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Material Disposal Areas Core Document

Environmental Restoration Project
A Department of Energy Environmental Cleanup Program

Los Alamos
NATIONAL LABORATORY
Los Alamos, NM 87545

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TABLE OF CONTENTS

ATTACHMENT A ACRONYMS AND ABBREVIATIONS

ATTACHMENT B MATERIAL DISPOSAL AREA FACT SHEETS

ATTACHMENT C LANDFILL COVER AND POST-CLOSURE MONITORING DESIGNS FOR BASELINE PLANNING

List of Figures

List of Tables

1.0 INTRODUCTION

Between 1945 and 1985, the Los Alamos National Laboratory (LANL or the Laboratory) disposed radioactive and hazardous waste in material disposal areas (MDAs), which are currently under investigation as solid waste management units (SWMUs) under the purview of the Laboratory's Environmental Restoration (ER) Project. There are 26 MDAs located across the 43-square-mile Laboratory campus. The MDAs have various inventories, including liquids, sludges, solids, liquid and volatile organic chemicals, nonnuclear explosives residues, and radioactive compounds. Disposal of these wastes was in accordance with the practices at the time however, more protective regulations have since been enacted to ensure that SWMUs do not pose unacceptable risks to human or ecological receptors, either now or in the future. At a national level, the Hazardous and Solid Waste Amendments (HSWA) of the Resource Conservation and Recovery Act (RCRA) authorizes the US Environmental Protection Agency (EPA) to enforce corrective action for SWMUs. Locally, the New Mexico Hazardous Waste Act provides this authority to the New Mexico Environment Division (NMED).

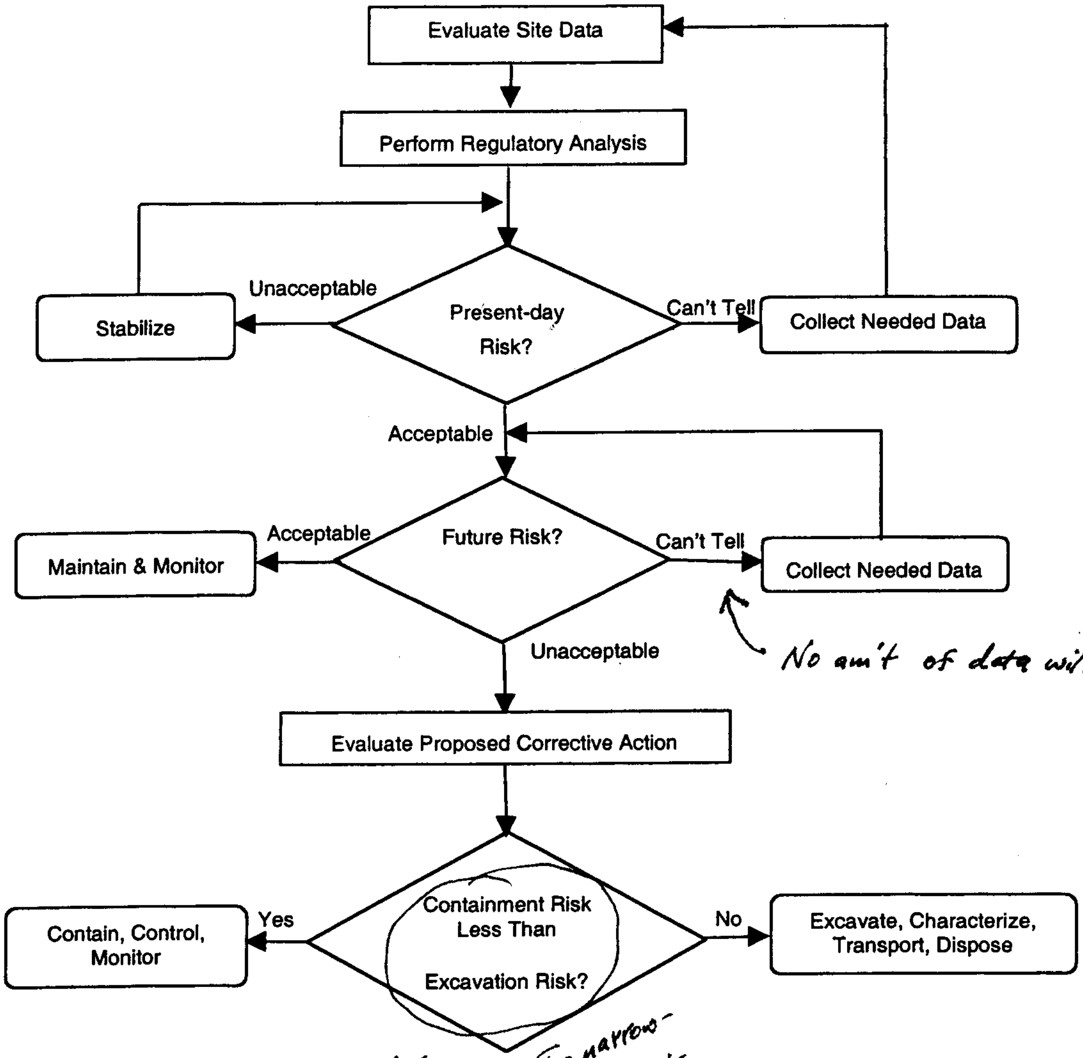
The ER Project performs corrective actions at MDAs and other SWMUs according to the terms of Module VIII of the Laboratory's hazardous waste permit (the "HSWA Module"), which was issued to the Laboratory by the NMED. The HSWA Module substantially incorporates EPA's "Advance Notification of Proposed Rulemaking, Corrective Actions for Releases From Solid Waste Management Facilities at Hazardous Waste Management Facilities" (hereinafter referred to as Subpart S). Subpart S provides guidance on a nationwide basis for addressing corrective action at SWMUs, describing graded requirements for RCRA facility investigations (RFIs), corrective measures studies (CMS), and corrective measures implementation (CMI). The MDAs Core Document describes the process developed by the ER Project to complete the RCRA corrective actions at MDAs.

In accordance with the ER Project's integrated technical strategy (LANL 1999, 63524), corrective actions at MDAs will, in general, proceed based on the priority of the watershed aggregate where each MDA exists. The exception to this generality is that the corrective action process at MDAs G, H, and L at Technical Area (TA) 54 will be initiated ahead of other activities in the Lower Pajarito aggregate of the Pajarito watershed. The reason for initiating the corrective action process at MDAs G, H, and L ahead of schedule (relative to aggregate priority) is that MDA G plays an important role in the corrective action process for other MDAs, and that role is demonstrated using MDAs H and L as "test cases."

1.1 Purpose

This document establishes the process for completing corrective action at MDAs in accordance with Subpart S. In general, RCRA corrective action incorporates RCRA facility assessments, RFIs, CMSs, and CMIs. Investigations have begun for most of the Laboratory's MDAs, with Phase I RFIs complete at the majority of the larger inventory sites. To evaluate RFI data in an objective, systematic, and cost-effective manner, the ER Project will implement anew decision logic. Figure 1.1-1 shows this decision logic; its implementation is discussed later in this document.

ER Project personnel will use the decision logic to evaluate the adequacy of MDA-specific data, assembled during Phase I RFI, to support conclusions regarding risk to human and ecological receptors. If existing data are inadequate to confidently assess risk, researchers will use the decision logic to identify what data are required during Phase II RFI to increase confidence in risk-based decisions. If existing data are sufficient to confidently assess risk, Phase II investigations will not be conducted and the decision logic will identify measures to ensure that the risk associated with an MDA is acceptable.



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Ans. Known

Too narrow - 9 criteria

Figure 1.1-1. **General framework of decision logic for streamlining the corrective action process for Laboratory MDAs**

Risk will be evaluated for both human and ecological receptors on multiple spatial and temporal scales. To evaluate present-day risk, researchers will evaluate present-day contaminant nature and extent, and current land-use patterns. To evaluate future risk to human and ecological receptors, subject-matter experts will calculate future contaminant nature and extent using fate and transport models, and will consider multiple potential exposure pathways in cumulative risk assessments to bound possible alternative future uses of an MDA and its environs. They will also use fate and transport models to evaluate the relative effectiveness of alternative corrective measures.

1.2 Regulatory Framework

Under Subpart S, corrective actions are performed to minimize present-day and future risks to human and ecological receptors. Decisions regarding corrective actions at Laboratory MDAs will be guided by the EPA standard target risk range stated in Subpart S:

> "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. Risk-based media cleanup standards are generally considered protective if they achieve a level of risk which falls within 10^{-6} and 10^{-4} risk range."

The Subpart S risk range is conservative relative to potentially applicable EPA and Department of Energy (DOE) performance objectives for doses of radiation received from radioactive waste. These objectives range from 15 to 100 mrem/yr., a risk of 3×10^{-4} to 2×10^{-3}. The EPA's Office of Solid Waste and Emergency Response document 9200.4-18, "Establishment of Cleanup Levels for CERCLA Sites with Radioactive Contamination," (EPA 1997, 58693) states the following:

> "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., and the national emissions standards for hazardous air pollutants radionuclide regulations, which limit the dose from radioactivity in the air to 10 mrem/yr.

A decision-logic based on risk rather than dose is appropriate because MDAs containing hazardous, radioactive, and/or mixed waste can be assessed and compared to each other using a common framework. Further, the target risk range meets other potentially applicable regulatory standards, including the DOE standard for public radiation protection and the EPA Clean Water and Clean Air Acts. Finally, a risk-based approach is consistent with the "Risk-Based Decision Tree" from the "New Mexico Environment Department Hazardous and Radioactive Materials Bureau RCRA Permits Management Program Document Requirement Guide" (NMED 1998, 57897).

To expedite corrective action for MDAs, the MDA Focus Area of the ER Project will limit the corrective measure alternatives considered to those that are both protective and practicable for a given site, and then compare those alternatives through cost-benefit analyses. In so doing, this document's approach adheres to Subpart S:

> "The earlier in the corrective action process potential remedies can be identified, the more effectively information gathering can be focused.... For example, in situations where the contamination being addressed involves a large mixed fill landfill, the remedial alternatives will

> likely involve physical and institutional controls. These alternatives should be identified early, enabling the facility owner/operator to tailor site characterization toward collection of information necessary to support development of appropriate physical controls. . . . EPA advises program implementers and facility owners/operators to focus corrective measures studies on realistic remedies and to tailor the scope and substance of studies to the extent, nature and complexity of releases and contamination at any given facility. For example, some potential remedies should not be considered because they are simply implausible."

Alternative corrective actions for MDAs must ensure that risks to human and ecological receptors are acceptable, now and in the future. Specific points and times of compliance will be addressed with NMED to efficiently reduce and manage risk across the Laboratory complex. Present-day risks posed by MDAs are generally low because of institutional controls and because contamination is buried below-ground. Risks could increase in the future if natural hydrogeological processes or other disruptive events disperse contamination; however, as long as contamination remains inaccessible to human or ecological receptors risks will remain low. We can limit accessibility of contamination to human or ecological receptors by:

- removing some or all of the material within an MDA and disposing the inventory elsewhere
- stabilizing the contamination within the MDA
- controlling access to the MDA, and/or
- monitoring environmental media to ensure that contamination transported away from an MDA remains below acceptable risk thresholds

Excavation and off-site disposal may be a practical alternative for MDAs that contain a small shallow homogeneous well-characterized inventory. Most MDAs contain large volumes of deeply buried heterogeneous materials contaminated with a variety of constituents, making excavation difficult or impracticable and off-site disposal unlikely or virtually impossible. For these MDAs, capping, administrative controls, and long-term monitoring are likely to be the optimal corrective actions. This approach is consistent with Subpart S which states the following:

> "EPA expects to use a combination of methods (e.g., treatment, engineering and institutional controls), as appropriate, to achieve protection of human health and the environment. . . [with] institutional controls such as land use restrictions primarily to supplement engineering controls. . . . "

1.3 Scope

The RFI/CMS process for MDAs, expedited through a quantitative decision logic, will be used for the MDAs listed in Table 1.3-1, sited at the locations shown in Figure 1.3-1.

These MDAs have waste disposed or otherwise placed below-ground in excavated pits, trenches, shafts, and cavities. Most of these sites, including those with the largest inventories of radioactive or hazardous contaminants, are located on mesa tops. Even before environmental laws were enacted to ensure groundwater protection, these mesa top locations were chosen based on knowledge of favorable hydrogeologic conditions to prevent groundwater transport of contaminants. The scope of this document is to describe the MDAs that will be evaluated by a streamlined RFI/CMS process, and to describe that process.

The RFI phase of the RCRA corrective action process uses information to do the following:

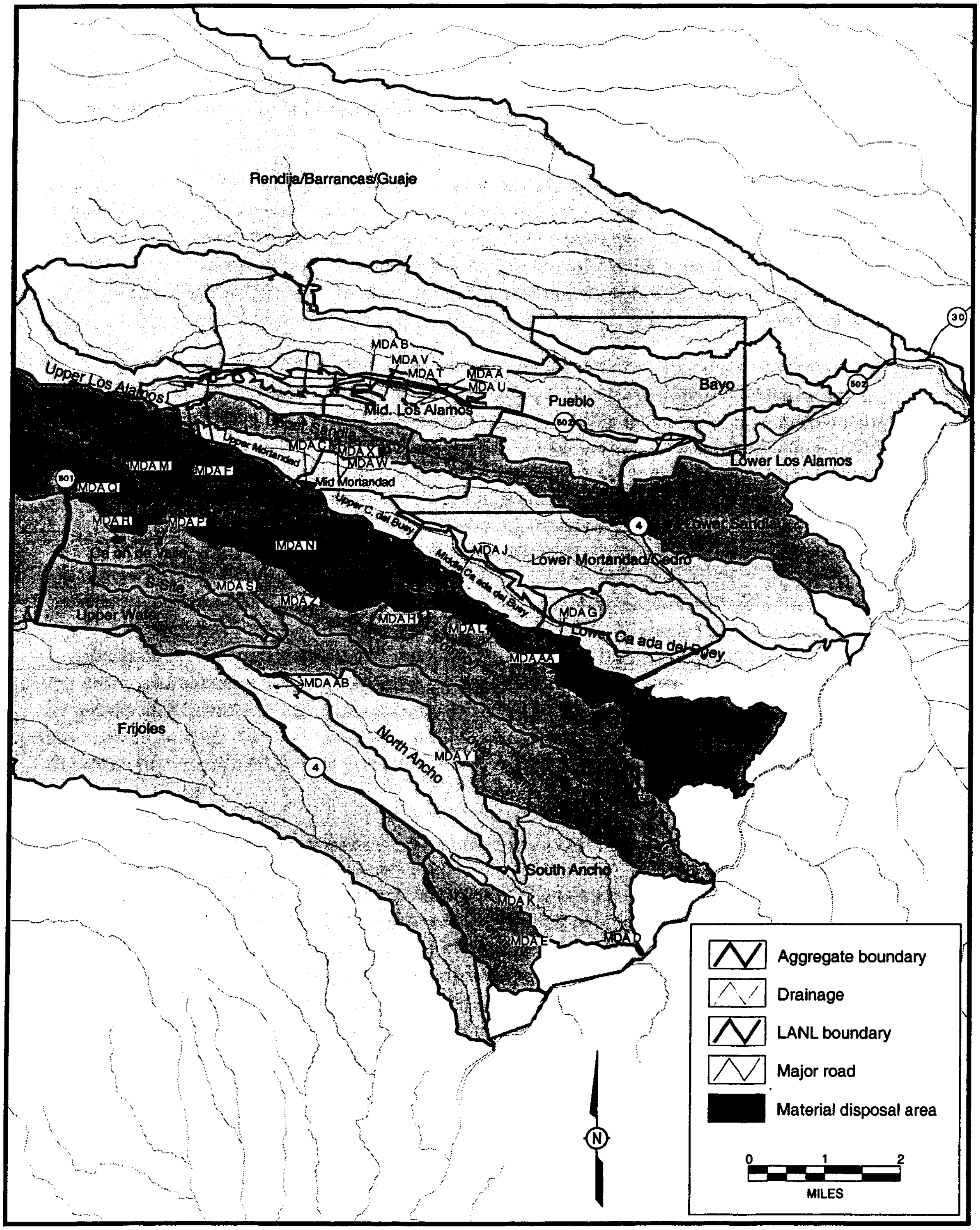
- characterize the nature and extent of any release(s) to air, groundwater, surface water, or soil
- evaluate the potential threat to human health and to the environment
- develop corrective measure proposals

Table 1.3-1
Description of Laboratory MDAs and Anticipated Cleanup Plans

MDA	TA	PRS	Description	Current Status	Anticipated Path to Completion
A	21	21-014	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	CMS/CMI
B	21	21-015	6-acre site used primarily for solid waste disposal; small section used for chemical waste disposal	Phase I RFI field work complete, RFI report to be written	CMS/CMI
C	50	50-009	7 pits and 108 shafts within 11.8-acre site	Phase I RFI field work complete, RFI report to be written	CMS/CMI
D	33	33-003(a–b)	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)	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 the capping option is planned
F	6	6-007(a)	Classified trash was interred here during the late 1940s	Geophysics studies have been completed but not documented in a report	CMS/CMI
G	54	54-013(b), 54-014(b, c, d), 54-017, 54-018, 54-019, 54-020	34 disposal pits, 174 disposal shafts, and 4 transuranic waste trenches within a 65-acre site	RFI report in progress	CMS/CMI
H	54	54-004	9 vertical shafts within a 0.3-acre site	RFI report in progress	CMS/CMI
J	54	54-005	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)	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)	1 chemical waste disposal pit, 34 disposal shafts and 3 chemical waste disposal impoundments within a 2.5-acre site	RFI Report in progress	CMS/CMI
M	9	9-013	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)	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	HE burn ground residues disposed of here	Phase I of clean closure in progress	RCRA clean closure
Q	8	8-006(a–b)	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

Table 1.3-1 (continued)

MDA	TA	PRS	Description	Current Status	Anticipated Path to Completion
R	16	16-019	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
S	11	11-009	HE degradation experiment in progress	Approved for deferred action in OU 1082 work plan	Complete
T	21	21-016 (a–c)	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	CMS/CMI
U	21	21-017 (a–c)	1.3-acre site containing 2 absorption beds and associated sump	Phase I RFI field work complete, RFI report to be written	CMS/CMI
V	21	21-018 (a–b)	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	CMS/CMI
W	35	35-001	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	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)	Construction, office, and firing site debris buried in 5 shallow trenches.	RFI report complete with RSI	CMS/CMI to evaluate stabilization in place versus removal
Z	15	15-007 (b)	Approximately 2000 yd. of construction debris and other debris from firing site activities. uranium present.	RFI report complete.	VCM proposed
AA	36	36-001	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 evaluating capping and other cleanup options
AB	49	49-001 (a–g)	Multiple shafts and chambers at depths between 60 ft and 80 ft (18m 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	CMS/CMI



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F1.3-1 / MDA Core Doc / 081299 / PTM

Figure 1.3-1. **Map showing locations of MDAs across the Laboratory installation**

After a SWMU and its associated potential environmental and human health risks are characterized, CMS may be undertaken to evaluate alternative means of mitigating those risks. While tailoring the RFI and CMS to individual MDAs to streamline corrective actions, we established a technical framework that reflects Subpart S:

> "EPA continues to emphasize that the components of corrective action should not be viewed as isolated steps in a linear process. . . . In the Agency's experience, it is generally more efficient to focus data collection on information needed to support an appropriate, implementable remedy than to attempt to complete separate evaluations at each step. . . . [T]he earlier in the corrective action process potential remedies can be identified, the more effectively information gathering can be focused . . . ."

The fact that contamination at MDAs is in the subsurface and not readily accessible has important implications in terms of site characterization and identification of viable remediation alternatives. Unless they are thoughtfully designed, sampling and analysis programs implemented to determine the nature and extent of contamination will be costly and will not serve the purpose of mitigating potential risks. Traditional risk assessment considers the contaminant concentrations, exposure pathways, and consequences. The MDAs require similar considerations but at time scales that extend 1000 yr. or more into the future. A combination of modeling and site characterization data will be used to define contaminant nature and extent to support well-defined decisions in the corrective action process. ✓

The CMS will be streamlined by evaluating capping as a baseline or default corrective action for MDAs. All MDAs are presently covered with evapotranspiration caps, the performance of which has been the subject of extensive field investigations and computer simulations. The existing cap will be modeled during the risk assessment of the RFI. The cap will be optimized during the CMS if the results of the RFI indicate a necessity for it optimization. If the RFI or CMS risk assessments demonstrate that capping is not a protective or practical final action, then alternatives (including excavation) will be considered. Where significant inventory will be left in place after capping, a monitoring program will be deployed to assure that the final cap design is effective.

The MDA focus area will assess the risk of alternative future land-use scenarios by using mathematical models that simulate processes affecting contaminant mobility while considering a host of exposure pathways that encompass potential resources uses. These models calculate contaminant concentrations in environmental media at various times and locations, which are used to assess the risk to human or ecological receptors under assumed exposure scenarios. There are several generic computer models used at RCRA corrective action sites to calculate contaminant fate and transport by way of surface water and groundwater; two examples are MODFLOW and HELP[1]. These generic models are adequate for simple sites. However, site-specific models may be required to accurately simulate fate and transport in natural settings which are more complex. The use of site-specific models is consistent with Subpart S which states the following: ✓

> "Site-specific risk assessments conducted at RCRA facilities . . . based on . . . methods developed expressly for application at specific sites or types of sites could result in more valid and reliable characterizations of risks to human health and the environment."

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[1] HELP is currently recognized as the EPA's landfill cover design code and is adequate for most surface water balance calculations, but it does not address soil physics within a cover in a robust way. MODFLOW is widely used for groundwater transport calculations and could conceivable be used to handle many aspects of the groundwater flow in the main aquifer, although the representation of complex stratigraphy is not the forte of this code.

Site-specific models inform corrective action decisions for the Laboratory's MDAs because of the complexity of the natural setting. The same models were used to simulate fate and transport of radiological contaminants at MDA G for the performance assessment and composite analysis, required to demonstrate compliance with DOE waste requirements. The performance assessment and composite analysis are also substantively equivalent to EPA risk assessments that support ER activities across the DOE complex and ensure that compliance with EPA standards for radiological protection of human health and the environment. The MDA G performance assessment and composite analysis are substantively equivalent to the analyses required by the Nuclear Regulatory Commission to license low-level radioactive waste disposal sites under 10 CFR (Code of Federal Regulations) 61, Licensing Requirements for Land Disposal of Radioactive Waste (e.g., the Chem-Nuclear disposal facility in South Carolina). They are also similar to the analyses required by the EPA for licensing disposal facilities under 40 CFR 191, Environmental Radiation Protection Standards for Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes (e.g., Waste Isolation Pilot Project facility in New Mexico and Yucca Mountain in Nevada).

Minor correction

The modeling framework developed, peer reviewed, and successfully implemented for fate and transport calculations at MDA G will be used to assess risk for other MDAs. Wherever possible, the MDA G results will be used to indirectly model (by scaling) contaminant fate and transport, and risk. Decision analysis will be used to determine if "scaling" of MDA G results is viable, or if an MDA must be modeled explicitly.

1.4 Document Organization

Section 2 of this document summarizes the state of knowledge regarding the MDAs at the Laboratory. Section 3 summarizes the natural features and events that affect the assessment of long-term risk of MDAs. Section 4 discusses (1) the results of several investigations into the processes that may affect long-term risk and (2) our approach to risk assessment in corrective action, which uses the MDA G performance assessment and composite analysis as a starting point. Section 5 integrates the information from preceding sections into a conceptual site model that will serve as the preliminary physical conceptual model for all MDAs. Section 6 describes how the preliminary physical conceptual model and risk-based decision analysis will be used to complete the RFI for MDAs. Section 7 describes the alternative approaches to CMS that may result from the RFI. Finally, Section 8 discusses the reporting format that the MDA Focus Area will follow in implementing the approach to corrective actions described in this document. Attachment A lists acronyms; Attachment B includes fact sheets for all the MDAs; and Attachment C is the report, "Landfill Cover and Post-Closure Monitoring Designs for Baseline Planning."

2.0 MDA DESCRIPTIONS

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 B. 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.

The locations of the Technical Area (TA) 21 MDAs are shown in Figure 1.1-1 in Chapter 1 of this document. An operational summary of all the MDAs is presented in Table 2.1-1.

There are 28 MDAs at the Laboratory. They are designated with single letters from A to Z then double letters AA, AB etc. Several of the MDAs are collocated, or assembled within a single TA. These collocated MDAs will be discussed first, then the unassembled MDAs will be discussed in alphabetical order.

2.1 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.

2.1.1 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 2.1-1
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

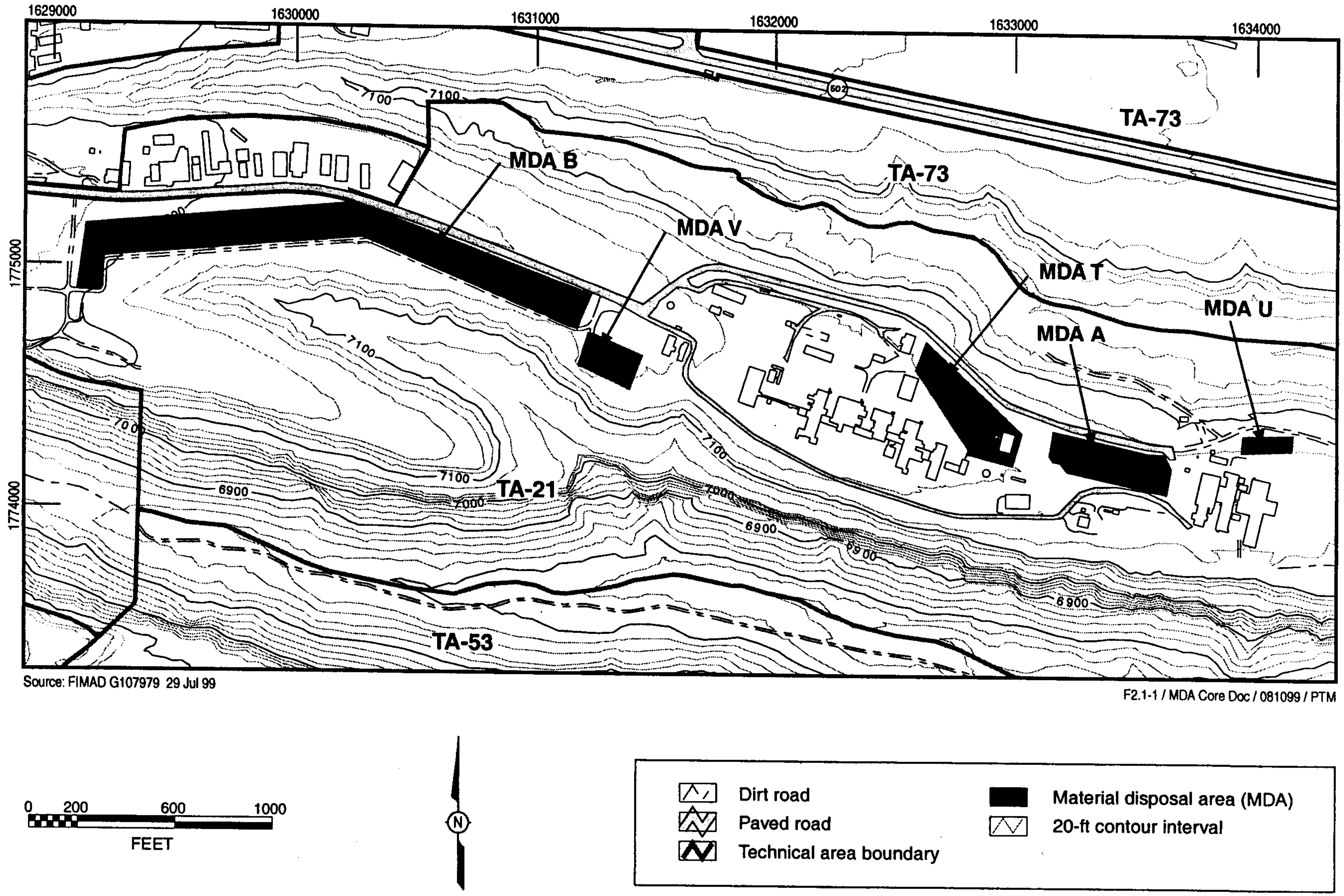
[a] TRU = transuranic waste.

[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.



Source: FIMAD G107979 29 Jul 99

F2.1-1 / MDA Core Doc / 081099 / PTM

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

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

2.1.2 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.

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

2.1.3 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.

#'s of shafts don't comput

?

Cement paste not on WM screen

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.

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

2.1.4 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.

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

2.1.5 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.

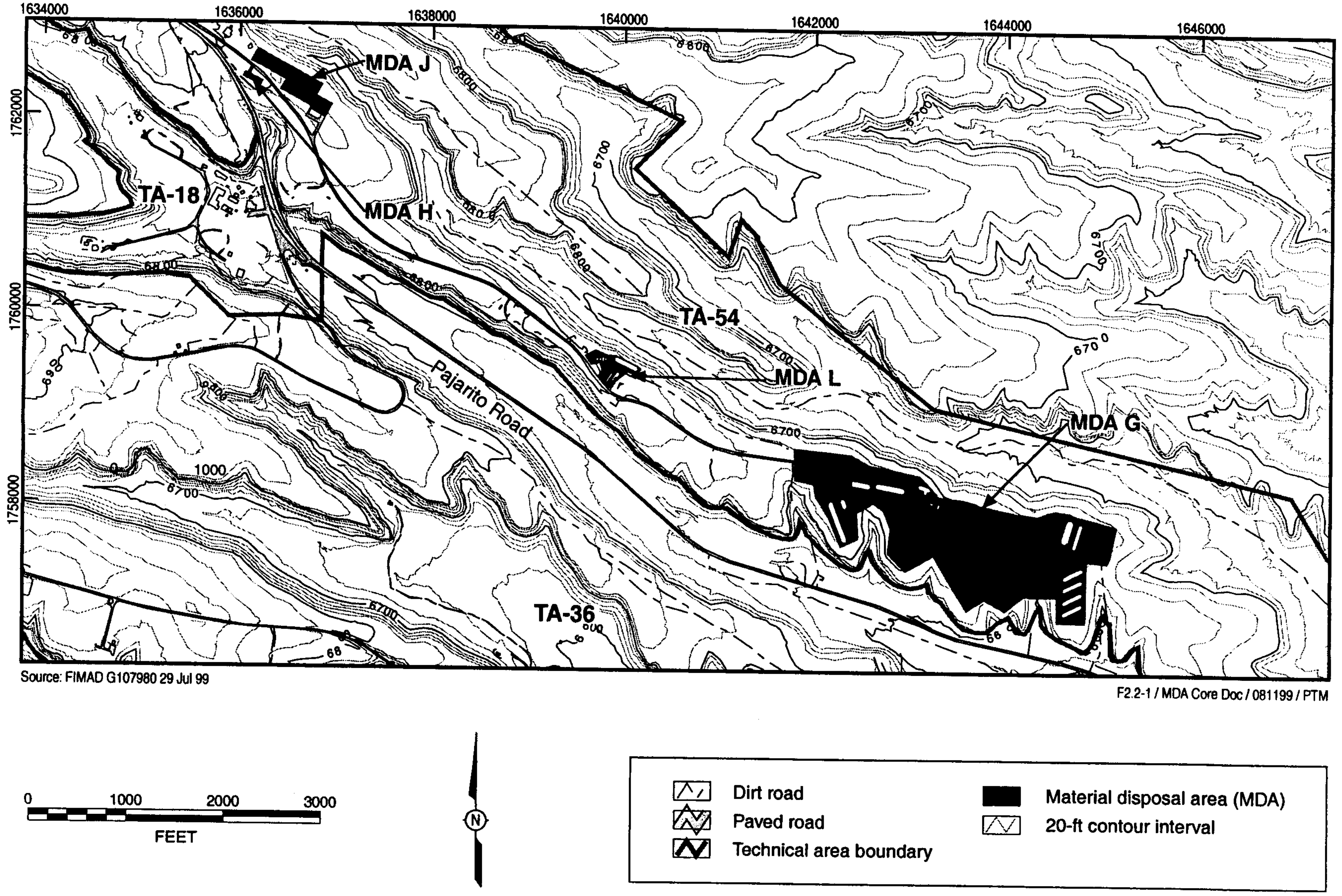
2.2 MDAs G, H, J, and L at TA-54

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.

2.2.1 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.



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F2.2-1 / MDA Core Doc / 081199 / PTM

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

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.

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.

2.2.2 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.

2.2.3 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.

2.2.4 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).

2.3 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.

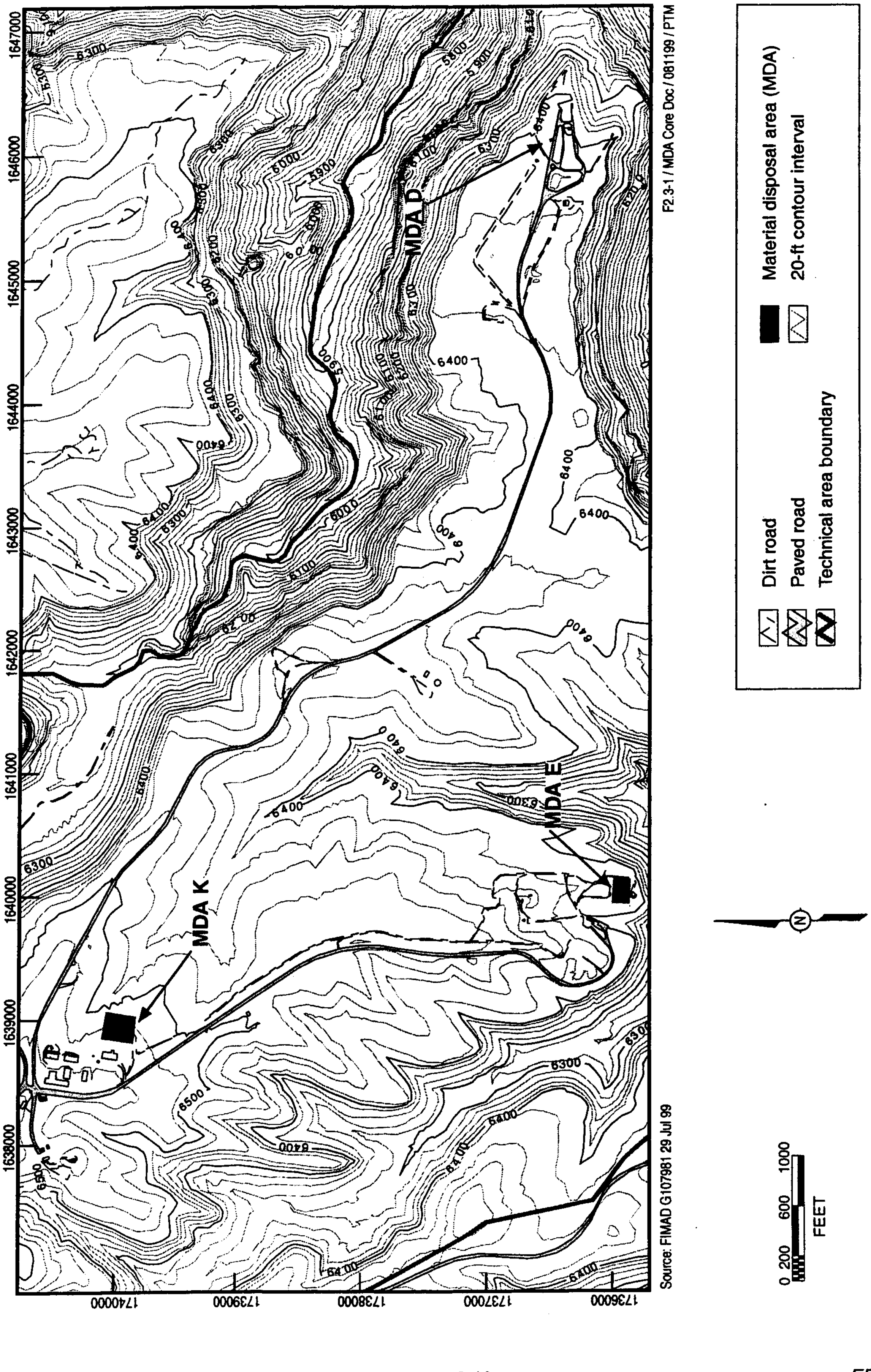

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Figure 2.3-1. Locations of MDAs at TA-33 (D,E,K)

2.3.1 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).

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

2.3.2 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.

2.3.3 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).

RFI data for MDA K will be evaluated in accordance with the methodology described in this document.

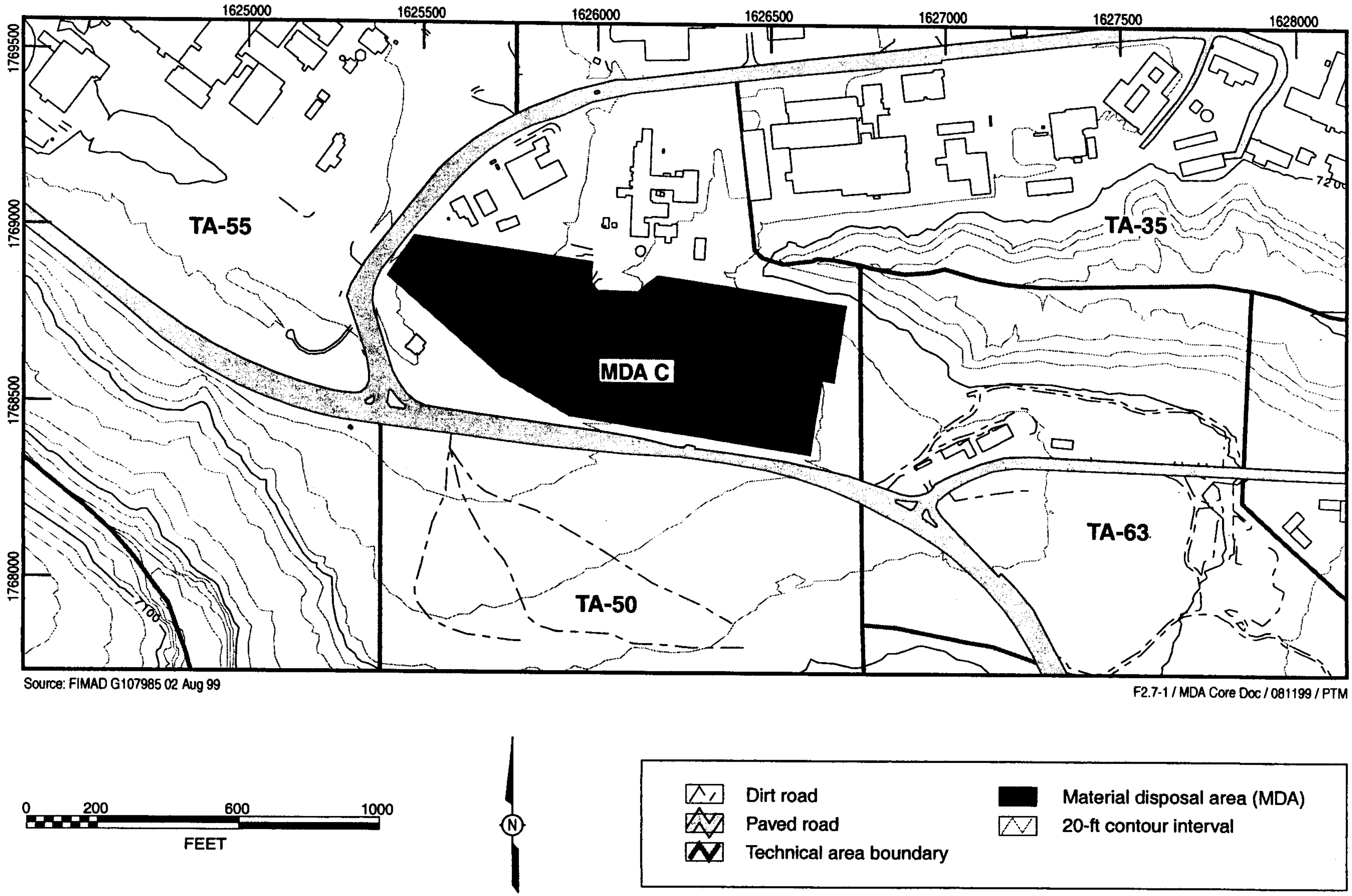
2.4 MDAs N and Z at TA-15

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.

2.4.1 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.



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F2.7-1 / MDA Core Doc / 081199 / PTM

Figure 2.7-1. Location of MDA C at TA-50

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.

2.8 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.

MDA F will not be evaluated in accordance with the methodology described in this document.

2.9 Location of MDA M at TA-9

MDA M (PRS 09-013) is located at an elevation of 7500 ft (2250 m) on Pajarito Mesa southwest of Pajarito Canyon. Figure 2.9-1 shows the layout of MDA M at TA-9.

