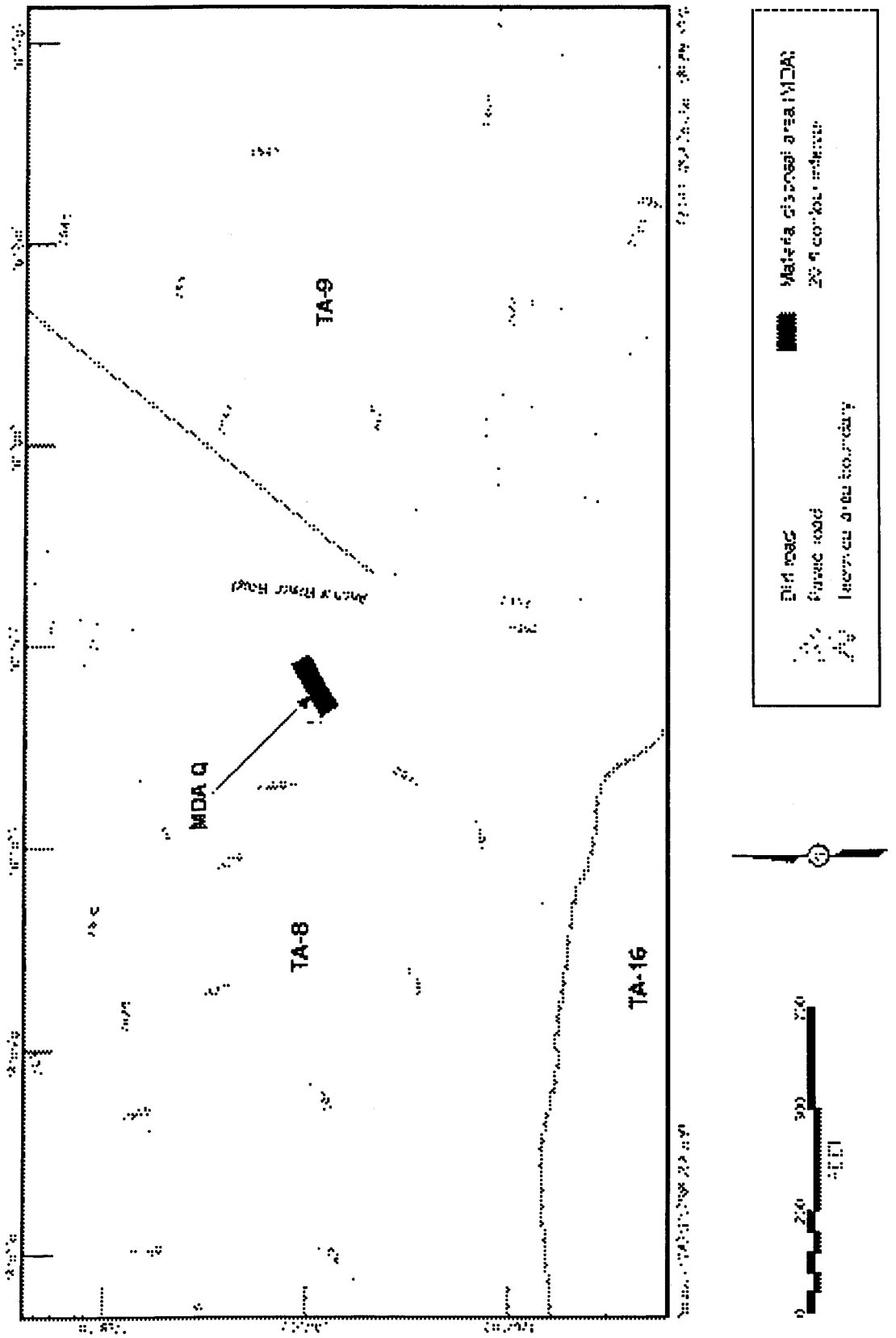

Figure C.11-1 Location of MDA Q at TA-8

C.12. MDA S AT TA-11

MDA S (PRS 11-009) is a fenced, active experimental plot at TA-11 measuring approximately 10 ft by 10 ft (3 m by 3 m) and located within the Water Canyon watershed. Figure 2.11-1 shows the layout of MDA S at TA-11. MDA S sits at an elevation of approximately 7300 ft (2190 m). The depth to groundwater below MDA S is approximately 1160 ft (348 m). The area is used to study the effect of soil and weather on the decomposition of explosives. The area, which slopes to the southwest, is well vegetated with grasses and weeds, locust shrubs, and two small ponderosa pines. The surrounding area is covered with ponderosa pines and no drainage intersects the site. Experiments to determine the persistence of explosives in soil near the drop tower complex at TA-11 (where the sensitivity of HE is studied) were initiated in March 1965. Some experiments are still active, having less than 80 g (0.18 lb.) of HE in their inventory.

The SWMU at this MDA is listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. No RFI activities have been completed at MDA S.

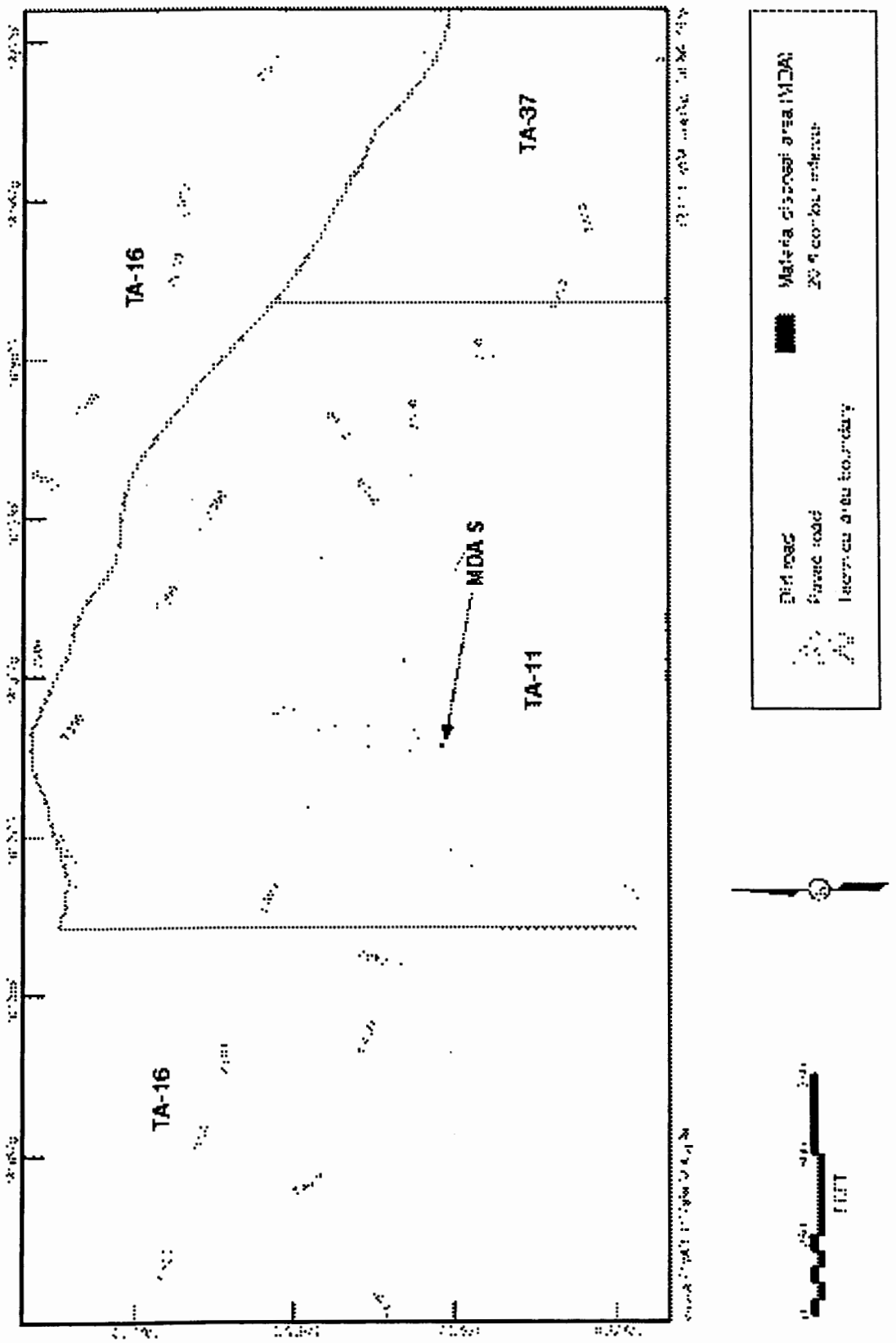

Figure C.12-1 Location of MDA S at TA-11

C.13. MDA Y AT TA-39

Figure 2.12-1 shows MDA Y [PRS 39-001(b)], which is located at an elevation of 6400 ft (1920 m) within Ancho Canyon. The depth to groundwater below MDA Y is approximately 590 ft (177 m).

Run-off from this site directly enters Ancho Canyon. MDA Y was one of several pits at TA-39 used for disposing waste consisting primarily of debris from firing site experiments, empty chemical containers, and office waste. MDA Y was the first disposal pit at TA-39 and was used from 1973 until approximately 1976, when pit 2 was put in use.

The SWMU at this MDA is listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. Activities completed at MDA Y are reported in these documents:

- "RFI Report for Potential Release Sites at TA-39 39-001(a, b) 39-004(a-e) 39-008" (Environmental Restoration Project 1997, 55633)
- "Request for Supplemental Information for RCRA Facility Investigation Report for Potential Release Sites at TA-39: 39-001(a&b), 39-004(a-e) and 39-008" (NMED 1997, 56705)
- "Extension Request for Resubmission of the TA-39 RFI Report for PRSs 39-001(a and b), 39-004(a-e), and 39-008" (LANL 1998, 59905)

C.14. MDA AA AT TA-36

MDA AA (PRS 36-001) is located at an elevation of approximately 6700 ft (2010 m) within Potrillo Canyon, which is located within the Water Canyon watershed. The depth to groundwater below MDA AA is approximately 770 ft (231 m). The first MDA AA trench was dug in mid-1960s to burn and dispose debris and sand from the firing sites. The exact number of trenches is unknown; however, information from two sources indicates that there are from two to four trenches (LANL 1990, 54733). Figure 2.13-1 shows the layout of MDA AA at TA-36.

The trenches provided safety and administrative controls for explosives and for materials possibly contaminated with explosives; they also reduced the volume of firing site debris. The last active trench on the south side of MDA AA was closed May 12, 1989 in accordance with New Mexico solid waste regulations. After the last trench was filled with burned debris and covered with clean soil, the entire MDA AA trench area was graded to lessen the potential of stormwater run-on and run-off that would erode the site and impact the Water Canyon watershed. Combustible firing site debris, such as wood, is still burned on the surface of a permitted burn area 100–300 ft (30–90 m) west of MDA. AA.

The SWMU at this MDA is listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA AA are reported in these documents:

- "RFI Report for Potential Release Sites at TA-36 36-001, 36-004(d) Skunk Works and Burn Pits, 36-006" (Environmental Restoration Project 1996, 54733)
- "Denial of RCRA Facility Investigation Report at TA-36 Potential Release Sites (PRSs) 36-001, 36-004(d), and 36-006 Dated June 21, 1996 LANL NM 0890010515" (NMED 1997, 56667)
- "Interim Action Completion Report for Potential Release Site at TA-36 36-001" (Environmental Restoration Project 1996, 54992)
- "Approval of Interim Action Completion Report for Potential Release Site at TA-36 36-001 MDA AA Dated July 1996 EPA #NM0890010515 (NMED 1997, 56305)
- "Request for Extension for Submittal of New/Revised RFI Report PRSs 36-001, 36-004(d), and 36-006 at TA-36" (Environmental Restoration Project 1998, 56927)
- "Extension Request for Phase II Sampling and Analysis Plan SAP Addressing Deficiencies in the TA-36 RFI Report for PRSs 36-001, 36-004(d), and 36-006 (Former OU 1130 FU 2)" (Environmental Restoration Project 1998, 59900)

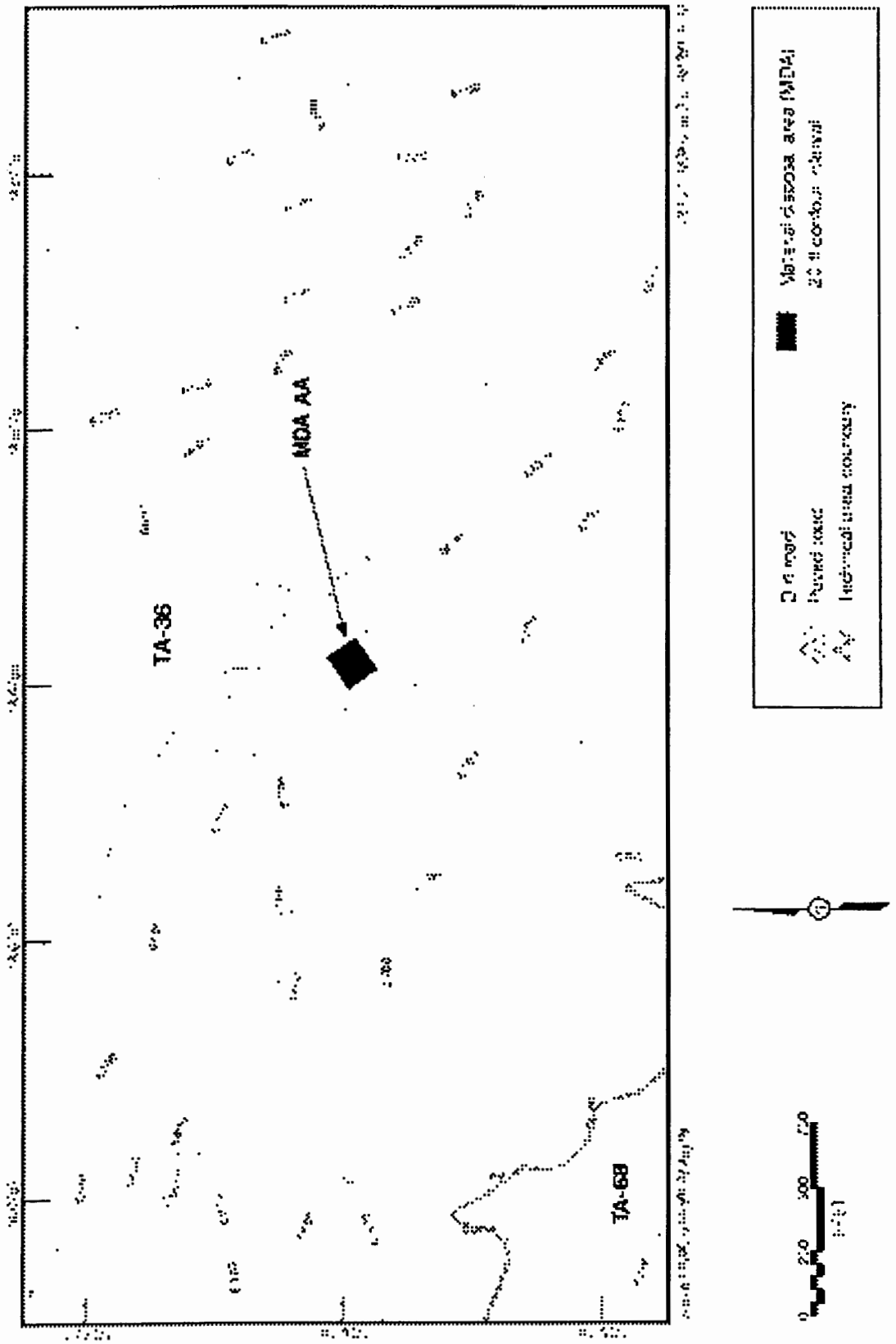

Figure 2.13-1. Location of MDA AA at TA-35

Figure C.14-1 Location of MDA AA at TA-35

C.15. MDA AB AT TA-49

MDA AB [PRS 49-001(a–g)] is located at an elevation of 7200 ft (2160 m) on Frijoles Mesa within the Ancho Canyon watershed. The depth to groundwater below MDA AB is approximately 1120 ft (336 m).

MDA AB was the location of the hydronuclear and related experiments performed from late 1959 to mid-1961 that deposited virtually all the contaminants that are expected at TA-49. MDA AB and TA-49 have had very few other uses. The experiments were conducted to assess safety of the storage and transportation of nuclear weapons components. The experiments were conducted in multiple shafts and chambers at depths between 60 ft and 80 ft (18 m to 24 m). The total volume of contaminated tuff has been estimated at about 1,000,000 ft^3 (30,000 m^3). The radiological inventory has been estimated as 0.2 Ci uranium-235 and 2,450 Ci plutonium-239, with some fission and activation products also likely to be present. Solid lead used as shielding as well as small amounts of beryllium are also contained in the experiment chambers. The experimental shafts were installed in four different areas in what are now, roughly, the corners of MDA AB. The areas were numbered 1 through 4 with Area 2 being subdivided into areas 2A and 2B. Figure 2.14-1 shows the layout of MDA AB at TA-49.

In 1961, the surface over the shafts in Area 2 was covered with a clay/gravel layer overlain with asphalt to stabilize residual surface contamination. This pavement was removed in 1999 as part of an interim measure (IM) of the RFI to protect the site from subsurface moisture which results from surface water ponding, run-on, and inhibited evapotranspiration. That IM was completed by installing a clean, crushed-tuff cap containing a wire-mesh layer to inhibit burrowing animals. It was covered with native grasses to promote transpiration of moisture and inhibit erosion, and gravel also to inhibit erosion.

The SWMUs at this MDA are listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities completed at MDA AB include the following:

- Phase I investigation was conducted in 1994 in accordance with the RFI work plan for OU 1144 (LANL 1992, 7670).
- A plan for stabilization activities was presented in the "Stabilization Plan for Implementing Interim Measures and Best Management Practices at Potential Release Sites 49-001(b, c, d, and g)" (Environmental Restoration Project 1998, 59166).
- The stabilization plan received an RSI (NMED 1998, 59899) and then a NOD on the response to the RSI (NMED 1998, 62663); responses were developed to both (Environmental Restoration Project 1998, 62040; Environmental Restoration Project 1998, 62813).
- Best management practices (BMPs) were performed at PRSs 49-001(b, c, d, and g) as described in the BMP completion report (Environmental Restoration Project 1999, 63041). Activities included construction and stabilization of a diversion channel; installation of a silt fence; down-gradient channel stabilization; removal of a power pole; and placement of straw bales in the up-gradient run-off channel.

Subsequent RFI activities at MDA AB will be developed in accordance with the methodology described in this document.

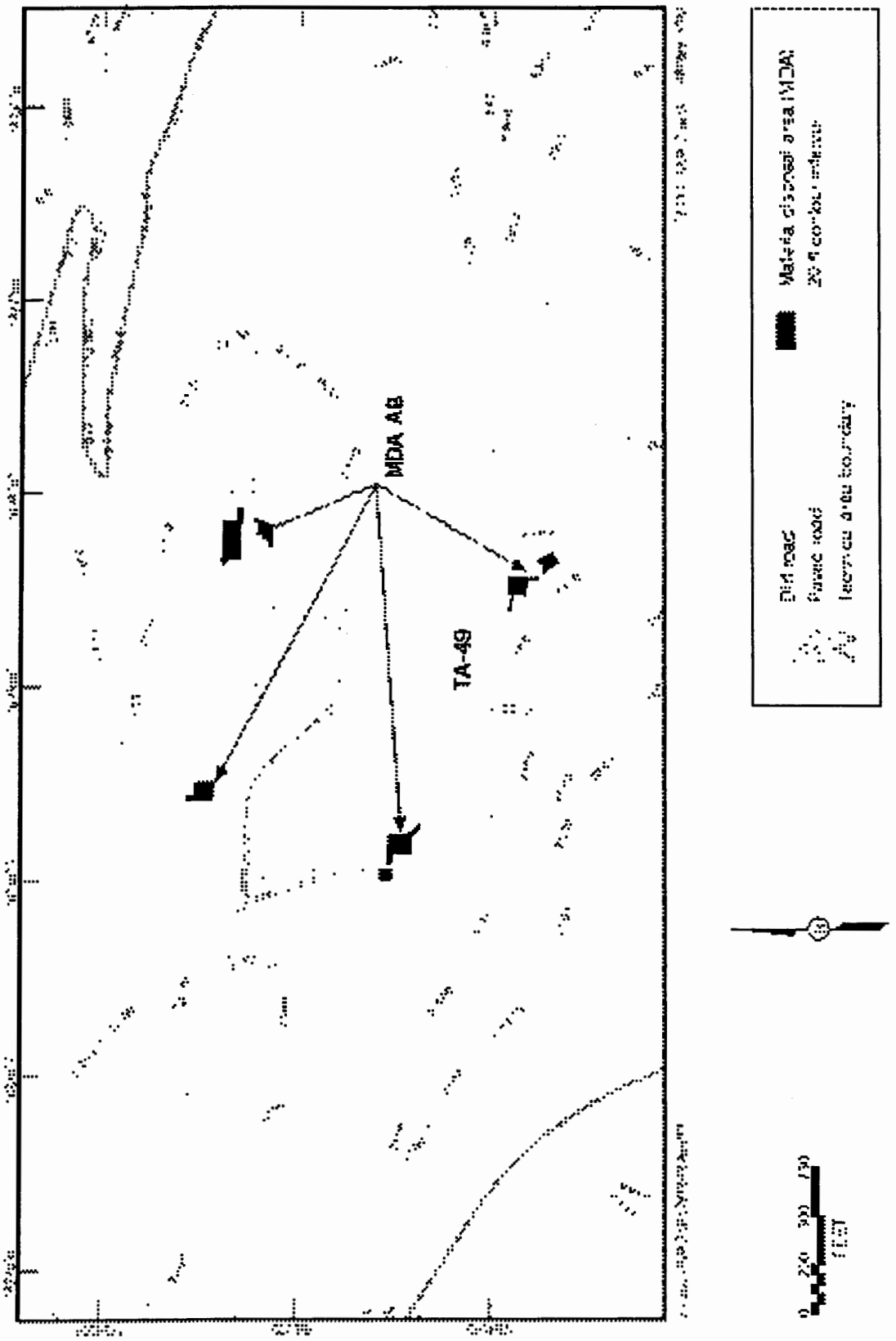

Figure 2.14-1. Location of MDA AB at TA-49

Figure C.15-1 Location of MDA AB at TA-49

APPENDIX D

FEP LIST AND DESCRIPTIONS

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

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TABLE OF CONTENTS

D.1. INTRODUCTION **1**
D.1.1. FEP Screening 1
D.1.2. Base-Case and Alternate Conceptual Models 2
D.2. MDA FEP LIST **4**
D.3. FEP DESCRIPTIONS **8**

List of Figures

Figure D-1 Generic Interaction Matrix for Candidate MDAs 3

List of Tables

Table D-1 Catalog of Features 5
Table D-2 Catalog of Events and processes 6
Table D-3 Feature Definitions 9
Table D-4 Event Definitions 10
Table D-5 Process Definitions 11

APPENDIX D

FEP LIST AND DESCRIPTIONS

D.1. INTRODUCTION

The documentation supporting the initial, comprehensive interaction matrix for mesa-top MDAs is given in this appendix. This matrix is thought to contain all feasible features, events and processes. The interaction matrix is presented in Figure D-1. Section D.2 provides documentation of the "features", "events", and "processes" (FEPs) included in the matrix: features are cataloged in Table D-1, and Table D-2 catalogs the complete list of events and processes. Section D.3 gives detailed descriptions of each feature (Table D-3), event (Table D-4), and process (Table D-5).

"Features" are the conditions of the system within the boundaries of the model (such as inventory and geology) as well as external conditions (such as climate) that may influence the system. "Events and processes" are influences that may induce changes in the system conditions. Events are sudden or episodic (such as drought or seismic events), while processes produce gradual and continuing changes (such as erosion or human land use). Events and processes that affect external features are not included in the FEP list, but may need to be considered to determine correlations between external influences.

Information used to construct the FEP list is obtained from ER Project reference documents (e.g., the installation work plan (IWP), RFI work plans and SAPs, environmental surveillance reports, biological assessments, threatened and endangered species habitat management plans, and the preliminary hydrogeologic atlas for Los Alamos National Laboratory [Environmental Restoration Project 1999, 64039]), generic FEP lists for geological waste repositories, from scientific publications, and subject matter expert elicitation.

The FEP list is divided at the highest level into natural FEPs, waste and repository FEPs, and human-induced FEPs. Additional subdivisions are introduced by technical discipline. Each entry in the FEP list is annotated with information useful in the development of the mathematical model and reference information. Detailed textual descriptions of each entry are also provided.

The list is not final, rather it is dynamic in the sense that it can be expanded with additional information obtained from scientific literature or subject matter expert elicitation to refine understanding of the FEPs and reduce uncertainties associated with the prediction of interactions over long assessment periods.

The FEP list for MDAs (presented in Appendix D) shows the organizational structure of the list at a high categorical level and presently considers FEPs applicable in the present day setting and over a long-term assessment (e.g., >10,000 years). Appendix E presents descriptions of FEPs based on present day understanding of concepts and theory; these descriptions may also be expanded and refined as additional supporting information is identified.

D.1.1. FEP Screening

Each entry in the comprehensive FEP list is labeled as to whether it is included or excluded from the conceptual model, and the reasons for the decision are documented. Valid reasons for exclusion include low probability, low consequence or regulatory exclusion. We use a hazard identification procedure to identify likely FEPs and unlikely FEPs that have a potential for significant consequences from the set of FEPs that are not excluded for regulatory reasons. These FEPs are "included" in the comprehensive conceptual model, the remaining FEPs are considered "excluded".

Alternatives are screened for probability based on modeling and expert elicitation. The probability of an alternate conceptual model with several unlikely FEPs is usually very low, except when the FEPs are strongly correlated. A hazard reduction analysis (Kessler, et al, 1998) is used to assist in the estimation of consequences. Alternatives are screened for consequence based on their potential for influencing protective systems with a high hazard reduction magnitude, described further in Chapter 5.

D.1.2. Base-Case and Alternate Conceptual Models

The base-case conceptual model consists of the list of likely FEPs and the associated textual descriptions, including the justification for exclusions and low probability ratings. An alternate conceptual model is similar to the base-case conceptual model, but also includes one or more FEP that is rated unlikely but having a potential for significant consequences. The relationships between the base-case and the alternate conceptual models are represented by a logic tree, described further in Chapter 5.

Note: It is planned that this comprehensive matrix will be refined, and reduced in size and complexity, by focusing it on FEPs that are important for long term risk evaluation. The matrix will be evaluated against existing data from MDAs, expert opinion, and process and systems modeling results to identify FEPs that can be eliminated, and those that must be kept. This process is not reflected in this appendix, which presents the full set of FEPs for the comprehensive matrix.

