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Title: Closure Plan for Los Alamos National Laboratory Technical Area 54, Area G

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Submitted to: Los Alamos National Laboratory

Los Alamos NATIONAL LABORATORY

Executive Summary

Area G at Technical Area (TA) 54 has been used for the disposal of radioactive waste generated at the Los Alamos National Laboratory (LANL) since 1957. It is the only active low-level waste (LLW) disposal facility at the Laboratory today, and is expected to remain so for the foreseeable future. Consistent with Department of Energy Order 435.1 and DOE M 435.1-1, disposal units at Area G must undergo operational closure when they are filled with waste; final closure of the entire facility must occur at the end of disposal operations. This closure plan documents the activities that will be undertaken to implement operational and final closure at Area G and complies with DOE guidance on the format and content of LLW disposal facility closure plans.

Disposal Facility Characteristics

Area G is located within TA-54, which lies in the east-central portion of the Laboratory. Annual precipitation averages 34 cm (13 in.) at the site; almost all of the moisture gained through precipitation is lost as a result of evaporation and transpiration. The regional aquifer lies approximately 260 m (850 ft) below the ground surface and rates of recharge are low. The terrain and vegetation characteristics in the vicinity of Area G result in complex patterns of atmospheric transport and dispersion. The canyon and mesa terrain characteristic of the Laboratory provides a variety of habitats for plants and animals.

Waste disposal operations began at Area G in 1957 with the disposal of nonroutine waste; the disposal of routine waste started in 1959 and has continued to the present. The majority of the waste is buried in large rectangular pits; waste is also disposed of in 0.3 to 6 m (1 to 20 ft) diameter shafts. Disposal units are set back at least 15 m (50 ft) from the nearest canyon rim and dug to within 3 m (10 ft) of the adjacent canyon floor. Historically, LLW was placed in lifts in the disposal pits, alternated with lifts of clean crushed tuff, and compacted using heavy equipment. Current operational procedures require that waste, with the exception of bulk soils and debris, be packaged prior to placement in the pits. Bulk materials are placed directly in the disposal units, and may be used to fill void spaces within and between waste containers. Waste is lowered into the shafts from above, using remote-handled procedures as necessary.

Waste disposal operations are assumed to continue until 2044, after which the facility will undergo final closure over a 2-year period. An active institutional control period of 100 years, extending from 2047 through 2146, will follow final closure of the facility. Passive institutional control will begin in 2147 and will continue until the disposal facility no longer poses a significant risk to human health and safety and the environment.

Operational Closure

Operational closure of the Area G disposal pits and shafts is conducted when disposal units are filled. Lifts of crushed tuff are placed to fill each pit from the top of the waste to the ground surface; successive lifts are consolidated in place using standard earthmoving equipment. The operational cover is contoured to conform to the surrounding grade. If the surface of the disposal pit is not needed for temporary waste management operations, crushed tuff is also used as surcharge material over the operational cover. The surcharge is consolidated using standard earthmoving equipment, seeded, and left in place until final closure. The surcharge is not applied if the surface of the filled pit will be used for the construction of temporary surface structures that are needed for waste management operations.

Crushed tuff is used to fill each shaft from the top of the waste to the ground surface and the operational cover is contoured to conform to the surrounding grade. Crushed tuff surcharge material is applied over the operational cover and is left in place until final closure, unless the area is needed for the construction of temporary surface structures.

Benchmarks are placed at all corners of the closed pits and adjacent to each shaft to mark closed disposal units; these benchmarks are linked with the disposal and engineering records to facilitate any material recovery that may be required at a later date. Easily identifiable fiberglass stakes displaying pit and shaft information are placed next to each disposal unit. Site operators monitor and maintain the operational covers to ensure cover integrity.

The operational covers are designed to isolate the waste from those portions of the environment accessible to human receptors, thereby minimizing exposures received by the general public and on-site personnel, and promoting stability of the closed disposal units. The operational covers are less robust than the final cover design and, therefore, less resistant to the impacts of biotic intrusion and surface erosion. Routine maintenance of the covers is expected to compensate for this.

The schedule for operational closure depends upon the rate at which waste requiring disposal at Area G is generated, the types of waste sent for burial, and the capacities of the disposal pits and shafts receiving the material. The majority of the waste sent to Area G is placed in pits, which have large disposal capacities. Most pits are filled within 2 to 4 years, although some have remained active for longer periods of time. Lesser quantities of waste are disposed of in shafts, which have much smaller capacities. Historically, shafts remained active for 4 years or less; more recently, shafts have remained active for longer periods of time.

Final Closure

The objective of final closure is to achieve long-term stability of the waste in a manner that protects human health and safety and the environment, and minimizes the need for active maintenance. Satisfactory long-term performance of the closed facility will depend largely on the final cover placed over the disposal units. The proposed final cover design for Area G was developed using an iterative approach in which successive cover designs underwent long-term erosion analyses using the SIBERIA computer code. The result is an optimized design that is expected to be capable of meeting performance criteria under a range of potential site conditions that could occur over the 1,000-year compliance period.

The first step of the final cover design process was to identify the minimum amount of cover required to safely isolate the waste throughout the 1,000-year compliance period. Using this as the final target thickness, the performance of the initial and each subsequent conceptual design was evaluated for a period of 1,000 years using the SIBERIA erosion model. Each successive cover design was evaluated to determine its ability to satisfy the minimum cover requirements and to identify areas where projected erosion impacts appeared to be severe. The analyses generally indicated that the cover over much of the site performed adequately; however, some elevated rates of erosion were observed in localized areas along mesa edges or adjacent to drainages. These vulnerable locations were fortified using engineered features such as rock armor and the design evaluation process was repeated until a satisfactory design was identified.

The portion of Area G that is currently receiving waste is referred to as Material Disposal Area (MDA) G; MDA G is scheduled to undergo final closure by 2015. Disposal operations will then move into an area west of MDA G known as the Zone 4 expansion area. Current expectations are that the disposal of waste in Zone 4 pits will start in 2011waste; the disposal of waste in Zone 4 shafts is expected to start in 2016. It is assumed that the expansion area will receive waste until the year 2044, at which time this portion of the site will undergo final closure. Final closure of the expansion area is assumed to require 2 years to complete once the last disposal unit has undergone operational closure.

The final cover design presented in this plan was evaluated in Revision 4 of the Area G performance assessment and composite analysis. These analyses indicate that the disposal facility is capable of satisfying all DOE Order 435.1 performance objectives. The application of a minimum of 2.5 m (8.2 ft) of cover over the disposal units effectively will limit the degree to which plants and animals inhabiting the closed site can penetrate into the buried waste. This will result in small amounts of contamination deposited on the surface of the facility and low subsequent exposures for persons living downwind of Area G or in the canyons adjacent to the facility. The thickness and the engineered aspects of the final cover (e.g., rock armor around the edge of the facility) will mitigate the effects of surface erosion in a manner that will limit the impacts of biotic intrusion throughout the 1,000-year compliance period; these same features will limit the degree to which inadvertent human intrusion disrupts the waste and, therefore, the exposures received by an intruder. The hydraulic properties of the cover will limit the amount of water that percolates through the waste, thereby minimizing exposures received by persons living downgradient of the disposal facility.

Table of Contents

Table of Contents (Continued)

List of Figures

List of Tables

Acronyms and Abbreviations

ALARA	As low as reasonably achievable
CAP	Corrective Actions Project
CFR	Code of Federal Regulations
D&D	Decontamination and decommissioning
DOE	Department of Energy
DQO	Data quality objectives
EPA	U.S. Environmental Protection Agency
ER	Environmental restoration
Laboratory	Los Alamos National Laboratory
LANL	Los Alamos National Laboratory
LLW	Low-level (radioactive) waste
Ma	Million years ago
MDA	Material Disposal Area
MLLW	Mixed low-level waste
msl	Mean sea level
MTRU	Mixed transuranic
NMED	New Mexico Environment Department
RCRA	Resource Conservation and Recovery Act
TA	Technical Area
TRU	Transuranic
TSCA	Toxic Substances Control Act
USGS	U.S. Geological Survey
WAC	Waste acceptance criteria
WDP	Waste Disposition Project
WIPP	Waste Isolation Pilot Plant

1.0 Introduction

Area G at Technical Area (TA) 54 has been used for the disposal of radioactive waste generated at the Los Alamos National Laboratory (LANL, the Laboratory) since 1957. The facility is the only active low-level waste (LLW) disposal facility at the Laboratory today, and is expected to remain so for the foreseeable future. Consistent with Department of Energy (DOE) Order 435.1 (DOE, 2001a) and DOE M 435.1-1 (DOE, 2001b), disposal units at Area G must undergo operational closure when they are filled with waste; final closure of the entire facility must occur at the end of disposal operations. This closure plan documents the activities that will be undertaken to implement operational and final closure of Area G. It complies with guidance on the format and content of LLW disposal facility closure plans issued by the DOE (DOE, 2001c).

This section summarizes the information and activities associated with the closure of Area G. Section 1.1 describes the disposal facility, discusses the types of waste that have been or will be disposed of at Area G, and summarizes land use patterns in the vicinity. The general approach used to conduct the operational and final closure of disposal units is discussed in Section 1.2. Section 1.3 provides the anticipated schedule of closure activities, while Section 1.4 discusses other Laboratory activities and programs related to facility closure. Key assumptions upon which the closure plan for Area G is based are provided in Section 1.5.

1.1 General Facility Description

Los Alamos National Laboratory is located in northwestern New Mexico, about 45 km (28 mi) northwest of the state capitol of Santa Fe, and about 100 km (60 mi) north-northeast of Albuquerque, the state's largest city. The Laboratory owns and occupies some 111 km^2 (43 mi^2) of land. Area G is located within TA-54, which lies in the east-central portion of the Laboratory (Figure 1-1). It is situated on Mesita del Büey, an east-west trending mesa bounded by Pajarito Canyon to the south and Cañada del Buey to the north. The north and east borders of TA-54 coincide with the LANL property boundary, while the west and south borders lie within Laboratory lands.

Area G was selected for the disposal of radioactive waste generated at LANL on the basis of recommendations made by the U.S. Geological Survey (USGS) in the mid-1950s (Rogers, 1977). The portion of the facility within which waste is currently being disposed of is referred to as Material Disposal Area (MDA) G. Disposal operations began in MDA G in 1957 with the placement of nonroutine waste in the first pit excavated at the facility; the disposal of routine waste started in 1959 and has continued to the present. To date, disposal operations at the facility have used approximately 26 ha (65 ac) of the 40-ha (100-ac) site. Current plans call for the expansion of disposal operations to an area west of MDA G, referred to as the Zone 4 expansion area (Figure 1-2). It is assumed that all disposal operations at Area G will cease in the year 2044.

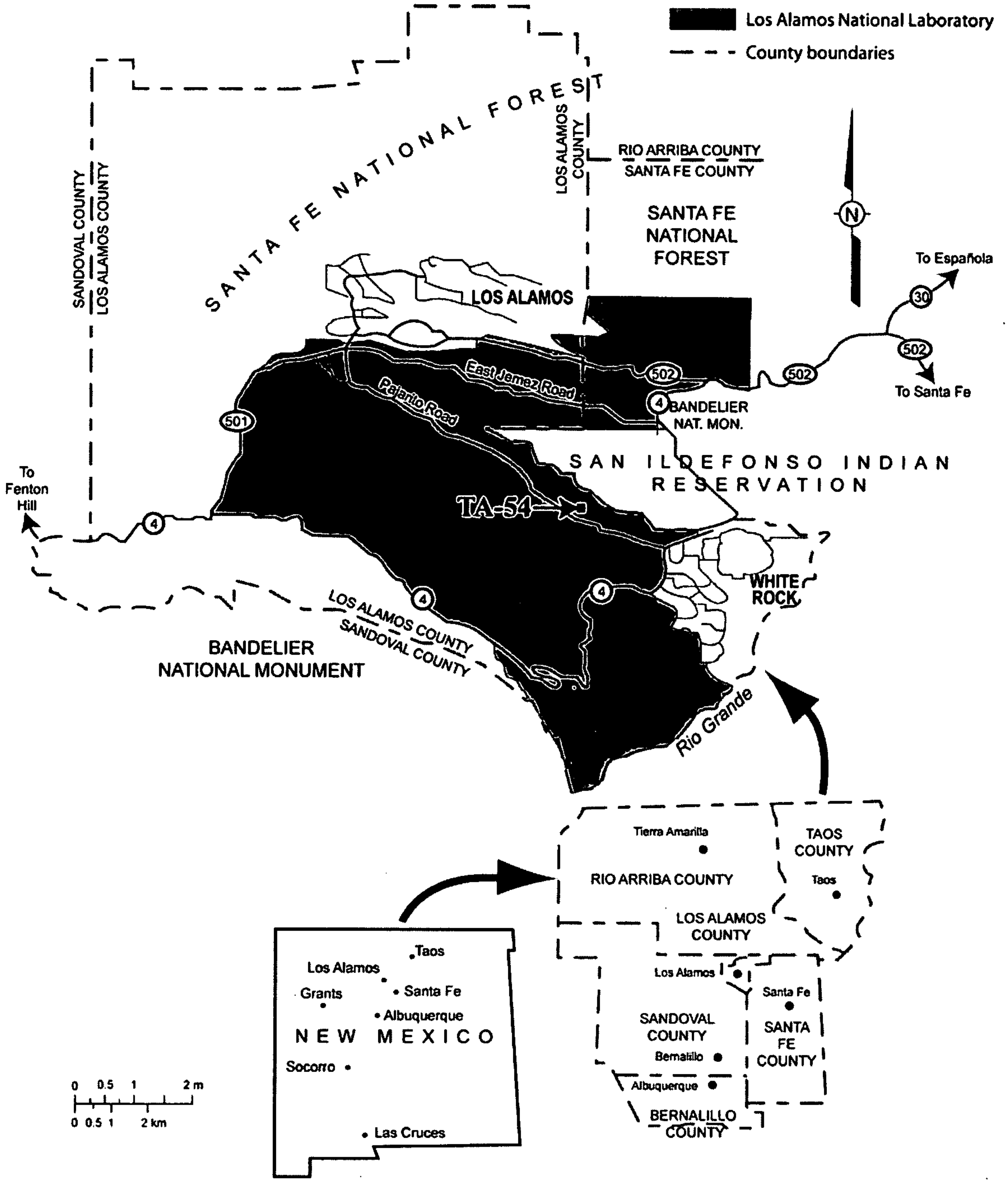


Figure 1-1
Location of TA-54 and Area G

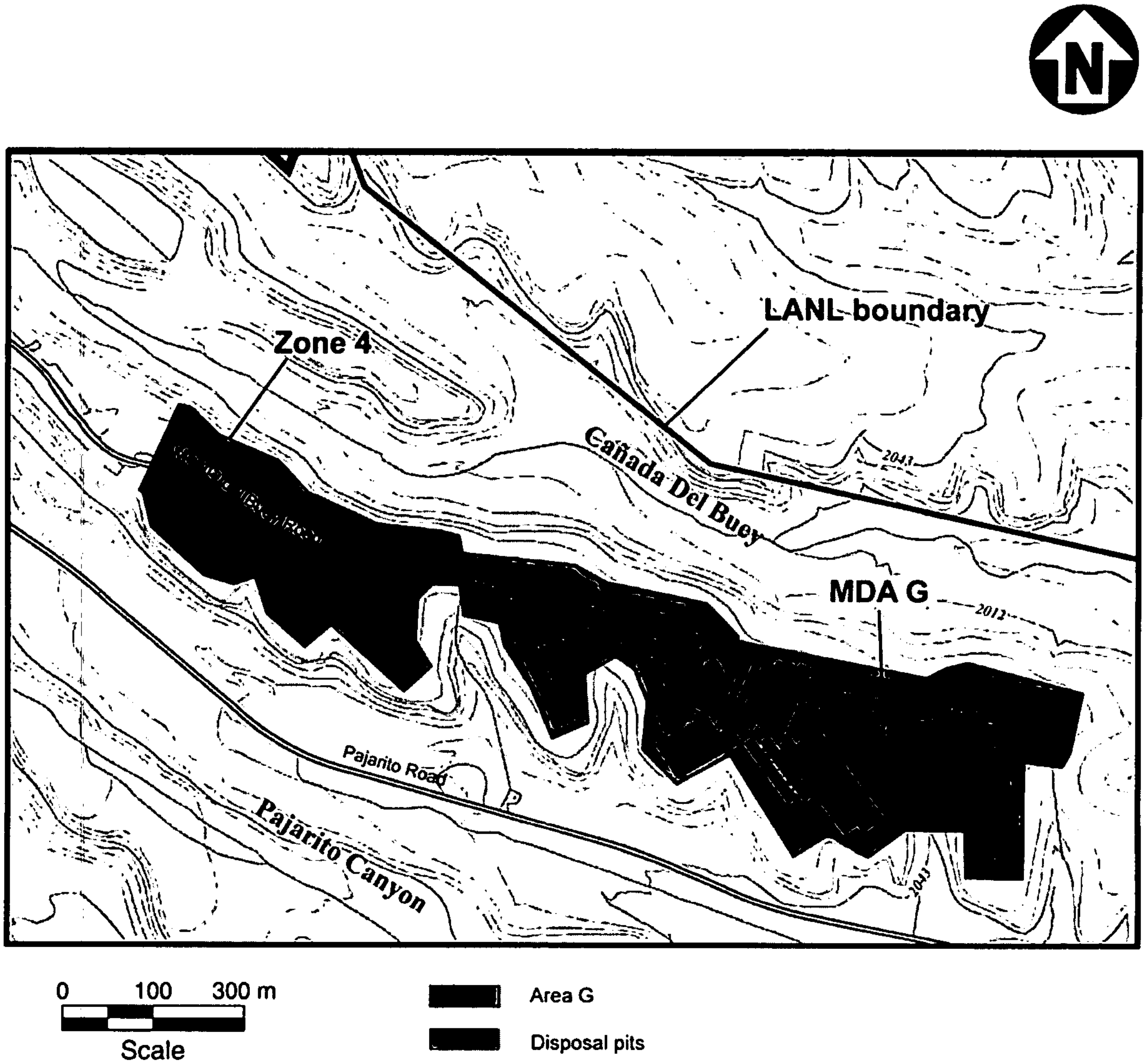


Figure 1-2
MDA G and the Zone 4 Expansion Area

Waste has been disposed of at Area G in a series of large, generally rectangular pits and circular shafts. The first units developed at the site were pits; these units have continued to receive most of the waste (on a volume basis) disposed of at the facility. Disposal pits are set back at least 15 m (50 ft) from the nearest canyon rim and are dug to within 3 m (10 ft) of the adjacent canyon floor. This has resulted in pits with a maximum depth of about 20 m (65 ft). Prior to the mid-1990s, the waste disposed of in pits was typically placed in lifts; each layer of waste was covered with uncontaminated crushed tuff and compacted by driving heavy equipment over the crushed tuff. Exceptions to this approach occurred primarily when it was thought that the waste might be retrieved at a later date. Current operational procedures require that all waste other than bulk soils and debris be packaged prior to disposal. Bulk materials are placed directly in the disposal pits, and may be used to fill void spaces between and within waste containers.