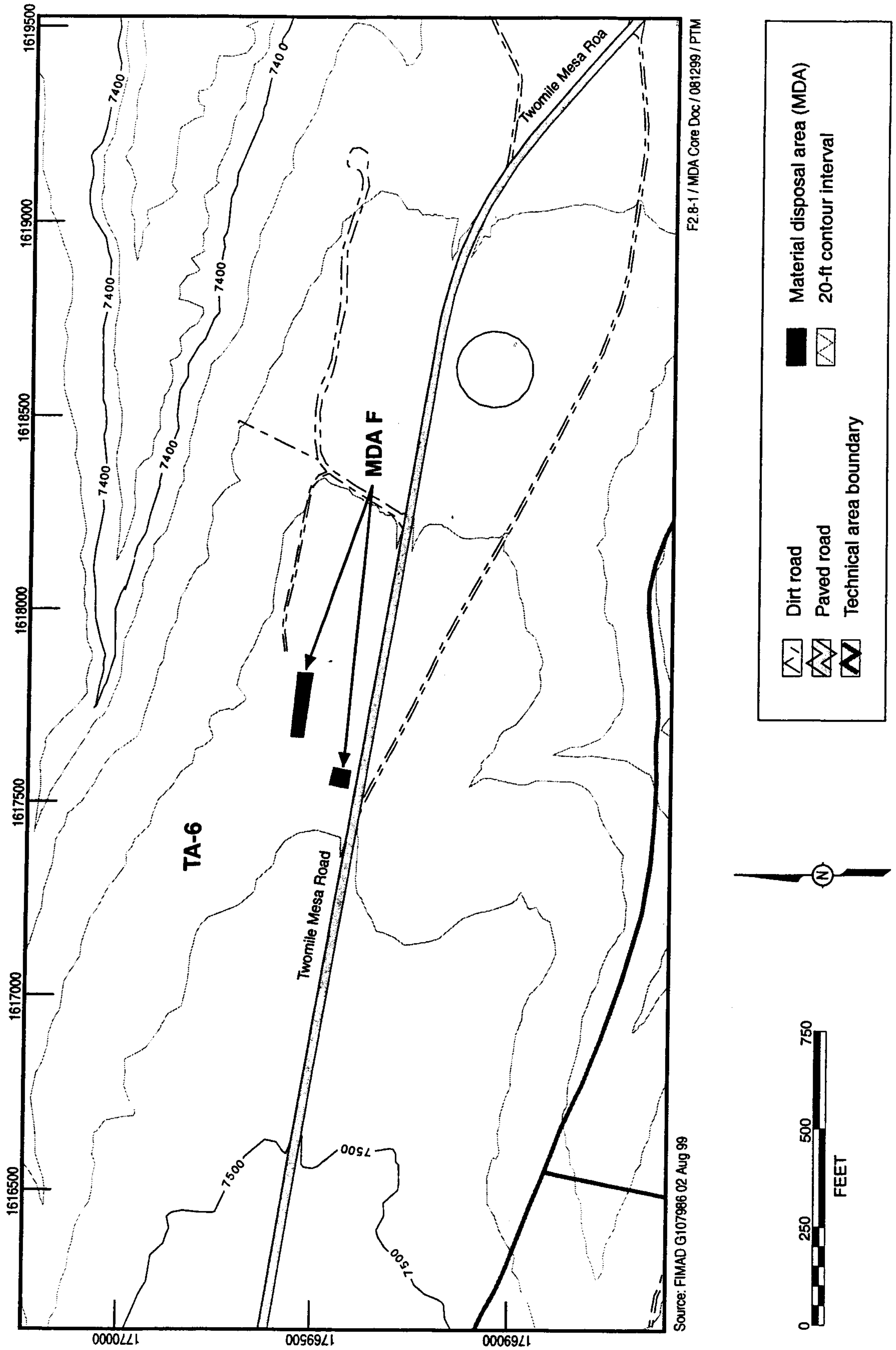

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Figure 2.8-1. Location of MDA F at TA-6

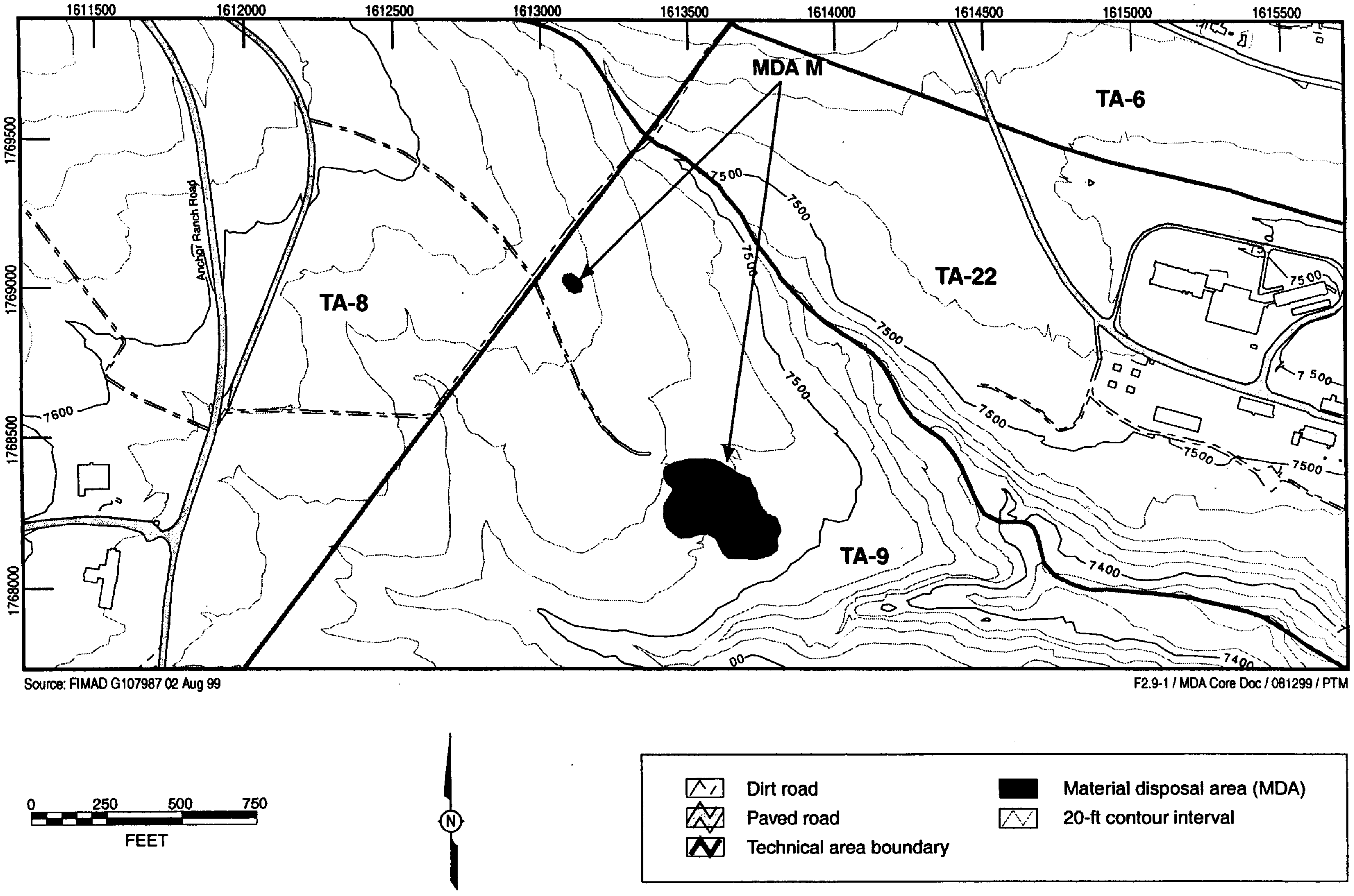

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Figure 2.9-1. Location of MDA M at TA-9

The depth to groundwater below MDA M is approximately 1220 ft (366 m). Run-off from MDA M drains northeastward to Pajarito Canyon and southward to a tributary informally known as Starmer Gulch, which is located within the Pajarito Canyon watershed. Metal and debris, generated during the removal of Old Anchor Sites (East and West) and during the construction of the present TA-8 and TA-9 facilities (1948–65), have been flashed and deposited over the surface of this 3-acre area. Nonhazardous waste from the construction of other sites within the Laboratory was also dumped here from 1960 to 1965.

RFI activities at MDA M include the following:

- An expedited cleanup (EC) was performed at MDA M as described in the "Expedited Cleanup Plan for Solid Waste Management Unit 9-013" (Environmental Restoration Project 1995, 47257).
- Phase I of the EC was conducted between November 1995 and March 1996 (Environmental Restoration Project 1996 62053; Environmental Restoration Project 1997, 56936).
- Phase II of the EC is planned to confirm that cleanup action levels established in the Phase I RFI are still appropriate. Additional site excavations and sampling will be done for confirmation.

MDA M will not be evaluated in accordance with the methodology described in this document.

2.10 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.

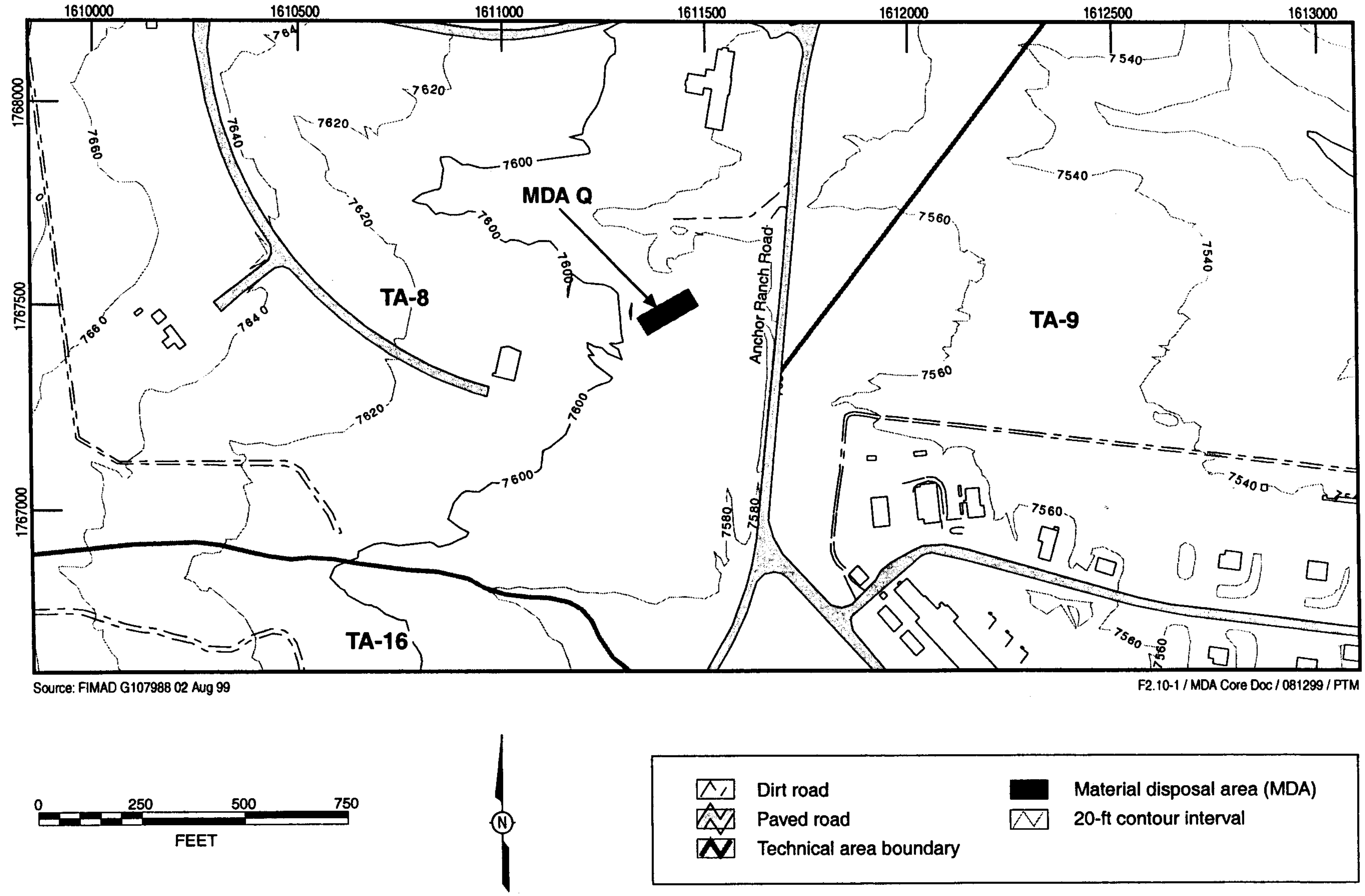
The SWMUs at this MDA are listed in Module VIII of the Laboratory's RCRA hazardous waste facility permit. RFI activities including radiological and geophysical surveys were conducted at MDA Q in November 1993.

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

2.11 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.



Source: FIMAD G107988 02 Aug 99

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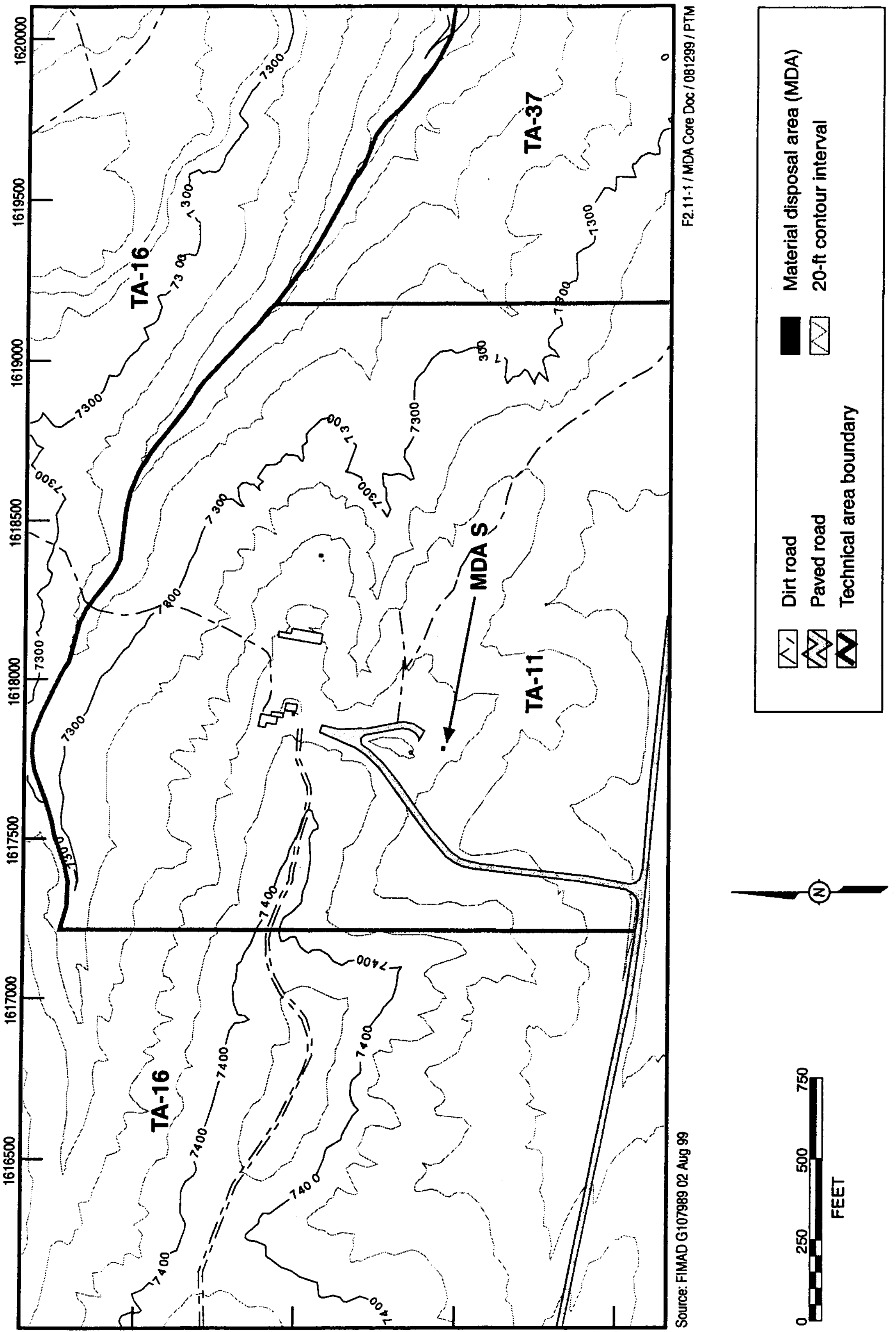
Figure 2.10-1. Location of MDA Q at TA-8



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Source: FIMAD G107989 02 Aug 99

Figure 2.11-1. Location of MDA S at TA-11

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

2.12 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:

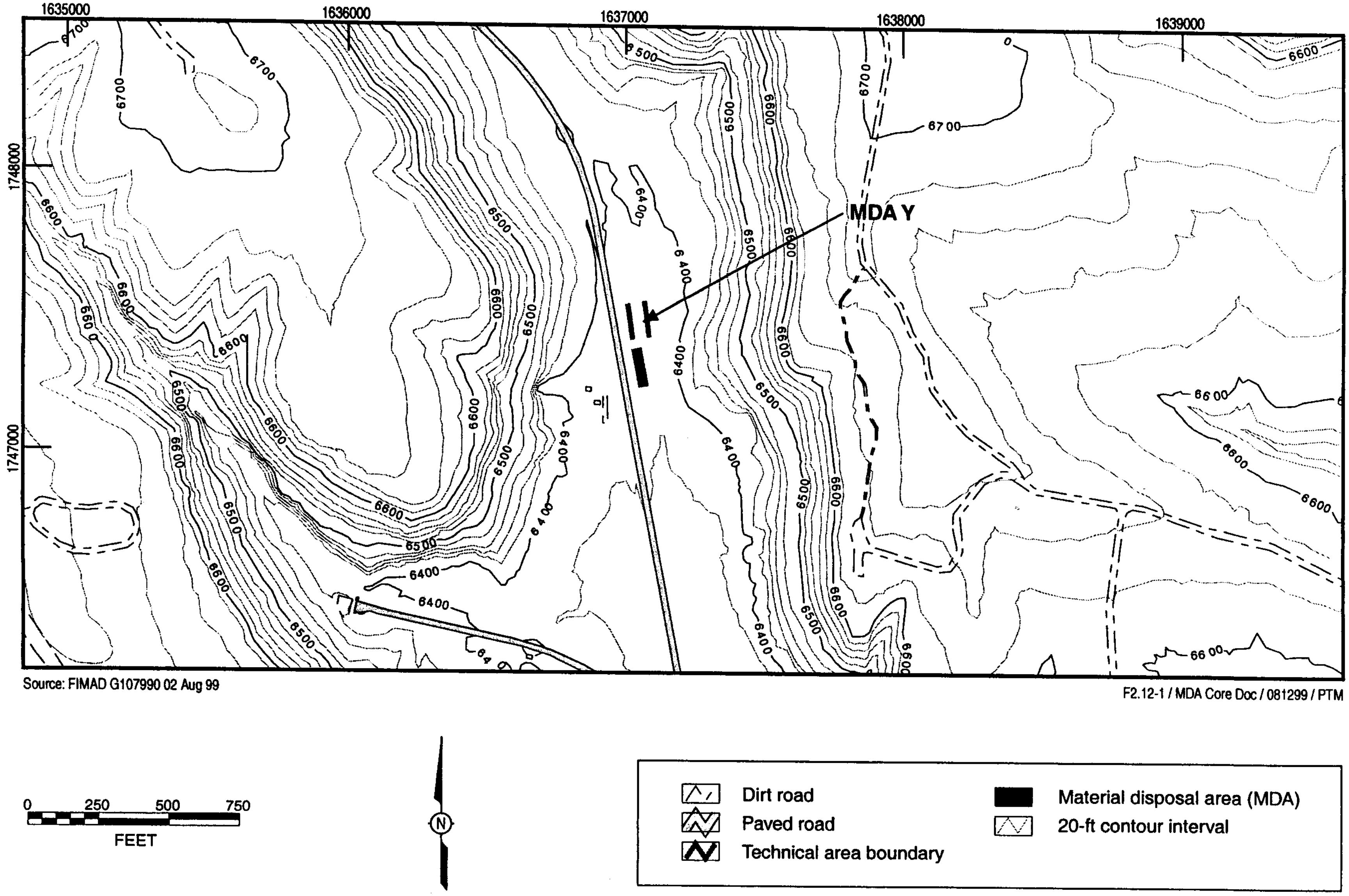
- "RFI Report for Potential Release Sites at TA-39 39-001(a, b) 39-004(a-e) 39-008" (Environmental Restoration Project 1997, 55633)
- "Request for Supplemental Information for RCRA Facility Investigation Report for Potential Release Sites at TA-39: 39-001(a&b), 39-004(a-e) and 39-008" (NMED 1997, 56705)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

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

2.13 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.



Source: FIMAD G107990 02 Aug 99

F2.12-1 / MDA Core Doc / 081299 / PTM

Figure 2.12-1. **Location of MDA Y at TA-39**

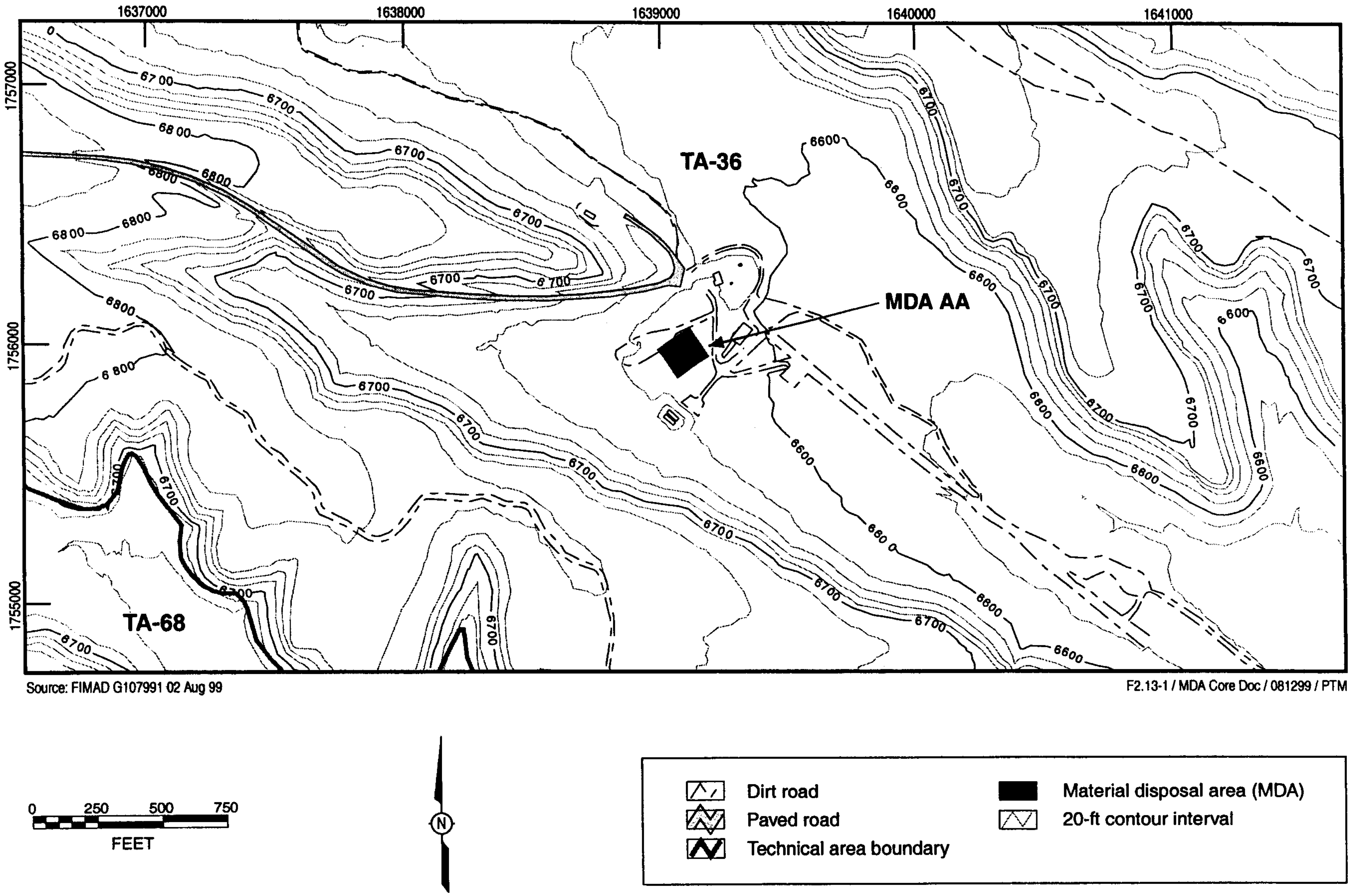


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Figure 2.13-1. Location of MDA AA at TA-36

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)

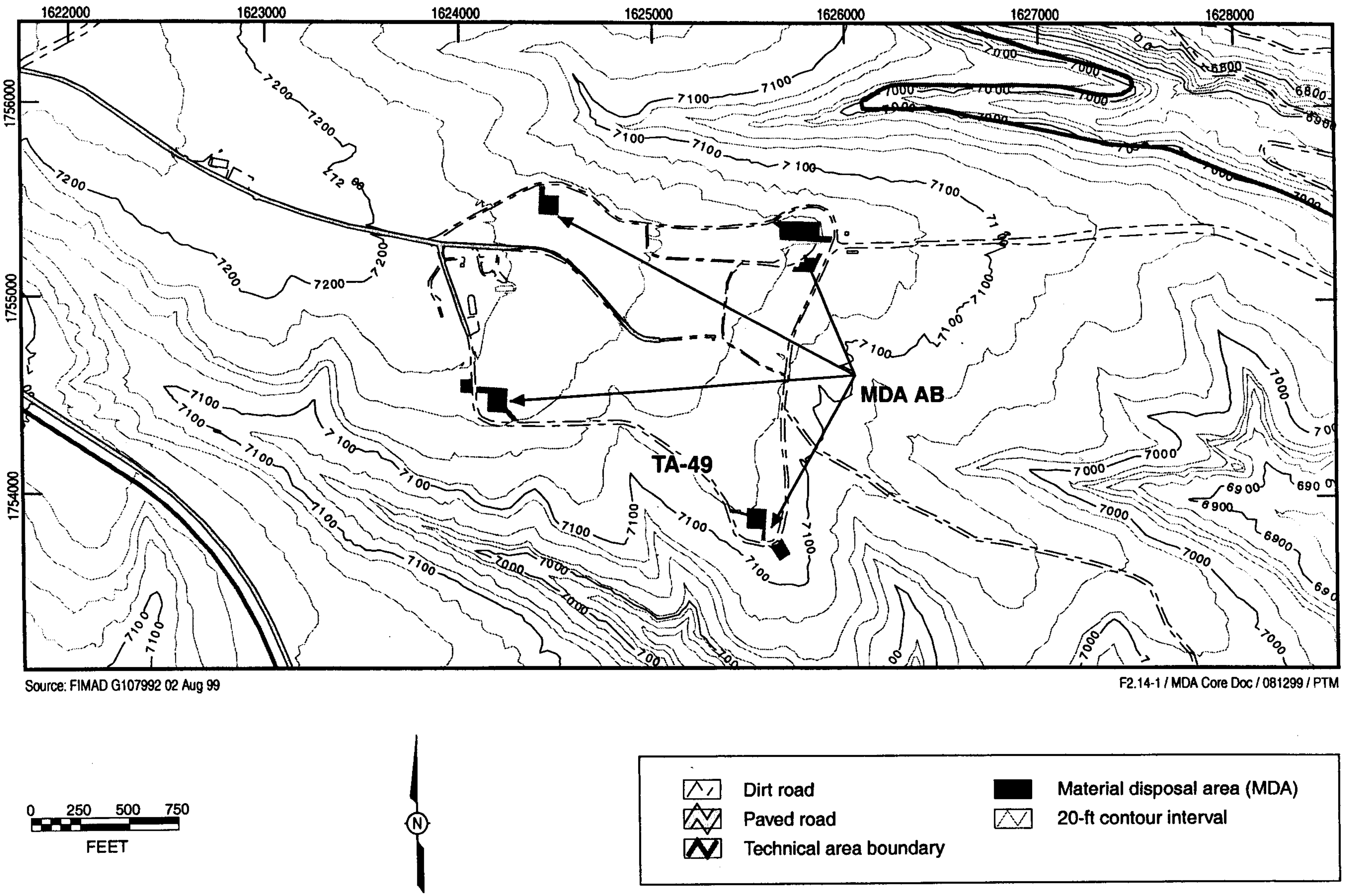
MDA AA will be evaluated in accordance with the methodology described in this document.

2.14 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.



Source: FIMAD G107992 02 Aug 99

F2.14-1 / MDA Core Doc / 081299 / PTM

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

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.

3.0 ENVIRONMENTAL SETTING

Los Alamos National Laboratory (the Laboratory) is located on the Pajarito Plateau in north central New Mexico. The 43 mi^2 (112 km^2) plateau slopes gently to the east-southeast between the Jemez Mountains on the west and the broad Grande Valley on the east which runs north to south. Elevations range from 7600 to 6300 ft (2317 to 1920 m) above mean sea level. The local relief of the plateau consists of east-southeast-trending canyons and mesas. This section of the document describes the natural features and events of the region, focussing on those that may impact the release or transport of contaminants from material disposal areas (MDAs) around the Laboratory. Since most MDAs are located on mesa tops, the emphasis of the hydrology summary is on mesas, rather than canyons.

3.1 Climate

The Pajarito Plateau has a temperate semiarid mountain climate. Spring is typically windy and dry. Summer begins with warm, usually dry conditions in June, followed by a two-month rainy season in July and August. The rainy season ends in autumn when the climate becomes drier, cooler, and calmer, and winters are generally mild with occasional winter storms. General information about the climate of the Laboratory area is provided in the annual environmental surveillance reports (e.g., Environmental Surveillance Program 1998, 59904) and in Chapter 2 of the Environmental Restoration (ER) Project's installation work plan (IWP) (LANL 1996, 55574). Bowen (1990, 6899) provides detailed data compilations and extensive statistical summaries including projected probabilities for climate in the Los Alamos area.

Meteorological variables at the Laboratory are measured at five towers on the Pajarito Plateau. Four of the towers are located on mesas and one tower is located in Los Alamos Canyon. Local and regional topographical features significantly influence the local meteorology of the Laboratory (Baars et al. 1998, 63896).

3.1.1 Temperature

The elevation of the Pajarito Plateau is the primary influence of temperature; the plateau is cooler in the summer than the surrounding low-lying desert. In the evenings and at night, cool air sinks off the plateau and flows down the canyons; thus, nighttime temperatures on the mesas are often warmer than in the canyons and at lower elevations. The general lack of moisture in the atmosphere also influences temperature. With less moisture, there is less cloud cover, which allows a significant amount of solar heating during the daytime and radiative cooling during the nighttime. This heating and cooling causes a wide range of daily temperatures. The averages range is 13°C (LANL 1998, 59904).

3.1.2 Precipitation

The average annual precipitation, from rainfall and the water equivalent from frozen precipitation, is 47.6 cm (18.7 in.). However, the annual total fluctuates considerably from year to year, with the standard deviation of the fluctuation being 12.2 cm (4.8 in.). The lowest recorded annual precipitation is 17.3 cm (6.8 in.) and the highest is 77.1 cm (30.3 in.). The maximum precipitation recorded for a 24-h period is 8.8 cm (3.5 in.) and the maximum for a15-minute period is 2.3 cm (0.9 in.). The eastern portion of the plateau often receives 13 cm (5.1 in.) less annual precipitation than the west-central portion of the plateau. About 36% of the annual precipitation falls during the July/August rainy season.

Winter precipitation occurs mostly as snow. The snow is typically dry; 20 units of snow are equivalent to 1 unit of water. The annual snowfall averages 150 cm (59 in.) but from year to year the amount of snow is quite variable. The standard deviation of annual snowfall is 71 cm (28 in.). The highest recorded snowfall for one season is 389 cm (153 in.), and the highest recorded snowfall for a 24-h period is 56 cm (22 in.). In a typical winter there are 14 days during which snowfall exceeds 2.6 cm (1 in.) and 4 days of snowfall exceeding 10.2 cm (4 in.). The most extreme single-storm snowfall on record is 122 cm (4 ft).

Relative humidity varies considerably daily, but monthly averages vary little during the year. Relative humidity ranges from 39% in June to 56% in December, and averages 51% over the entire year. Absolute humidity ranges from 2.4 g of water/m^3 of air in January to 8.7 g/m^3 in July and August, when moist subtropical air invades the region during the rainy season. Fog in the Pajarito Plateau area is very rare, occurring less than five times a year on average.

3.1.3 Winds

Wind conditions on the Pajarito Plateau are generally light, and the average annual wind speed is 2.5 m/s (5.5 mi/h). However, the windy season from mid-March to early June sustains wind speeds exceeding 4 m/s (8.8 mi/h) 20% of the time during the day and the daily maximum wind gust exceeds 14 m/s (31 mi/h) about 20% of the time. The highest wind gust on record is 343.4 m/s (77 mi/h). Tornadoes have not touched the ground in the Pajarito Plateau area; however, funnel clouds have been observed in Los Alamos and Santa Fe Counties.

Winds over the Pajarito Plateau show considerable spatial structure and temporal variability. During sunny, light-wind days, an upslope flow greatest along the western margin of the plateau usually develops over the plateau in the morning. By midday a southerly flow usually prevails over the entire plateau.

The prevailing nighttime winds over the western portion of the plateau are west-southwesterly to northwesterly. These nighttime westerlies result from cold air drainage off the Jemez Mountains and the Pajarito plateau; the drainage layer is typically 50 m (165 ft) deep in the vicinity of Technical Area (TA) 6. At stations farther from the mountains, the nighttime direction is more variable but usually has a relatively strong westerly component. Just above the drainage layer, the prevailing nighttime flow is usually southwesterly.

Observations made at meteorological stations in canyons show that atmospheric flow there is quite different from flow over the mesas. During the nighttime, cold air flows down the canyons about 75% of the time. This gravity flow is steady and continues for an hour or two after sunrise when it abruptly ceases and is followed by an unsteady up-canyon flow for a couple of hours.

3.1.4 Solar Irradiance

Solar irradiance measurements show that Los Alamos receives more than 75% of possible sunshine annually. (Possible sunshine is defined as the amount received when the sky is cloud-free.) During most of the year, when there is no snow on the ground, about 80% of this incoming solar energy is absorbed at the ground surface. About half of this absorbed shortwave energy is offset by longwave radiation to space. The remainder of the radiant energy, called the net all-wave radiation, is dissipated into the soil, into the lower layer of the atmosphere, and evaporates water from the soil and plants (evapotranspiration). Preliminary analyses suggest that monthly total evapotranspiration reaches a maximum of 7.4 cm (2.9 in.) in July. Monthly totals during January and February are about 0.8 cm (0.3 in.). It appears that evapotranspiration equals approximately 90% of the annual precipitation.

3.1.5 MDA-Specific Climate

The variations in local climate across the plateau and between individual MDAs are primarily influenced by an MDA's location. The western third of the laboratory property is typically wetter and more temperate than the rest of the Laboratory. Typically, mesas are sunnier and have stronger winds than the canyons or slopes. Therefore, an MDA's location determines the wind velocities, temperature variability, precipitation, and solar irradiance there. The combination of these local parameters establish an evapotranspiration potential. A summary of local climate data for the MDAs as measured at the nearest Laboratory meteorological station is presented in Table 3.1-1.

Table 3.1-1
Summary of MDA Climate Data

MDA	Location	Closest Met Station	Distance from MDA to Met Station (mi.)	Average Temperature (°C)		Precipitation (in./yr.)	Winds (m/s)	Short Wave Irradiance (MJ/m^2)	Evapotranspiration Potential
				Min	Max				
A	Mesa	TA-53	1.2	4.36	16.58	15.97	2.9	18.94	High
B	Mesa	TA-53	1.8	4.36	16.58	15.97	2.9	18.94	High
C	Mesa	TA-6	1.2	1.77	15.03	19.69	2.49	18.87	High
D	Mesa	TA-54	3.7	0.99	17.58	14.57	2.74	19.23	High
E	Mesa	TA-54	4.1	0.99	17.58	14.57	2.74	19.23	High
F	Slope	TA-6	0.4	1.77	15.03	19.69	2.49	18.87	Medium
G	Mesa	TA-54	1.0	0.99	17.58	14.57	2.74	19.23	High
H	Mesa	TA-54	2.6	0.99	17.58	14.57	2.74	19.23	High
K	Slope	TA-54	3.5	0.99	17.58	14.57	2.74	19.23	High
L	Mesa	TA-54	1.8	0.99	17.58	14.57	2.74	19.23	Low
M	Slope	TA-6	1.2	1.77	15.03	19.69	2.49	18.87	Medium
N	Slope	TA-6	1.4	1.77	15.03	19.69	2.49	18.87	Medium
P	Slope	TA-6	1.1	1.77	15.03	19.69	2.49	18.87	Medium
Q	Slope	TA-6	1.6	1.77	15.03	19.69	2.49	18.87	Medium
R	Slope	TA-6	1.5	1.77	15.03	19.69	2.49	18.87	Medium
S	Slope	TA-6	1.7	1.77	15.03	19.69	2.49	18.87	Medium
T	Mesa	TA-53	1.3	4.36	16.58	15.97	2.9	18.94	High
U	Mesa	TA-53	1.1	4.36	16.58	15.97	2.9	18.94	High
V	Mesa	TA-53	1.2	4.36	16.58	15.97	2.9	18.94	High
W	Mesa	TA-6	1.6	1.77	15.03	19.69	2.49	18.87	High
X	Slope	TA-6	1.6	1.77	15.03	19.69	2.49	18.87	Medium
Y	Canyon	TA-49	2.2	3.44	16.18	18.68	2.41	19.14	Low
Z	Mesa	TA-6	1.9	1.77	15.03	19.69	2.49	18.87	High
AA	Canyon	TA-54	1.8	0.99	17.58	14.57	2.74	19.23	Low
AB	Mesa	TA-49	0.7	3.44	16.18	18.68	2.41	19.14	High

3.2 Geology

Discussions of the regional geologic setting of the Pajarito Plateau are presented in Griggs (1964, 8795); the IWP (LANL 1996, 55574); the Hydrogeologic Workplan (LANL 1996, 55430); and, most recently, the Core Document for Canyons Investigations (LANL 1997, 55622, p. 3-6).

The surface distribution of bedrock geologic units in the Pajarito Plateau area is shown on geologic maps that have been prepared by Griggs (1964, 8795); Smith et al. (1970, 9752); Purtymun and Kennedy (1971, 4798); Vaniman and Wohletz (1990, 21589); Rogers (1995, 54419); Dethier (1997, 49843); and others. The subsurface geology has been investigated with a number of deep boreholes including the test wells (TW-well), deep test holes (DT-holes) municipal supply wells (LA-wells, O-wells, and G-wells) (e.g., Purtymun 1995, 45344), and more recently by the regional aquifer characterization holes (R-wells) that are described in the Hydrogeologic Workplan (LANL 1996, 55430).

The principal bedrock units in the Pajarito Plateau area consist of the following, in ascending order:

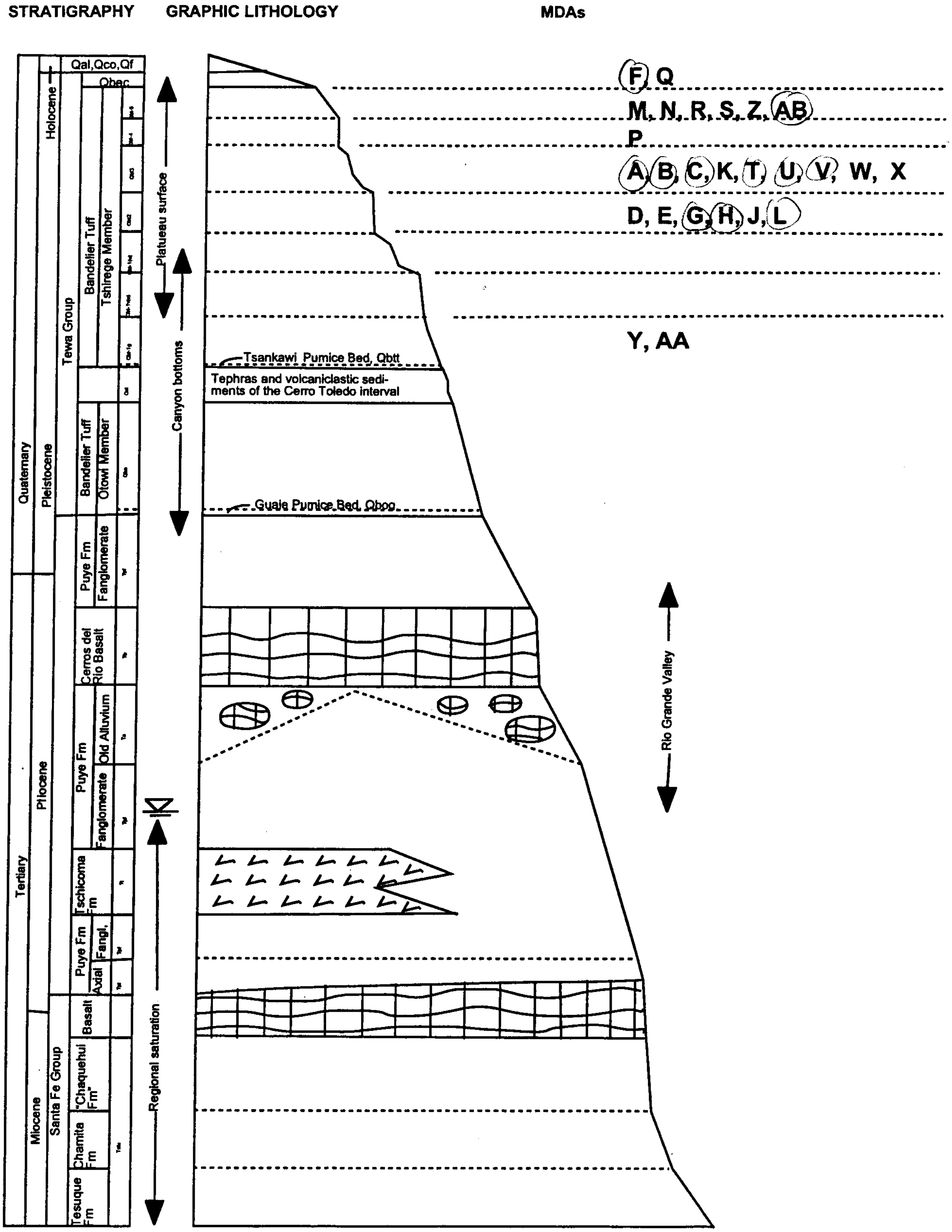
- Santa Fe Group: 4–21 Ma (Manley 1979, 11714)
- Puye Formation: 1.7–4 Ma (Turbeville et al. 1989, 21587; Spell et al. 1990, 21586) and interstratified volcanic rocks including the Tschicoma Formation on the west: (2.53–6.7 Ma) (Gardner and Goff 1984, 44021; WoldeGabriel et al. 1996, 54427) and basalts of the Cerros del Rio volcanic field on the east: (2–3 Ma) (Gardner and Goff 1984, 44021).
- Otowi Member of the Bandelier Tuff: ca 1.61 Ma (Izett and Obradovich 1994, 48817), tephras and volcaniclastic sediments of the Cerro Toledo interval (Broxton and Reneau 1995, 49726, p. 11)
- Tshirege Member of the Bandelier Tuff: ca 1.22 Ma (Izett and Obradovich 1994, 48817; Spell et al. 1990, 21586)

Figure 3.2-1 shows the generalized stratigraphy of the Pajarito Plateau. Figure 3.2-2 shows a generalized cross-section from west to east across the plateau.

3.2.1 Santa Fe Group

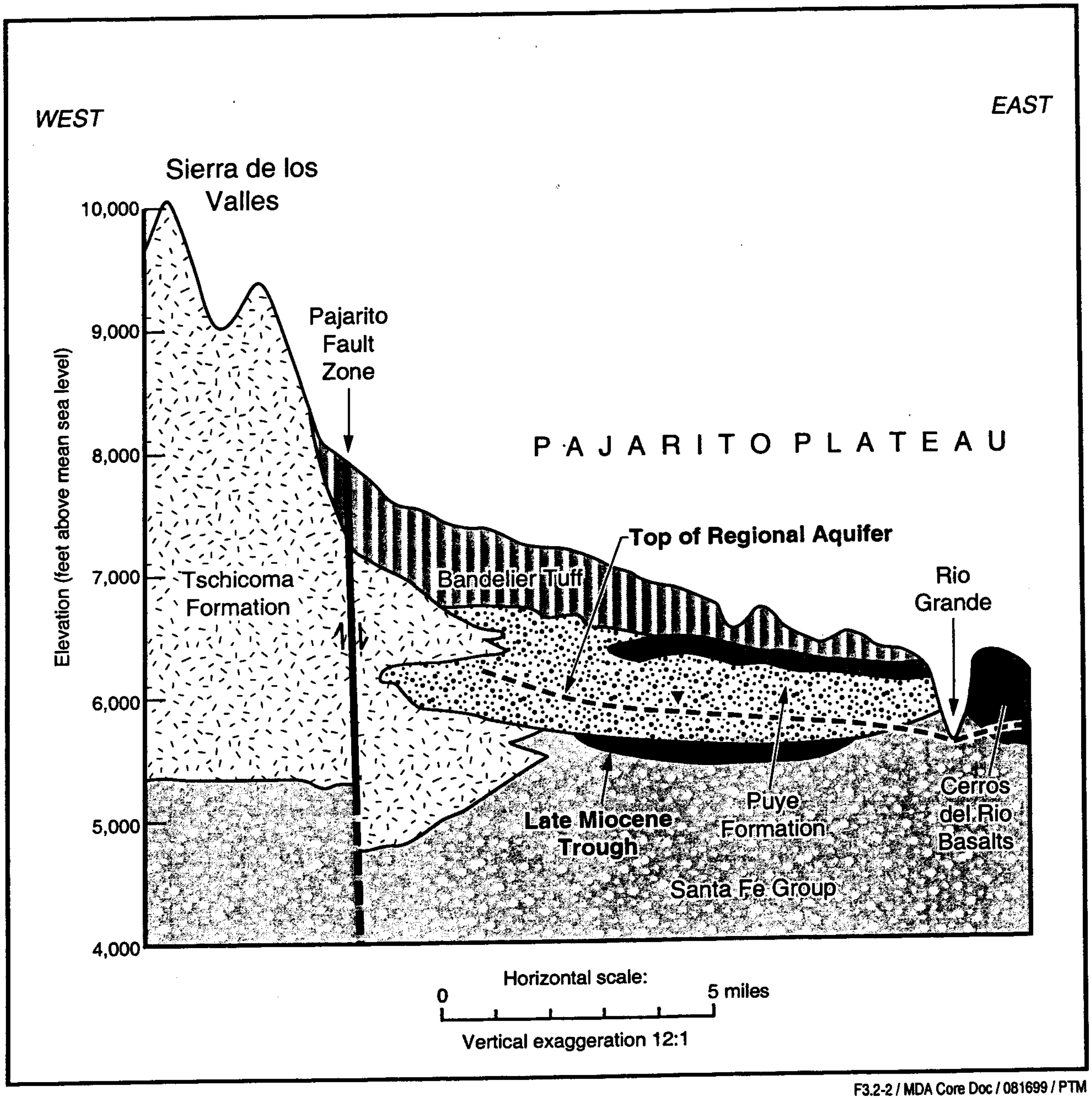
Based on borehole lithological and geophysical logs, Purtymun (1995, 45344, p. 4) informally divided the Santa Fe Group into three formations, which are (in ascending order) the Tesuque Formation, the Chamita Formation, and a coarse-grained upper facies.