Figure D-1 Generic Interaction Matrix for Candidate MDAs

1.1 **Air**	1.2 Deposition Gas exchange Precipitation	1.3	1.4	1.5 Deposition Gas exchange Precipitation	1.6 Deposition Gas exchange Precipitation	1.7 Deposition Gas exchange Precipitation	1.8	1.9	1.10	1.11	1.12	1.13	1.14 Condensation Deposition Respiration Precipitation	1.15 Condensation Deposition Inhalation Precipitation
2.1 Entrainment Gas exchange	2.2 **Mesa Top Soil**	2.3 Subsidence	2.4	2.5 Mass wasting	2.6 Weathering Run-off Erosion Suspension Desorption Advection Diffusion	2.7 Weathering Run-off Erosion Suspension Desorption Advection Diffusion	2.8	2.9	2.10	2.11	2.12	2.13	2.14 Root uptake External contact	2.15 Ingestion External contact
3.1 Gas exchange	3.2 Gas exchange Erosion Excavation	3.3 Shallow (Mesa Top) **Vadose Zone**	3.4 Percolation Unsaturated flow Gas exchange	3.5 Mass wasting	3.6 Gas exchange Erosion	3.7 Gas exchange Erosion	3.8	3.9	3.10	3.11	3.12	3.13	3.14 Root uptake External contact	3.15 Ingestion External contact
4.1 Gas exchange	4.2	4.3 Capillary rise Adsorption Gas exchange	4.4 **Perched Groundwater Within Mesas**	4.5	4.6	4.7 Discharge Desorption Advection Diffusion Gas exchange	4.8 Discharge Infiltration Percolation Advection Diffusion Adsorption Gas exchange	4.9	4.10 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	4.11	4.12	4.13	4.14 Deep root uptake External contact	4.15
5.1 Entrainment Gas exchange	5.2	5.3	5.4	5.5 **Slope and Canyon Sediment and Soil**	5.6 Flooding Erosion Suspension Desorption Advection Diffusion	5.7 Erosion Suspension Desorption Advection Diffusion	5.8	5.9	5.10	5.11	5.12	5.13	5.14 Root uptake External contact	5.15 Ingestion External contact
6.1 Gas exchange	6.2 Infiltration Deposition Adsorption	6.3 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.4 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.5 Infiltration Deposition Adsorption	6.6 **Stormwater**	6.7 Mixing	6.8 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.9 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.10 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.11	6.12 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.13	6.14 Root uptake External contact	6.15 Ingestion External contact
7.1 Gas exchange	7.2 Infiltration Deposition Adsorption	7.3	7.4	7.5 Infiltration Deposition Adsorption	7.6 Mixing	7.7 **Surface Water**	7.8 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.9 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.10 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.11	7.12 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.13	7.14 Root uptake External contact	7.15 Ingestion External contact
8.1 Gas exchange	8.2	8.3	8.4	8.5 Gas exchange	8.6 Gas exchange Erosion	8.7 Gas exchange Erosion	8.8 **Alluvial Vadose Zone**	8.9 Percolation Unsaturated flow Gas exchange	8.10	8.11	8.12	8.13	8.14 Root uptake	8.15 Bioturbation Ingestion External contact
9.1 Gas exchange	9.2	9.3	9.4	9.5	9.6	9.7 Discharge Mixing Desorption Advection Diffusion Gas exchange	9.8 Capillary rise Adsorption Gas exchange	9.9 **Alluvial Groundwater**	9.10 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	9.11	9.12 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	9.13	9.14 Root uptake External contact	9.15
10.1 Gas exchange	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	10.10 **Intermediate Vadose Zone**	10.11 Percolation Unsaturated flow Gas exchange	10.12	10.13	10.14	10.15
11.1 Gas exchange	11.2	11.3	11.4	11.5	11.6	11.7 Desorption Advection Diffusion Gas exchange Discharge	11.8	11.9	11.10 Capillary rise Adsorption Gas exchange	11.11 **Intermediate Groundwater**	11.12 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	11.13	11.14	11.15
12.1 Gas exchange	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	12.10	12.11	12.12 **Deep (Regional) Vadose Zone**	12.13 Percolation Unsaturated flow Gas exchange	12.14	12.15
13.1 Gas exchange	13.2	13.3	13.4	13.5	13.6	13.7 Desorption Advection Diffusion Gas exchange Discharge	13.8	13.9	13.10	13.11	13.12 Capillary rise Adsorption Gas exchange	13.13 **Regional Groundwater**	13.14	13.15
14.1 Respiration Biomass	14.2 Biomass	14.3 Biomass	14.4	14.5 Biomass	14.6 Biomass	14.7 Biomass	14.8 Biomass	14.9	14.10 Biomass	14.11	14.12 Biomass	14.13	14.14 **Flora**	14.15 Ingestion External contact
15.1 Exhalation Biogas exchange	15.2 Bioturbation Biomass	15.3 Bioturbation Biomass	15.4	15.5 Bioturbation Biomass	15.6 Biomass	15.7 Bioturbation Biomass	15.8 Bioturbation Biomass	15.9	15.10 Bioturbation Biomass	15.11	15.12 Bioturbation Biomass	15.13	15.14 Biomass External contact	15.15 **Fauna**

Mesa-Top MDAs Implementation Plan

D.2. MDA FEP LIST

Table D-1 presents the full catalog of "features" included in the comprehensive mesa-top MDA interaction matrix. Table D-2 presents the catalog of "event" and "processes". Detailed descriptions of the FEPs are given in Section D.3.

Table D-1 Catalog of Features

1	FEATURES
1.1	**assessment context**
1.1.1	assessment purpose
1.1.1.1	protective remedy
1.1.1.2	risk-based compliance
1.1.2	assessment endpoints
1.1.2.1	compliance monitoring
1.1.2.2	receptor exposure
1.1.2.3	regulatory
1.1.3	repository type
1.1.3.1	mesa top buried disposal area
1.1.4	site context
1.1.4.1	pits
1.1.4.2	shafts
1.1.4.3	distance to mesa edge
1.1.4.4	configuration
1.1.4.4.1	area
1.1.4.4.2	depth
1.1.4.5	construction materials
1.1.4.6	cover design
1.1.4.6.1	slope
1.1.4.6.2	depth
1.1.4.6.3	area
1.1.4.6.4	materials
1.1.4.6.5	biotic barrier
1.2	**source term**
1.2.1	geosphere/biosphere interface
1.2.1.1	shallow vadose zone
1.2.2	release mechanism
1.2.2.1	container breach
1.2.2.2	pit/shaft breach
1.2.3	source term characteristics
1.2.3.1	solid
1.2.3.2	liquid
1.2.3.1	composition - LLW/MDA specific
1.3	**basic system description**
1.3.1	general climate description
1.3.1.1	present day climate conditions
1.3.2	general system description
1.3.2.1	present day environmental setting
1.3.2.1.1	stratigraphy/lithology
1.3.2.1.1.1	hydraulic properties
1.3.2.1.1.2	structure
1.3.2.1.2	water sources
1.3.2.1.2.1	surface water
1.3.2.1.2.2	stormwater
1.3.2.1.2.3	groundwater
1.3.3	general human society description
1.3.3.1	present day and foreseen institutional control

Table D-2 Catalog of Events and processes

2	**EVENTS AND PROCESSES**
2.1	**natural events and processes**
2.1.1	environmental evolution
2.1.1.1	environmental dynamics
2.1.1.1.1	rare events - varying time scales
2.1.1.1.1.1	seismicity
2.1.1.1.1.2	volcanism
2.1.1.1.1.3	fire
2.1.1.2	climate-driven changes - varying time scales
2.1.1.2.1	precipitation
2.1.1.2.2	winds
2.1.1.2.3	ecology
2.1.1.2.4	vegetative cover
2.1.1.2.5	lithologic unit/cap degradation
2.1.2	contaminant transport
2.1.2.1	atmospheric transport processes
2.1.2.1.1	entrainment
2.1.2.1.2	deposition
2.1.2.1.3	gas exchange
2.1.2.2	surface water aqueous transport processes
2.1.2.2.1	suspension
2.1.2.2.2	advection
2.1.2.2.3	deposition
2.1.2.3	porous media aqueous transport processes
2.1.2.3.1	advection
2.1.2.3.2	diffusion
2.1.2.3.3	adsorption
2.1.2.3.4	desorption
2.1.2.4	transport processes between surface waters and porous media
2.1.2.4.1	percolation
2.1.2.4.2	adsorption
2.1.2.4.3	desorption
2.1.2.5	solid phase transport
2.1.2.5.1	advection
2.1.2.6	vapor phase transport
2.1.2.6.1	gas exchange
2.1.2.6.2	diffusion
2.1.2.7	transport mediated by flora and fauna
2.1.2.7.1	biomass
2.1.2.7.2	bioturbation
2.1.3	processes affecting contaminant concentrations
2.1.3.1	chemical reactions
2.1.3.2	physical processes
2.1.4	contaminant metabolism
2.1.4.1	crops and flora
2.1.4.1.1	root uptake
2.1.4.1.2	external contact (rainsplash/deposition)
2.1.4.1.3	respiration
2.1.4.2	livestock and fauna
2.1.4.2.1	ingestion
2.1.4.2.2	external contact
2.2	**events and processes related to human activity**

2.2.1	chemical changes by human action
2.2.2	physical changes by human action
2.2.2.1	land use
2.2.3	contaminant transport mediated by human exposure
2.2.3.1	human intrusion - rare event
2.2.3.2	resource usage
2.3	**events and processes related to human exposure**
2.3.1	human habits
2.3.1.1	resource usage
2.3.1.2	air, water, and food processing
2.3.1.3	location and shielding factors
2.3.1.4	diet
2.3.2	external exposure processes
2.3.2.1	active controls
2.3.2.2	passive controls
2.3.3	monitoring

Table D-3 Feature Definitions

Features	Contextual Definition
Air	Refers to the earth's atmosphere as a medium for contaminant transport.
Mesa Top Soil	Includes naturally occurring soil and anthropogenically placed backfill materials present on mesa tops.
Slope and Canyon Sediment and Soil	Includes soils and sediments present on mesa slopes and canyon bottoms, both formed in-situ and derived from mesa tops.
Stormwater	Surface water flow derived from short, intense precipitation events. Stormwater flow has a significant influence on soil and sediment erosion and surface water transport.
Surface Water	Includes water in perennial and ephemeral stream reaches (both naturally occurring and effluent-driven), the Rio Grande, groundwater discharged via springs, semi-permanent and permanent wetlands (including those occurring as a function of alluvial groundwater intersecting the canyon floor), and unlined surface impoundments and ponds. May also include lined surface impoundments in which the integrity of the liner is unknown or suspect. Such impoundments capable of storing precipitation or effluent may allow leaching of contaminants remaining in residual sludge (if present) and infiltration into the subsurface.
Vadose Zone	Interval of unsaturated media located between the ground surface and locally present groundwater, or between saturated zones, whether the groundwater is present at shallow, intermediate, or regional aquifer depths.
	The shallow vadose zone represents approximately the upper 100' interval beneath mesa tops. This interval is represented as a disposal horizon and is subject to surface processes such as interactions with the atmosphere, mesa top and canyon slope soils and sediments, and biotic intrusion.
	The alluvial vadose zone is located within canyons represents the unsaturated interval between the ground surface and alluvial water.
	The intermediate vadose zone represents the unsaturated interval between the base of the shallow vadose zone and the top of the intermediate saturated zone, or the base of the alluvial saturated zone (if present) and the top of the intermediate saturated zone.
	The regional vadose zone represents the unsaturated interval between the base of the shallow vadose zone and the top of the regional saturated zone, or the base of an overlying saturated zone (alluvial or intermediate, if present) and the top of the regional saturated zone.
Perched Groundwater	Groundwater that lies above the regional water table and is separated from it by one or more unsaturated zones. Specifically, groundwater present within a mesa at an elevation above the adjacent canyon floor.
Alluvial Groundwater	Groundwater present in canyon alluvium or shallow paleochannels.
Intermediate Groundwater	Groundwater present at intermediate depths.
Regional Groundwater	Groundwater present in the regional zones of saturation, which typically occur in the Puye Formation, sediments of the Santa Fe Group, Cerros del Rio Basalts, and the Tschicoma Formation.

Table D-4 Event Definitions

Events	Concepts/Hypotheses
Rare events	Significant uncertainty is associated with estimating the probability, magnitude, and effects of the following events. These events may disrupt the present day environmental setting and result in potential significant impacts on processes affecting contaminant transport within varying areal and temporal scales.
Flooding	A 6-hour storm was modeled for all the major canyons within the canyon systems to support the determination of 100-year floodplain elevations for the watersheds that traverse Laboratory property and drain the Pajarito Plateau (McLin 1992, 12014). Parameter inputs (e.g., precipitation, surface runoff, and initial soil moisture content) were selected to represent a reasonable worst case scenario and thus present a conservative estimate of a 100-year flood event. (Draft 1-hr and 6-hr flood flow estimates were recalculated for 12 stations on/near LANL following the Cerro Grande Fire; these estimates are not final - LANL 2000, ER ID __). Post-Cerro Grande Fire floodplain maps indicate that no candidate MDAs lie within presently delineated floodplains derived from the revised flow estimates.
Fire	Fire effects may include vegetative denudation, increased erosion, decreased infiltration, ecological shift, and atmospheric contaminant release associated with incineration of buried disposal units.
Volcanism	A volcanic event producing flow or airfall deposits may "bury" a disposal unit or physically alter the unit if near the temperature gradient contact (e.g., vitrification). Volcanic deposits may significantly change the existing topography by filling the canyons and changing drainage patterns. Additional effects would be the same as for "fire", but likely at a significantly greater magnitude.
Seismicity	Seismic events of varying magnitudes may result in effects ranging from non-detectable to catastrophic. Seismic events may increase the number, frequency, or size of fractures in relevant stratigraphic units, increase the potential for mass wasting or cliff retreat, or directly expose buried waste.
Climate change	Climatic cycles will impact temperature, precipitation, wind patterns, and ecological shift (flora and fauna zones), which in turn impact the potential for erosion, infiltration, and biotic processes such as root uptake and bioturbation.
Human intrusion	Human activities (e.g., construction, agricultural, natural resource use) at a disposal site may alter the environmental setting which may impact the significance of processes and exposure pathways.

Table D-5 Process Definitions

Processes	Concepts/Hypotheses
Surface water and sediment transport pathways and mechanisms	
Surface contamination	Surface contamination may occur through direct contact with source term (i.e., a surface spill); contaminants tend to adsorb onto soil and sediment particles, which can be transported by surface water or gravitational processes and concentrated in depositional areas of a canyon system or dispersed by wind.
Precipitation	Precipitation is water that falls to the surface from the atmosphere as rain, snow, hail, or sleet. Precipitation will partition among evaporation, transpiration, infiltration, and runoff.
	The average annual precipitation on Los Alamos County varies from 13 in. at lower elevations to the east to 23 in. at higher elevations in the Sierra de los Valles (Bowen 1990, 6899).
	Approximately 50% of the precipitation on the Pajarito Plateau occurs during brief, intense thunderstorms in July and August, which can cause significant water runoff. The prevalence of short, intense storms is important to causing surface erosion and surface water transport, processes than move surface contaminants into and within the canyon systems, particularly during the summer months.
	Approximately 20% of the normal annual precipitation occurs as snowfall in December, January, and February; the remaining 30% is distributed throughout the other seven months of the year.
	The form, frequency, intensity, and evaporation potential of precipitation can strongly influence surface water runoff and infiltration within the canyons.
Mixing	Precipitation events may result in the co-mingling of stormwater with surface water.
	Stormwater may introduce suspended or dissolved contaminants to surface water bodies. Contaminants present in surface water may be redistributed via overflow during heavy precipitation events.
Runoff	Runoff is the portion of the precipitation on a drainage area that is discharged from the area either by sheet flow or adjacent stream channels (LANL 2000, 64356).
	Runoff is a function of soil and vegetation properties, precipitation intensity, and initial soil moisture content.
	Runoff is concentrated by natural topographic features and man-made diversions.
	Runoff and effluent discharge across potential release sites can mobilize contaminants and move them in either suspended or dissolved phases into the canyon stream or groundwater. Precipitation runoff and surface flow transport of contaminants associated with suspended particles or bed sediments will dominate the transport of radionuclides and metals. However, some radionuclide contamination, such as tritium and ^{90}Sr, can also be transported in solution.
	Runoff and effluent discharges have redistributed contaminants on both suspended and bedload sediments substantial distances downstream from their original sources.

Table D-5 Continued

Processes	Concepts/Hypotheses
Weathering	Weathering is the destructive process by which rocks are changed on exposure to atmospheric agents at or near the earth's surface, with little or no transport of the loosened or altered material; specifically the physical disintegration and chemical decomposition of rock that produce an in-situ mantle of waste and prepare sediments for transport (Bates and Jackson 1987, 50287).
	The climate in various canyon systems influences soil development and the transport of contaminants in surface and subsurface environments. A large variety of soils have developed on the Pajarito Plateau as the result of interactions of the underlying bedrock, slope, and climate.
	The mineral components of the soils are in large part derived from the Bandelier Tuff, but dacitic lavas of the Tschicoma Formations, basalts of the Cerros del Rio volcanic field, and sedimentary rocks of the Puye Formation are locally important, and additional material may be transported to the canyons from the mesa tops by wind. 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 (LANL 1995, 52009).
	South-facing canyon walls are steep and usually have little or no soil material or vegetation; the north-facing walls generally have areas of very shallow, dark-colored soils and are more heavily vegetated. The canyons floors generally contain poorly developed, deep, well-drained soils (Nyhan et al. 1978, 5702).
Deposition	Accumulation of sedimentary deposits within the canyon systems consist mainly of alluvium, colluvium, and landslide deposits.
	Contaminants tend to adsorb onto soil and sediment particles, which can be transported by surface flow and concentrated in depositional areas of the canyon system.
	Sediment transport segregates sediments by size, which might reconcentrate contaminants in low-energy depositional areas
	The deposition and storage of contaminated sediments generally increase downstream. Contaminants carried by floods can be dispersed over progressively wider areas of the canyon floor downstream, which results in relatively high contaminant inventories in some downstream locations. These deposits are potentially subject to remobilization.
	Contaminant concentrations vary with depositional setting and also with the age and type of sediment deposit (e.g., active channel versus floodplain deposit). Sediment deposits of similar age particle size, and depositional setting within a given canyon reach generally will have similar contaminant concentrations.
	Locally, contaminant concentrations at depth may be significantly higher than at the surface because of burial by younger and cleaner sediments.
Suspension	Suspension refers to the mobilization of contaminants by runoff and effluent discharge as either suspended or dissolved phases into the canyon stream or groundwater. Runoff and surface flow transport of contaminants associated with suspended particles or bed sediments will dominate the transport of radionuclides and metals.

Table D-5 Continued

Processes	Concepts/Hypotheses
	Contaminant transport in streams occurs predominantly be bedload and suspended sediment transport with lesser transport in the dissolved phase. Coarse-to medium-grained sand and gravel generally are transported as bedload. Fine sand, silt, and clay are transported as suspended load.
	Concentrations of contaminants in sediments generally decrease downstream because of dilution with clean sediments. Dilution will also tend to decrease contaminant concentrations over time if contaminant releases are stopped or reduced. However, higher concentrations may occur in fine-grained sediments where impoundment of surface flow allows the fine-grained suspended sediments to settle. In the absence of impoundments, the tendency is for the fine-grained sediment to be deposited farthest downstream and in other locations where surface flow decreases.
Flooding	Flooding is the inundation of the land surface by runoff resulting in surface water overtopping normal stream channel banks and the submergence of normally dry areas.
	The climate and topography in the region of the Laboratory are conducive to short-term, high-intensity storms and rapid associated runoff.
	Flooding extends the area of contaminant dispersal in the canyon floor away from the channel, especially as the canyon widens and the gradient decreases.
Discharge	The regional aquifer discharges into the Rio Grande through release of groundwater at the land surface at springs, seeps and at the river.
	Alluvial and intermediate groundwater is discharged through numerous perennial springs present in canyon reaches throughout Laboratory property. Springs discharge an estimated 4300 to 5000 acre-feet of water annually in White Rock Canyon.
Advection	Advection is the process by which solutes are transported by the motion of flowing groundwater (Fetter 1988, ER ID __).
Diffusion	Diffusion is the process by which ionic or molecular species dissolved in water move from areas of higher concentration to areas of lower concentration, tending to equalize concentrations in all parts of the system (Fetter 1988, ER ID __).
Erosion:	
Erosion	Erosion is the wearing away of soils and rock by weathering, mass wasting, and the action of streams, glaciers, wind, and underground water (Bates and Jackson 1987, 50287).
	Surface soil erosion and sediment transport are a function of precipitation runoff intensity and frequency, vegetative cover, topography, soil properties, and land use.
	Erosion within the canyons occurs by rockfall, landslides, and colluvial transport from the canyon walls; runoff into and within the canyons; water transport within the streams of the canyons; and wind transport.
	Sheet erosion gradually reduces the thickness of the cover at a more or less uniform rate across the mesa over extended periods of time (i.e., tens of thousands of years).
	The initiation of rills, runnels, or gullies, because of severe precipitation events, may result in much greater rates of soil removal on a local scale.

Table D-5 Continued

Processes	Concepts/Hypotheses
	Disturbance of the soil surface by vertebrates affects the rates of erosion processes.
	Vegetative cover affects erosion by both water and wind. Animal feeding behaviors affect vegetative cover.
Cliff retreat	Cliff retreat may result in the exposure of waste in MDA units located close to the edges of the canyons. Cliff retreat is a discrete process; estimates of long-term rates of cliff retreat suggest that waste may be exposed in 40,000 to 400,000 years from the present day.
Mass wasting	A general term for the downslope movement of soils and rock material under the direct influence of gravity. The debris is not carried within, on, or under another medium (Bates and Jackson 1987, 50287).
Bank collapse	Lateral bank erosion or bank collapse will be most active during large floods that may have return periods of years to decades in different canyon reaches.
Subsidence	Sinking or downward settling of the earth's surface, not restricted in rate, magnitude, or area involved (Bates and Jackson 1987, 50287).
Groundwater transport pathways and mechanisms	
Infiltration/Percolation	Infiltration is the entry of water into the ground. Percolation is the gravity flow of soil water through the pore spaces in soil or rock below the ground surface (LANL 2000, 64356).
	Precipitation runoff and discharges infiltrate the alluvium. Dissolved contaminants infiltrate more readily than contaminants that are adsorbed onto sediment particles. Nonsorbing species (for example, tritium and anionic species) migrate in solution virtually as fast as the water physically moves.
	The rates of infiltration into and percolation through tuff and the underlying units by unsaturated flow depend primarily on the unsaturated hydraulic properties of the rock units and the degree of saturation.
	Dissolved contaminants infiltrate alluvium more readily than contaminants adsorbed onto sediment particles.
Matrix flow (unsaturated flow)	Transport of normally insoluble or strongly sorbed contaminants in the unsaturated zone can occur by movement of colloidal-size suspended solids. Nonsorbing species (e.g., tritium or anionic species) migrate in solution.
	Steady-state liquid flow at depth can be very slow in unsaturated tuff and other bedrock units.
	The rate of contaminant migration through the unsaturated zone varies and may be retarded by mineral precipitation and sorption onto mineral grains in the bedrock units, especially the Bandelier Tuff.
Capillary rise (unsaturated flow)	Capillary rise is the movement of water from a saturated zone into unsaturated rock or soil as a result of surface tension. The magnitude of rise is a function of matrix grain size.
Fracture flow (unsaturated and saturated flow)	Joints and fractures in bedrock can provide additional pathways for relatively rapid infiltration, transient flow, and lateral transport in the subsurface.
	Fractures contribute to liquid flow and transport at moisture contents above some critical value. Below this value, flow in the rock matrix will predominate.
	Saturated fracture flow conditions have been observed in the Cerros del Rio basalts and in the upper units of the Bandelier Tuff.
Advection	Advection is the process by which solutes are transported by the motion of flowing groundwater (Fetter 1988, ER ID __).

Table D-5 Continued

Processes	Concepts/Hypotheses
Diffusion	Diffusion is the process by which ionic or molecular species dissolved in water move from areas of higher concentration to areas of lower concentration, tending to equalize concentrations in all parts of the system (Fetter 1988, ER ID __).
Contaminant/matrix interaction mechanisms	
Adsorption	Contaminant movement as dissolved species will be partly retarded by adsorption onto natural organic, clay, metal hydrous oxides, and other highly sorptive phases in solid porous media.
	Contaminants tend to adsorb onto soil and sediment particles, which can be transported by runoff and concentrated in depositional areas in the canyons.
Desorption	Sorbed contaminants may desorb and migrate in solution as dissolved species.
Atmospheric transport pathways and mechanisms	
Entrainment, dispersal, and deposition	Entrainment is limited to contaminants in surface sediments and soils.
	Entrainment, dispersal, and deposition are controlled by sediment properties, surface roughness, vegetative cover, terrain, moisture content, and other climatic factors.
	Entrainment, dispersal, and deposition are affected by wind speed, stability of the wind direction, and precipitation.
Gas exchange:	
Gas transfer	Gas transfer between the subsurface and the atmosphere provides the release mechanism for volatile contaminants.
	Gas transfer between the rock or soil and the atmosphere is a function of temperature and pressure gradients.
	Fractures can facilitate gas transfer between rock and the atmosphere.
	Atmospheric conditions affecting gas dispersal include wind speed, stability of the wind direction, and precipitation.
Barometric pumping/drying	Migration of water vapor has been observed in the Bandelier Tuff and is a function of an effective vapor or gas phase diffusion coefficient, the subsurface propagation of atmospheric pressure fluctuations (barometric pumping), and the permeability of the geologic unit, which is enhanced in fractured media.
Vapor transport	Vapor-phase transport is important only for tritium and volatile organic compounds.
	Vapor-phase transport is controlled primarily by the vapor pressure of the contaminant and the porosity permeability, moisture content, and moisture characteristic properties of the unsaturated medium (soil, sediment, or rock).
	Exchange of pore gas with the atmosphere (a significant mechanism for tritium release) is controlled by temperature gradients and atmospheric pressure variations.
	Fractures in bedrock can facilitate gas exchange between rock and the atmosphere. In certain environments water vapor exchange can be a significant component of overall water flux.
Evaporation	Contaminants may be converted from a liquid (e.g., surface water) to a gaseous state and released to the atmosphere through evaporation. Evaporation may also result in the concentration of contaminants in soil or sediment through the extraction of surface water to vapor.