First used for disposal in 1966, shafts are designated for waste with high external radiation levels and other unique waste streams. The disposal shafts are also set back at least 15 m (50 ft) from the nearest canyon rim and are dug no deeper than 3 m (10 ft) above the adjacent canyon floor. The shafts are drilled using augers and generally range from 0.3 to 6 m (1 to 20 ft) in diameter. Waste packages are lowered into the shafts and stacked on top of one another; crushed tuff may be added as backfill around and between the waste packages to minimize void spaces in the units and to reduce external radiation levels. Active shafts are covered with metal lids in between disposals.

A variety of waste types have been disposed of at Area G since operations began. Waste that is considered to be transuranic (TRU) waste under current definitions was routinely disposed of at the facility until the early 1970s. Since that time, the vast majority of the TRU waste generated at LANL has been segregated and retrievably stored for off-site disposal, although small amounts of TRU waste were inadvertently disposed of at Area G between 1971 and 1988. Some of the LLW and TRU waste disposed of at Area G prior to 1986 would meet the current regulatory definition of mixed waste. Since 1986, mixed TRU (MTRU) waste and mixed LLW (MLLW) has been segregated from the LLW. The MTRU waste is stored for off-site disposal, while the MLLW is sent off site for treatment and/or disposal. Although small amounts of MLLW were inadvertently placed in one pit and one shaft between 1986 and 1990, no mixed waste has been disposed of at Area G since 1990. The facility is also authorized for the disposal of low-level Toxic Substances Control Act (TSCA) waste (i.e., asbestos and polychlorinated biphenyls).

As mentioned, several waste management functions are conducted at Area G in addition to LLW disposal. The facility is used for the storage of TRU and MTRU waste destined for disposal at the Waste Isolation Pilot Plant (WIPP). This material has been placed in large aboveground domes and in below-grade retrievable arrays (i.e., pits 9 and 29, trenches A through D, and several shafts). All stored TRU waste will be sent to WIPP prior to final closure of Area G. Mixed LLW generated at the Laboratory is stored at Area G and sent off site for treatment or final disposal.

The types and quantities of waste that have been and are expected to be disposed of at Area G were estimated in 2008 (Shuman, 2008). Separate inventory projections were prepared for the disposal pits and shafts. All told, inventory projections for Area G estimate that approximately 4.0×10^5 m^3 (1.4×10^7 ft^3) of waste with an activity of 3.7×10^6 Ci will be disposed of at the facility by the time operations end in 2044.

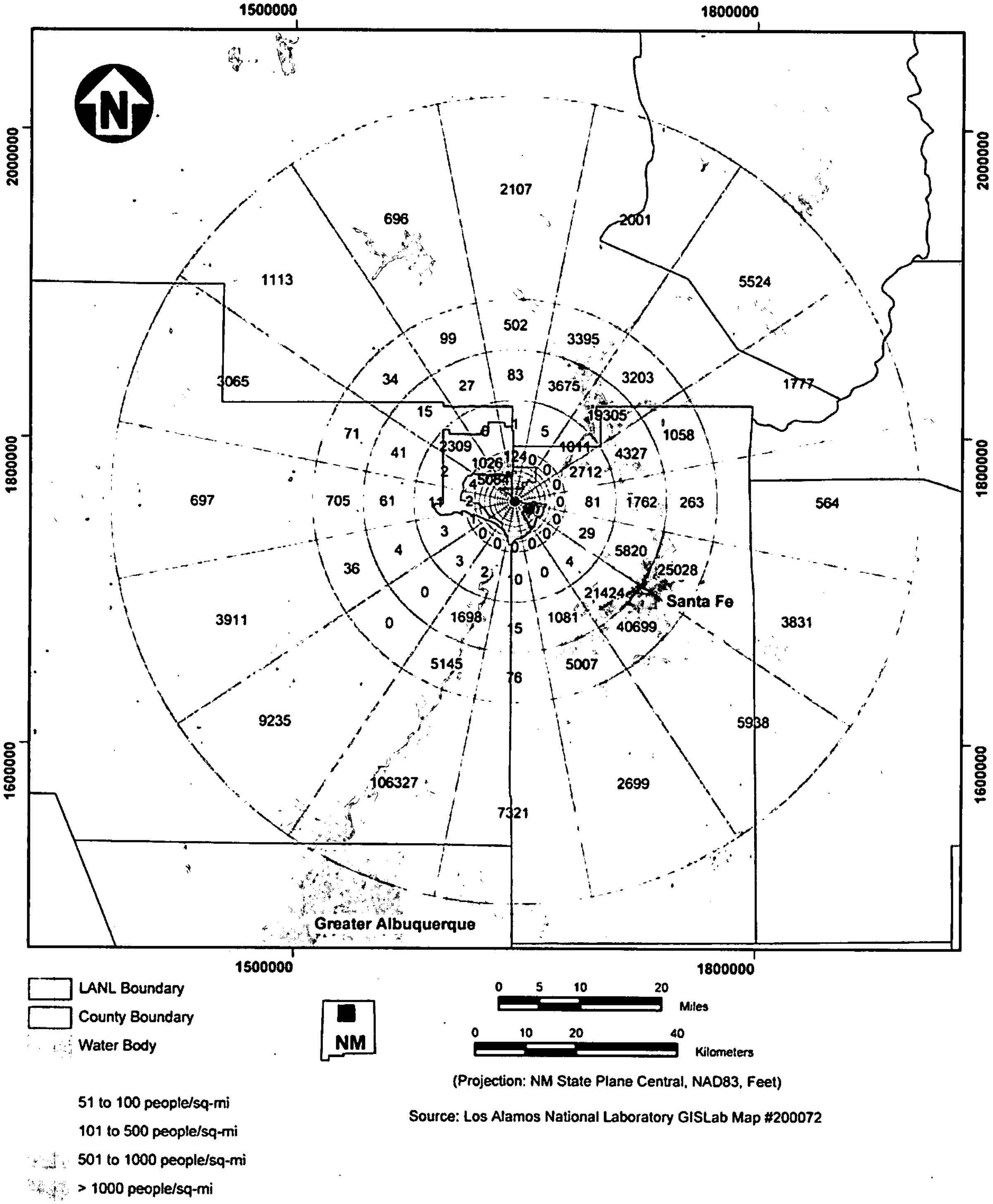
The estimated population of Los Alamos County, the county in which the Laboratory resides, was 18,400 in 2000 (BBER, 2005). Two residential and associated commercial areas exist in the county, Los Alamos with a population of 11,400 and White Rock with a population of 6,800 (LANL, 2003a). White Rock, on the LANL boundary to the east, is approximately 2 km (1.2 mi) east of Area G. Other major residential population centers within an 80-km (50-mi) radius of the Laboratory include Española to the northeast, Santa Fe to the southeast, and portions of greater Albuquerque and Taos. Santa Fe, with a population of about 80,000, is expected to remain the major urban center of the region. Figure 1-3 provides a population data array for the area within 80 km (50 mi) of Area G.

Three federal agencies—the U.S. Forest Service, Bureau of Indian Affairs, and Bureau of Land Management—control the majority of land in the area. The Santa Fe National Forest borders DOE land to the northwest and southeast, while the Bandelier National Monument, managed by the National Park Service, borders the southwest portion of the LANL complex. The San Ildefonso Pueblo owns property that directly borders Area G within Cañada del Buey to the north of the disposal facility (Figure 1-1). In addition to hunting wildlife for food, Pueblo people harvest the fruit of piñon and juniper trees indigenous to the area, grow domestic crops, and graze livestock near the Laboratory.

1.2 General Closure Approach

Operational closure of the pits and shafts used to dispose of waste at Area G is conducted as the disposal units are filled. Historically, the operational cover has consisted of 0.6 to 2 m (2.0 to 6.6 ft) of crushed tuff. Under current operational closure guidelines (LANL, 2008a), crushed tuff is used to fill the pits and shafts from the top of the waste to the ground surface. Surcharge material is placed over operational covers and left in place until final closure unless the area occupied by the disposal units is needed for the construction of temporary surface structures. Until recently, concrete caps were placed over the closed shafts; this is no longer the case.

The 1997 Area G performance assessment and composite analysis (Hollis et al., 1997) evaluated the ability of the disposal facility to safely isolate the waste assuming that only the operational cover was present. Since that time, a more robust final cover design has been developed and is the basis of this closure plan. This cover was developed to address the impacts of surface erosion



Entire Model Rings at .2, .4, .6, .8, 1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, 7, 8, 10, 20, 30, 40, and 80 kilometers.

Note: Populations for grid sectors within first 8 km of Area G not shown because of space; this includes populations for White Rock and some portions of Los Alamos.

Figure 1-3
Population Data Array within 80-kilometer Radius of Area G

and biotic intrusion that may be more severe than originally estimated and to ensure continued protection of human health and the environment in the event that the site is actively maintained for only 100 years after facility closure. Revision 4 of the Area G performance assessment and composite analysis (LANL, 2008b) evaluates the long-term performance of the disposal facility using this final cover configuration.

The closure plan calls for the application of a minimum final cover thickness of 2.5 m (8.2 ft) over all waste disposal units at Area G. A cross section of the conceptual design for the final cover is shown in Figure 1-4. The design relies on the total cover depth as the primary means of mitigating biotic and human intrusion into the waste and the effects of surface erosion. The hydraulic properties of the cover limit the rate of water infiltration through the waste. A complete description of the conceptual design is provided in Section 3 of this report.

1.3 Closure Schedule

Disposal pits and shafts undergo operational closure at Area G as they are filled. Thus, the schedule for operational closure depends upon the rate at which waste requiring disposal at Area G is generated, the types of waste sent for burial, and the capacities of the disposal pits and shafts receiving the material. The majority of the waste sent to Area G is disposed of in pits, which have large disposal capacities. Historically, most pits have been filled within 2 to 4 years, although some of these units have remained active for longer periods of time. Lesser quantities of waste are disposed of in shafts, which have much smaller capacities. Historically, shafts typically remained active for 4 years or less; more recently, shafts have remained open for longer periods of time to provide options for the disposal of various waste types. Three disposal pits were open and receiving waste in early 2008, and a fourth pit may receive waste before it undergoes operational closure; approximately 20 shafts were open and had remaining disposal capacity in early 2008.

The disposal units in MDA G (Figure 1-2) are expected to undergo phased final closure that could begin as early as 2010. Current plans call for all pits and shafts within MDA G to be closed by the year 2015 (DOE, 2002). It is expected that pit disposal operations will shift to the Zone 4 expansion area in 2011 and continue until 2044. Shaft disposal in MDA G is assumed to continue until 2015; after this, shafts in Zone 4 are expected to receive waste until 2044. It is assumed that it will take 2 years from the time of the last disposal shipment until closure of the pits and shafts in the expansion area is complete and the final cover is in place. Based on this assumption, final closure of the site will be complete in 2046.

1.4 Related Activities

The closure of Area G will be linked to several other activities or programs at LANL. These related activities and programs are discussed below.

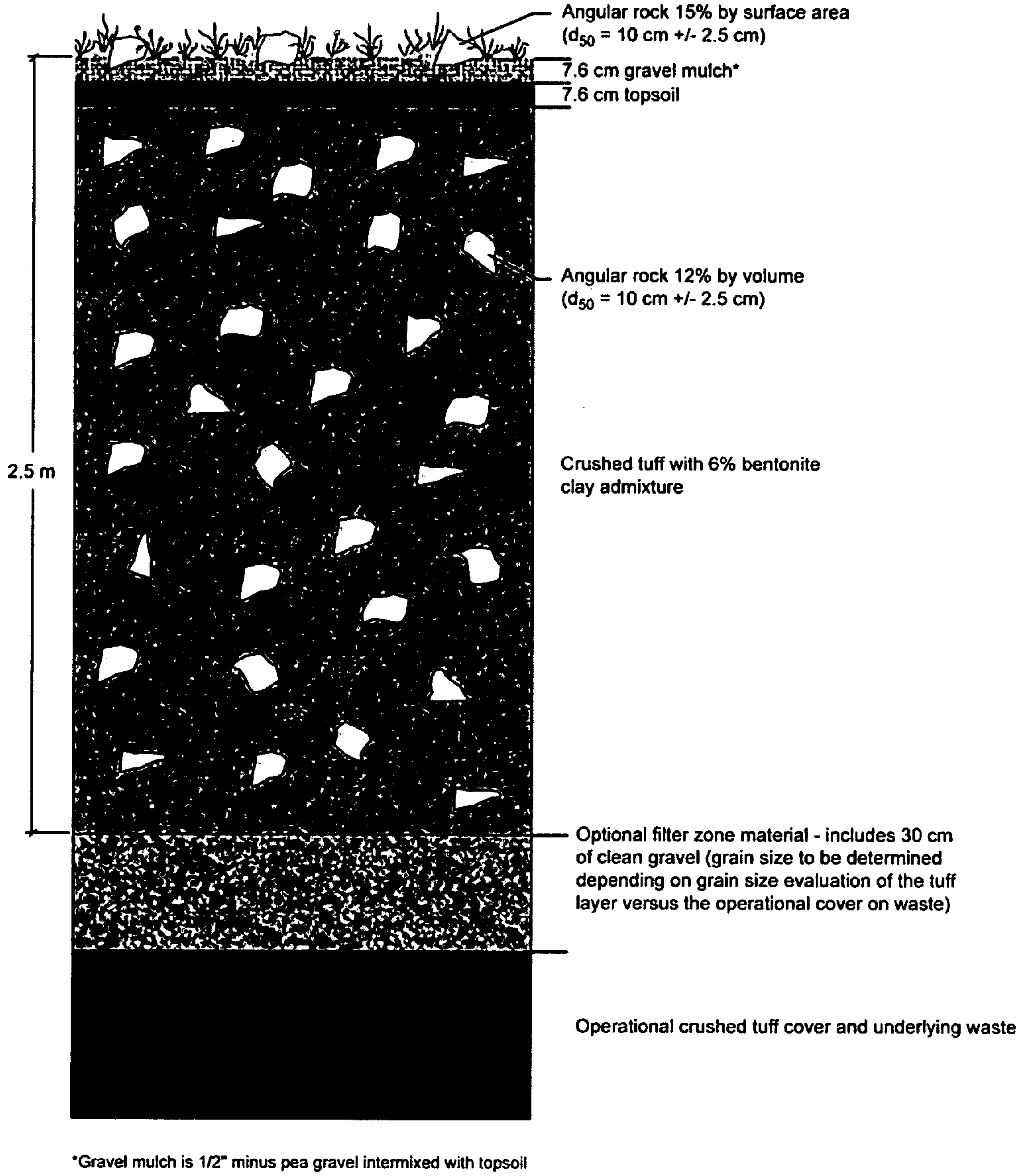


Figure 1-4
Cross Section of the Conceptual Cover for Area G

1.4.1 Environmental Programs Directorate Closure Activities

Operational and final closure of all disposal units at Area G is the responsibility of the Associate Environmental Programs Directorate. Within the directorate, the Waste Disposition Project (WDP) is responsible for day-to-day waste disposal operations, including operational closure of the pits and shafts. The directorate's Corrective Actions Project (CAP) is responsible for final closure of all Resource Conservation and Recovery Act (RCRA, 1976) and non-RCRA regulated disposal units at TA-54 that are operational through the year 2015.

Safe and effective closure of Area G will require a closely coordinated effort by the two divisions within the directorate. Although Revision 4 of the performance assessment and composite analysis (LANL, 2008b) evaluated the final closure configuration described here, the CAP has not conducted the assessments necessary to establish that this closure strategy will, in fact, be implemented. Given this, the closure plan presented here will be reevaluated when the CAP completes its site studies and the overall closure strategy has been identified.

1.4.2 Area G Performance Assessment and Composite Analysis

Revision 4 of the Area G performance assessment and composite analysis (LANL, 2008b) evaluates the long-term performance of the disposal facility and its ability to comply with DOE Order 435.1 performance objectives (DOE, 2001a). The ability of the disposal facility to satisfy the performance objectives depends, in part, on the final closure configuration of Area G. As such, the closure plan and the performance assessment and composite analysis must be mutually responsive. The final closure concept presented in this plan was formally evaluated in the performance assessment and composite analysis. Any changes to the closure concept for Area G will require that the performance assessment and composite analysis be revisited.

1.4.3 Area G Monitoring Program

Routine environmental monitoring is conducted at Area G to determine compliance with appropriate standards and to identify potentially undesirable trends (LANL, 2007a). The data generated by the monitoring program are potentially useful in terms of evaluating the effectiveness of closure measures implemented at the facility. However, operational monitoring results are typically indicative of contaminants released or dispersed during waste management operations rather than of contaminants originating from buried waste. Thus, much of the monitoring data has little bearing on the performance of the operational covers. Monitoring conducted during the active institutional control period is expected to have a direct relationship to facility performance because the buried waste will be the only source of significant contamination present at the site.

The use of monitoring data to evaluate the performance of closure measures requires that the monitoring and closure plans remain mutually consistent. The monitoring program should collect data that will aid in evaluating the effectiveness of the closure configuration. Changes in the closure concept may influence the nature of the information required to conduct these evaluations. Consequently, revisions of the monitoring program plan may need to accompany closure plan updates and revisions.

1.4.4 Site Stewardship

This closure plan specifies a final closure configuration that assumes active DOE institutional control over the closed site for 100 years. This period of control is consistent with DOE M 435.1-1, Chapter IV §P.2.h (DOE, 2001b), which states that institutional controls shall be assumed to be effective in deterring human intrusion into the waste for at least 100 years. Based on this assumption, the final closure configuration presented in this plan is generally expected to be capable of meeting DOE performance objectives. A shorter period of active control may require revaluation of the long-term performance of the disposal facility.

1.5 Summary of Key Assumptions

The closure plan presented in this document is based on several key assumptions about Area G operations. Perhaps most importantly, it assumes that DOE will maintain control over the entire Laboratory throughout the 100-year active institutional control period; a subsequent period of passive institutional control over Area G is assumed to continue until the site no longer poses an unacceptable risk to human health and safety, and the environment. It is assumed that the level of control during the active institutional control period will restrict exposures to members of the public to locations outside of the LANL boundary. Active DOE control will also prevent inadvertent intrusion into the waste, delay the establishment of deep-rooting trees over the disposal units, and limit significant damage to the final cover due to surface erosion. During the passive institutional control period, it is assumed that DOE control will be reduced to preventing long-term occupation of the site by members of the public.

Revision 4 of the Area G performance assessment and composite analysis (LANL, 2008b) formally evaluated the long-term performance of the final cover design presented in this plan. Those analyses assumed that climatic conditions in the vicinity of the disposal facility will not change significantly over time. Furthermore, they assumed no significant subsidence of the disposal units at Area G after the facility undergoes final closure. Changes in either of these assumptions may impact the level of performance projected for the final cover design.

2.0 Disposal Site, Facility, and Waste Characteristics

The long-term performance of Area G will be determined by a variety of site, facility, and waste characteristics. Consequently, these characteristics need to be understood to demonstrate the long-term effectiveness of closure strategies used at the disposal facility. Sections 2.1 and 2.2 summarize important Area G site and facility characteristics, while the characteristics of the waste disposed of at the facility are summarized in Section 2.3.