The Tesuque and Chamita Formations are terrestrial sedimentary deposits that filled the Española Basin of the Rio Grande during subsidence in late Tertiary time. The coarse-grained upper facies of the Santa Fe Group was deposited in a late Miocene trough 3- to 4- mi- (4.8- to 6.4- km) wide and 7- to 8- mi- (11- to 13- km) long that extended northeastward beneath the Pajarito Plateau (see Figure 2-4 in the hydrogeologic work plan [LANL 1996, 55430]). This trough is filled with up to 1500 ft (approximately 450 m) of gravels, cobbles, and boulders derived from the Jemez volcanic field and with volcanic, metamorphic, and sedimentary rocks derived from highlands to the north and east. The trough is partly coincident with low-gravity anomalies that Ferguson et al. (1995, 56018) interpreted as a sediment-filled graben on the western side of the Española basin of the Rio Grande rift. The eastern side of this trough crosses Cañada del Buey near state road NM4. The western margin of the trough is not well constrained but may be located in the western portion of the Laboratory.



F3.2-1 / MDA Core Doc / 081699 / PTM

Figure 3.2-1. Generalized stratigraphy of bedrock geologic units of the Pajarito Plateau



F3.2-2 / MDA Core Doc / 081699 / PTM
modified: F2-4 / Hydrogeologic Workplan / 1296

Figure 3.2-2. **Generalized cross-section of the Pajarito Plateau**

3.2.1.1 Tesuque Formation

The Tesuque Formation primarily consists of poorly consolidated, light pinkish brown, silty sandstone, siltstone, and claystone (Cooper et al. 1965, 8582, p. 59). The sandstones are predominately fine- to medium-grained, and the sand grains are subrounded to well rounded. The Tesuque Formation also contains interbedded gravel and conglomerate beds and basalt flows in the eastern part of the Pajarito Plateau.

3.2.1.2 Chamita Formation

The Chamita Formation is similar in appearance to the Tesuque Formation but reportedly contains a larger proportion of volcanic and granitic clasts in its gravel layers (Galusha and Blick 1971, 21526, p. 71) and Paleozoic limestone cobbles in its conglomerate layers (Dethier and Manley 1985, 21506). The Chamita Formation contains lithologically distinct quartzitic gravels (Galusha and Blick 1971, 21526, p. 71). Upper layers of the Chamita Formation may contain cobbles of Jemez volcanic rocks, primarily andesites and dacites. However, because of similarities of appearance, obvious time overlaps, and interfingering relations, differentiation of the Chamita Formation from the coarse-grained upper facies of the Santa Fe Group is often difficult, particularly in borehole investigations. The coarse-grained upper facies of the Santa Fe Group may be a facies variation of the Chamita Formation.

3.2.1.3 Coarse-Grained Upper Facies of the Santa Fe Group

The coarse-grained upper facies of the Santa Fe Group is composed of a mixture of volcanic debris from the Sierra de los Valles and arkosic and granitic debris from the highlands to the north and east of the Pajarito Plateau. Purtymun (1995, 45344, p. 6) called this distinctive group of coarse-grained sediments at the top of the Santa Fe Group the "Chaquehui Formation." The name "Chaquehui Formation" as related to Santa Fe Group sediments is a potentially confusing designation because the type section of the "Chaquehui Formation" in Chaquehui Canyon is much younger than the coarse-grained upper facies of the Santa Fe Group identified in boreholes on the Pajarito Plateau. The "Chaquehui Formation" constitutes quartzite clast-bearing maar deposits of the Cerros del Rio volcanic field. In PM-3 the upper coarse-grained facies consists of medium- to coarse-grained sandstone, conglomerate, and siltstone (Purtymun 1967, 11829, p. 9). Because of the high permeability characteristics of this facies, it is an important aquifer for the development of high-yield, low-drawdown municipal and industrial water supply wells on the Pajarito Plateau.

The deep boreholes in the eastern part of the Pajarito Plateau encountered basaltic lava flows that are interbedded with the sedimentary deposits of the upper Santa Fe Group. These basalts range in thickness from 30–480 ft (9.1–146 m). They generally are described as dark gray and dense, but red vesicular zones are also present (Cooper et al. 1965, 8582, p. 60; Purtymun 1967, 11829, p. 9; Purtymun 1995, 45344, p. 263).

3.2.2 Puye Formation, Tschicoma Formation, and Cerros del Rio Basalts

The Puye Formation is mostly a fanglomerate deposit generally consisting of poorly sorted boulders, cobbles, and coarse sands. At PM-3 the clasts are composed of dacite, rhyolite, and fragments of basalt and pumice (Purtymun 1967, 11829, p. 8). At TW-8 in Mortandad Canyon, the fanglomerate consists predominately of fine- to coarse-grained sands and interbedded clay, silt, and gravel (Baltz et al. 1963, 8402, Figure 4). The lower fanglomerate includes more than 95 ft (29 m) of light tan to light gray tuff and tuffaceous sand.

The lower Puye Formation includes coarse sand and boulder deposits interpreted to represent an axial facies deposit of the ancestral Rio Grande as described by Manley (1976, 57673) and Dethier (1997, 49843). The axial facies deposit was previously (informally) called the "Totavi Lentil" of Griggs (1964, 8795). This deposit is composed of gravel and boulders of dacite, rhyolite, and quartzite (Purtymun 1967, 11829, p. 9). The thickness of the axial facies deposit varies from 40–70 ft (12–21 m) (Purtymun 1995, 45344, pp. 275–277). The axial facies deposit interfingers with the fanglomerates of the Puye Formation and basaltic rocks of the Cerros del Rio volcanic field in White Rock Canyon.

Beneath the eastern part of the Pajarito Plateau, a sequence of brown and gray basaltic lava flows split the Puye Formation into the main lower part and a thin upper part (Purtymun 1995, 45344, pp. 275–277). In some areas, these basalts are present beneath the Guaje Pumice Bed, although variable thickness of fanglomerate facies may be present above the basalts. The basalts are stratigraphically equivalent to the basaltic rocks of the Cerros del Rio volcanic field and probably represent an extension of that volcanic field beneath the Pajarito Plateau.

Dacitic volcanic rocks, presumably representing the distal edge of a Tschicoma Formation lava flow, were encountered beneath the Bandelier Tuff in borehole SHB-1 (located west of TA-55). The dacite flow appears to occupy a similar stratigraphic position within the Puye Formation, as do the basalts. Similar dacite flows may underlie the upper and middle sections of Sandia Canyon. This may indicate that the volcanic flows in the Puye Formation do not extend laterally beneath the entire Pajarito Plateau.

The top of the regional zone of saturation beneath the Pajarito Plateau is usually encountered within the fanglomerate facies of the Puye Formation and the associated interbedded basalts.

3.2.3 Otowi Member of the Bandelier Tuff

The Otowi Member is a nonwelded, poorly consolidated ignimbrite sheet composed of stacked ash-flow units. These units are composed of pumice lapilli supported by a matrix of ash and crystal fragments. The Otowi Member varies in reported thickness from 184–465 ft (56–142 m). The deposits of the Otowi Member beneath upper Sandia and middle Mortandad Canyon (near TW-8 and EGH-LA-1) are among the thickest on the Pajarito Plateau from deposition in a pre-Bandelier Tuff paleovalley (see Figure 5 in Broxton and Reneau 1996 [55429, p. 330]). The paleovalley containing the thick Otowi Member sediments continues southward across the Pajarito Plateau.

The basal part of the Otowi Member includes the Guaje Pumice Bed, which is a sequence of well-stratified pumice-fall and ash-fall deposits. The Guaje Pumice Bed typically is 30- to 35- ft- (9.1- 10.7-m) thick beneath the Pajarito Plateau (27 ft [8 m] at PM-2).

3.2.4 Tephras and Volcaniclastic Sediments of the Cerro Toledo Interval

Tephras and volcaniclastic sediments of the Cerro Toledo interval is an informal name given to a complex sequence of epiclastic sediments and tephras of mixed provenance (Broxton and Reneau 1995, 49726, p. 11). This unit includes well-stratified tuffaceous sandstones and siltstones, primary ash-fall and pumice-fall deposits, and dacite-rich gravel and boulder deposits. The Cerro Toledo deposits, which vary in thickness from 0 to more than 100 ft (30 m), likely were deposited episodically with unevenly distributed local deposits. Some sediments were deposited in drainage channels developed on top of the Otowi Member before deposition of the Tshirege Member. Other blanket-type fallout deposits were deposited across the plateau, including on paleotopographic drainage divides. Erosion and possible redeposition of the Cerro Toledo interval sediments and possibly the underlying Otowi Member occurred in places before deposition of the Tshirege Qbt 1 unit, which may have contributed to locally variable thickness. The Cerro

Toledo interval is approximately 140-ft-(43 m) thick in SHB-1 (Gardner et al. 1993, 12582, p. 9) and approximately 80-ft-(24 m) thick in borehole 35-2028 located in Ten Site Canyon (Environmental Restoration Project 1996, 54422, p. 2-3).

3.2.5 Tshirege Member of the Bandelier Tuff

The Tshirege Member is a multiple-flow ignimbrite sheet that forms the prominent cliffs and mesas of the Pajarito Plateau. The Tshirege Member includes a number of subunits that can be recognized based on differences in physical and weathering properties. This document follows the nomenclature of Broxton and Reneau (1995, 49726, p. 8), which was adopted as a standard by the ER Project.

Subunits of the Tshirege Member

- The Tsankawi Pumice Bed (Qbtt) is the basal pumice fallout deposit of the Tshirege Member. This pumice bed typically is 1- to 3-ft-(0.30- to 0.91-m) thick in this part of the Laboratory. It is composed of angular to subangular clast-supported pumice lapilli up to 2.4 in. (6 cm) in diameter.
- Qbt 1g is the lowermost unit in the thick ignimbrite sheet that makes up most of the Tshirege Member. Qbt 1g is a porous, nonwelded, poorly sorted, vitric ignimbrite. It is poorly indurated but nonetheless forms steep cliffs because a resistant bench near the top of the unit forms a protective cap over the softer underlying tuff. Qbt 1g underlies most of the mesas and is exposed in canyon walls on the Pajarito Plateau.
- Qbt 1v is a series of cliff- and slope-forming outcrops composed of porous, nonwelded, devitrified ignimbrite. (All units above Qbt 1g are vapor-phase-altered and devitrified.) The base of the unit is a thin, horizontal zone of preferential weathering that marks the abrupt transition from vitric tuffs below to devitrified tuffs above; this feature forms a mappable marker horizon on canyon walls in portions of middle and lower Sandia Canyon. The lower part of Qbt 1v is a resistant orange brown colonnade tuff (Qbt 1v-c) that forms a distinctive low cliff characterized by columnar jointing. The colonnade tuff is overlain by a distinctive white band of slope-forming tuffs. Qbt 1v is exposed in canyon walls and is present beneath portions of canyon floors.
- Qbt 2 forms a distinctive, medium-brown, vertical cliff-forming unit that stands out in marked contrast to the slope-forming, lighter-colored tuffs above and below. This unit is devitrified, relatively highly welded, and forms the steep, narrow canyon walls in the central and eastern portions of the Pajarito Plateau and underlies canyon floors in the central and western portions of the plateau. Qbt 2 forms a resistant caprock on mesa tops in the eastern portion of the Pajarito Plateau and is the mesa caprock at Mesita del Buey and at many of the MDAs.
- Qbt 3 is a nonwelded to partially welded, devitrified ignimbrite. The basal part of Qbt 3 consists of a soft, nonwelded tuff that forms a broad gently sloping bench on top of Qbt 2 in canyon wall exposures and on the broad canyon floors in the central part of the Pajarito Plateau. The upper part of Qbt 3 is a partially welded tuff that forms the caprock of mesas in the central part of the Pajarito Plateau, such as at TA-50 and the town of Los Alamos. This unit is more densely welded to the west and locally contains apparent horizontal bedding and/or fracturing.
- Qbt 4 is a partially to densely welded ignimbrite characterized by small, sparse pumices and numerous intercalated surge deposits. This unit is exposed on mesa tops on the western part of the Pajarito Plateau such as at TA-3. Some of the most densely welded areas occur on the western margin of the Laboratory.

The majority of MDAs are located within the upper units of the Tshirege Member of the Bandelier Tuff. A summary of local geology present at the MDAs is presented in Table 3.2-1.

Table 3.2-1
Summary of MDA Local Geology

MDA	Stratigraphic Unit			Geohydrologic			
	Surface Unit	Depth Disposal Bottom (ft)	Disposal Bottom Unit	Devitrification	Welding	Induration	Fracture Occurrence
A	Tshirege Member, Unit 3	30	Unit 3	Devitrified	Non	Slight	Rare
B	Tshirege Member, Unit 3	18.5	Unit 3	Devitrified	Non	Slight	Rare
C	Tshirege Member, Unit 3	20	Unit 3	Devitrified	Non	Slight	Rare
D	Tshirege Member, Unit 2	48	Unit 2	Devitrified	Slight	Strong	Many
E	Tshirege Member, Unit 2	48	Unit 2	Devitrified	Slight	Strong	Many
F	El Cajete/Alluvial fan	<20	Unit 4	Devitrified	Non	Slight	Rare
G	Tshirege Member, Unit 2	60–70	Unit 1v	Devitrified	Slight	Strong	Many
H	Tshirege Member, Unit 2	60	Unit 1v(u)	Devitrified	Slight	Strong	Many
K	Tshirege Member, Unit 3	8	Unit 3	Devitrified	Non	Slight	Rare
L	Tshirege Member, Unit 2	65	Unit 1v(u)	Devitrified	Slight	Strong	Many
M	El Cajete/Unit 4	n/a*	Unit 4	Devitrified	Non/mod	Non/mod	Rare/many
N	El Cajete/Unit 4	<20	Unit 4	Devitrified	Non/mod	Non/mod	Rare/many
P	Unit 4/Unit 3	n/a	Unit 4	Devitrified	Mod/non	Mod/slight	Many/mod
Q	Alluvial fan/El Cajete	<20	El Cajete	Devitrified	Non	Slight	Rare
R	Alluvial fan/Unit 4	n/a	Unit 4	Devitrified	Non/mod	Non/mod	Rare/many
S	Alluvial fan/Unit 4	<10	Unit 4	Devitrified	Non/mod	Non/mod	Rare/many
T	Tshirege Member, Unit 3	60	Unit 3	Devitrified	Non	Slight	Rare
U	Tshirege Member, Unit 3	13	Unit 3	Devitrified	Non	Slight	Rare
V	Tshirege Member, Unit 3	10	Unit 3	Devitrified	Non	Slight	Rare
W	Tshirege Member, Unit 3	135	Unit 3	Devitrified	Non	Slight	Rare
X	Tshirege Member, Unit 3	35	Unit 3	Devitrified	Non	Slight	Rare
Y	Alluvium/Unit 1g	12–15	Unit 1g	Vitric	Non/non	Non/slight	Rare/some
Z	El Cajete/Unit 4	10	Unit 4	Devitrified	Non/mod	Mod/strong	Rare/many
AA	Colluvium/Unit 1g	<20	Unit 1g	Vitric	Non/non	Non/slight	Rare/some
AB Area 4	Tshirege Member, Unit 4	65–80	Unit 4	Devitrified	Mod	Strong	Many

* n/a = not applicable (MDA is a surface unit).

3.2.6 Geological Structure

Subunits of the Tshirege Member dip gently southeastward on the Pajarito Plateau. The southeastward dip of these tuffs probably is the primary initial dip, mainly resulting from the burial of a southeast-dipping paleotopographic surface and thinning of subunits away from the volcanic source to the west.

The paleotopography of the pre-Tshirege surface may strongly influence the direction of possible groundwater flow and contaminant migration in subsurface units beneath MDAs. Sediments of the Cerro

Toledo interval are present beneath the Tshirege Member of the Bandelier Tuff. Available data from test wells and borehole drilling on the Pajarito Plateau, especially data from the Pajarito Mesa municipal supply well field and at TA-54, help define this paleotopographic surface. The existing data indicate that a Cerro Toledo-age drainage system likely heads on the flanks of the Sierra de los Valles in the area of the headwaters of Los Alamos Canyon. The channel system appears to trend to the southeast and crosses obliquely beneath the Pajarito Plateau and continues southeastward to south of the White Rock basalt high (Broxton and Reneau 1996, 55429, p. 331). Dacite boulders in the Cerro Toledo interval are exposed in lower Water Canyon east of state road NM4, which indicates the presence of a large channel system within the Cerro Toledo interval. Similar volcanic boulders in the Cerro Toledo interval have also been encountered in boreholes SHB-1 and 35-2028 (in Ten Site Canyon) and outcrop in lower Sandia Canyon near PM-1. The dacite boulders in lower Sandia Canyon may represent a separate channel system within the Cerro Toledo interval that may head in the upper reaches of the modern Rendija Canyon watershed (Broxton and Reneau 1996, 55429, p. 331).

Paleotopography of the pre-Otowi surface may also influence the flow direction of potential perched groundwater beneath MDAs. A significant zone of intermediate perched zone groundwater occurs in the Guaje Pumice Bed approximately 300 ft (91 m) beneath Los Alamos Canyon. This intermediate perched zone groundwater contains elevated concentrations of tritium (Broxton et al. 1995, 50121, p. 97), which are declining over time, suggesting the passage of a tritiated groundwater plume (Longmire et al. 1996, 54168, p. 476). Although this perched groundwater has been found only in the area beneath Los Alamos Canyon, structure contour maps suggest that the gradient of the perching layer changes from eastward to southward near TA-21 and that water confined to this zone may move down gradient along the axis of a large pre-Otowi paleodrainage toward the south (Broxton and Reneau 1996, 55429, p. 329; Davis et al. 1996, 55446, p. 54). The location of the axis of this paleodrainage cannot be constrained precisely, but the available data suggest that the axis crosses beneath Sandia Canyon near TA-53 and crosses Mesita del Buey near water supply well PM-4. Groundwater infiltrating to and potentially perching in the Guaje Pumice Bed from Los Alamos Canyon could tend to migrate toward the axis of this paleodrainage and then flow toward the south or southwest beneath Sandia Canyon and Cañada del Buey.

Faults and fractures may play a role as infiltration pathways if they become saturated beneath MDAs and beneath canyon floors. A complex zone of faulting associated with the southern part of the Rendija Canyon fault zone is exposed at the Los Alamos County landfill and crosses the middle part of the Pajarito Plateau (Gardner et al. 1999, 63492, p. 20). The Guaje Mountain fault is present north of the town of Los Alamos and could also extend southward onto the Laboratory but the location of the southern end of this fault is not certain. Numerous small-displacement faults have also been documented at TA-54 on Mesita del Buey (Reneau et al. 1998, 63135, 63497) and likely occur in other areas.

3.3 Hydrology

Pursuant to the Laboratory's Hydrogeologic Workplan (LANL 1998, 59599), the hydrology of the Pajarito Plateau is discussed as it applies to mesas and canyons. Mesas are generally devoid of water, both on the surface and within the rock forming the mesa. Canyons are either wet or dry; the wet canyons contain continuous streams and may contain groundwater in the canyon bottom alluvium. Dry canyons have only occasional stream flow and lack alluvial groundwater. Intermediate perched groundwater in known to exist in several locations, and the regional aquifer water table is found at depths of about 600–1,200 ft (200–360 m) beneath the Plateau.

3.3.1 Surface Water

Rivers and streams located within 80 km (53 mi) of the Laboratory include the Rio Grande and its tributaries including the Chama, Ojo Caliente, Santa Cruz, Nambe, and Tesuque rivers to the north and east; the Jemez River and San Antonio creeks to the west; and the Santa Fe and Galisteo rivers to the south. The Rio Grande receives all surface water drainage from the Pajarito Plateau. Reservoirs within 80 km (50 mi) include the Cochiti, Abiquiu, Santa Cruz, and Jemez.

Despite the dramatic erosional topography of the Pajarito Plateau that resulted from greater surface flows in the past, only a few streams currently flow year-round; most flow only after heavy rains and snowmelt. Run-off from heavy rainfall and snowmelt reaches the Rio Grande several times a year in some drainages.

Springs occur at elevations between 2,400- and 2,700-m (7,900- and 8,900-ft) on the eastern slopes of the Jemez Mountains and supply water to the upper reaches of several major canyons. These springs discharge at rates from 7–530 l/min (1.8–140 gal./m), which is insufficient to maintain surface flow for more than the upper third of the canyons before it is depleted by evaporation to the atmosphere and infiltration into the underlying alluvium. On the mesas, water flows only as stormwater and snowmelt run-off. As a result of run-off, surface erosion occurs, typically as shallow sheet erosion on the relatively flat parts of the mesa, or by local established erosion channels during sustained storm run-off.

Run-off from summer storms reaches a maximum in less than 2 hours and lasts less than 24 hours. In contrast, run-off from spring snowmelt occurs over a period of several weeks at a low discharge rate. The amount of eroded material transported in run-off waters is generally higher in summer rainfall events than during snowmelt.

Flooding of the MDAs is not a major concern due to most being located on mesas. Exceptions to this are MDA Y and MDA AA, which are in canyons. At MDA G, temporary ponding within disposal pits has occurred. Stormwater likely flows at a number of points along the perimeter of each MDA. Stormwater run-on at some MDAs has been stabilized by ditches or other BMPs, for example, MDA G and MDA AB. A summary of surface water conditions at the MDAs is presented in Table 3.3-1.

3.3.2 Groundwater

Groundwater in the Laboratory area occurs as shallow alluvial groundwater in canyons, perched zones beneath some canyons and along the Jemez Mountains within the Bandelier Tuff, the Cerros del Rio Basalt, and the upper part of the Puye Formation, and in the regional aquifer. The regional aquifer is the only source capable of serving municipal and industrial water needs.

Alluvial groundwater in canyons is investigated according to the Core Document for Canyons Investigations (LANL 1997, 55622). Perched intermediate groundwater and the regional aquifer are undergoing continuous characterization via the Monitoring Well Installation Project, which implements the Laboratory's Hydrogeologic Workplan. Table 3.3-2 lists the regional aquifer wells (planned and existing) in relation to the MDAs. It also identifies any water supply wells downgradient from any MDA.

Table 3.3-1
Summary of MDA Surface Water Conditions

MDA	Run-on Potential*	Run-off Potential*	Erosion Matrix Score	BMPs in Place	Outfall in MDA	Depth to Regional Water (ft)
A	None	High ✓	50	No	No	1230
B	Slight	High ✓	56	No	No	1300
C	None	High ✓	60	No	No	1175
D	Slight	High	17	No	No	910
E	None	High	22	No	No	760
F	Moderate	Moderate ✓	40	No	No	1275
G	None	High ✓	60	Yes	No	900
H	None	Moderate	60	No	No	980
K	Moderate	Moderate	51	No	Yes	820
L	None	High ✓	60	Yes	Yes	940
M	Moderate	Moderate	68	Yes	No	1220
N	Moderate	Moderate	28	No	No	1170
P	Moderate	High	65	Yes	No	1150
Q	Moderate	Moderate	39	No	No	1200
R	Moderate	High	53	No	Yes	1240
S	Moderate	Moderate	No score	No	Yes	1160
T	None	High ✓	57	Yes	No	1240
U	Slight	High ✓	47	Yes	No	1220
V	Slight	High ✓	No score	Yes	No	1260
W	Moderate	High	No score	No	No	1170
X	Slight	Slight	No score	No	No	1160
Y	High	Moderate	65	No	No	590
Z	Slight	Moderate	58	No	No	1200
AA	High	Moderate	43	Yes	No	770
AB	Moderate	High ✓	39	Yes	No	1120

* Run-on/off potential scale (none, slight, moderate, and high) is derived from general slope and MDA position relative to mesa cliff.

Table 3.3-2
Existing and Planned Water Monitoring and Supply Wells in Relation to the MDAs

MDA	Upgradient R-Wells	Downgradient R-Wells	Downgradient Supply Wells
A	R-7	R-8, R-9	O-1, O-4, PM-3
B	R-6	R-7, R-8	O-1, O-4, PM-3
C	R-17	R-13, R-14, R-15	PM-1, PM-3, PM-5
D	R-31, R-32	—*	—
E	R-31	—	—
F	R-24	R-18	PM-1, PM-2, PM-3, PM-4, PM-5
G	R-20, R-21	R-22	—
H	R-19	R-12	O-1, PM-1
K	R-31	R-32	—
L	R-28, R-30	—	—
M	R-24	R-18	PM-1, PM-2, PM-3, PM-4, PM-5
N	R-25	R-20, R-21	PM-1, PM-2, PM-4
P	R-25	R-20, R-21, R-27	PM-2
Q	R-24	R-25	PM-1, PM-2, PM-3, PM-4, PM-5
R	R-24	R-19, R-20	PM-2
S	R-24, R-26	R-27, R-30	PM-2
T	R-7	R-8, R-9	O-1, O-4, PM-3
U	R-7	R-8, R-9	O-1, O-4, PM-3
V	R-6	R-7, R-8	O-1, O-4, PM-3
W	R-17	R-13, R-14, R-15	PM-1, PM-3, PM-5
X	R-17	R-13, R-14, R-15	PM-1, PM-3, PM-5
Y	R-30	R-31, R-32	—
Z	R-27	R-28	PM-2
AA	R-28	R-22	None
AB	R-26	R-28, R-30	None

* A dash in the table means no wells.

3.3.2.1 Alluvial Groundwater

Ephemeral streamflows in the canyons of the Pajarito Plateau have deposited alluvium that locally may be up to 100-ft-(30 m) thick and typically more permeable than the underlying volcanic tuff and sediments. Ephemeral run-off in some canyons infiltrates the alluvium until downward movement is impeded by the less permeable underlying strata which results in a buildup of shallow alluvial groundwater. In addition to the alluvium, in some cases relatively thin zones of shallow groundwater can also be contained in the weathered tuff or some other unit immediately underlying the alluvium. Depletion by evapotranspiration and movement into the underlying rocks limit the horizontal and vertical extent of the alluvial groundwater (Purtymun et al. 1977, 5704). Lateral flow of the alluvial groundwater is in an easterly, down-canyon direction. Tracer studies in Mortandad Canyon have shown that the velocity of water ranges from about 60 ft/day (18 m/day) in the upper reach to about 7 ft/day (2 m/day) in the lower reach of the canyon (Purtymun 1995, 45344). Similar tests are taking place in DP Canyon in fiscal year 1999.

3.3.2.2 Intermediate Perched Zone Groundwater

Perched groundwater is known to exist beneath several canyons in the eastern portion of the Laboratory, along the eastern flanks of the Jemez Mountains west of the Laboratory, and beneath the mesas and canyons at S Site (TA-16), located in the southwestern part of the Laboratory near the Jemez Mountains. Perched groundwater zones possibly exist beneath other canyons in the south and central portions of the Laboratory. As planned, the Laboratory's monitoring well installation program is providing new data regarding intermediate perched water zones beneath the Laboratory, the interpretations of which are integrated into the Hydrogeologic Workplan with annual updates.

3.3.2.3 Regional Aquifer

Figure 3.3-1 shows the surface contours of the regional aquifer, from which flow directions can be inferred. The figure identifies the wells wherefrom most of the information on the figure is derived.

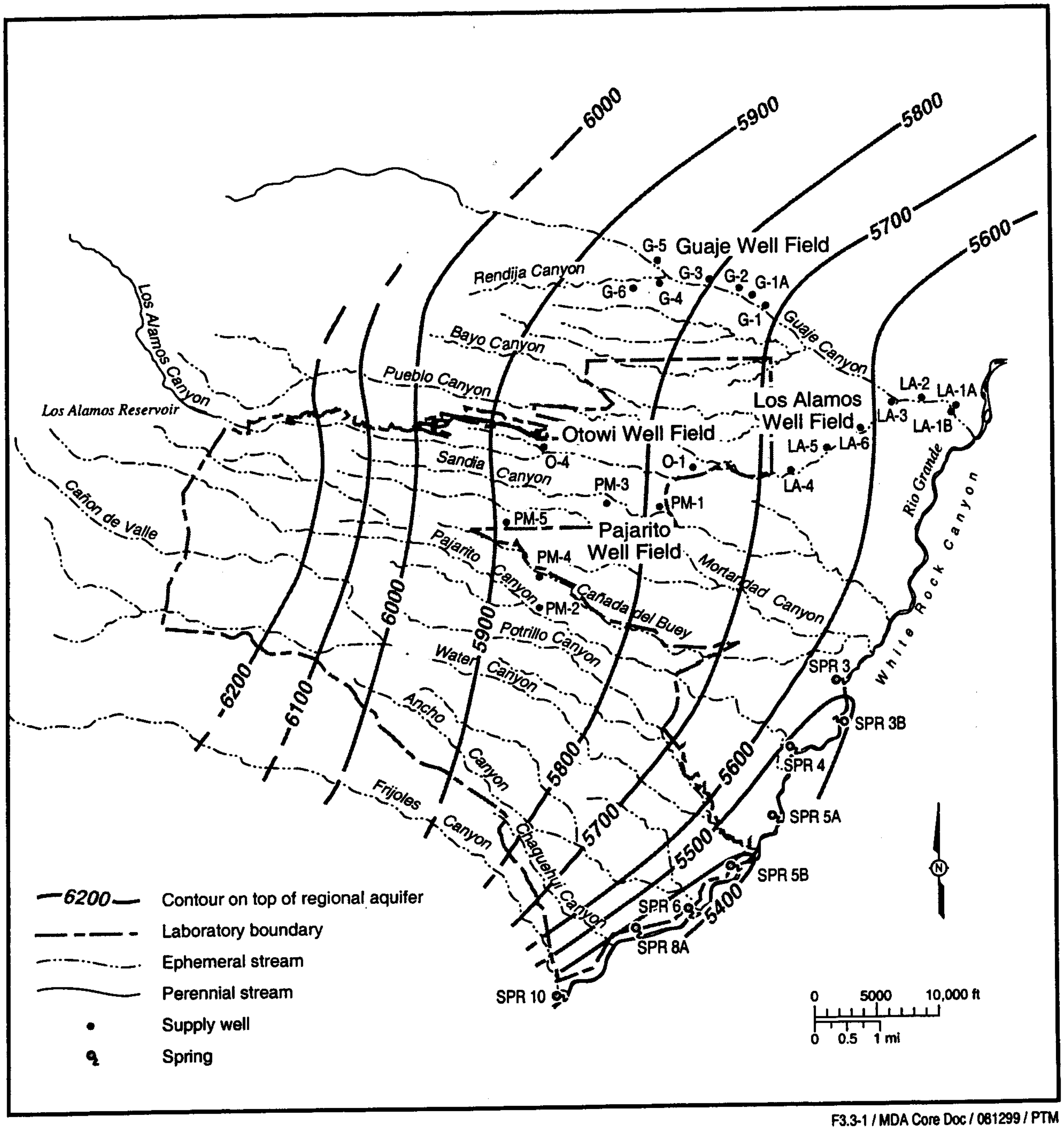
The hydraulic gradient or slope of the regional aquifer water table ranges from 0.011–0.015. At MDA G, the flow rate has been estimated at 29 m/year (95 ft/year) using data from the Pajarito well field. This rate is an average over the thickness of the aquifer intercepted by the well screens.

The regional aquifer of the Los Alamos area is the only aquifer capable of large-scale municipal water supply (Purtymun 1984, 6513). In 1989, water for the Laboratory, the communities of Los Alamos and White Rock, and Bandelier National Monument was supplied from 11 deep wells in 3 well fields. The wells are located on the Pajarito Plateau and in Los Alamos and Guaje canyons east of the plateau. Municipal and industrial water supply pump volume during 1997 was 1.29 billion gal. (4.9 billion l). Yields from individual wells ranged from about 175–1400 gal./min (665–5320 l/min) (Stoker et al. 1992, 12017). Purtymun (1984, 6513) summarized the hydraulic characteristics of the aquifer as determined during aquifer tests and during periods of production of supply wells and test holes.

The surface of the regional aquifer rises westward from the Rio Grande within the Santa Fe Group into the lower part of the Puye Formation beneath the central and western part of the Pajarito Plateau. The depths of groundwater below the mesa tops range from about 1200 ft (360 m) along the western margin of the plateau to about 600 ft (180 m) at the eastern margin. The regional aquifer is separated from the alluvial groundwater and intermediate perched zone groundwater by 350 to 620 ft (100- to 200-m) of tuff, basalt, and sediments (Environmental Protection Group 1993, 23249). The regional aquifer exhibits artesian conditions in the eastern part along the Rio Grande (Purtymun 1984, 6513). Continuously recorded water level measurements collected in test wells since fall, 1992 indicate that, throughout the plateau, the regional aquifer responds to barometric and earth tide effects in the manner typical of confined aquifers.

3.3.3 Hydrologic Characteristics of Geologic Units Hosting MDAs

Typically, most of the units of the Tshirege Member, which form the mesas and slopes on the Plateau, are very dry and do not readily transmit moisture. However, relatively thin subunits such as pumice falls, surge beds, and the Colonnade Tuff demonstrate elevated moisture contents and enhanced fluid-flow properties. Most of the pores in the tuff are small enough to be of capillary size, and hold water against gravity by surface tension forces. Moisture content is generally more variable near the top of the mesa than in the central portions as a result of variations in temperature, humidity, and evapotranspiration. Vegetation is very effective at removing moisture near the surface by transpiration. During the summer rainy season when rainfall is highest, near-surface moisture content is variable due to the effects of higher rates of evaporation and of transpiration by vegetation, which flourishes during this time.



F3.3-1 / MDA Core Doc / 081299 / PTM
modified: F2-10 / Hydrogeologic WP / 12/96

Figure 3.3-1. **Generalized water-level contours on top of the regional aquifer across the Plateau**

This section focuses on the characteristics of the vadose zone beneath MDAs that are most relevant to modeling contaminant transport. A great deal of information is needed to first conceptualize and then model moisture flow and contaminant transport in the vadose zone. The necessary information includes basic properties of the geologic strata (e.g., porosity, density, fracture patterns, and mineralogy), which can be accurately measured, and complicated relationships describing how fluids move through the rock (e.g., moisture content, matric suction, and hydraulic conductivity), which are difficult to establish with certainty in rock with very low moisture content. To support the development of conceptual and mathematical models for flow and transport in the vadose zone, a number of field, laboratory, and analytical studies have been performed.

Table 3.3-3 summarizes measurements, observations, and interpretations of geohydrologic properties of the various stratigraphic units in the generalized stratigraphic column (see Figure 3.2-1). The properties listed in the table are the following:

- Bulk Density, the mass of rock per unit volume of rock (g/cc)
- Mean Porosity, the ratio of the air-filled volume to the total volume of the rock (%)
- Mean Volumetric Moisture, the ratio of the water volume to the total volume of the rock (%)
- Saturation, the ratio of the pore volume containing water to the total porosity (%)
- Saturated Hydraulic Conductivity (Ksat), the rate at which moisture moves through rock under the influence of gravity when the rock is fully saturated (cm/sec)
- Gravimetric Moisture Content
- Induration
- Fracture prevalence

These data are obtained from either intact tuff (e.g., fracture spacing), from direct measurements of rock samples from MDA G (e.g., density), or from experiments performed on rock samples (e.g., Ksat).

Since 24 of the 28 MDAs are located on mesa tops or hillsides, the recharge rate beneath the mesa top is perhaps the most important parameter in modeling the subsurface transport of contaminants from the MDAs. Recharge largely controls the minimum time required for contamination to be transported from any MDA through the vadose zone(s), and possible intercalated perched water zones, into the regional aquifer, where it may lead to exposures of the general public. The recharge through the undisturbed vadose zone is complex and is complicated further at any MDA by man-made disturbances associated with waste management activities.

Characteristic curves are relationships required to model unsaturated liquid flow through rock. They include moisture retention curves that describe the energy-state or tension of pore water in tuff, and the hydraulic conductivity of the rock. The moisture tension curve of a material is the relationship between suction within the matrix and the volumetric water content (i.e., the volume of water contained in a volume of tuff) for a porous material. Hydraulic conductivity is simply the rate at which water can travel through a sample of rock or soil under the influence of gravity. In general, soils and rock have higher hydraulic conductivity when more moisture is present, the maximum occurs when the material is fully saturated with water, and is called the saturated hydraulic conductivity.

Unsaturated hydraulic conductivity curves for stratigraphic unit mesa subsurfaces are plotted in Figure 3.3-2. The data plotted on the graph are obtained in experiments conducted on small samples of rock recovered from borehole cores. Measurements hydraulic conductivity are made as water is added to the sample.

Table 3.3-3
Summary of Average Geohydrologic Properties Arranged by Stratigraphic Unit

Stratigraphic Units/Subunits		Hydraulic Properties[a]					Geohydrologic Characteristics[b]		
Stratigraphic Unit[c]	Stratigraphic ub-unit[d]	Bulk Density (g/cm^3)	Mean Porosity (%)	Mean Volumetric Moisture Content (%)	Saturation (%)	Saturated Hydraulic Conductivity (cm/s)	Gravimetric Moisture Content (%)	Induration[e]	Fracture Prevalence[f]
4	N/A[g]							Strong	Many
3	N/A							Nonslight	Rare
2	2(u)	1.37	45.7	2.57	5.7	4.37 X 10^{-4}	2.12	Moderate	Many
	2(l)						1.24	Strong	Many
1v(u)	1v(u_2)	1.24	8.7	1.89	3.7	1.48 X 10^{-4}	1.03	Slight	Moderate
	1v(u_1)						1.79	Non	None
1v(c)	1v(c)	1.18	49.3	10.88	21.3	1.67 X 10^{-4}	5.11	Moderate	Moderate
1g	1g(u)[h]	1.15	46.2	8.94	16.9	1.88 X 10^{-4}	5.77	Moderate	Moderate
	1g						5.83	Non	None
Tsankawi	Tsankawi	1.12	47.3	14.0	30.3	8.65 X 10^{-4}	10.80	Moderate	Rare
Cerro Toledo	Cerro Toledo						8.49	Slight	Rare

[a] From Table 3, Appendix 2a, MDA G performance assessment (Hollis et al. 1997, 63131).

[b] From MDA L and MDA G RFI boreholes.

[c] Stratigraphic nomenclature follows Broxton and Reneau (1995, 49726).

[d] Stratigraphic subunits from MDA L and MDA G RFI borehole logging.

[e] Qualitative induration (hardness) scale is non = nonindurated, slight = slightly indurated, moderate = moderately indurated, strong = strongly indurated.

[f] Qualitative fracture scale is none = not present, rare = few present, moderate = some present, many = fractures abundant.

[g] Not yet available (under publication).

[h] Subunit 1g(u) includes the upper indurated and iron-rich portion.

At the mesa top MDAs, volumetric moisture content varies between about two and 14 percent. The characteristic curves are very steep at low moisture contents, indicating that for a unit increase in water, there is a large increase in hydraulic conductivity. The slope of the conductivity curves generally level out when moisture content reaches about seven percent. The relatively flat portion of the curves indicate that hydraulic conductivity remain constant over a wide range of moisture content, between about 10 and 30 percent. At moisture content greater than about 34 percent, the conductivity curves again become very steep. Note that this is an artificially high moisture content obtained under experimental conditions. Such high moisture content would only occur in the Laboratory region if there were a major climatic change.