Table D-5 Continued

Processes	Concepts/Hypotheses
Volatilization	The vapor pressure of a solute in solution determines the potential for the solute to be released to the atmosphere as vapor.
Aerosols formation (aerosolization)	Colloids consisting of liquid droplets (e.g., mist, haze, smoke, or fog) may be entrained and dispersed by air.
Condensation	Airborne contaminants may be concentrated and deposited on land surfaces by the reduction of a gas of vapor to a liquid or solid form.
Combustion	Combustion of contaminated media (including flora and fauna) may result in the release of airborne contaminants or surface/subsurface residues susceptible to leaching, erosion or entrainment.
Biologic transport and exposure pathways	
Root uptake	The ability of plants to absorb contaminants depends on soil and water chemistry, soil microflora activities, contaminant characteristics, climatic conditions, and the characteristics of individual plant species.
	Contaminants in the rooting zone can be assimilated into the roots and redistributed throughout plant tissues. The rooting zone can include alluvial groundwater.
	Flood events may cause the redistribution of contaminants in surface water, soil, and resuspended sediment to be more available to plants located away from the source area via root uptake.
Respiration	Contaminants previously taken up through the roots can be released with expelled water vapor through the process of respiration. A plant may draw in contaminants present in the air via stomates.
Inhalation / Exhalation	Animals can inhale and exhale contaminants absorbed to airborne particles.
External contact	Animals and plants may come into direct contact with contamination associated with certain types of source terms (e.g., surface spills or discharges).
	Animals can absorb contaminants through abraded or injured skin while bathing or swimming in contaminated water.
	Flood events may cause the redistribution of contaminants in surface water, soil, and resuspended sediment to be more available to plants located away from the source area via external contact.
Bioturbation	Burrowing invertebrates (such as earthworms) and vertebrates (such as pocket gophers) redistribute contaminants vertically and horizontally.
	Large, hoofed animals can alter the characteristics of the plant cover and the soil surface.
Ingestion	Animals can ingest contaminants by consuming water from streams or wells (e.g., stock tanks).
	Animals consume leaves, stems, and roots and plant products (such as nectar) and any contamination they contain; surficial contamination is the largest contribution. Predators ingest contaminants that are in or on their prey.
	Animals can ingest soil intentionally or incidentally while grooming.
	Animals can consume the flesh of contaminated animals that have moved away from contaminated areas.

Table D-5 Continued

Processes	Concepts/Hypotheses
	Behavior can decrease the degree of exposure to environmental contaminants because food or water might not be obtained from a single site, or behavior might cause animals to be exposed to multiple, antagonistic contaminants.
Biomass:	
Burning	Burning of plants may release contaminants to the atmosphere as airborne particles or gases and to the soil as residues. Combustion products of contaminated plants may be inhaled by humans or animals.
Biogas exchange	Animals may release contaminants to the atmosphere through the generation of gas accumulated in the intestinal tract.
Excretion	Animal behavior patterns and the elimination of feces and urine can disperse contaminants away from source areas.
Fertilization	Contaminants may be transferred from animals to plants through the enrichment of soil associated with animal excretion.
Decay	Contaminants present in decaying plant and animal matter may be re-introduced to surface soils in-situ, may be consumed by other animals, or may be redistributed in air, surface soils, or surface/storm water by surface transport processes.

APPENDIX E

RARE EVENTS

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

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TABLE OF CONTENTS

E.1. INTRODUCTION **2**

E.2. RARE EVENT IMPACT ON GENERIC MDA INTERACTION MATRIX **2**

List of Figures

Figure E-1. Generic MDA Interaction Matrix - Human Intrusion Scenario Assessment 4

Figure E-2. Generic MDA Interaction Matrix - Human Intrusion Scenario Model Components 7

List of Tables

Error! No table of figures entries found.

APPENDIX E

RARE EVENTS

E.1. INTRODUCTION

E.2. RARE EVENT IMPACT ON GENERIC MDA INTERACTION MATRIX

A rare event, either naturally occurring or resulting from human action, may alter the present day site setting and result in a preferential impact on certain processes and pathways.

An example scenario has been developed to illustrate this concept. The scenario selected is human intrusion based on the following simplified assumptions:

- Intrusion occurs as excavation into an MDA from the mesa top for the purpose of constructing a house. Excavation occurs into one waste pit; upon discovery of waste, excavation operations are ceased. The excavation is abandoned without being backfilled.
- The excavation is of unspecified area and depth. One drum is ruptured during the excavation and left in the pit. The excavated material (disposal unit cover and backfill) is piled on the surface adjacent to the excavation.
- Perched water is present within the mesa below the shallow vadose zone (i.e., at a depth >100 ft).
- The canyon systems bounding the mesa contain alluvial, intermediate, and regional zones of saturation.

Primary results of the scenario include:

- Introduction of contaminated media to the surface.
- Direct exposure of the excavated portion of the disposal unit to the atmosphere and biota.
- Breach of a drum that releases free liquid to the pit.

As the intrusion scenario directly impacts a buried disposal unit, the incident origin occurs on the interaction matrix (Figure F-1) in field 3.3 (Shallow Vadose Zone). The bolded fields on the interaction matrix illustrate the processes that are most likely to bear an important role in the redistribution of contaminants based on this scenario. The primary pathways of concern are related to surface interactions (erosion of excavated material onto the canyon slopes and into the canyons, entrainment, and transport mediated by flora and fauna) and transport vertically through the vadose zone (associated with increased exposure to precipitation coupled with the availability of additional free liquid from the breached drum).

Figure F-1 shows the assessment of relevant processes participating in this event. Figure F-1 presents a general illustration of primary interactions; additional refinement of key processes within a given field may be based on the specifics of a lithologic unit (e.g., hydraulic conductivity) or contaminant species behavior (e.g., sorbing tendency vs. mobility). Figure F-2 represents the

next progression as the non-participating processes are removed, and represents the outcome of the assessment and the final components of the model for the event.

Assessments will be performed for each type of rare event. For some rare events (e.g., seismicity), multiple assessments may be performed to evaluate potential change in process participation associated with earthquakes of varying magnitudes. As rare events may not occur in isolation, the cumulative effects of multiple events will be evaluated in a similar manner where appropriate.

The uncertainties affecting human intruder dose analyses include factors such as thickness and integrity of disposal unit covers, inventory uncertainty at the excavation location, and contaminant concentrations (e.g., relative radioactivity at the time of intrusion, allowing for decay). Analysis of human intruder dose is excluded from this illustration due to the simplicity of the scenario, however will be included in the model development of assessing the efficacy of remedy profiles.

Figure E-1. Generic MDA Interaction Matrix - Human Intrusion Scenario Assessment

1.1 **Air**	1.2 **Deposition** **Gas exchange** Precipitation	1.3	1.4	1.5 **Deposition** **Gas exchange** Precipitation	1.6 **Deposition** **Gas exchange** Precipitation	1.7 **Deposition** **Gas exchange** Precipitation	1.8	1.9	1.10	1.11	1.12	1.13	1.14 **Condensation** **Deposition** **Respiration** Precipitation	1.15 **Condensatio n** **Deposition** **Inhalation** Precipitation
2.1 **Entrainment** **Gas exchange**	2.2 **Mesa Top Soil**	2.3 Subsidence	2.4	2.5 **Mass wasting**	2.6 **Weathering** **Run-off** **Erosion** **Suspension** **Desorption** **Advection** **Diffusion**	2.7 **Weathering** **Run-off** **Erosion** **Suspension** **Desorption** **Advection** **Diffusion**	2.8	2.9	2.10	2.11	2.12	2.13	2.14 **Root uptake** **External contact**	2.15 **Ingestion** **External contact**
3.1 **Gas exchange**	3.2 **Gas exchange** **Erosion** **Excavation**	3.3 **Shallow (Mesa Top) Vadose Zone**	3.4 **Percolation** **Unsaturated flow** **Gas exchange**	3.5 Mass wasting	3.6 **Gas exchange** Erosion	3.7 Gas exchange Erosion	3.8	3.9	3.10	3.11	3.12	3.13	3.14 Root uptake External contact	3.15 Ingestion External contact
4.1 **Gas exchange**	4.2	4.3 Capillary rise Adsorption Gas exchange	4.4 **Perched Groundwater Within Mesas**	4.5	4.6	4.7 Discharge Desorption Advection Diffusion Gas exchange	4.8	4.9	4.10 **Percolation** **Unsaturated flow** **Saturated flow** **Advection** **Diffusion** **Adsorption** **Gas exchange**	4.11	4.12	4.13	4.14 Deep root uptake External contact	4.15
5.1 **Entrainment** **Gas exchange**	5.2	5.3	5.4	5.5 **Slope and Canyon Sediment and Soil**	5.6 **Flooding** **Erosion** **Suspension** **Desorption** **Advection** **Diffusion**	5.7 **Erosion** **Suspension** **Desorption** **Advection** **Diffusion**	5.8	5.9	5.10	5.11	5.12	5.13	5.14 **Root uptake** **External contact**	5.15 **Ingestion** **External contact**
6.1 **Gas exchange**	6.2 Infiltration Deposition Adsorption	6.3 **Infiltration** **Percolation** **Advection** **Diffusion** **Adsorption** **Gas exchange**	6.4 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.5 **Infiltration** **Deposition** **Adsorption**	6.6 **Stormwater**	6.7 **Mixing**	6.8 **Infiltration** **Percolation** **Advection** **Diffusion** **Adsorption** **Gas exchange**	6.9	6.10 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.11	6.12 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.13	6.14 **Root uptake** **External contact**	6.15 **Ingestion** **External contact**
7.1 **Gas exchange**	7.2 Infiltration Deposition Adsorption	7.3	7.4	7.5 Infiltration Deposition Adsorption	7.6 Mixing	7.7 **Surface Water**	7.8 **Infiltration** **Percolation** **Advection** **Diffusion** **Adsorption** **Gas exchange**	7.9 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.10 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.11	7.12 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.13	7.14 **Root uptake** **External contact**	7.15 **Ingestion** **External contact**

8.1 **Gas exchange**	8.2	8.3	8.4	8.5 **Gas exchange**	8.6 **Gas exchange** **Erosion**	8.7 **Gas exchange** **Erosion**	8.8 **Alluvial Vadose Zone**	8.9 Percolation Unsaturated flow Gas exchange	8.10	8.11	8.12	8.13	8.14 **Root uptake**	8.15 **Bioturbation** **Ingestion** **External contact**
9.1 **Gas exchange**	9.2	9.3	9.4	9.5	9.6	9.7 **Discharge** **Mixing** **Desorption** **Advection** **Diffusion** **Gas exchange**	9.8 Capillary rise Adsorption Gas exchange	9.9 **Alluvial Groundwater**	9.10 **Percolation** **Unsaturated flow** **Saturated flow** **Advection** **Diffusion** **Adsorption** **Gas exchange**	9.11	9.12 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	9.13	9.14 **Root uptake** **External contact**	9.15
10.1 Gas exchange	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	10.10 **Intermediate Vadose Zone**	10.11 **Percolation** **Unsaturated flow** **Gas exchange**	10.12	10.13	10.14	10.15
11.1 Gas exchange	11.2	11.3	11.4	11.5	11.6	11.7 **Desorption** **Advection** **Diffusion** **Gas exchange** **Discharge**	11.8	11.9	11.10 Capillary rise Adsorption Gas exchange	11.11 **Intermediate Groundwater**	11.12 **Percolation** **Unsaturated flow** **Saturated flow** **Advection** **Diffusion** **Adsorption** **Gas exchange**	11.13	11.14	11.15
12.1 Gas exchange	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	12.10	12.11	12.12 **Deep (Regional) Vadose Zone**	12.13 **Percolation** **Unsaturated flow** **Gas exchange**	12.14	12.15
13.1 Gas exchange	13.2	13.3	13.4	13.5	13.6	13.7 **Desorption** **Advection** **Diffusion** **Gas exchange** **Discharge**	13.8	13.9	13.10	13.11	13.12 Capillary rise Adsorption Gas exchange	13.13 **Regional Groundwater**	13.14	13.15
14.1 **Respiration** **Biomass**	14.2 **Biomass**	14.3 **Biomass**	14.4	14.5 **Biomass**	14.6 **Biomass**	14.7 **Biomass**	14.8 **Biomass**	14.9	14.10 **Biomass**	14.11	14.12	14.13	14.14 **Flora**	14.15 **Ingestion** **External contact**
15.1 **Exhalation** **Biogas exchange**	15.2 **Bioturbation** **Biomass**	15.3 **Bioturbation** **Biomass**	15.4	15.5 **Bioturbation** **Biomass**	15.6 **Biomass**	15.7 **Bioturbation** **Biomass**	15.8 **Bioturbation** **Biomass**	15.9	15.10 **Bioturbation** **Biomass**	15.11	15.12	15.13	15.14 **Biomass** **External contact**	15.15 **Fauna**

Figure E-2. Generic MDA Interaction Matrix - Human Intrusion Scenario Model Components

1.1 Air	1.2 Deposition Gas exchange	1.3	1.4	1.5 Deposition Gas exchange	1.6 Deposition Gas exchange	1.7 Deposition Gas exchange	1.8	1.9	1.10	1.11	1.12	1.13	1.14 Condensation Deposition Respiration	1.15 Condensatio n Deposition Inhalation
2.1 Entrainment Gas exchange	2.2 Mesa Top Soil	2.3	2.4	2.5 Mass wasting	2.6 Weathering Run-off Erosion Suspension Desorption Advection Diffusion	2.7 Weathering Run-off Erosion Suspension Desorption Advection Diffusion	2.8	2.9	2.10	2.11	2.12	2.13	2.14 Root uptake External contact	2.15 Ingestion External contact
3.1 Gas exchange	3.2 Gas exchange Erosion Excavation	3.3 Shallow (Mesa Top) Vadose Zone	3.4 Percolation Unsaturated flow Gas exchange	3.5	3.6 Gas exchange	3.7	3.8	3.9	3.10	3.11	3.12	3.13	3.14	3.15
4.1 Gas exchange	4.2	4.3	4.4 Perched Groundwater Within Mesas	4.5	4.6	4.7	4.8	4.9	4.10 Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange	4.11	4.12	4.13	4.14	4.15
5.1 Entrainment Gas exchange	5.2	5.3	5.4	5.5 Slope and Canyon Sediment and Soil	5.6 Flooding Erosion Suspension Desorption Advection Diffusion	5.7 Erosion Suspension Desorption Advection Diffusion	5.8	5.9	5.10	5.11	5.12	5.13	5.14 Root uptake External contact	5.15 Ingestion External contact
6.1 Gas exchange	6.2	6.3 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.4	6.5 Infiltration Deposition Adsorption	6.6 Stormwater	6.7 Mixing	6.8 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	6.9	6.10	6.11	6.12	6.13	6.14 Root uptake External contact	6.15 Ingestion External contact
7.1 Gas exchange	7.2	7.3	7.4	7.5	7.6	7.7 Surface Water	7.8 Infiltration Percolation Advection Diffusion Adsorption Gas exchange	7.9	7.10	7.11	7.12	7.13	7.14 Root uptake External contact	7.15 Ingestion External contact
8.1 Gas exchange	8.2	8.3	8.4	8.5 Gas exchange	8.6 Gas exchange Erosion	8.7 Gas exchange Erosion	8.8 Alluvial Vadose Zone	8.9	8.10	8.11	8.12	8.13	8.14 Root uptake	8.15 Bioturbation Ingestion External

														contact
9.1 **Gas exchange**	9.2	9.3	9.4	9.5	9.6	9.7 **Discharge Mixing Desorption Advection Diffusion Gas exchange**	9.8	9.9 **Alluvial Groundwater**	9.10 **Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange**	9.11	9.12	9.13	9.14 **Root uptake External contact**	9.15
10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	10.10 **Intermediate Vadose Zone**	10.11 **Percolation Unsaturated flow Gas exchange**	10.12	10.13	10.14	10.15
11.1	11.2	11.3	11.4	11.5	11.6	11.7 **Desorption Advection Diffusion Gas exchange Discharge**	11.8	11.9	11.10	11.11 **Intermediate Groundwater**	11.12 **Percolation Unsaturated flow Saturated flow Advection Diffusion Adsorption Gas exchange**	11.13	11.14	11.15
12.1	12.2	12.3	12.4	12.5	12.6	12.7	12.8	12.9	12.10	12.11	12.12 **Deep (Regional) Vadose Zone**	12.13 **Percolation Unsaturated flow Gas exchange**	12.14	12.15
13.1	13.2	13.3	13.4	13.5	13.6	13.7 **Desorption Advection Diffusion Gas exchange Discharge**	13.8	13.9	13.10	13.11	13.12	13.13 **Regional Groundwater**	13.14	13.15
14.1 **Respiration Biomass**	14.2 **Biomass**	14.3 **Biomass**	14.4	14.5 **Biomass**	14.6 **Biomass**	14.7 **Biomass**	14.8 **Biomass**	14.9	14.10 **Biomass**	14.11	14.12	14.13	14.14 **Flora**	14.15 **Ingestion External contact**
15.1 **Exhalation Biogas exchange**	15.2 **Bioturbation Biomass**	15.3 **Bioturbation Biomass**	15.4	15.5 **Bioturbation Biomass**	15.6 **Biomass**	15.7 **Bioturbation Biomass**	15.8 **Bioturbation Biomass**	15.9	15.10 **Bioturbation Biomass**	15.11	15.12	15.13	15.14 **Biomass External contact**	15.15 **Fauna**

NEEDS TO BE PREPARED FROM MEETING NOTES, AND TO UPDATED FOLLOWING SECOND SESSION

APPENDIX F

EXPERT ELICITATION

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

8/27/00 1:32 PM

APPENDIX F

EXPERT ELICITATION

F.1. INTRODUCTION

F.1.1. Background

F.1.2. Purpose and Scope

F.2. UNDERLYING CONCEPTS

F.2.1. Organization of Document

APPENDIX G

SPECIAL STUDIES RELATED TO MDA PERFORMANCE

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

8/27/00 1:27 PM

TABLE OF CONTENTS

G.1. INTRODUCTION **2**

G.2. SPECIAL STUDIES RELATED TO MDA PERFORMANCE **2**

G.2.1. Contaminant Transport 2

G.2.1.1. Radionuclide Transport beneath Pits at MDA G 2

G.2.1.2. Tritium Transport around Disposal Shafts at MDA G 3

G.2.1.3. VOC Transport at MDA L and MDA G 3

G.2.1.4. Plutonium Migration from MDA T 4

G.2.1.5. Summary of the Results of Contaminant Transport Investigations 7

G.2.2. Vadose Zone Hydrologic Characterization 7

G.2.2.1. Injection Well Tests 7

G.2.2.2. Natural Tracer Analyses 8

G.2.2.3. MDA G In Situ Moisture Monitoring 10

G.2.3. Surface Processes and Cap Performance 11

G.3. REFERENCES FOR APPENDIX G **17**

List of Figures

Figure G.2-1 Representative unsaturated hydraulic conductivity curves for the upper subunits of the Bandelier Tuff comprising the vadose zone beneath mesas 12

List of Tables

Table G.2-1 Frequency of Core Samples from Horizontal Boreholes beneath Pits 36 & 37 at MDA G 3

APPENDIX G

SPECIAL STUDIES RELATED TO MDA PERFORMANCE

G.1. INTRODUCTION

The ability of material disposal areas (MDAs) to contain near-subsurface contaminants for long periods of time depends upon interrelated surface and subsurface processes. To model MDAs as a system and to predict how contaminants might be released from (or can be contained within) MDAs over long periods of time depends upon our understanding of these processes. This section discusses (in G.2.1 through G.2.3) several historical field experiments performed to characterize surface and subsurface processes under disturbed conditions (i.e., in the presence of MDAs) that are relevant to the performance of MDAs. Many, but not all, of the field experiments summarized below were performed at Technical Area (TA) 54 (on Mesita del Buey), where MDA G is located. Some were performed directly in support of the development of the MDA G performance assessment (PA) model (LANL 1997, 63131). Nonetheless, all of the information is important to consider in developing a general preliminary conceptual model for MDAs at the Laboratory.

G.2. SPECIAL STUDIES RELATED TO MDA PERFORMANCE

G.2.1. Contaminant Transport

Several investigations have been performed to assess the presence of contaminants in the vicinity of disposal units at several MDAs. These investigations have involved the installation of vertical, horizontal, and angled boreholes, and the sampling of borehole core and pore gas to characterize the nature and extent of contaminants associated with MDAs, including volatile organic compounds (VOCs), semivolatile organic compounds, dissolved, or sorbed organic and inorganic compounds, other hazardous chemicals, and radiological constituents. This section describes the historical investigations and presents a summary of the results of the investigations as they relate to understanding contaminant transport associated with MDAs.

G.2.1.1. Radionuclide Transport beneath Pits at MDA G

In 1976 core samples were collected from five horizontal boreholes drilled beneath Pit 1 at MDA G from Pajarito Canyon into the Tshirege Member of the Bandelier Tuff. Pit 1 at MDA G was capped in 1966. The core samples were analyzed for tritium, strontium-90, cesium-137, plutonium-238, plutonium-239/240, and americium-241. The results of the analyses showed that tritium was measured above detection limits but no other radionuclides were detected above detection limits (Purtymun 1978, 5728).

In 1995, three sub-horizontal boreholes were drilled from the floor of the newly-excavated Pit 38 into the subsurface just beneath previously-filled Pits 36 and 37 (Puglisi and Vold 1995, 63894). Core samples were retrieved from the boreholes at the intervals shown in Table G.2.1-1. They were analyzed for radiological and hazardous contaminants, moisture content, matric potential, and geotechnical properties.

The results of the analyses showed that vapor-phase tritium and ethyl acetate were detected in the samples, tritium at levels slightly above background, and ethyl acetate slightly above detection limits. No inorganic contaminants were detected.

Table G.2-1 Frequency of Core Samples from Horizontal Boreholes beneath Pits 36 & 37 at MDA G

Borehole	Sample Interval	Total Samples
1	2 ft	35
2	2 ft	42
3	5 ft	31

G.2.1.2. Tritium Transport around Disposal Shafts at MDA G

In 1970, an investigation into the movement of tritium in the subsurface at MDA G was undertaken (Purtymun 1973, 4975). Fourteen test boreholes were drilled in the vicinity of the disposal shafts to investigate the movement of tritium through the tuff units. The boreholes were 50-ft (15 m) deep and were spaced within about 100 ft (30 m) of the tritium disposal shafts. As a result of drilling the test boreholes, it was determined that infiltration of natural moisture from the surface had penetrated to a depth of about 10 ft (3.5 m). The moisture content in the upper 10-ft (3.5-m) interval varied from 3 to 8% by weight, whereas the moisture content of the tuff from 10 to 50 ft (3.5 to 15 m) varied from 0.4 to about 3% by weight. The movement of tritium in the drier zone at depth was primarily by diffusion in the vapor phase.

The results of the investigation into the movement of tritium in the subsurface showed that the major movement of tritium took place along fractures in the tuff and along a contact zone between two tuff ash-flow units. Tritium also moved through the ash-flow tuff matrix but at a reduced rate. The surge-bed contact between ash-flow units contained higher porosity and permeability due to the presence of abundant pumice fragments and reworked tuff fragments along the contact line. The tritiated moisture preferentially migrated along the contact zone, which served as a source for secondary movement of the tritiated moisture into the upper and lower ash-flow units along the contact zone. Because the ash flow contact zone provides increased lateral (sub-horizontal) movement of the tritiated moisture, the contact zone effectively slowed the vertical migration of tritiated moisture deeper into the subsurface (Purtymun 1973, 4975).

Around the disposal shafts at MDA G, the tritiated moisture in the tuff assumed the shape of an irregular lens, elongated along the ash-flow unit contact zone. Because the tritium was generally at depths greater than 10 ft (3.5 m), which is the extent of penetration of natural surface moisture, there was virtually no moisture available in the tuff units at depth to further mobilize the tritiated moisture into deeper units. This investigation suggests that tritiated moisture migrated through the ash-flow tuff units to the surface where evaporation from the soil and transpiration from plants released the tritium to the atmosphere (Purtymun 1973, 4975).

G.2.1.3. VOC Transport at MDA L and MDA G

Site characterization investigations performed at TA-54 by the Environmental Surveillance Group (now ESH-18) beginning in 1985 and later by the Environmental Restoration (ER) Project revealed a vapor plume of VOCs beneath MDA L (Kearl et al 1986, 8414; Kearl 1986, 15368; Purtymun 1995, 45344, p. 185). Since discovery of the vapor plume, the site has been monitored on a quarterly basis (NMEID 1989, 11737). The major constituent of the MDA L subsurface vapor plume is 1,1,1-trichloroethane (TCA). The source of the plume is a series of vertical shafts, where containerized and non-containerized chemical wastes were disposed. Quarterly monitoring involves analyzing samples of pore gas collected from 29 boreholes, each of which contains several sampling ports at different depths. Monitoring results show that the maximum TCA concentration occurs at depths between 120 ft and 200 ft (36 m to 60 m). Recent sampling during 1998 showed that TCA vapor is not present at depths greater than 380 ft

(115 m). Estimates of contaminant volume based on the results of analyzing pore gas samples suggest that the plume contains less than 1000 kg (454 lb.) of organic vapors. Analysis of more than 170 core samples obtained from drilling 18 boreholes within and around MDA L indicated that the rock matrix does not contain liquid or sorbed VOCs.

The subsurface vapor plume behaves as though it came from one or more original releases at MDA L, with little or no release of contaminants continuing at present. The concentration of organic vapors is a maximum beneath MDA L and decreases to nearly zero 500 ft (156 m) from the site. Since 1991, the maximum concentration of organic vapors has decreased while the edges of the vapor plume have expanded slowly. The total contaminant inventory of the vapor plume is decreasing as the VOCs biodegrade and diffuse to the atmosphere.

The characteristics of the MDA L TCA vapor plume (e.g., low and decreasing contaminant concentrations, slow diffusion rates) do not indicate a need for remediation. However, the presence of open boreholes provided an opportunity to investigate passive and active plume extraction methods. The results of the existing studies indicate that the natural (passive) flow of air through the Bandelier Tuff is sufficient to attenuate the TCA vapor plume.

G.2.1.4. Plutonium Migration from MDA T

Multiple investigations into the subsurface radionuclide movement beneath MDA T have been conducted from 1953 to the 1990s. A description of the investigations is presented in the work plan for TA-21 (LANL 1991, 7529) and a summary of the investigations is provided below.