2.1 Site Characteristics

The characteristics of the disposal site, in combination with the facility characteristics, will determine the rates at which waste radionuclides are released and transported to locations accessible to humans. Physical properties such as the site geology, meteorology, climate, and ecology will play an important role in determining the modes of release and the media through which contaminants are transported. The likelihood of human exposures resulting from radionuclides transported off site will depend, in part, on demographic characteristics and predominant land use patterns in the vicinity of Area G. Important features of the disposal site and surrounding area are described below. The majority of this discussion has been taken from the Revision 4 performance assessment and composite analysis report (LANL, 2008b), which provides additional details about the site.

2.1.1 Geography and Demography

Los Alamos National Laboratory is located in Los Alamos County in north-central New Mexico, about 45 km (28 mi) northwest of the state capitol, Santa Fe, and about 100 km (60 mi) north-northeast of Albuquerque, the state's largest city. The DOE controls some 111 km^2 (43 mi^2) of federally owned land occupied by the Laboratory.

2.1.1.1 Disposal Site Location

Area G is located on Mesita del Buey, a finger-like mesa that extends to the southeast from the broad, east-sloping flank of the Jemez Mountains called the Pajarito Plateau. The site lies entirely within TA-54 in the east-southeast portion of the Laboratory complex (Figure 1-1). The northern and eastern borders of TA-54 are coincident with the LANL property boundary. The community of White Rock, about 2 km (1.2 mi) east of Area G, is the closest population center; other nearby communities include Los Alamos, 8 km (5 mi) to the northwest; Española, 24 km (15 mi) to the northeast; Santa Fe, 34 km (21 mi) to the southeast; and Albuquerque, 97 km (60 mi) to the south-southwest. The Rio Grande, New Mexico's largest river, passes within 10 km (6 mi) of the site, to the east of White Rock.

2.1.1.2 Disposal Site Description

Mesita del Buey is relatively flat and narrow, sloping gently from an altitude of about 2,100 m (6,900 ft) above mean sea level (msl) at its western end to about 2,000 m (6,600 ft) above msl near its eastern end. The mesa has steep sides draining into Cañada del Buey to the north and Pajarito Canyon to the south; the floors of these canyons lie 15 to 30 m (50 to 100 ft) below the surface of the mesa. The northern side of the mesa is more gently sloping than the south faces, which are almost vertical near the rim, becoming more sloped toward the canyon floor. Storm water runoff from Mesita del Buey feeds the streams in both canyons, mostly along the natural drainages evident along the south mesa wall. Pajarito Canyon is a perennial to near-perennial stream, fed by rainfall, snowmelt, and a few springs in the upper reaches of the canyon. Cañada del Buey is much drier than Pajarito Canyon, with a small stream that flows only a few days each year.

The natural drainage pattern is locally disturbed as a result of waste management activities at Area G. Erosion controls are used to divert water away from waste management activities and disposal units. These controls include graded drainage channels, installed culverts, riprap, silt fences, asphalt channels, asphalt curbing, earthen berms, and weirs. Runoff controls are designed to guide surface water into the natural drainages. Certain surface structures at Area G also alter the natural erosion patterns along the mesa, but only on a local scale. Signs of erosion are identified and mitigation measures are taken as a part of the storm water compliance process.

The developed portions of Area G are characterized as grassland, although vegetation is sparse or nonexistent in areas because of ongoing activities. The vegetation within Zone 4, which has remained relatively undisturbed, is typical of the piñon-juniper woodlands found at similar elevations in northern New Mexico.

2.1.1.3 Population Distribution

In 1991, Los Alamos County had an estimated population of 18,200 (EPG, 1994). According to 2002 estimates made by the University of New Mexico Bureau of Business and Economic Research (BBER, 2005), the population of Los Alamos County in 2000 was approximately 18,400 and the projected population for the county in 2030 is approximately 20,700. As described in Section 1.1, the two primary population centers of the county are Los Alamos and White Rock. Several other major population centers exist within an 80-km (50-mi) radius of the Laboratory, bringing the total population within this radius to approximately 270,000.

In 2003, about 12,350 Laboratory and associated contractor employees worked within the Laboratory's geographic boundaries. Approximately 68 of the Laboratory employees worked at TA-54 (LANL, 2003a).

2.1.1.4 Uses of Adjacent Lands

As indicated earlier, the U.S. Forest Service, Bureau of Indian Affairs, and Bureau of Land Management control the majority of land in the area. The Santa Fe National Forest comprises approximately 6.5×10^5 ha (1.6×10^6 ac) of land in several counties. The Española District of the Santa Fe National Forest includes 1.4×10^5 ha (3.5×10^5 ac) that border DOE land to the northwest and southeast. The Bandelier National Monument occupies 1.3×10^4 ha (3.3×10^4 ac) of land and borders the southwest portion of the LANL complex. All access routes to the monument pass through or along Laboratory property.

Thirteen Native American Pueblos are located within 80 km (50 mi) of LANL. Each has 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, approximately 1.1×10^4 ha (2.6×10^4 ac) in size, that directly borders Area G within Cañada del Buey to the north of the disposal facility (Figure 1-1). As discussed in Section 1.1, hunting and gathering activities occur on the land directly adjacent to Mesita del Buey.

Approximately 49 percent of the land in Los Alamos County is vacant. Agriculture in the vicinity of LANL has been declining for the past several decades and is no longer considered an important economic activity in terms of cash income to area residents. Much of the land now occupied by LANL was used historically for grazing. The people of the Pueblos in the region continue to graze livestock on their lands near LANL, and numerous private landowners in rural areas keep small numbers of livestock on land that surrounds Los Alamos County. All cattle are range fed in northern New Mexico; livestock forage primarily on native short-grass species. 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 such as corn, chile, squash, beans, and tomatoes for domestic consumption and some local marketing.

2.1.2 Meteorology and Climatology

The semiarid, temperate mountain climate of Los Alamos County has been extensively monitored and described (Bowen, 1990). Five meteorological towers at LANL collect data on precipitation, temperature, humidity, evapotranspiration, and wind speed and direction. The main Los Alamos gauge was initially installed at TA-59, west of and at a higher elevation than TA-54. In 1990, this gauge was moved to TA-6. Additional gauges have been installed at TA-41, TA-49, TA-53, and TA-54. The TA-54 monitoring station operated within the Area G facility boundary from 1980 through 1994; it is presently located at the eastern tip of Mesita del Buey, between the outer boundary of Area G and the community of White Rock. Table 2-1 summarizes pertinent meteorological data measured from 1993 through 2004 at the TA-54 meteorological tower.

Table 2-1
Summary of 12 Years of Meteorological Data at Area G (1993–2004)

Month	Temperature (°F)		Total Precipitation (cm)	Average Relative Humidity (%)
	Avg. Maximum	Avg. Minimum		
January	43.8	16.2	1.71	60.5
February	47.8	20.1	1.50	56.4
March	56.5	25.7	1.96	49.2
April	63.4	32.0	2.47	42.3
May	75.1	41.1	2.01	35.8
June	84.1	49.1	3.12	34.8
July	86.9	54.5	4.10	46.5
August	83.4	53.4	6.82	55.1
September	77.6	45.6	3.32	50.0
October	65.0	33.8	4.42	52.3
November	51.8	23.3	1.94	57.6
December	43.3	15.4	0.96	60.0

Source: LANL, 2008b, Table 2-1.

2.1.2.1 Precipitation and Evapotranspiration

For the 12-year period shown in Table 2-1, the average precipitation is just over 34 cm (13 in.) per year. About 37 percent of the annual average precipitation falls during July and August, a period referred to as the monsoon season. Snowfall is greatest from December through March, with annual accumulations of about 150 cm (59 in.). Annual variations in precipitation can be quite large. Because of a number of factors including temperature, humidity, and air movement, evaporation is generally high; on an annual basis, the moisture lost through evaporation and transpiration is roughly equivalent to the moisture gained through precipitation. Evapotranspiration is highest in the summer months, when vegetation is lush, temperatures are high, and relative humidity is low.

The average annual precipitation measured over a period of 30 years (1961 through 1990) at the Los Alamos gauge is 46 cm (18 in.), which is considerably higher than the 34 cm (13 in.) average measured in more recent years at TA-54. The 30-year record from the Los Alamos precipitation gauge has been used for predicting annual precipitation in the region, including a 100-year daily rainfall extreme of 6.4 cm (2.5 in.) and a 100-year annual precipitation event for Los Alamos of 84 cm (33 in.) (Nyhan et al., 1989). Daily rainfall extremes of 2.5 cm (1 in.) or more occur in most years.

Additional longer-term insight into local precipitation history is provided by dendroclimatology, which compares modern meteorological records with contemporaneous tree growth (tree rings) (Schulman, 1951). Semiarid climates exhibit a very strong correlation between precipitation and tree-ring width. The best correlations have been found for long-lived coniferous species that survive arid cycles, including ponderosa pine (Abeele and Wheeler, 1981). Although there are no ponderosa pine trees at Mesita del Buey, they are abundant at slightly higher elevations on the Pajarito Plateau, including both locales where the Los Alamos weather gauge has been stationed (TA-59 and TA-6). Dendroclimatology has been used to estimate annual precipitation back to the year 1510. The analysis indicates the following precipitation extremes:

- Maximum annual precipitation events were 100 cm (40 in.), 58 cm (23 in.), and 79 cm (31 in.), occurring in 1597, 1794, and 1919, respectively.
- Minimum annual precipitation events were 14 cm (5.5 in.), 11 cm (4.3 in.), and 6 cm (2.4 in.), occurring in 1523, 1585, and 1685, respectively.

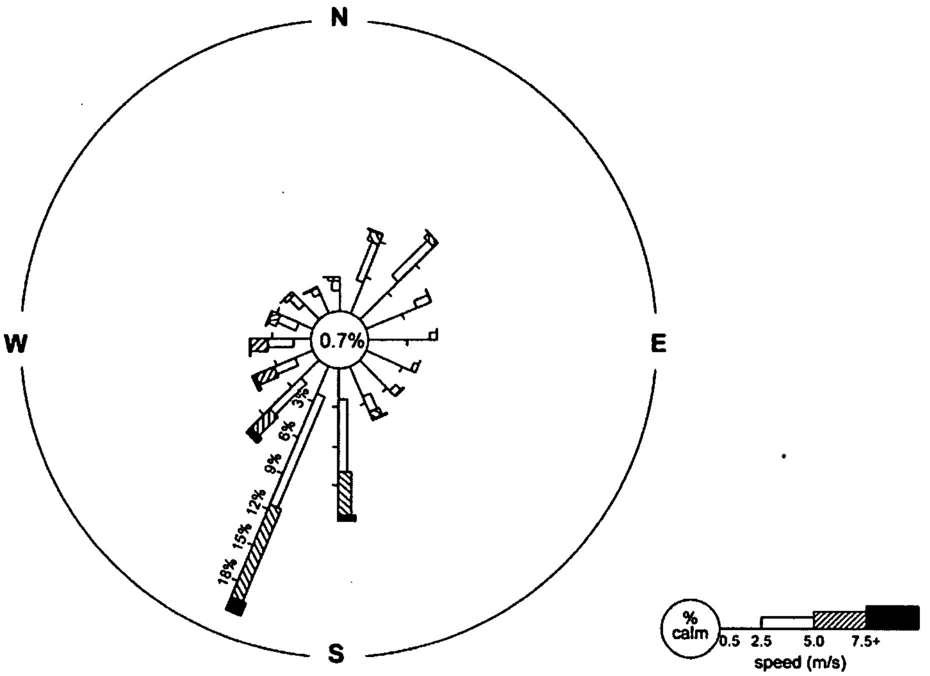
These values compare well with the estimated maximum precipitation based on pluviometric records. Both sets of data suggest a maximum annual precipitation of about 80 cm (31 in.) every century. These precipitation extremes are based on pluviometric and dendroclimatic records at TA-59 and TA-6, where annual precipitation generally exceeds that at TA-54 by about 10 cm (3.9 in.).

2.1.2.2 Wind Speed and Direction

Wind patterns across the Pajarito Plateau are greatly influenced by the mesa-canyon topography of the area. In general, surface winds at Los Alamos are light, with an average speed of nearly 3 m/s (7 mph). On days with sunshine and light large-scale winds, a deep, thermally driven, upslope wind develops over the Pajarito Plateau. Winds reverse at night, and a shallow, cold-air drainage wind often forms and flows down the plateau on clear nights with large-scale, light wind speeds of approximately 3 to 4 m/s (6 to 8 mph). Upslope and drainage winds are generally less than 2.5 m/s (5.5 mph); however, gusts exceeding 22 m/s (50 mph) are quite common in the spring. Wind speeds are greatest from March through June and weakest in December and January.

Wind speed and direction vary with site, height above ground, and time of day. Mean wind speed and direction frequencies have been calculated for day and night at Mesita del Buey and Pajarito Canyon. The frequencies are presented as "wind roses," which show the percentage of time that the wind blows from each of 16 compass points and the distribution of wind speed for each of those directions. The wind roses shown in Figures 2-1 and 2-2 represent 2002 and 1998 wind data from Mesita del Buey and Pajarito Canyon, respectively. Winds on the mesa are primarily from the south and southwest during the day and the west and northwest at night (Figure 2-1). Canyon winds are strongly channeled (Figure 2-2), blowing up canyon from the southeast during the day and down canyon at night.

Daytime



Nighttime

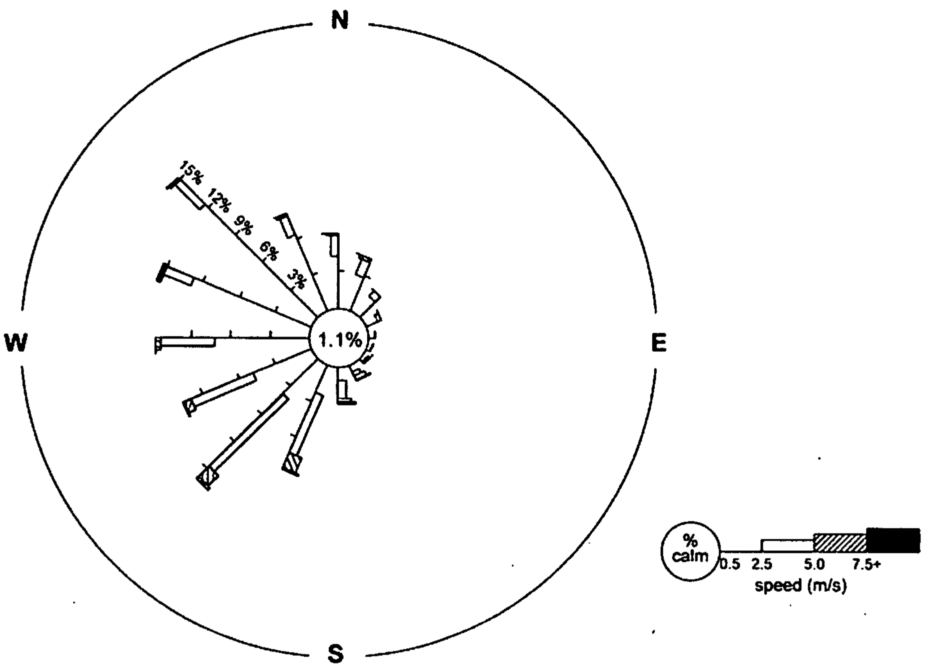


Figure 2-1
Windroses Illustrating Prevailing Daytime and Nighttime Winds at Mesita del Buey (2002)

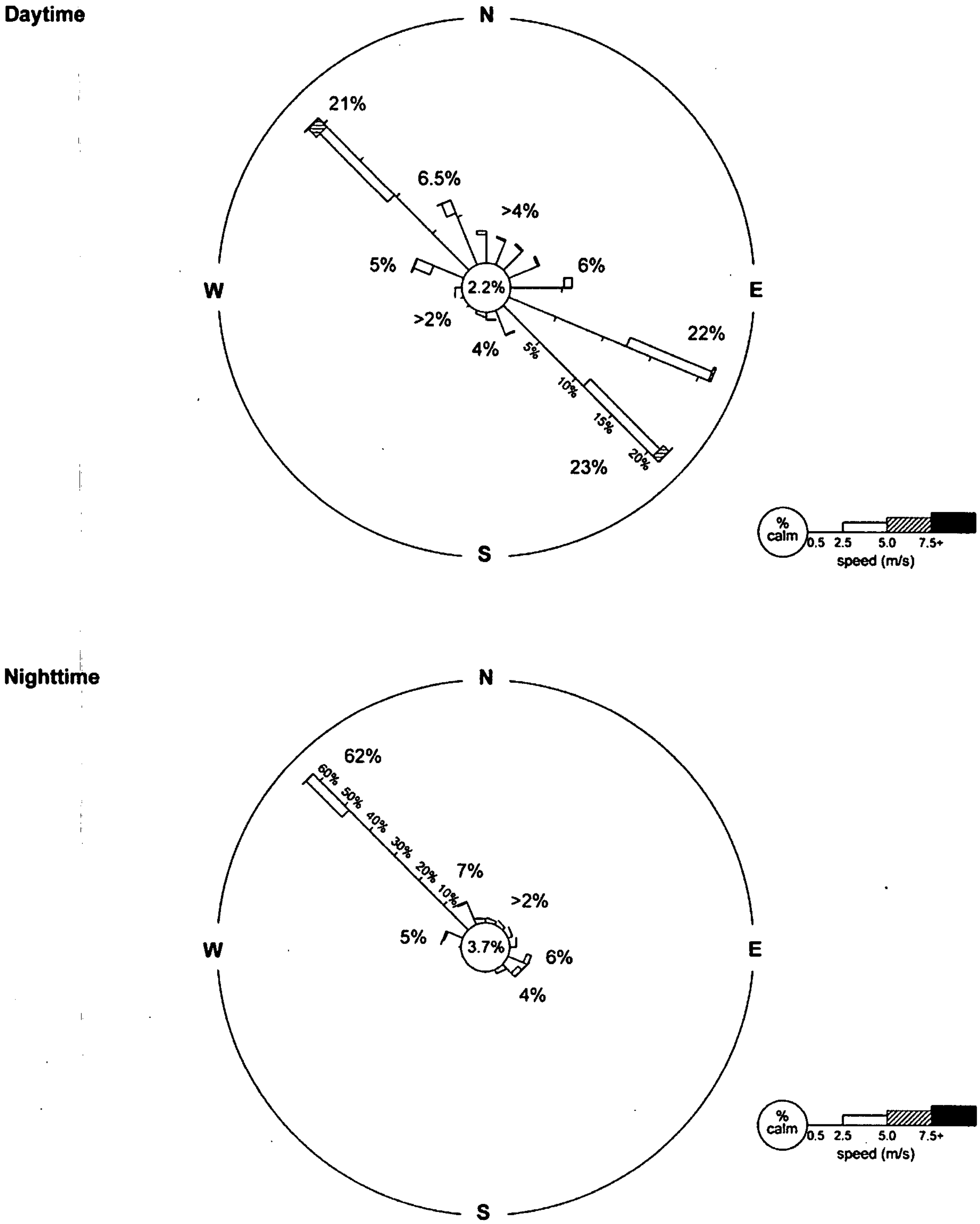


Figure 2-2
Windroses Illustrating Prevailing Daytime and Nighttime Winds at Pajarito Canyon (1998)

2.1.2.3 Atmospheric Dispersion

The complex terrain and vegetation characteristics at the Laboratory result in complex patterns of atmospheric transport and dispersion. These factors create an aerodynamically rough surface, resulting in increased horizontal and vertical turbulence and dispersion. The frequent clear skies and light winds cause daytime vertical dispersion, especially during the warm season. Clear skies and light winds have a different effect on dispersion at night, causing strong, shallow surface inversions to form; these inversions severely restrict near-surface vertical and, to a lesser extent, horizontal dispersion. Overall, atmospheric dispersion tends to be greatest in the spring when winds are strongest.