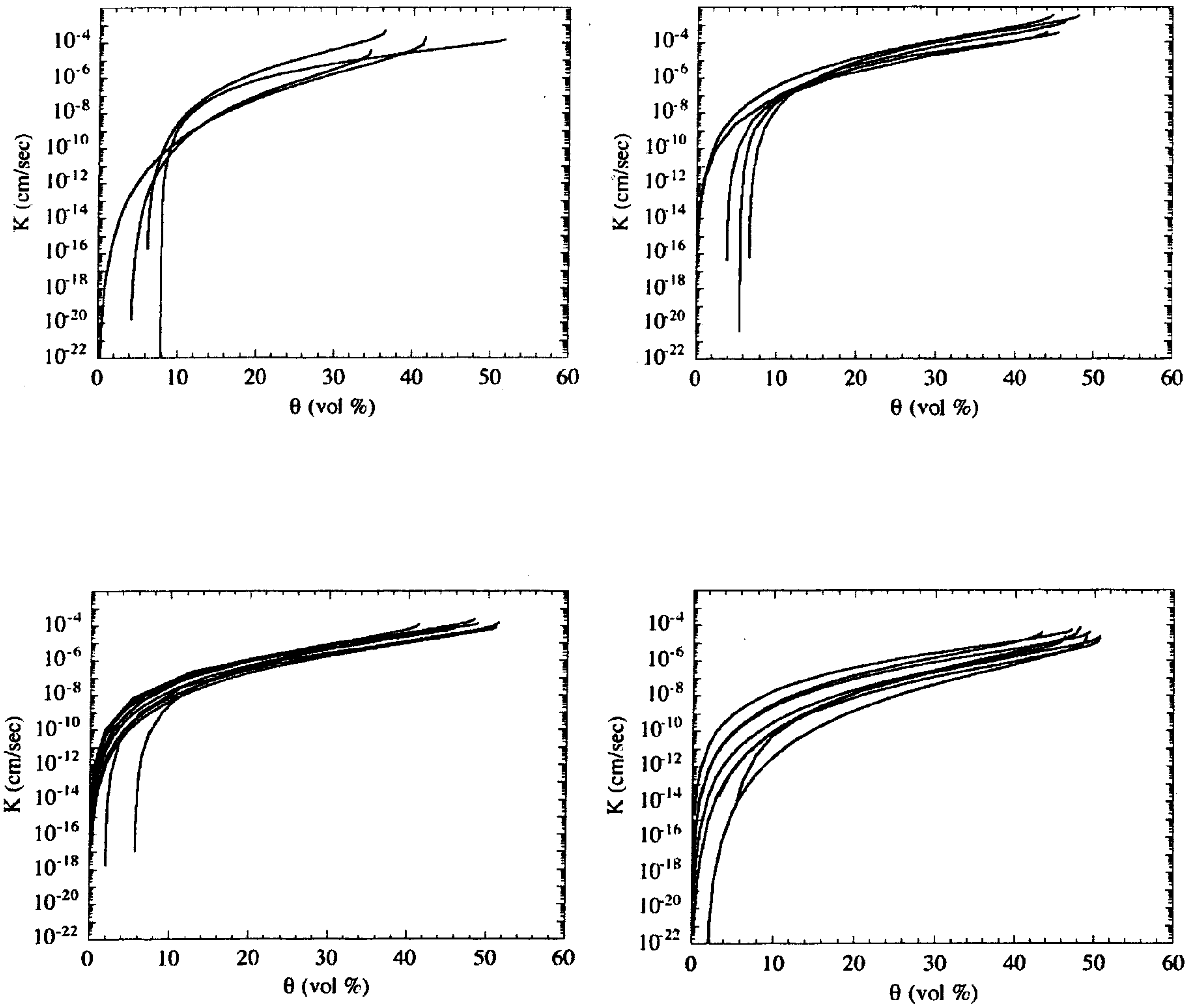


Figure 3.3-2. **Representative unsaturated hydraulic conductivity curves for the upper subunits of the Bandelier Tuff comprising the vadose zone beneath mesas**

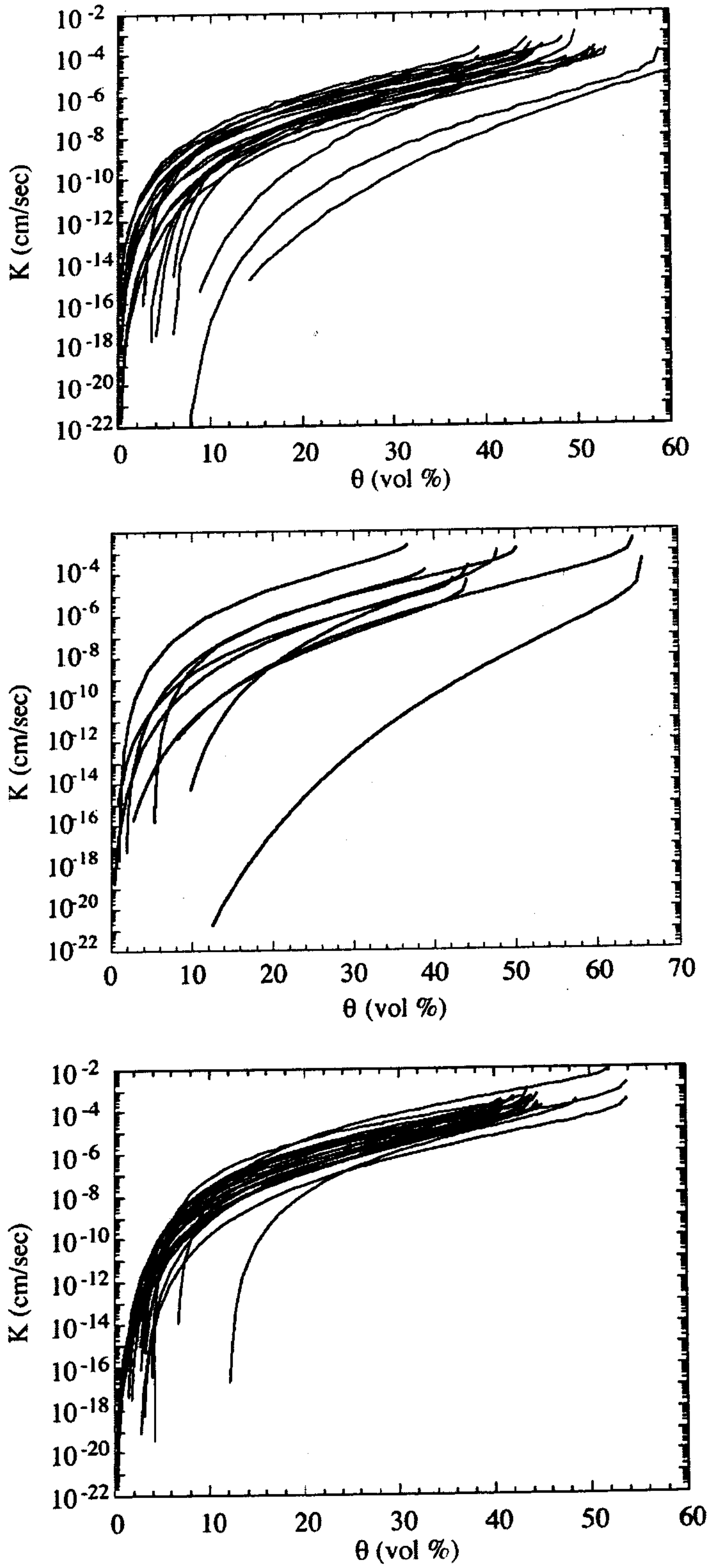


Figure 3.3-2 (continued). **Representative unsaturated hydraulic conductivity curves for the upper subunits of the Bandelier Tuff comprising the vadose zone beneath mesas**

Taken as a group, the hydraulic conductivity curves and tension curves are very similar among the geologic units, with one exception: the Tsankawi/Cerro Toledo Interval graph. The Tsankawi/Cerro Toledo Interval characteristic curves show a much greater spread than the others. This reflects the highly varied size of the pore spaces in the rock as compared to other units. In general, the curves indicate that the Tsankawi/Cerro Toledo Interval may conduct water more readily than the other units of the Bandelier Tuff. Curves like these are often used as a basis for mathematical models for unsaturated flow. To do this, the curves must be translated into mathematical equations. One popular "curve-fitting function" is the van Genuchten formulation. The van Genuchten method requires three variables, α, N, and θr to be evaluated to fit the curve to the measured data. The van Genuchten parameters α and N are important derived hydraulic properties for modeling moisture flow in unsaturated materials. In general, materials with relatively high values of α can hold more water with less suction, while materials with relatively large values of N may undergo large changes in moisture content with small changes in suction. The residual moisture content, θr, represents the lowest moisture content at which flow will occur in the van Genuchten formulation. Residual moisture is not well defined in arid regions where moisture may be transported in the vapor phase rather than the liquid phase.

Not labelled on graphs

Measurement on core samples show that the surge beds at the base of Unit 2 have relatively high capillary suction and low hydraulic pressure. The interpretation of these measurements is that moisture is being drawn towards the surge beds from above and below. The driving force for this movement may be evaporation aided by air movement along the fractures within these units or along the more permeable surge beds found at the base of Unit 2. Similar surge beds are found at the Unit 3/4 interface, also; less is known about the air permeability there.

3.4 Ecology

The ecological setting of each MDA is important in modeling the potential for transport and uptake of radioactivity for several reasons. Animals may burrow into disposal units, disturbing the cover and excavating contaminated material. Plants can interfere with facility performance by growing roots into disposal units, incorporating radioactivity that may contaminate surface soil when plants defoliate. Plants can also enhance facility performance, in two ways. First, they provide surface cover that reduces erosion of disposal unit covers, and second, they remove moisture from the soil that might otherwise percolate into disposal units.

3.4.1 Local Plants

The plants and animals native to the Los Alamos region are diverse, partly because of the large elevation gradient between the Rio Grande (1500 m above sea level) and the Jemez Mountains (2,100 m above sea level) and also because of the canyon and mesa terrain. Locally, the vegetation on Mesita del Buey is dominated by the Piñon-Juniper Series of the Great Basin Conifer Woodland. One-seed juniper and piñon pines are the dominant tree species in undisturbed areas. Common shrub species include big sagebrush (Artemisia tridentata), wax currant (Ribes cerceum), four-wing salt bush (Atriplex canescens), currant (Ribes sp.), and mountain mahogany (Cercocarpus betuloides).

Blue grama grass (Bouteloua gracilis), cryp-togamic soil crust, and prickly pear cactus (Opuntia spp.) are the most common low-growing (understory) plants on the mesa top. Other common understory plants include snake weed (Gutierrezia microcephala and Gutierrezia sarothrae), pinque (Hymenoxys richardsonii), wild chrysanthemum (Bahia dissecta), leafy golden aster (Chrysopsis filiosa), purple horned-toothed moss (Ceratadon purpureus), several lichen species, three-lawn grass (Aristida spp.), bottlebrush squirreltail (Sitanion hystrix), bluegrass (Poa spp.), false tarragon (Artemisia dracunculus), and a species of Mammalaria cactus.

A representative list of average measured rooting depths for native plants is presented in Table 3.4-1.

Table 3.4-1
Plant Species Common to the Pajarito Plateau and Measured Rooting Depths

Species	Common Name	Root Depth (m)
Quercus spp.	Oak	0.80
Gutierrezia sarothrae	Snakeweed	1.00
Ribes cereum	Wax Currant	1.00
Falugia paradoxa	Apache Plume	1.00
Rhus trilobata	Squawberry	1.60
Atriplex canescens	Saltbush	0.80
Chrysothamnus nauseosus	Chamisa	1.50
Artemisia tridentata	Sagebrush	1.50
Juniperus monosperma	One-Seed Juniper	0.60
Pinus pondersosa	Ponderosa Pine	1.30
Bouteloua gracilis	Blue Grama	0.50
Cercocarpus montanus	Mountain Mahogany	0.40
Helianthus petiolarius	Wild Sunflower	0.40
Opuntia polycantha	Cactus	0.20
Yucca angustifolia	Yucca	0.10

In a study of 21 species of plants common at the Laboratory, roots were found to be most abundant in the upper 2 m (6.4 ft) of soil. Roots of Chamisa, apache plume, oak, piñon pine and one-seed juniper were found at depths greater than 2 m (6.6 ft), the biomass of plant roots was greatest in the upper 2 m (6.6 ft) of the soil surface.

As a result of MDA operations, many of the native under-story plants are being replaced by exotic species. Recently disturbed areas support plants such as goosefoot (Chenopodium fremontii), tumbleweed (Salsola kali), cutleaf evening primrose (Oenothera caespitosa), common sunflower (Helianthus anuus), and other colonizing species. Vegetation used to cover some of the MDAs include native grass species (e.g., blue grama), which provide dense ground cover and have short roots, protecting against erosion, while maximizing transpiration of water.

3.4.2 Local Animals

Insects, reptiles, mammals, and birds inhabit the Laboratory region. Harvester ants are the most abundant insect, while common reptiles include fence lizards (Sceloporous undulatus), Plateau striped whiptails (Cnemidophorus velux), gopher snakes (Pituophis melanoleucus), and garter snakes (Thamnophilis elegans). Many mammals inhabit the Pajarito Plateau, including rodents, mule deer, elk, black bear, mountain lion, bobcat, fox, and coyote, all of which pass through the MDA G vicinity at least occasionally. The plateau supports a wide variety of bird species. In addition to a range of songbirds, a variety of nesting and migrating raptors have been identified in less-disturbed areas of the canyons. Burrowing animals are common to the mesa tops across the Plateau. Table 3.4-2 lists the indigenous burrowing animals and their average burrow depths.

Table 3.4-2
Indigenous Burrowing (Fossorial) Animal Species and their Average Measured Burrow Depths

Species or Taxon	Common Name	Burrow Depth (m)
Pogonomyrmex spp.	Harvester Ant	3.0
Gopheropus polyphemus	Gopher tortoise	0.75
Terrapene carolina	Box turtle	0.1
Blarina brevicaudata	Shorttailed shrew	0.5
Scalopus aquaticus	Mole	0.6
Microtus ochrogaster	Prairie vole	0.2
Peromyscus gossypinus	Cotton mouse	0.75
Ochrotomys nuttalli	Golden mouse	0.13
Perognathus parvus	Pocket mouse	1.4
Thomomys talpoides	Pocket gopher	<1
Dipodomys ordii	Kangaroo rat	0.7
Cynomys leucurus	Prairie dog	1.83
Peromyscus maniculatus	Deer mouse	<2
Marmota monax	Woodchuck	1.5

Ecological characteristics of MDAs relevant to the assessment of risk include wetlands, vegetation, animals, and threatened and endangered species. These features are listed in Table 3.4-3 for each MDA.

3.5 Geography and Demography

The population distribution and current and potential land-use at or near the MDAs is summarized in this section.

3.5.1 Population Distribution

The projected population of Los Alamos County in 1994 was approximately 18,200. Two residential and associated commercial areas exist in the county: Los Alamos with a population of 11,400, and White Rock with a population of 6,800. White Rock borders the Laboratory boundary to the east. Other major residential population centers within an 80 km (53 mi) radius of the Laboratory include Española to the northeast and Santa Fe to the southeast. Santa Fe, with a population of about 80,000, is expected to remain the major urban center of the region. In all, approximately 224,000 persons live within an 80 km (53 mi) radius of the Laboratory.

3.5.2 Uses of Adjacent Lands

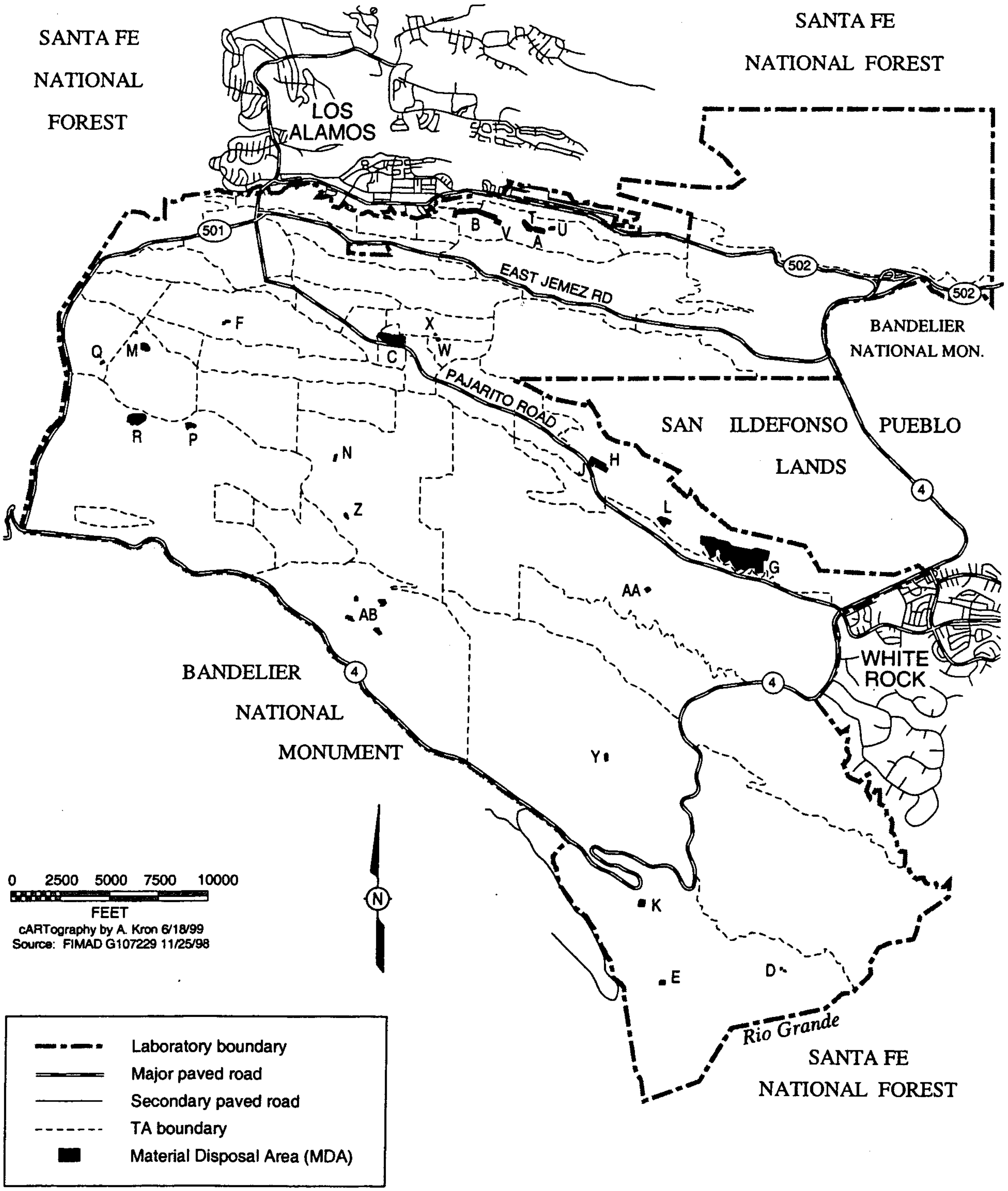
Ownership of land surrounding the Laboratory is indicated in Figure 3.5-1. State and federal government agencies and local Indian tribes control land surrounding Los Alamos County. Of these, three federal agencies (i.e., Bureau of Indian Affairs, U.S. Forest Service, and Bureau of Land Management) control the majority of land in the area. The Santa Fe National Forest comprises 634,486 hectares (1,567,181 acres) of land in several counties. The Española District of the Santa Fe National Forest includes 142,521 hectares (352,170 acres) that border DOE land to the northwest and southeast.

Table 3.4-3
Summary of MDA Ecological Features

MDA	Watershed/Canyon	Wetlands	Ecozone*	Area of Environmental Interest
A	DP	No	P-J	Core
B	Los Alamos	No	P-J; P	Core
C	Ten Site	No	P	Core/buffer
D	Rio Grande	No	P-J	Core/buffer
E	Chaquehui	No	J	Core/buffer
F	Two Mile	No	P	No
G	Pajarito, Cañada del Buey	No	P-J	No
H	Pajarito	No	P-J	No
K	Chaquehui	Yes	J	Core/buffer
L	Cañada del Buey	No	P-J	No
M	Pajarito	No	P	No
N	Cañon de Valle	No	P	Buffer
P	Cañon de Valle	Yes	P	Buffer
Q	Pajarito	No	P	No
R	Cañon de Valle	Yes	P	No
S	Water	No	P	No
T	DP	No	P	Core
U	DP	No	P-J; P	Core
V	Los Alamos	No	P-J	Core
W	Ten Site	No	P-J; P	Core
X	Ten Site	No	P-J; P	Core
Y	North Ancho	No	~~Cyn~~ P-J	Buffer
Z	Cañon de Valle	No	P-J; P	Buffer
AA	Potrillo	No	P-J; P	No
AB	Ancho	No	P-J;P	Buffer

* P= ponderosa, P-J = piñon-juniper, P-J;P = transition zone, Cyn = canyon setting, J = juniper/savannah

The Bandelier National Monument borders the southwest portion of the Laboratory complex and is managed by the National Park Service. The monument includes 12,950 hectares (32,000 acres) of land, 9,308 hectares (23,000 acres) of which are designated wilderness. All access routes to the monument pass through or along the Laboratory property. Thirteen Native American Pueblos are located within 80 km (53 mi) of the Laboratory. Each is governed by its own tribal government with technical and administrative assistance from the Bureau of Indian Affairs. The San Ildefonso Pueblo owns a triangular piece of land that directly borders MDA G within Cañada del Buey to the north of the facility. The total area owned by the Pueblo is 10,600 hectares (26,192 acres). In addition to hunting wildlife for food, Pueblo people also harvest the fruit of piñon and juniper trees indigenous to the area. Hunting and gathering activities occur on the land directly adjacent to Mesita del Buey. A summary of MDA demography is presented in Table 3.5-1.



F3.5-1 / MDA Core Doc / 081299 / PTM

Figure 3.5-1. **Map showing the ownership of land around the Laboratory and the location of MDAs**

Table 3.5-1
Summary of MDA Demography

MDA	TA	Distance to Residential Area (mi)	Distance to Pueblo Boundary (mi)	Distance to Bandelier National Monument (mi)
A	21	0.4	1.4	4.7
B	21	0.2	1.6	4.1
C	50	1.3	1.2	2.6
D	33	1.8	3.9	1.5
E	33	2.6	4.4	0.4
F	06	1.3	2.8	2.2
G	54	1.1	0.2	3.1
H	54	2.8	0.3	3.0
J	54	2.7	0.3	3.1
K	33	2.6	3.6	0.5
L	54	1.9	0.3	3.0
M	09	1.7	3.6	2.5
N	15	2.5	1.8	1.4
P	16	2.2	3.1	1.2
Q	08	2.0	4.0	1.7
R	16	2.3	3.6	1.2
S	11	3.0	3.0	0.6
T	21	0.4	1.4	4.2
U	21	0.6	1.4	4.3
V	21	0.4	1.5	4.1
W	35	1.4	0.9	2.9
X	35	1.3	0.9	2.9
Y	39	2.1	2.5	0.8
Z	15	2.9	2.0	1.0
AA	36	1.9	0.9	2.4
AB	49	4.1	2.6	0.5

Within Los Alamos County, vacant land dominates all categories of land use, accounting for 49 percent of the area. Recreational use of accessible lands is prevalent, including hiking, rock climbing, and skiing.

Agricultural activities in the vicinity of the Laboratory have been declining for the past several decades and are no longer considered an important economic activity in terms of cash income to area residents. Livestock (primarily cattle) provide nearly 75 percent of the cash revenue from farm commodities in the region; crops (including hay, corn, chile, and apples) provide the remaining 25 percent. Small farms remain an important means of supplemental income and domestic food in the northern New Mexico region. The San Ildefonso Pueblo grows crops for domestic consumption and some local marketing.

Among the crops grown are corn, chile, squash, beans, and tomatoes. The following points summarize local agricultural activity:

- A small percentage of land (1 to 2 percent) is used for growing crops.
- Hay, corn, and chile are the most common crops in Los Alamos, Rio Arriba, and Santa Fe counties.
- Most of the agricultural acreage is irrigated.
- Surface water irrigation is much more common than groundwater irrigation in Sandoval and Rio Arriba Counties; the opposite is true in Santa Fe County.
- Livestock density is low (1 per 300 acres).

All cattle are range fed in northern New Mexico, livestock forage primarily on native short-grass species. Much of the land now occupied by the Laboratory was historically used for grazing. The people of the Pueblos in the region also graze livestock on their lands near the Laboratory, and numerous private land owners in rural areas keep small numbers of livestock on land that surrounds Los Alamos County.

4.0 SPECIAL STUDIES RELATED TO MDA PERFORMANCE

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. Section 3 of this document describes the natural setting of the Pajarito Plateau, focusing on features and events of the environment in the undisturbed condition (i.e., in the absence of MDAs) that affect the performance of MDAs. This section discusses (in 4.1 through 4.3) 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 and then (in 4.4) describes a modeled simulation of the performance of MDA G. 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. Nonetheless, all of the information is important to consider in developing a general preliminary conceptual model for MDAs at the Laboratory, which is the subject of Section 5 of this document.

4.1 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.

4.1.1 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 4.1-1. They were analyzed for radiological and hazardous contaminants, moisture content, matric potential, and geotechnical properties.

Table 4.1-1
Frequency of Core Samples from Horizontal Boreholes beneath Pits 36 and 37 at MDA G

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

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.

4.1.2 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).

4.1.3 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 (NMED 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.

4.1.4 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).

4.1.5 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.

4.2 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 (described in Section 3) due to MDA operations.

4.2.1 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).

4.2.2 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.

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).

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).

4.2.3 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.

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.

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%.

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.

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 previously in Figure 3.3-2, indicating that moisture moves at the same rate despite measured differences in moisture content.

4.3 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.

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.

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.

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.

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.

4.4 MDA G PA and Composite Analysis

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 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 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 4.4-1.

Table 4.4-1
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.

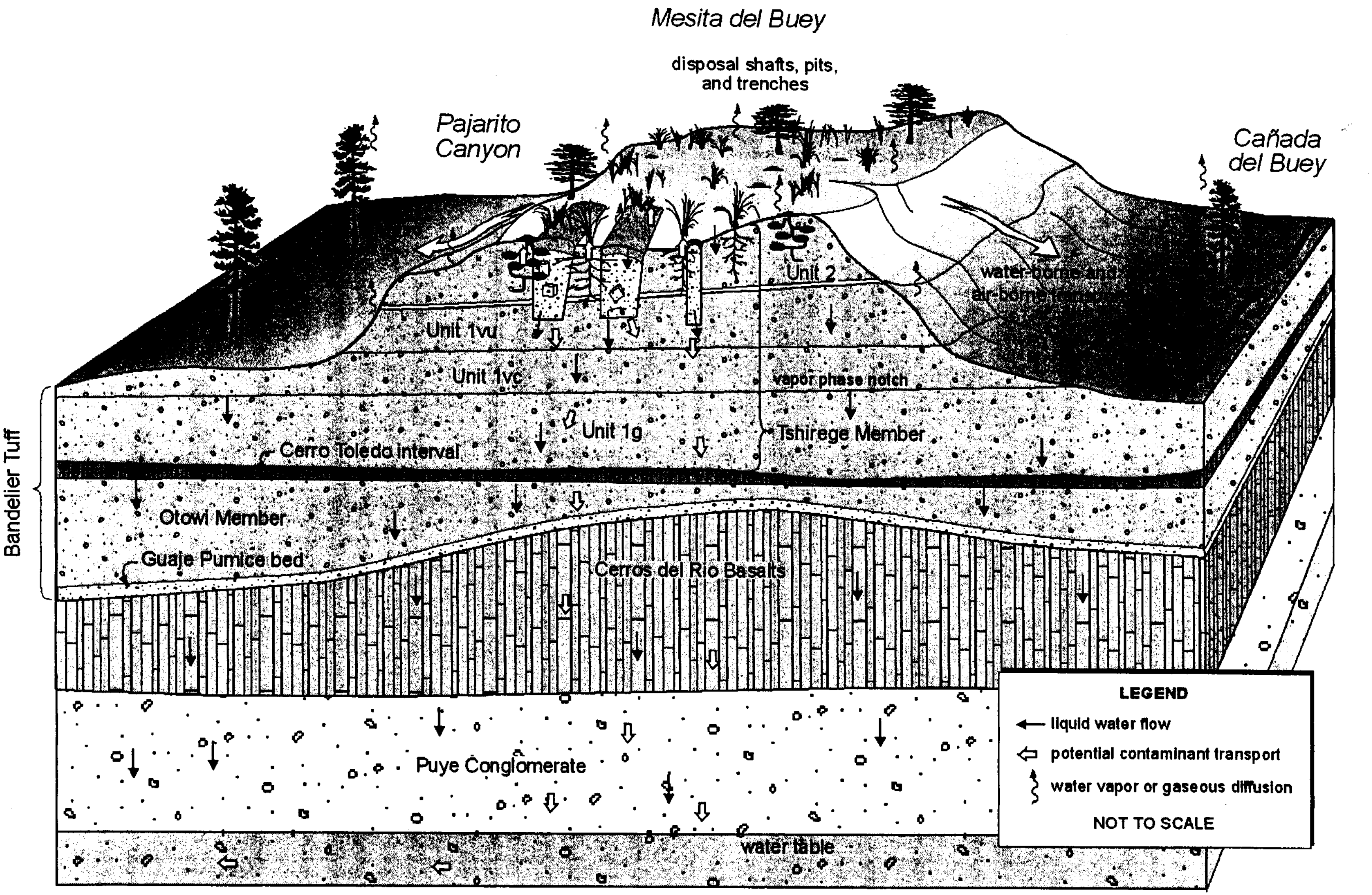
* Performance objective represents the maximum projected exposure from all releases at the Laboratory.

4.4.1 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 4.4-1.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.



F4.4-1 / MDA Core Doc / 081699 / PTM

Figure 4.4-1. 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.

4.4.2 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

4.4.3 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 (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.

4.4.4 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.

4.4.5 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 x 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 x 10^{-4} mrem, which is a factor of 250,000 less than the performance objective (LANL 1997, 63131).

5.0 CONCEPTUAL MODEL FOR MATERIAL DISPOSAL AREAS

One of the goals of the material disposal areas (MDAs) core document is to provide a consistent approach to the development of conceptual models for MDAs based on the conceptual model for the MDA G performance assessment (PA)/composite analysis (CA) described in Section 4.4 of this document. These site-specific conceptual models will be used as the basis for risk assessment in the Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) and corrective measures study (CMS) process for MDAs. This section describes the systematic approach that will be followed to develop conceptual models for the Laboratory's MDAs based on the MDA G conceptual model. The process allows the MDA G conceptual physical model to be adapted as necessary to accommodate the significant features, events, and processes (FEPs) at other MDAs, which were described in Sections 2 and 3.

5.1 Systematic Approach to Developing Conceptual Models for Other MDAs

The systematic approach to MDA conceptual model development makes use of recommendations of the BIOMOVS II working group on reference biospheres (Davis et al. 1999, 63521). This is a technical working group of the biospheric model validation study (BIOMOVS), an international cooperative program composed of 160 organizations from 31 countries supported by the Atomic Energy Control Board, Canada; Atomic Energy of Canada Limited; Centro de Investigaciones Energeticas Medioambiantales and Tecnologicas, Spain; Emprese Nacional de Residuos Radioactivos, Spain; (Davis et al. 1999, 63521, pp. 118-119). The reference biospheres working group has advanced a methodology for developing conceptual models for solid radioactive waste and hazardous waste disposal sites. The recommended methodology was applied within an Electric Power Research Institute total systems PA of Yucca Mountain (Watkins et al. 1999, 63523).

The approach proposed by the Environmental Restoration Project is a site-specific application of the methodology recommended by the reference biospheres working group (van Dorp et al. 1999, 63522, p. 227). It consists of these steps:

- Develop a baseline model of the long-term conditions of a geologic waste repository. The MDA G baseline risk assessment (i.e., PA/CA expanded to include all contaminant sources) will serve this function (LANL 19967 63131).
- Develop a FEP list for the MDA under consideration, using a generic international FEP as a point of reference (van Dorp et al, 1999, 63522, p. 232).
- Screen the FEP list against the baseline model.
- Develop a relational FEP list specific to the MDA under consideration by identifying relationships between FEPs. This relational FEP list is the basis for the conceptual model.
- Implement the conceptual model using computer codes.

For the purposes of the MDAs Core Document, "features" are static conditions (such as inventory, geology, hydrology, and climate). "Events" and "processes" are naturally dynamic (such as groundwater recharge and erosion), naturally episodic (such as storm water runoff), or the result of human decisions (such as land use).

5.1.1 Baseline Model

The MDA G PA/CA, described in detail in Section 4.4, was performed to demonstrate the long-term (greater than 1000 years) effectiveness of the operational cover installed over disposal units at that site. In order to evaluate the effectiveness of this remedy in maintaining radiological doses below the performance measures a conceptual model was developed defining the exposure pathways. By design, the MDA G PA/CA considers only radiological constituents, but it can be adapted to consider hazardous constituents because the PA/CA evaluates environmental transport and exposure pathways that are applicable to both radioactive and hazardous chemicals.

In completing the RFI for MDA G, the detailed all-pathways modeling conducted for the MDA G PA/CA will be expanded to estimate future cumulative risks from all sources and all pathways to all receptors. In expanding the PA/CA analysis for the purposes of RCRA risk assessment, the following will occur.

- Hazardous constituents in the MDA G inventory will be added to the PA/CA inventory.
- Risk from exposure to hazardous constituents transported away from disposal units at MDA G will be calculated.

This expanded analysis (including both hazardous and radioactive constituents) will be the baseline risk assessment for MDA G. It is anticipated that the results of this risk assessment will lead to a recommendation for a streamlined CMS for MDA G. The CMS for MDA G will use the baseline risk assessment to support a recommendation of capping as the final remedy for the site, with a long-term monitoring plan to ensure effectiveness. Upon approval of the MDA G CMS this remedial alternative will be evaluated as part of the CMS and may become the presumptive remedy for other MDAs. That evaluation will be carried out in a methodical fashion using the quantitative decision analysis described in Section 6 of this document. MDA G is proposed as the standard for evaluating other MDAs for two reasons. First, environmental and facility conditions at MDA G are well characterized and are likely to represent a conservative conceptual site model that will bound risks posed by most other MDAs. Second, the significant investment in detailed risk modeling has already been made for the MDA G PA/CA, and the analysis has passed extensive technical and regulatory review.

The MDA G PA/CA forms a preliminary basis for understanding the potentially important characteristics of an MDA, which can be summarized for each environmental transport pathways included in the model.

For the groundwater pathway

- total inventory of non-sorbing, long-lived radionuclides (a feature)
- waste form (a feature)
- infiltration rate through the disposal units (a process)
- percolation rate of leachate through the vadose zone (a process)
- factors affecting dilution in the regional aquifer (processes and events)
- uses of impacted water supply (events)

For the air pathway

- animal burrow depth (an event)
- waste form (a feature)
- total actinide inventory and concentration (a feature and an event)
- effect of canyons channeling (a process)
- resource and land use in impacted area (events)

For the surface water pathway

- animal burrow depth (an event)
- waste form (a process)
- total actinide inventory and concentration (a feature and an event)
- sediment transport characteristics (features and processes)
- resource and land use in impacted area (events)

5.1.2 Generic FEP List

An FEP list is a way to subdivide a complex system (in this case, an MDA) into its components (such as inventory and hydrology), which are more easily analyzed, both conceptually and analytically (Watkins et al. 1999, 63523, p. 358). Generally a process is used to relate features and events to each other. For example, three important features of a conceptual model for an MDA could be the MDA inventory, the vadose zone, and the regional supply aquifer. The processes by which these features are connected as a system include leachate production and vadose zone transport.

The generic FEP list shown here is cross-referenced to information summarized in previous sections of this document.

Features

- MDA type, Section 2 (e.g., Table 2.1-1)
- Inventory characteristics, Section 2 (e.g., Table 2.1-1)
- Static natural setting, Section 3 (e.g., Tables 3.1-1)

Events and Processes

- Dynamic natural setting, Section 3 (e.g., Table 3.3-1)
- Man-made setting and impacts, Section 3
- Resource and land use, Section 3 (e.g., Table 3.5-1)

5.1.3 Relational FEP Lists

A relational FEP list is a way to reconstruct the environmental fate and transport system that has been deconstructed in developing the FEP list. The relational FEP list connect the features of the fate and transport system through events and processes. The BIOMOVS II working group recommends various methods for developing relational FEP lists (van Dorp et al. 1999, 63522). The method used here is called the reverse method, which has been most often applied. In the reverse method, an MDA's FEP is compared to MDA G's FEP to identify relationships between them that might affect the performance of the MDA.

The relational FEP list is used to categorize FEPs in one of three categories:

- demonstrated or judged to have significant impact
- demonstrated or judged to have insignificant impact
- poorly understood.

5.2 Decision Rules

5.2.1 Application

The biosphere modeling methodology can be applied to MDA conceptual model development by using a generic FEP list and a reverse approach in which the list of relevant FEPs is mapped against the conceptual model developed for MDA G.

Biosphere modeling includes inherent benefits such as:

- the resultant audit trail and documentation that facilitates the detailed examination of all steps in a site-specific assessment
- the reduction of differences in site-specific models and help identifying a better understanding of the differences

The methodology requires the justification of all aspects of the model structure and application to assess all sources of uncertainty. Using a standardized methodology reduces the unresolved differences that occur between different models. A key recommendation is that site-specific assessments should not be undertaken by one individual using only one model but should be a multidisciplinary effort with different approaches and techniques used to confirm results.

Effectively documenting the audit trail and assessing the sources of uncertainty will support the determination whether the presumptive remedy will apply.

6.0 RFI APPROACH

The purpose of the Resource Conservation and Recovery Act facility investigation (RFI) is to evaluate risks to human and ecological receptors posed by contamination in the environment. When so warranted it will identify and (in the case of interim measures [IMs], voluntary corrective actions [VCAs], or voluntary corrective measures [VCMs]) implement actions to minimize those risks. Factors that contribute to risk from an material disposal are (MDA) are the following:

- type and amount of toxic chemicals (including radionuclides) in the inventory
- concentrations of those chemicals in environmental media
- duration, frequency, and intensity of exposure of a receptor to chemicals in environmental media
- toxicological or radiological effects that a chemical has on the receptor

Imminent risk of MDAs can be determined by present-day nature and extent data, but potential future risk can only be extrapolated by using fate and transport modeling to calculate future nature and extent. Present-day risk associated with MDAs is low because contaminants are inaccessible to receptors. However, future risk may be greater due to the abundance of persistent, toxic contaminants and their potential mobilization. The complexity in the RFI assessment accounts for the potential for contaminants in the geosphere (where they present little or no risk) to be transported into the biosphere (where they potentially present significant risk). The approach to completing the RFI process for MDAs takes their characteristic complexity into account, as described in this section.

6.1 Decision Framework

Decision analysis is the basis for completing corrective actions and RFIs for MDAs. Decision analysis integrates decision definition and decision-making "tools," which are applied to decision making and uncertainty resolution. Decisions are defined before data are assessed so that data are assessed appropriately. Decisions in the RFI need to be made regarding the following questions:

- Is contamination present in the biosphere now? (nature and extent delineation)
- If contamination is present in the biosphere now, do concentrations exceed risk or regulatory thresholds currently? (screening assessment)
- If contamination in the biosphere exceeds risk or regulatory thresholds currently, what is the optimal means of reducing the risk and achieving compliance? (IM, VCA, VCM plan)
- Is contamination likely to be transported by environmental processes into the biosphere in the future? (conceptual site model development)
- If contamination is likely to be transported into the biosphere, are concentrations likely to exceed risk or regulatory thresholds in the future? (fate, transport, and exposure modeling)
- If in the future contamination is transported into the biosphere will it exceed risk or regulatory thresholds? What are the alternatives for reducing future risk and ensuring compliance? (corrective measures study [CMS] plan)

Decision rules ensure that each decision in the analytical framework is made confidently (Figure 1.1-1 is repeated here as Figure 6.1-1 for direct reference).

Decision rules are built around action levels, and specify uncertainties that are either acceptable or unacceptable in data used to support a decision. Examples of action levels include screening action levels (SALs), background values (BVs), and minimum concentration limits. Examples of decision rules include standard deviation, upper confidence interval, and upper tolerance level (UTL). Together, these particular action levels and decision rules are used to assess analytical laboratory results (and inherent uncertainties) in the context of imminent risk.

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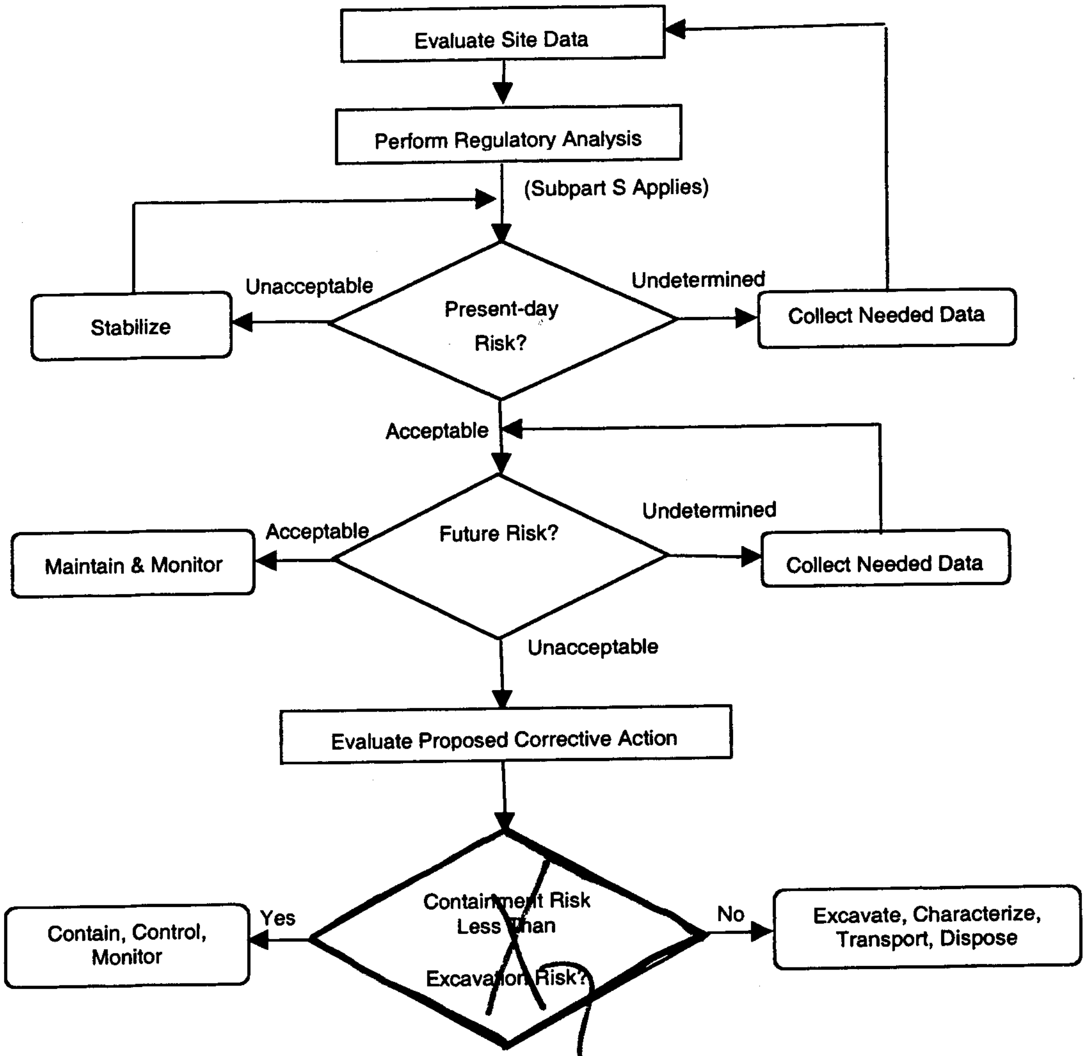

Nine Criteria of EPA

Figure 6.1-1. **General framework of the decision logic for streamlining the corrective action process for Los Alamos National Laboratory MDAs**

6.2 Decision Rules

Sanguine evaluation

Decision rules are used to assess the adequacy and sufficiency of both analytical data and modeling results (and inherent uncertainties) to confidently evaluate future risks. There will be no action taken on an MDA if it has an acceptable cumulative future risk, taking into account the concentrations of all contaminants in all environmental media that have a potential to impact a common receptor. Decision rules allow for high uncertainty in data and/or modeling results where projected future risk is far below the action level, but require lower uncertainty where projected future risk is near the action level. Sensitivity and uncertainty analyses will be performed on the baseline model (MDA G) to develop decision rules regarding the adequacy and sufficiency of data used to develop relational features, events, and processes (FEPs) for each MDA.

The baseline model is subject to errors because of uncertainties in the generic FEP list used to develop the conceptual model, uncertainties in mathematical geosphere and biosphere models, and uncertainties in data used to implement those models. The sensitivity of the projected risk (the action threshold) to these uncertainties will be the basis of decision rules. Once these decision rules are developed around the baseline model FEPs, they will be used to examine the effect of uncertainties in the relational FEPs developed for other MDAs.

Two alternative approaches will be considered as tools for sensitivity and uncertainty analyses. Both will be used to develop decision rules for the baseline model. The approach used to examine the effects of uncertainties information from other MDAs will depend, in part, upon the magnitude of the risk posed by the MDAs being evaluated. If the risk posed by a given site is expected to be small, a deterministic, or bounding, approach to evaluating the impacts of uncertainty may be appropriate. In this approach, the assumptions and data used to model a site are chosen conservatively to yield projected risks that can reasonably be expected to bound actual risks at the MDA. The result is an overstatement of the impact of the associated uncertainties, providing confidence that the MDA will perform at least as well as projected.