In 1953 five boreholes were drilled in the vicinity of the absorption beds to depths ranging from 13 to 20 ft (1.7 to 6 m). Two of the boreholes were drilled between the absorption beds, one of the boreholes was a slant borehole into absorption bed no. 1, and two of the boreholes were drilled into absorption beds nos. 1 and 2. The tuff between absorption beds did not contain plutonium concentrations greater than 2 pCi/g but the surface soil between beds 1 and 3 contained 32 pCi/g plutonium and 4 pCi/g at a depth of 1 ft. The slant borehole drilled into bed no. 1 contained 15 pCi/g at the surface and the intervening tuff between the surface and absorption bed contained 1 to 4 pCi/g plutonium; when the borehole intersected the absorption bed, plutonium concentrations within the bed were 205 pCi/g to 686 pCi/g. Samples from the borehole drilled vertically into absorption bed no. 1 contained the highest concentrations of plutonium, where from 2- to 3-ft-depth (0.6- to 0.9-m), up to 20,730 pCi/g was present. Concentrations of plutonium in absorption bed no. 1 decreased with depth to less than 11 pCi/g from 18-to 20-ft-depth. The subsurface samples from the borehole drilled into absorption bed no. 2 contained significantly lower plutonium concentrations, which were a maximum of 1550 pCi/g at a depth of 4 ft. At the bottom of this borehole (15-ft-depth), the samples contained 1090 pCi/g plutonium (LANL 1991, 7529).

In 1959 a caisson was constructed adjacent to the northeast corner of absorption bed no. 1 to investigate the distribution of subsurface plutonium associated with the absorption bed. The caisson was 30 ft (9 m) deep, 6 ft (2 m) wide, and 12 ft (4 m) long. Horizontal holes were constructed from the caisson into the center of the absorption bed and instrumented for the measurement of moisture content and gross alpha activity. The highest alpha activity was coincident with the highest moisture content, which was at a depth of 12 to 14 ft (3.6 to 4.3 m) where up to 2094 counts per minute (cpm) per dry gram of material were measured. At the 28-ft (8.5 m) depth near the bottom of the caisson, boreholes into the absorption bed measured a maximum of 156 cpm per dry gram of material. The results of the investigation indicated that alpha activity (plutonium) had moved into the tuff (LANL 1991, 7529).

In 1960 an investigation into the characteristics of infiltration of water into absorption bed no. 1 was initiated. Raw wastewater containing radionuclides from TA-21 was discharged to the absorption bed for

26 days in July 1960 at an approximate rate of 8000 gpd (30.3 m^3/d), for a total volume of approximately 200,000 gal. (760 m^3). For 38 days in August and September 1960, tap water was discharged to the absorption bed at an approximate rate of 6500 gpd (24.6 m^3/d) for a total volume of about 250,000 gal. (950 m^3) of water. After the wastewater and the tap water was discharged to the absorption bed, six boreholes were drilled around the periphery of the absorption bed to study the distribution of moisture in the subsurface. The boreholes ranged in depths from 76 to 99 ft (23 to 30 m). Cuttings samples collected from the boreholes were measured for alpha activity; the highest alpha activity was from depths of 30 to 45 ft (9 to 17 m) in a borehole drilled at an angle through the absorption bed. The boreholes were cased with PVC pipe and installed as moisture access tubes to measure the amount of moisture in the absorption bed and in the surrounding tuff (LANL 1991, 7529).

In 1961 the infiltration investigation at absorption bed no. 1 at MDA T continued. For 33 days from June to August 1961, raw radioactive liquid wastes were discharged to the absorption bed at a rate of 6400 gpd (24.2 m^3/d), for a total volume of approximately 210,000 gal. (800 m^3). Similar to the infiltration tests performed in 1960, the discharge of wastewater was followed by a continuous discharge of tap water to the absorption bed for 25 days at a rate of 7100 gpd (26.9 m^3/d) for a total volume of about 177,500 gal. (672 m^3) of tap water. The moisture distribution in the absorption bed and in the tuff around the absorption bed was monitored using the six moisture access tubes that were installed in 1960 around the absorption bed. In 1961, moisture profiles of the moisture access tubes were obtained in March, April, June, July (twice), and August (twice), which provided time-series moisture profiles about the absorption bed and the surrounding tuff.

The results of the investigation showed that the moisture content in the tuff in three holes around the central and western end of the absorption bed increased slightly from about 10 to 30 ft (3 to 9 m) depth and also from depths of 45 to 50 ft (14 to 15 m). Analysis of six time-series moisture profiles of these three holes indicated that the absorption bed had a high infiltration capacity and that significant amounts of water did not move laterally to the south, west, or north from the absorption bed into the tuff. However, three other boreholes at the northeastern side of the absorption bed contained variable moisture curves through time. A hole at the northeast corner of the absorption bed that extended at an angle beneath the eastern end of the bed showed a relatively brief time interval of increased moisture content from 5 to 20 ft (1.5 to 6 m) depth and another transient moisture pulse from 50 to 60 ft (15 to 18 m) depth. The time series moisture profiles of another angle hole north of the absorption bed that did not extend beneath the bed showed an increase in moisture content from 30 to 50 ft (9 to 15 m) that persisted through the measuring interval of the investigation, suggesting that some moisture had moved into the adjacent tuff north of the absorption bed. An angle borehole adjacent to the north side of the absorption bed and drilled beneath the east-central portion of the bed showed a significant increase in moisture content from depths of 10 to 60 ft (3 to 18 m) which correlates to the area of tuff directly beneath the absorption bed. The time series moisture curves show that from 40 to 60 ft (12 to 18 m) in this hole the moisture decayed away after cessation of discharge of water to the bed but the moisture content from 10 to 40 ft (3 to 12 m) remained high. The results of the investigation showed that moisture was moving out of the absorption bed and suggested that water may perch and move laterally in preferred zones within the tuff and/or may move away from the absorption bed along preferred zones such as fractures in the tuff (LANL 1991, 7529).

In 1974 a borehole was cored to a depth of 14 ft (4.3 m) into absorption bed no. 3. Samples of the core were collected from each 0.5-ft (15-cm) interval and analyzed for americium-241 and plutonium-239/240. The results of the analyses showed that plutonium concentrations were as high as 790 pCi/g in the top 1 ft (0.3 m) of the absorption bed. Below this level, the concentrations of plutonium were significantly lower, and generally less than 100 pCi/g except at 4.5 ft (1.4 m) and 13.5 ft (4.1 m) where concentrations of plutonium were over 200 pCi/l. In the tuff beneath the absorption bed, from 6 to 11-ft (1.8 to 3.3-m)

depth, the plutonium concentrations decreased from around 80 pCi/g to less than 10 pCi/g, showing the absorbing capacity of the tuff for plutonium (LANL 1991, 7529). The increase in concentration of plutonium-239/240 at 13.5 ft (4.1 m) suggest that the source of the contaminants at depth may be from lateral movement of contaminants in the tuff, possibly from absorption bed no. 1. Similar to the subsurface distribution of plutonium, high concentrations of americium-241 were present in the upper 1 ft (0.3 m) of the absorption bed, where concentrations were as high as 23 pCi/g. Beneath this zone, concentrations of americium-214 in absorption bed no. 3 were generally less than 10 pCi/g except in the depth interval 8.5 to 10 ft (2.6 to 3 m) where americium-241 concentrations ranged from 18 to 24 pCi/g. This interval is within the bedrock tuff 2.5 to 4 ft (0.8 to 1.2 m) below the floor of the absorption bed.

In 1978 four boreholes were drilled into absorption beds no. 1 and no. 2 at MDA T (two holes in each bed). Each of the holes was cored to a depth of 100 ft (30 m) and samples of the core were collected from each 6-in.-(15 cm) interval and analyzed for moisture content, plutonium, and americium-241 (LANL 1991, 7529, p. 16-105; Nyhan et al. 1984, 6529). The moisture content in absorption bed no. 1 and in the underlying tuff was 25 to 28% (by weight) from depths of 6 ft (2 m) down to about 20 ft (7 m); these moisture contents approached saturated conditions. The source of the moisture was attributed to the water infiltration experiments that were conducted in 1960 and 1961. Below a depth of 20 ft (7 m) moisture contents were generally below 10% (by weight) except that one of the boreholes in absorption bed no. 1 encountered nearly saturated conditions at depths of 30 to 35 ft (9 to 11 m) and at 78 to 80 ft (24 to 25 m). The moisture content of absorption bed no. 2 and the underlying tuff was significantly less than associated with absorption bed no. 1. The highest moisture content encountered beneath bed no. 2 was about 20% (by weight) at a depth of 8 to 10 ft (2.5 to 3 m), which is in the tuff directly below the absorption bed. Beneath a depth of 15 ft (5 m) below bed no. 2 the moisture content was generally less than 7% (by weight) except that in one hole elevated moisture (to 18% by weight) was present from 55- to 60-ft (17- to 19-m) depth. Some of the high moisture zones in the tuff were correlated to unit boundaries with the Bandelier Tuff (Nyhan et al. 1984, 6529).

The plutonium concentrations in the tuff beneath the absorption beds were found to correlate with the moisture content. Beneath absorption bed no. 1 plutonium was measured in concentrations as high as 30,000 pCi/g and greater than 1000 pCi/g down to a depth of 40 ft (12 m) and below that depth in concentrations of around 100 pCi/g to a depth of 90 ft (27 m). Below 90 ft beneath absorption bed no. 1, the concentrations of plutonium generally decreased to below the detection limit of 30 pCi/g. Beneath absorption bed no. 2 the concentration of plutonium was as high as 10,000 pCi/g for about 3 ft (1 m), below which the concentrations decreased rapidly to 100 to 200 pCi/g from a depth of 13 ft (4 m) down to a depth of 20 ft (6 m), below which the plutonium concentrations were below the detection limit of 20 pCi/g (Nyhan et al. 1984, 6529).

In an effort to understand the moisture and radionuclide distributions beneath MDA T, an investigation into the hydraulic properties of the tuff was initiated by a bench-scale experiment on Mesita del Buey. Water was added to a 3- by 3- by 3-ft (0.91- by 0.91- by 0.91-m) pit in the tuff for 230 days, similar to the 1961 investigation at MDA T. Moisture in the tuff was monitored to a depth of 36 ft (11 m). The results of the investigation showed that the moisture drained from the tuff after about 286 days, suggesting that most of the moisture and radionuclide movement beneath MDA T probably took place within a year or so after the infiltration studies were completed in 1961. After redistribution of the moisture in the tuff and concurrent reduction in hydraulic saturation, the unsaturated conductivity beneath MDA T in 1962 was probably several orders of magnitude less than after the infiltration experiments, which significantly slowed moisture and radionuclide movement (Nyhan et al. 1984, 6529).

The results of the historical subsurface investigations at MDA T indicate that movement of plutonium and americium has occurred to depths of at least 100 ft (30 m) beneath the disposal pits. However, the total vertical and horizontal extent of contamination at the site have not been determined (LANL 1991, 7529).

In 1984 and 1986 two soil sampling surveys were conducted at MDA T to determine the extent of radionuclide concentrations in near-surface soils. Both sampling events followed excavation and removal of some of the disposal units from MDA T to MDA G in 1984 and 1986 (Nyhan and Drennon 1993, 23248, p. 3). In 1984 soil samples were collected from 30 sample sites arranged on a grid at 20-m intervals; surface and subsurface soil samples were collected from three depths: 0 to 1 cm, 1 to 10 cm, and 10 to 30 cm. The samples collected in 1984 were analyzed for tritium, plutonium-238, and plutonium-239. Plutonium 238 concentrations ranged from 0.01 to 1 pCi/g and plutonium-239 concentrations ranged from 10 to 100 pCi/g. The highest plutonium concentrations were in the western portion of MDA T, above the former site of the corrugated metal pipe lined shafts that were removed to MDA G (Nyhan and Drennon 1993, 23248, pp. 27, 41).

In 1986 surface soil samples were collected from 71 sample sites on a grid pattern spaced at 10-m-intervals; the samples were collected from one depth only, 0-5 cm. These samples were analyzed for plutonium-238, plutonium-239/240, and americium-241. The results of the investigation in 1986 showed an area of elevated plutonium and americium concentrations in the soil that extended from southwest to northeast across the western end of the disposal shafts. Plutonium-238 concentrations ranged up to 35 pCi/g and plutonium-239/240 concentrations were as high as 70 pCi/g. Americium-241 concentrations ranged up to 260 pCi/g in the soil samples (Nyhan and Drennon 1993, 23248, p. 41; LANL 1991, 7529).

G.2.1.5. Summary of the Results of Contaminant Transport Investigations

In the general context of MDA performance as it relates to vadose zone transport, the results of historical investigations suggest the following:

- Aqueous-phase transport of contaminants is minimal under normal unsaturated conditions.
- Diffusion of volatile contaminants is significant under normal saturation conditions.
- Both aqueous- and vapor-phase transport are controlled by high air permeability zones (fractured units and surge beds) within the mesa.

G.2.2. Vadose Zone Hydrologic Characterization

This section summarizes information compiled from various ER and non-ER sources describing the hydrological properties and processes that impact subsurface transport of contaminants at MDAs. The information relates to the impact of disturbances to the natural system due to MDA operations.

G.2.2.1. Injection Well Tests

In the mid-1980s, field tests were performed to measure the rate of liquid water flow through the Tshirege Member of the Bandelier Tuff under a variety of saturated and unsaturated conditions. Water was injected under controlled hydraulic-head conditions into a vertical borehole (injection well), and moisture content was measured at various times in a series of vertical boreholes differentially spaced around the injection well. Several injection tests were conducted to simulate different conditions of potential seepage from underground pits or shafts at MDAs on mesas around the Laboratory (Purtymun et al. 1989, 6880).

One test was conducted using an injection well with a 10-ft (3-ft) injection zone and seven observation holes to monitor the movement of 335,000 gal. (1360 m^3) of water that was injected into the tuff at a

constant head but at a resulting gradually declining rate over 89 days. This injection test resulted in a pear-shaped cloud of moisture (called a nephol, which is Greek for 'cloud') that reached a depth of 210 ft (64 m) and had a total diameter of about 120 ft (36 m) (Purtymun et al. 1989, 6880).

During injection of water into the tuff, the movement of water was initially dominated by capillary flow, which can be restrictive enough to limit the injection rate. After injection of a sufficient volume of fluids, the saturation of the tuff increases around the injection site and locally, saturated flow conditions can prevail, which is primarily driven by gravity and supplemented by capillary flow around the edge of the localized saturated zone. As more water is injected, the nephol expands and the unsaturated hydraulic conductivity at the fringes of the nephol increase as the moisture content increases. However, as the surface area of the nephol fringe increases, there is a resulting increase in flow resistance, which also restricts the overall rate of injection (Purtymun et al. 1989, 6880).

A subsequent test was conducted to determine the effect of intermittent discharges of fluids into the injection well. Due to changing hydraulic conductivity of the tuff under different saturation conditions, the amount of fluid that the tuff is able to accept and dissipate varies. It was found that intermittent releases of fluid may increase the total volume of fluid that can be injected. The primary movement of moisture in the nephol was downward beneath the injection well. At the end of the test period, the nephol extended to a depth of 220 ft (67 m) below surface and had a diameter of about 80 ft (24 m) (Purtymun et al. 1989, 6880).

The results of the fluid injection tests indicated that the hydrologic characteristics of the unsaturated tuff can retain or arrest the movement of water-soluble contaminants originating from the liquid or solid wastes stored in the tuff such as at an MDA. A nearly continuous and sufficiently adequate water source would have to be available before water-soluble contaminants could be rapidly mobilized to completely penetrate the thickness of the unsaturated tuff, and no such water supply is normally at disposal sites such as the MDAs. An irregular or seasonally fluctuating water source could also be sufficient to potentially mobilize water-soluble contaminants, but the migration rate of a seasonally fluctuating water source would be slower than if the water source was continuous (Purtymun et al. 1989, 6880).

After injection of water into the tuff over an 89-day injection test, the size of the moisture cloud or nephol suspended in the tuff continued to expand for an additional 200 days. The expansion of the moisture plume caused the moisture content of the center of the nephol to decline, thereby reducing the relative hydraulic conductivity of the unsaturated tuff and reducing the rate of movement of the water. When equilibrium of moisture conditions in the tuff is reached, the movement of any water-soluble contaminants ceases and any contaminants would remain suspended in the tuff as long as no additional moisture enters the system to disturb the dynamic equilibrium (Purtymun et al. 1989, 6880).

G.2.2.2. Natural Tracer Analyses

Natural tracers are constituents found in the environment that serve as an indicator of certain conditions, events, or processes. Natural tracers used to infer information about moisture in the vadose zone include chloride, oxygen-18, and deuterium. All are constituents present in precipitation in relatively constant amounts. All are present, then, in vadose-zone pore water, which is derived from precipitation. If no precipitation were lost to evaporation and transpiration, then the concentration of the tracers in pore water could be expected to be equal to the concentration in precipitation. Conversely, the relative concentration of tracers in pore water compared with the amount expected based on precipitation records can be used to infer such things as recharge rates, age of water, and the occurrence of evaporation. Two natural tracer analyses were performed in FY 1995 to support the development of a conceptual model of vadose-zone hydrology at MDA G (Newman 1996, 59372). Similar analyses were subsequently performed on

core retrieved from TA-49 (near MDA AB) (Newman 1997, 59371), TA-21 (near MDAs A, B, T, U, V), and TA-16 (near MDAs R and P). The results of the MDA G analysis are summarized here, which are generally representative of the analyses performed at the other sites.

G.2.2.2.1. Chloride

Pore water was extracted (gravimetrically) from core samples collected from various depths within the Mesita del Buey subsurface. Using standard methodologies, pore-water chloride concentrations were measured and compared to theoretical meteoritic water chloride concentrations (i.e., the concentration of chloride accumulated in precipitation over time). The ratio of measured to theoretical concentrations is used to estimate the amount of pore water evaporated, the age of pore water, and the time required for pore water to reach specific depths, provided that the following assumptions are valid.

- Chloride is deposited solely from the atmosphere in relatively constant amounts over time.
- Chloride dissolved in water is carried vertically downward through the vadose zone.
- Chloride uptake by plants is very small.
- There are no sinks or sources of water other than surface precipitation.

If these assumptions are valid, it may be inferred that the downward flux of water is relatively constant in regions where chloride concentrations are uniform. The magnitude of the downward moisture flux is high in regions where chloride concentrations are low relative to background levels, while fluxes will be low in regions characterized by relatively high chloride concentrations.

The results of the study showed a steady increase in chloride concentration to a depth of about 15 m (50 ft). The extremely high chloride concentrations indicate a low liquid flux rate and/or a sink for water. The chloride "bulge" is a characteristic of every borehole examined at MDA G, and it is very unlikely that the high concentrations are the result of climate change. Instead, the concentration of chloride is assumed to be the result of evaporative processes within the mesa. The near-surface and deep-mesa fluxes are high relative to the mid-mesa flux. Inferred flux rates are on the order of a 2 to 3 mm/yr. (0.08 to 0.1 in/yr.) in the shallow and deep zones and are 0.03 to 0.8 mm/yr. (0.001 to 0.03 in/yr.) in the intermediate zone. Within the mid-mesa region, cumulative chloride increases faster than cumulative water, indicating that water is being lost from the system at that location (Newman 1996, 59372).

To provide another estimate of recharge, the time required for the total amount of chloride in the core to accumulate was calculated. Chloride accumulation ages can be interpreted as the length time that water has been in the mesa. The accumulation ages for chloride in the MDA G cores were calculated to be between 2,000 and 17,000 years. Though uncertainties associated with estimates of chloride input and evaporation introduce errors into these age estimates, the values used are judged to be conservative. Estimated ages are expected to be greater than actual ages, and in all cases suggest that water movement through Mesita del Buey is slow (Newman 1996, 59372).

G.2.2.2.2. Stable Isotopes

The naturally occurring stable isotopes of oxygen and hydrogen (oxygen-18 and hydrogen-2) that, as constituents of water, are useful indicators of evaporation. The comparative abundances of oxygen-18 to oxygen-16, and hydrogen-2 (deuterium, D) to hydrogen-1, are relatively constant in precipitation. However, since both oxygen-18 and hydrogen-2 are "heavier" than the more abundant isotopes (oxygen-16 and hydrogen-1), they do not evaporate as readily.

The relative abundances of these two heavy isotopes compared with the more prominent isotopes are designated "δ^{18} O" and "δD." Pore water was extracted using vacuum distillation from core samples from

borehole 54-1117 at MDA G. Results were compared with the chloride profiles to test the deep-evaporation hypothesis, indicating that the lighter isotopes had been evaporated at depths much greater than could be influenced by surface evaporation. Surface evaporation effects are limited to the shallowest 1 to 2 m (3.3 to 6.6 ft); the presence of heavy waters at depths of 5 m (16 ft) and deeper is strong evidence that there is an evaporative sink at intermediate depths in the mesa (Newman 1996, 59372).

G.2.2.3. MDA G In Situ Moisture Monitoring

Moisture content is an extremely important parameter in assessing contaminant fate and transport in unsaturated fractured, porous media, such as the Bandelier Tuff. Moisture content within disposal units is directly related to the leachate concentrations and contaminant release rate (i.e., the aqueous-phase source term), and moisture content beneath disposal units is directly related to the rate at which contaminants may be transported through the subsurface.

G.2.2.3.1. Pit 1 and Pit 2 Covers

In 1973, neutron-probe moisture measurements were obtained at MDA G from holes augered into the covers over Pit 1 and Pit 2, which were closed in 1961 and 1963, respectively. Moisture content varied between 12% and 17% by volume in the Pit 1 cover and between 4 and 8% in the Pit 2 cover. In all measurements, peak water concentrations occurred at depths of 2 m (6.6 ft), and decreased between 2 m and 3 m (6.6 ft and 10 ft). The variation in moisture contents observed between the pits was tentatively attributed to variations in soil conductivity or differences in surface slope.

G.2.2.3.2. Pit 37 Inventory

The volumetric moisture content within Pit 37 has been measured periodically for several years. Measurements are obtained using a neutron probe inserted into a vertical PVC pipe installed in the center of the pit. Pit 37 is expected to have moisture contents in excess of most pits at MDA G because it has been open for a relatively long period of time. While most pits are excavated, filled, and covered within two to four years, Pit 37 has been receiving waste since 1990, and has still not yet been covered. Multiple measurements from Pit 37 show a maximum moisture content of about 11% by volume, with a mean of about 8%.

G.2.2.3.3. Vertical Boreholes

Neutron-probe measurements of moisture within the subsurface at MDA G consistently show three moisture-content zones. The profiles generally have a zone between 8- and 23-m (25- and 75-ft) depths where volumetric moisture content is 0.5% to 2.0%, with higher moisture contents above and below. Estimates of flux rates through this low moisture content region, based on unsaturated hydraulic conductivity estimates, are negligible. Water pressure profiles estimated beneath the mesa using hydraulic properties from cores suggest liquid water moves towards the base of Tshirege Unit 2, a depth of about 15 m (50 ft) from above and below.

G.2.2.3.4. Horizontal Boreholes

In 1992 the five horizontal boreholes that were drilled in 1976 beneath Pit 1 at MDA G were reentered and moisture measurements were obtained using a neutron probe. Volumetric moisture content values beneath the pits were in the range of 1 to 4%, and were generally 1 to 2% higher beneath the pit than

moisture levels away from the pit. These measurements suggest that pit excavation might have a small effect on moisture contents beneath the pits.

Volumetric moisture content in over 100 core samples from the off-horizontal boreholes drilled in 1995 beneath Pits 37 and 36 at MDA G measured between 0.2% and 15%, with an average of about 5%. The maximum moisture content (15%) was measured in a single sample, 100 ft (30 m) beneath Pit 36. This single maximum was bounded by measurements of 10% within 5-ft (1.5-m) intervals, and 8% within 10-ft (3-m) intervals. All of the measurements fall within the same "plateau" region of the unsaturated hydraulic conductivity curve shown in Figure G.2.2-1, indicating that moisture moves at the same rate despite measured differences in moisture content.

Unsaturated hydraulic conductivity curves for stratigraphic unit mesa subsurfaces are plotted in Figure G-2.2-1. The data plotted on the graph are obtained in experiments conducted on small samples of rock recovered from borehole cores. Measurements of hydraulic conductivity are made as water is added to the sample.

G.2.3. Surface Processes and Cap Performance

Under the sponsorship of the US Department of Energy (DOE), US Nuclear Regulatory Commission, Environmental Protection Agency (EPA), Air Force, and Navy, the Environmental Science Group at the Laboratory has performed studies and demonstrations on landfill surface covers and processes that affect landfill performance for nearly two decades. The guiding principles for landfill cover design projects are to reduce risks to human health and the environment and to reduce costs associated with post-closure monitoring and maintenance. The demonstrations and studies are grouped into three general categories:

- materials and their arrangements for landfill covers
- processes that affect long-term performance of the landfill
- post-closure monitoring to measure landfill performance

Although supporting national interests, the studies have focused on optimal designs for arid climates. They feature robust capillary barriers that are not subject to desiccation and cracking. Processes that affect long-term integrity have been investigated, including intrusion by animals and vegetation, subsidence, surface erosion, vegetation establishment and succession, and climate. Instruments that measure water content to determine cover performance and landfill response have been tested, as have automated data collection techniques.

G.2.3.1.1. Los Alamos Experimental Engineered Test Facility

Between 1981 and 1988, a field research and development program funded by the DOE and performed at the Laboratory developed and evaluated technology to address shallow-land barrier problems in arid environments. The objectives of the program were to develop and field-test:

- biointrusion barriers (biobarriers)
- systems for ground and surface water management

Field experiments were installed within an 8.6-ha (21-acre) plot of land designated the "LANL Experimental Engineered Test Facility (EETF)." A plant root intrusion study was conducted in lysimeters containing various combinations of vegetation, soil, and barrier material. Conditions were optimized for rapid plant growth to produce maximum root penetration. Stable cesium, which is absorbed by plant roots and translocated to above-ground plant tissues, was applied beneath each cover profile as a simulated waste. Samples of vegetation were analyzed using neutron activation of cesium at various times through the experiment.