2.1.2.4 Severe Weather Events

Thunderstorms are quite common in Los Alamos, with about 58 occurring in an average year. Lightning and hail can be frequent and intense during the thunderstorms. Typically, the hailstones have diameters of about 0.64 cm (0.25 in.), but may be even larger.

No tornado has ever been reported in Los Alamos County, but strong dust devils can produce winds up to 34 m/s (75 mph) at isolated spots in the county, especially at lower elevations. According to the DOE publication, *Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities* (1996), a design basis tornado need not be considered at Los Alamos because the annual hazard probability of exceedance is smaller than 2×10^{-5}.

2.1.3 Ecology

A diverse array of plants and animals is found in the Los Alamos region. This is due in part to the 1,500 m (4,900 ft) elevation difference between the Rio Grande and the top of the Jemez Mountains. The canyon and mesa terrain (DOE, 1979) also contributes to this diversity by providing a variety of habitats.

2.1.3.1 Local Flora

Six major vegetative community types are found in Los Alamos County including juniper-grassland, piñon-juniper, ponderosa pine, mixed conifer, spruce-fir, and subalpine grassland. Juniper-grassland, piñon-juniper, and ponderosa pine predominate throughout the Laboratory; Figure 2-3 provides a generalized illustration showing the approximate elevations of these communities. The juniper-grassland occurs along the Rio Grande and the eastern Pajarito Plateau, extending up to elevations of 1,700 to 1,900 m (5,600 to 6,200 ft) above msl on the south-facing sides of canyons. The piñon-juniper community covers large portions of mesa tops at elevations ranging from about 1,900 to 2,100 m (6,200 to 6,900 ft) above msl. Ponderosa pines are found at elevations ranging from 2,100 to 2,300 m (6,900 to 7,500 ft) above msl in the western portion of the plateau.

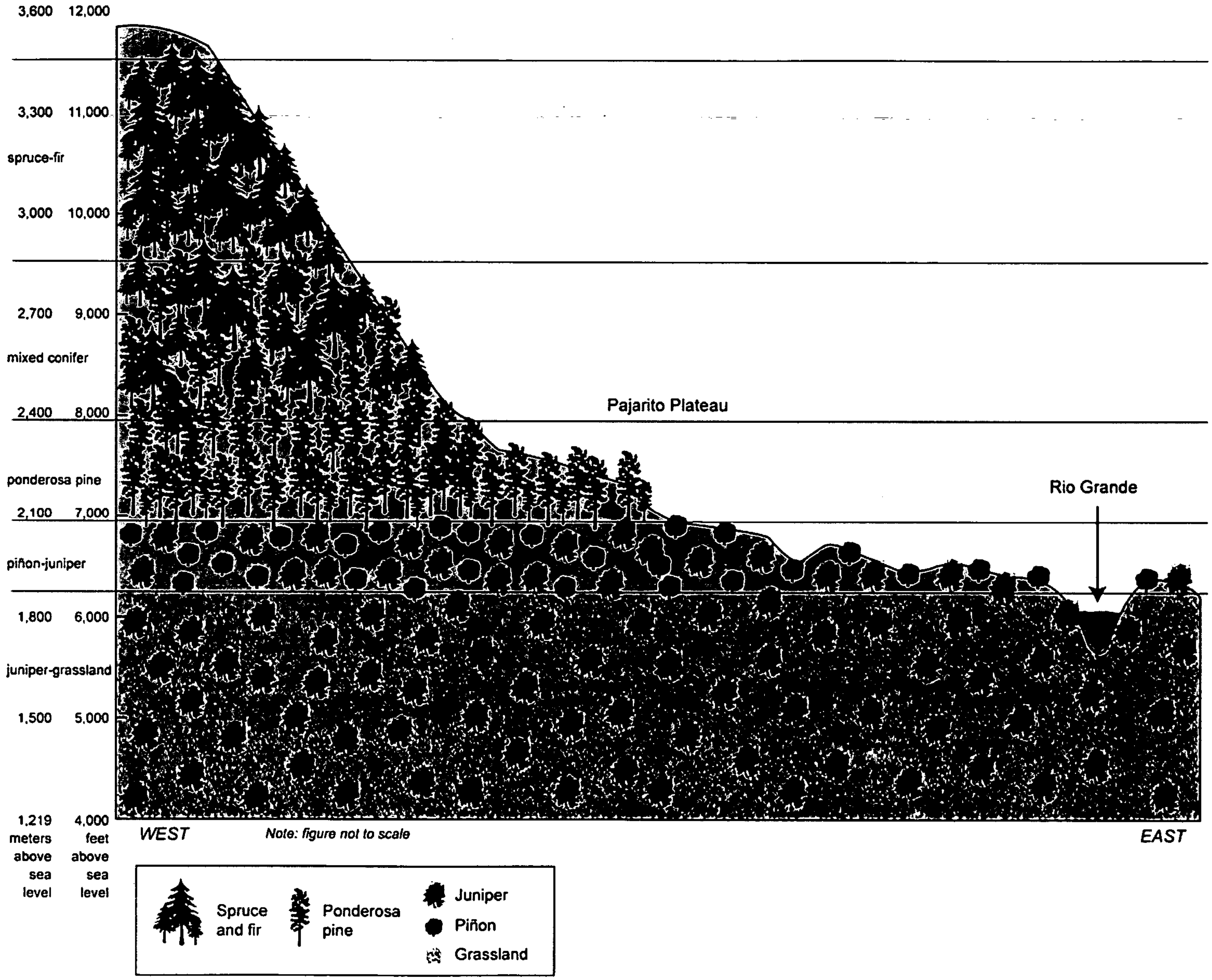


Figure 2-3
Generalized Vegetation Zones of the Pajarito Plateau

Undisturbed areas on Mesita del Buey are dominated by piñon-juniper woodland. Piñon pine (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*) are the dominant tree species, while common shrub species include big sagebrush (*Artemisia tridentata*), four-wing saltbush (*Atriplex canescens*), currant (*Ribes cereum*), and mountain mahogany (*Cercocarpus montanus*). Blue grama (*Bouteloua gracilis*), cryptogamic soil crust, and prickly pear cactus (*Opuntia polyacantha*) are among the most common understory plants on the mesa top. Others include snakeweed (*Gutierrezia sarothrae*), pingue (*Hymenoxys richardsonii*), wild chrysanthemum (*Bahia dissecta*), leafy golden aster (*Chrysopsis filiosa*), purple horned-toothed moss (*Ceratadon purpureus*), lichen, three-awn grass (*Aristida* spp.), bottlebrush squirreltail (*Sitanion hystrix*), bluegrass (*Poa* spp.), and false tarragon (*Artemisia dracunculus*).

Waste management operations at Area G have replaced a number of the understory plants native to the area. Recently disturbed areas support plants such as goosefoot (*Chenopodium fremontii*), Russian thistle (*Salsola kali*), cutleaf evening primrose (*Oenothera caespitosa*), common sunflower (*Helianthus anuus*), and other colonizing species. Vegetation introduced as disposal pits are closed consists of native grasses, including blue grama, sideoats grama (*Bouteloua curtipendula*), Indian ricegrass (*Oryzopsis hymenoides*), sand dropseed (*Sporobolus cryptandrus*), sheep fescue (*Festuca ovina*), western wheatgrass (*Agropyron smithii*), and forbs such as blue flax (*Linum perenne lewisii*) and prairie coneflower (*Ratibida columnifera*).

Operational areas at Area G are expected to undergo ecological succession from a disturbed state shortly after facility closure to a piñon-juniper woodland such as is characteristic of the undisturbed portions of Mesita del Buey. Annual and perennial grasses and forbs will predominate when the site is in its early successional stages, becoming established as covers over disposal units are seeded and as grasses and forbs invade from surrounding areas on the mesa. Over time, shrubs and trees will take hold and become established at the site. While some species of grasses and forbs will die out, others will continue to thrive. Given enough time, it is assumed that a condition approximating the climax piñon-juniper woodland will result.

2.1.3.2 Local Fauna

The plant communities in the LANL region create habitats used by many species of mammals, birds, insects, and reptiles. Of the 60 species of mammals inhabiting the Pajarito Plateau, about 15 are carnivores such as black bear (*Ursus americanus*), mountain lion (*Felis concolor*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), and coyote (*Canis latrans*). More common mammals include mice, squirrels (*Citellus* spp., *Sciurus* spp.), gophers (*Thomomys* spp.), chipmunks (*Eutamias* spp.), voles (*Microtus* spp.), porcupines (*Erethizon dorsatum*), elk (*Cervus canadensis*), and mule deer (*Odocoileus hemionus*). Over 100 species of birds breed in Los Alamos County; these include many different songbirds as well as nesting and migrating raptors. Habitats for federally threatened and endangered species such as the bald eagle (*Haliaeetus leucoephalus*), southwestern willow flycatcher (*Empidonax traillii extimus*), and Mexican spotted owl (*Strix occidentalis*) have been identified within the Laboratory (NMED, 2004). Harvester ants (*Pogonomyrmex* spp.) are the most abundant insect at Area G. Common reptiles include fence lizards (*Sceloporus undulatus*), plateau striped whiptails (*Cnemidophorus velox*), gopher snakes (*Pituophis melanoleucus*), and garter snakes (*Thamnophis* spp.).

Several species of burrowing animals are currently found at Area G and the area surrounding the site; others may reasonably be expected to inhabit the site after widespread disturbance of the area ceases and as the site undergoes ecological succession to piñon-juniper woodland. The DOE (1979) lists the deer mouse (*Peromyscus maniculatus*), pocket mouse (*Perognathus* spp.), woodrat (*Neotoma* spp.), and mountain cottontail (*Sylvilagus nuttalli*) as inhabitants of juniper grassland within Los Alamos County, while the Colorado chipmunk (*Eutamias quadrivittatus*) is found in conjunction with these species in piñon-juniper woodland. Harvester ants are routinely sighted in recently covered disposal sites and piñon-juniper woodland, pocket gophers have also been observed at Area G. Several species of mice have been commonly trapped at Area G (Biggs et al., 1995, 1997; Bennett et al., 1997, 1998, and 2002).

2.1.4 Geology, Seismology, and Volcanology

The Laboratory is located in a complex geological and topographic setting. Prominent features are largely the result of extensive regional volcanism and subsequent erosional forces that have shaped the landscape.

2.1.4.1 Regional and Site-Specific Geology/Topography

The Laboratory is located at an average elevation of 2,100 m (6,900 ft) above msl on the Pajarito Plateau, east of the Jemez Mountains. This plateau consists of a series of east-trending, finger-like mesas separated by deep erosional canyons. Mesa tops range in elevation from 2,400 m (7,800 ft) above msl on the flank of the Jemez Mountains to approximately 1,900 m (6,200 ft) above msl at the east end of the plateau. The eastern plateau ranges between approximately 90 and 275 m (300 and 900 ft) above the Rio Grande valley.

Figure 2-4 illustrates the general geology in the vicinity of Area G. The disposal facility is located near the eastern edge of the Pajarito Plateau, as indicated in this figure, and sits relatively low in the overall stratigraphy; the stratigraphy generally thins from its western source (the Jemez Mountains) to its eastern terminus (the Rio Grande valley).

The Pajarito Plateau is formed of consolidated ash (tuff) from two major volcanic eruptions that occurred in the Jemez Mountains about 1.6 and 1.2 million years ago (Ma). These eruptions produced widespread, massive deposits that consolidated into a formation known as the Bandelier Tuff (Spell et al., 1990). The two eruptions produced two deposits with different characteristics known as the Otowi and Tshirege Members of the Bandelier Tuff. Smaller eruptions that occurred between the two major events produced an interbedded sequence of silica-rich (rhyolitic) tuffs and sediments referred to as the Cerro Toledo interval; these deposits occur commonly but not uniformly between the Otowi and Tshirege Members. Table 2-2 summarizes the lithologic characteristics and thicknesses of various units found at Area G based on data from boreholes drilled at the site.

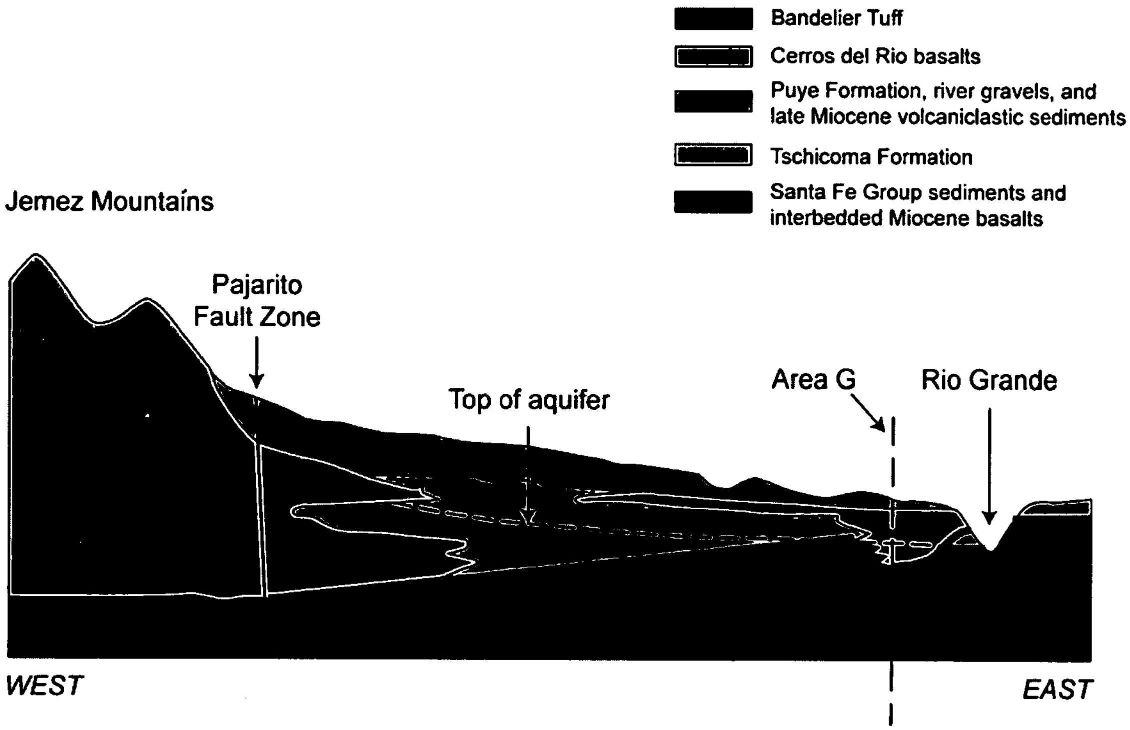


Figure 2-4
Generalized Stratigraphic Relationships of the Pajarito Plateau
Source: Adapted from Hollis et al. (1997) with input from Stauffer (2005) and Broxton (2005

Table 2-2
Lithology of Geologic Units Encountered in Boreholes at Area G

Geologic Unit	Thickness (m)	Lithology	Fracture Spacing (m)	Fracture Median Dip (°) / Aperture (mm)	Fracture Fill (%) [a]
Tshirege Member unit 2	12.2	massive, crystal-rich, slightly welded tuff; devitrified; vapor-phase altered; pumice swarms; basal surge	1–1.3	87 / 3	72–F 9–P 19–O
Tshirege Member unit 1vu	13.7	massive, crystal-rich, nonwelded tuff; devitrified; pumiceous; crystal-rich lapilli	1–1.3	84 / 3	82–F, P 18–O
Tshirege Member Unit 1vc	7.6	massive, crystal-rich nonwelded tuff; pumiceous; pumice swarms; ash falls; crystal-rich lapilli	few fractures	ND	---
Tshirege Member Unit 1g	15.2	massive, nonwelded, nonindurated tuff; vitric; pumiceous; crystal-rich lapilli	some fractures	ND	---
Tsankawi Pumice/ Cerro Toledo interval	1.8	massive air-fall tuff; large white pumice lapilli; topical surge bed of crystals and ash	rare fractures	ND	---
Otowi Member	36.6	massive, moderately crystal-rich, nonwelded vitric tuff; ~30% pumice	few fractures	ND	observed calcite
Guaje Pumice	3.7	basal nonwelded pumice lapilli bed; vitric	rare fractures	ND	---
Cerros del Rio basalts	>36.3 [b]	dense, fractured, basaltic tondesitic lava flows with flow breccias and conglomerate interbeds	~0.3 (observed)	~5 (observed)	---
Puye Formation	~200 [b]	fanglomerates and conglomerates; fluviatile and debris-flow deposits; interbedded ash and pumice falls, basalt flows	poorly developed in outcrop	ND	---

Source: LANL, 2008b, Table 2-4 (after Hollis et al., 1997).

ND = No data; assumed vertical. *--- = No data.*

[a] *Fracture fill abbreviations: F = filled, P = plated, O = open.*

[b] *Regional characterization wells drilled since 1997 indicate that the Cerros del Rio basalts are much thicker and the Puye Formation much thinner in the area of Area G than reflected in this table (Stauffer et al., 2005a).*

Typically, the older Otowi Member is unwelded to poorly welded and tends to form slopes rather than cliffs; the Tshirege Member contains strata that range from strongly welded to unwelded. The Tshirege Member is further subdivided into "cooling units" that represent successive ash-flow deposits separated by periods of inactivity. The properties of the Tshirege Member related to water flow and contaminant migration (e.g., density, porosity, degree of welding, fracture-content, and mineralogy) vary both vertically and laterally as a result of localized emplacement temperature, thickness, gas content, and composition. Additional information about the Bandelier Tuff and its units can be found in Broxton and Reneau (1995).

The Bandelier Tuff is underlain by interstratified sedimentary and volcanic rock (Broxton and Reneau, 1995 and 1996; Goff et al., 2002). Prominent sedimentary deposits include the Puye Formation, the Totavi Formation, and the Santa Fe Group. Major volcanic rock units include the Tschicoma Formation and the Cerros del Rio basalt.

Information provided by five regional characterization wells drilled as part of the Environmental Restoration (ER) Project have improved the understanding of the subsurface geology at Area G. Data collected from the characterization wells have led to improved understanding of the deep subsurface directly beneath Area G and to subsequent modifications in the model used for contaminant transport. Figure 2-5 presents an interpretive geologic cross section between two regional characterization wells: R-22, completed in 2000, and R-21, completed in 2003 (Ball et al., 2002; Kleinfelder, 2003).