The deterministic approach to uncertainty analysis is best applied to sites that pose little risk to human health and the environment. This is because these sites will still be capable of complying with regulatory requirements despite the fact that the risks are overstated. Uncertainties associated with sites posing potentially significant risks will need to be evaluated using more sophisticated techniques. In recognition of this, probabilistic analyses will be used to evaluate the impact of uncertainties at some of the MDAs.

Probabilistic uncertainty analysis is generally used to address uncertainties inherent in the model-input parameters. Distributions describing the variability of the parameters are developed for model endpoints such as contaminant concentrations or risks. These model endpoint distributions can then be used to estimate the probabilities of the MDA exceeding pertinent regulatory criteria. The probabilistic analysis provides a more complete understanding of the actual uncertainties inherent in the modeling compared to the deterministic approach. However, such analyses generally require extensive information about the site. Depending upon how they are implemented, probabilistic analyses may cost considerably more to conduct.

will not answer everything e.g. intruder

As indicated in Figure 6.1-1, data are needed at several steps in the MDAs Core document decision framework. Information may be needed to support RFI decisions about nature and extent of contamination, selection of appropriate remedial options within the context of the CMS, and the establishment and operation of long-term monitoring systems. Because data should be collected only if the information will significantly reduce the uncertainty in the decisions to be made (e.g., decisions about present-day or future risks, appropriate remedial options, and monitoring system configurations), a value-of-information analysis should be conducted.

will remain speculative

Probabilistic uncertainty analysis, in conjunction with information about model sensitivities to parameter variations, provides insight into the importance of parameters relative to the decisions being made. As such, they lend themselves to value-of-information analysis. Deterministic analyses of uncertainty provide little information on the relative importance of parameters, limiting attempts to establish the value of collecting specific data. If a deterministic uncertainty analysis was performed for a site that exceeds regulatory thresholds, consideration should be given to the comparative costs of conducting a probabilistic analysis and taking action at the site.

DQO process

6.3 Contaminant Nature and Extent Delineation

When completing an RFI for an MDA, the nature and extent of contaminants in accessible environmental media are measured by sampling and analyzing for decreasing concentration trends, and comparing analytical results against applicable chemical BVs. In general, this applies to ambient air, surface soil, and near-subsurface soil, alluvium, and sediment given that the majority of MDA inventory is below ground and inaccessible.

The nature of inaccessible, heterogeneous MDA inventories is estimated or bounded using a balance of data and modeling. Models are used to evaluate the adequacy and sufficiency of existing inventory data to confidently evaluate potential risk, and to identify data gaps where data are inadequate to confidently assess risk. The extent of potential contamination within inaccessible media will be, in general, bounded by sampling and analyzing geologic media outside of the disposal unit boundaries, ensuring that contaminant concentrations there are either at BVs or below risk-significant thresholds.

MDA RFI samples will be collected in accordance with the most recent revisions of ER Project standard operating procedures. Analyte lists, estimated quantitation limits, required quality control procedures, and the acceptance criteria are found in the 1995 ER Project analytical services statement of work (LANL 1995, 49738) or the version that is current when the RFI is implemented.

6.4 Screening Evaluation

Sources for data to be used in the RFI include not only analytical results from ER field campaigns, but also surveillance, monitoring, and site characterization data from the following:

- EES-1 (geology and hydrology)
- ESH-17 (regional air)
- ESH-18 (surface water, surface sediment, intermediate and regional aquifer groundwater)
- ESH-20 (ecology)

These data are used to the relational FEP list (which forms the basis of the conceptual site exposure model, as discussed in Section 5 of this document). The RFI process requires the evaluation of conditions at an MDA that pose an immediate risk to human health and the environment. For accessible contaminated media, screening evaluations are performed after contaminant nature and extent have been delineated. Figure 6.4-1 shows the decision framework for this step in the RFI for MDAs.

Existing screening methods will be used to identify contaminants of concern in the context of human and ecological risk (LANL 1996, 55574; Ryti et al. 1999, 63303).

When evaluating conditions at an MDA in the context of present-day risk, it is also important to consider factors that may exacerbate future risk. The ER Project has procedures for evaluating imminent present-day risks. If present-day risks or the potential for exacerbating future risks prove to be unacceptable, it may be necessary to initiate site stabilization. The rationale for site stabilization is provided in the Environmental Protection Agency's (EPA's) stabilization initiative.

> "The goal of the Stabilization Initiative is to increase the rate of corrective actions by focusing on near-term activities to control or abate threats to human health and the environment and prevent or minimize the further spread of contamination. . . . Controlling exposures or the migration of a release may stabilize a facility, but does not necessarily mean that a facility is completely cleaned up. At some stabilized facilities, contamination is still present and additional investigations or remediation may be required. . . . Stabilization activities should be a component of, or at least consistent with, final remedies."

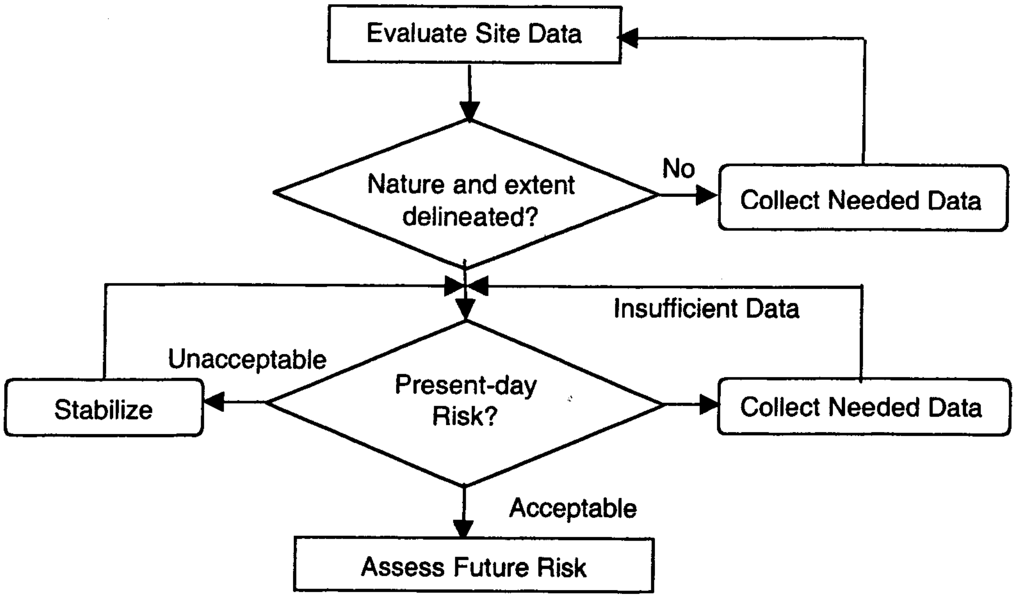

Figure 6.4-1. **Initial data review and screening in the RFI process**

Stabilization of a site may be necessary if, for example, contaminant concentrations in surface soil pose imminent threat to persons working in or otherwise accessing the area. Alternatively, stabilization may be required if conditions at an MDA have a potential for increasing rates of contaminant release and environmental transport in the future. An accurate evaluation of conditions such as these requires an understanding of site processes. The conceptual model described through the relational FEP list (see Section 5 of this document) will be used to determine the need for stabilization on the basis of future contaminant transport potential. Regardless of the cause for a stabilization action, activities will be conducted in a manner that is consistent with the likely final remedy.

6.5 Fate and Transport Modeling and Future Risk Assessment

It is the intent of the MDA focus area to use the fate and transport modeling conducted for MDA G PA/CA (described in Section 4.4 of this document) to assess future risks posed by the Los Alamos National Laboratory MDAs, without having to directly model each MDA. A quantitative decision analysis approach provides such efficiencies in the risk-assessment process without compromising the credibility of that process. The decision framework, shown in Figure 6.5-1, allows for comparisons of contaminant transport pathways, as well as extrapolations of potential future risk by evaluating MDA-specific data in the context of data and modeling from MDA G.

Evaluating potential future human or ecological risks associated with a given MDA is fundamentally different than estimating present-day risks. Unlike the evaluation of present-day risks, future risks cannot be determined in real time, using current conditions as an indicator. Instead, fate and transport models are used to estimate potential rates of contaminant release and transport from the disposal facility and any subsequent impacts on human health and the environment. Projected risks to humans and the environment are compared to regulatory risk criteria; the results of the comparison will be in the corrective action process to identify effective remediation strategies.

The decision analysis uses quantitative decision rules, formulated through the EPA data quality objective process and sensitivity and uncertainty analyses, to evaluate data from an MDA to determine the following:

- the applicability of the baseline conceptual model for MDAs, considering each contaminant/transport/receptor pathway individually by developing a relational FEP list
- the adequacy of site-specific data to confidently extrapolate potential future risk at the MDA in question using the MDA G analysis

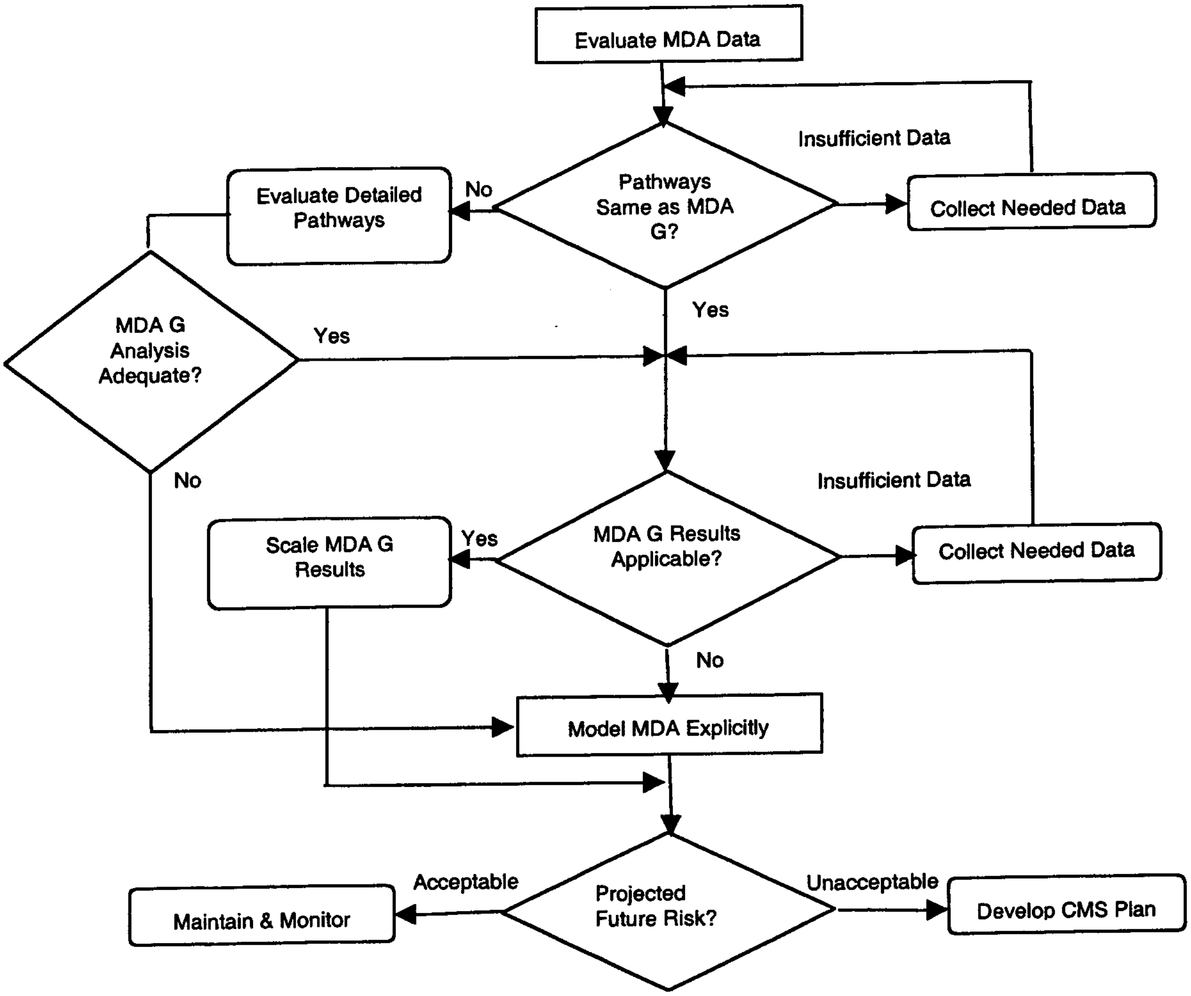

Figure 6.5-1. **Decision framework for expedited corrective actions at MDAs**

In summary, for assessments of future risk supporting the RFI for MDAs are the following:

- Fate and transport models will be used, directly or indirectly (i.e., scaled), to project contaminant extent as a function of time in surface soils, surface water, groundwater, and air, over a period of several thousand years.
- Calculated contaminant concentrations will be used to assess risk to human and ecological receptors using standard exposure scenarios as a point of departure; tailored exposure scenarios will be evaluated if site-specific information supports them.
- Baseline risk assessments will be performed under the "no action" assumption (i.e., current conditions) to determine the need to evaluate corrective measures.
- If results of the risk assessment confidently suggest an unacceptable risk, then a reassessment will be conducted to evaluate the presumptive remedy.
- If risk assessments confidently indicate low risk, then no additional or minimal "landscape" actions will be proposed.
- Models will be used to identify the source term(s), transport pathway(s), and exposure route(s) contributing most significantly to the calculated risk.
- For MDAs containing multiple disposal units, models will be used to differentiate units based on their relative contribution to total risk.

This process or approach will result in either: (1) a presumed remedial alternative (focused CMS or perhaps successful negotiations with the New Mexico Environment Department resulting in a decision to proceed directly to corrective measures implementation [CMI]) or (2) the need for the collection of additional site data (Phase II RFI). The outcome depends on site specific conditions and the quality and quantity of the information about the subject MDA, the comparability between that MDA and MDA G, and the risk projected for the MDA.

6.6 Focused Phase II RFI

We will be implement the following approach:

- Borehole location and number will be optimized using models to calculate the maximum extent of contaminant migration based on site-specific conditions.
- Boreholes will be drilled to bound the extent of contamination.
- Geophysics will be used to ensure that boreholes will not intercept disposal units.
- Directionally drilled horizontal boreholes and/or angled boreholes will be drilled to maximize the coverage beneath an MDA, where appropriate.
- Core, cuttings, and moisture-protected core samples may be collected.
- Most analytical suites will contain analyses for contaminants of concern, moisture content, and various hydrologic properties (e.g., bulk density, saturated hydraulic conductivity); other data will be gathered to perform analyses such as moisture retention curves and analyses for stable isotopes may be conducted.

For MDAs whose inventory is heterogeneous solid materials, characterization of the nature of contamination will *not* be accomplished through direct sampling within a disposal unit, since representative samples cannot be assured and invasive sampling would likely pose an unacceptable threat to site workers and the public. Coring within the boundary of an MDA disposal unit may be considered if that MDA was used for disposal of liquid constituents.

X Need way to bound inventories w/o historical info

7.0 MATERIAL DISPOSAL AREA CORRECTIVE MEASURES PROCESS

The purpose of the Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) is to define the nature and extent of contaminant releases. The RFI will result in either a recommendation for no further action or a recommendation to proceed to the corrective measures study (CMS)/corrective measures implementation (CMI) phases of the RCRA corrective action process. Based on the results of the RFI, the CMS will evaluate alternative corrective measures and identify the optimal one based in part on protectiveness, practicality, acceptability, and cost. Based on the results of the CMS, the CMI establishes how the selected corrective measure will be completed. The recommendation to proceed to CMS/CMI is typically, but not always, based on the results of the RFI indicating a exceedance of some pre-established action level. The action level proposed for material disposal area (MDAs) is unacceptable risk, with the risk threshold being determined jointly by Environmental Restoration (ER) Project managers, our Department of Energy (DOE) counterparts, regulators, and other stakeholders who follow guidelines established by the Environmental Protection Agency (EPA).

This chapter of this report supplements, but does not supplant, the basic requirements of the traditional CMS/CMI approach outlined in the Hazardous and Solid Waste Amendments of 1984 (HSWA) Module of the Los Alamos National Laboratory's (the Laboratory's) RCRA permit. This chapter is specific to RCRA corrective measures for MDAs, and does not address emergency response actions, voluntary corrective actions, or best management practices undertaken as normal "housekeeping" by the ER Project.

The traditional RFI/CMS/CMI process is summarized below, as a point of departure for six alternate strategies that the ER Project anticipates based on the approach described in Chapters 3, 4, and 5 of this document. While this chapter describes an approach to corrective measure planning and implementation, the ER Project recognizes that each MDA is unique and that the final corrective actions for MDA will be developed jointly with DOE and New Mexico Environment Department (NMED). In addition, the schedule for implementing corrective actions at MDAs will be consistent with the ER Project's integrated technical strategy.

7.1 Traditional Strategy: RFI → CMS → CMI

The traditional strategy includes the completion of the RFI process in accordance with the requirements outlined in the HSWA module of the RCRA permit, as well as the annotated outlines and report formats agreed upon with NMED and DOE. The assumption in this strategy is that the RFI report recommends CMS/CMI for the site. To simplify the regulatory and technical process, Subpart S advocates limiting the CMS to realistic options: "The CMS does not necessarily have to address all potential remedies for every corrective action. EPA advises program implementers and facility owners/operators to focus corrective measures studies on realistic remedies and to tailor the scope and substance of studies to the extent, nature and complexity of releases and contamination at any given facility. For example, some potential remedies should not be considered because they are simply implausible."

The CMS consists of six stages: identification, screening, development, evaluation justification, and recommendation. The scope and substance of the study should be tailored to fit the complexity of the situation. Based on RFI conclusions and CMS objectives, the Laboratory will identify, screen, and develop all reasonable alternatives for removal, containment, and/or treatment. The Laboratory will use standard engineering practices to determine which alternatives appear most suitable for the site. Technologies can be combined to form the overall corrective action alternatives. The identified alternatives are then screened to eliminate those that may not prove feasible to implement, are unlikely to perform satisfactorily, or do not achieve corrective action objective(s) within a reasonable time period. This screening focuses on site, waste, and technology characteristics. The remaining alternatives are further developed which may include laboratory or bench-scale testing for new technologies.

Each alternative that passed the initial screening is evaluated against technical, environmental, human health, and institutional concerns. The first phase of evaluation consists of the following threshold criteria: (1) protecting overall human health and the environment (2) attainment of media cleanup standards (3) controlled source(s) of releases and (4) compliance with standards for management of wastes. The remedies that meet the threshold criteria are then further evaluated using various balancing criteria to identify the remedy that provides the best relative combination of attributes. The five balancing criteria are: (1) long-term reliability and effectiveness (2) reduction of toxicity, mobility or volume of wastes (3) short-term effectiveness (4) implementability and (5) cost. The detailed evaluation will result in a decision on the preferred remedial alternative. The Laboratory will justify and recommend a corrective measure alternative based on the above criteria and document it in the CMS report.

Alternatives should be protective of human health and the environment, and maintain protection over time. In meeting this remedial goal, EPA has learned that certain combinations of site-specific conditions can be addressed by similar approaches. These approaches include the following:

- The use of treatment to address principal threats posed by a site whenever practicable and cost-effective, "bias for treatment,"
- Directly treating the principal threats (i.e., contaminants) at a site whenever it is practicable and cost-effective
- Using engineering controls (such as containment) on contaminated media (for which treatment is impracticable) that can be reliably contained while posing relatively low long-term threats
- Using a combination of technologies, as appropriate to achieve protection of human health and the environment
- Using institutional controls such as land use restrictions to supplement engineering controls as appropriate for short- and long-term management
- Using innovative technology when such technology offers the potential for superior performance or implementability or lower costs
- Returning usable groundwaters to their maximum beneficial uses wherever practicable
- Remediating contaminated soils as necessary to prevent or limit direct exposure of human and environmental receptors and to prevent the transfer of contaminants to other media

The ER Project anticipates that the traditional CMS approach of evaluating a number of remedial alternatives for MDA sites would only be appropriate in a limited number of situations including the following:

- The first CMS to be performed on an MDA site (probably Technical Area [TA] 54, Area G)
- "High risk" sites which have large waste volumes and associated contamination, and for which several treatment technologies could be applied to achieve varying degrees of effectiveness
- Contaminant problems for which several different approaches are practicable
- Sites for which innovative technologies may be viable

Table 7.1-1 identifies MDA sites that may be candidates for the traditional approach to the corrective measures process (e.g., MDAs B, F, G, H, L, T, V, and Y). However, every attempt will be made to streamline the process. At this time no formal negotiations or discussions have been initiated with the administrative authority (AA) and Table 7.1-1 is just a tool representing options.

7.2 Alternate Strategy 1: RFI/IM → CMS → CMI

Alternate strategy 1 is identical to the traditional strategy with the exception that before the completion of the RFI phase some type of interim measure (IM) is identified. This IM will be implemented to increase stability of an unstable site, reduce an immediate threat to human health or the environment, prevent future releases from a site, or reduce a source term at the site.

Table 7.1-1
Potential Corrective Action Approaches for MDA Sites

MDA	Traditional	Alternate 1	Alternate 2	Alternate 3	Alternate 4	Alternate 5	Alternate 6	CMS/CMI not required
A	X	—[a]	—	X	X	X	—	n/a[b]
B	X	—	—	—	—	—	—	n/a
C	X	—	—	X	—	—	X	n/a
D	X	—	—	—	—	—	—	X
E	X	—	—	—	—	—	—	X
F	X	—	—	X	—	—	—	n/a
G	X	—	—	—	—	—	X	n/a
H	X	—	—	—	—	—	X	n/a
K	X	—	—	—	—	—	—	X
L	X	—	—	—	—	—	X	n/a
M	X	—	—	—	—	—	—	X
N	X	—	—	—	—	—	—	X
P	X	—	—	—	—	—	—	X
Q	X	—	—	—	—	—	—	X
R	X	—	—	—	—	—	—	X
S	X	—	—	—	—	—	—	X
T	X	—	X	X	—	—	—	n/a
U	X	—	—	—	X	X	—	n/a
V	X	—	—	—	X	X	—	n/a
W	X	—	—	—	—	—	—	X
X	X	—	—	—	—	—	—	X
Y	X	—	—	X	—	—	—	n/a
Z	X	—	—	—	—	—	—	X
AA	X	—	—	—	—	—	—	X
AB	X	X	—	—	—	X	—	n/a

[a] These alternatives are not being considered for this MDA.

[b] n/a = not applicable.

This strategy appears to be more onerous than the traditional approach. However, it is based on the Superfund accelerated cleanup model (SACM) guidance published by the EPA, Office of Solid Waste and Emergency Response (EPA 1992, 63529). The basis of SACM is an approach that fosters immediate action at a site at the same time that studies are being conducted. The AA in conjunction with DOE and the Laboratory will decide whether a site requires early action, long-term action, or a combination of both. In this strategy any early actions required to correct immediate problems at a site will be implemented while the site is under investigation. Ideally, this strategy should take no longer than the traditional method because you are performing the IM during the RFI phase.

Table 7.1-1 identifies MDA sites that may be candidates for this alternative approach to the corrective measures process (e.g., MDA AB). At this time, the Laboratory has not identified additional MDAs for which early actions are needed.

surface or subsurface?

7.3 Alternate Strategy 2: RFI → IM → CMS → CMI

Alternate strategy 2 is identical to the traditional strategy with the exception that upon completion of the RFI phase an IM is identified and implemented before moving to the CMS phase.

Table 7.1-1 identifies MDA sites that may be candidates for this alternative approach to the corrective measures process (e.g., MDA T). The RFI for this site is ongoing and there is a possibility that there could be a recommendation for an interim action before the final action.

7.4 Alternate Strategy 3: RFI → Streamlined CMS → CMI

Alternate strategy 3 is identical to the traditional strategy with the exception of using a streamlined CMS approach. In keeping with the goals of this document, the ER Project anticipates that there will be sites for which the implementing agency will allow a streamlined approach to remedy selection, enabling the site to move from RFI to CMI more rapidly. This section describes the streamlined CMS process for MDAs shown to have an unacceptable future risk.

In cases where EPA has identified a presumptive remedy, the purpose of the CMS will be to confirm that the presumptive remedy is appropriate to site-specific conditions. The EPA's presumptive remedy approach is a key element of the streamlined CMS process. Presumptive remedies are preferred remedial technologies for common categories of sites. These remedies are typically based on historic patterns of remedy selection and on scientific and engineering evaluation of performance data on technology implementation. Presumptive remedies should be used to focus the RFI, simplify evaluation of alternatives in the CMS, and influence remedy selection in the CMI. This process is expected to ensure the consistent selection of remedial actions and reduce cost and time required to cleanup similar sites.

The Laboratory proposes to use presumptive remedies at certain sites (e.g., landfills), so long as site-specific conditions indicate that a presumptive remedy is appropriate. The presumptive remedy process will, to the extent possible, rely on existing data, use a streamlined risk assessment approach, and incorporate a focused CMS that only analyzes the appropriate components of the presumptive remedy and the no-action alternative. The assumption of this Core document is that capping and monitoring will be selected as the preferred alternative resulting from the streamlined CMS process using the presumptive remedy approach. This assumption is based on the results of the MDA G composite analysis, and long-term field studies at the Laboratory. A description of the generic capping and monitoring design is included in Attachment C.

The streamlined CMS approach will be reflected in a decision by the implementing agency to evaluate only a limited number of remedial alternatives. The ER Project anticipates that the streamlined or highly focused approach may be appropriate in the following types of situations:

- "Low risk" sites where environmental problems are relatively small, and releases represent minimal exposure concerns.
- Sites with straightforward remedial solutions. For some contamination problems, standard-engineering solutions can be applied that have proven effective in similar situations. This option includes presumptive remedies.
- Sites which can be scaled to TA-54, Area G for which the remedial alternative has already been approved.

Table 7.1-1 identifies MDA sites that may be candidates for this alternative approach to the corrective measures process (e.g., MDAs A, C, F, T, and Y).

7.5 Alternate Strategy 4: RFI → CMI

Alternate strategy 4 is the case where you proceed directly from RFI to CMI and do not implement a CMS. In cases where the Laboratory is using performance standards or a similar approach to corrective measures, the AA should not require submission or approval of a formal CMS plan or Report. EPA continues to emphasize that it does not want studies to be undertaken simply for the purpose of completing a perceived step in a perceived process. It is anticipated that after successful completion of the traditional strategy on complex MDA sites that the AA will allow the Laboratory to proceed directly from RFI to CMI on less complex MDA sites where the presumptive remedy approach would be used to recommend capping and monitoring.

Table 7.1-1 identifies MDA sites that may be candidates for this alternative approach to the corrective measures process (e.g., MDAs A, U, and V).

7.6 Alternate Strategy 5: RFI/CMS → CMI

Alternate strategy 5 is designed to integrate the CMS with the site characterization or RFI process. In this strategy, the ER Project anticipates that a remedial alternative is obvious, but not necessarily a presumptive remedy or a remedy that has been used at the Laboratory MDA sites. In this strategy, the Laboratory will negotiate with the AA during the RFI to incorporate the necessary pieces of the CMS so as not to require a separate study. The final report resulting from this effort will include the required information from both the RFI and CMS phases.

Table 7.1-1 identifies MDA sites that may be candidates for this alternative approach to the corrective measures process (e.g., MDAs A, U, V, and AB).

7.7 Alternate Strategy 6: RFI → CMS → Conditional Remedy

Alternate strategy 6 is identical to the traditional strategy with the exception of using a conditional remedy. Conditional remedies are not final remedies because they do not necessarily meet all standards included in proposed 40 CFR 264.525(a). Conditional remedies may be appropriate for facilities that contain a mix of active and inactive units where it is difficult or impossible to distinguish influences. The ER Project may propose a conditional remedy for such MDA sites provided that the conditional remedy do the following:

- Protects human health and the environment based on current exposures
- Achieves conservative media cleanup standards or levels (e.g., maximum concentration levels) beyond the facility boundary
- Prevents further significant degradation of the environmental media through treatment and/or engineering methods
- Includes institutional or other controls necessary to prevent significant exposures (including deed restrictions)
- Includes continued monitoring to determine whether further significant degradation occurs
- Complies with standards for management of wastes

Table 7.1-1 identifies MDA sites that may be candidates for this alternative approach to the corrective measures process (e.g., MDAs C, G, H, and L). These MDAs were identified because they have ongoing operations.

8.0 REPORTING

The purpose of the corrective measures study (CMS) is to identify and evaluate alternative corrective actions to cleanup contaminant releases from solid waste management units such as Los Alamos National Laboratory's (the Laboratory's) material disposal areas (MDAs). Given that the MDAs generally contain relatively large volumes of contaminated materials, the scope and requirements of the CMS need to be balanced with the expeditious initiation of remedies and timely restoration of contaminated sites. The documents required for the CMS are a CMS plan and CMS final report.

The documents required for the corrective measures implementation (CMI) are a conceptual design, operation and maintenance (O&M) plan, intermediate design plans and specifications, final design plans and specifications, construction work plan, construction completion report, corrective measure completion report, health and safety plan, public involvement plan, and progress reports. If the Laboratory can justify to the administrative authority (AA), that a plan and/or report, or portions thereof, are not needed in a given situation, then the AA may waive that requirement. This strategy of streamlining the CMI will be negotiated during the planning of the CMS.

Each report or plan developed during the corrective action process establishes the foundation for subsequent planning and documentation. Document reviews provide the primary method for Department of Energy (DOE) and New Mexico Environment Department (NMED) oversight of the process. As such, it is important to plan for the review process and to focus the reviews to manage limited resources and optimize the value of documents.

8.1 RFI Work Plan

There are no further Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) work plans anticipated for MDA sites.

8.2 RFI Report

RFI reports will follow the requirements outlined in the Hazardous and Solid Waste Amendments of 1984 (HSWA) module of the RCRA permit, as well as the annotated outline and report format agreed upon with DOE and NMED.

8.3 Sampling and Analysis Plans

Following the annotated sampling and analysis plan (SAP) outline the following sections will be prepared for each potential release site (PRS) or group of PRSs: characterization and setting, site description, operational history, waste characteristics, investigatory approach, existing data, conceptual model, nature and extent of contamination, contaminant fate and transport, data gaps, sampling activities, contaminant source, media characterization, quality assurance/quality control, field activities, and project management sections. Included as part of the SAP preparation is the compilation of the reference set library, data tables in the NMED agreed format, and the electronic data deliverable, as well as production (including tables, figures, and maps) and editing of the document.

8.4 CMS Work Plan

The Environmental Restoration (ER) Project will submit a draft CMS plan to the AA within 90 calendar days from the notification of the requirement to conduct a CMS. The CMS plan will include the following:

- site-specific description of the overall purpose of the CMS
- description of the corrective measure objectives, including proposed target media cleanup standards and points of compliance or a description of how risk assessment will be preformed
- description of the specific corrective measure technologies and/or alternatives which will be studied
- description of the general approach to investigating and evaluating potential corrective measures
- detailed description of any proposed pilot studies
- proposed outline for the CMS Report
- description of overall project management

The requirements of the National Environmental Policy Act will be integrated into the RCRA corrective measures process. The CMS plan will be used to trigger a determination of whether an environmental assessment is required, and if so, CMS reports can serve that function. In the event that a full environmental impact statement is required, the CMS report serves as a support document for that effort.

8.5 CMS Report

The CMS will be implemented no later than 15 calendar days after the Laboratory has received written approval from the AA for the CMS plan, and in accordance with the schedule specified in the plan. Within 60 calendar days of the completion of the CMS, the Laboratory will submit a CMS report. The CMS report will document the results of the study and will include the following elements:

- purpose
- description of current conditions
- media cleanup standards
- identification, screening, and development of corrective measure alternatives
- evaluation of final corrective measure alternative
- recommendation for final corrective measure alternative
- public involvement plan

8.6 CMS Progress Reports

Monthly progress reports will be prepared during the CMS and submitted to the AA. These reports will, at a minimum, include the following:

- a description and estimate of the percentage of the CMS completed
- summary of all findings during the report period
- summary of all changes made in the CMS during the reporting period
- summary of contacts made with representatives of the local community, public interest groups, and state government during the reporting period
- summary of all contacts made regarding access to off-site property
- summary of all problems encountered during the reporting period
- actions being taken to correct problems
- changes in relevant personnel during the reporting period
- projected work for the next reporting period
- copies of daily reports, inspection reports, data, etc.

8.7 Statement of Basis/Permit Modification

The AA approves the CMS report and its preferred remedial alternative. The AA then prepares a statement of basis and permit modification that provide a brief summary of all alternatives studied in the detailed analysis phase of the RFI/CMS, highlighting all the key factors that led to the identification of the proposed remedy. The SB and permit modification are submitted for public comment. The AA prepares a response to the public comments before the CMI phase is implemented.

8.8 CMI Design

The corrective measure design establishes the size, scope, and character of the project. It details and addresses the technical requirements of the corrective measure. The design begins with conceptual design and ends with the completion of a detailed set of engineering plans and specifications. The conceptual design is used to achieve consensus on the significant aspects of the design approach.

The conceptual design package will be developed and include the following:

- purpose
- corrective measures objectives
- conceptual model of contaminant migration
- description of corrective measures
- project management
- project schedule
- design criteria
- design basis
- waste management practices
- required permits
- identification of unresolved data needs
- long-lead procurement considerations
- appendixes (e.g. design data, equations, sample calculations, etc.), as identified

A conceptual design will be prepared that clearly describes the size, shape, form, and content of the proposed corrective measure, the key elements that are needed, the designers vision of the corrective measure in the form of conceptual drawings and schematics, and the procedures and schedule for implementation.

The intermediate design plans and specifications shall be based on the conceptual design but with more detail. The draft O&M plan and the construction work plan shall be submitted to the regulatory authority simultaneously with the intermediate design package. The draft intermediate design package must include drawings and specifications needed to construct the corrective measure. General correlation between drawings and technical specifications is a basic requirement. Some of the elements required may be the following:

- general site plans
- detailed design drawings
- piping and instrumentation diagrams
- excavation and earthwork drawings
- equipment lists
- site preparation and field work standards
- preliminary specifications for equipment and material

The construction work plan shall document the overall management strategy and include the following:

- construction quality assurance procedures
- procedures to address changes to the design or specifications
- identification of inspections, hold points, and reports
- identification of protocol and coordination of field oversight and inspections
- emergency procedures
- decontamination and decommissioning plan, if applicable
- cost estimate
- schedule for constructing the corrective measure

The O&M plan shall outline procedures for performing operations, long term maintenance and monitoring of the corrective measure. At a minimum, the O&M plan will include the following:

- project management
- system description
- personnel training
- start-up procedures
- O&M procedures
- replacement schedule for equipment
- waste management plans
- sampling and analysis activities
- corrective measure completion criteria
- procedures to address system breakdowns and operational problems
- data management and documentation requirements

The final design plans and specifications must be sufficient to be included in a request for proposal. The final O&M plan and construction plan shall be submitted simultaneously with the final design package.

8.9 CMI Plan

The CMI Plan will include the following:

- final design package (including O&M plan and construction work plan),
- health and safety plan
- public involvement plan

8.10 Construction Completion Report

This purpose of this report is to document the completion of the construction phase of the CMI. In the case where long-term monitoring and maintenance is required after the construction phase, it is assumed that the ER Project will perform all activities through the CMI construction completion report. At that time the site will be transferred to Facility and Waste Operations (FWO) Division or Environment, Safety, and Health (ESH) Division for long-term O&M and monitoring activities at the conclusion of which they will prepare the CMI completion report for submittal to the AA.

There are no RCRA corrective action regulations that require the preparation of a CMI construction completion report. It will be developed to ensure that the construction phase of the CM is completed in accordance with plans and specifications and ensure this information is documented and passed along to FM/ESH for inclusion in the CMI completion report at a later date.

The CMI construction completion report will include the following:

- Description of the actual construction of the CM
- Summaries of construction inspections including resolution of findings
- Results of any acceptance testing
- Summary of construction costs and schedule
- Description of any changes to the design and updated drawings
- Data collected during the construction phase
- Documentation that the plans and performance standards have been met
- Description of any changes identified for the O&M plan (including long-term monitoring, if applicable)
- Schedule for CMI completion report and any interim status reports required by the AA.

8.11 Corrective Measure Completion Report

Remedies shall be considered complete when the AA determines the following:

- Compliance with all media cleanup standards as specified in the permit have been achieved, according to the requirements of 40 CFR 264.525(e)
- All actions required to control the source(s) of contamination have been satisfied; and
- Procedures specified for removal. Decontamination, closure, or post-closure care of units, equipment, devices, or structures required to implement the remedy have been complied with.

Upon completion of the remedy, the Laboratory shall submit to the AA, by registered mail, a request for termination of the corrective action schedule of compliance according to procedures for a Class III modification. The request will include a certification that the remedy has been completed in accordance with requirements and must be signed by the Laboratory and by an independent professional who is skilled in the appropriate technical discipline.

8.12 CMI Progress Reports

Monthly progress reports will be prepared during the corrective measure design, construction and O&M phases of the project and submitted to the AA. These reports will, at a minimum, include the following:

- a description of significant activities and work completed during the reporting period
- summary of system effectiveness
- summary of all findings
- summary of all contacts with representatives of the local community, public interest groups or State government during the reporting period
- summary of all problems encountered during the reporting period
- actions being taken to correct problems
- changes in personnel during the reporting period
- projected work for the next reporting period
- the results of any sampling or other data generated during the reporting period

9.0 REFERENCES

The following list includes all references cited in this document. Parenthetical information following each reference provides the author, publication date, and the environmental restoration record identification (ER ID) number. This information also is included in the citations in the text. ER ID numbers are assigned by the Laboratory's ER Project to track records associated with the Project. These numbers can be used to locate copies of the actual documents at the ER Project's Records Processing Facility and will also be located in the ER Project reference library titled "Reference Set for Material Disposal Areas, Technical Area 54" when it is compiled at the end of Fiscal Year 1999.

Copies of the reference library are maintained at the New Mexico Environment Department Hazardous and Radioactive Materials Bureau; the Department of Energy Los Alamos Area Office; United States Environmental Protection Agency, Region VI; and the ER Project Material Disposal Areas Focus Area. This library is a living document that was developed to ensure that the administrative authority (AA) has all the necessary material to review the decisions and actions proposed in this document. However, documents previously submitted to the AA are not included in the reference library.

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Attachment A

Acronyms and Abbreviations

AA	administrative authority
ARAR	applicable or relevant and appropriate requirement
BMP	best management practice
BV	background value
CA	composite analysis
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CMI	corrective measures implementation
CMS	corrective measures study
D&D	decontamination and decommissioning
DOE	US Department of Energy
EC	expedited cleanup
EETF	Experimental Engineered Test Facility
EPA	US Environmental Protection Agency
ER	environmental restoration
ESH	Environment, Safety, and Health (Division)
FEP	features, events, and processes
FWO	Facility and Waste Operations (Division)
FY	fiscal year
HE	high explosives
HP	Hot Point (site)
HSWA	Hazardous and Solid Waste Amendments of 1984
IM	interim measure
Laboratory	Los Alamos National Laboratory
LANL	Los Alamos National Laboratory
LAPRE	Los Alamos Power Reactor Experiment
LLW	low-level waste
MDA	material disposal area
NFA	no further action
NMED	New Mexico Environment Department (New Mexico Environmental Improvement Division before 1991)
NOD	notice of deficiency
O&M	operation and maintenance
OU	operable unit
PA	performance assessment
PRS	potential release site
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation

RSI	request for supplemental information
SACM	Superfund accelerated cleanup model
SAL	screening action level
SAP	sampling and analysis plan
SVOC	semivolatile organic compound
SWMU	solid waste management unit
TA	technical area
TCA	trichloroethane
TNT	trinitrotoluene
TRU	transuranic
TSCA	Toxic Substances Control Act
VCA	voluntary corrective action
VCM	voluntary corrective measure
VOC	volatile organic compound

Attachment B

Material Disposal Area Fact Sheets

Los Alamos
NATIONAL LABORATORY

Environmental Restoration Project

Fact Sheet for Technical Area 6, Material Disposal Area F

August 1999

Acronyms

MDA	Material disposal area
PRS	Potential release site
RFI	Resource Conservation and Recovery Act facility investigation
VCA	Voluntary corrective action

Site Description

Material Disposal Area (MDA) F, Potential Release Site (PRS) 6-007(a)-99, consists of two fenced areas located at Technical Area 6 on Twomile Mesa north of Twomile Mesa Road and south of the southwest fork of Twomile Canyon. MDA F sits at an elevation of approximately 7460 ft (2238 m). The depth to groundwater below MDA F is approximately 1275 feet (383 m). Runoff 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 TNT. In 1946, a pit was excavated for the disposal of large classified objects that could not easily be destroyed by cutting. The objects were buried to protect their classification. In 1947, another pit was excavated for the disposal of 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 of spark gaps containing small amounts of cesium-137. None of these disposals correlate with job and work orders found in the archives. The three shafts are probably in the area of the smaller fence at MDA F. The areas inside the fences at MDA F have been monitored for radioactivity on a continuing basis since 1981 as part of the Los Alamos Environmental Surveillance Program. No readings above background have been observed.

Resource Conservation and Recovery Act Facility Investigation Status

A Resource Conservation and Recovery Act facility investigation (RFI) Phase I sampling was conducted in July 1994 in accordance with the "RFI Work Plan for Operable Unit 1111."

A voluntary corrective action (VCA) was implemented in August 1995 as described in the "Voluntary Corrective Action Completion Report for Potential Release Site 06-007(f)." Site restoration consisted of recontouring and reseeding the site with native grasses. A formal request for Environmental Protection Agency concurrence to remove PRS 6-007(f) from the Hazardous and Solid Waste Amendments of 1984 module was presented in the VCA report.

Surface Water Assessment

Watershed: Pajarito Canyon

Erosion Matrix Score: Not determined

Los Alamos
NATIONAL LABORATORY

Environmental Restoration Project

Fact Sheet for Technical Area 8, Material Disposal Area Q

August 1999

Acronyms

MDA	Material disposal area
PRS	Potential release site
TA	Technical area

Site Description

Material Disposal Area (MDA) Q, Potential Release Site (PRS) 8-006(a) is located at Technical Area (TA) 8 west of Anchor Ranch Road and south of Building TA-8-21 (the DX Division Office) in an area known as the TA-8 Gun-Firing site. MDA Q is a 0.2-acre 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 used in 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 material disposal area associated with the gun-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). MDA Q is not believed to have been used for any other disposal since 1946.

The solid waste management units at this MDA are listed in Module VIII of the Laboratory's Resource Conservation and Recovery Act (RCRA) Hazardous Waste Facility Permit.

RCRA Facility Investigation Status

Radiological and geophysical surveys were conducted in November 1993.

Surface Water Assessment

Watershed: Pajarito Canyon

Erosion Matrix Score: Not determined

Los Alamos
NATIONAL LABORATORY

Environmental Restoration Project

Fact Sheet for Technical Area 9, Material Disposal Area M

August 1999

Acronyms

EC	Expedited cleanup
MDA	Material disposal area
PRS	Potential release site

Site Description

Material Disposal Area (MDA) M (Potential Release Site 09-013) is located at an elevation of 7500 ft (2250 m) on Pajarito Mesa and southwest of Pajarito Canyon. The depth to groundwater below MDA M is approximately 1220 ft (366 m). Runoff from MDA M drains northeastward to Pajarito Canyon and southward to a tributary informally known as Starmer Gulch, which is located within the Pajarito Canyon watershed. Metal and debris, generated during the removal of Old Anchor Sites East and West and the construction of the new and present TA-8 and TA-9 facilities (1948–65), have been flashed and deposited over the surface of this 3-acre area. Nonhazardous waste from the construction of other sites within the Laboratory was also dumped here from 1960 to 1965.