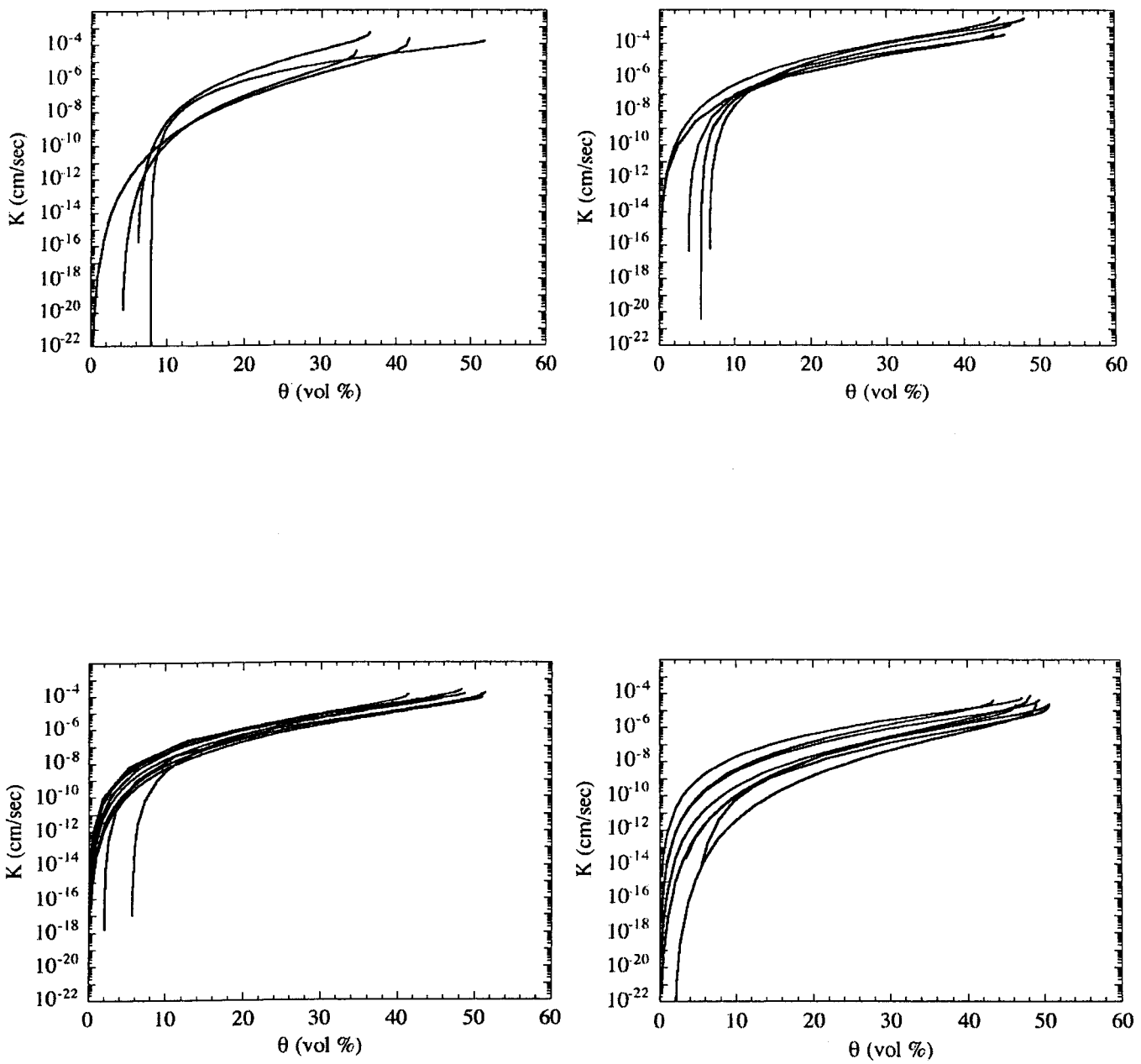

Figure G.2-1 Representative unsaturated hydraulic conductivity curves for the upper subunits of the Bandelier Tuff comprising the vadose zone beneath mesas

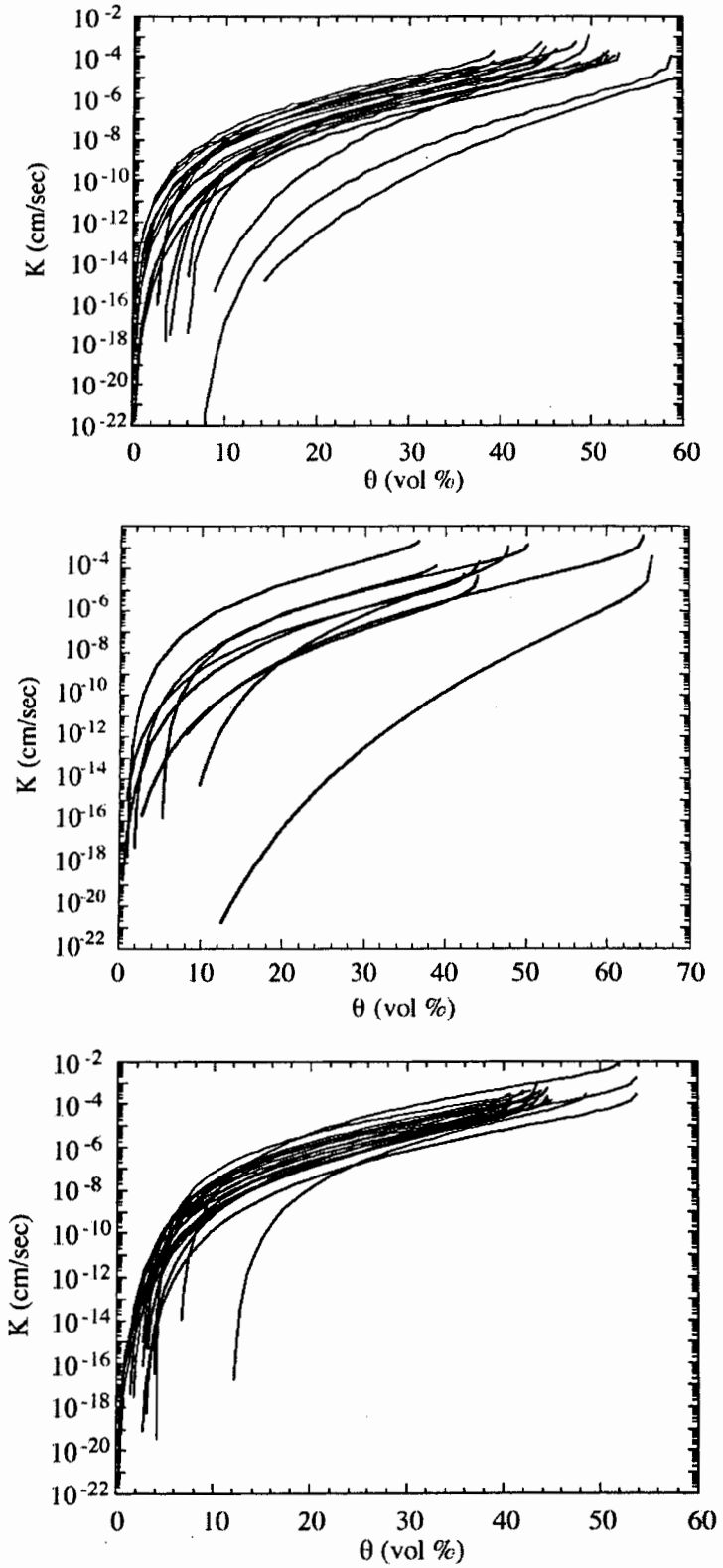

Figure G.2-1 (continued) **Representative unsaturated hydraulic conductivity curves for the upper subunits of the Bandelier Tuff comprising the vadose zone beneath mesas**

Cobble, gravel, and clay were tested as biobarrier components in the following designs:

- topsoil underlain by 30, 60, and 90 cm (12, 24, and 36 in.) crushed tuff (control)
- topsoil underlain by 15, 30, and 45 cm (6, 12, and 18 in.) bentonite clay
- topsoil underlain by 30, 60, and 90 cm (12, 24, and 36 in.) cobble
- topsoil underlain by 30, 60, and 90 cm (12, 24, and 36 in.) cobble/gravel mixture

Results showed that crushed tuff offers little protection against root intrusion, while the clay, cobble, and cobble/gravel barriers were very effective. Increasing barrier thickness greatly improved the performance of each system; maximum thickness generally reduced root intrusion to less than 20% of the control plot.

An animal intrusion barrier experiment was conducted by filling metal culverts with crushed-tuff backfill and 90 cm of each of the four barriers described above. A single pocket gopher (Thomomya bottae) was maintained in each culvert and allowed to construct a burrow system within the cover profile over a period of 4 months. At the end of the study period, the gophers were removed and their tunnel systems were injected with an expanding polyurethane foam to provide a cast of the tunnel system. The tunnel case was exposed by excavation to provide a qualitative evaluation of intrusion barrier effectiveness.

Results of the gopher intrusion experiment demonstrated that cobble, cobble/gravel, and clay were equally effective in preventing animal intrusion with depth. The crushed-tuff barrier, however, was readily used for tunneling.

In assessing the overall effectiveness of the clay, cobble, and cobble/gravel biobarriers, it was determined that the clay was less useful in that it is subject to desiccation, shrinkage, and cracking in the semi-arid environment of the Laboratory. Additionally, cobble, although effective in preventing animal burrowing, may not be a viable long-term plant intrusion barrier because of the potential for interpenetration of soil into the rocks, which would support root growth. Thus, the cobble/gravel barrier was judged most effective at minimizing both plant and animal penetration.

Two moisture-barrier field experiments were conducted in the Laboratory EETF, consisting of 3-m-(10-ft-) diameter by 6-m (19-ft) deep caissons. One was filled with tuff overlying gravel (control), and the other was filled with a tuff-bentonite (2%) mix overlying sand. The tuff-bentonite interface was sloped at 10% to provide additional information on the "wick effect" of the finer tuff-bentonite mixture: Percolating liquid will penetrate the coarser sand only after the finer tuff-bentonite layer nears saturation; at unsaturated conditions, moisture will move laterally along the interface. Soil moisture determinations were performed using neutron moisture gauges. Measurements were made every 30 cm (12 in.) across the entire width of each caisson. Soil water tension was determined with a tensiometer.

Results indicate that a capillary barrier made of crushed tuff and clay would work effectively over a relatively wide range of soil moistures in the field, providing protection to underlying wastes in varying moisture conditions. Use of local tuff with low amounts of added bentonite appeared to be very promising in greatly decreasing hydraulic conductivity without showing any of the mechanical impairments of clay mentioned above. Furthermore, results suggested that the wick phenomenon of unsaturated flow is potentially useful in the design of capillary barriers.

G.2.3.1.2. Los Alamos Integrated Test Plot Experiments

The Los Alamos Integrated Test Plot (ITP) was installed in 1984 to test and demonstrate, on a large-scale and long-term, design features including the following:

- soil erosion
- subsidence

- biointrusion
- capillary barriers

The ITP compared water balance and biological intrusion on a conventional control plot (compacted crushed tuff) and an engineered design, which incorporated the best available knowledge on methods to control erosion, subsidence, percolation, and biological intrusion. Two 3- by 10-m (10- by 33-ft) demonstration plots for each of the two cover designs were installed at the Laboratory EETF. Each was instrumented to measure run-off, soil water storage, and seepage.

The technology for soil erosion control on both cover designs was a 60% to 70% gravel mulch and a vegetative cover of native grasses (Bouteloua gracilis and Agropyron smithii). The dominant downhill slope was limited to 0.5% to limit run-off. Subsidence in the test plots was minimized by optimally compacting each layer of soil placed in the plot. The control cover consisted of 15 cm (6 in.) of topsoil over 76 cm (30 in.) of crushed tuff. The engineered design featured 71 cm (28 in.) of topsoil over a 46-cm (18-in.) gravel capillary barrier at a 5% slope to provide for soil water storage and to divert vertical flow; a 91-cm (36-in.) cobble biobarrier; and crushed tuff.

The experiments measured root intrusion and water balance (precipitation, leachate production, and soil moisture) to assess cover performance. To measure root intrusion and leachate production, cesium iodide was applied to the crushed tuff layer in each plot. Being immobile in soil but readily assimilated by plant roots, cesium in plant tissue indicated root penetration through the cover. The highly mobile iodide served as a hydrologic tracer in leachate water sample collected at the bottom of the caissons.

After the initial 3-year phase of this study, results showed that the engineered design had four distinct advantages over the control cover. First, the layering sequence results in a capillary barrier that generally retains water in the upper fine-grained layer, making it more available for evapotranspiration. Second, the biobarrier keeps plant roots from growing through the cover. Third, water retained in the upper layer supports enhanced root mass near the surface, which increases transpiration and improves the soil erosion protection provided by vegetation. Fourth, percolation from snowmelt (when evapotranspirative losses are small) that penetrates into the coarse layers can be diverted by drains emplaced in this layer.

G.2.3.1.3. Erosion Control Study

To study the water balance and erosional behavior of several cover conditions, a 15- by 63-m (50 by 200 ft) simulated trench cap of the conventional control design was constructed at the EETF; over this, eight surface treatments were applied. Each test plot had a slope of 7%. The plots were subjected to simulated rainfall to generate infiltration, run-off, and erosion. The surface treatment criteria were selected to support the development of the Universal Soil Loss Equation. There were four surface variations investigated:

- Bare soil treatment: not tilled and left bare;
- Plant treatment: tilled and seeded with native grasses;
- Gravel treatment: gravel over the bare soil; and
- Gravel and plant treatment: seeded and graveled.

Results of this study are summarized as follows:

- The disking process used to prepare the plant treatment plot resulted in an opening and loosening of the soil and decreased the occurrence of extensive cracks observed on the bare soil plot.
- The gravel treatment dramatically reduced soil erosion but increased infiltration by reducing evaporation.

- The gravel and plant treatment exhibited decreased water content beneath the cap due to transpiration from the vegetation.

G.2.3.1.4. Protective Barrier Landfill Cover Demonstration

The Protective Barrier Landfill Cover Demonstration examined the hydrologic performance of four different engineered landfill cover designs with downhill slopes of 5, 10, 15, and 25. Over a period of 44 months, field measurements of seepage, precipitation, interflow, run-off, evaporation, and soil-water content were collected to quantify the performance of the engineered barriers as a function of slope length.

The four designs were the following:

- Conventional design (control):15-cm (6-in.) loam over 76-cm (30-in.) crushed tuff over 30-cm (12-in.) gravel
- EPA design: 61-cm (24-in.) loam over 30-cm (12-in.) sand over 61-cm (24-in.) clay-tuff over 30-cm (12-in.) gravel
- Loam capillary barrier design: 61-cm (24-in.) loam over 76-cm (30-in.) fine sand over 30-cm (12-in.) gravel
- Clay-loam capillary barrier design: 61-cm (24-in.) clay-loam over 76-cm (30-in.) fine sand over 30-cm (12-in.) medium gravel

The ultimate objective of this on-going study is to optimize a design for a specific slope that minimizes run-off and seepage and maximizes interflow and evaporation (and transpiration, although the field plots are not vegetated). Significant results of the study are the following:

- The maximum amount of seepage occurred in the Conventional Design at 5%, reaching a maximum of 10% of the precipitation with the 5% slope.
- No seepage was observed on the Clay-Loam Capillary Barrier Design at 10, 15, and 25% slopes.
- Field plots with larger slopes had more evaporation generally resulting in less stress to the underlying layers.

G.3. REFERENCES FOR APPENDIX G

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APPENDIX H

SUMMARY FOR MDA G

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

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TABLE OF CONTENTS

H.1. SETTING AND OPERATIONAL HISTORY 2

H.2. MDA G PERFORMANCE ASSESSMENT AND COMPOSITE ANALYSIS 3

H.2.1. MDA G Performance Assessment and Composite Analysis Summary 3

H.2.2. MDA G Conceptual Exposure Model 4

H.2.2.1. Groundwater Pathway Analysis 6

H.2.2.2. Air Pathway Analysis 7

H.2.2.3. Surface Water Pathways Analysis 7

H.2.2.4. All Pathways Analysis 8

H.3. RFI ACTIVITIES 8

H.3.1. Non-ER Investigations 8

H.3.1.1. Surface Soil and Sediment Sampling 8

H.3.1.2. Surface Water Sampling 10

H.3.1.3. Air Sampling 11

H.3.2. ER Activities 11

H.3.2.1. Surface Soil and Sediment 12

H.3.2.2. Surface Water 12

H.3.2.3. Air 12

H.3.2.4. Pore Gas 13

H.3.2.5. Core Samples 14

H.4. MDA G CONCEPTUAL MODEL 16

H.5. MDA G RFI RISK ASSESSMENT 16

H.5.1. MDA G Present-Day Risk Assessment 16

H.5.2. Conclusions from MDA G Future Risk Assessment 17

H.6. REFERENCES FOR APPENDIX H 18

List of Figures

Figure H.2-1 Conceptual exposure model developed for the MDA G PA and CA 5

List of Tables

Table H.2-1 Summary Results of the MDA G PA/CA 4

Table H.3-1 Pore-Gas Monitoring Boreholes and Sampling Ports at MDA G 14

Table H.3-2 Information about Boreholes Drilled at MDA G 15

APPENDIX H

SUMMARY FOR MDA G

H.1. SETTING AND OPERATIONAL HISTORY

MDA G was established in the late 1950s for the disposal of radioactive waste generated at the LANL. The 65-acre site is situated on Mesita del Buey, near the eastern edge of the Laboratory, on the terminal fringes of the Pajarito Plateau. The Pajarito Plateau is upheld by the Bandelier Tuff, comprising two voluminous volcanic deposits- the Otowi Member and the overlying Tshirege Member. Along Mesita del Buey, Units 2b and 1v of the Tshirege Member are completely exposed, while Unit 1g is partially exposed on the thicker, western reaches of the mesa. Mesita del Buey is, on average, about 30 m above the two flanking canyons, Canada del Buey to the north and Pajarito Canyon to the south. Disposal units are excavated within Unit 2b, to depths of about 18 m, and are set back a distance of 15 m from the sides of the mesa. The surface of Mesita del Buey is about 275 m above the regional aquifer, which supplies the drinking water for area residents. The climate is semiarid, the ecosystem is Pinon-Juniper woodland.

The majority of the waste disposed of at MDA G is placed in large rectangular pits excavated using backhoes. While the sizes of the pits vary, the typical pit measures 20 m wide, 150 m long, and 20 m deep. Historically, unpackaged waste was placed in lifts in the pits and compacted by running heavy equipment over the material. Successive lifts were separated by a layer of uncontaminated crushed tuff. In addition to the 36 pits, over 200 cylindrical shafts containing waste are also present.

Pits and shafts are filled with waste to within 1 to 3 m of the ground surface, then backfilled and covered with compacted crushed tuff. A layer of topsoil is placed over the crushed tuff and seeded with native grasses to minimize surface erosion and water infiltration. Crushed tuff is mounded over the disposal shafts and allowed to settle for up to five years. Concrete caps are placed over closed shafts after this period.

Records of waste disposals have been carefully maintained since 1971, which is when the DOE began to segregate low-level radioactive waste and transuranic waste. Since 1971, transuranic waste has been stored at MDA G, awaiting disposal at the Waste Isolation Pilot Project (WIPP) repository. Separate databases record volumes, masses, disposal/storage location, waste form, and radionuclide content for each package of low-level or transuranic waste accepted at MDA G. Information from the databases was used directly to estimate the quantities of low-level waste disposed of between 1971 and 1995. Quantities of the waste disposed at MDA G prior to 1971 were interpolated from low-level waste disposal records and transuranic waste storage data from the 1970s. Volumes and activities of waste requiring disposal in the future were estimated from the 1990 to 1995 disposal records and ER waste projections.

The mesa-canyon topography of the Pajarito Plateau in general, and of Mesita del Buey in particular, has important implications with respect to the potential transport of contaminants in the environment. The movement of water in the unsaturated zone is dominated by matrix flow through the porous Bandelier Tuff. While flow through fractures near the mesa surface may occasionally occur during episodic wetting events, fracture flow does not appear to result in increased recharge through Unit 2b. In fact, the predominant effect of fractures may be to remove water from the system through evaporation. The natural hydrology of Mesita del Buey appears to be only minimally impacted by waste management activities. Site-specific moisture content, matric suction, and natural-tracer data all indicated that the natural process of evaporation through fractures and surge beds effectively minimize potentially problematic impacts of increased moisture due to disposal activities.

The hydrologic connection between Mesita del Buey and its adjacent canyons appears to be primarily surficial. Runoff of rain and snowmelt communicates with the intermittent alluvial systems within Canada del Buey and Pajarito Canyon. The majority of the runoff follows natural drainages into Pajarito Canyon, which bears water most of the year. The runoff carries sediment, much of which is deposited in the drainages.

The local MDA G topography has important effects upon the wind patterns at MDA G. Wind direction measured over the mesa generally trends north-northeast following the Rio Grande valley, with nocturnal shifts to the east and seasonal variations. In contrast, measurements of wind speed, direction, and frequency in canyons show a channeling effect, with winds blowing up canyon toward the west-northwest during the day, and down canyon toward the east-southeast at night.

H.2. MDA G PERFORMANCE ASSESSMENT AND COMPOSITE ANALYSIS

H.2.1. MDA G Performance Assessment and Composite Analysis Summary

The DOE radioactive waste disposal sites are managed, in part, based on whether the sites were active before or after the issuance of DOE Order 5820.2A (September 25, 1988). DOE Order 5820.2A requires a radiological performance assessment (PA) to demonstrate and document the safety basis for disposal sites accepting low-level radioactive waste (LLW) after September 25, 1988. The order defers radioactive waste disposal sites used before that date to either Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) or Resource Conservation and Recovery Act (RCRA) corrective action, with the latter applying at the Laboratory. To ensure that the cumulative radiological impact of all radioactive waste disposals will not adversely impact human health or the environment for future generations, a composite analysis (CA) is also required by the DOE.

The PA is required to determine if LLW generated since September 26, 1988 has been, and will continue to be, disposed at MDA G in a manner that will not result in radiation doses to the public that exceed performance objectives specified by the DOE. In a complementary fashion, the CA is used to evaluate options for ensuring that exposures from all radioactive waste disposed of at MDA G will not exceed specified limits in the future. The CA is also meant to influence corrective actions at ER sites.

The PA/CA for MDA G (LANL 1997, 63131) is equivalent to a baseline human-health risk assessment for radiological constituents, evaluating environmental fate, transport, and human-health risk consequence of radioactivity disposed there. Consistent with DOE guidance, the all-pathways, all-sources risk analysis covers a time period of 1,000 years post closure.

The performance objectives for the PA that are comparable to RCRA and CERCLA risk assessment requirements are the following:

- Maximum effective dose equivalent of 25 mrem/yr. to any member of the public resulting from external exposure and concentrations of radioactive material released into surface water, groundwater, soil, plants, and animals.
- Maximum effective dose equivalent of 10 mrem/yr. to any member of the public from concentrations of radioactive material released to the atmosphere (excluding radon) from Area G and all other facilities at the Laboratory.
- Maximum effective dose equivalent of 4 mrem/yr. to any member of the public from the consumption of drinking water drawn from wells outside of the land-use boundary.

The performance objective for the CA is the DOE primary annual dose limit of 100 mrem/yr.

The results of the PA/CA are compared to their associated performance measure in Table H.2 -1.

Table H.2-1 Summary Results of the MDA G PA/CA

Inventory	Analysis	Location	Calculated Peak Dose	Performance Objective*
PA	Air pathway	Cañada del Buey	6.6×10^{-2} mrem/yr.	10 mrem/yr.
CA	All pathways	Cañada del Buey	5.8 mrem/yr.	30 to 100 mrem/yr.
PA	Groundwater protection	White Rock Pajarito Canyon	3.5×10^{-5} mrem/yr.	4 mrem/yr.
PA	All pathways	White Rock Pajarito Canyon	1.0×10^{-4} mrem/yr.	25 mrem/yr.
CA	All pathways	White Rock Pajarito Canyon	7.2×10^{-3} mrem/yr.	30 to 100 mrem/yr.

*Performance objective represents the maximum projected exposure from all releases at the Laboratory.

H.2.2. MDA G Conceptual Exposure Model

Like risk assessments performed under RCRA, PAs and CAs required for DOE LLW disposal sites are based on a conceptual site exposure model, which is a three-dimensional picture of what is known or suspected about the contaminant sources, releases, fate and transport, and potential receptors. The conceptual model for MDAs is shown in Figure H.2 -1.This conceptual model is based on an extensive body of information derived from historical site-specific investigations at MDAs, including those summarized above in this section.

The solid arrows on the figure emanating from the mesa surface and vegetation represent the movement of water as a liquid (straight arrows) and as a vapor (serpentine arrows). Liquid water generally moves downward into the bedrock formations (i.e., infiltrates), while water vapor generally remains static within the Bandelier Tuff or moves upward and outward through the mesa top and the mesa sides (i.e., evaporates) and up through vegetation (i.e., transpires).

On the conceptual model, straight and serpentine arrows represent contaminant migration from the source terms (i.e., releases from disposal units). The straight arrows represent movement of leachate percolating through the disposal units. The serpentine arrows depict releases of contaminants into the air, either as gases or as dust particles. The original source term for resuspended particulates involves processes that lead to deposition of contaminants at the surface, including erosion and intrusion by plants and animals.