Surface sediments across the Pajarito Plateau are composed of thin soils developed on the mesa top, alluvial (water-transported) and colluvial (gravity-transported) residues on the mesa flanks, and alluvial deposition in the canyon bottoms (Longmire et al., 1996). The soils on Mesita del Buey, which were mapped by Nyhan et al. in 1978, are the weathering product of the Tshirege Member tuffs and wind-blown sources. On much of the mesa surface, native soils have been disturbed by waste-management operations. In less-disturbed portions of the mesa, native soils are thickest near the center of the mesa and thinner toward the edges. Soils on the flanks of the mesa are developed on Tshirege Member tuffs and colluvium with additional deposits of wind-blown and water-transported material; on north-facing slopes soils are more highly developed and richer in organic matter. Soils tend to be sandy in texture near the surface and more clayey beneath the surface. Soil-forming processes have been identified along fractures in the upper part of the mesa, and the translocation of clay minerals from surface soils into fractures has been described at Area G (Purtymun et al., 1978; Reneau and Vaniman, 1998).

Mesa surfaces erode at a very slow rate as a result of storm water runoff and wind. The long-term accumulation of biomass may compete with erosion, especially along the centerlines of mesas, away from major drainages. Modern drainages, including the steep-sided east-trending

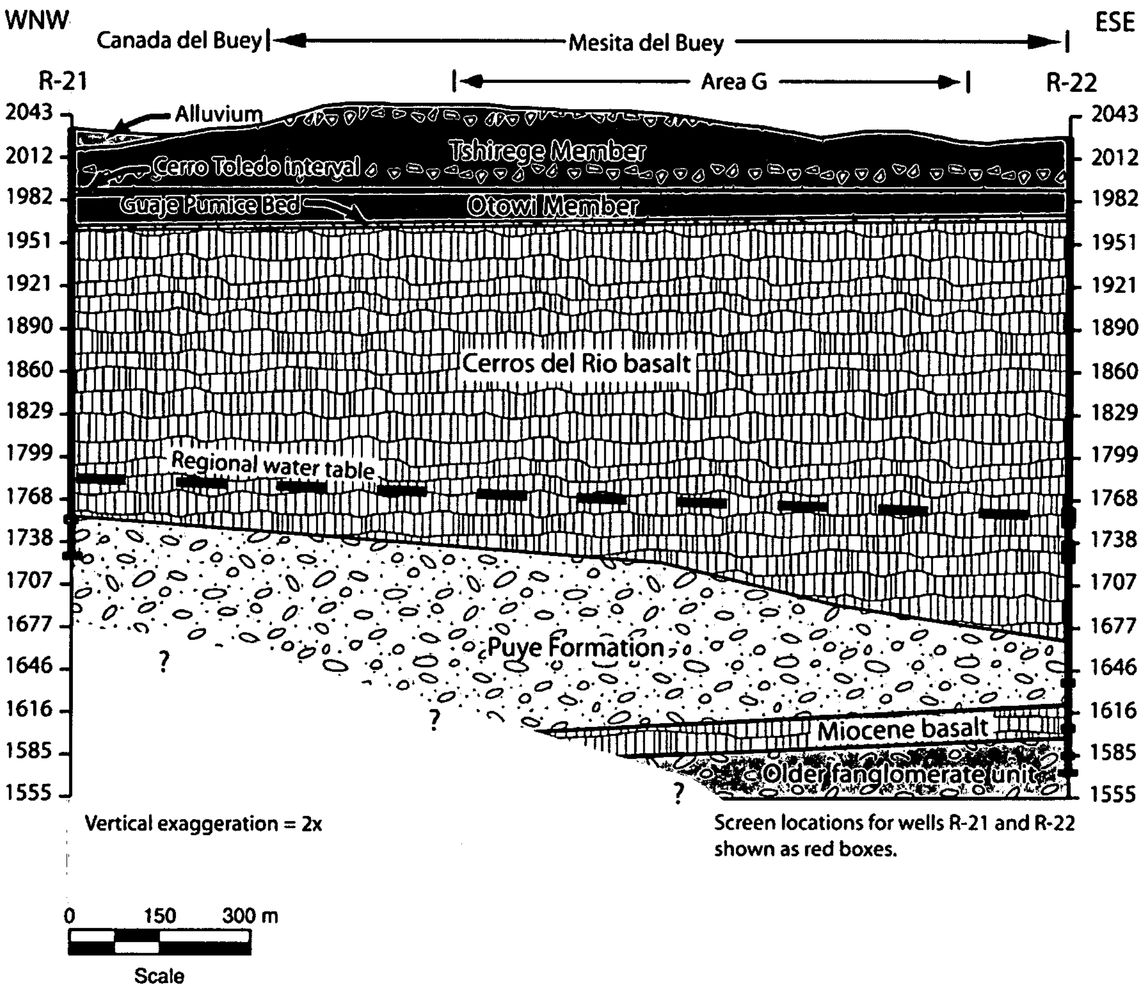


Figure 2-5
Interpretive Geologic Cross Section between Regional Characterization Wells R-21 and R-22

canyons that drain the Pajarito Plateau, are eroded into the Tshirege Member. The current surface drainage pattern across the plateau is generally southeast, at an oblique angle to the south-southwest paleochannels, or buried drainages. The pre-Bandelier landscape was apparently exposed for sufficient time to allow for the development of strong soil horizons in many locations, some of which are clay and mineral rich.

In addition to wind and water erosion, mesas erode or "retreat" laterally as a result of mass wasting, including rock falls and larger-scale landslides. Some canyon rims display large-scale mass movement (landslides) in zones determined by a threshold combination of slope gradient and canyon depth (Reneau, 1995), although most rims retreat as a result of infrequent failures of fractured or jointed tuff blocks. Evidence suggests that blocks may dislodge along cooling joints or tectonic fractures. Mesita del Buey is a relatively low mesa, ranging from 15 to 30 m (50 to 100 ft) above the adjacent canyons. Although mass wasting does occur on the north and south faces of the mesa, the effects are not nearly as dramatic as those observed along deeper canyons across the Pajarito Plateau. Reneau (1995) concluded that a 15 m (50 ft) setback such as is used in the placement of disposal units at Area G, should be sufficient to ensure the units' integrity for at least 10,000 years.

2.1.4.2 Seismology

The Laboratory is located within the northern Rio Grande rift, a seismically active region undergoing east-west extension. A number of small to moderate earthquakes not associated with mapped faults (i.e., background earthquakes) have occurred in north-central New Mexico within the past 100 years. In recent times, however, only six earthquakes of estimated Richter magnitude 5.0 or greater have occurred in the region. The most significant was the May 18, 1918 Cerrillos earthquake that occurred approximately 50 km (30 mi) southeast of the Laboratory and had an estimated magnitude of 5.5. Since 1973, local seismicity has been monitored by the Los Alamos Seismograph Network. Measured events have not exceeded a magnitude of 4, which is relatively weak compared with earthquakes producing damage to buildings and structures (LANL, 2001). There is no physical evidence of seismic motion at the site.

Wong et al. (1995) identified 26 faults and 5 seismic zones as potentially significant seismic sources in terms of ground shaking at LANL. The Pajarito, Rendija Canyon, and Guaje Mountain faults, shown in Figure 2-6, were the focus of these studies. The Pajarito Fault, at the western margin of the Laboratory, is a 47-km (29-mi), north-trending, discontinuous fault zone that defines the active western boundary of the Rio Grande rift. The 10-km (6-mi) long Rendija Canyon Fault is located 3 km (2 mi) east of the Pajarito Fault and trends north-south across the Laboratory. The 14-km (9-mi) Guaje Mountain Fault, located 1 to 2 km (0.6 to 1.3 mi) east of the Rendija Canyon Fault, is similar to the Rendija Canyon Fault in its orientation, tectonic setting, and probable sense of slip.

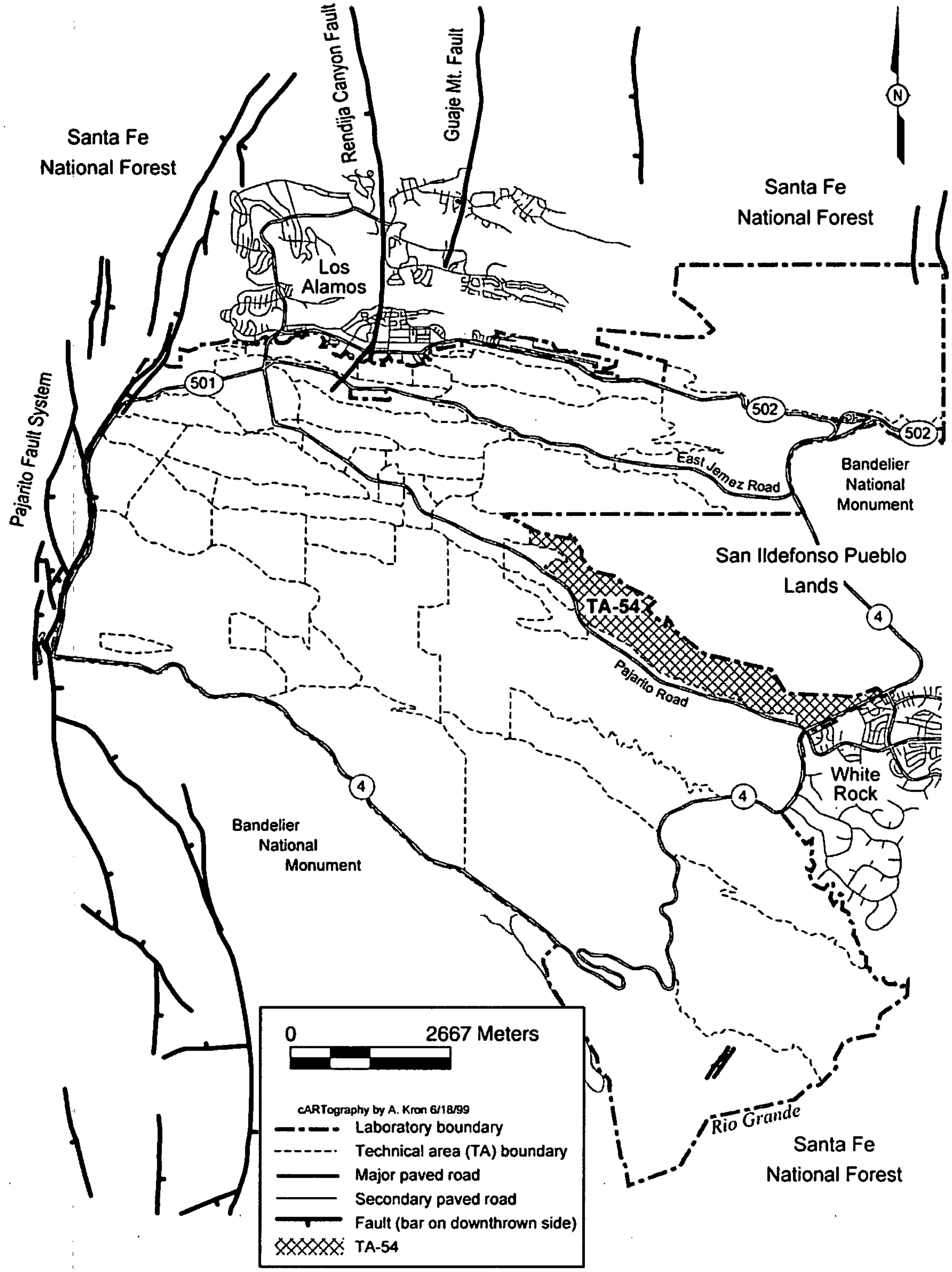


Figure 2-6
Locations of Major Faults at Los Alamos National Laboratory
Source: LANL, 2001

The Pajarito Fault is considered active; exploratory work has revealed that it has ruptured during multiple surface-faulting events in the past 100,000 to 200,000 years (Wong et al., 1995). Although not well constrained, recurrence intervals between events are estimated to range from 10,000 to 40,000 years. The Rendija Canyon Fault has repeatedly ruptured during the late Quaternary, with the most recent event occurring at about 8,000 to 9,000 years ago; estimated recurrence intervals for the Rendija Canyon Fault range from 25,000 to 100,000 years. The Guaje Mountain Fault exhibits evidence of multiple surface ruptures during the past 150,000 to 300,000 years; recurrence intervals for this fault are estimated to range from 50,000 to 150,000 years.

A seismic hazard evaluation (Olig, 1997) indicated that two potential seismic hazards could impact the ability of Area G to contain and isolate radioactivity. The first of these is the potential for small displacements or deformation of the disposal unit cover resulting from surface faulting along minor secondary faults, and the second is the potential disturbance or deformation of the disposal unit cover due to ground shaking. Although there is a potential for earthquake-induced mass wasting of the cliff walls, there have been no large landslides or other large slope-failures identified near Area G. Should such events occur, the 15 m (50 ft) setback from the edge of the cliffs is judged to provide reasonable protection against loss of integrity of disposal units due to mass wasting.

2.1.4.3 Volcanology

The 16.5-million-year volcanic history of the Pajarito Plateau has been studied extensively (Heiken et al., 1986). Evidence suggests that regional eruptions such as those that deposited the Tshirege and Otowi Members of the Bandelier Tuff have recurred every 200,000 to 500,000 years. The last such event, which deposited the Tshirege Member of the Bandelier Tuff, occurred about 1 Ma. The fact that a million years have passed without a similarly sized eruption suggests that the probability of such an event occurring again in this cycle of volcanism is very small (LANL, 2003a). Small, localized eruptions occurred about 50,000 years ago, but were contained within the Valles Caldera in the Jemez Mountains to the west of the Pajarito Plateau.

2.1.5 Hydrology

The hydrology of the Pajarito Plateau is defined by the geography, geology, and climate of the area (RAC, 2003). Mesas are generally devoid of water, both on the surface and within the rock forming the mesa; Mesita del Buey is one of the drier mesas within the Laboratory. The wet canyons of Pajarito Plateau, such as Pajarito Canyon to the south of Mesita del Buey, have perennial or near-perennial streams and may contain groundwater in the canyon-bottom alluvium. The dry canyons of the plateau, which include Cañada del Buey, have only intermittent stream flow and lack alluvial groundwater. Beneath the surface, intermediate perched groundwater has been found at some locations away from Area G; no perched water has been found beneath the disposal facility. The regional aquifer is found at depths of about 180 to 370 m

(600 to 1,200 ft) or more below ground surface. This section discusses the occurrence, distribution, and movement of surface water and groundwater across the Pajarito Plateau in general, and in the vicinity of Area G in particular.

2.1.5.1 Surface Water

Rivers and streams located within 80 km (50 mi) of LANL include the Rio Grande and its tributaries: the Chama, Ojo Caliente, Santa Cruz, Nambe, and Tesuque rivers to the north and east; the Jemez River and San Antonio Creek to the west; and the Santa Fe and Galisteo rivers to the south. All surface water from the Pajarito Plateau drains to the Rio Grande. At its closest point, the Rio Grande is 5 km (3.1 mi) hydraulically downgradient from Mesita del Buey. Reservoirs within 80 km (50 mi) include the Cochiti, Abiquiu, Santa Cruz, and Jemez.

The Pajarito Plateau has dramatic erosional topography, the result of greater surface flows in the past. Today, however, only a few streams are perennial or near-perennial; the rest flow only after heavy rains and as a result of snowmelt. Pajarito Canyon, one of the wetter canyons, has flow about 8 months out of the year and is fed by a cluster of springs located at TA-9 on the western edge of the Laboratory (RAC, 2003). In contrast, Cañada del Buey is a dry canyon that carries ephemeral flow only after storms or snowmelt (RAC, 2003).

The springs that feed the upper reaches of Pajarito Canyon exist at elevations between 2,400 and 2,700 m (7,870 and 8,850 ft) above msl on the slopes of the Sierra de los Valles to the west of the Pajarito Plateau. The source of these springs is perched water in the Bandelier Tuff and Tschicoma Formations. Typical discharge from these springs is between 7 and 530 L/min (1.8 to 140 gpm), a rate that is sufficient to maintain surface flow only in the upper third of the east-draining canyons of the Pajarito Plateau. Below this, the spring-fed flows are depleted by evaporation and infiltration into the underlying alluvium.

There are no streams on Mesita del Buey; any surface water is a result of storms and snowmelt. Runoff from these events leads to shallow sheet erosion on the relatively flat parts of the mesa, and deeper erosion channels in more sloped areas. After summer storms, runoff reaches a maximum in less than 2 hours and lasts less than 24 hours. In contrast, runoff from spring snowmelt occurs over a period of several weeks at a low discharge rate. In general, more eroded material is transported in summer runoff events than during snowmelt.

Flooding of the disposal facility is not a major concern because excess water typically drains into the canyons on either side of the mesa; however, temporary ponding does occur occasionally within disposal pits. The perimeter of Area G includes nine distinct natural drainage channels, six of which are monitored for potential surface water pollution. In addition, there are a number of areas over which water flows in sheets off the mesa edge after rains. Disposal pit covers are subject to sheet erosion, with infrequent development of small, localized rills.

2.1.5.2 Groundwater

The groundwater system of the Pajarito Plateau, like that of most basins on the margins of the Rio Grande rift, is recharged primarily from adjacent mountains. Within LANL, groundwater occurs (1) in the deep regional aquifer, (2) as moderately deep perched water in bedrock units of the vadose zone, and (3) as shallow groundwater in canyon-floor alluvium (Broxton and Vaniman, 2005). Groundwater flows generally to the east, toward the Rio Grande (RAC, 2003).

The regional aquifer, which extends from the mountains west of the Laboratory to the Rio Grande on the east, is the only source of water capable of serving municipal and industrial needs (Purtymun, 1995). 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 main aquifer also extends to the north of Los Alamos, beneath the Pajarito Plateau around the northwestern flanks of the Jemez Mountains. Water movement is to the east and northeast in the Puye Conglomerate and the Tesuque Formation beneath the Pajarito Plateau and within the Tesuque Formation in the Española Valley. Depths to groundwater below the mesa tops range from about 180 m (600 ft) at the eastern margin of the plateau to 370 m (1,200 ft) or more along the western margin.

The regional aquifer is separated from the alluvial groundwater and intermediate perched zone groundwater by about 110 to 190 m (360 to 620 ft) of tuff, basalt, and sediments (EPG, 1993). Continuously recorded water-level measurements collected in test wells since the fall of 1992 indicate that, throughout the plateau, the regional aquifer responds to barometric and earth tide effects in the manner typical of confined aquifers. The hydraulic gradient of the regional aquifer averages about 12 to 15 m/km (60 to 80 ft/mi) within the Puye Formation but increases to 15 to 19 m/km (80 to 100 ft/mi) along the eastern edge of the plateau as the groundwater enters the less permeable sediments of the Santa Fe Group. The hydraulic slope of the regional aquifer ranges from 0.011 to 0.015. The flow rate beneath Area G has been estimated at 29 m/yr (95 ft/yr) using data from the Pajarito well field. This rate is an average over the thickness of the aquifer intercepted by the well screens. Part of the regional aquifer discharges into the Rio Grande east of the Laboratory; the 18 km (11 mi) reach of the Rio Grande in White Rock Canyon receives about 6×10^6 m^3 (5,500 ac-ft) of water annually.