Resource Conservation and Recovery Act Facility Investigation Status

An expedited cleanup (EC) was performed at MDA M as described in the "Expedited Cleanup Plan for Solid Waste Management Unit 9-013."

Phase I of the EC was conducted between November 1995 and March 1996.

Phase II of the EC is planned to consist of the evaluation of the confirmatory sampling results to determine if the cleanup action levels established based on the Phase I Resource Conservation and Recovery Act facility investigation data are still appropriate, followed by additional site excavation and subsequent round(s) of confirmatory sample collection.

Surface Water Assessment

Watershed: Pajarito Canyon

Erosion Matrix Score: 56

Best Management Practices: An earth berm and silt fence were installed in August 1996.

Los Alamos
NATIONAL LABORATORY

Environmental Restoration Project

Fact Sheet for Technical Area 11, Material Disposal Area S

August 1999

Acronyms

HE
High explosives

MDA
Material disposal area

RCRA
Resource Conservation and Recovery Act

TA
Technical area

Site Description

Material Disposal Area (MDA) S (Potential Release Site 11-009) is a fenced, active experimental plot at Technical Area (TA) 11. It measures approximately 10 ft by 10 ft (3 m by 3 m) and is located north of Water Canyon. MDA S sits at an elevation of approximately 7300 ft (2190 m). The depth to groundwater below MDA S is approximately 1160 feet (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 general area is covered with ponderosa pines, and no drainage intersects the site.

The studies conducted (and in some cases are still ongoing) were initiated in March 1965 to determine the persistence of explosives in soil in the area of the drop tower complex at TA-11 where the sensitivity of high explosives (HE) is studied. The studies continue with a maximum inventory of less than 80 g (0.18 lb.) of HE remaining in the experimental plot.

The solid waste management unit at this MDA is listed in Module VIII of the Laboratory's Resource Conservation and Recovery Act (RCRA) Hazardous Waste Facility Permit.

RCRA Facility Investigation Status

No RCRA facility investigation activities have been completed at MDA S.

Surface Water Assessment

Watershed: Water Canyon

Erosion Matrix Score: Not determined

Los Alamos
NATIONAL LABORATORY

Environmental Restoration Project

Fact Sheet for Technical Area 15, Material Disposal Area Aggregate

August 1999

Site Description

Technical Area (TA) 15 is located on Threemile Mesa at an elevation of approximately 7200 ft (2160 m). The depth to groundwater beneath 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.

Material Disposal Area N

Material Disposal Area (MDA) N, Potential Release Site (PRS) 15-007(a) is located at an elevation of approximately 7280 feet (2184 m). The depth to groundwater beneath MDA N is approximately 1170 feet (351 m). Runoff 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 1965. MDA N is described in the 1990 solid waste management unit (SWMU) report as a pit containing the remnants of several structures from the TA-15 firing site, also designated as R-Site. The site had been exposed to 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 the buildings. No other information is available on debris deposited in the MDA. The pit is described as covered and revegetated. The Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) work plan for Operable Unit (OU) 1086 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 Status

A Phase I investigation was conducted in accordance with the RFI work plan for OU 1086; the investigation was not successful in locating this MDA through geophysical or sampling efforts.

Surface Water Assessment

Watershed: Water Canyon

Erosion Matrix Score: 3.6

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) with a depth to groundwater around 1200 ft (360 m). Runoff 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; they were probably piled as a retaining wall, and other debris may have been filled in behind it. One face grades to native soil, while the

Acronyms

OU
Operable unit

MDA
Material disposal area

PRS
Potential release site

RCRA
Resource Conservation and Recovery Act

RFI
RCRA facility investigation

SWMU
Solid waste management unit

TA
Technical area

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 and blast mats, volatile organic compounds and/or semivolatile organic compounds from charred wood, road and construction debris, and radioactive substances (e.g., from the blast mats). Visible chunks of uranium are present at the site.

The SWMU at this MDA is listed in Module VIII of the Laboratory's RCRA Hazardous Waste Facility Permit.

RFI Status

No RFI activities have been completed at MDA Z.

Surface Water Assessment

Watershed: Cañon del Valle

Erosion Matrix Score: 40.2

Los Alamos
NATIONAL LABORATORY

Environmental Restoration Project

Fact Sheet for Technical Area 16, Material Disposal Area Aggregate

August 1999

Site Description

Technical Area (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 material disposal areas (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 high explosives and include casting, pressing, and machining of high explosives (HE); assembly of explosive test devices; fabrication of plastic components; development of new materials; and nondestructive examination. TA-16 has been in use since the early 1940s and is still active with the recent installation of a high-pressure tritium facility.

MDA P

MDA P (Potential Release Site [PRS] 16-018) is a 1.4-acre industrial landfill located at TA-16 near the south rim of Canon 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). Runoff from MDA P enters the Canon 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 nonconstruction debris, such as flasks, bottles, morticians' tables, and other items used in the formulation, processing, and assembly of HE components.

Before being designated as a disposal area for S-Site wastes in the early 1950s, the area that currently is MDA P served as a detonator burning ground. Both 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 activities were initiated at the western end of the landfill and proceeded eastward. The landfill was used to dispose of residues resulting from the burning of 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 of in MDA P.

RCRA Facility Investigation Status

The MDA P landfill was closed as a Resource Conservation and Recovery Act (RCRA) unit in Fiscal Year 1999.

Surface Water Assessment

Watershed: Cañon de Valle

Erosion Matrix Score: 69.3

Best Management Practices: Asphalt/concrete repaving, plastic covering, permanent seeding, and a straw bale barrier were installed in September 1996; an earth berm, sediment trap, and silt fence were installed in September 1998.

Acronyms

HE
High explosives

MDA
Material disposal area

PRS
Potential release site

RCRA
Resource Conservation and Recovery Act

TA
Technical area

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 site located on the mesa edge on the south side of Canon de Valle, and runoff from the site enters the Canon 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 the actual contaminated area is likely to be 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. Significant amounts of debris are located along the north side of MDA R. A geophysical survey at MDA R suggests that the waste depth is shallow.

The solid waste management unit at this MDA is listed in Module VIII of the Laboratory's RCRA Hazardous Waste Facility Permit.

RCRA Facility Investigation Status

A Phase I investigation was conducted in accordance with RCRA facility investigation work plan for Operable Unit 1082. Weekly status reports were prepared in 1997.

Surface Water Assessment

Watershed: Cañon de Valle

Erosion Matrix Score: 83

Los Alamos
NATIONAL LABORATORY

Environmental Restoration Project

Fact Sheet for Technical Area 21, Material Disposal Area Aggregate

August 1999

Acronyms

BMP	Best management practice
MDA	Material disposal area
NMED	New Mexico Environment Department
NOD	Notice of deficiency
NTISV	Nontraditional in situ vitrification
PRS	Potential release site
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
RSI	Request for supplemental information
SAP	Sampling and analysis plan
TA	Technical area

Site Description

Technical Area (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). Runoff from TA-21 drains to Los Alamos Canyon and DP Canyon, which are located within the Los Alamos Canyon watershed. Groundwater lies at a depth of approximately 1150 ft (345 m). TA-21 has been used for both chemical research and plutonium metal production from 1945 to 1978. The major industrial activity was related to plutonium refinement so the major waste disposal activities were plutonium related as well. Material disposal areas (MDAs) located at TA-21 include MDA A, MDA B, MDA T, MDA U, and MDA V; these MDAs are all listed as Hazardous and Solid Waste Amendments of 1984 solid waste management units in Module VIII of the Laboratory's Resource Conservation and Recovery Act (RCRA) permit.

MDA A

MDA A (Potential Release Site [PRS] 21-014) is a 1.25-acre site that was used for waste disposal during two periods: 1945–1949 and 1969–1977. Between 1944 and 1947, two shallow pits that were about 13 ft (4 m) deep were used to dispose of about 36,000 ft^3 (1020 m^3) of "solid wastes with alpha contamination accompanied by small amounts of beta and gamma." During this same period, two underground storage tanks (the General's Tanks) were installed to store a total of 49,000 gal. of a sodium hydroxide solution containing 334 g 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 was 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 30-ft- (9-m-) 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. Remediation of the site cap was conducted in 1985 and 1987.

RCRA Facility Investigation Status

A Phase I surface investigation was completed in 1994 in accordance with the TA-21 operable unit RCRA facility investigation (RFI) work plan.

Surface Water Assessment

Watershed: Los Alamos Canyon

Erosion Matrix Score: Not determined

Best Management Practices (BMPs): Remediation of the site cap was conducted in 1985 and 1987.

MDA B

MDA B (PRS 21-015) is an inactive disposal site located on DP Mesa just west of the fenced area of TA-21 and south of commercial businesses on DP Road. MDA B operated from 1945 through 1948. The approximate area of the MDA is 6 acres; the TA-21 work plan states that buried waste pits occupy about 5580 yd^2 (4650 m^2) with an estimated volume of 27,612 yd^3 (21,240 m^3). MDA B consists of two areas: an unpaved fenced eastern area and a paved, fenced western area, neither of which has any surface structures. The number of trenches in MDA B is unknown. The disposal trenches were reported to be approximately 15 ft wide by

300 ft long by 12 ft deep, and they were not lined. A geophysical survey was conducted as part of the 1998 RFI to delineate the dimensions of the trenches.

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

In 1984, the unpaved portion of MDA B was resurfaced with a variety of cover systems during a pilot study conducted in support of the National Low Level Waste Management Program and the Environmental Protection Agency's Land Pollution Control Division, Contaminant Branch. Its present state incorporates several variations of a nominal 3-ft-thick crushed-tuff cover, which is placed over the original crushed-tuff cover. Variations include cobble and gravel biobarriers between the old and new covers, as well as shrub, grass, and gravel mulch surface treatments. The total cover thickness on this portion of MDA B is nominally 6.5 ft.

RFI Status

A Phase I surface investigation was conducted at MDA B and associated drainages and completed in accordance with the TA-21 operable unit RFI work plan.

A Phase I subsurface sampling and analysis plan (SAP) RFI work plan revision was submitted to New Mexico Environment Department (NMED) in September 1998.

A request for supplemental information (RSI) for Phase I subsurface SAP was issued by NMED.

A response to RSI was submitted to NMED in February 1999.

A Phase I subsurface investigation is on-going during 1999.

Data summary and SAP addendum will be submitted to NMED by September 1999.

Surface Water Assessment

Watershed: Los Alamos Canyon

Erosion Matrix Score: 17.9

MDA T

MDA T (PRS 21-016) includes four absorption beds and 62 shafts where radioactively contaminated liquid waste from the plutonium-processing laboratories at TA-21 was disposed of between 1945 and 1952. Stormwater runoff from this site enters the DP Canyon watershed. In 1952, a liquid waste treatment plant was installed to remove plutonium and other radionuclides. 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 buried at MDA T. There were 62 shafts at MDA T used for the permanent disposal of cement-treated liquid waste.

Approximately 18,300,000 gal. of liquid waste was disposed of in 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, 3761 Ci of americium-241, and 3 Ci of mixed fission product. The total volume of cement paste permanently disposed of in the shafts at MDA T was 122,500 ft^3.

RFI Status

A Phase I surface investigation conducted at MDA T and associated drainages was completed in accordance with the TA-21 operable unit RFI work plan.

A Phase I subsurface investigation SAP was submitted to NMED in the SAP for Group 21-016.

A Phase I subsurface investigation was completed at risk.

An RSI on Phase I subsurface SAP issued by NMED July 29, 1997.

A response to the RSI was sent to NMED, but there is no record of it in the RPF yet.

Surface Water Assessment

Watershed: DP Canyon

Erosion Matrix Score: 54.

BMPs installed in September 1996 include a run-on diversion and straw bale barrier.

MDA U

MDA U [PRSs 21-017 (a,b, and c)] is an inactive disposal site located north of buildings TA-21-152 and -153 at TA-21 on DP Mesa; the MDA is fenced on all sides. MDA U covers an area of approximately 0.2 acres (1200 m^2) and contains two absorption beds [PRSs 21-017(a) and (b)]. Stormwater runoff from this site enters the DP Canyon watershed. The TA-21 work plan states that the absorption beds were used for subsurface disposal of radioactively contaminated liquid wastes from 1948 to 1968, and as constructed, the two absorption beds had a surface area of approximately 1800 ft with an estimated volume of about 18,000 ft^3. An associated distribution box, TA-21 164 [PRS 21-017(c)], was located between the two beds. The distribution box and associated distribution lines in PRSs 21-017(a and b) were removed in 1985.

RFI Status

A Phase I surface investigation was conducted in 1994 in accordance with the TA-21 Operable Unit RFI Work Plan.

An additional Phase I surface investigation SAP was submitted to NMED in 1998.

A Phase I surface RFI was completed in 1998.

A Phase I subsurface SAP was submitted to NMED in the Sampling and Analysis Plan for Potential Release Sites 21-017(a,b, and c).

A Phase I subsurface RFI was ongoing at risk, 1999

Surface Water Assessment

Watershed: DP Canyon

Erosion Matrix Score: 8.8

BMPs installed in January 1990 include a run-on diversion and a swale.

MDA V

MDA V [PRS 21-018(a)] is 0.88-acre site at TA-21, which contains three absorption beds that occupy 15,000 ft^2 and have a volume capacity of 4250 m^3. Stormwater runoff from this site enters the LA Canyon watershed. The absorption beds were used for liquid waste disposal from a laundry operation at building TA-21-20 and were in continuous use from October 1945 to 1961. The laundry facility mainly processed clothing from plutonium refinement operations, but other processes and waste streams may have used the absorption beds for disposal.

A nontraditional in situ vitrification (NTISV) cold test was performed near MDA V in early in 1999 in preparation of a plan to vitrify a portion of one of the absorption beds. Results of the cold test have not been finalized.

RFI Status

A 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 Operable Unit RFI Work Plan.

An RFI report recommending NFA was submitted to NMED in 1996.

A notice of deficiency (NOD) on Phase I surface and subsurface RFI report issued by NMED and response to NOD are reported in a 1997 Laboratory memorandum (EM/ER:97-295).

Surface Water Assessment

Watershed: Los Alamos Canyon

Erosion Matrix Score: 18.1

Los Alamos
NATIONAL LABORATORY

Environmental Restoration Project

Fact Sheet for Technical Area 33, Material Disposal Area Aggregate

August 1999

Acronyms

NFA	No further action
MDA	Material disposal area
PRS	Potential release site
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
SAP	Sampling and analysis plan
SWMU	Solid waste management unit
TA	Technical area

Site Description

Technical Area (TA) 33, also known as Hot Point 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 between 760 ft and 910 ft (228 m and 273 m). TA-33 was created in 1947 as a test site for weapons experiments using conventional high explosives, 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.

MDA D

Material Disposal Area (MDA) D, Potential Release Sites (PRSs) 33-003(a and b), is located at an elevation of approximately 6500 ft (1950 m) on a mesa formed by Ancho Canyon and White Rock Canyon. The depth to groundwater beneath MDA D is approximately 910 ft (273 m). Runoff 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], which were 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 high explosives. 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 solid waste management units (SWMUs) at this MDA are listed in Module VIII of the Laboratory's Resource Conservation and Recovery Act (RCRA) Hazardous Waste Facility Permit.

RCRA Facility Investigation Status

A Phase I investigation was conducted in 1994 in accordance with the RCRA facility investigation (RFI) work plan for Operable Unit 1122.

An additional investigation was conducted in 1996 in accordance with the revised sampling and analysis plan (SAP) presented in the "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.

Surface Water Assessment

Watershed: Ancho Canyon

Erosion Matrix Score: Not determined

MDA E

MDA E [PRSs 33-001(a–e)] lies on a point formed by Chaquehui Canyon and one of its tributaries. MDA E is located on a mesa at an elevation of approximately 6500 ft (1950 m). The depth to groundwater beneath MDA E is approximately 760 feet (228 m). Runoff from this site enters the Chaquehui Canyon watershed. MDA E was operated between 1948 and 1955 to dispose of gun-type initiators and debris. Test material contaminated with polonium-210 was carried to the open pits. The first structure at South Site 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 memorandum 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 states that the area contains several hundred kilograms of depleted uranium. Exact curie contents of pits 1 and 2 are reported as 240 Ci and 60 Ci, respectively. Brief descriptions of the contents of pits 3 and 4 implicate the presence of hazardous waste (GI can of beryllium dust immersed in kerosene). No information is available on pits 5 and 6; South Site 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.

RFI Status

No RFI activities have been completed at MDA E.

Surface Water Assessment

Watershed: Chaquehui Canyon

Erosion Matrix Score: Ranges between 35 and 40.2 for the five PRSs in MDA E

MDA K

MDA K [PRSs 33-002(a–e)] is a 1.0-acre site located 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). Runoff 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 TA-33 from 1955 until 1990. This facility housed equipment used to transfer tritium from large transportation tanks to smaller vessels for use at various Laboratory locations. The building was occasionally 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 Status

A Phase I investigation was conducted at PRSs 33-002(a and b) in 1993 in accordance with the RFI work plan for Operable Unit 1122.

Phase I investigations and Phase II SAPs for PRSs 33-002(a and b) are presented in "RFI Report for MDA K, PRSs 33-002(a,b,c,d,e)."

PRSs 33-002(band c) were recommended for no further action (NFA) for human health in "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."

PRS 33-002(d and e) were recommended for NFA in "RFI Report for MDA K, PRSs 33-002(a,b,c,d,e)."

Surface Water Assessment

Watershed: Chaquehui Canyon

Erosion Matrix Score: Ranges between 3.6 and 26.2 for the five PRSs in MDA K

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Environmental Restoration Project

Fact Sheet for Technical Area 35, Material Disposal Area Aggregate

August 1999

Acronyms

LAPRE-II	Los Alamos Power Reactor Experiment No. 2
MDA	Material disposal area
NFA	No further action
PRS	Potential release site
TA	Technical area

Site Description

Technical Area (TA) 35, which is also known as Ten Site Laboratory, is located at an elevation of approximately 7000 feet (2100 m) on a finger mesa between Mortandad Canyon and Ten Site Canyon, which is 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. Past operations at TA-35 related to waste disposal at its material disposal areas (MDAs) includes source preparation, radionuclide experimentation, and nuclear fission reactor development.

MDA W

MDA W, Potential Release Site (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 is backfilled under pressure with nitrogen and is 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 runoff 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). There are no administrative controls regarding access to the site.

Resource Conservation and Recovery Act Facility Investigation Status

MDA W was recommended for no further action (NFA) in "Addendum to the OU 1129 RFI Work Plan" on the basis that no evidence of a release exists. The engineered controls presently in place 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.

Surface Water Assessment

Watershed: Mortandad Canyon

Erosion Matrix Score: Not determined

MDA X

MDA X (PRS 35-002) is the former site of the Los Alamos Power Reactor Experiment No. 2 (LAPRE-II) reactor, 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. There are no administrative controls regarding access to the site.

Resource Conservation and Recovery Act Facility Investigation Status

MDA X was recommended for NFA in the "Addendum to the OU 1129 RFI Work Plan" because all reactor-related equipment and contaminated soils were removed. Confirmatory soil sampling was conducted to verify the removal of all constituents of concern including radionuclides and hazardous chemicals.

Surface Water Assessment

Watershed: Mortandad Canyon

Erosion Matrix Score: Not determined

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Environmental Restoration Project

Fact Sheet for Technical Area 36, Material Disposal Area AA

August 1999

Acronyms

MDA	Material disposal area
NMED	New Mexico Environment Department
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation

Site Description

Material Disposal Area (MDA) AA (Potential Release Site 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 of 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. The trenches provided safety and administrative controls for explosives and for materials possibly contaminated with explosives; they also provided a way of reducing 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 runoff to 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 ft to 300 ft (30 m to 90 m) west of the MDA.

The solid waste management unit at this MDA is listed in Module VIII of the Laboratory's Resource Conservation and Recovery Act (RCRA) Hazardous Waste Facility Permit.

RCRA Facility Investigation Status

MDA AA was reported in the "RFI Report for Potential Release Sites at TA-36 36-001, 36-004(d) Skunk Works and Burn Pits, 36-006."

The New Mexico Environment Department (NMED) issued a letter of denial for the RCRA facility investigation (RFI) report.

An interim action was conducted in May 1996 that addressed numerous erosion channels draining the site. Wire mesh and cobbles were placed in three erosion channels at the southern trench area that posed an immediate threat to the integrity of the trench soil cover. Remaining supplies and cobbles were used to pack additional trenches. The interim action report was approved by NMED.

Los Alamos National Laboratory requested extensions for the resubmission of the RFI report in November 1997 and for the submission of the Phase II sampling and analysis plan in August 1998.

Surface Water Assessment

Watershed: Water Canyon

Erosion Matrix Score: 45.7

Best Management Practices: A silt fence and straw bale barrier were installed in July 1996.

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Environmental Restoration Project

Fact Sheet for Technical Area 39, Material Disposal Area Y

August 1999

Acronyms

MDA	Material disposal area
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation

Site Description

Material Disposal Area (MDA) Y [Potential Release Site 39-001(b)] 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). Runoff from this site directly enters Ancho Canyon. MDA Y was one of several pits at TA-39 used for disposal of waste consisting primarily of debris from firing site experiments, empty chemical containers, and office waste. MDA Y was the first disposal pit at Technical Area 39 and was in use from 1973 until approximately 1976, when pit 2 was put into use.

The solid waste management unit at this MDA is listed in Module VIII of the Laboratory's Resource Conservation and Recovery Act (RCRA) Hazardous Waste Facility Permit.

RCRA Facility Investigation Status

MDA Y was proposed for no further action in the "RFI Report for Potential Release Sites at TA-39 39-001(a and b), 39-004(a-e), 39-008."

The New Mexico Environment Department issued a request for supplemental information for the RCRA facility investigation (RFI) report in November 1997.

Los Alamos National Laboratory requested an extension for resubmission of the RFI report in August 1998.

Surface Water Assessment

Watershed: Ancho Canyon

Erosion Matrix Score: Not determined

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Environmental Restoration Project

Fact Sheet for Technical Area 49, Material Disposal Area AB

August 1999

Acronyms

BMP	Best management practice
MDA	Material disposal area
PRS	Potential release site
RCRA	Resource Conservation and Recovery Act
RFI	RCRA facility investigation
RSI	Request for supplemental information

Site Description

Material Disposal Area (MDA) AB, Potential Release Site (PRS) 49-001(a–g) is located at an elevation of 7200 feet (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 to exist at TA-49. Very little other use has been made of MDA AB and TA-49. The experiments were conducted to assess safety concerns related to 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 of uranium-235 and 2450 Ci of plutonium-239, with some fission and activation products also likely to be present. Solid lead used as shielding for the experiments is also contained in the experiment chambers as well as small amounts of beryllium. 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 further subdivided into areas 2A and 2B.

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 surface pavement was removed in 1998 as part of an interim measure undertaken as part of the Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) to stabilize the site against subsurface moisture resulting from surface water ponding, run-on, and inhibited evapotranspiration. That interim measure was completed with the installation of a clean, crushed-tuff cap containing a wire-mesh layer to inhibit intrusion by burrowing animals and covered with native grasses to promote transpiration of moisture and inhibit erosion and gravel to further inhibit erosion.

The solid waste management units at this MDA are listed in Module VIII of the Laboratory's RCRA Hazardous Waste Facility Permit.

RFI Status

A Phase I investigation was conducted in 1994 in accordance with "RFI Work Plan for Operable Unit 1144."

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)."

The stabilization plan received a request for supplemental information (RSI) and then a notice of deficiency on the response to the RSI; responses were developed to both.

Best management practices (BMPs) were performed at PRSs 49-001(b,c,d, and g) as described in the BMP completion report. Activities included construction and stabilization of a diversion channel; installation of a silt fence; downgradient channel stabilization; removal of a power pole; and placement of straw bales in the upgradient runoff channel.

Surface Water Assessment

Watershed: Ancho Canyon

Erosion Matrix Score: 59.2 [PRS 49-001(g)]

BMPs: Run-on diversions, silt fences, straw bale barriers, velocity dissipation devices, and asphalt/concrete repaving were installed in June 1998.

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Fact Sheet for Technical Area 50, Material Disposal Area C

August 1999

Site Description

Material Disposal Area (MDA) C landfill at Technical Area (TA) 50 (Potential Release Site 50-009] was established in May 1948 as a 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). The depth to groundwater below MDA C is approximately 1175 feet (353 m) and runoff from this site enters Ten Site Canyon, which is located in the Mortandad Canyon watershed. MDA C is a fence-enclosed 11.8-acre site. Radioactive and hazardous waste was disposed of 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), while the average depth of the shafts was approximately 16 ft (4.8 m). The pits were filled between 1948 and 1959, and the shafts were filled between 1958 and 1965. Logbooks were used to record limited information about waste disposals after 1954. Estimates of the total radiological inventory at MDA C are 196 Ci in pits and 49,483 Ci in shafts. This estimate includes 28 Ci of uranium (i.e., uranium-233, uranium-234, uranium-235, uranium-236, and uranium-238); 49,136 Ci of cesium-137; 31 Ci of strontium-90; 26 Ci of plutonium-239; 149 Ci of amercium-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 and a list of interred contaminants (based on site logbooks) is in Table 2-10 of the Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) work plan for Operable Unit 1147 (LA-UR-92-969).

The solid waste management unit at this MDA is listed in Module VIII of the Laboratory's RCRA Hazardous Waste Facility Permit.

RFI Status

A Phase I surface investigation was conducted in 1993 in accordance with the "RFI Work Plan for Operable Unit 1147."

A Phase I subsurface investigation was conducted between 1994 and 1996 in accordance with the "RFI Work Plan for Operable Unit 1147."

Surface Water Assessment

Watershed: Mortandad Canyon

Erosion Matrix Score: Not determined

Acronyms

MDA
Material disposal area

RCRA
Resource Conservation and Recovery Act

RFI
RCRA facility investigation

TA
Technical area

Attachment C

Landfill Cover and Post-Closure Monitoring Designs for Baseline Planning

LANDFILL COVER AND POST-CLOSURE MONITORING DESIGNS FOR BASELINE PLANNING

By

Environmental Science Group, EES-15

Performed for Deba Daymon, Focus Area Leader for MDAs
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May 11, 1999

LANDFILL COVER AND POST-CLOSURE MONITORING DESIGNS FOR BASELINE PLANNING

Table of Contents

LANDFILL COVER AND POST-CLOSURE MONITORING DESIGNS FOR BASELINE PLANNING

Abstract

Two alternative landfill covers are proposed for a Materials Disposal Area (MDA) using an Integrated Risk-Based Approach For Landfill Cover Design (Figure 1) that also takes into account the hydrologic conditions and contaminant source term at the MDA. The Crushed Tuff-Biointrusion Landfill Cover will generally be used for MDAs at dry sites with pre-existing slopes of about 5% and with low human and ecological risk, where the relative importance of risks is: biointrusion > erosion > seepage/interflow. The Capillary-Biointrusion Landfill Cover will be used for MDAs at sites that are wetter than the previous sites and/or that have higher potential human and ecological risk, where the relative importance of risks is: biointrusion ≥ seepage/interflow > erosion. We have field performance data to send to NMED, EPA, and DOE to support the performance of both of these landfill cover designs from the Protective Barrier Landfill Cover Demonstration plots, from other field studies of engineered covers tested at the pilot scale and on actual waste sites, and from natural analog studies in Ponderosa Pine forests and Pinyon-Juniper woodlands.

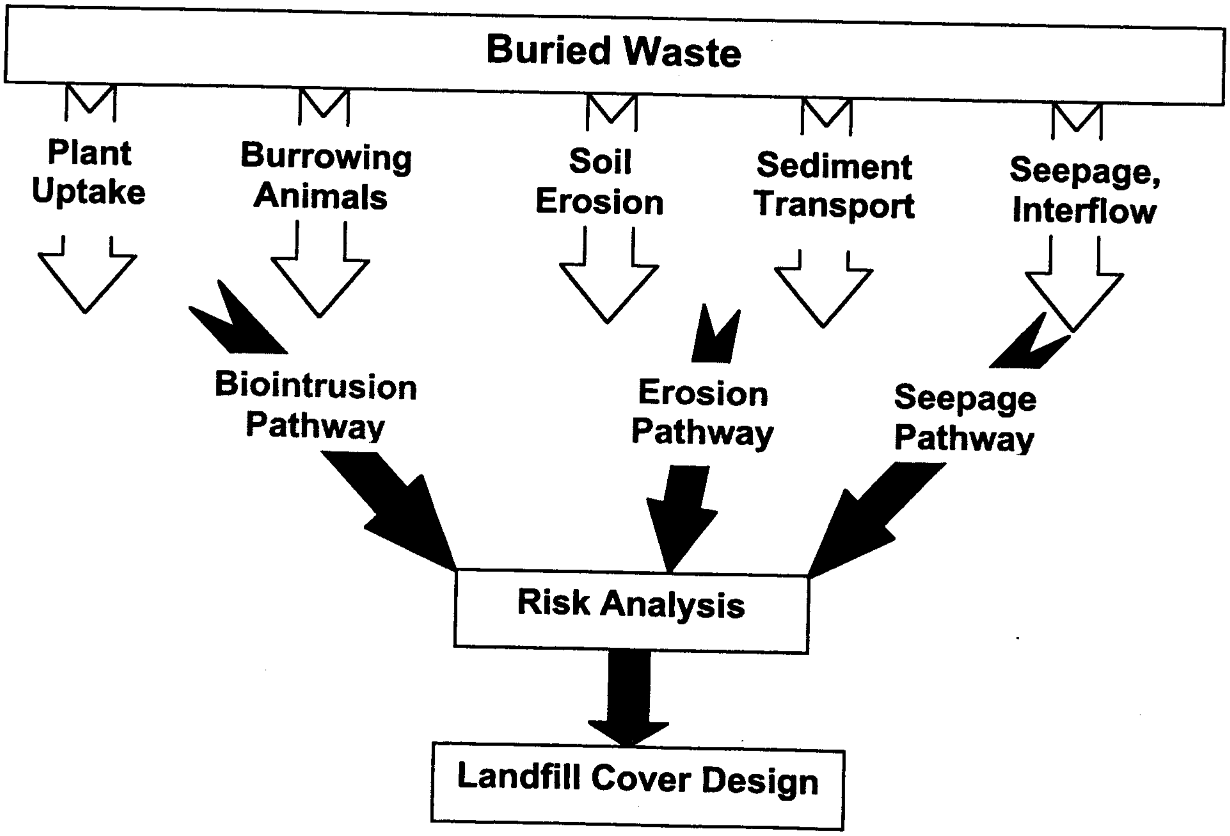


Figure 1. Integrated Risk-Based Approach For Landfill Cover Design.

A. Introduction

An Integrated Risk-Based Approach For Landfill Cover Design (Figure 1) is used to develop conceptual landfill cover designs. 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. The options associated with mitigating each risk pathway (e.g., options/tools for biointrusion risk pathway that might include gravel, fence for gophers, etc.) are then discussed, as well as the problems associated with each option, and a recommended approach. This analysis, along with results of previous applied research on engineered covers, on covers emplaced at actual waste sites, and natural analog studies, results in proposed landfill cover designs. 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 herein.

B. Scope of Study

Although current Environmental Restoration Project activities are limited to only a few MDAs, there are several other PRSs where landfill covers and post-closure monitoring either will or might be required in the remediation of the site. This study was performed to support a specific request to provide technical justification for designs of landfill covers and post-closure monitoring systems to be used at LANL MDAs. More specifically, these cover designs are intended to apply to MDAs such as those at LANL Technical Areas 21, 54, 50/51, and 49. Given the Environmental Science Group's experimental and natural analog surface processes pilot studies data and available applied research data for semiarid sites, these are the cover designs suggested for use at LANL MDAs. This document serves as the technical basis for the Environmental Restoration (ER) Project landfill cover cost estimates for MDAs.

C. General Assumptions Made in Developing Designs

The conceptual designs in this document 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 following are general assumptions made in this document:

- It is assumed that 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.
- Ideally, one would apply a formal, site-specific risk assessment to a given MDA, using site characterization data (defining nature and extent of contamination) and modeling, evaluate all of the remediation options to reduce the risk, and then evaluate the most cost-effective remediation option to reduce this risk. This formal process was not within the scope of this document and is currently still in various stages of completion within the ER Project for various sites. These MDA-specific analyses may result in modifications to the conceptual

designs proposed herein; however, the conceptual designs herein are assumed to be reasonable for the majority of MDAs at this time.

- This document provides information on monitoring to determine if the engineered landfill cover design is performing to design expectations. It does not provide information on monitoring for contaminant migration below the landfill cover.
- It is assumed that 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 unknown. Natural materials are used in the landfill cover design to maximize the cover's design life. No assumptions are made with regard to possible replacement time frames for either cover components or monitoring equipment. The cover design provides some redundancy in terms of important risk pathway concerns (e.g., multiple layers of different materials) which should help mitigate this issue.
- It is assumed that the landfill cover reduces the total external radiation dose to any potential receptors on the landfill surface to an acceptable level.

D. Previous Assessments of Risk at LANL MDAs

(1) Early Risk Studies

Several risk analyses have been made between 1975 and 1983 of a number of natural phenomena which could result in the release of plutonium from radioactive wastes buried at the Los Alamos National Laboratory (Gallegos et al., 1975; Gallegos and Johnson, 1976; Hanson and Rodgers, 1983; Walker et al., 1981; Wheeler et al., 1977). Background information concerning the history and practice of radioactive waste disposal at LANL is provided in these modeling studies. The potential impact of buried radioactive wastes on the environment is addressed through the mechanisms and rates by which the radionuclides can enter the environment. Only mechanisms independent of human activity are considered and are divided into two classes, acute and chronic. The acute release mechanisms considered are earthquakes, meteorite impacts, and tornadoes, which have been typified (Wheeler et al., 1977) by low occurrence probabilities (10^{-6} to 10^{-7}/yr). The chronic mechanisms that have been considered are release through uptake by plant roots, exposure by soil erosion, and transport by soil water, which we will cover in this report in the next three subsections.

The rates of uptake by plant roots, soil erosion and transport by soil water are low, but may result in radionuclide release over long time periods. The analysis of uptake by plant roots was made using an environmental model, BIOTRAN and BIOTRAN.2 (Gallegos et al., 1980).

Some of the conclusions reached in these studies can be summarized as:

- For several simulations a pit at MDA-G was assumed to have a uniform plutonium concentration of 10 nCi/g, covered by a 1.5-m-thick horizon of clean backfilled soil. The only means for radionuclide release considered in these scenarios is uptake by plant roots, with transfer to aboveground biomass and subsequent movement to the surface soils via humus decay.

- In simulations of a Pinyon-Juniper woodland over MDA-G, topsoil concentrations increased to about 8 fCi/g after 5000 yr. Thus, the plutonium concentration in the soil directly over the burial grounds may be expected to about double, over that period of time, due to plant root penetration of the waste.
- The erosion rate for the mesa tops has been estimated using the age of the volcanic tuff as determined by radiodating, and the estimated original thickness of the ash flow. On this basis, the vertical erosion rate at MDA-G has been estimated as 2.2 cm/1000 yr (Wheeler et al., 1977)
- Determination of the width and age of canyon systems leads to an estimated lateral erosion rate of 10 cm/1000 yr.
- The two preceding erosional processes will expose the surface of buried waste material in approximately 50 000 yr; during the following 100 000 yr, approximately 2 m of waste will be removed, at which time lateral erosion of the mesas will expose the wastes in the trenches closest to the canyon rim.
- Plutonium concentrations, as estimated for the preceding 50,000 yr period, are above levels currently used as contamination guidelines, and, by present practice, would require some form of area control.
- An estimated water movement rate of 1.2 cm/yr was used in many of these simulations, with a plutonium migration rate of 2×10^{-8} cm/yr.
- In effect, these calculations indicate that plutonium will not migrate from its present location within the waste pits on a time scale that is long compared with the 24,000 yr half-life of plutonium.

(2) Performance Assessment and Composite Analysis for MDA-G

The source term for the Composite Analysis (CA) included the Performance Assessment (PA) inventory, plus waste disposed of before September 26,1988 at MDA-G (Hollis et al., 1997). The performance objective for the CA is a maximum dose of 100 mrem/yr to a future member of the public from all exposure pathways. The results of the CA are qualitatively similar to the results of the PA, with air-pathway doses associated with the biotic-intrusion source term being dominant. Cumulative air pathway doses were calculated in Cañada del Buey and White Rock, and cumulative all-pathway doses were projected at the location of maximum groundwater concentration downgradient of MDA-G and in Pajarito Canyon.

Since this PA was written so eloquently, we decided that three quotations from the PA would suffice to communicate information pertaining to the biointrusion, seepage/interflow, and erosion risk pathways:

(1) "Two mechanisms of release were considered in the source-term modeling for the air pathway analysis: the diffusion of radioactive gases from waste, and the resuspension of contamination transported to the surface by plants and burrowing animals. Potentially important uncertainties in the air-pathway source term analyses are discussed below.

Potentially important sources of uncertainty in the biotic intrusion source release model relate to whether plants or animals are responsible for the translocation. For the radioactinides responsible for the majority of the air-pathway dose, burrowing animals were the primary transport vectors. As modeled, the projected releases of radioactivity due to the intrusion of animals depend upon the burrow distributions and the densities of the burrows at the site. The source-release model was based on a burrow distribution representative of the pocket mouse. The burrow characteristics of this species were used to estimate those of the deer mouse, a species of small mammal commonly observed at MDA G. Burrow densities used in the model were consistent with densities observed for deer mice. In the base case, the depth of burrowing was 2 m (6.6 ft), with 10 percent of the burrows assumed to occur below a depth of 1 m (3.3 ft). Deeper and more extensive burrowing examined as an extreme case resulted in contamination levels almost 3 times greater than the base case." (from section 4.3.2.1, Air Pathway)

(2) "In the groundwater protection analysis, radioactivity dissolved from the surface of waste into water percolating through the disposal units was transported both vertically and laterally through the vadose zone. Radioactivity transported vertically followed a straight-down path into the regional aquifer, while radioactivity transport-ed laterally was instantaneously rinsed from the mesa edge into the alluvial system into the canyon and then transported down to the regional aquifer. Once reaching the regional aquifer, the vertically-transported radioactivity was transported within the saturated zone to a downgradient receptor well; laterally-transported radioactivity was assumed to be accessed by a supply well directly beneath the Pajarito Canyon receptor location. Important factors in evaluating compliance with the groundwater protection performance objective relate to the time required for radioactivity to reach the receptor well, and the concentration of radioactivity at the location of the receptor well.

Radionuclide travel time is a function of the groundwater travel time, the sorption behavior of the contaminants, and the degree of dilution that occurs in the regional aquifer. Uncertainties in sorption are not important, since none of the radionuclides contributing to the drinking-water dose were sorbed within the vadose zone. Uncertainties in groundwater travel time, or recharge, and aquifer dilution are recognized and have an effect on the groundwater pathway analysis.

Groundwater travel times in the unsaturated zone are proportional to the amount of water percolating through the disposal site and to the hydraulic conductivities and moisture retention characteristics of the vadose zone. As reported in Appendix 3g, groundwater travel times were affected by only about 25 percent to uncertain-ties in hydraulic conductivity. Larger differences were found when extreme flow fields were considered. To bound the uncertainty in the base-case flow field, a set of high-flow and low-flow boundary conditions were considered in the vadose zone transport calculations. The high-flow case modeled infiltration rates of 10 mm/year (0.4 in/year) atop Mesita del Buey, 5 mm/yr (0.2 in/year) in Cañada del Buey, and 100 mm/year (0.2 and 4 in/year) in Pajarito Canyon; the low-flow case modeled rates of 1, 1, and 20 mm/year (0.04, 0.04, and 0.8 in/year) at the top of the mesa, in Cañada del Buey, and in Pajarito Canyon, respectively. The high-flow case resulted in earlier and larger fluxes to the regional aquifer for both lateral and vertical transport, while the low-flow case resulted in later and smaller fluxes. Compared with the base-case peak flux at 2,500 years and 600 years for vertical and lateral-then-vertical groundwater flux to the saturated zone, breakthrough occurred at about 1,000 and 300 years, respectively.

Groundwater simulations indicate that the total mass of contamination exiting the sides of the mesa over 10,000 years is approximately 30 percent of the mass discharged to the aquifer. Based on these results, doses received by the receptor located east-southeast of Area G would be no more than 30 percent greater if all contamination were transported vertically to the regional aquifer." (From section 4.3.3.2, Groundwater Protection)

(3) "The uncertainties discussed above for the groundwater pathway analysis apply to all-pathway environmental transport. In addition, uncertainties in sediment transport of surface contamination into Pajarito Canyon also apply, as do uncertainties in factors related to contamination of foodstuffs due to radionuclides present in irrigation water.

The mean erosion rate of 4.0 x 10^{-7} m/year (1.3 x 10^{-6} ft/year) calculated in a surface-water balance model was used to transport contamination from the surface of Mesita del Buey into Pajarito Canyon in the all-pathways analysis. This erosion rate has a standard deviation of about 1 x 10^{-6} m/ year (3.3 x 10^{-6} ft/year), and a maximum value of almost 5 x 10^{-5} m/year (1.6 x 10^{-4} ft/year). Based on these statistics, the actual erosion rate would be expected to fall within an order of magnitude of the mean rate. Hence, doses to the canyon resident would increase by 10 times or less due to errors in the erosion rate estimate.

Radioactivity transported into the canyons by surface runoff was assumed to uniformly disperse over an area that is equivalent to the area of contamination on the mesa. In actuality, relatively high contaminant concentrations are expected to occur in local depressions where surface runoff collects, while little or no contamination may occur in other areas. Though the actual distribution of contamination across the landscape will influence the projected exposures for the canyon resident, it is not readily projected. Consequently, the error introduced by this source of uncertainty was not considered further in the sensitivity and uncertainty analysis.

The contamination transported to the canyon floor was assumed to be mixed to a depth of 15 cm (6 in) over the resident's entire lot. This depth is expected to be reasonable for the individual's garden, but may overestimate the mixing depth over the remainder of the lot and therefore, radionuclide concentrations in surface soil. Under worst-case conditions, however, reduced mixing depths will result in no more than a ten-fold increase in the projected doses.

The food crops considered in the all-pathways analysis were assumed to be contaminated by radioactivity deposited on plant surfaces during irrigation, as a result of rainsplash, and by root uptake of contamination in water reaching the ground. All radioactivity deposited on plants was assumed to be transferred to the edible portions of leafy vegetables grown by the resident, while 10 percent of the activity deposited on protected produce, fruit, and grain was assumed to be assimilated into the edible portion. Moderate increases in the translocation factor for protected produce, fruit, and grain will have limited impacts on the projected ingestion doses, given the small contribution that contamination deposited directly on the plants makes to the peak projected doses. For example, a five-fold increase in the translocation factor for non-leafy vegetables results in food pathway doses that are about 20 percent greater than those projected for the nominal case. The amount of radioactivity initially retained by a plant during irrigation and the rate at which it is weathered from plant surfaces are not easily quantified. The fraction of activity initially retained will depend largely upon the rate at which water is applied to the crops and the morphology of the plants. The rate of weathering will vary with meteorological conditions at the site and characteristics of the food crops. While the magnitude of the error introduced by these uncertainties is unknown, it is not expected to be significant.