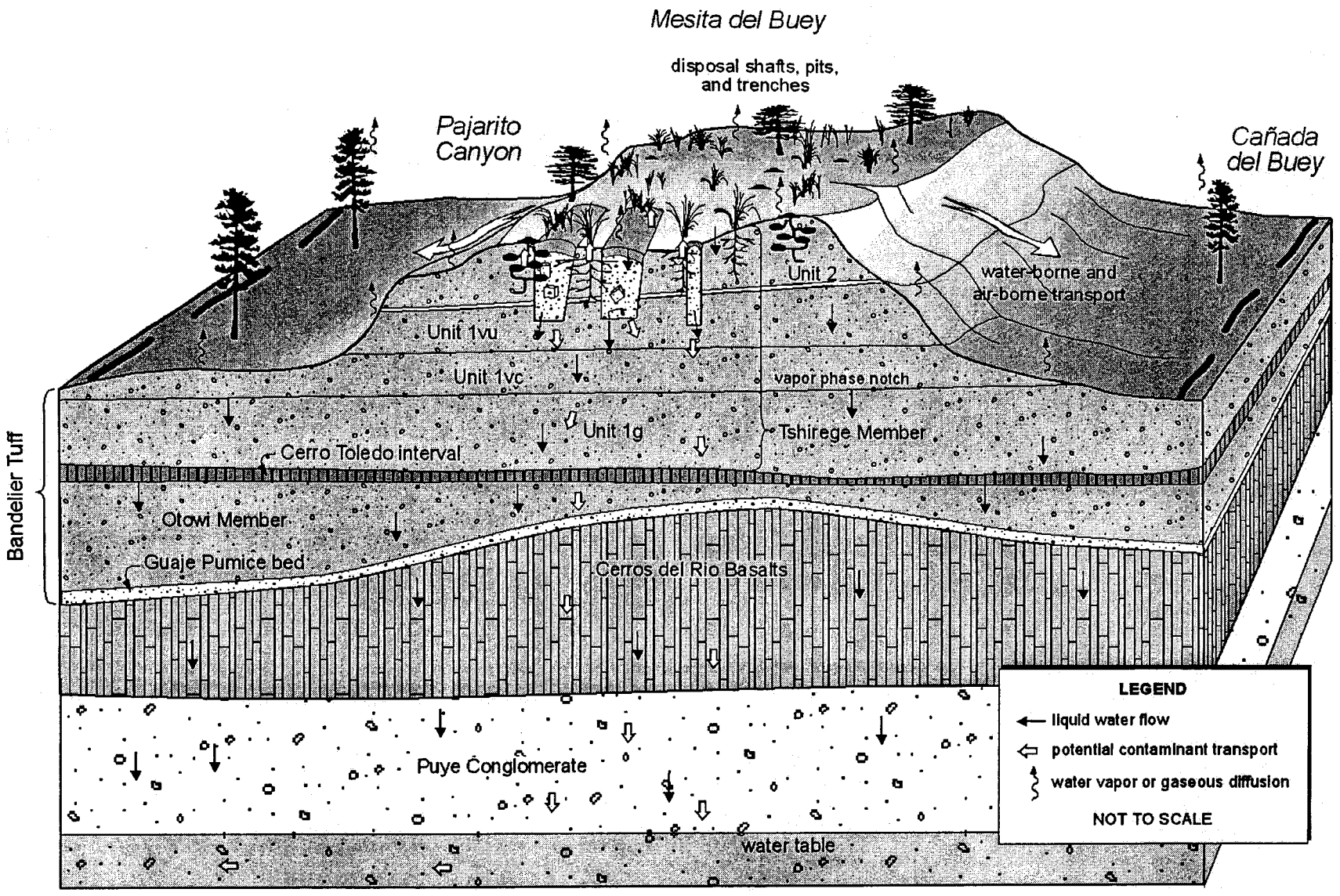

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Figure H.2-1 Conceptual exposure model developed for the MDA G PA and CA

A source release combined with air or water can transport contaminants away from the disposal site to locations where it might be accessed by human or ecological receptors. Contaminant transport mechanisms identified by open arrows on the figure are the following:

- Leachate transported downward by gravity and other natural forces (e.g., vapor pressure, water pressure) through the bedrock beneath the disposal units in the direction of the regional aquifer
- Gas-phase releases and resuspended particulates transported in air to downwind receptors
- Deposition of contaminants on the surface resulting from biotic translocation and erosion transported off the mesa by stormwater run-off

Exposure pathways can include one or more source terms and transport media. For example, contaminants in water (either shallow groundwater or surface water) can be assimilated by plants; resuspended radioactivity in air can be deposited on plants; and contaminants in surface soils can be splashed onto plants.

H.2.2.1. Groundwater Pathway Analysis

The groundwater pathway analysis used in the MDA G PA/CA is based on a sequence of events selected as a worst case, most conservative scenario. This sequence of events is as follows:

- Radionuclides are leached by water percolating through disposal units at MDA G
- Contaminants in leachate are transported vertically downward through the vadose zone to the regional aquifer or laterally to alluvial groundwater in Pajarito Canyon, from where contaminants may be transported downward to the regional aquifer
- Radionuclide contaminants may be diluted and transported within the regional aquifer to locations down gradient of MDA G
- Individuals at off-site locations may receive doses as a result of using contaminated water drawn from the regional aquifer for drinking, crop irrigation, and watering animals

It is important to note that the conceptual groundwater migration pathway at MDA G does not appear to actually occur but was modeled as a possible occurrence to obtain a conservative result for modeling purposes. The lateral transport mechanism to the sides of the mesa and into the adjacent canyon alluvial system has no basis in reality, but was included as a conceptual fast-path of groundwater contaminant transport to the regional aquifer.

The maximum annual groundwater-pathway dose calculated during the 1000-yr compliance period in the MDA G CA was 1.2×10^{-5} mrem at the downgradient receptor location. Carbon-14 was responsible for most of this dose, with technetium-99, and iodine-129 also contributing. Even when worst-case bounds on the uncertainties in the groundwater analysis were considered, doses were five orders of magnitude below EPA's 4-mrem/yr threshold (LANL 1997, 63131).

The largest uncertainties in the conceptual groundwater contaminant migration pathway analysis were in the following:

- the total inventory of non-sorbing, long-lived radionuclides
- the infiltration rate through the disposal units
- the percolation rate of leachate through the vadose zone
- the factors affecting dilution in the regional aquifer

H.2.2.2. Air Pathway Analysis

The air pathway analysis of MDA G is based on the following assumptions:

- Radionuclides are brought to the surface of MDA G by plants and animals penetrating into the disposal units and by gaseous radionuclides diffusing upward and outward to the ground surface.
- Contaminants in soils are resuspended in the air above the disposal unit and together with gaseous radionuclides are transported to an off-site receptor by the prevailing winds.
- An individual receives doses from the inhalation of airborne particulates and gases, ingestion of contaminated food crops, and external radiation from airborne radionuclides and contaminated soils.

The resulting maximum air-pathway dose projected for the MDA G CA was 5.5 mrem per year at the point of maximum exposure in the adjacent canyon, Cañada del Buey. The radionuclides responsible for the vast majority of the air-pathway dose were actinides from the oldest waste.

The model used for biotic translocation assumes a maximum burrowing depth of 2 m (6.6 ft) based on site-specific data and assumes that burrowing animals readily excavate waste contaminated with actinides. This is a conservative depth based on information indicating that the largest amount of the plutonium-bearing waste in that portion of the inventory is dewatered sludge that is buried at depths of three meters or more (LANL 1997, 63131).

The largest uncertainties in the air pathway analysis were associated with the following parameters:

- animal burrow depth
- total actinide inventory and concentration
- the extent of channeling of winds into Cañada del Buey.

H.2.2.3. Surface Water Pathways Analysis

The surface water pathway analysis is based on the following assumptions:

- Radionuclides are brought to the surface of MDA G by plant uptake with plant roots growing into the waste and animals burrowing into the waste.
- Contaminants in soils are transported from the mesa top to the floor of the adjacent canyon by stormwater run-off.
- Mobile (soluble) contaminants are transported vertically downward into the alluvial groundwater, and then to the regional aquifer.
- An individual receives doses as a result of exposure to contaminated soils and of using contaminated water drawn from the regional aquifer for drinking, for crop irrigation, and for watering animals.

The maximum surface water pathways dose calculated during the 1000-yr compliance period of the CA was 7.2×10^{-3} mrem/yr. The majority of the dose was attributed to inhalation of resuspended contaminated sediments and ingestion of vegetables contaminated with sediment (by way of rain splash). Important radionuclides were plutonium-239, silver-106m, and americium-241 brought to the surface of the disposal site by burrowing animals. Assumptions about the distribution of actinides in the disposal units, discussed previously with respect to the air-pathway analysis, are expected to result in conservative dose projections for the surface water pathway (LANL 1997, 63131).

The primary uncertainties in the surface water pathways analysis are associated with the following parameters:

- animal burrow depth
- total actinide inventory and concentration
- the amount of sediment transported in stormwater.

H.2.2.4. All Pathways Analysis

The results for the all pathways analysis were compared against a performance objective of 25 mrem/yr. for the MDA G PA. Locations for projected doses included the receptor location near the nearby town of White Rock before the end of institutional control and the receptor locations 100 m (330 ft) east-southeast of MDA G, and in the adjacent canyon thereafter. No significant exposures were found to occur at the location near White Rock. The peak dose projected for the receptor 100 m (330 ft) east-southeast of MDA G was 2.0×10^{-7} mrem. While this is 60 % greater than the dose for the groundwater pathway analysis, it is still a small fraction of the performance objective. Larger doses were calculated for the adjacent canyon receptor. The maximum dose during the 1,000-year compliance period was 1.0×10^{-4} mrem, which is a factor of 250,000 less than the performance objective (LANL 1997, 63131).

H.3. RFI ACTIVITIES

MDA G is the best characterized of the Laboratory's 26 MDAs. This section summarizes MDA G site investigations undertaken outside of and within the ER Project. A complete discussion of RFI activities is presented in the RFI Report for Material Disposal Areas G, H, and L at Technical Area 54 (LANL 2000, 64360).

H.3.1. Non-ER Investigations

This section summarizes investigations undertaken by the Laboratory's Waste Management Program and/or ESH Division. The RFI for MDA G is supported by several investigations undertaken by the Laboratory but outside of the ER Project. The results of these investigations are used, either qualitatively or quantitatively, to supplement the RFI investigations completed by the ER Project.

H.3.1.1. Surface Soil and Sediment Sampling

Extensive surface soil and channel sediment sampling (stormwater runoff) has been performed at MDA G by ESH Division. Several of the surface soil studies were performed by the Waste Management Program in accordance with environmental protection requirements specified in DOE Order 5400.1, "General Environmental Protection Program," and waste management requirements in DOE Order 5820.2A, "Radioactive Waste Management." Other sampling was conducted for environmental health and safety or for environmental monitoring.

ESH-19 Sampling. Throughout the 1990s, ESH-19 collected surface soil samples; from 1993 through 1995, the surface soil samples were collected concurrently with single-stage water samples (LANL 1996, 55621; Conrad et al. 1995, 52014; Conrad et al. 1995, 55614; Conrad et al. 1996, 55615; Conrad et al. 1996, 55616; Conrad et al. 1996, 55617; and Conrad 1995, 55618).

ESH-18 Sampling. ESH-18 also sampled stormwater runoff and sediment in the drainage channels around MDA G to monitor potential off-site contaminant migration. Permanent runoff water and sediment-sampling stations were established in 1982 and are now served by continuous automated

water-sampling stations. Channel sediments have been collected at these stations nearly every year since 1982. These samples were collected to monitor the possible transport of radionuclides by stormwater runoff from the MDA. Metals have rarely been detected at levels considered greater than background, and organic chemicals have rarely been detected.

Temporal trends in the plutonium data have been observed in some of the sampling stations around the east end of MDA G, indicating that plutonium concentrations exceeded background. Tritium has also been detected at concentrations exceeding background. Other radionuclides appear to be at or below background levels.

Of the 15 drainages identified, runoff and sediment from the following drainages is most likely to affect the environment because their locations are near the open pits, TRU pads, and TWISP area where surface activity is ongoing.

- drainages G-8, G-9, G-14, and G-15, which receive runoff from the TWISP area;
- drainages G-9 and G-15, which receive runoff from the TRU waste storage pads;
- drainage G-10, which receives runoff from around pit 37;
- drainage G-3, which receives runoff from around pit 39; and
- drainages G-3, G-4, and G-13, which receive runoff from the tritium shaft areas.

Several surface soil sampling campaigns have been performed at MDA G, some to support the Waste Management Program and others to support environmental surveillance at the Laboratory. These investigations are described as follows:

- *TWISP Preoperational Sampling (7/93–2/95).* This activity was conducted under the direction of the Waste Management Program to provide a baseline for comparison when TWISP operations come to closure; ESH-19 conducted the sampling. A total of 55 sampling locations were defined; 35 were sampled from points on a 75-ft grid. A subset of the samples was submitted for metals and volatile organic chemical analysis while all the samples were submitted for radionuclide analysis.

- *TRU Pads Sampling (6/93–7/95).* The area where the sprung domes for TWISP drums are located was sampled to evaluate the potential for off-site migration, a Waste Management Program initiative, and to assess health and safety before pad and dome construction activities, an ESH initiative. Three years of sampling were performed by ESH-19. A 50-ft grid was established. A total of 139 sampling locations were defined, from which 192 samples were collected. Some samples were submitted for metals and volatile organic chemical analysis, and all samples were submitted for radionuclide analysis.

- *Pits 37 and 39 Sampling (6/94–7/94).* Surface soil samples were collected from near pits 37 and 39. The Waste Management Program was interested in effectiveness of disposal operations. Samples around these pits were collected during and soon after disposal operations to determine if radiation releases were occurring as a consequence of disposal activities. A total of 27 samples were collected and submitted for radionuclide analysis.

- *Site-Wide Sampling (7/93–7/95).* The 65-acre operational area of MDA G was sampled by ESH-19 at the request of the Waste Management Program. The intention was to evaluate health and safety and to provide data that could be used to support the air-modeling efforts used in the MDA G performance assessment. A 200-ft grid was established across MDA G, from which a total of 136 samples were collected and submitted for radionuclide analysis. Twenty-six of these samples collected in close proximity to the PCB disposal shafts were submitted for PCB analysis.

- *Site-Wide Perimeter Sampling (7/93–8/96).* Soil samples were also collected in the sediment depositional area on the perimeter of the active area of MDA G. These samples were collected by ESH-19 in response to interest shown by the pueblos and public interest groups regarding the potential for contaminant migration into Cañada del Buey and Pajarito Canyon. Sample locations were selected based on recent erosional history, as determined by geomorphic field observations. Drainage channel soils were sampled on an annual basis at the first depositional area outside the perimeter fence. A total of 250 samples were collected, some of which were submitted for metals analysis and all were submitted for radionuclides analysis. Samples from 51 perimeter locations were also analyzed for PCBs.

- *Development Area Sampling (7/94–6/95).* The Waste Management Program requested characterization of the area immediately to the west of MDA G to provide a baseline for TA-54 for comparison with on-site concentrations. This area is slated for future incorporation into MDA G and is know as the development area. ESH-19 designed a 100-ft grid from which 53 sampling stations were selected. Thirty-five samples were also collected from the canyon rim around the development area. All of these samples were submitted for laboratory analysis of radionuclides; some of the samples were submitted for analysis of metals and volatile organic chemicals.

The total number of surface soil and sediment samples from all non-ER investigations submitted for various contaminant analyses are as follows:

- 728 samples were analyzed for radionuclides,
- 140 samples were analyzed for metals,
- 82 samples were analyzed for VOCs, and
- 77 samples were analyzed for PCBs.

All data described above were used in the RFI to identify COPCs in surface soil and channel sediment at MDA G.

H.3.1.2. Surface Water Sampling

Continuous Automated Stormwater Sampling. Since 1982, 6 of the 15 drainages around MDA G are monitored yearly by ESH-18, using telemetry-based stormwater samplers, for compliance with the facility's NPDES Permit for stormwater. The NPDES permit requires stormwater runoff to be analyzed for certain metals. Since 1995, in response to identification of low levels of mercury in some samples, ESH-18 has included these sampling stations in the Laboratory-wide environmental surveillance program. As part of the surveillance program, the analytical suite was expanded to include radionuclides, according to DOE Order 5400.1, "General Environmental Protection Program." The procedure by which ESH-18 collects the NPDES stormwater runoff samples is dictated by the terms of the Laboratory's permit agreed upon with the Environmental Protection Agency (EPA), under the guidance found in 40 CFR 122.26, "Final NPDES General Permit for Storm Water Discharges Associated with Industrial Activity."

The continuous automated sampler collects stormwater runoff flowing through a weir installed across a drainage. The term *continuous* in this context refers to sampling over an entire runoff event and does not imply sampling between events. ESH-18 surface water sampling data have been collected at MDA G since 1992; however, samples were not collected at each of the six NPDES stations each year nor were metals analyzed on every water sample collected. ESH-18 surface water samples are not filtered before

chemical analysis, and total suspended solids information is not available. For these reasons, the ESH-18 automated-sampler data are used only qualitatively to support the RFI for MDA G, but the data are good indicators of contaminant migration.

Single-Stage Water Sampling. In addition to the ESH-18 sampling, single-stage water samplers were sited in minor feeder drainages that originate within MDA G. Single-stage water samples were collected by ESH-19 from 1993 to 1995 concurrently with the perimeter surface soil samples and had the same objective of assessing potential migration of radioactive contamination from MDA G. In contrast to the continuous samplers, single-stage water samplers collect only the first water in a drainage during a particular runoff event. On the Cañada del Buey (north) side of MDA G, two lines of single-stage samplers were located downgradient of the active area of MDA G. The first line of samplers was located on top of the mesa as close to the perimeter fence as possible. The second line of samplers was located nearer the bottom of Cañada del Buey. The water and sediment fractions of these samples were separated before analysis. Water fraction results are available for cesium, uranium, americium-241, plutonium-238, and plutonium-239 from samples that were collected in 1993 only. Results are available from samples analyzed for tritium for the entire period (1993–1995).

ESH-19 single-stage stormwater runoff samples were not sampled every year nor was every location in the same program sampled during any one given year. A total of 399 stormwater samples were collected from 108 single-stage locations. The data from the single-stage water samplers are used to identify COPCs in sediment at MDA G.

H.3.1.3. Air Sampling

ESH-17 routinely monitors ambient air at nine air-sampling stations around MDA G. Between two and four samples each year are collected and analyzed for uranium, plutonium, and americium, and approximately 25 samples each year are collected and analyzed for tritium. Ambient air samplers at MDA G contain a particulate filter for trapping alpha emitters and a silica gel cartridge for trapping tritium as water vapor. Although samples are typically collected biweekly during the sampling period, the samples for the alpha emitters are composited for quarterly or semiannual analysis to ensure that adequate amounts of radionuclides are present to allow quantification of air concentrations. Details of the sample collection and analysis protocols and the data management and QA/QC programs are described in the Air Monitoring Network (AIRNET) project plan (Environmental Surveillance Program 1998, 59904). The ESH-17 AIRNET data were used to identify COPCs in air at MDA G and have been included in the data review.

In 1994, ESH-17 collected 16 air samples from two locations and analyzed these samples for VOCs. Ambient air samples were collected on eight days from two sampling locations on the northern perimeter of MDA G during the summer of 1994. At the same time, samples (for comparison) were collected at a background sampling station adjacent to Bandelier National Monument, which is 3 mi. south-southwest of MDA G. Details of this sampling are discussed in "Ambient Monitoring of Volatile Organic Compounds at Los Alamos National Laboratory in Technical Area 54, Areas G & L" (Mischler and Anderson 1994, 63525). The data from this investigation were used to identify COPCs in ambient air at MDA G and are included along with RFI data in the data review.

H.3.2. ER Activities

The ER Project performed activities at MDA G between 1993 and 1999. The fieldwork conducted in support of the RFI is presented in detail in the RFI report (LANL 2000, 64360) and is summarized in this appendix.

H.3.2.1. Surface Soil and Sediment

H.3.2.1.1. Surface Soil

Surface soil samples collected by ESH-19 and summarized in the RFI report were used to identify COPCs in surface soils at MDA G. More than 700 samples were collected during the investigation. The samples were collected and analyzed following protocols similar to those used in ER; the results provided information for metals, organic chemicals (volatile organic chemicals and pesticides and PCBs), and radionuclides. These data have been summarized in an ER Project draft report and are described in more detail in Appendix E of the RFI report (LANL 2000, 64360).

H.3.2.1.2. Channel Sediments

Drainage channel sediments at MDA G were sampled and analyzed by the ER Project in 1994. This investigation was reported in "RFI Report for Channel Sediment Pathways from MDAs, G, H, J, and L, TA-54" (Environmental Restoration Project 1996, 54462). During the 1994 field investigation, samples of unconsolidated sediments were collected at 135 locations. Samples were collected from depths between 0 in. and 10 in. (0 cm and 25 cm) using stainless-steel trowels. Sixteen field-duplicate samples were also collected from the drainages; background samples were collected from 10 locations in two channels that drain portions of Mesita del Buey not used for waste management. Sediment samples were collected from 7 to 10 locations in each of the MDA G drainages. All samples were field-screened by the Laboratory's Mobile Radiological Analysis Laboratory. Screening was used to identify 56 samples for laboratory analysis, which included four samples from each of the drainage channels. These samples were analyzed for inorganic chemicals, radionuclides, and organic chemicals.

H.3.2.2. Surface Water

Stormwater samples collected by ESH-19 and ESH-18 (discussed in Section 3.3.1.1 of the RFI report [LANL 2000, 64360]) were used in a qualitative manner to support conceptual model development for the MDA G RFI. The data are not appropriate for identifying COPCs in surface water partly because not all samples are routinely subject to the same analysis. However, the single-stage water samples are suitable for qualitatively supporting evaluation of nature and extent for the most prominent COPCs identified in other surface media.

H.3.2.3. Air

The ER Project conducted three ambient air investigations to supplement ESH-17 monitoring data in identifying COPCs in air at MDA G. The ESH-17 investigation is summarized in the RFI report (LANL 2000, 64360). The investigations performed by the ER Project are presented in detail in the RFI report and are summarized here.

H.3.2.3.1. Surface Flux Chamber Measurements for Tritium

During the summer of 1993, surface tritium flux was measured in a flux chamber at 130 locations within and around MDA G. Sample locations were selected to distinguish between baseline areas and high-flux areas. Three suspected tritium high-flux areas were sampled. Thirty-seven, 35, and 18 sampling locations were sampled in 1993 at areas 1, 2, and 3, respectively. The flux chamber sampling apparatus consisted of a 1300 cm^2 Plexiglas flux chamber pressed about 1 in. into the soil through which a sweep gas was fed at a constant rate. Air was pulled through the chamber with a pump at a rate slightly less than the sweep

gas rate to avoid dilution with ambient air. Tritium samples were collected on primary and secondary silica gel tubes.

In 1994, approximately 44 surface locations were sampled again for tritium emissions. The areas resampled in 1994 included locations in tritium hot spots 1 and 2.

H.3.2.3.2. Surface Flux Chamber Measurements for VOCs

In 1993 and 1994, VOC flux chamber data were collected to establish overall rates of VOC flux from MDA G. Sample locations were not specifically targeted to the area where a subsurface VOC plume is now known to exist. In the report for this sampling (Eklund 1995, 56033), samples that were collected in the development zone, at MDA L, or in drainages relatively distant from the mesa top were designated as MDA G samples. The same type of flux chamber apparatus was used as in the tritium sampling discussed above. Gas samples were collected in SUMMA passivated canisters attached to a manifold along the exit gas line from the flux chamber.

In 1993, VOC flux chamber data came from four sample locations. Two duplicate samples, a field blank, a system blank, and a control point were also collected in 1993. Of the seven locations sampled in 1994, three were located on the mesa top, and four were on the mesa slopes. Three duplicate samples, two field blanks, a system blank, and a background sample at Bandelier National Monument were also collected in 1994. As another QA measure, five sampling locations were sampled at two different times in 1993. In 1994, twenty eight locations were sampled at two different times. Approximately 180 individual organic compounds were included in the VOC analytical suite including alkanes, alkenes, ethers, alcohols, aromatic compounds, and halogenated VOCs.

H.3.2.3.3. Surface Adsorbent-Cartridge Measurements of VOCs

Soil-gas emissions were collected in a device consisting of 100 mg of adsorbent material suspended on a stainless steel stake beneath a stainless steel shell with an area of 62 cm^2 (an EMFLUX device). VOC analytes included were those specified in EPA's target compound list and an additional 15 VOCs specified by the Laboratory.

Approximately 174 collection devices were deployed at MDA G during Survey I in late August 1993 and collected after four days. During Survey II in the following year, Trujillo et al. (1998, 58242) record that another 74 devices were deployed at MDA G on August 15 and collected August 19, 1994. The majority of the 1993 samples were located on the mesa top, while most of the 1994 samples were collected from the slopes and drainages on the sides of the mesa. Details of the investigations are reported in a 1993 Quadrel Services report (1993, 63868), a 1994 Quadrel Services report (1994, 63869), and Trujillo et al. (1998, 58242).

H.3.2.4. Pore Gas

Sampling and analysis of subsurface pore gas at MDA G is required by Module VIII of the Laboratory's Hazardous Waste Facility Permit in Section C.5, Unsaturated Zone Monitoring (EPA 1990, 1585). The EPA-approved plan for pore-gas sampling and analysis is described in the Laboratory's response (LANL 1993, 22430) to an EPA notice of deficiency (Driscoll 1992, 3849) addressing the Laboratory's RFI work plan for OU 1148 (LANL 1992, 7669).

The pore-gas sampling and analysis plan requires sampling 12 of 28 available boreholes each quarter at MDAs G and L. Of these 12, two must be selected from a list of four boreholes located at MDA G. The

borehole numbers and sampling ports within each of the four boreholes at MDA G are listed in Table H.3-1.

Table H.3-1 Pore-Gas Monitoring Boreholes and Sampling Ports at MDA G

Borehole Number	Sample Port Depth (ft from surface)
54-2009	37, 62, 79, 92
54-2010	30, 53, 95
54-2032	20, 60,100, 130, 156
54-2033	20, 60, 100, 160, 200, 220, 260, 277

Pore-gas samples were collected using SUMMA canisters; analysis was by gas chromatography/mass spectrometry by EPA T014 method. SUMMA canister samples were drawn from one of the several sampling ports available at each borehole. To select the sample ports, each port is first screened using a Bruel & Kjaer (B&K) model 1302 infrared field-screening instrument. The port sampled is the one with the highest field-screening reading. Selected sampling ports are purged and monitored with field instruments until CO_2 levels have stabilized at values representative of subsurface pore-gas conditions; pore gas at each port is then analyzed using a field-screening instrument for four VOCs (TCA, TCE, Freon 11, and Freon 113). Field QA samples include a duplicate sample drawn from one well, an equipment blank of *zero* air or nitrogen drawn through the sampling apparatus in the working area, and a sample of a known calibration gas. Laboratory QA for the EPA T014 gas chromatography method includes internal surrogates, replicates, blanks, laboratory control samples, and reference standards. The history of pore-gas sampling at MDA G is included in Attachment 2 in the RFI report (LANL 2000, 64360).

H.3.2.5. Core Samples

A total of 20 boreholes were drilled at MDA G during two different drilling programs. In June 1994, two boreholes designated as 54-1110 and 54-1111 were drilled in the southern portion of MDA G, and from September 29 to December 20, 1995, 18 additional boreholes were drilled. On December 5, 1995, borehole 54-1107 was extended to a depth of 130 ft to obtain additional characterization data. Borehole specifics such as depth, inclinations, and adjacent disposal areas are listed in Table H.3-2. Boreholes ranged in depth between 17.5 ft and 153 ft below ground surface.