The Laboratory and the communities of White Rock and Los Alamos obtain water supplies from the regional aquifer (RAC, 2003), which contains the greatest quantity of stored groundwater in the region. The supply wells are located in four well fields, Los Alamos (seven wells), Guaje (seven wells), Pajarito (five wells), and Otowi (two wells). Only one of the Los Alamos field wells currently serves as a source of water. The Guaje and Otowi well fields primarily serve the community of Los Alamos, while the Pajarito well field serves White Rock and the Laboratory.

The hydrologic characteristics of the regional aquifer measured at the supply wells and some of the test wells differ due to the geology of the aquifer and the thickness of the region penetrated by the well. The Pajarito Field (the field nearest Area G) contains the most productive supply wells; the aquifer here has an average saturated thickness of 550 m (1,800 ft).

Vadose-Zone Hydrogeology

The vadose-zone lithology in the vicinity of Area G consists primarily of various units of the Bandelier Tuff. The extent to which the tuff has been welded or devitrified affects vadose-zone fluid flow. These properties result from the prolonged presence of residual gases and high temperatures at, and shortly after, the time of deposition. The Bandelier Tuff units were deposited at varying temperatures and thicknesses over different landscapes; as a result, cooling was not uniform. Consequently, welding varies spatially, both laterally and vertically, even within a single lithological unit.

There are several competing effects that determine moisture content and fluid flux in welded, devitrified tuff. Welded tuffs tend to be more fractured than nonwelded tuffs. Water moves slowly through the unsaturated tuff matrix, and although it can move relatively rapidly through fractured tuff, this occurs only if nearly saturated conditions exist (Abrahams, 1963). Modeling studies indicate that moisture is absorbed into the matrix when fractures disappear at contacts between stratigraphic subunits, when fracture fills are encountered, or when coatings are interrupted. Thus, fractures may provide conduits for fluid flow, but only in discrete, disconnected intervals of the subsurface. Also, because they are open to the passage of both air and water, fractures can have either wetting or drying effects, depending on the relative abundance of water in the fractures and matrix.

Normally, the Tshirege Member of the Bandelier Tuff, which forms Mesita del Buey, is very dry and does not readily transmit moisture because its small pore spaces have a strong tendency to hold water against gravity by surface-tension forces. Moisture content is generally more variable near the surface of the mesa than at depth as a result of variations in temperature, humidity, and evapotranspiration. 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.

Table 2-3 provides the hydrologic or hydraulic properties used to represent the vadose-zone lithologic units for the Area G performance assessment and composite analysis modeling (Revision 4). More information about these properties is provided in LANL (2008b) and Springer (2005).

Table 2-3
Hydrogeologic Characteristics of Area G Vadose Zone Used for Groundwater Pathway Modeling

Geologic Unit	Bulk Density (g/cm³)	Permeability (m²)	Porosity	Saturated Vol. Water Content cm³/cm³	Saturated Hydraulic Conductivity	Residual Vol. Water Content	van Genuchten Fitting Parameters		
							θ_r	α (m⁻¹)	n
Soil	1.5E+00	---	---	4.1E–01	4.7E–06	0.0E+00	---	---	---
Tshirege Member unit 2	1.4E+00	2.0E–13	4.1E–01	4.1E–01	3.4E–04	1.0E–01	2.4E–02	4.7E–01	2.1E+00
Tshirege Member unit 1v	1.2E+00	1.2E–13	4.9E–01	4.9E–02	2.4E–04	3.0E–03	6.0E–03	3.6E–01	1.7E+00
Vapor-phase notch	1.1E+00	---	---	4.8E–01	9.3E–05	3.0E–03	---	5.E–01	1.6E+00
Tshirege Member unit 1g	1.2E+00	1.5E–13	4.6E–01	4.6E–01	2.0E–04	1.0E–02	2.2E-02	5.0E-01	1.8E+00
Tsankawi Pumice/Cerro Toledo interval	1.2E+00	1.8E–13	4.5E–01	4.5E–01	3.4E–04	3.0E–03	7.0E–03	1.3E+00	1.5E+00
Otowi Member above Guaje Pumice	1.2E+00	2.3E–13	4.4E–01	4.4E–01	2.5E–04	1.9E–02	4.3E–02	5.9E–01	1.8E+00
Otowi Member Guaje Pumice	8.0E–01 [c]	1.5E–13 [a]	6.7E–01 [a]	---	---	---	0.0E+00 [a]	8.1E–02 [a]	4.0E+00 [a]
Cerros del Rio basalts vadose zone	2.7E+00	1.0E–12 [b]	1.0E–03 [b]	1.0E–01	2.1E–09	0.0E+00	1.0E–03 [a]	3.8E+00 [a]	1.5E+00 [a]

Source: LANL, 2008b, Table 2-6; All data represents mean values from Springer (2005) unless otherwise noted.

Numbers are rounded to two significant digits.

NA = Not applicable.

--- = No data available.

[a] *Birdsell, et al., 1999 and 2000.*

[b] *Stauffer et al., 2005b.*

[c] *Estimated (see Stauffer et al., 2005a).*

Hydrologic Characteristics of Canyons

Pajarito Canyon is relatively wide and has a fairly flat bottom in the vicinity of Area G. Runoff from higher elevations is focused into Pajarito Canyon and creates a transient stream that flows intermittently, sometimes resulting in pooled water in the canyon bottom to the south of Area G

(Pratt, 1998). The most recent estimate of average annual infiltration in lower Pajarito Canyon is 18.5 m^3/m (200 ft^3/ft) (Kwicklis et al., 2005, Table 2). This value represents the average infiltration per meter of canyon across the average canyon width between two stream gauges; the upstream gauge is located several kilometers west of Area G and the downstream gauge lies just west of White Rock. The infiltration value does not account for stream losses due to evapotranspiration.

Perched water was encountered at two drill holes in Pajarito Canyon; however, this water was confined to the alluvium in the stream channel (Devaurs and Purtymun, 1985). No perched groundwater has been identified beneath Mesita del Buey (LANL, 1998a, as cited in LANL, 2001).

Recharge Beneath Area G

Rates and patterns of surface water infiltration through the mesa are a function of precipitation, evaporation, and transpiration. These factors vary throughout the year. Evaporation, highest in the warm summer months, generally occurs within several centimeters of the surface or more, especially in fractured or very permeable rock. Transpiration, which occurs throughout the root zone as a result of root uptake, is also greatest in the summer. Natural recharge through the Bandelier Tuff also varies according to climate and local rock characteristics. The unsaturated upper units of the Bandelier Tuff tend to retain water, which promotes the removal of water through evapotranspiration.

Infiltration rates at Area G have been estimated on a number of occasions. For example, Kwicklis et al. (2005) developed an infiltration map for the Los Alamos region. Based on this map, rates of infiltration ranging from about 0 to 10 mm/yr (0 to 0.4 in./yr) are estimated for Mesita del Buey; this range of infiltration rates was also adopted for the modeling conducted in support of the 1997 performance assessment and composite analysis (Hollis et al., 1997). Newman et al. (2005) estimated infiltration rates in undisturbed portions of the disposal facility and in areas impacted by disposal operations and found that fluxes were generally on the order of 0.2 mm/yr (0.0079 in./yr) in undisturbed areas and 0 to 10 mm/yr (0 to 0.4 in./yr) in areas impacted by disposal and surface structures. Levitt (2008) modeled rates of water passage through the proposed final cover, and estimated rates ranging from 1.3×10^{-4} to 7 mm/yr (5.1×10^{-6} to 0.28 in./yr).

Deep infiltration at Area G may or may not result in recharge of the regional aquifer. The presence of cooling joints or fractures within some units of the Tshirege Member of the Bandelier Tuff may dry out portions of the mesa. The driest zone within the mesa generally occurs within the lower portion of Tshirege unit 2 and the upper part of unit 1v, a region that coincides with fractures reported by Krier et al. (1997). Rogers et al. (1997) note that this region is also generally a zone of high matric suction and a hydraulic head minimum, suggesting that moisture is being mobilized toward this depth, both from above and below, by physical properties of the tuff. The driving force for this movement of water may be evaporation aided by air flow within the fractures or along the surge beds found at the base of unit 2. Chloride and stable isotope analyses conducted by Newman (1996) support the presence of a dry region within the mesa resulting from deep evaporation.

Birdsell et al. (1997) discuss three distinct moisture content zones within the Bandelier Tuff beneath Area G and indicate that three different recharge rates are necessary to match these moisture conditions. Within unit 2 and the upper portion of unit 1v, a recharge rate of about of 0 to 0.1 mm/yr (0 to 0.004 in./yr) most closely match site saturation data, while a range of about 0.1 to 1 mm/yr (0.004 to 0.04 in./yr) is needed to match moisture content data in the lower portion of the Tshirege Member. A recharge rate of about 10 mm/yr (0.4 in./yr) is required to match saturation data for the Cerro Toledo interval and the Otowi Member of the Bandelier Tuff. The vertical disconnects in these estimated recharge rates supports the hypothesis that recharge is not steady state, or that significant moisture sources and sinks exist at depths.

2.1.6 Geochemistry

Krier et al. (1997) indicate that rainwater and snowmelt have a low total dissolved solids content and an acidic pH because of low concentrations of bicarbonate, calcium, sodium, and magnesium; storm runoff at Area G may have a higher dissolved solids content and near-neutral pH because of its contact with soils, backfill, and Bandelier Tuff. Surface water may approach equilibrium with crushed tuff, waste, and associated radionuclides as it infiltrates the pore spaces of the waste disposal units. Geochemical reactions that control contaminant releases will, themselves, be controlled by pH, oxidation-reduction potential, speciation of the contaminants, temperature, advection, and residence time of the pore water (Krier et al., 1997).

Certain minerals in the Bandelier Tuff have high sorptive capacity for many radionuclides present in the Area G inventory (Broxton et al., 1995); these include hematite, kaolinite, smectite, and calcite. For example, sources cited by Broxton et al. indicate that smectites are highly selective for cationic radionuclides, and that magnetite and its alteration products (e.g., hematite) have an affinity for uranium and actinide species through surface-complexation. Although these minerals occur only in small quantities at Area G, they are present throughout the entire thickness of the tuff, as fracture linings as well as within the tuff itself. As a result, the aggregate abundance of these minerals and their surface area available for adsorption are large when the long groundwater flow paths are taken into account. Less important in terms of transport is dissolved organic carbon, which can form soluble complexes with certain radionuclides to form relatively mobile solutes; the organic carbon content of pore water within the Bandelier Tuff is typically less than 1 percent (by weight) (Longmire et al., 1995).

Certain highly sorptive solid phases, including clay minerals, iron oxides, solid organic matter, and carbonate minerals, are known to be present in subsurface soils found across the Laboratory. Calcium carbonate and clay-rich horizons do exist beneath Area G at the top of the Cerros del Rio basalts, although they are laterally inconsistent. Calcium carbonate appears as calcrete-like coatings on basalt cobbles and the paleosol above the basalts is clay rich (LANL, 2005a). Little is known about the effect of these coatings on the hydrology beneath Area G, but they may be important for sorbing radionuclides. Also, vertical water flow may be inhibited and lateral flow enhanced by clay layers because of their low permeability.

2.1.7 Natural Resources

A number of mineral and energy resources exist or have been exploited in the vicinity of the Laboratory. These resources and regional water sources are summarized below.

2.1.7.1 Geologic Resources

There are several mines and quarries in Los Alamos County, none of which is currently active. Small surface mines in Sandoval, Santa Fe, and Rio Arriba Counties near Los Alamos extract pumice. The nearest pumice mine is about 10 km (6 mi) north of Area G. Other active surface mining operations in the region recover sand, gravel, crushed rock, and other fill materials. The nearest of these is located in Santa Fe County, about 10 km (6 mi) east of Area G. Surface mines for volcanic cinders operate approximately 8 km (5 mi) east and 25 km (15 mi) south of the Area G, and a surface mine for humate (a soil conditioner) operates approximately 55 km (34 mi) west of LANL. Gypsum is also mined at a few locations south of LANL.

Historically, metal deposits (primarily silver, copper, and gold) were mined in the Cochiti (Bland) mining district, about 16 km (10 mi) south of LANL. Mines in the district have been inactive since about 1940, but prospecting and a small amount of production still occur in the Cochiti District. The closest active metal mines to LANL are located in the San Pedro Mountains, approximately 45 km (28 mi) to the south. Turquoise is also mined 45 km (28 mi) south of the Laboratory.

The natural gas field closest to the Laboratory is approximately 64 km (40 mi) to the northwest in the San Juan Basin. The nearest oil fields are also in the San Juan Basin, with other small fields located about 70 km (45 mi) west of LANL. The USGS considers the potential for oil and gas discoveries in Los Alamos County area to be poor. In the Española Basin, just a few kilometers northeast of LANL, exploration wells have encountered evidence of oil and gas.

The nearest coal fields to LANL are in the San Juan Basin. These extend to within 40 km (25 mi) of the northern boundary of LANL. Small coal deposits south of Santa Fe—the Hagen and Cerrillos fields—are located about the same distance to the south of Los Alamos. Relatively small uranium deposits occur in the Nacimiento-Jemez uranium area, about 35 km (22 mi) southwest of LANL. Also, relatively high concentrations of uranium sediments have been found on the southeast flank of the Jemez Mountains.

The USGS has designated portions of the Jemez Mountains as a "Known Geothermal Resource Area." Many of the thermal springs and wells in this area are within 32 km (20 mi) of the Laboratory. To date, test wells installed near Area G show low potential for geothermal resources.

2.1.7.2 Water Resources

Most of the water taken from the Guaje and Otowi well fields serves only the town of Los Alamos. Of the five wells in the Pajarito field, two normally serve the town of White Rock and three serve LANL. Under unusual circumstances, water from any well can be routed to any destination. Of the three Los Alamos wells transferred to the San Ildefonso tribe in the early 1990s, only LA-5 is used for water supply (for San Ildefonso's Totavi gas station and housing complex). Well LA-1B serves as a monitoring well and LA-2 was taken out of service in 1993 (Glasco, 2005). The wells are no longer used for drinking water but do provide nonpotable water for irrigation. In addition, nonpotable industrial water is obtained from the spring gallery in Water Canyon.

The Cochiti reservoir dam is located on the Rio Grande, about 15 km (9 mi) from the southernmost point of the LANL boundary. The dam provides flood control, sediment retention, recreation, and fishery development. The permanent pool extends upstream some 12 km (8 mi) to a point about 5 km (3 mi) from the southernmost point of the LANL boundary. The dam is estimated to trap at least 90 percent of the sediments carried by the Rio Grande.

No municipal water supplies are taken directly from the Rio Grande between LANL and the Cochiti Dam. The river along this stretch is used primarily for recreation. Below the dam, irrigation water is taken from the Rio Grande at numerous diversions.

2.2 Facility Characteristics

Mesita del Buey (and most of TA-54) was identified in 1956 by the USGS as a prospective radioactive waste disposal site because of its favorable hydrogeologic properties. Since 1957, about 26 ha (65 ac) of TA-54 have been used for radioactive waste disposal; the site has served as the primary low-level radioactive waste disposal site for the Laboratory since 1959. The development of disposal units has progressed generally from east to west, in accordance with the pit and shaft construction guidelines in effect at the time of construction. The result has been the construction of 35 disposal pits and more than 200 shafts, the general layout of which is shown in Figure 2-7.

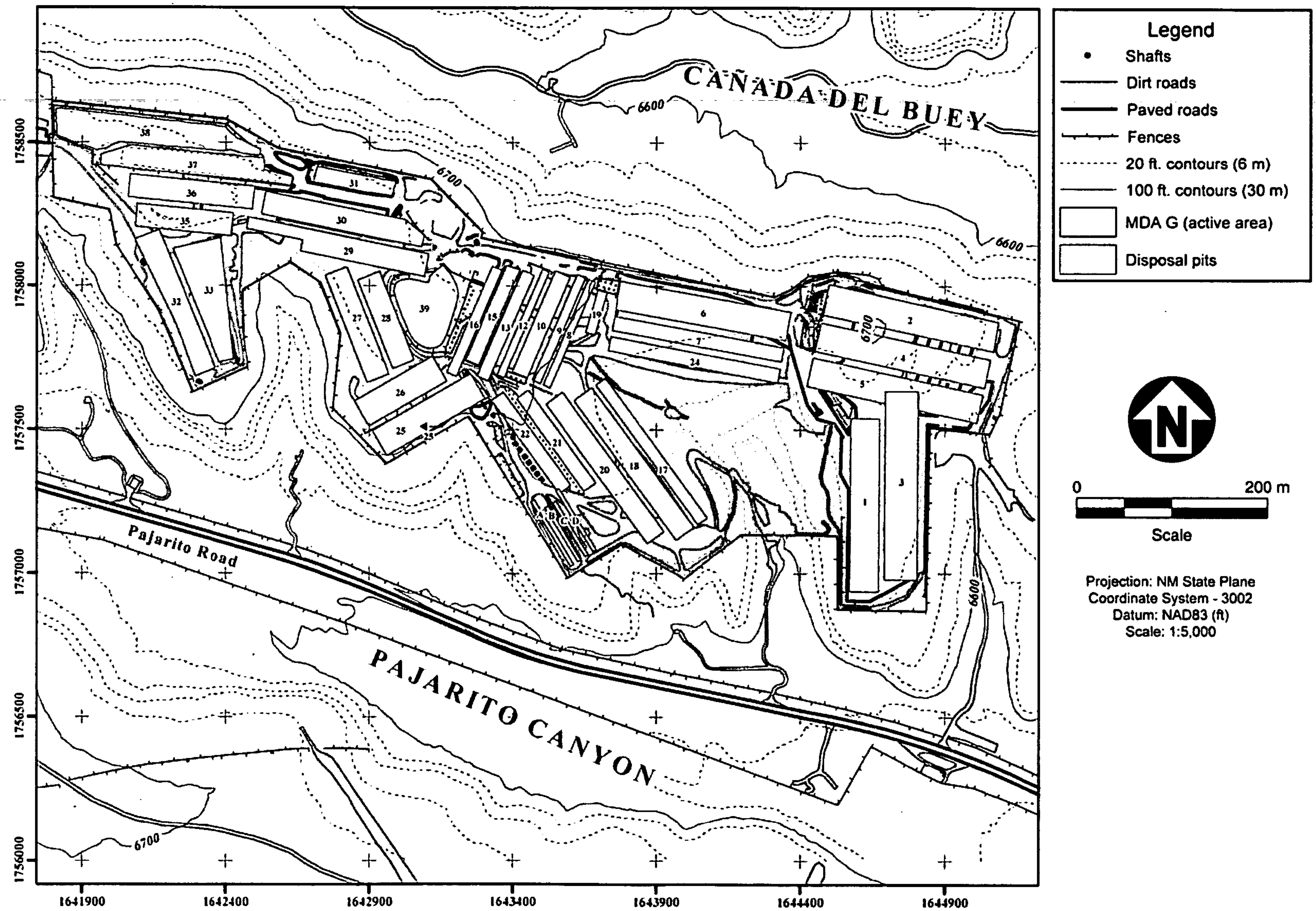


Figure 2-7
Waste Disposal Units at Area G

Source: Apogen Technologies (formerly SEA);
LANL RRES Database, Map ID" 4531.021 (1) Rev. 2

Routine LLW, including operational and ER waste, is placed in disposal pits that have been excavated into the Bandelier Tuff using heavy equipment. Disposal pits are set back at least 15 m (50 ft) from the nearest canyon rim and are dug no deeper than 3 m (10 ft) above the adjacent canyon floor. Historically, most waste was placed in lifts; successive lifts were separated by a layer of uncontaminated crushed tuff and compacted with heavy equipment. Exceptions included material that was disposed of in containers when retrieval of the material was considered likely.Since the mid-1990s, all waste except bulk soils and debris has been placed in metal or wooden containers prior to disposal. Bulk waste may be used to fill void spaces within and between the waste packages.