The root uptake pathway was the more significant of the three, accounting for more than 85 percent of the dose projected for the food ingestion pathway. The soil concentrations of ^{14}C, ^{99}Tc, and ^{129}I due to irrigation are expected to be overestimated by the models used in the dose assessment. A soil buildup time of 15 years was assumed to apply to all radionuclides in irrigation water. While accounting for build-up may be appropriate for radionuclides that sorb to soils, these highly mobile radionuclides will tend to be transported downward with water percolating through the garden. As the contamination is rinsed from the soils, it will become unavailable for root uptake by plants. Under these conditions, the plant radionuclide concentrations of ^{14}C and ^{99}Tc would be 19 and 16 percent, respectively, of the projected values. Concentrations of ^{129}I would be about 80 percent of the modeled values.

The uptake factors used in the dose assessment for ^{14}C and ^{99}Tc both exceed 1.0, indicating plant radionuclide concentrations exceeding those observed in soils. Moderately higher uptake factors for these radionuclides (e.g., 2 times the nominal values) would result in food pathway doses that are almost 2 times higher than projected. However, these higher doses would increase the peak scenario doses by less than 20 percent. The uptake factors for ^{129}I would need to increase by 100 times or more to have significant effects on the peak.

The plant radionuclide concentrations resulting from the assimilation of radioactivity directly from the irrigation water are a function of the amount of water applied to the crops, crop yields, the plant translocation factor, the fraction of the radioactivity deposited on the plant that is initially retained, and the rate at which radioactivity deposited on plant surfaces is removed due to weathering. The amount of water that was assumed to be applied to the crops is based on information for the greater Los Alamos area and, as such, is expected to reasonably approximate the amount of water applied to food crops. While rates of water application could vary for short periods, the total amount of water applied to the crops over the course of a growing season is not expected to change substantially." (from section 4.3.3.3, All Pathways)

E. Major Risk Pathways

From the studies of the assessment of risk discussed in the previous section, we decided to evaluate the biointrusion, erosion, and seepage/interflow risk pathways.

(1) Biointrusion Pathway

Although vegetation is important in controlling erosion and percolation (Hakonson et al., 1984), deep-rooted plants can access buried radionuclides and bring them to the surface of the site (Wenzel et al., 1987). Radionuclides in plant tissue can be transported through the food chain to man by herbivores or nectar-collecting organisms such as honeybees. At Los Alamos, New Mexico, one of the pathways of tritium transport away from a controlled low-level waste site is via the soil moisture/plant nectar/honeybee/honey pathway (Hakonson and Bostick, 1976); however, radiation doses to humans who might consume this honey are very small. Likewise, tumbleweeds growing on low-level waste sites are effective in transporting Sr-90 to the ground surface at Hanford, Washington (Klepper, et al., 1979).

The role of animal burrowing in mobilizing buried waste is generally unknown. A limited data base (Hakonson, et al., 1982; O'Farrell and Gilbert, 1975; Winsor and Whicker, 1980; Arthur and Markham, 1983) demonstrates that burrowing animals can transport radionuclides vertically in the soil profile and may also influence water balance and erosion by changing the physical characteristics (i.e. porosity, water holding capacity) of surface and subsurface soils. Trench covers are disturbed soil systems, often loosely compacted, and are easily invaded by plants and animals. Burrowing animals use the void spaces left after trench backfilling as natural tunnels and nesting sites (Connolly and Landstrom,1969; Arthur and Markham,1983; Hakonson et al., 1999).

Burrowing activities by animals play an important role in chemical cycling in the soil profile. The vertical transport of Fe, Se, Al, Ca, Mg, U, Ra, and Th from deep soil layers to the surface by the mechanical action of rodents (Abaturov,1972; Maslov, et al., 1967) has given rise to the statement that burrowing rodents serve as nutrient pumps that bring materials to the soil surface for weathering (Chew,1974;Chew,1976). As mentioned before, soil and chemicals brought to the surface are more readily available for resuspension and transport into biological pathways by physical processes.

It is important to prevent buried waste from reaching the ground surface. Radionuclides buried below the ground surface can be absorbed by plant roots and deposited in aboveground plant tissue. However, when the radionuclides are present on the soil surface, as is the case at several waste sites, physical resuspension of soil particles (especially the clays) by wind and water can deposit contaminated soil particles on plant surfaces (i.e., leaves, stems, and fruiting bodies; Dreicer, et al., 1984). Field studies (Watters, et al., 1980; Hakonson and Nyhan, 1980) with plutonium, as well as other radionuclides show that for every picocurie taken up through plant roots, at least 10 (and often 100 to 1000) picocuries can be deposited in association with soil particles on foliage surfaces. Of course, most herbivores consume those radionuclides whether they are on or in the plant. Even in humans, who usually wash vegetables before consumption, as much as 50% of the radionuclide intake from consuming certain garden vegetables may be from very small soil particles, such as clays, that are not removed from crop surfaces by standard household food washing procedures (White, et al., 1981).

The results of a study at MDA-B also offer insight into the biointrusion pathway relate to plant succession and the overall impact of time on biointrusion processes. This landfill that had been covered with about 90 cm of topsoil and had been closed for 34 years, when it was found to have a number of tree and shrub species growing on the cover, with some trees rooting directly into waste material (Wenzel et al., 1987). Pocket gophers had also exposed waste material. While MDA-B (closed in 1948) did not include the liner and cover technology required today, its condition shows that a variety of woody, deep-rooted species can be expected to appear on landfill covers within 30 years. The cover design chosen may influence the relative proportions of herbaceous plants, shallow-rooted woody plants, and deeper-rooted woody plants that will coexist at a site (Breshears and Barnes, 1999), which are likely to differ in ability to penetrate landfill covers (Reynolds, 1990).

While plants can mobilize buried waste, they also play an extremely important role in water balance. In arid/semiarid climates, plants may transpire from 65-100% of the annual precipitation (Saxton, 1982; Federer, 1975). This means that very little soil water may be available for percolation below the root zone. While tree and shrub roots particularly may pose a threat to the integrity of landfill covers, many woody evergreen species also are able to remove soil water throughout the year. For example, many of the landfill sites at Los Alamos are situated within piñon-juniper (*Pinus edulis-Juniperus monosperma*) woodlands. Both of these both *P. edulis* and *J. monosperma* transpire throughout the winter (Breshears, 1993), when a significant proportion of the annual precipitation at Los Alamos occurs and fluctuating temperatures can result in saturated soils as a result of snowmelt. The senescent herbaceous species cannot remove this excess soil water, but *P. edulis* and *J. monosperma* can help dry the topsoil during this period and prevent saturated conditions that could lead to seepage through the cover. Thus, these woody species can help minimize seepage through buried waste.

The data from these studies have helped us conceptualize the long-term performance of landfill covers in semiarid regions. The performance of a landfill cover is dependent on both the engineering factors that form the basis of the initial cover and the environmental factors that affect the cover through time. With time, we expect an increase in the relative importance of environmental factors in determining cover performance, while the relative importance of engineering factors should decrease, as discussed by Suter et al. (1993). The exact shape of the curves will of course depend on the cover design and local climate. For a conventional design at Los Alamos, we can estimate some time points along the curve. Initial conditions are for cover performance are presented by Nyhan et al. (1990), demonstrating that the covers remained intact over in the first three years following installation. Nyhan et al. (1990), however, did note the important influence of plant community composition on water balance, as have others (e.g., Anderson et al., 1993; Nyhan et al., 1998). The results of the current ITP study (Davenport et al, 1999) indicate that the landfill covers largely remained intact after more than a decade, although there was certainly evidence of landfill-cover deterioration (e.g., high infiltration due to animal burrowing). The study of Wenzel et al. (1987) on a similar cover design at Los Alamos shows breakdown of the cover and dominance of environmental processes in determining landfill-cover performance in less than 35 years. As studies of landfill-cover performance for periods of a century or longer are lacking, we have been conducting studies of environmental in "natural" ecosystems; these studies serve as long-term analogues for landfill performance, at which time we expect environmental processes will largely determine landfill cover.

Although burrowing animals can gain access and transport waste to the ground surface, less obvious infractions with the cover and trench backfill may be of greater importance. For example, pocket gophers inhabiting a low-level waste site at Los Alamos excavated about 12,000 kg of soil per ha from a trench cover during a 1-year period (Hakonson et al., 1982). Displacement of that amount of soil created about 8 m^3 of void space in the cover or about 2800 m of tunnel system. In the case of the field studies of the Integrated Test Plots (ITP), a single pocket gopher burrow increased the infiltration capacity of a cover by nearly an order of magnitude, and moved ponded water (analogous to an intense thunderstorm or rapid snowmelt) rapidly into the installed cover. Other work at this site has shown that pocket gophers can increase infiltration rates by 200-300% (Hakonson, 1998). Pocket gophers and other small mammals can displace large amounts of soil (Cox, 1990; Spencer et al., 1985; Hakonson et al., 1982; Mielke, 1977), translocating it to the soil surface (Gonzales et al., 1995; Arthur et al., 1987; O'Farrel and Gilbert, 1975; Schuman and Whicker, 1986; Winsor and Whicker 1980). Therefore biobarriers, such as our gravel and cobble layers or gravel incorporated into the topsoil, may be essential to even the short-term success of any cover design. Soil disturbance of a similar or greater magnitude, caused by burrowing animals, has been documented in many parts of the Western US (Gunderson, 1976; Ellison, 1946; Thorpe, 1949; Hoover, 1971).

Our studies of "natural" ecosystems have yielded many important insights into the performance of landfill-covers over periods of decades, centuries, or longer and associated potential problems. Here we highlight three examples. Runoff in semiarid woodlands may be low when vegetation cover is high (Wilcox, 1994), but rapid changes in vegetation in response to climate can greatly increase erosion rates (Wilcox et al., 1996; Davenport et al., 1998; Allen and Breshears, 1998). Tree roots penetrating clay layers can generate large amounts of interflow (subsurface lateral flow of water—Wilcox, et al. 1997; Newman et al.; 1998), which can affect landfill performance substantially (Wilcox and Breshears, 1997). The proportions of herbaceous and woody plants have an important effect on spatial variability in fluxes of water and energy (Breshears et al., 1997b, 1998), and these proportions can be influenced by landfill cover designs factors that influence the vertical distribution of soil moisture (Martens et al., 1997; Breshears et al., 1997a; Breshears and Barnes 1999). Collectively these studies highlight the importance of integrating an understanding of basic environmental processes with engineering factors into landfill-cover design. In conclusion, the results that we report here provide an important step in extending the evaluation of landfill covers from the first initial years to periods of decades or longer over which landfill covers must perform to minimize risks to human health and the environment.

Tunnel systems created by pocket gophers in Colorado have been shown to increase rates of water infiltration (by decreasing soil bulk density) into the soil profile by a factor of two over similar but undisturbed profiles (Grant, 1974; Hanson and Morris, 1968). Compared with undisturbed vegetated soil surfaces, soil cast to the surface by burrowing activity may be subject to accelerated erosion (Ellison, 1946).

Burrowing animals may greatly alter the integrity of engineered, multilayered soil profiles by penetrating through such profiles and/or by vertically displacing the layers. In native ranges, under high population densities pocket gophers are estimated to turn over 15% to 22% of the soil near the surface in a single year (Thorpe, 1949; Hoover, 1971).

Operating experience at the 11 LLW sites in the United States suggests that many of the short term problems that relate to radionuclide transport often do not involve ground water and invariably involve interactions that occur with the trench cap. Those interactions, which involve both water and biota, are not well understood, particularly the role that plants and animals play in modifying water balance in the cap and the importance of biological intrusion into the waste as a radionuclide transport pathway. Few comprehensive, long-term pathway analyses have been attempted to determine the relative importance of subsurface and surface processes in transporting LLW to man. Under a home farm scenario, where a family living on an abandoned low-level waste site at Savannah River Laboratory derived most of their food and water from the site, model calculations suggest that uptake of Sr-90 by cereal grains provided the most significant, albeit very low, dose to the family (King,1982).

The potential significance of the biological transport of buried waste in contributing to human exposure to radiation was further explored for both arid and humid site conditions (McKenzie, et al., 1982; McKenzie et al., 1984) and compared with dose estimates based on several human intrusion scenarios as established by the US Nuclear Regulatory Commission

(USNRC, 1981). Results of the simulation study demonstrated that biological transport processes involving both plants and burrowing animals resulted in human exposures 100 years after site closure that were about 50% of those calculated for the human intrusion scenarios. Despite the uncertainties associated with the dose estimates for all of the scenarios, the study suggested that dismissal of biological transport as a significant contributing factor in radiation exposures to humans is unsupportable with current knowledge.

(2) Erosion Pathway

Watershed erosion is described in terms of processes occurring on upland areas, in small stream channels, and over entire watersheds. A basic source document for these concepts is a book entitled *The Fluvial System* (Schumm, 1977). An idealized fluvial system is described as consisting of Zone 1—the drainage basin as a sediment and runoff source, Zone 2—the main river channels as a transfer component, and Zone 3—the alluvial fans, deltas, etc., as zones of deposition. Further elaboration on these concepts is given by Schumm (1977) and in an American Society of Civil Engineers Task Committee Report (ASCE , 1982). The emphasis here is on Schumm's Zone 1 as further divided into upland areas and small stream channels. Considered together, they form the watershed. Because of the engineered features of SLB systems, usual design and construction techniques place SLB facilities in upland areas, which are configured to minimize surface runoff flow concentration and the resulting channel erosion. Therefore, discussions herein are limited to upland areas that are subject to overland flow and interrill and rill erosion processes.

Sediment yield from upland areas is simply the final and net result of detachment, transport, and deposition processes occurring from the watershed divide to the point of interest where sediment yield information is needed. Depending on the scale of investigation and definition of the problem, this point of interest can be a position on a hillslope, a property boundary at a SLB site, the edge of a farm field, delivery point to a stream channel, or some other location dependent on topography. Therefore, erosion control technology, designed to reduce soil loss or sediment yield from a given area, must account for and manage the processes of detachment, transport, and deposition.

Scientific planning for surface and subsurface water management at the SLB site requires knowledge of the relationships between those factors that cause a loss of soil and water. Controlled studies on field plots and small watersheds have supplied much valuable information regarding these complex factor interrelationships, mostly from the agricultural community. The greatest benefit from this research can be realized only when the findings from the agricultural and nuclear communities are converted to sound practice on the numerous waste disposal areas throughout the US. Specific guidelines are needed for selecting the control practices best suited to the particular needs of each SLB site, and we are suggesting the use of the Universal Soil Loss Equation for the determination of long-term annual average erosion for these purposes.

(a) Universal Soil Loss Equation and Rainfall Simulator Studies

Our studies (Nyhan and Lane, 1986) investigated the water balance and erosional behavior of Shallow Land Burial (SLB) trench caps for several cover conditions. Plots were established at the Los Alamos Experimental Engineered Test Facility (EETF) and were subjected to simulated rainfall to generate infiltration, runoff, and erosion. The effects of antecedent soil water content were evaluated, and the soil erodibility factor, K, and the cover management factor, C, of the Universal Soil Loss Equation (USLE) were estimated for our trench cap configuration. The USLE is written as:

$$A = RLSKCP \qquad \text{Eq. 1}$$

Where:

A is the computed loss per unit area, expressed in the units selected for K and for the period selected for R (in practice, these are usually so selected that they compute A in tons per acre per year, but other units can be selected);

R, the rainfall factor, is the number of rainfall erosion index units plus a factor for runoff from snowmelt or applied water where such runoff is significant;

L, the slope-length factor, is the ratio of soil loss from the field slope length to that from a 72.6-ft length under identical conditions;

S, the slope-steepness factor, is the ratio of soil loss from the field slope gradient to that from a 9% slope under otherwise identical conditions;

K, the soil erodibility factor, is the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, which is defined as a 72.6-ft length of uniform 9% slope continuously in clean-tilled fallow;

C, the cover management factor, the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow; and

P, the support practice factor, is the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to that with straight-row farming up and down the slope.

A 15- by 63-m simulated trench cap was constructed at the EETF (DePoorter, 1981) to closely match trench caps used for shallow land burial at Los Alamos (Warren, 1980). The configuration of this trench cap consisted of a 15-cm layer of backfilled Hackroy series topsoil, which had been stockpiled at the site, underlain by a 90-cm layer of crushed Bandelier tuff backfill that was classified as belonging to geologic mapping unit 3 (Rogers,1977). Both layers were installed with dominant downhill slopes of 7%. We compared the hydrologic behavior of this highly disturbed system with an adjacent undisturbed soil profile that had natural cover.

The criteria for erosion plot selection were based on the requirements set forth during the original development of the USLE on rangeland (Wischmeier and Smith, 1978) and on the constraints of the rainfall simulator (Simanton and Renard 1982). The eight experimental plots on the simulated trench cap and the two natural plots were each 3.1- by 11-m, with the long axis parallel to the slope. Each plot pair on the trench cap was constructed on centers located 17 m apart and with metal plot borders as described previously (Simanton and Renard, 1982). Runoff from the plots was collected in troughs, which diverted the runoff into a runoff-measuring flume with an FW-1 water-level recorder that measured continuous stage height.

Rainfall simulators, such as the one used in this study, are useful to determine USLE parameters for a rapidly changing soil surface such as that found on trench caps covering waste materials. Rainfall simulators have been used extensively to collect soil erodibility data, to measure the effect of cropping and tillage on soil erosion, and to determine the effects of various soil treatments on soil erosion (Alberts et al., 1980; Foster et al.,1968; Laflen,1982; Meyer et al., 1972; Wischmeier and Mannering, 1969,Wischmeier et al., 1971). The rainfall simulator used in this study was a trailer-mounted rotating boom simulator capable of applying either 60 or 120 mm h^{-1} of water (Swanson,1965), producing drop-size distributions and impact velocities similar to those of natural rainfall (Swanson 1979), and rainfall energies at about 80% of those of natural rainfall.

Three treatments were imposed on the eight plots on the trench cap in 1982 (Nyhan et al., 1984). Two plots received an up- and downslope disking (cultivated treatment). Both standard tilled plots were comparable, except for lengthened slope, to the 22.1-m USLE unit plot of continuous tilled fallow (used to determine the USLE soil erodibility factor). Two other plots were not tilled and also had no vegetative cover (bare soil treatment). To determine the influence of vegetation on soil erosion, four plots were seeded with barley.

The hydrograph and sedigraph measurements generated during simulated rain events demonstrated that antecedent soil water content of the surface soils significantly affected infiltration and erosion rates for all erosion plots. Values of apparent run-off/ precipitation ratios were much lower on the plots with natural cover (0.26-0.65) than plots on the highly disturbed trench cap (0.82-0.99). Although ratios as high as 0.99 may be influenced by measurement errors, these ratios are higher on the disturbed plots. Soil losses from the plots were influenced more by variations in sediment concentrations than by discharge rates. Variation in soil loss between replicated plot treatments was less on the trench cap plots (14-23%) than on the natural plots (39%). Soil loss from the plots with natural cover was about 2% of that from the cultivated plots on the trench cap, and the soil loss from plots with the bare soil and barley cover treatments on the trench cap had 66 and 33%, respectively, less soil loss than did the cultivated plots.

The soil erodibility K factor and soil loss ratios for the cover management C factor of the USLE were quantified from the soil loss data. An average K value of 0.085 Mg ha h ha^{-1} MJ^{-1} mm^{-1} was estimated from our cultivated plot data, with a CV of 16%. Soil loss ratio values for the barley plots on the trench cap were about 20 times larger than corresponding soil loss ratios for the natural plots.

Four treatments were imposed on the eight erosion plots by the end of July 1983. As in 1982, two plots received a new up- and downslope disking (cultivated treatment). Both standard tilled plots were thus again comparable to the standard USLE plot used to determine the soil erodibility factor. A second year's data were collected on the two plots that were not tilled and had no vegetative cover (bare soil treatment). To determine the influence of partial gravel covers on soil erosion, two plots were prepared as the bare soil treatment and they then received a gravel (<13 mm diameter) cover at an application rate of 60 t/A (gravel cover treatment). The influence of partial gravel covers plus vegetation on soil erosion was determined on two plots that were first seeded with Western Wheatgrass and then received the same gravel application rate as the gravel cover treatment (gravel and plant cover treatment).

We calculated estimates of the USLE cover management factor, which reflect the soil loss ratio from a plot with certain amounts of gravel and/or plant cover to the corresponding loss from the clean-tilled, unprotected soil of a unit plot. Soil loss ratios ranged from 0.040 to 0.050 for the trench cap plots with gravel cover and from 0.016 to 0.048 for the plots with a cover of gravel plus wheatgrass. Gravel cover estimates ranged from 70 to 75%, with the young, small wheatgrass plants contributing very little additional cover in the two plots with the gravel plus wheatgrass cover.

These soil loss ratio values are generally slightly lower than standard soil loss ratios observed in other field studies for gravel and mulch covers with this amount of ground cover (Wischmeier and Smith,1978; Meyer et al., 1972). Data from Wischmeier and Smith (1978) indicate that soil loss ratios equal to about 0.10 to 0.15 would be expected for the amount of ground cover we observed. A similar study of stone mulches on construction sites in Indiana also resulted in high soil loss ratio values relative to this amount of plant cover (Meyer et al., 1972). However, the explanation for our small soil loss ratio values lies in the fact that, even with the low landslope (7%) on our erosion plots relative to much larger landslope values on erosion plots in other field studies, our unprotected, highly erosive trench cap soil had larger soil loss rates than unprotected soil surfaces in other studies. Thus, any amount of plant or gravel cover would reduce the amount of soil loss from our trench cap plots even more than from less erodible soils in other field studies.

We also found that although the partial gravel cover treatment dramatically reduced the amount of soil erosion from the simulated trench cap, this treatment also increased the amount of precipitation that infiltrated the trench cap during the rain simulator runs.

(b) Pilot Studies on Soil Erosion

Runoff occurred throughout the year on the unvegetated Protective Barrier Landfill Cover Demonstration plots as a result of snowmelt and thunderstorm activity (Nyhan et al., 1997). Only 18% of the total runoff between 1992-1994 came from snowmelt events, with 82% of the runoff generated on the study plots being generated during summer thunderstorms. On an individual precipitation basis, no consistent relationship was detected between slope and runoff for either the clay loam topsoil or the loam topsoil, because of the large spatial and temporal variation in runoff observed for both of these soils. For example, the largest daily runoff observed during our field study (1.34 cm) occurred on the Conventional Design with the 25% slope during a record-breaking 3.56-cm precipitation event on August 27, 1993; on this same day, the Conventional Design plots with slopes of 5, 10, and 15% exhibited 1.03, 0.91, and 0.78 cm of runoff, respectively. However, for the entire period between 1991 and mid-1995, runoff did increase with increasing slope for each of the designs and runoff generally accounted for about 2-3% of the precipitation losses across all of the plots studied.

The DOE ER Project compared the performance of several different surface covers at MDA-B in Los Alamos, as summarized in Nyhan et al. (1998). Two versions of a conventional landfill design, consisting of only a layer of topsoil seeded with grasses, were compared with an improved cover containing a biobarrier designed to minimize plant and animal intrusion and to minimize infiltration of water into the underlying wastes. The conventional covers varied in depth, and both conventional and improved designs had different combinations of vegetation (grass verses shrub) and gravel mulch (no mulch verses mulch). These treatments were applied to each of 12 plots and water balance parameters were measured from March 1987 through June 1995, resulting in the longest-term study of water balance on a remediated site.

Several analyses of the MDA-B runoff data collected (Barnes et al., 1986; Barnes and Rodgers, 1987, 1988; Barnes and Warren, 1988; Lopez et al., 1988, 1989) and soil erosion data (LANL, 1991) have been performed (Nyhan et al., 1998). A preliminary analysis of the runoff data from the MDA-B plots was performed with the idea that the decreases in runoff with time were due to increases in vegetative cover. This analysis did not take into account the occurrence of cryptogams, which started to appear on the soil surfaces of many of the plots in 1987, about 3 years after the plots were emplaced at the site. Since this effect was not quantified, the percentage of ground cover (with or without cryptogams) for each of the 12 plots was plotted as a function of annual runoff for each of the years where both types of data were available (1988, 1989, 1990, and 1994). This analysis did not show a very good relationship between these two variables for our field study because the amounts of runoff generated during the 3.62-year event were so large that the influence of ground cover was not an important factor for 1988.

Taking the 1988 runoff and ground cover data out of the comparisons, the data was regraphed and presented in Figure 2. Ground cover was found to be significantly related to annual runoff, in spite of the fact that other factors influencing runoff, such as slope, were not taken into account (Fig. 2). Almost 61% of the variance in runoff was described by a model describing a power relationship between cm of runoff and percent ground cover, with a standard error only 2.22 cm of runoff. This model predicts that as ground cover is increased from 30 to 90%, annual runoff is reduced from 8.8 to 0.98 cm, almost a 9-fold decrease!

Several interesting observations can be made relative to the influence of the gravel treatment on the plots (Figures 3, 4). The gravel mulch increased the plant cover on our study

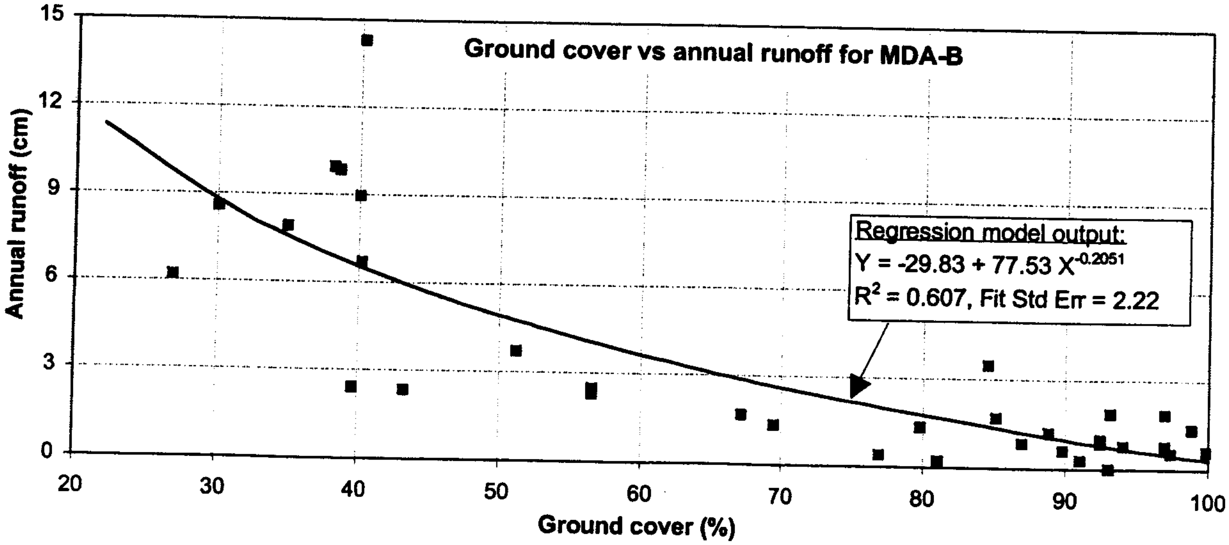
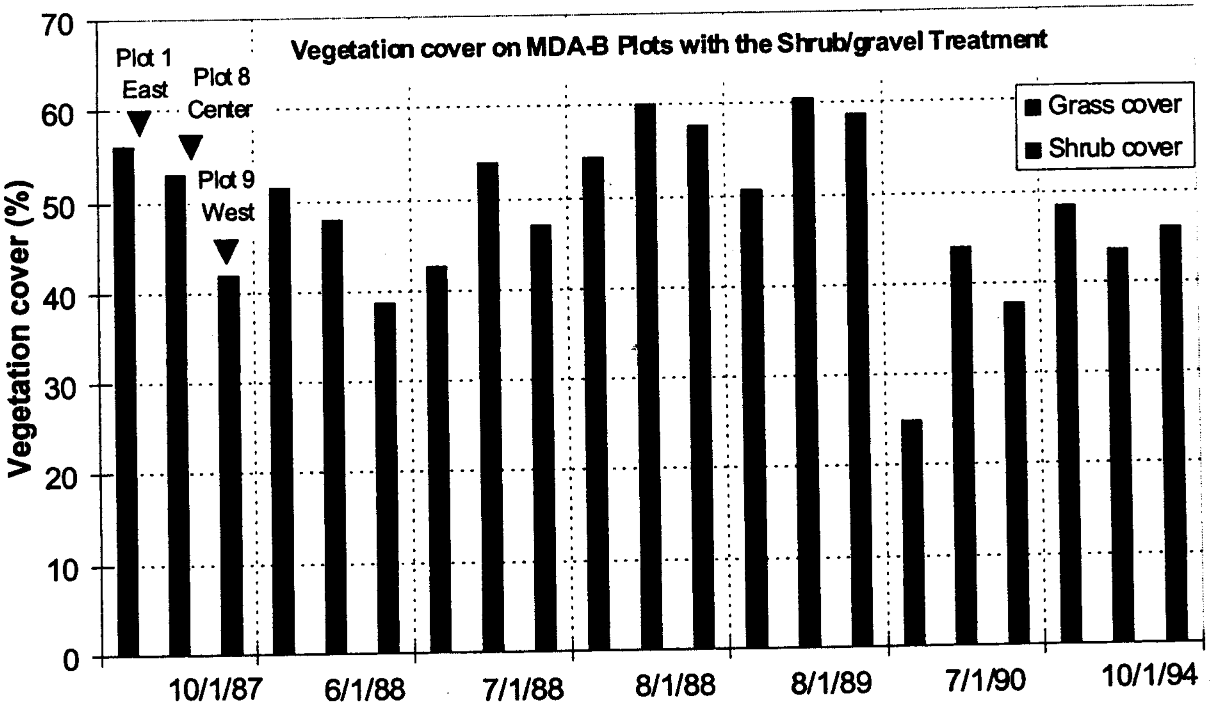


Figure 2. Ground cover and annual runoff for the MDA-B plots for 1989, 1990, and 1994.



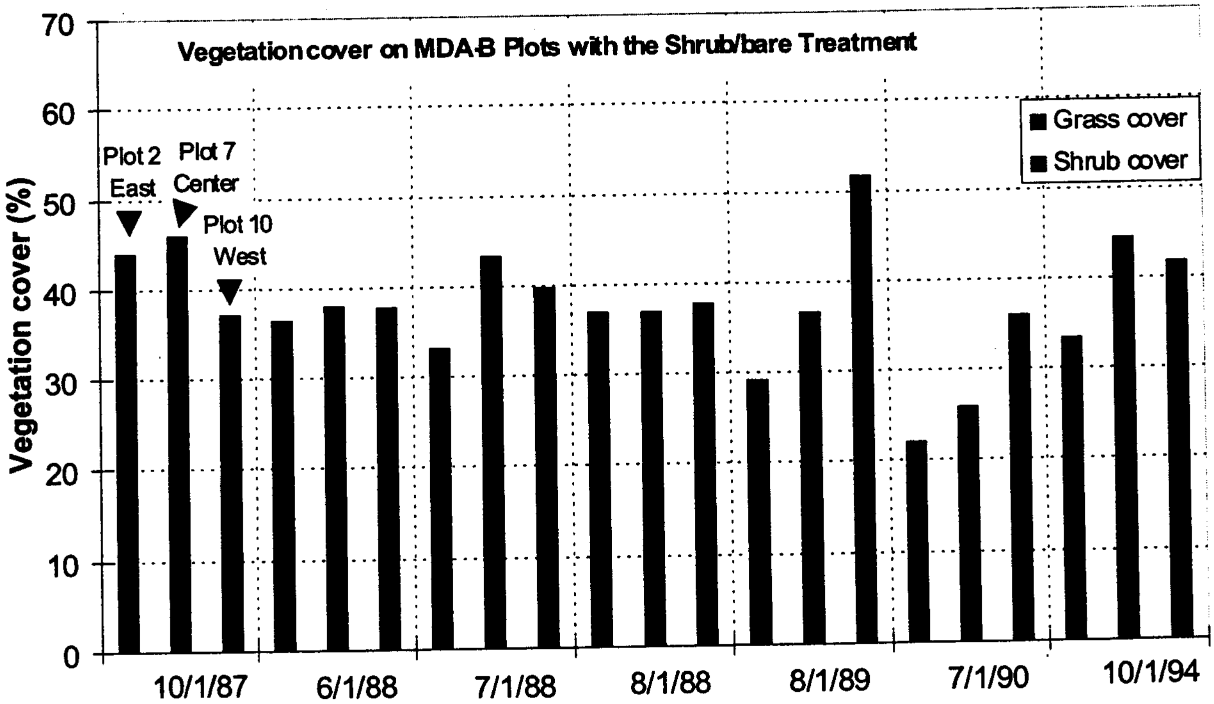
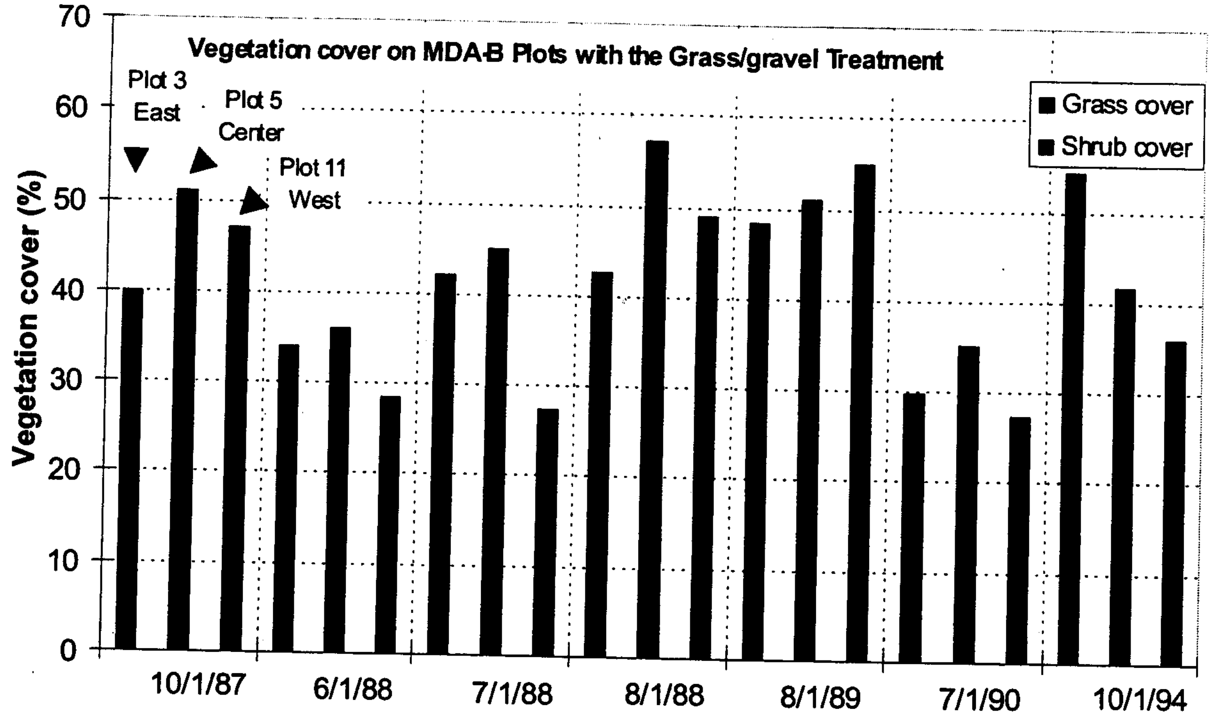


Figure 3. Grass and shrub cover on MDA-B study plots with the Shrub/gravel and Shrub/bare treatments from 1987 to 1994.



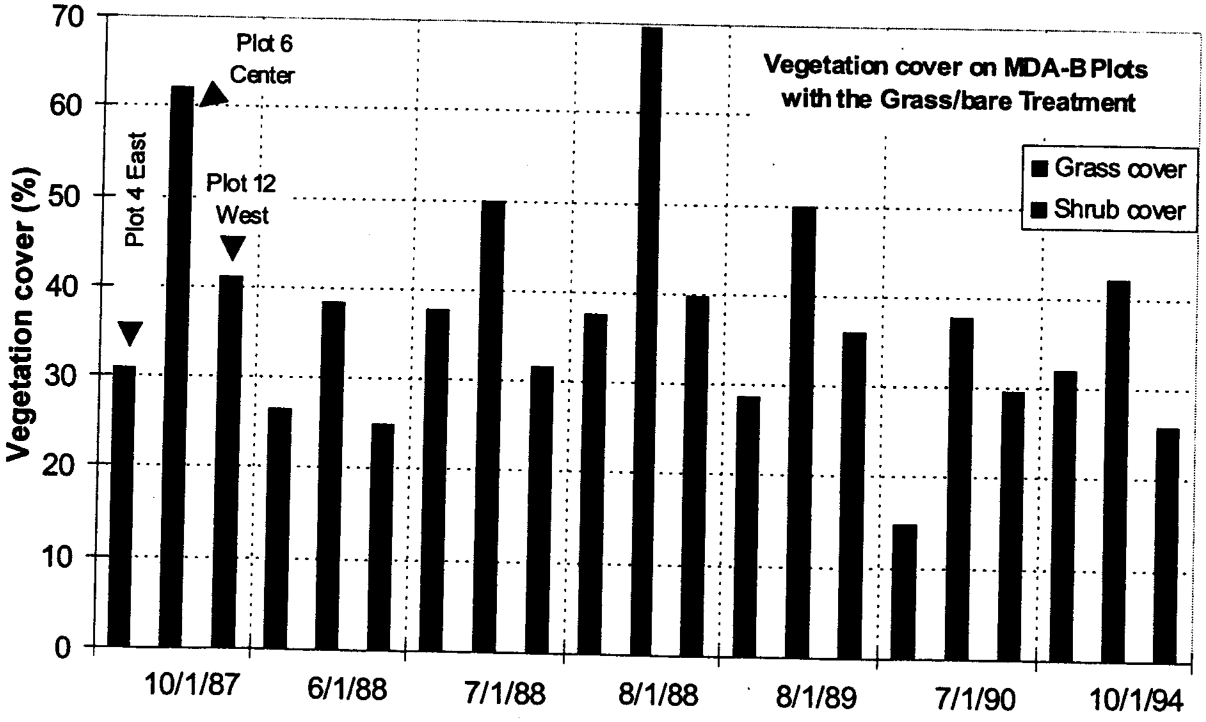


Figure 4. Grass and shrub cover on MDA-B study plots with the Grass/gravel and Grass/bare treatments from 1987 to 1994.

Table 1. Average grass and shrub cover for Shrub and Grass Treatment Plots with and without gravel mulch at MDA-B.

	Average grass cover (%)		Average shrub cover (%)	
Plot Location	With gravel mulch	No gravel mulch	With gravel mulch	No gravel mulch
Shrub treatment plots				
East	24.8	16.4	22.1	17.2
Center	21.9	18.2	29.9	20.6
West	22.7	14.5	24.1	25.8
Average:	*23.1*	*16.3*	*25.4*	*21.2*
Grass treatment plots				
East	41.0	29.7	0.7	0.1
Center	45.1	49.9	0.3	0.1
West	34.7	28.6	3.9	4.1
Average:	*40.2*	*36.1*	*1.6*	*1.4*

plots: the shrub and grass cover estimates were averaged over time and are presented for each of the field plots in Table 1 to further illustrate this point. On the plots where shrubs were added (Shrub/gravel and Shrub/bare treatments), plots receiving no gravel mulch averaged 21.2% shrub cover, while plots with gravel had a 20% larger percent cover of shrubs (Table 1). However, the influence of gravel mulch was even more pronounced on the grass cover on these plots, where the average grass cover on the plots with no gravel was 16.3%, compared with a 42% increase in percent grass cover due to gravel mulch. Similar results were observed with grass cover on the plots where only grass was added to the plots, except for the plots in the center location (Table 1).

(3) Seepage Pathway

Historically, repositories have been plagued by problems of trench-cover instability, which result in seepage into the wastes beneath the landfill cover. These problems have resulted from poor drainage of trench-cover areas, unstable waste forms that collapse by weathering and overburden pressure, and desiccation and cracking of trench-cover material. Other processes enhancing seepage production include weathering and biointrusion of plant roots and burrowing animals. Whereas collapse features will presumably decrease in frequency over time, weathering and biointrusion will be a long-term, continuing process causing progressive deterioration of the landfill cover to inhibit seepage with time (Bedinger, 1989).

Seepage in most natural systems and waste repositories is a water balance factor that is largely determined by climate. The quantity and seasonal distribution of precipitation and evapotranspiration directly influence the infiltration of water into a repository, as well as the contact of soil moisture with the waste and the flow of water for transporting wastes. Climate generally affects the thickness of the unsaturated zone, stream density, and consequently the distance a repository can be located from the ground-water-discharge point (Bedinger, 1989). Thus, areas of great aridity, such as Beatty, Nevada, are normally considered to be well suited for waste disposal, compared with more humid areas, such as Barnwell, South Carolina.

Consider a comparison of the climatology and site hydrology of Beatty, Barnwell, and Los Alamos. Beatty receives 4.5 in of annual precipitation, has a 131,200 ft distance to ground-water discharge with an associated ground-water travel time of 500-1000 years, and exhibits a recharge rate of 0.0016 in/yr (Nichols, 1985; Bedinger et al, 1984). Barnwell has 46.1 in of annual precipitation, a 1083 ft distance to ground-water discharge which can be achieved in only 50 years, and exhibits a recharge rate of 15.0 in/yr (Cahill, 1982; Dennehy and McMahon, 1985). In comparison, the mean annual precipitation in Los Alamos over the last 65 years is 18.1 in, decreasing significantly with distance from the Jemez Mountains east to the Rio Grande.

Ideally, selection of a plant cover in combination with an optimal topsoil configuration (slope, soil type, soil depth), would serve as a primary component of the cap in controlling seepage and root penetration, while the underlying gravel biointrusion barrier could function as a secondary barrier to these processes. The importance of carefully selecting the plant cover can be inferred from modeling studies (Nyhan and Lane, 1982), which show that annual percolation below the rooting zone of native grasses in arid sites is very low and is often far less than 10% of the long-term average annual precipitation. In contrast, evapotranspiration may account for at least 90% of the annual precipitation. Thus, only a slight increase in plant transpiration may completely preclude the occurrence of seepage.

Studies were performed at Area B to examine the effects of different plant covers on soil moisture in order to select optimum species or species mixes for optimal evapotranspiration (Rodgers et al., 1985; Nyhan et al., 1998). These studies showed that doubling the percent shrub (rubber rabbitbrush) plus grass cover from 25 to 50% on these landfill covers increased the evapotranspiration observed from 1987 through 1995 by 28% (Nyhan et al., 1998). As shrub cover increased from 0.13 to 23%, natural increases in soil water inventory in deep tuff layers occurring in the winter and spring decreased from 5.73 to 1.19 cm.

F. Risk Management Options and Recommendations

(1) Biointrusion Pathway

(a) Approaches To Limit Biointrusion

Desirable features of a biointrusion barrier system include:

- effective minimizing of plant root and burrowing animal intrusion into the soil profile and into buried wastes,
- remaining serviceable over the lifetime of the site,
- no adverse effect on other processes affecting waste site integrity (e.g., erosion or percolation), and
- cost effectiveness.

Several approaches have been suggested to reduce the biointrusion potential at waste disposal sites. Most of those approaches rely on physical or chemical barriers to prevent plant roots and/or burrowing animals from accessing the waste. Examples of physical barrier systems include natural geologic materials such as rocks or manmade barrier materials such as hypalon sheeting or asphalt emulsions. Chemical barrier systems include the use of biotoxins.

Past studies with manmade physical and chemical intrusion barriers lead to questions about the serviceable life of such materials under field conditions. One analysis suggests that materials such as asphalt, hypalon, and concrete have a field life of no more than 25 years (Pertusa,1980).