Table H.3-2 Information about Boreholes Drilled at MDA G

Borehole ID	Date Drilled	Depth (ft)	Inclination From Horizontal (degrees)	Adjacent Disposal Areas
54-1102	October 4,1995	121.5	-32	Pit 32
54-1105	October 12,1995	68.0	-45	Pit 27
54-1106	October 16, 1995	73.5	-45	Pit 25
54-1107	September 29–October 3,1995	90.5	Vertical	Pit 16
54-1107 ext.	December 5,1995	130.0	Vertical	Pit 16
54-1108	October 19–24,1995	73.5	-45	Pit 10
54-1110	June 1994	102.0	Vertical	Pit 23
54-1111	June 1994	153.0	Vertical	Pit A
54-1112	December 6–7,1995	60.5	Vertical	Pit 6
54-1113	December 1–4,1995 (abandoned)	17.5	Vertical	Pit 6
54-1114	October 25–26,1995	59.0	-45	Pit 17
54-1115	October 26–31,1995	135.0	-32	Pit 18
54-1116	October 18–19,1995	89.5	Vertical	Shaft field
54-1117	November 17–27,1995	90.0	Vertical	Shaft field
54-1120	November 14–16,1995	70.0	-45	Pit 2
54-1121	December 13–18,1995	148.0	Vertical	Pit 1
54-1123	December 8–12,1995	100.0	Vertical	Pit 2
54-1124	November 3–7,1995	77.0	-30	Pit 4
54-1125	December 18–20,1995	63.5	Vertical	Pits 3 and 5
54-1126	November 8–13,1995	102.0	-30	Pit 3
54-1128	October 31–November 2,1995	82.5	-30	Pit 1

Following the subsurface investigation, the ownership of RFI boreholes at MDA G was assumed by CST-14, then operational custodian of MDA G. With the exception of boreholes 54-1110, 54-1111, and 54-1113, all boreholes were capped with a steel well casing for subsequent air monitoring. Boreholes 54-1110 and 54-1111 have been instrumental for pore-gas monitoring by waste management. Borehole

54-1113 was abandoned at 17.5 ft and covered with a steel plate because it was inadvertently sited within a subsurface disposal area (Marin 1995, 56694). The two samples that were collected from borehole 54-1113 were not used in the RFI data review because they represent samples of the disposed waste rather than the surrounding tuff.

Twenty-one samples were collected from continuous core from the two boreholes drilled in 1994. From continuous core collected from the 18 boreholes drilled in 1995, 106 samples were collected at 10- to 20-ft intervals. All samples were analyzed for a full suite of metals, VOCs, SVOCs, pesticides, PCBs, and radionuclides. Appendix C of the RFI report provides more details on this field investigation (LANL 2000, 64360).

H.4. MDA G CONCEPTUAL MODEL

The nature and extent analyses of MDA G RFI data (presented in the RFI report [LANL 2000, 64360]) indicate that the known sources of environmental contamination are limited to

- vapor-phase contamination from subsurface PRSs and
- surface soil contamination associated with waste-handling activities and surface disturbances (in this case, trenching and excavation).

Important environmental transport pathways are

- diffusion in pore gas and dispersion in air for vapor-phase releases and
- resuspension and dispersion in air and sediment transport in surface water for surface soil contamination.

Although the preliminary (pre-RFI) site conceptual model for MDA G identifies aqueous-phase subsurface transport of soluble contaminants, this pathway was not indicated by the data. Nonetheless, this pathway is preserved in the revised site conceptual model for evaluating potential future risk because it may be operative over longer time periods.

H.5. MDA G RFI RISK ASSESSMENT

H.5.1. MDA G Present-Day Risk Assessment

The present-day human health risk assessment for MDA G (LANL 2000, 64360, Section 7.1.1) concluded that residual contamination in surface soil, sediments, and air do not pose the potential for unacceptable risk. Chemicals of potential concern (COPCs) evaluated in soil and sediments during the risk assessment included americium-241, tritium, plutonium-238, plutonium-239, Aroclor-1260, and methoxychlor. No inorganic chemicals were detected at concentrations that exceed background values (BVs) in surface soils and sediments. Carcinogenic risks posed by ambient air concentrations of volatile organic compounds (VOCs) were approximately equal to or below the low end of the Environmental Protection Agency's (EPA's) 10^{-4} to 10^{-6} risk range. Chemical hazards from these compounds and radiation doses from tritium diffusing upward from the site were orders of magnitude less than pertinent health effects criteria of 15 mrem/yr. (radionuclides) and a hazard quotient (HQ) of 1.0 for chemical hazard.

The present-day ecological screening assessment for MDA G identified Aroclor-1260 in surface soils at MDA G as a (chemical of potential ecological concern) COPEC. However, based on the low detection frequency and low measured concentrations of polychlorinated biphenyls (PCBs), as well as the spatial pattern of contamination, no additional investigation of PCBs was recommended.

H.5.2. Conclusions from MDA G Future Risk Assessment

The future risk assessment for MDA G was based on hypothetical exposures to concentrations of contaminants in surface soil, groundwater, biota, and air calculated by mathematical models.

A detailed evaluation of future risks posed by MDA G was conducted for the RFI (LANL 2000, 64360, Section 7.1.2). Fate and transport models were used to estimate the rates of contaminant release and transport from the subsurface disposal units and calculate contaminant concentrations in surface soils and groundwater. Calculated contaminant concentrations were used to identify potentially risk-significant COPCs and exposure pathways through a screening analysis. Potential future risks for these COPCs and pathways using exposure scenarios that reflect different intensities of potential land use were then quantified.

The results of the future human health risk assessment indicate there is the potential for unacceptable risks to people that live or spend extended periods of time on the closed disposal site. The future risk assessment evaluated the risk associated with unrestricted land use on the site as it is today, that is, with its operational cover and not an optimized final cover. The purpose of the future risk assessment is to identify the key attributes of potentially unacceptable risk for receptors exposed by way of a variety of pathways and land-use conditions. This information may then be used as the basis for evaluating options for reducing the predicted risk in alternatives assessment.

The future risk assessment indicates that exposure conditions associated with the residential farmer and industrial-use scenarios may result in unacceptable radionuclide dose. Potential chemical cancer risk and hazard were determined to be of potential concern in the residential farmer scenario when exposure occurs in the western area of MDA G. Potential future risk can be maintained at acceptably low levels if the subsurface inventory is isolated from the environment. This implies that site access controls and an optimized final cover design are possible viable alternatives to be considered in the alternatives assessment.

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APPENDIX I

MDA L SUMMARY

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

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TABLE OF CONTENTS

I.1. SETTING AND OPERATIONAL HISTORY 1

I.2. VOC TRANSPORT STUDIES AND MODELING AT MDA L 1

I.3. RFI ACTIVITIES 2

I.3.1. Non-ER Field Investigations 2

I.3.1.1. Subsurface Air Permeability Measurements 2

I.3.1.2. Subsurface Pore-Gas Sampling 2

I.3.2. ER Field Investigations 3

I.3.2.1. Air 3

I.3.2.2. Pore-Gas Sampling 4

I.3.2.3. Core Sampling 6

I.4. MDA L CONCEPTUAL MODEL 8

I.5. MDA L RFI RISK ASSESSMENT 9

I.5.1. MDA L Present-Day Risk Assessment 9

I.5.2. Conclusions from MDA L Future Risk Assessment 9

I.6. REFERENCES FOR APPENDIX I 11

List of Figures

Error! No table of figures entries found.

List of Tables

Table I.3-1 Depths of Pore-Gas Sampling Ports in Boreholes at MDA L 5

Table I. 3-2 RFI Boreholes Drilled at MDA L 6

APPENDIX I

SUMMARY FOR MDA L

I.1. SETTING AND OPERATIONAL HISTORY

MDA L is located on Mesita del Buey approximately 2000 ft (600 m) west of MDA G. A general description of the Mesita del Buey setting is presented in the discussion of MDA G in Section H.1 of Appendix H of this document and is applicable to MDA L.

MDA L is an 1100-ft by 3000-ft (2.5-acre) fenced area located on Mesita del Buey, which lies between Pajarito Canyon and Cañada del Buey in the north-central portion of Technical Area (TA) 54. MDA L contains surface structures in which hazardous wastes generated throughout the Laboratory are currently managed and temporarily stored; interim status container storage units for lead stringers; and 1 inactive subsurface disposal pit (A), 3 inactive subsurface treatment and disposal impoundments (B, C, and D), and 34 inactive disposal shafts (shafts 1 through 34). The subsurface disposal units at MDA L are designated as Potential Release Site (PRS) 54-006; the MDA L surface PRSs are 54-001(a–e), 54-002, 54-008, 54-009, 54-012(b), 54-014(a), and 54-015(g, i).

MDA L was used for the subsurface disposal of liquid hazardous wastes from the early 1960s until 1986. Disposal no longer occurs at this site. The surface of MDA L is presently used for RCRA-permitted chemical waste storage and treatment and for mixed-waste storage under interim status authority in the Laboratory's RCRA operating permit.

Early disposal activities resulted in a subsurface volatile organic vapor plume that extends beyond the MDA boundary. The plume is monitored on a quarterly basis in numerous monitoring wells. Few surface spills are documented for MDA L, and transport pathways appear limited to migration of chemicals in the subsurface.

I.2. VOC TRANSPORT STUDIES AND MODELING AT MDA L

A detailed summary of special studies related to MDA performance is presented in Section G.2 of Appendix G in this document. Of particular relevance is the evaluation of VOC transport at MDA L, which is described in Section G.2.1.3. Quarterly pore-gas monitoring has been conducted at MDA L since 1985 in accordance with a compliance order issued by the state of New Mexico (LANL, 2000, 64360). The evaluation of over a decade of quarterly monitoring data suggests that diffusion of volatile contaminants is significant under normal saturation conditions.

In addition to the evaluation of present-day plume behavior, a calibrated numerical model for the vapor plume beneath MDA L was developed that can be used to analyze the current and future state of the plume (Stauffer et al 2000, ER ID). A diffusion model for TCA transport at MDA L was developed that predicts the migration of the vapor-phase plume from the shafts through the subsurface. The model assumes that the movement of the vapor plume can be described through its most prevalent component, TCA, and that plume growth is controlled by diffusive processes rather than by airflow within the mesa top. The model is calibrated to pore-gas data collected at the site. Simulations of several different cases used various diffusion coefficients, source-term concentrations, and boundary conditions.

The model demonstrates that diffusive behavior captures the general characteristics of the vapor plume. The best-fit simulation maintains a zero concentration boundary in the subsurface basalt unit and along

the northern and western boundary of the model. No liquid source was used, in agreement with field observations.

The observed site data and simulated results indicate that the vapor plume is currently at a near steady condition, both in size and in concentration. The constant flushing of the plume at the mesa sides and in the deep basalt should maintain the plume at its current size until the liquid source, which remains in buried drums, has been exhausted. Estimates based on a conservative TCA source predict that the plume will start to shrink when the source is depleted, before the year 2060.The simulations show that both current and future plume growth (over the next 50 years) are quite small.

I.3. RFI ACTIVITIES

This section summarizes both ER and non-ER investigations and field studies related to VOC transport that have been conducted at MDA L. A complete discussion of RFI activities is presented in the RFI report (LANL 2000, 64360).

I.3.1. Non-ER Field Investigations

The RFI for MDA L is supported by several investigations undertaken by the Laboratory but outside of the ER Project. The results of these investigations are used, either qualitatively or quantitatively, to supplement the RFI investigations completed by the ER Project.

I.3.1.1. Subsurface Air Permeability Measurements

In 1986, five vertical boreholes near MDA L (and MDA G) were used to measure air permeability in Units 2 and 1v of the Tshirege Member of the Bandelier Tuff (Kearl et al. 1986, 15368). Impermeable straddle packers were installed at various depths within the boreholes. Air was injected under positive pressure and extracted under negative (vacuum) pressure between intervals to measure how fast air moves through the solid subsurface. The highest air permeabilities were measured in Unit 2, which is more densely welded and fractured than the underlying Unit 1v. The data resulting from this study were used to evaluate the nature and extent and fate and transport of subsurface contamination at MDA L.

I.3.1.2. Subsurface Pore-Gas Sampling

On May 7, 1985, the Laboratory received a compliance order from the state of New Mexico requiring quarterly pore-gas monitoring at MDAs G and L. Nine boreholes were installed from 1985 to 1988, and sample tubes and sample ports were installed in the boreholes to monitor the subsurface VOC plume. Analytical results for discrete pore-gas samples collected from the MDA L monitoring well network from 1985 to 1988 are presented in Trent (1990, 12557) and from 1988 to 1990 in Trent (1992, 11881). Review of analytical data from pore-gas sampling conducted from 1986 to 1990 (IT Corporation 1991, 11729) indicated that

- TCA is the primary constituent of the VOC plume,
- TCA is present to at least 200 ft below the surface of the mesa, and
- TCA concentrations vary across the plume.

Analytical results for pore-gas samples collected during 1988 to 1992 are summarized in "Pilot Extraction Study Plan for the Organic Vapor Plume at MDA L" (LANL 1993, 22430). This study describes the VOC plume at MDA L as follows: "the principal vapor phase organic compounds, listed in descending order of concentration were TCA, TCE, carbon tetrachloride, chloroform, tetrachloroethene (PCE), toluene, and

benzene. Other contaminants that have been detected, but at much lower concentrations, include chlorobenzene, xylenes, and 1,2,4 trimethylbenzene. In addition to having the greatest concentration, TCA also exhibits the greatest lateral and vertical extent in the organic vapor plume. The measured concentrations of TCA are almost an order of magnitude greater than values measured for TCE, the contaminant of second highest concentration."

I.3.2. ER Field Investigations

The ER Project at the Laboratory conducted RFI fieldwork at MDA L from 1993 through 1999. The preliminary sampling plan outlined in Chapter 5 of OU 1148 work plan and the June 8, 1994, modification to the work plan was modified during implementation. Field work actually performed and deviations from the work plan is described in Chapter 5 of the RFI report (LANL 2000, 64360). The following represents a summary of investigations related to VOC evaluation; a complete description of ER field investigations is presented in the RFI report.

I.3.2.1. Air

I.3.2.1.1. Ambient Air Sampling

During the summer of 1994, ambient air samples were collected for VOC analysis on eight days at two sampling locations on the northern perimeter of MDA L. Air samples were also collected at a background location adjacent to Bandelier National Monument. Sampling dates included June 16, 17, 29, and 30; July 28; and August 1, 2, and 3. The June samples coincide with the height of the dry season on the Pajarito Plateau, while the July and August samples were taken during the rainy season. Samples were collected over approximately an 8-hr period beginning at 8 a.m. Meteorological data that may influence VOC concentrations (i.e., ambient temperature and wind data) were also recorded.

A more detailed discussion of this work is discussed in "Ambient Monitoring of Volatile Organic Compounds at Los Alamos National Laboratory in Technical Area 54, Areas G & L" (Mischler and Anderson 1994, 63525).

I.3.2.1.2. Surface Tritium and VOC Flux Chamber Measurements

During the summer of 1993, a flux chamber was used to measure tritium surface flux at eight locations near MDA L and VOC fluxes at six locations. The data were collected as part of a sampling program designed to establish overall rates of tritium and VOC flux from MDA G (Eklund 1995, 56033). Sampling locations were not specifically targeted to locations where the subsurface VOC plume is known to exist.

I.3.2.1.3. Surface Flux Measurements for VOCs

VOC flux data were collected in 1993 and 1994. Details of the investigation are reported in two reports (Quadrel Services 1993, 63868; Quadrel Services 1994, 63869). Trujillo et al. (1998, 58242) issued a Laboratory report on the results of the flux measurement investigations.

Approximately 70 flux chamber sampling devices were deployed at MDA L in late August 1993 and collected after four days. Trujillo et al. (1998, 58242) noted that another 32 devices were deployed on August 15, 1994, and collected on August 19. The majority of the 1993 samples were located on the mesa top, while most of the 1994 samples were collected from the slopes and drainages on the sides of the mesa.

I.3.2.1.4. Open Borehole VOC Flux Measurements

In 1997 and 1998, the ER Project evaluated the effectiveness of passive vapor extraction of subsurface vapor-phase VOCs at MDA L. Passive vapor extraction utilizes natural changes in atmospheric barometric pressure as a *pump* to exhaust VOCs through one or more open boreholes. The volume of air flowing out of a borehole and the concentration of VOCs in that air may be used to calculate an annual emission rate of VOCs from the borehole. In 1997, measurements were made at borehole 54-1006 and recorded in the report "Passive Vapor Extraction Test at TA-54, Well 54-1006 During 1997" (Neeper and Kisiel 1998, 63999). In 1998, the tests were repeated using a one-way valve on the borehole to allow only exhalation of subsurface air without replenishment by way of the borehole during periods of relatively high atmospheric pressure. The 1998 study measured vapor concentrations and pressure at several subsurface ports in three boreholes and in atmospheric air. The 1998 results are recorded in the report "Passive Vapor Extraction Test with a One-Way Valve at Borehole 54-1006, MDA L, TA-54" (Kisiel and Mason 1998, 63526).

As described in the Neeper and Chipman report (1998, 63527), the screened interval of borehole 54-1006 is the largest of all the open wells at MDA L and coincides with the portion of the VOC plume with the highest concentrations. Consequently, VOC emissions from this well are expected to represent an upper-bound estimate of VOC emissions from passively vented boreholes at MDA L.

Two monitoring systems were used in the 1997 and 1998 studies. The 1997 study included borehole velocity transducers to measure borehole airflow, an outdoor humidity sensor, and both atmospheric and atmosphere-to-subsurface pressure transducers. The 1998 study used the same system except a one-way valve was added.

The 1998 study was performed over a 64-day period from March 12 to May 15. During the last week of April, the atmospheric conditions shifted abruptly from a winter pattern (characterized by synoptic 3–5 day weather events of high and low pressure) to a summer pattern (where such events are relatively rare). Flow data indicated larger and longer borehole exhalations during the winter pattern.

I.3.2.2. Pore-Gas Sampling

Sampling of subsurface pore gas at MDA L is required by the Module VIII of the Laboratory's Hazardous Waste Facility Permit in Section C.5, "Unsaturated Zone Monitoring" (EPA 1990, 1585). The sampling and analysis plan requires sampling 12 of 28 available boreholes each quarter. Of these 12, 10 are to be selected from a list of 24 boreholes located at MDA L.

The 24 boreholes currently sampled at MDA L are listed in Table I.3-1. Detailed borehole logs, including lithologies and well construction diagrams, are presented in Attachment 3 of the RFI report (LANL 2000, 64360). Pore-gas monitoring methods have changed over the years in response to sampling and detection capabilities. A summary of historical pore-gas sampling is included in Attachment 2 of the RFI report (LANL 2000, 64360).

These boreholes and sampling ports were to be used to study and optimize alternative active and passive VOC extraction processes as a potential remedial action. The pilot extraction study plan, as originally described in the OU 1148 work plan, was modified in 1996 (LANL 1992, 7669) to replace two of the vertical boreholes with two angled boreholes. The angled boreholes 54-1015 and 54-1016 were drilled between November 1994 and March 1995 from Cañada del Buey to a vertical depth of 400 ft and 600 ft below the surface of MDA L. These boreholes were drilled into the basalt underlying the Bandelier Tuff. Borehole 54-1015 was drilled to intersect the region below the closed disposal shafts located in the western part of MDA L. Borehole 54-1016 was drilled to intersect the region below the closed pit, impoundments, and shafts located in the eastern part of MDA L.

I.3.2.3. Core Sampling

From September 9, 1993, to May 8, 1995, a total of 18 boreholes were installed as part of the MDA L RFI field work. Pertinent information on each borehole, such as depth, declination, and adjacent disposal unit are listed in Table I.3-2.

Table I. 3-2 RFI Boreholes Drilled at MDA L

Borehole ID	Date Drilled	Depth (ft)	Declination (degrees from horizontal)	Adjacent Disposal Unit	Status
54-1001	9/9–9/16/93	315	-63.5	None	Monitoring well
54-1002	9/20–9/23/93	310	-69	None	Monitoring well
54-1003	10/3–10/4/93	299	Vertical	None	Monitoring well
54-1004	10/8–10/14/93	340	Vertical	None	Monitoring well
54-1005	12/1–12/3/93	291	-69	None	Monitoring well
54-1006	9/24–10/1/93	320	-65	None	Monitoring well
54-1007	11/23–11/30/93	150	Vertical	Shafts 1-6	Backfilled
54-1008	11/18–11/19/93	150	Vertical	Shaft 1	Backfilled
54-1009	11/16–11/17/93	150	Vertical	Shaft 27; pit A	Backfilled
54-1010	7/28–8/1/94	60	-45	Pit A	Backfilled
54-1011	7/26–7/27/94	50	-55	Pit A	Backfilled
54-1012	7/25–7/26/94	50	-55	Impoundment B	Backfilled
54-1013	7/15–7/20/94	50	-55	Impoundment C	Backfilled
54-1014	7/22/94	50	-55	Impoundment D	Backfilled
54-1015	11/17/94–1/9/95	530	-61.5	None	Monitoring well
54-1016	2/1–3/17/95	607	-59.5	None	Monitoring well

54-1017	4/19–4/20/95	159	Vertical	None	Extraction well
54-1018	4/21–5/8/95	328	Vertical	None	Monitoring well

Boreholes 54-1001 through 54-1009 were drilled at MDA L in 1993. Of these, borehole 54-1001 through 54-1006 were drilled just east of MDA L. These six boreholes were drilled to depths ranging between 299 ft and 340 ft using an 8-in.-diameter hollow-stem auger and continuous coring technique; they were instrumented with vapor-monitoring systems using Seamist borehole liners.

From continuous core drilled in boreholes 54-1001 through 54-1006, 95 samples were collected at 20-ft intervals. From continuous core drilled in boreholes 54-1007 through 54-1009, 38 samples were collected at 10-ft intervals. All samples were analyzed for target analyte list metals, cyanide, pesticides, PCBs, herbicides, SVOCs, VOCs, and the following radiological isotopes: americium-241, cesium-137, plutonium-238, plutonium-239/240, uranium-234, uranium-235, and uranium-238).

Boreholes 54-1010 through 54-1014 were drilled at an angle using an 8-in.-diameter hollow-stem auger and continuous coring technique in 1994 beneath former disposal units at MDA L; they were subsequently backfilled upon completion. From continuous core, 28 samples were collected at 10-ft intervals and analyzed for metals, cyanide, pesticides, PCBs, SVOCs, VOCs, gross alpha, gross beta, total uranium, and tritium.

During the winter of 1994 and 1995, two deep angle boreholes designated as 54-1015 and 54-1016 were drilled from the adjacent canyon slope northeast of MDA L. These boreholes were drilled to depths of 530 ft and 607 ft, respectively, using air rotary installation of 8-in.-diameter STRATEX casing to the bottom of each borehole. The boreholes were selectively cored for approximately 10 ft within every 40-ft interval below 260 ft. Following the installation of a Solinst multiport monitoring well in each borehole, the STRATEX casing was withdrawn while annular well completion materials were emplaced. From discontinuous core, 22 samples were collected at 50-ft intervals and analyzed for VOCs and tritium.

During the spring of 1995, two additional boreholes, designated as 54-1017 and 54-1018, were installed in the MDA G development area east of MDA L. Borehole 54-1017 was designed as the extraction well for the pilot vapor extraction test, and borehole 54-1018 was an additional monitoring well located 20 ft from 54-1017. Borehole 54-1017 was drilled to a depth of 159 ft using an 8-in.-diameter hollow-stem auger and reamed to 10-in. diameter. Borehole 54-1017 contains 75 ft of 10-in.-diameter steel casing and is open below the casing to a depth of 150 ft. Borehole 54-1018 was drilled to a depth of 328 ft using an 8-in.-diameter hollow-stem auger and continuous coring technique. Borehole 54-1018 contains 30 ft of 8-in.-diameter steel surface casing. No samples were collected for chemical analyses.

In addition to the chemical analyses performed on core samples, the following analyses were performed for use in modeling contaminant fate and transport:

- descriptive lithology;
- saturated hydraulic conductivity;
- moisture content, bulk density, and porosity;
- moisture characteristic curves;
- specific gravity;
- specific surface area;
- air permeability; and
- VOCs.

I.4. MDA L CONCEPTUAL MODEL

The nature and extent analyses of MDA L RFI data (presented in the RFI report [LANL 2000, 64360]) indicate that the known sources of environmental contamination are limited to

- vapor-phase releases of tritium and VOCs from subsurface PRSs and
- releases of metals dissolved in liquid solvents into tuff below the subsurface PRSs.

Important environmental transport pathways are

- resuspension and dispersion in air and sediment transport in surface water for surface soil and sediment contaminated with methoxychlor (source unknown),
- diffusion in pore gas and dispersion in air for vapor-phase VOCs and tritium, and
- saturated transport of dissolved metals, followed by sorption onto minerals and solid phases in tuff.

The subsurface solute-transport pathway at MDA L is indicated by the data. Although limited liquid-phase contaminant transport may have occurred in the past as indicated by the presence of metals in core samples below the PRSs, shallow drilling beneath MDA L has not discovered any residual solvent saturation or any adsorbed VOCs. Additionally, moisture content in core samples from beneath the PRSs is within the range of background in tuff. This evidence implies that there is no liquid source present now. Nonetheless, because liquid VOCs may still be present in the MDA L inventory (e.g., intact drums), the possibility of future liquid-phase solute transport is retained in the site conceptual model.

If intact drums of chemicals are still present, it is assumed that liquid-phase transport of solvents and associated metallic residue will occur. The depth of transport will be limited by the volume of tuff that will become saturated by the liquid waste. Saturation is limited by the volume of liquid (e.g., 55 gal.) and the porosity of the tuff, assuming that liquid solvent will displace residual pore water. To evaluate the potential for liquid VOC flux (aqueous-phase transport) given the uncertainty in remaining inventory, the rate of volatilization was compared to the rate of saturated and unsaturated flux. Based on conservative assumptions, a 55-gal. drum of trichloroethane would volatilize within a year and would only move about 30 m even under continuous saturation. Therefore, the future risk assessment focuses on the risk associated with vapor-phase transport of VOCs in the subsurface and not aqueous-phase transport.

Once saturation is achieved and the liquid source is depleted, unsaturated flow conditions will prevail. Thereafter, volatile chemicals will diffuse through the pore space in the tuff, and metals will sorb onto solid phases. The introduction of 55 gal. of liquid into the subsurface at MDA L will not result in prevailing saturated flow conditions. For example, the Purtymun injection well tests (1989, 6889) injected the equivalent of approximately 20 55-gal. drums per day under 26 psi pressure (i.e., the equivalent of a 60-ft column of water); after 14 days, the water source was removed, and unsaturated conditions prevailed beneath a depth of 140 ft below the injection zone.

After coming in contact with air that occupies pores in the tuff, VOCs begin to evaporate into the pore air. In theory, vapor-phase VOCs can dissolve into capillary water or be adsorbed onto mineral surfaces or soil organic matter. However, the low moisture content, absence of organic carbon, and poor mineral adsorptive qualities of the tuff render these processes unimportant at TA-54. All site data indicate VOCs reside predominantly in the vapor phase in the tuff.

Depending on the air permeability of the medium and density of the compound(s), movement of VOC plumes can be represented as advective (density driven) or diffusive (concentration driven) (Conant et al.

1996, 64608). Density-driven flow increases the downward migration rate of a VOC and affects the distribution of the plume in solid media with air permeabilities greater than 10^{-11} cm^2 (10 darcies). This is the upper limit for air permeability for the Bandelier Tuff. Based on relatively low air permeability, vapor movement beneath MDA L is expected to be dominated by diffusion, with the rate of diffusion being determined by the concentration gradient between the source and the ambient pore gas. In a homogeneous media subject to atmospheric pressure variations, which has been indicated at TA-54, VOC migration is characterized by a higher effective diffusion coefficient than in the isobaric case.