Waste is disposed of in shafts because of its regulatory status, to provide additional shielding of material with high external radiation levels, to facilitate placement using remote handling techniques, and to accommodate special handling requirements. The shafts are drilled into the Bandelier Tuff using augers. Like the disposal pits, shafts are set back at least 15 m (50 ft) from the nearest canyon rim and dug no deeper than 3 m (10 ft) above the adjacent canyon floor. The diameters of the shafts typically range from about 0.3 to 6 m (1 to 20 ft).

Revision 4 of the performance assessment and composite analysis assumes waste disposal operations will continue at Area G through the year 2044. By the end of 2007, however, almost all available pit disposal capacity within MDA G had been exhausted. Plans have been made to construct additional disposal pits in the 12-ha (30-ac) Zone 4 expansion area immediately west of MDA G (Figure 1-2). The shaft disposal capacity within MDA G is capable of satisfying disposal needs until this portion of Area G is closed in 2015; shaft disposal operations are assumed to move to Zone 4 in 2016.

A phased development approach has been established for Zone 4, as illustrated in Figure 2-8; the design capacities estimated for the different phases are summarized in Table 2-4 for several design options. It is expected that Zone 4 will provide more than enough LLW disposal capacity to support future Laboratory needs. Based on inventory projections, approximately 1.2×10^5 m^3 (4.2×10^6 ft^3) of waste is projected to be disposed of in Zone 4. As shown in Table 2-4, this capacity can be realized using several approaches. For example, excavation of all phase 1 pits to a depth of 24 m (82 ft), with or without ramp excavation, would provide the requisite disposal volume. If pits are excavated to a depth of only 18 m (60 ft), some development of the phase 2 area would be needed.

Several design features of the final closure configuration play important roles in the long-term performance of the disposal facility and, hence, its ability to safely isolate the waste. The remainder of this section addresses several of these design aspects.

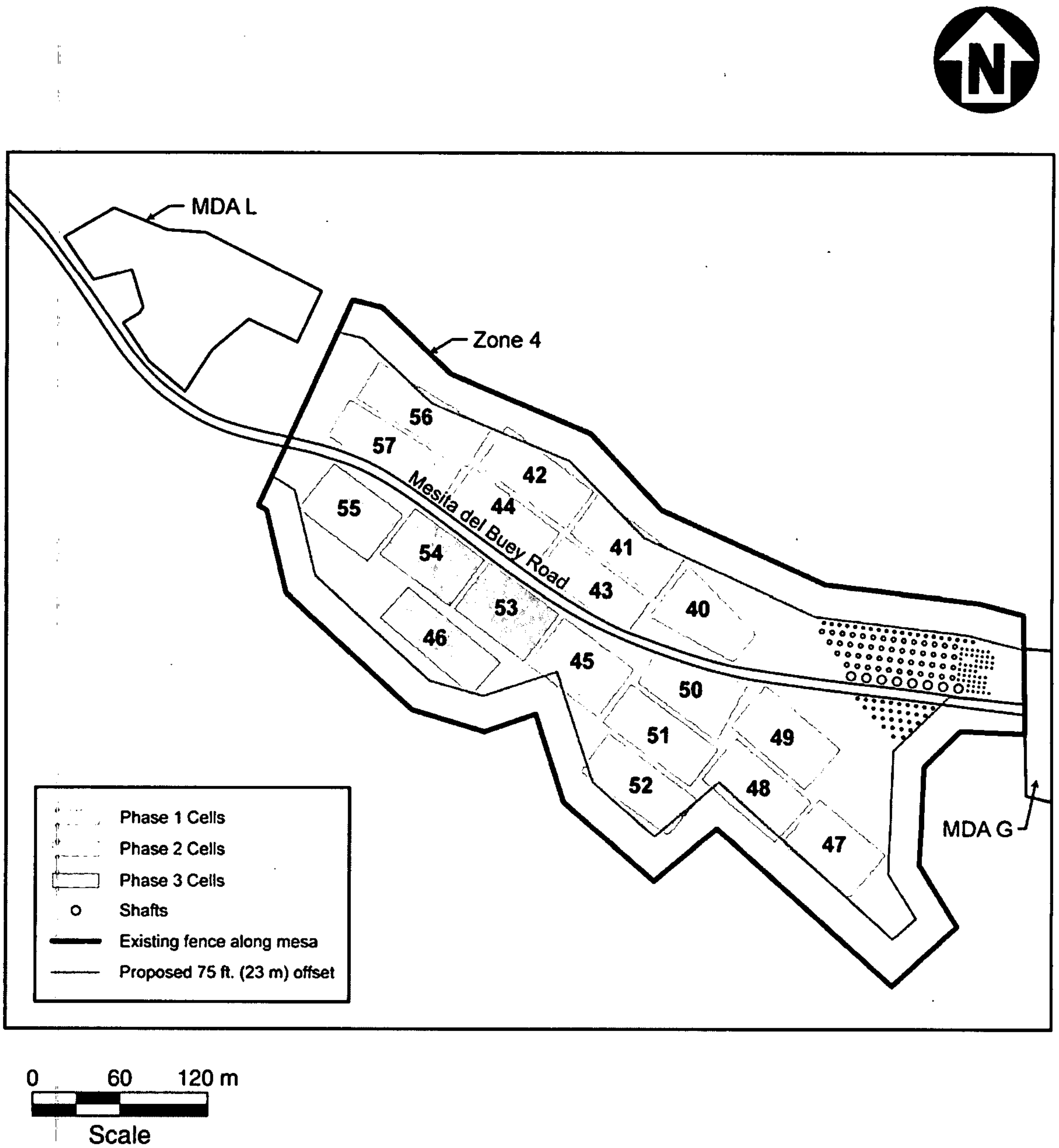


Figure 2-8
Proposed Disposal Unit Development at Zone 4

Source: French, 2005a
(after URS 2004a, 2004b, 2004c)

Table 2-4
Design Capacities of Zone 4 Development Phases

Design Options	Design Capacity					
	Phase 1		Phase 1 + Phase 2		Phases 1, 2 and 3	
	Waste Volume (m^3)	Life Expectancy (yr)	Waste Volume (m^3)	Life Expectancy (yr)	Waste Volume (m^3)	Life Expectancy (yr)
18-m depth, no ramp excavation	8.7E+04	31	1.7E+05	60	2.2E+05	77
18-m depth, 50% ramp excavation	1.0E+05	36	2.0E+05	72	2.6E+05	92
24-m depth, no ramp excavation	1.2E+05	43	2.4E+05	83	3.0E+05	106
24-m depth, 50% ramp excavation	1.4E+05	49	2.8E+05	98	3.6E+05	125

Source: French, 2005a, Table 1.

2.2.1 Water Infiltration

Minimizing infiltration through the disposal units will reduce the rates at which radionuclides are leached from the waste and extend the amount of time required for contaminated water to reach the regional aquifer. A large portion of the precipitation falling on the site will be directed away from the disposal units by the contoured surface of the cover. The proposed final cover is designed to function as an evapotranspiration system, which will provide water storage sufficient to contain spring snowmelt until it is either used for transpiration by plants or evaporated (Bonaparte et al., 2004; ITRC, 2003; Nyhan, 2005; and Scanlon et al., 2002). The 6 percent bentonite admixture included in the crushed tuff layer (Figure 1-4) will reduce the hydraulic conductivity of the cover, slowing the infiltration of water through the site. The topsoil layer applied at the surface will promote plant growth, which will tend to maximize water loss through transpiration.

2.2.2 Disposal Unit Cover Integrity

The long-term integrity of the final cover will depend, to a large extent, on its ability to withstand the effects of surface erosion. The final cover design for Area G was developed using an iterative approach in which successive cover designs underwent long-term erosion analyses using the SIBERIA computer code. The result is an optimized design that is expected to be capable of meeting performance criteria under a range of potential site and climate conditions that could occur over the 1,000-year compliance period.

The first step of the design process was to identify the minimum amount of cover required to safely isolate the waste throughout the 1,000-year compliance period. Based on biotic intrusion modeling conducted by Shuman (1999), it was estimated that a minimum cover thickness of 1.5 m (4.9 ft) throughout the 1,000-year compliance period would provide reasonable assurance that the disposal facility would continue to satisfy all performance objectives. On the basis of preliminary estimates of erosion potential that were developed using the SIBERIA erosion model (Wilson et al., 2005), it was concluded that adopting a minimum initial cover thickness of 2.5 m (8.2 ft) would enable the minimum cover requirement to be met for most, if not all, of the disposal site.

After the minimum initial cover depth was identified, an iterative process was used to evaluate cover designs. The performance of each successive conceptual design was evaluated for a period of 1,000 years using refinements of the SIBERIA erosion model (Wilson et al., 2005). The cover designs were evaluated to determine their ability to satisfy the minimum cover requirements and to identify areas where projected erosion impacts appeared to be severe. Generally, the erosion modeling indicated that the cover over much of the site performed adequately; however, elevated rates of erosion were observed in localized areas along mesa edges or adjacent to drainages. These vulnerable locations were fortified using engineered features such as rock armor and the design evaluation process was repeated until a satisfactory design was identified.

2.2.3 Structural Stability

On a volume basis, most of the waste at Area G has been placed in the large, generally rectangular pits. Before the mid-1990s, most waste placed in pits was packaged in plastic bags and cardboard boxes. The material was typically placed in lifts; each layer of waste was covered with uncontaminated crushed tuff and compacted using heavy equipment. Exceptions occurred, primarily when there was a possibility that the waste might be retrieved at a later date; in these cases the waste may have been placed in wooden boxes and metal drums prior to disposal.

The disposal pit operations used prior to the mid-1990s are generally expected to confer structural stability to the pits. Layering waste and crushed tuff and compacting these layers with heavy equipment effectively filled void spaces within the waste and provided an even consolidated surface for the disposal of more waste. However, this disposal method probably did not maximize the use of the available disposal capacity. Estimates developed for the 1997 performance assessment and composite analysis suggest more than 60 percent of the disposal pit capacity consisted of uncontaminated backfill.

To more efficiently use the available pit disposal capacity, disposal procedures were modified in the mid-1990s; since that time all waste other than bulk soils and debris is required to be placed in metal containers prior to disposal. The containers used to date have included steel drums, B-25 containers, compactor boxes, and transportainers. These containers are stacked in the disposal units to maximize usage of the available disposal capacity. Bulk materials are placed directly in the disposal pits, and may be used to fill void spaces within and between waste containers.

The use of containers is expected to reduce the amount of uncontaminated fill needed to ensure waste stability. For example, the conceptual design for the pits in the Zone 4 expansion area is based on the assumption that 50 percent of the material in the disposal units is waste, taking into account the volume occupied by ramps used to access the units and the sloped walls. The use of containers may, however, increase the potential for subsidence when incompletely filled containers corrode or otherwise fail. To minimize the potential for subsidence following container failure, the waste acceptance criteria (WAC) for Area G specify the maximum amount of void space that is permissible inside containers of waste. Current requirements call for 95 percent or more of the container to be filled with waste.

The waste disposed of in shafts is generally placed in small metal cans or 0.11 to 0.32 m^3 (30 to 85 gal) drums, depending upon the nature of the waste. The packages are lowered into the disposal units and stacked on top of one another. Crushed tuff may be added as backfill around the waste packages, thereby reducing void spaces in the disposal units. In general, backfilling the disposal shafts is expected to adequately stabilize the waste. However, isolated instances of subsidence near these units have been observed over the 45-year history of the facility.

Significant subsidence of one or more disposal units at Area G may compromise the ability of the site to comply with the performance objectives cited in DOE M 435.1-1 (DOE, 2001b). If such subsidence were to occur, rates of infiltration through the affected units may rise, thus increasing the rates of contaminant release due to leaching and facilitating radionuclide transport to the regional aquifer. Localized failure of the final cover may also provide greater opportunities for plants and animals to penetrate into the waste; any additional contamination deposited on the surface of the site may result in increased exposures to persons living downwind of Area G and in the adjacent canyons. Under extreme conditions, the buried waste may be exposed, further elevating rates of release.

2.2.4 Inadvertent Intruder Barrier

A combination of administrative controls and design features is relied upon to prevent or limit the impacts of inadvertent human intrusion into the disposal facility. As stated earlier, DOE control over the disposal facility is assumed to prevent intrusion throughout the 100-year active institutional control period.

The primary design feature used to limit intruder exposures is the total depth of the cover; no other engineered or structural barriers are incorporated into the final closure configuration for this purpose. The final cover design includes the placement of a minimum of 2.5 m (8.2 ft) of cover material across all disposal pits and shafts; in actuality, considerably more cover than this exists over the majority of the site at the time of closure. Taking into account the effects of surface erosion, this design is expected to be capable of maintaining intruder exposures within the acceptable limits.

2.3 Waste Characteristics

The nature of the waste that has been disposed of at Area G has changed over the facility's lifetime. As discussed in Section 1.1, material that is currently defined as TRU waste was routinely disposed of at the facility through 1970. The vast majority of the TRU waste generated at the Laboratory has been segregated and retrievably stored for permanent disposal at WIPP since that time. This material has been placed in large aboveground domes and in below-grade retrievable arrays (i.e., pits 9 and 29, trenches A through D, and several shafts). Small quantities of TRU waste were inadvertently disposed of at Area G between 1971 and 1988.

Mixed LLW was placed in pits and shafts through 1985; MTRU waste was disposed of prior to 1971. Since 1986, the vast majority of the MLLW has been segregated from LLW and sent off site for treatment and disposal. Small amounts of MLLW were inadvertently placed in one pit and one shaft between 1986 and 1990, no mixed waste has been disposed of at Area G since 1990. In addition to LLW, Area G is permitted to accept low-level TSCA waste (i.e., asbestos and polychlorinated biphenyls). Solid LLW is the only type of waste disposed of at Area G today.

A characterization of the radiological inventory was undertaken in conjunction with Revision 4 of the Area G performance assessment and composite analysis. A summary of these efforts is provided below; Shuman (2008) provides a complete description of how these estimates were developed and a discussion of the uncertainties associated with these projections.

Revision 4 of the Area G performance assessment addresses the LLW disposed of since September 26, 1988 and the waste expected to require disposal over the remainder of the facility's lifetime (through 2044). The total volumes and activities of waste projected to be disposed of in pits from September 27, 1988 through 2010 and from 2011 through 2044 are listed in Table 2-5; projections for waste disposed of in shafts from September 27, 1988 through 2015 and from 2016 through 2044 are also included. Radionuclide-specific inventories for the disposal pits and shafts are provided in Table 2-6. All activities listed in Tables 2-5 and 2-6 are as-disposed activities.

The inventory developed for the composite analysis includes all waste that has been or will be disposed of at Area G from the time the facility opened in 1957 until the facility closes in 2044. The total volumes and activities projected for the composite analysis are included in Table 2-5; the radionuclide-specific inventories are listed in Tables 2-7 and 2-8 for pits and shafts, respectively. The activities listed in Tables 2-5, 2-7, and 2-8 represent as-disposed activities.

Table 2-5
Volumes and Activities for Waste Included in the
Area G Performance Assessment and Composite Analysis Inventories

Analysis and Period of Disposal	Disposal Pits		Disposal Shafts	
	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Performance Assessment				
September 27, 1988–2007	8.9E+04	3.5E+03	5.2E+02	1.7E+06
2008–2044	1.6E+05	3.9E+02	1.0E+03	9.8E+05
Total	2.5E+05	3.9E+03	1.6E+03	2.7E+06
Composite Analysis				
Pre-1971	4.9E+04	1.8E+04	4.8E+01	6.4E+04
1971–September 26, 1988	9.9E+04	4.3E+04	9.2E+02	8.2E+05
September 27, 1988–2007	8.9E+04	3.5E+03	5.2E+02	1.7E+06
2008–2044	1.6E+05	3.9E+02	1.0E+03	9.8E+05
Total	4.0E+05	6.5E+04	2.5E+03	3.6E+06

Source: Shuman, 2008, Table 32.

Source: Shuman, 2008, Table 34

--- = None

Table 2-6
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Performance Assessment

Constituent	Activity (Ci)					
	Disposal Pits			Disposal Shafts		
	September 27, 1988–2007 Waste	2008–2044 Waste	Total	September 27, 1988–2007 Waste	2008–2044 Waste	Total
Ac-227	1.8E-05	6.6E-05	8.4E-05	5.3E-07	---	5.3E-07
Ag-108m	1.7E-04	5.8E-05	2.3E-04	4.4E+00	4.2E-08	4.4E+00
Al-26	2.6E-04	1.2E-06	2.6E-04	---	---	---
Am-241	8.1E+00	1.5E+01	2.3E+01	3.2E-01	1.2E-03	3.2E-01
Am-243	8.6E-03	3.8E-02	4.7E-02	1.0E-09	---	1.0E-09
Ba-133	6.9E-01	3.2E+00	3.9E+00	2.8E-03	---	3.7E-03
Be-10	4.6E-03	---	4.6E-03	---	---	---
Bi-207	1.5E-02	7.0E-02	8.6E-02	6.0E-05	7.3E-06	6.8E-05
Bk-247	2.8E-07	---	2.8E-07	---	---	---
C-14	3.3E+00	1.2E-02	3.3E+00	1.6E+01	3.5E-01	1.6E+01
Ca-41	2.7E-01	---	2.7E-01	---	---	---
Cf-249	1.0E-04	4.7E-04	5.7E-04	---	---	---
Cf-252	2.0E-05	---	2.0E-05	9.6E-06	3.6E-05	4.5E-05
Cl-36	1.8E-02	---	1.8E-02	2.5E-04	---	2.5E-04
Cm-243	4.2E-05	5.1E-05	9.2E-05	---	---	---
Cm-244	2.8E-03	1.3E-02	1.6E-02	2.2E-03	9.3E-03	1.1E-02
Cm-245	4.6E-05	2.1E-04	2.6E-04	---	---	---

Source: Shuman, 2008, Table 33.