The persistence of herbicides, in general, is not sufficiently long to control vegetation over several decades unless frequent applications are made. Additionally, chemotoxins may adversely affect plant cover and, indirectly, plant transpiration. In arid ecosystems, 65-100% of the annual precipitation may be transpired by plants back to the atmosphere. Soil water that is not transpired to the atmosphere is available for subsurface transport. However, experiments with polymer beads, which slowly release root growth inhibitors, appear promising for preventing plant root intrusion (Burton, et al., 1982).

Los Alamos studies on biointrusion barriers emphasized the use of soil and rock because these materials are long lived in the environment, they are relatively inexpensive, and preliminary experiments on their performance had already been conducted by colleagues at Battelle Pacific Northwest Laboratory (Cline, et al., 1980). Our work extended that of Cline (Cline, et al., 1980) using carefully designed field experiments and computer modeling.

Based on the results of the small, intermediate, and field-scale studies, with their attendant limitations, Hakonson (1986) concludes the following:

- The gravel/cobble intrusion barrier, although not 100% effective, did reduce uptake of a cesium tracer by plants by factors of about 3 to 8 over the conventional soil/tuff design at several different scales under suboptimum design configurations and extreme moisture inputs.
- Qualitative observations indicate that the gravel/cobble barrier design prevents burrowing through the trench cap by pocket gophers, although the long-term impact of such activities on soil movement into the gravel and on soil bulk density as it influences percolation is unknown.
- Percolation of water through a soil/rock design may be greater than for a soil/tuff design under upper extreme moisture additions or when topsoil depths are suboptimal for storage of infiltration (MDA-G).
- Under field-scale conditions and natural precipitation at Los Alamos, the soil/rock design appears to impede percolation with a corresponding reduction in the moisture content of backfill under the trench cap.
- Snowmelt, rather than rainfall, places more stress on the cap relative to percolation.

The Integrated Test Plot study was also performed at the Los Alamos EETF to determine water balance relationships on two landfill cover designs, one of which contained a gravel/cobble biointrusion barrier (Nyhan et al., 1990). This data set yielded similar conclusions to those of Hakonson (1986) relative to the biointrusion of the gravel/cobble layer.

(b) Biointrusion Control Recommendations

In terms of the overall waste management approach to biointrusion, we refer to the risk analysis performed as low as reasonably achievable (ALARA) subsection of the MDA-G PA (Hollis et al., 1997):

> "Any of several options that would decrease the potential for biotic intrusion into disposal units at MDA G would substantially reduce the collective air-pathway doses in both Cañada del Buey and in White Rock. Among these options are a thicker cover and active maintenance of the site to eliminate the potential for biotic intrusion. The passive solution is attractive for several reasons. The estimated cost for 250,000 m 3 of crushed tuff (40 acres, 1 m thick) is $1,500,000. This cost would be augmented by the cost to prepare the existing covers, to emplace the new covers, to recontour the surface, and to revegetate the new cover. Even so, it may be ALARA to emplace an additional 1 m of crushed tuff over the closed disposal units. However, before such a decision is made, it is prudent to evaluate the results of the sensitivity and uncertainty analysis and to refine the air pathway analysis accordingly.
>
> The results of the sensitivity and uncertainty analysis show that projected air pathway doses are sensitive to the actinide inventory extrapolated for the period 1957 through 1971. That inventory is expected to be grossly overestimated. A more thorough characterization of the pre 1971 inventory is warranted if the results are going to be used as a basis for the closure plan. The air-pathway doses are also sensitive to the extent of biotic intrusion and subsequent translocation. In the biotic translocation model, actinides are extracted by deer mice rather than plants. No material will be excavated by deer mice if their burrows do not penetrate through the cover and into the waste. Assuming a 1 m (3.3 ft) cover and a 2 m (6.6 ft) burrowing depth, contamination will be translocated to the surface. The radionuclide content of the material will not likely be what was modeled, which assumed a homogeneous mix and distribution of all radionuclides contained in a given disposal unit. Certain records for the pre-1971 inventory suggest that much of the more highly contaminated plutonium waste is buried at the bottom of pits, thereby making it unavailable for extraction from the top-most lift. Again, a more careful consideration of the pre-1971 inventory is warranted before any decision is made on the basis of this analysis."

One of the more serious limitations of the biointrusion studies is related to the time dimension. Virtually all of the data from a particular study (lysimeters) span as little as 6 months to a maximum of about 31 months (Area G). On time scales of 100-250 years, as are required for low-level waste isolation, those short-term observations and conclusions on biointrusion barrier performance are subject to several shortcomings, including the possible effects of

- plant succession, and particularly larger growth forms such as trees and shrubs;
- full root development of perennial species that may require several years;
- topsoil interpenetration into the rock barrier material; and
- subsidence of barrier integrity.

Because existing vegetation is destroyed during the construction of a low-level waste site, the final trench cap, upon closeout of the site, usually provides an excellent medium for the establishment of invader plant species because these species are adapted to growth in a highly disturbed soil. Despite vigorous attempts to establish a plant cover, natural seed sources present in the cap soil or seeds arriving from surrounding areas will become established on the site with time. Those plants may eventually dominate the plant cover given the lack of intensive management. For example, in 1983, a mixture of trees, shrubs, forbs, and grasses, none of which had been seeded into the site, covered Area B (which was closed in 1947). Rooting depths of the species growing on MDA-B could vary, based upon a survey of the literature (Foxx et al., 1984), from 5 cm to about 610 cm depending on species and physical characteristics of the site. Of course, our studies have not examined root intrusion by any of the larger growth forms, although alfalfa is typically one of the deepest rooting plants (Foxx et al., 1984), with records of root penetration to 4200 cm. However, many species including alfalfa require several years to develop mature root systems so that observation periods of less than two years are not likely to be adequate to determine long-term barrier performance under field conditions.

Final recommendations on the use of biointrusion barriers at an MDA are based on the answers to two questions relative to the use of soil-gravel/cobble cap designs:

1. Do sufficient supporting data exist to indicate that the soil/rock system reduces biointrusion and, possibly, percolation?
2. What is the optimum configuration for arid site conditions?

The answer to the first question is a qualified "yes" based on short-term data obtained under both intermediate- and field-scale conditions and under extreme and average precipitation regimes. Based on the experiments at MDA-G and in the caissons at EETF, where percolation was encouraged through intentional suboptimal design or enhanced precipitation, uptake of cesium was reduced by a factor of at least 2.5 and by as much as a factor of nearly 10 (Hakonson, 1986).

A cap design incorporating an optimum mix of the physical and biological features described above would also serve to reduce plant root intrusion through the cap by confining water and roots to the cap. Ideally, cap soil depth would be sufficiently large to store all (at a specified probability level) precipitation infiltrating into the cap where it would then be available to complete loss by evapotranspiration.

It is especially important that the cap thickness be governed by the season during which soil moisture storage capacity is most needed. For example, our studies suggest that cap thickness should be based on snowmelt sources of infiltration. However, an optimum cap configuration may not be feasible due to the lack or scarcity of a "best" soil. Likewise, the lack of information on rooting distribution and water-use efficiency of species selected for revegetation limits our ability to select species that exploit the added moisture stored in the thicker cap profile. In either case, inadequate moisture storage capacity or less than optimum evapotranspiration losses of soil water can result in percolation below the root zone into deeper regions of the site. Unfortunately, using deeper-rooted plant species to revegetate the site presents potential problems with biointrusion and transport of waste to the surface of the site.

That, perhaps, is where the soil/rock intrusion barrier design may offer some advantage over the conventional soil cap design for arid sites. A relatively thin layer (60-100cm) of topsoil over at least 100 cm of gravel and cobble not only reduced root intrusion, but also at the same time appeared to retard percolation through the cap. Although many questions remain concerning the long-term field performance of the soil/rock cap design, the experience we have gained through field studies and modeling is encouraging with respect to design for semiarid and arid sites. Although we did not evaluate the soil/rock cap design for humid site conditions, the experiments in the caissons at the EETF, which received large inputs of water approximating humid site conditions, suggest that failure of the soil/rock cap design can lead to greater percolation than would be experienced from a conventional soil cap design. However, topsoil depths of 60 cm used in the caisson experiments were not optimized for storage capacity for the upper extreme precipitation regime used in the experiment.

(2) Erosion pathway

(a) Applications of Erosion Control Technologies

To compute the USLE-predicted average annual soil loss from a particular SLB, the first step is to refer to the tables, charts, and techniques discussed in Nyhan and Lane (1986), and select the values of K, LS, C, and P that apply to the specific conditions at that field site. In evaluating both the K and C factors for the SLB site, the site operator should contact both the soil test laboratory at the local land-grant university and the Natural Resource Conservation Service of the US Department of Agriculture. These two organizations will give the site operator information on local soils, how to collect representative samples of the trench cap soil to a depth of 6 in., and provide soil assays and site evaluations so that the K and C factors can be successfully estimated.

Next the site operator must select a tolerable soil loss. The term "soil loss tolerance" denotes the maximum amount of soil erosion that will permit the SLB trench cap to maintain its integrity over the projected life of the SLB site. This term was originally used to designate the maximum amount of erosion that would permit a high level of crop productivity to be sustained economically and indefinitely (Wischmeier and Smith, 1978). In either case, when erosion is to be limited by a predetermined tolerance, T, the term, A, in the USLE is replaced by T.

The US Environmental Protection Agency (EPA) recommends using a value of 2 tons/acre/year for SLB landfill covers (US EPA, 1989). However, in evaluating the long-term impact of soil erosion on SLB trench caps, these T values may be reasonable, especially since it is necessary to make assumptions about rates of soil formation, most of which have not been proven by research. However, Wight and Lovely (1982) point out that rangeland in arid and semiarid climates are inherently more fragile than eastern croplands, and are characterized as having slow soil formation processes. They also indicated that even small increases in soil losses on rangeland can initiate accelerated soil erosion trends, because soil losses are accompanied by reduced production of protective vegetation.

(b) Erosion Control Recommendations

We recommend adopting the EPA's guideline for waste sites of 2 tons/acre/year, and emplacing a 70% cover of gravel on the landfill cover. However, an erosion control program should be developed for a SLB site by considering two rewritten versions of the USLE, with the term A in the equation replaced by the soil loss tolerance term T:

$$\mathbf{LS = T/RKCP} \qquad \text{(Eq. 2)}$$

$$\mathbf{CP = T/RKLS} \qquad \text{(Eq. 3)}$$

Use of Eq (3) involves selecting various slope steepness and length fractures for the new SLB trench cap. Substituting the SLB site values of the fixed USLE factors in Eq (3) and solving for CP gives the maximum value that the product, CP, may assume under the specified field conditions. With no supporting practices, P = 1, and the most intensive plant cover plant that can be safely used on the field is one for which C just equals this value. When a supporting practice like contouring or stripcropping is added, the computed value of T/RKLS is divided by the practice factor, P, to obtain the maximum permissible cover and management factor value. Terracing increases the value of T/RKLS by decreasing the value L or LS.

Thus, by this procedure a site-operator lists all the alternative plant cover and management combinations that would control erosion at an acceptable level. Study of this list will show how an erosion control program can be improved and increase SLB site performance. In addition, the site operator should set up a program for long-term monitoring of the C factor, once selection of all the USLE factors has been made for the SLB site. This erosion control program should ensure that normal plant succession and soil formation processes allow the site to meet the selected tolerable soil losses from the surface of the trench cap over the lifetime of the site.

In addition, technology exists (Nyhan and Lane, 1984) for determining optimum cap soil configurations by combining physical features of the cap (i.e., soil type, soil thickness, surface slope, and management practice) with plant cover to minimize erosion and percolation. The modeling technology can be used at any site when certain parameters for the site are known (Nyhan and Lane, 1982). Other models besides the CREAMS model used in this study, such as the HELP and HYDRUS, can also be used for these purposes.

(2) Seepage pathway

(a) Approaches to Limit Seepage

Engineered barriers placed in landfill covers usually consist of hydraulic barriers and capillary barriers, but biointrusion barriers can also limit seepage. The standard RCRA cap contains a hydraulic barrier, which is basically a low-permeability bed that retards the flow of water. In contrast, an effective capillary barrier allows infiltrating water to enter it's fine-grained bed (sand or fine sand) but not the underlying coarse-grained bed (gravel), promoting interflow at the interface of these two beds for a limited distance. Our examples of rock biointrusion barriers limiting seepage, in contrast to the hydrology of hydraulic and capillary barriers, really represents more of a layered-soil hydrologic case.

1. Rock Biointrusion Barriers

The ITP study was also performed at the Los Alamos EETF to determine water balance relationships on two landfill cover designs, one of which contained a gravel/cobble biointrusion barrier (Nyhan et al., 1990). A study of four landfill cover designs at MDA-B also involved both determinations of water balance relationships and a gravel/cobble biointrusion barrier (Nyhan et al., 1998). In both of these field studies, the water content in the tuff beneath a landfill cover design containing a rock biointrusion barrier was significantly lower with time compared with the tuff beneath a landfill cover design not containing a biointrusion or engineered barrier. In the ITP study, seepage measurements were also collected to show that there was less seepage in the plots containing the rock biointrusion barrier in the profile than in the plots with no rock barrier; measurements of interflow occurring at the interface between the soil and the gravel were also made in the plots containing the rock biointrusion barrier (Nyhan et al., 1990).

2. Hydraulic Barriers

Only three field studies testing the water balance relationships of hydraulic barriers such as found in the RCRA cap have been performed. The first was a study performed by the Environmental Science Group at Hill Air Force Base in Layton, Utah (Warren et al., 1996). The second study involved the EPA design in the Protective Barrier Landfill Cover Demonstration funded by the ER Project from 1991 through 1998 at TA-51 (Nyhan et al., 1997). The third study involved a RCRA cover tested at Sandia National Laboratories (Dwyer, 1998).

EPA-sponsored studies revealed that a large percentage of landfills utilizing a hydraulic barrier have failed (US EPA, 1988). Similar experiences in northern Germany have lead to designs where a capillary barrier is emplaced beneath a RCRA cap to handle the seepage through the RCRA cap (Melchoir et al., 1990). In fact, our own ER Project studies of natural systems at the Ponderosa site have shown that Ponderosa roots can penetrate a hydraulic barrier in the field resulting in seepage occurring along the roots.

3. Capillary Barriers

Capillary barriers have recently been recognized as an acceptable alternative final landfill cover design (US EPA, 1989), but very few field studies of their performance have been performed. Since 1991 we have been evaluating how two capillary barrier designs function as slope and slope length vary at the Protective Barrier Landfill Cover Demonstration (Nyhan et al., 1997). Field data from this experiment has shown that capillary barrier performance is a function of interactive water balance processes, which are traditionally ignored (Nyhan et al., 1993). Sandia National Laboratories also has evaluated a landfill cover design containing a capillary barrier, referred to as the Anisotropic Barrier (Dwyer, 1998).

Ross (1990) derived an analytical expression to estimate the diversion capacity and maximum effective lengths of capillary barriers, which was later generalized by Steenhuis et al. (1991) and Ross (1991). The maximum effective length (L) is calculated from the saturated hydraulic conductivity (K_s) of the fine-grained upper layer of the capillary barrier, the angle of the slope (ϕ), the steady flux of water entering the fine-grained upper layer of the capillary barrier (q), and the fitting parameter (α) describing the quasi-linear approximation of the slope of the conductivity vs. tension curve as:

$$L < [K_s \tan \phi] / [q\, \alpha] \qquad \text{(Eq. 4)}$$

Using the results of the moisture retention characteristics determined in the laboratory, the parameter α in Equation 4 can be determined by fitting the relative conductivity-soil water tension curve obtained from the RETC analysis (van Genuchten et al., 1991) for the fine-textured layer in a capillary barrier, i.e., for the fine sand layer of the capillary barriers used in the Protective Barrier Landfill Cover plots (Nyhan et al., 1990).

As long as the pressure at the interface between the fine and coarse-textured soils in capillary barriers remains negative, water infiltrating the fine-grained layer will not cross the interface (resulting in seepage) and will be diverted horizontally (resulting in interflow). Thus, when a capillary barrier experiment is performed (Tables 2, 3), measurements of both the amounts of seepage and interflow that occur (Melchior et al., 1990; Wohnlich, 1991; von der Hude, 1991; O'Donnell et al., 1992; Jelinek and Mock, 1993; von der Hude et al., 1993; Warren et al., 1996) yield more direct quantitative information than just measuring changes in either soil water tension or volumetric water content in the soil layers in and around the capillary barrier (Rancon, 1980; Abeele and DePoorter, 1984; Cartwright et al., 1987; Miyazaki, 1988; Nyhan, 1989; Kung, 1990; Khire et al., 1995).

Laboratory studies (Table 2) and field experiments (Table 3) have shown that capillary barriers can effectively divert water infiltrating the soil. However, most of the capillary barrier studies performed in the laboratory, except for the studies of von der Hude (1991) and von der Hude et al. (1993), were confined to slope lengths less than 2 m (Table 2). These laboratory studies were generally performed in a controlled environment, involved experimental designs with single additions of water, and were characterized by a high concentration of hydrologic sensors that collected data at frequent sampling intervals. Although the field studies (Table 3) had slope lengths up to 55 m (Jelinek and Mock, 1993), they were generally conducted with a small concentration of hydrologic sensors that collected data infrequently in an environment characterized by large spatial and temporal variation.

Another important difference between the experiments performed in the laboratory and the field involves the slope of the capillary barriers. Whereas the slope of the capillary barrier is usually a variable in the laboratory studies (Table 2), field experiments have usually been performed at a single, uniform slope (Table 3). The exception to this observation is the test bed at the Am Stempel Landfill (Jelinek and Mock, 1993) that has a compound slope varying from 17 to 29%.

Table 2. Laboratory studies of capillary barriers.

Reference	Description of apparatus	Slope length (m)	Slope (%)	Description of capillary barrier Fine-grained upper layer	Description of capillary barrier Coarse-grained lower layer	Flow measured Interflow	Flow measured Seepage
Miyazaki (1988)	Lab large box: 1.6 m long, 0.2 m wide	1.6	27%	Masa sandy loam (50 cm thick)	Dried, cut plant pieces, 3 cm thick	no	yes
	Lab small box: 0.5 m long, 0.3 m wide	0.5	0.0, 27, and 70%	Masa sandy loam (12 cm thick)	Gravel: 2-5 mm diam, 3 cm thick	no	yes
Wohnlich (1991)	Lab glass tank: 1.19 m long, 0.43 m wide with a height of 0.60 m	1.19	4.3%	Ottawa coarse sand: 0.59- 0.84 mm diam, 30 cm thick	Gravel: 5-25 mm diam, 15 cm thick	yes	yes
			4.3, 6.8 and 8.6%	Mortar sand: 0.1-2.0 mm diam, 30 cm thick	Gravel: 5-25 mm diam, 15 cm thick	yes	yes
			4.3%	Hill AFB sand: 0.1-1.0 mm diam, 30 cm thick	Gravel: 5-25 mm diam, 15 cm thick	yes	yes
von der Hude (1991) and von der Hude and Mock (1993)	Lab test flume: 8.0 m long, 0.2 m wide	8.0	0-58%	Fine sand, 40 cm thick	Coarse sand, 30 cm thick	yes	yes

Table 3. Field studies of capillary barriers.

				Description of capillary barrier		Flow measured	
Reference	Location	Slope length (m)	Slope (%)	Fine-grained upper layer	Coarse-grained lower layer	Interflow	Seepage
Rancon (1980)	Experimental trench at Saint-Paul-lez-Durance, France	1.3	70.0%	Fine sand: <0.2 mm diam, 136 cm thick	Gravel: 1.0-1.5 cm diam, 175 cm thick	no	no
Abeele and DePoorter (1984)	Caisson (3-m-diam, 1 m deep) at Los Alamos, NM	3.0	15%	Silty sand: <2 mm diam, 115 cm thick	Gravel: 1.0-2.5 cm diam, 70 cm thick	no	no
Cartwright et al. (1987)	Four field plots, Sheffield, IL	15	5%	Tiskilwa loam or Peoria loess (silt), 61 or 91 cm thick	Gravel: 5-9 mm diam, 30 or 61 cm thick	no	yes
Nyhan (1989)	Caisson (3-m-diam, 6 m deep) at Los Alamos, NM	2.0	10%	Ottawa coarse sand: 0.59- 0.84 mm diam, 1.4 m thick	Gravel: 1.0-2.5 cm diam, 70 cm thick	no	yes
Kung (1990)	Potato field plot in Central Sand Area of Wisconsin	3.6	Unknown	Interbedded glacial outwash deposits	Interbedded glacial outwash deposits	no	no
Melchior et al. (1990)	Georgswerder landfill, Hamburg, Germany (S3 design)	50	20%	Fine sand, 60 cm thick	Coarse sand and fine gravel, 25 cm thick	yes	yes
O'Donnell et al. (1992)	Lysimeter with conductive layer design, Beltsville, MD	21	20%	Medium sand: 0.21-0.30 mm diam, 46 cm thick	Gravel: 1.9 cm diam, 10-15 cm thick	yes	yes
Jelinek and Mock (1993)	Am Stempel landfill test plot, Marburg, Germany	55 m	17 to 29%	Fine sand, 40 cm thick	Coarse sand, 30 cm thick	yes	yes
Khire et al. (1995)	Landfill with capillary barrier plot at East Wenatchee, WA	18	38%	Clayey silt topsoil, 15 cm thick	Sand: 0.1-1.0 mm diam, 75 cm thick	no	yes
Warren et al. (1996)	Field plots in Ogden, UT	10	4.0%	Sandy loam, 150 cm thick	Gravel: <1.0 cm diam, 30 cm thick	yes	yes

In the 7 years of our field study at the Protective Barrier Landfill Cover Demonstration, a 4-year and 10-year event occurred in terms of precipitation inputs to stress the landfill covers (Nyhan et al., 1990). When using a capillary barrier as the engineered barrier, our field studies show that the topsoil used above the engineered barrier does make a difference. A loam topsoil with a saturated conductivity of 1.2×10^{-2} cm/s allowed precipitation to be added too quickly to the capillary barrier, resulting in multiple barrier failures (seepage production) along the slope length, especially when the landfill design (Loam Capillary Barrier Design) had a slope of only 5%. If the topsoil consisted of a finer-textured soil, such as a clay loam with a saturated conductivity of 2.5×10^{-4} cm/s, then capillary barrier failures in the landfill design were limited to slope lengths of 7.68-9.70 m and only on plots with a slope of 5%.

(b) Seepage Control Recommendations

We have recently discovered that a gravel layer beneath a landfill cover consisting of topsoil underlain by crushed tuff can perform two very important hydrologic functions. The gravel layer, which is an effective biointrusion barrier, can effectively slow down the downward transport of water in this profile (see subsection 1 in subsection F3a above), allowing more water to be available for deep evaporation in soil profiles containing topsoil and crushed tuff. In addition, soil water infiltrating this cover from snowmelt collects in the crushed tuff above the gravel, and is transported horizontally in interflow above the gravel layer. Between the enhanced evaporation and the interflow that is produced, only a small amount of seepage occurs through this design.

When the topsoil used in a capillary barrier design consists of a clay loam, the capillary barrier can perform satisfactorily to eliminate seepage from occurring (Nyhan et al., 1993, 1997). However, the slope of the capillary barrier needs to be 10% or larger for this to happen effectively; seepage does occur at the bottom of a 10-m long plot when the slope is only 5%.

(4) Summary of Recommendations for Landfill Cover Designs

Although most of the recommendations from each of the risk pathway subsections listed above in this section can simply be summarized here, some of the recommendations end up being competing recommendations. This is not surprising upon consideration of the water balance equation (Equation 5), and simple hydrologic relationships. Table 4 represents an attempt to analyze a few of these 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

Table 4. 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

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.

G. Designs for Landfill Covers

(1) Overview of Landfill Cover Designs

We are proposing that two alternative landfill covers be used for an MDA depending on the hydrologic conditions and contaminant source term at the MDA, in light of the preceding consideration of the risk pathways and their associated management. The Crushed Tuff-Biointrusion Landfill Cover (Figure 5) is proposed for use for MDAs at dry sites with pre-existing slopes of about 5% and with low human and ecological risk, 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 6) is proposed for MDAs at sites that are wetter than the previous sites and/or that have higher potential human and ecological risk, where the relative importance of risks is: biointrusion ≥ seepage/interflow > erosion. An example of a site where this landfill cover could be used might be at an MDA closer to the Jemez Mountains that might receive larger amounts of precipitation than MDAs located on the eastern portions of the Laboratory.

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. We just performed a study for the ER Project where the water balance performance of the Crushed Tuff-Biointrusion Landfill Cover was summarized for the time period between 1991 through 1997 (Breshears, 1999).

(2) Specific Landfill Cover Design Details

Information is presented on the materials needed for the landfill covers, the procedures for compacting the soil layers of the cover, the structures to control run-on, runoff, and interflow, and the post-closure monitoring systems to be installed.

(a) Materials Needed for Landfill Covers

Figures 1 and 2 show the arrangement and depths of the various soils to be used in the

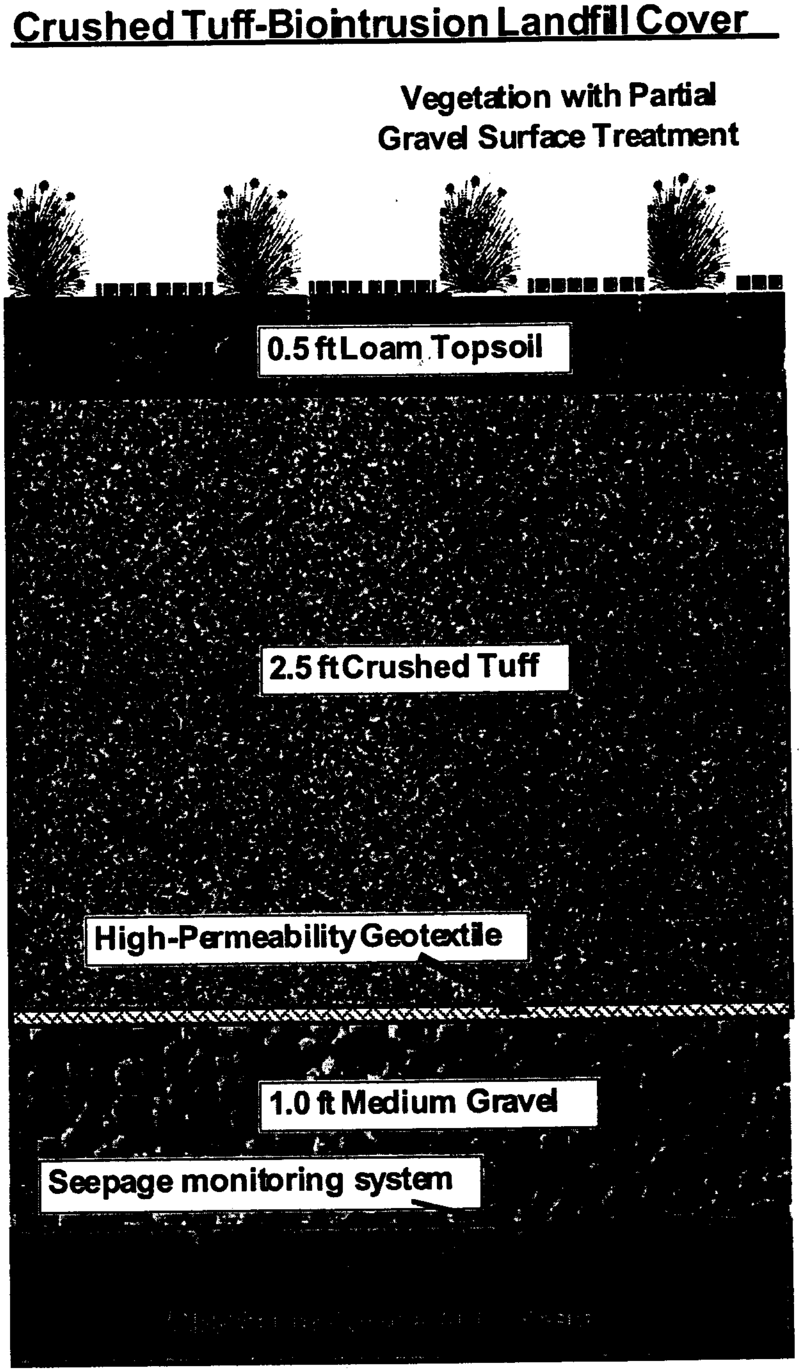


Figure 5. Crushed Tuff-Biointrusion Landfill Cover (5% slope).

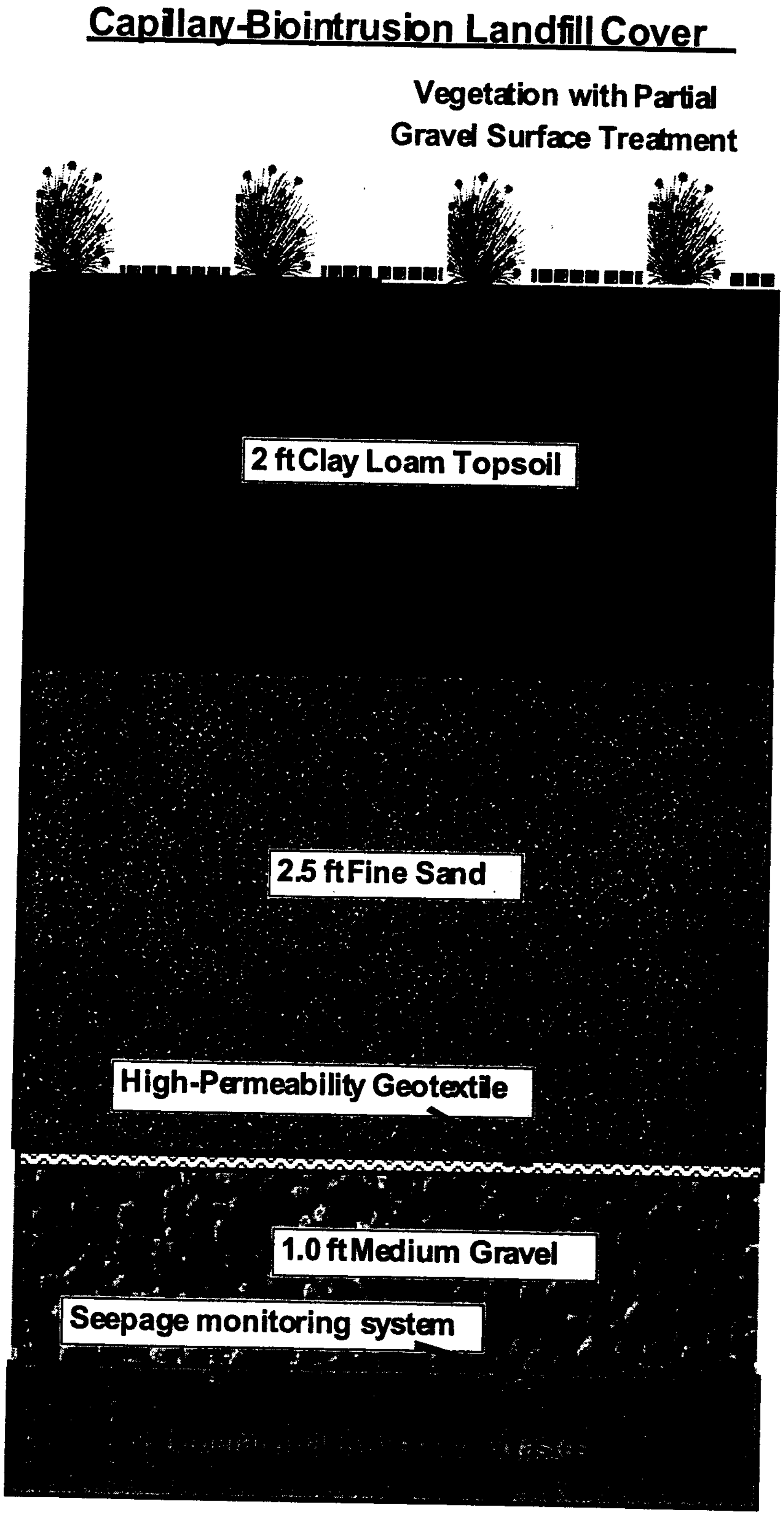


Figure 6. Capillary-Biointrusion Landfill Cover (10% slope).

two landfill covers. We are assuming that the slopes of the soil layers in these two designs are parallel and that these two designs will be installed with 5% and 10% slopes for the Crushed Tuff-Biointrusion Landfill Cover (Figure 5) and the Capillary-Biointrusion Landfill Cover (Figure 6), respectively. More site-specific engineered designs will deal with slope and other topographic features at a later date.

Descriptions of all of the materials to be purchased follows, described from the top of the final cover to the bottom, but not including the components of the post-closure monitoring system, which are described in the following section.

Some of the soil materials can be obtained locally, such as the tuff and the clay loam topsoil, which might be stockpiled at a few MDAs; some of the current waste site operators have taken our recommendation to scrap the topsoil off of the site when initially installing a landfill. However, the rest of the materials cannot be obtained locally for two reasons: (a) materials with acceptable specifications are not available in any of the MDAs or borrow areas around the county, and (b) they cannot be transported from one area to another within the Laboratory, because of the potential for spreading contamination around the Laboratory. Thus, if acceptable soil materials could be found within a Laboratory area, expensive characterization of these backfill materials would have to be performed to prove they were not contaminated, which would not be time or cost-effective.

Material required:

(1) Vegetation with partial gravel surface treatment

The vegetative treatment will consist of applying a mixture of grasses (native to the elevation of the specific MDA) to the topsoil. We will then apply a 70% surface cover of medium gravel (8.0- to 25-mm diam) to control soil water erosion until the vegetative stand gets established.

(2) Loam topsoil

The loam topsoil consists of a 2:1:1 (V:V:V) mixture of topsoil (either a loam or a clay loam), sand, and aged sawdust (<9.5-mm diam), as can be commonly purchased in bulk at several local landscaping firms.

(3) Crushed tuff

The tuff is obtained from JCI, who mine it south of the truck route near TA-53, crush it with heavy equipment, and then bring it to their asphalt batch plant (recently-cleaned). When the crushed tuff is sent through the plant it is both screened (0.125-inch diameter) and dried, and water is added to the tuff before it is delivered to the site as a material at known water content for optimum compaction.

(4) High-permeability geotextile

A high conductivity MIRAFI geotextile is used to keep fine particles out of the underlying soil or gravel layer, and to maintain a sharp interface between soil layers. We have used a 600X brand geotextile with a conductivity of 0.024 m/s obtained from MIRAFI, El Toro, CA for the last 20 years.

(5) Medium gravel

This gravel (8.0- to 25-mm diam) can be obtained at local sand, gravel, and cement plants.

(6) Clay loam topsoil

The clay loam is mapped as the Hackroy clay loam in the soil survey of the county, and is usually screened through a _-inch screen before using.

(7) Fine sand

A sand and gravel company in Albuquerque made the fine sand (0.05-0.425 mm diam) with a sand classifying/blending tank system (Portec Kolberg Division, Yankton, SD).

(8) Operational cover and wastes

This layer corresponds to the current soil surface to be covered.

Table 5 presents the saturated conductivity of each of the soils materials described above for additional materials specifications. We are currently not sure of the exact quality control variances on these saturated conductivity values; this is a subject for further study and needs the input of a good engineering firm with experience in this field. Part of the answer to this question is dependant on the packing densities of these materials in the field, as covered in the next subsection; the reason for this, of course, is that soil compaction and saturated hydraulic conductivity are directly correlated.

(b) Procedures for Compacting Landfill Cover Layers

The top of the operational cover and the new landfill cover should be compacted just as if a Laboratory building were to be built on the surface in terms of compaction. This is done to prevent massive settlement and subsidence of the new landfill cover. All of the soil materials used in each landfill cover design except the medium gravel (Figures 5 and 6) will be compacted in 1-ft-layers, except for the 0.5-ft-thick loam topsoil. Laboratory compaction tests will be performed on the sands using Standard Test Methods for Maximum Index Density of Soils Using a Vibratory Table (ASTM, 1979; Test Method D4253-83) and on the other soils using the Modified Proctor Method (ASTM, 1979; Test Method D1557).

To determine how many Proctor determinations should be performed on each type of soil material emplaced in the cover, we suggest the following procedure be followed. After the first layer of each type of soil material is added to the new cover at the MDA and compacted, a set of

Table 5. Hydrologic data for soils materials.

Soil description	Saturated conductivity (cm/s)
Loam topsoil	5.7×10^{-3}
Hackroy clay loam	2.5×10^{-4}
Fine sand	1.2×10^{-2}
Crushed tuff	8.2×10^{-4}
Medium gravel	2.0

24 Proctor measurements of soil water content and bulk density will be collected over the depth of the newly-placed layer every 6 ft down the length of the layer applied at the MDA. A semivariogram analysis of this data will be performed, which might show, for example, that only 5 Proctor determinations are necessary to characterize the compaction of each layer of the same type of soil. The loam surface layer and the clay loam surface layer will be compacted to averages of 87% (CV = 3.6%) and 92% (CV = 3.3%) of the maximum dry unit weight from standard Proctor compaction, respectively. Average values for the fine sand and crushed tuff will be 96 and 90%, respectively; with acceptable CV's ranging from 1.5 to 2.7%.

H. Designs for Post-closure Monitoring Systems

The designs of the engineered structures and post-closure monitoring systems each specific MDA will have to be tailored according to the needs of each site. For example, an engineering structure to control runoff, run-on, and interflow (the horizontal flow of water within the natural soil or landfill cover) entering and leaving the site may need to be built around the site. This engineered structure must be designed to the size and specific location of each MDA, since each MDA will have a unique area contributing run-on, for example.

Post-closure Monitoring Systems will be installed in and around the new landfill cover and in boreholes located through and beneath the MDAs, if available. We will only address water balance monitoring within the new landfill cover and tuff water monitoring beneath the waste site in this report, and not monitoring for contaminants. In terms of landfill cover monitoring, we are suggesting solving the water balance equation (Equation 5) using an automated data acquisition system, due to the episodic nature of the water balance parameters. We will do this to show that we reduced seepage (S) and diverted and measured interflow (I) and runoff (R) within and on top of the landfill cover, while measuring the change in soil water inventory (ΔS) and precipitation (P), and determining evapotranspiration (ET) by difference, as summarized in Equation 5:

$$\Delta S = P - ET - R - S - I \qquad \text{(Eq. 5)}$$

We suggest that before the new landfill cover is constructed over the current, newly-compacted operational cover, 5-6 seepage collection strips (about 2-ft wide) be laid out over each acre of the current surface (see Figures 5 and 6). These strips will contain HDPE floors and sides, and will function as French drains made to collect water percolating vertically through all of the soil layers in each landfill cover design. This will allow us to say how much water percolates into the underlying wastes at each site, i.e. – the effectiveness of the landfill cover design in diverting infiltrating water.

One of the benefits of several of the pilot studies on landfill covers is that gravel biointrusion barriers were found to promote interflow (Hakonson, 1986; Nyhan et al., 1993, 1997). Thus, interflow will be generated within each cover as a result of water accumulating and being transported horizontally at either the interface of the crushed tuff and the gravel (Crushed Tuff-Biointrusion Landfill Cover) or within the capillary barrier at the bottom of the fine sand layer (Capillary-Biointrusion Landfill Cover). The objective will be to maximize interflow so as to minimize seepage, so we will claim successful diversion of known amounts of water every spring as snowmelt penetrates the landfill cover. This water has to be diverted away from the cover and the MDA anyway, and measurements of interflow can be used to support landfill cover performance standards.

Runoff from the entire site is similar to interflow in that it has to be diverted and carried away from the entire MDA cover, so this also can be measured, as well as precipitation and snowfall at the site. Thus, only changes in soil water content need to be determined to solve the water balance equation, since ET is determined by difference.

Flows of seepage (if there is any), interflow, and runoff will be measured with pressure transducers in temporary holding tanks that will be emplaced below-ground, outside of the landfill area, and in a flow collection system. The pressure transducers will be connected to data loggers that will measure these three flows and automatically empty the holding tanks. Since these data loggers will be automated, we will be able to monitor daily episodic events and solve the water balance equation on a daily basis if necessary. Since these flows will be temporarily stored in holding tanks, we can also sample these flows for contaminants, and in the case of runoff, for sediment concentrations.

The final part of this Post-closure Monitoring System will consist of Time Domain Reflectometry (TDR) waveguide pairs installed in the cover which will be used to determine soil water content to estimate ΔS term of the water balance equation. These will also be connected to a data logger, which will automatically collect soil water content data as frequently as is necessary. We are proposing to install waveguide pairs at 12 sampling locations per acre and emplace one waveguide pair for every foot of depth in the landfill cover at each location (see summary in Table 6). Current studies are in progress to further evaluate more precisely how many sampling locations will be necessary to evaluate this important water balance parameter. However, this sampling location density is much lower than that used on the Protective Barrier Landfill Cover Demonstration plots (4 locations per 100 square ft), and is similar to (1) the sampling densities for neutron probe access tubes proposed by the Environmental Restoration Project at Sandia National Laboratories for their Mixed Waste Landfill and (2) the eight monitoring cells equipped with TDR at mixed waste cell U3ax/bl located in Area 3 of the Nevada Test Site.

In addition to the measurements of volumetric water content collected within the landfill cover (Table 6), we might have an opportunity to measure the water content of tuff beneath an MDA. Exactly how and where these measurements are collected will be dependent upon site characterization data and contaminants present at the MDA. However, if boreholes have been drilled beneath the site, they could either be instrumented with TDR or equipped to receive a neutron moisture probe to monitor soil moisture migration beneath the waste site. If TDR is used in these sampling locations, one TDR every 10 ft beneath the MDA should suffice.

Table 6. Number of soil moisture samples collected for each landfill cover design.

Landfill cover design	Number of sampling locations per acre	Number of depths sampled/sampling location	Total number of soil moisture samples per acre
Crushed Tuff-Biointrusion Cover	12	3	36
Capillary-Biointrusion Cover	12	5	60

I. Summary

After delineating several general assumptions, two alternative landfill covers are proposed for an MDA using an Integrated Risk-Based Approach For Landfill Cover Design. An analysis of previous assessments of risk at LANL and the Performance Assessment and Composite Analysis for MDA-G demonstrated that biointrusion, erosion, and seepage/interflow risk pathways should be of prime importance. Technology developed concerning these three major risk pathways was evaluated using results of studies from the Protective Barrier Landfill Cover Demonstration plots, from other field studies of engineered covers tested at the pilot scale and on actual waste sites, and from natural analog studies in Ponderosa Pine forests and Pinyon-Juniper woodlands. Various options to manage these risk pathways were also evaluated and final recommendations on how to best manage these were made, and were used to support the final two landfill cover designs.

The results of this analysis were that the Crushed Tuff-Biointrusion Landfill Cover will generally be used for MDAs at dry sites and with low human and ecological risk, where the relative importance of risks is: biointrusion > erosion > seepage/interflow. The Capillary-Biointrusion Landfill Cover will be used for MDAs at sites that are wetter than the previous sites and/or that have higher potential human and ecological risk, where the relative importance of risks is: biointrusion ≥ seepage/interflow > erosion. Specific details for the soil materials needed for these two designs are given for cost estimation purposes (current baseline planning for the ER Project), as well as procedures for compacting the landfill cover layers.

Finally, designs for post-closure monitoring of the landfill covers and for tuff water monitoring beneath the MDA are proposed. In terms of landfill cover monitoring, we are suggesting solving the water balance equation using an automated data acquisition system, due to the episodic nature of the water balance parameters. Post-closure monitoring instrumentation and sampling location densities are proposed for the water balance parameters to be measured at each MDA remediated.

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