I.5. MDA L RFI RISK ASSESSMENT

I.5.1. MDA L Present-Day Risk Assessment

The present-day risk assessment for MDA L concluded that surface contamination at the site posed no unacceptable risk to human health. No radionuclides or inorganic chemicals were detected in sediment samples collected at the site. A single organic compound, methoxychlor, was detected but at concentrations similar to those found to pose no unacceptable risk at MDA G. Results of an ambient air risk assessment for VOCs indicated carcinogenic risks that were approximately equal to or below the 10^{-6} risk that represents the lower end of EPA's acceptable risk range. Potential doses from tritium at MDAs H and L are well below those shown to pose an acceptable risk in the MDA G risk assessment. The ecological screening assessment found that chemicals did not have the potential for adverse ecological impacts to receptors at MDA L.

I.5.2. Conclusions from MDA L Future Risk Assessment

The types and quantities of waste disposed of at MDA L and the geohydrologic properties of the site play an important role in the evaluation of the potential future risk posed by this disposal site. The site was designed for the disposal of hazardous liquid waste that was essentially free of radioactivity. Records for the site indicate the disposal of tritium but no other radionuclides. These records are supported by subsurface sampling and analysis activities at the site, which found that only tritium was present at levels in excess of Laboratory fallout levels. Because the very large quantities of tritium disposed of at MDA G did not pose a risk to humans or the environment, it was concluded that the potential tritium dose at MDA L is acceptable.

MDA L was the laboratory's primary site for disposal of liquid wastes (including solvents) and did not include disposal of large quantities of radionuclides. In spite of these differences in inventory, the subsurface transport characteristics of certain chemicals (like cadmium and mercury) are not different, qualitatively, than the transport characteristics of radioactive metals (like uranium, plutonium, and americium). The rate and volume of groundwater transport is controlled, in large part, by the volume of *carrier* liquid.

The effect of the liquid discharges to subsurface PRSs at MDA L is evident in some of the subsurface sampling and analysis data collected at MDA L. Some metals and organic compounds have been detected 150 ft below the ground surface. Based on the *unsaturated* groundwater transport calculations conducted for MDA G, the depth of solute transport at MDA L indicates that *saturated* conditions existed for a brief period of time. Because core samples taken beneath the PRSs at MDA L do not differ in moisture content from background tuff values, future infiltration rates at MDA L are expected to be similar to those at MDA G, unless drums of liquid waste in the MDA L subsurface rupture in the future. Based on conservative assumptions, a 55-gal. drum of trichloroethane would volatilize within a year and would only move about 30 m even under continuous saturation.

To determine the potential consequences of liquid solvent releases in the future, numerical models were used to calculate the effect of increased liquid VOC on the existing plume. The results indicate that such releases may increase the concentration of the VOC plume in a very localized region within the shafts but will not significantly affect the amount of volatilized material released to the atmosphere. ICRs based on surface flux measurements of VOCs at MDA L were slightly below the lower end of EPA's 10^{-4} to 10^{-6} acceptable risk range (Section 7.2.1 of the RFI report [LANL 2000, 64360]). Because these concentrations are not likely to increase with additional liquid VOC releases, the future risk is expected to remain acceptable.

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APPENDIX J

MODELS

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

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TABLE OF CONTENTS

J.1. INTRODUCTION **1**

J.2. GLOSSARY **1**

J.3. DEVELOPMENT OF THE SYSTEMS MODEL **2**

J.3.1. Model Requirements for Point Estimates 3

J.3.2. Conservatism of Point Estimates and PRA 3

J.3.3. Hazard Reduction Approach 3

J.4. REMEDY PROFILES **4**

J.5. QA PROCEDURES **5**

J.5.1. Systems Models 5

J.5.2. Alternatives and alternate conceptual models 5

J.5.3. Hazard Reduction 5

List of Figures

Error! No table of figures entries found.

List of Tables

Error! No table of figures entries found.

APPENDIX J

MODELS

J.1. INTRODUCTION

J.2. GLOSSARY

Systems Model: a model that integrates all relevant processes in the system.

Deterministic Model: a function that produces a single value for a given set of input variable values.

Stochastic Model: a model that produces a probability distribution. In our case, the stochastic model is obtained from the deterministic model by defining some input variables by probability distributions.

Point Estimate: A point estimate of risk is a single evaluation of the deterministic model where all stochastic input variables are replace by the value of, say, their 90% upper confidence limit (UCL) as defined below. A point estimate of risk is always associated with a confidence level, the most commonly used value being 90%. For illustrative purposes, we use 90% in the remaining discussions. However, any other confidence level may be used for point estimates, as long as consistency throughout all variables is maintained.

Probabilistic Risk Assessment (PRA): evaluation of the output of the stochastic model as a probability distribution for the risk. The most common method is Monte-Carlo simulation. In this approach, samples are drawn from the stochastic input variables and a corresponding risk value is calculated using the deterministic model. The collection of risk values represents a sample drawn from the risk distribution. If enough samples are generated, the probability distribution for the risk may be estimated by numerical methods. To obtain convergence of this estimate in the tail of the distribution (say 90% UCL), many thousands of samples are required. However, the convergence may be accelerated by importance sampling techniques if the dominant stochastic variables are risk-monotone.

Risk-Monotone: An input variable is risk-increasing (decreasing) if for any feasible value of the input variable, an increase in the input variable always gives an increase (decrease) in risk. An input variable is risk-monotone if it is either risk-increasing or risk decreasing.

Upper Confidence Limit (UCL): for a risk-increasing variable, the probability that the actual value is less than the "90% UCL" is 90%. For a risk-decreasing variable, the probability that the actual value is greater than the "90% UCL" is 90%.

Base-Case Conceptual Model: the set of modeling assumptions determined likely to be true.

Alternate Conceptual Model: a set of modeling assumptions in which one or more base-case assumptions is violated.

Hazard Identification Procedure: a screening procedure for FEP's that have a potential to contribute to the risk. The first step of the hazard identification procedure is to list all possible FEP's relevant to the risk. The second step is to grade the FEP's in terms of their probability and consequences. A grading system of Low, Medium and High is used. The grades are defined relative to the regulatory risk thresholds.

Unlikely FEP: unlikely feature/event/process. A relevant FEP that receives a probability grade of Low or Medium in the hazard identification process.

Hazard Reduction Approach: a set of risk assessments with a hierarchical structure, in which protective systems are added to the model one at a time. The log (base 10) of the risk reduction factor associated with the protective system is its hazard reduction magnitude.

Conditional Risk Distribution: the probability distribution of risk conditioned on a particular set of assumptions.

Stochastic Domination: Given two probability distributions with respect to the same risk-increasing variable, we say that one probability distribution dominates the other if its cumulative distribution function (cdf) is always less than the cdf of the other. Equivalently, the dominating distribution will have a larger variable value at every percentile. The inequalities are reversed in the case of a risk-decreasing variable.

J.3. DEVELOPMENT OF THE SYSTEMS MODEL

The first step in the development of a systems model is the creation of the deterministic model. A deterministic model is a mathematical representation of the relationship between input variables and risk under certain specified assumptions. For example, the base-case deterministic model depends on the base-case assumptions, which is collectively called the base-case conceptual model. The base-case conceptual model includes all relevant FEP's that are considered likely, as determined in the hazard identification process.

Although systems models are small, they are by no means simple. The relationships between the composite quantities that make up the systems model often cannot be determined directly from first principles. The process of converting a process-level description of the relationships to a larger scale appropriate for the systems model is called up-scaling. Upscaling may be performed by analytical or empirical means. The mathematical relationship between the input variables and the risk may include the contributions from many different mechanisms. Detailed process models for each mechanism can be used to derive empirical up-scaled relationships. We may upscale by deleting or analytically approximating certain aspects. Significant effort using data and/or process models may be required to justify such approximations.

The second step is to estimate the uncertainty in all input variables. The probability distributions for input variables must represent the total uncertainty of the variable within the context of the conceptual model assumptions. In a few cases, direct observations of the variable are available. In these cases, traditional statistical techniques alone are suitable to express the uncertainty of the variable. More commonly, indirect observations are available. In this situation, a model is required to relate the indirect observation to the input variable. This model will have an inherent level of uncertainty associated with it. Bayesian estimation and expert elicitation are appropriate techniques for the development of probability distributions for input variables using indirect observations.

The third step is to perform a sensitivity analysis of the model. Sensitivity analysis evaluates the contribution to the total uncertainty from the uncertainty of each individual input variable. A number of techniques are available to perform sensitivity analysis. The most commonly used are correlation coefficients and scatter plots. Correlation coefficients are useful for screening many variables but are subject to inaccuracy if nonlinear behavior is present. Scatter plots are useful for detecting correlations as well as nonlinear behavior, but can be tedious when applied to large numbers of variables. If the stochastic variables are known to be risk-monotone, correlation coefficients will provide a reasonably accurate measure of sensitivity.

Finally, a stochastic model may be created. Although all input variables that enter the model have uncertainty associated with them, the stochastic model explicitly models the uncertainty of only those

variables to which the risk is highly sensitive. In the stochastic model, input variables to which the risk is not highly sensitive are treated deterministically, with values typically being the mean or median of their distributions.

Systems models are intentionally made as small as possible for a number of practical reasons. To achieve convergence in PRA, thousands of realizations must be performed. It is not feasible to obtain enough realizations for a large model. As discussed above, sensitivity analysis is required in the development of the stochastic model. It is difficult to obtain reliable sensitivity results for large models. To make use of point estimates, it must be possible to determine that all stochastic variables are risk-monotone. This may be impossible to determine for a large model.

J.3.1. Model Requirements for Point Estimates

For a 90% UCL point estimate to provide a bound for the 90% UCL of risk, all stochastic variables must be risk-monotone, as defined above.

J.3.2. Conservatism of Point Estimates and PRA

A point estimate of risk is at least as conservative as a risk estimate from PRA. The point-estimate may be known to be more conservative than PRA because additional approximations were required to obtain a stochastic model suitable for point-estimation. When the stochastic model for point estimates and PRA is the same, it may be difficult to predict in advance how conservative the point estimate is compared to PRA. An indicator of potential over-conservatism of the point estimate is the presence of more than one variable with high relative sensitivity ratings.

The stochastic model for PRA is usually based on conservative assumptions. Further, the scenarios used in the model are often conservative by design. Thus risk estimates from PRA, like point estimates, are upper bounds on the actual risk.

J.3.3. Hazard Reduction Approach

The idea of the hazard reduction approach is to start with an admittedly over-conservative bounding analysis, and then start adding protective systems one by one. The hazard reduction magnitude is the log (base 10) of the risk reduction factor as measured, in our case, by excess cancer risk and hazard quotient or an equivalent variable.

Here is a possible hazard reduction hierarchy for the upward transport pathway:

1. The complete inventory is immediately transported to the surface without backfill or surface spreading.
2. Allow for institutional control period and for radioactive decay.
3. Allow for reduction of concentration from uniform mixture with backfill during burial. Assume a zero-thickness cap that is never breached.
4. Allow for a finite speed of upward transport, taking the maximum from both animal and plant transport.
5. Allow for a variable rate of upward transport, assuming a uniform distribution of the inventory from the surface to the bottom of the pit.

6. Allow for the worst waste to occur lower in the pits.

7. Allow for additional depth due to a cap. Assume a uniform (but conservative) erosion rate.

8. Allow for a biobarrier layer in the cap design.

The results of such a study are presented as plots of risk (on a log scale) versus time. Risk reductions and risk deferments (shift of maximum risk to later times) can be read directly from the graph. The results of point estimates versus probabilistic calculations can be compared to see whether there is an advantage in the probabilistic calculation.

Similarly, hazard reduction hierarchies may be constructed for the other exposure pathways. A possible hierarchy for the groundwater pathway is:

1. The complete inventory is immediately transported to a glass of water, which is consumed by a single individual.

2. Allow for institutional control period and for radioactive decay.

3. Allow for finite solubility and reasonable water consumption rates.

4. Allow for a finite aqueous infiltration rate with a landscape cap, assuming current climate conditions and catchment area.

5. Allow for subsurface sorption of contaminants. This protective system also depends on finite subsurface aqueous flow rates. Probability of fracture flow enters here.

6. Allow for subsurface evaporation of water.

7. Allow for reduced infiltration for some cap designs.

8. Allow for dilution in the regional aquifer (CTE model only).

J.4. REMEDY PROFILES

Technical requirements pertaining to performance-based goals are determined from performance-based technical design of the remedy. Process models or experiments may be used to establish site-characteristics necessary for the remedy to be effective. For consistency with our probabilistic approach that accounts for uncertainty in all information, confidence levels should be a part of the statement of the constraint. For example: "the moisture content of the soil should be less than 20%, with 90% confidence."

The most fundamental formulation of the risk-based component of the remedy profile is that the risk associated with the remedy when applied to the site in question must fall below target risk levels. Direct application of this formulation of the remedy profile would require a full risk assessment (either point estimate or PRA) for each site, for each remedial alternative to be considered.

A more effective use of the plug-in approach would be to backcalculate from the systems model to obtain thresholds for the site-specific variables that influence risk. A systems model that is risk-monotone with respect to its stochastic variables is required. One method for backcalculation uses the point estimate calculation. Since this method of risk assessment is deterministic in nature, mathematical methods for inverting functions can be directly applied to derive constraints on UCL's of input variables.

The main advantage of using point estimates for back-calculation is the simplicity of the computation, assuming a small systems model is employed. The primary disadvantage of using point estimates for backcalculation is over-conservatism. The remedy profiles derived from backcalculation will identify with a high-degree of confidence those remedies that will be effective at a particular site. However, over-conservatism in the remedy profile may cause some remedies to be ruled out that might also have been effective and less costly.

Generic PRA's can also be used for backcalculation to obtain remedy profiles, provided systems models are small and risk-monotone. In this calculation, we restrict the input variable distributions to certain families described by a limited number of variables. In this way we create a single-valued function that maps the distribution variables into a risk distribution. This mathematical restriction allows us to back-calculate remedy profile constraints on the input distribution variables. To meet the requirements of the remedy profile, the site-specific input variable distribution must be stochastically-dominated by a distribution from the specified family with distribution variables satisfying the remedy profile constraints.

An advantage to using PRA in the backcalculation of remedy profiles is that there is more flexibility and less conservatism in the resulting remedy profile. A drawback to using PRA is that the backcalculation has more variables and so is more complicated and less transparent. Another drawback is that more detailed information about the probability distribution of the variables is required.

J.5. QA PROCEDURES

J.5.1. Systems Models

Software used for process or systems model simulations must be accepted by the technical community as validated. If the software does not already have such a status, validation by external reviewers will be obtained. Version control software will be used for computational model revisions. The systems model will be fully documented and reviewed. In particular, the deterministic model will be reviewed for consistency with the conceptual model and its mathematical realization. The interaction matrix (Ch. 3) will be used as a tool for verification of the deterministic model.

Input variables will be reviewed concerning their representation as deterministic or stochastic variables, based on sensitivity analysis. References for all deterministic values will be provided. Probability distributions for stochastic variables may be obtained from references or derived from modeling and/or expert elicitation. All derivations of probability distributions will be reviewed by the expert panel involved in elicitation and by peer review.

This QA procedure is applied to the base-case stochastic model, to all systems models for alternate conceptual models and hazard reduction models and to probabilities of alternate conceptual models.

J.5.2. Alternatives and alternate conceptual models

The alternatives and the alternate conceptual models are derived from the hazard identification process. QA will include review of the alternatives and alternate conceptual model by the hazard identification panel, followed by peer review.

J.5.3. Hazard Reduction

The hierarchical structure of the hazard reduction computation is an alternate representation of the base-case conceptual model. QA of the hierarchical structure is conducted by peer review, and includes verifying consistency with the base-case conceptual model.

Each hazard reduction computation uses a systems model. QA of each of the computations in the hazard reduction computation is the same as the QA for the base-case stochastic model.

PIECES STOLEN FROM THE TA-54 RFI REPORT (I THINK) NEEDS TO BE SUPPLEMENTED AND FOCUSED

APPENDIX K

COVER TECHNOLOGIES

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

8/27/00 1:46 PM

TABLE OF CONTENTS

K.1. INTRODUCTION 1
K.1.1. Surface Processes and Cap Performance 1
K.1.1.1. Los Alamos Experimental Engineered Test Facility 1
K.1.1.2. Los Alamos Integrated Test Plot Experiments 2
K.1.1.3. Erosion Control Study 3
K.1.1.4. Protective Barrier Landfill Cover Demonstration 4

List of Figures

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List of Tables

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APPENDIX K

COVER TECHNOLOGIES

K.1. INTRODUCTION

K.1.1. Surface Processes and Cap Performance

Under the sponsorship of the US Department of Energy (DOE), US Nuclear Regulatory Commission, Environmental Protection Agency (EPA), Air Force, and Navy, the Environmental Science Group at the Laboratory has performed studies and demonstrations on landfill surface covers and processes that affect landfill performance for nearly two decades. The guiding principles for landfill cover design projects are to reduce risks to human health and the environment and to reduce costs associated with post-closure monitoring and maintenance. The demonstrations and studies are grouped into three general categories:

- materials and their arrangements for landfill covers
- processes that affect long-term performance of the landfill
- post-closure monitoring to measure landfill performance

Although supporting national interests, the studies have focused on optimal designs for arid climates. They feature robust capillary barriers that are not subject to desiccation and cracking. Processes that affect long-term integrity have been investigated, including intrusion by animals and vegetation, subsidence, surface erosion, vegetation establishment and succession, and climate. Instruments that measure water content to determine cover performance and landfill response have been tested, as have automated data collection techniques.

K.1.1.1. Los Alamos Experimental Engineered Test Facility

Between 1981 and 1988, a field research and development program funded by the DOE and performed at the Laboratory developed and evaluated technology to address shallow-land barrier problems in arid environments. The objectives of the program were to develop and field-test:

- biointrusion barriers (biobarriers)
- systems for ground and surface water management

Field experiments were installed within an 8.6-ha (21-acre) plot of land designated the "LANL Experimental Engineered Test Facility (EETF)." A plant root intrusion study was conducted in lysimeters containing various combinations of vegetation, soil, and barrier material. Conditions were optimized for rapid plant growth to produce maximum root penetration. Stable cesium, which is absorbed by plant roots and translocated to above-ground plant tissues, was applied beneath each cover profile as a simulated waste. Samples of vegetation were analyzed using neutron activation of cesium at various times through the experiment.

Cobble, gravel, and clay were tested as biobarrier components in the following designs:

- topsoil underlain by 30, 60, and 90 cm (12, 24, and 36 in.) crushed tuff (control)
- topsoil underlain by 15, 30, and 45 cm (6, 12, and 18 in.) bentonite clay
- topsoil underlain by 30, 60, and 90 cm (12, 24, and 36 in.) cobble
- topsoil underlain by 30, 60, and 90 cm (12, 24, and 36 in.) cobble/gravel mixture

Results showed that crushed tuff offers little protection against root intrusion, while the clay, cobble, and cobble/gravel barriers were very effective. Increasing barrier thickness greatly improved the performance of each system; maximum thickness generally reduced root intrusion to less than 20% of the control plot.

An animal intrusion barrier experiment was conducted by filling metal culverts with crushed-tuff backfill and 90 cm of each of the four barriers described above. A single pocket gopher (Thomomya bottae) was maintained in each culvert and allowed to construct a burrow system within the cover profile over a period of 4 months. At the end of the study period, the gophers were removed and their tunnel systems were injected with an expanding polyurethane foam to provide a cast of the tunnel system. The tunnel case was exposed by excavation to provide a qualitative evaluation of intrusion barrier effectiveness.

Results of the gopher intrusion experiment demonstrated that cobble, cobble/gravel, and clay were equally effective in preventing animal intrusion with depth. The crushed-tuff barrier, however, was readily used for tunneling.

In assessing the overall effectiveness of the clay, cobble, and cobble/gravel biobarriers, it was determined that the clay was less useful in that it is subject to desiccation, shrinkage, and cracking in the semi-arid environment of the Laboratory. Additionally, cobble, although effective in preventing animal burrowing, may not be a viable long-term plant intrusion barrier because of the potential for interpenetration of soil into the rocks, which would support root growth. Thus, the cobble/gravel barrier was judged most effective at minimizing both plant and animal penetration.

Two moisture-barrier field experiments were conducted in the Laboratory EETF, consisting of 3-m-(10-ft-) diameter by 6-m (19-ft) deep caissons. One was filled with tuff overlying gravel (control), and the other was filled with a tuff-bentonite (2%) mix overlying sand. The tuff-bentonite interface was sloped at 10% to provide additional information on the "wick effect" of the finer tuff-bentonite mixture: Percolating liquid will penetrate the coarser sand only after the finer tuff-bentonite layer nears saturation; at unsaturated conditions, moisture will move laterally along the interface. Soil moisture determinations were performed using neutron moisture gauges. Measurements were made every 30 cm (12 in.) across the entire width of each caisson. Soil water tension was determined with a tensiometer.

Results indicate that a capillary barrier made of crushed tuff and clay would work effectively over a relatively wide range of soil moistures in the field, providing protection to underlying wastes in varying moisture conditions. Use of local tuff with low amounts of added bentonite appeared to be very promising in greatly decreasing hydraulic conductivity without showing any of the mechanical impairments of clay mentioned above. Furthermore, results suggested that the wick phenomenon of unsaturated flow is potentially useful in the design of capillary barriers.

K.1.1.2. Los Alamos Integrated Test Plot Experiments

The Los Alamos Integrated Test Plot (ITP) was installed in 1984 to test and demonstrate, on a large-scale and long-term, design features including the following:

- soil erosion
- subsidence
- biointrusion
- capillary barriers

The ITP compared water balance and biological intrusion on a conventional control plot (compacted crushed tuff) and an engineered design, which incorporated the best available knowledge on methods to control erosion, subsidence, percolation, and biological intrusion. Two 3- by 10-m (10- by 33-ft)

demonstration plots for each of the two cover designs were installed at the Laboratory EETF. Each was instrumented to measure run-off, soil water storage, and seepage.

The technology for soil erosion control on both cover designs was a 60% to 70% gravel mulch and a vegetative cover of native grasses (Bouteloua gracilis and Agropyron smithii). The dominant downhill slope was limited to 0.5% to limit run-off. Subsidence in the test plots was minimized by optimally compacting each layer of soil placed in the plot. The control cover consisted of 15 cm (6 in.) of topsoil over 76 cm (30 in.) of crushed tuff. The engineered design featured 71 cm (28 in.) of topsoil over a 46-cm (18-in.) gravel capillary barrier at a 5% slope to provide for soil water storage and to divert vertical flow; a 91-cm (36-in.) cobble biobarrier; and crushed tuff.

The experiments measured root intrusion and water balance (precipitation, leachate production, and soil moisture) to assess cover performance. To measure root intrusion and leachate production, cesium iodide was applied to the crushed tuff layer in each plot. Being immobile in soil but readily assimilated by plant roots, cesium in plant tissue indicated root penetration through the cover. The highly mobile iodide served as a hydrologic tracer in leachate water sample collected at the bottom of the caissons.

After the initial 3-year phase of this study, results showed that the engineered design had four distinct advantages over the control cover. First, the layering sequence results in a capillary barrier that generally retains water in the upper fine-grained layer, making it more available for evapotranspiration. Second, the biobarrier keeps plant roots from growing through the cover. Third, water retained in the upper layer supports enhanced root mass near the surface, which increases transpiration and improves the soil erosion protection provided by vegetation. Fourth, percolation from snowmelt (when evapotranspirative losses are small) that penetrates into the coarse layers can be diverted by drains emplaced in this layer.

K.1.1.3. Erosion Control Study

To study the water balance and erosional behavior of several cover conditions, a 15- by 63-m (50 by 200 ft) simulated trench cap of the conventional control design was constructed at the EETF; over this, eight surface treatments were applied. Each test plot had a slope of 7%. The plots were subjected to simulated rainfall to generate infiltration, run-off, and erosion. The surface treatment criteria were selected to support the development of the Universal Soil Loss Equation. There were four surface variations investigated:

- Bare soil treatment: not tilled and left bare;
- Plant treatment: tilled and seeded with native grasses;
- Gravel treatment: gravel over the bare soil; and
- Gravel and plant treatment: seeded and graveled.

Results of this study are summarized as follows:

- The disking process used to prepare the plant treatment plot resulted in an opening and loosening of the soil and decreased the occurrence of extensive cracks observed on the bare soil plot.
- The gravel treatment dramatically reduced soil erosion but increased infiltration by reducing evaporation.
- The gravel and plant treatment exhibited decreased water content beneath the cap due to transpiration from the vegetation.

K.1.1.4. Protective Barrier Landfill Cover Demonstration

The Protective Barrier Landfill Cover Demonstration examined the hydrologic performance of four different engineered landfill cover designs with downhill slopes of 5, 10, 15, and 25. Over a period of 44 months, field measurements of seepage, precipitation, interflow, run-off, evaporation, and soil-water content were collected to quantify the performance of the engineered barriers as a function of slope length.

The four designs were the following:

- Conventional design (control):15-cm (6-in.) loam over 76-cm (30-in.) crushed tuff over 30-cm (12-in.) gravel
- EPA design: 61-cm (24-in.) loam over 30-cm (12-in.) sand over 61-cm (24-in.) clay-tuff over 30-cm (12-in.) gravel
- Loam capillary barrier design: 61-cm (24-in.) loam over 76-cm (30-in.) fine sand over 30-cm (12-in.) gravel
- Clay-loam capillary barrier design: 61-cm (24-in.) clay-loam over 76-cm (30-in.) fine sand over 30-cm (12-in.) medium gravel

The ultimate objective of this on-going study is to optimize a design for a specific slope that minimizes run-off and seepage and maximizes interflow and evaporation (and transpiration, although the field plots are not vegetated). Significant results of the study are the following:

- The maximum amount of seepage occurred in the Conventional Design at 5%, reaching a maximum of 10% of the precipitation with the 5% slope.
- No seepage was observed on the Clay-Loam Capillary Barrier Design at 10, 15, and 25% slopes.
- Field plots with larger slopes had more evaporation generally resulting in less stress to the underlying layers.

THERE IS NOTHING IN THIS APPENDIX – IT IS A PLACE HOLDER

APPENDIX L

MONITORING TECHNOLOGIES

MESA-TOP MATERIAL DISPOSAL AREAS IMPLEMENTATION PLAN

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APPENDIX L

MONITORING TECHNOLOGIES

L.1. INTRODUCTION