--- = None

Table 2-6 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Performance Assessment

Constituent	Activity (Ci)					
	Disposal Pits			Disposal Shafts		
	September 27, 1988–2007 Waste	2008–2044 Waste	Total	September 27, 1988–2007 Waste	2008–2044 Waste	Total
Cm-248	4.5E-07	2.1E-06	2.5E-06	---	---	---
Co-60	4.5E+01	7.5E+01	1.2E+02	3.1E+03	3.8E+01	3.1E+03
Cs-135	1.3E-04	7.5E-06	1.4E-04	4.5E-06	---	4.5E-06
Cs-137	5.8E+00	4.8E+00	1.1E+01	8.3E+01	1.9E+00	8.5E+01
D38	4.0E+00	4.3E+00	8.3E+00	2.4E+00	7.0E+00	9.4E+00
Eu-152	4.4E-01	2.0E-01	6.4E-01	1.1E-02	3.0E-03	1.4E-02
Eu-154	5.2E-02	3.1E-03	5.5E-02	9.8E-02	---	9.8E-02
Gd-148	1.0E-05	---	1.0E-05	7.7E-09	---	7.7E-09
H-3	3.1E+03	1.9E+01	3.2E+03	1.7E+06	9.7E+05	2.7E+06
Ho-163	9.1E-01	---	9.1E-01	7.0E-02	---	7.0E-02
Ho-166m	1.4E-03	6.6E-03	8.0E-03	---	---	---
I-129	3.1E-05	1.4E-04	1.7E-04	3.0E-08	---	3.0E-08
K-40	2.7E-01	8.5E-01	1.1E+00	4.3E-07	2.0E-06	2.4E-06
Kr-85	4.6E-02	4.6E-04	4.7E-02	8.9E-03	3.7E-02	4.6E-02
Lu-176	1.7E-06	---	1.7E-06	---	---	---
MAP	1.3E+01	---	1.3E+01	5.6E+03	---	5.6E+03
MFP	1.8E+01	---	1.8E+01	6.0E+01	---	6.0E+01
Mo-93	2.0E-05	9.3E-05	1.1E-04	1.3E-02	---	6.8E-02

Source: Shuman, 2008, Table 34
--- = None

Table 2-6 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Performance Assessment

Constituent	Activity (Ci)					
	Disposal Pits			Disposal Shafts		
	September 27, 1988–2007 Waste	2008–2044 Waste	Total	September 27, 1988–2007 Waste	2008–2044 Waste	Total
Nb-91	1.2E-05	5.3E-05	6.5E-05	9.4E-03	4.3E-02	5.3E-02
Nb-92	3.0E-06	1.4E-05	1.7E-05	4.0E-03	---	4.0E-03
Nb-93m	1.0E-03	4.8E-03	5.8E-03	2.2E+00	1.0E+01	1.3E+01
Nb-94	4.0E-02	6.9E-02	1.1E-01	1.3E-04	---	1.3E-04
Nd-144	1.0E-08	4.6E-08	5.6E-08	---	---	---
Ni-59	6.3E-03	3.3E-05	6.3E-03	2.6E+00	---	1.4E+01
Ni-63	2.0E+00	9.5E-01	2.9E+00	1.2E+03	4.6E+01	1.2E+03
Np-237	4.9E-03	2.0E-02	2.4E-02	3.1E-08	1.4E-07	1.7E-07
Os-194	1.3E-07	6.0E-07	7.3E-07	---	---	---
Pa-231	4.2E-05	1.1E-04	1.5E-04	2.7E-03	2.3E-07	2.7E-03
Pb-210	2.7E-01	8.5E-02	3.5E-01	2.9E-08	1.2E-07	1.5E-07
Pm-145	1.1E-01	4.6E-08	1.1E-01	---	---	---
Pu-236	1.0E-09	4.6E-09	5.6E-09	---	---	---
Pu-238	1.4E+01	2.2E+01	3.6E+01	2.6E-01	3.5E-02	3.0E-01
Pu-239	1.6E+01	1.8E+01	3.4E+01	7.6E-02	3.2E-02	1.1E-01
Pu-240	5.3E-01	1.3E+00	1.8E+00	1.2E-03	---	1.2E-03
Pu-241	2.8E+00	4.9E+00	7.6E+00	3.7E-02	---	3.7E-02
Pu-242	6.3E-03	2.6E-02	3.2E-02	2.0E-06	---	2.0E-06

Source: Shuman, 2008, Table 34
--- = None

Table 2-6 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Performance Assessment

Constituent	Activity (Ci)					
	Disposal Pits			Disposal Shafts		
	September 27, 1988–2007 Waste	2008–2044 Waste	Total	September 27, 1988–2007 Waste	2008–2044 Waste	Total
Pu-244	3.5E-06	1.6E-05	2.0E-05	---	---	---
PU52	5.1E+00	---	5.1E+00	5.7E-02	---	5.7E-02
Ra-226	1.2E-01	3.2E-01	4.4E-01	7.8E-01	8.4E-05	7.8E-01
Ra-228	3.4E-02	1.1E-01	1.5E-01	---	---	---
Si-32	2.7E-05	7.7E-05	1.0E-04	---	---	---
Sm-151	3.4E-09	1.4E-08	1.8E-08	---	---	---
Sn-126	2.7E-06	---	2.7E-06	2.4E-02	---	2.4E-02
Sr-90	2.8E+00	9.8E+00	1.3E+01	8.7E+01	1.8E+00	8.8E+01
Tb-157	4.5E-08	2.1E-07	2.5E-07	---	---	---
Tc-97	2.1E-06	9.2E-08	2.2E-06	---	---	---
Tc-99	3.2E-01	2.8E-01	6.0E-01	1.2E-05	---	1.2E-05
Th-228	2.2E-03	3.0E-03	5.2E-03	6.9E-04	3.2E-03	3.9E-03
Th-229	3.8E-04	1.4E-03	1.8E-03	5.4E-08	---	5.4E-08
Th-230	1.2E-03	4.2E-04	1.6E-03	1.6E-08	---	1.6E-08
Th-232	3.2E-01	8.1E-03	3.3E-01	1.9E-01	6.0E-02	2.5E-01
TH88	3.7E-02	---	3.7E-02	---	---	---
Ti-44	2.6E-03	1.2E-02	1.5E-02	2.0E-02	9.0E-02	1.1E-01
U(DEP)	5.3E+00	2.4E+01	3.0E+01	4.4E-05	2.0E-04	2.5E-04

Source: Shuman, 2008, Table 34
--- = None

Table 2-6 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Performance Assessment

Constituent	Activity (Ci)					
	Disposal Pits			Disposal Shafts		
	September 27, 1988–2007 Waste	2008–2044 Waste	Total	September 27, 1988–2007 Waste	2008–2044 Waste	Total
U(NAT)	6.4E-05	2.9E-04	3.6E-04	1.8E-01	8.3E-01	1.0E+00
U11	8.7E-06	---	8.7E-06	---	---	---
U-232	8.8E-04	1.7E-04	1.1E-03	2.0E-04	---	2.0E-04
U-233	7.3E-02	2.4E-01	3.1E-01	5.8E-04	---	5.8E-04
U-234	1.1E+00	1.6E+00	2.6E+00	5.0E-01	2.3E+00	2.8E+00
U-235	8.7E-01	1.0E-01	9.7E-01	2.8E-02	1.3E-01	1.5E-01
U-236	3.7E-03	1.1E-02	1.5E-02	3.8E-06	1.8E-05	2.1E-05
U-238	1.2E+01	2.6E+00	1.4E+01	4.5E-01	1.1E+00	1.6E+00
U38	5.0E-02	---	5.0E-02	---	---	---
U39	3.1E-03	---	3.1E-03	---	---	---
U81	5.7E-04	---	5.7E-04	---	---	---
Zr-93	2.0E-08	---	2.0E-08	---	---	---

Source: Shuman, 2008, Table 34
--- = None

Table 2-7
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Composite Analysis, Disposal Pits

Constituent	Activity (Ci)				
	Pre-1971 Waste	1971–September 26, 1988 Waste	September 27, 1988–2007 Waste	2008–2044 Waste	Total
Ac-227	8.6E-01	7.0E-02	1.8E-05	6.6E-05	9.3E-01
Ag-108m	---	---	1.7E-04	5.8E-05	2.3E-04
Al-26	---	---	2.6E-04	1.2E-06	2.6E-04
Am-241	2.4E+03	2.4E+01	8.1E+00	1.5E+01	2.4E+03
Am-243	---	---	8.6E-03	3.8E-02	4.7E-02
Ba-133	---	---	6.9E-01	3.2E+00	3.9E+00
Be-10	---	---	4.6E-03	---	4.6E-03
Bi-207	---	---	1.5E-02	7.0E-02	8.6E-02
Bk-247	---	---	2.8E-07	---	2.8E-07
C-14	---	2.3E-01	3.3E+00	1.2E-02	3.6E+00
Ca-41	---	---	2.7E-01	---	2.7E-01
Cf-249	2.4E-03	4.1E-04	1.0E-04	4.7E-04	3.4E-03
Cf-251	2.7E-03	1.6E-03	---	---	4.3E-03
Cf-252	1.5E-02	8.6E-03	2.0E-05	---	2.3E-02
Cl-36	---	---	1.8E-02	---	1.8E-02
Cm242	1.8E-03	---	---	---	1.8E-03
Cm-243	---	---	4.2E-05	5.1E-05	9.2E-05
Cm-244	1.7E-03	---	2.8E-03	1.3E-02	1.7E-02
Cm-245	---	---	4.6E-05	2.1E-04	2.6E-04
Cm-248	---	---	4.5E-07	2.1E-06	2.5E-06
Co-60	---	1.3E+03	4.5E+01	7.5E+01	1.4E+03
Cs-135	---	---	1.3E-04	7.5E-06	1.4E-04
Cs-137	2.6E-01	1.1E+03	5.8E+00	4.8E+00	1.1E+03
D38	---	---	4.0E+00	4.3E+00	8.3E+00
Eu-152	---	---	4.4E-01	2.0E-01	6.4E-01
Eu-154	---	---	5.2E-02	3.1E-03	5.5E-02
Gd-148	---	---	1.0E-05	---	1.0E-05

Source: Shuman, 2008, Table 34

--- = *None*

Table 2-7 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the in the Composite Analysis, Disposal Pits

Constituent	Activity (Ci)				
	Pre-1971 Waste	1971–September 26, 1988 Waste	September 27, 1988–2007 Waste	2008–2044 Waste	Total
H-3	2.7E+00	7.5E+03	3.1E+03	1.9E+01	1.1E+04
Ho-163	---	---	9.1E-01	---	9.1E-01
Ho-166m	---	---	1.4E-03	6.6E-03	8.0E-03
I-129	---	---	3.1E-05	1.4E-04	1.7E-04
K-40	---	---	2.7E-01	8.5E-01	1.1E+00
Kr-85	1.7E-03	1.0E-03	4.6E-02	4.6E-04	4.9E-02
Lu-176	---	---	1.7E-06	---	1.7E-06
MAP	3.6E-01	1.2E+03	1.3E+01	---	1.2E+03
MFP	1.0E+03	6.5E+02	1.8E+01	---	1.7E+03
Mo-93	---	---	2.0E-05	9.3E-05	1.1E-04
Nb-91	---	---	1.2E-05	5.3E-05	6.5E-05
Nb-92	---	---	3.0E-06	1.4E-05	1.7E-05
Nb-93m	---	---	1.0E-03	4.8E-03	5.8E-03
Nb-94	---	8.0E-06	4.0E-02	6.9E-02	1.1E-01
Nd-144	---	---	1.0E-08	4.6E-08	5.6E-08
Ni-59	---	---	6.3E-03	3.3E-05	6.3E-03
Ni-63	---	---	2.0E+00	9.5E-01	2.9E+00
Np-237	4.0E-03	7.0E-07	4.9E-03	2.0E-02	2.8E-02
Os-194	---	---	1.3E-07	6.0E-07	7.3E-07
Pa-231	---	---	4.2E-05	1.1E-04	1.5E-04
Pb-210	---	---	2.7E-01	8.5E-02	3.5E-01
Pm-145	---	---	1.1E-01	4.6E-08	1.1E-01
Pu-236	---	---	1.0E-09	4.6E-09	5.6E-09
Pu-238	3.8E+03	4.9E+02	1.4E+01	2.2E+01	4.3E+03
Pu-239	1.7E+02	2.3E+01	1.6E+01	1.8E+01	2.2E+02
Pu-240	4.0E+00	2.8E-05	5.3E-01	1.3E+00	5.8E+00
Pu-241	---	5.8E-06	2.8E+00	4.9E+00	7.6E+00
Pu-242	---	7.8E-06	6.3E-03	2.6E-02	3.2E-02
Pu-244	---	---	3.5E-06	1.6E-05	2.0E-05

Source: Shuman, 2008, Table 34
--- = *None*

Table 2-7 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the in the Composite Analysis, Disposal Pits

Constituent	Activity (Ci)				
	Pre-1971 Waste	1971–September 26, 1988 Waste	September 27, 1988–2007 Waste	2008–2044 Waste	Total
PU51	1.6E+00	---	---	---	1.6E+00
PU52	7.7E+03	2.3E+00	5.1E+00	---	7.7E+03
PU53	2.5E+02	3.7E-04	---	---	2.5E+02
PU54	1.1E+03	1.5E-01	---	---	1.1E+03
PU55	6.8E+01	---	---	---	6.8E+01
PU56	1.2E+03	---	---	---	1.2E+03
PU57	7.1E+01	---	---	---	7.1E+01
PU83	5.0E+02	1.5E-02	---	---	5.0E+02
Ra-226	---	2.0E-01	1.2E-01	3.2E-01	6.4E-01
Ra-228	---	2.1E-01	3.4E-02	1.1E-01	3.6E-01
Si-32	---	---	2.7E-05	7.7E-05	1.0E-04
Sm-151	---	---	3.4E-09	1.4E-08	1.8E-08
Sn-126	---	---	2.7E-06	---	1.5E-05
Sr-90	2.9E-01	1.4E+03	2.8E+00	9.8E+00	1.4E+03
Tb-157	---	---	4.5E-08	2.1E-07	2.5E-07
Tc-97	---	---	2.1E-06	9.2E-08	2.2E-06
Tc-99	---	---	3.2E-01	2.8E-01	6.0E-01
Th-228	---	---	2.2E-03	3.0E-03	5.2E-03
Th-229	---	---	3.8E-04	1.4E-03	1.8E-03
Th-230	1.6E+01	9.5E+00	1.2E-03	4.2E-04	2.6E+01
Th-232	---	1.4E-03	3.2E-01	8.1E-03	3.3E-01
TH88	1.9E-03	2.7E-02	3.7E-02		6.6E-02
Ti-44	---	---	2.6E-03	1.2E-02	1.5E-02
U(DEP)	---	---	5.3E+00	2.4E+01	3.0E+01
U(NAT)	---	---	6.4E-05	2.9E-04	3.6E-04
U10	8.8E-01	5.1E-01	---	---	1.4E+00
U11	---	1.5E-01	8.7E-06	---	1.5E-01
U12	7.9E+00	5.8E+00	---	---	1.4E+01
U-232	---	---	8.8E-04	1.7E-04	1.1E-03

Source: Shuman, 2008, Table 34
--- = None

Table 2-7 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the in the Composite Analysis, Disposal Pits

Constituent	Activity (Ci)				
	Pre-1971 Waste	1971–September 26, 1988 Waste	September 27, 1988–2007 Waste	2008–2044 Waste	Total
U-233	6.1E+00	1.9E-02	7.3E-02	2.4E-01	6.4E+00
U-234	---	---	1.1E+00	1.6E+00	2.6E+00
U-235	3.7E-01	7.1E-01	8.7E-01	1.0E-01	2.1E+00
U-236	---	6.3E-08	3.7E-03	1.1E-02	1.5E-02
U-238	4.3E+00	1.1E+01	1.2E+01	2.6E+00	2.9E+01
U35	---	4.9E-04	---	---	4.9E-04
U36	---	2.2E-05	---	---	2.2E-05
U38	2.3E-02	4.5E-02	5.0E-02	---	1.2E-01
U39	---	---	3.1E-03	---	3.1E-03
U81	4.7E-03	2.8E-03	5.7E-04	---	8.1E-03
Zr-93	---	---	2.0E-08	---	2.0E-08

Source: Shuman, 2008, Table 34
--- = None

Table 2-8
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Composite Analysis, Disposal Shafts

Constituent	Activity (Ci)				
	Pre-1971 Waste	1971–September 26, 1988 Waste	September 27, 1988-2007 Waste	2008–2044 Waste	Total
Ac-227	---	---	5.3E-07	---	5.3E-07
Ag-108m	---	---	4.4E+00	4.2E-08	4.4E+00
Am-241	---	4.0E-02	3.2E-01	1.2E-03	3.6E-01
Am-243	2.0E-02	1.1E-05	1.0E-09	---	2.0E-02
Ba-133	---	---	2.8E-03	---	2.8E-03
Bi-207	---	---	6.0E-05	7.3E-06	6.8E-05
C-14	---	1.1E+00	1.6E+01	3.5E-01	1.7E+01
Cf-252	4.0E+00	5.5E+01	9.6E-06	3.6E-05	5.9E+01
Cl-36	---	---	2.5E-04	---	2.5E-04
Cm-244	2.3E-04	1.9E-01	2.2E-03	9.3E-03	2.0E-01
Co-60	1.8E+01	2.8E+03	3.1E+03	3.8E+01	5.9E+03
Cs-135	---	---	4.5E-06	---	4.5E-06
Cs-137	6.3E-01	4.2E+01	8.3E+01	1.9E+00	1.3E+02
D38	6.2E-05	---	2.4E+00	7.0E+00	9.4E+00
Eu-152	1.2E-01	---	1.1E-02	3.0E-03	1.4E-01
Eu-154	---	---	9.8E-02	---	9.8E-02
Gd-148	---	---	7.7E-09	---	7.7E-09
H-3	6.1E+04	8.0E+05	1.7E+06	9.7E+05	3.5E+06
Ho-163	---	---	7.0E-02	---	7.0E-02
I-129	---	---	3.0E-08	---	3.0E-08
K-40	---	---	4.3E-07	2.0E-06	2.4E-06
Kr-85	---	4.5E-04	8.9E-03	3.7E-02	4.6E-02
MAP	8.0E+01	1.4E+04	5.6E+03	---	1.9E+04
MFP	2.7E+03	7.4E+03	6.0E+01	---	1.0E+04
Mo-93	---	---	1.3E-02	---	1.3E-02
Nb-91	---	---	9.4E-03	4.3E-02	5.3E-02
Nb-92	---	---	4.0E-03	---	4.0E-03

Source: Shuman, 2008, Table 35

--- = None

Table 2-8 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Composite Analysis, Disposal Shafts

Constituent	Activity (Ci)				
	Pre-1971 Waste	1971–September 26, 1988 Waste	September 27, 1988-2007 Waste	2008–2044 Waste	Total
Nb-93m	---	---	2.2E+00	1.0E+01	1.3E+01
Nb-94	---	---	1.3E-04	---	1.3E-04
Ni-59	---	---	2.6E+00	---	2.6E+00
Ni-63	---	4.3E-03	1.2E+03	4.6E+01	1.2E+03
Np-237	1.4E-04	7.8E-05	3.1E-08	1.4E-07	2.2E-04
Pa-231	---	---	2.7E-03	2.3E-07	2.7E-03
Pb-210	---	---	2.9E-08	1.2E-07	1.5E-07
Pu-238	5.6E+00	9.7E-01	2.6E-01	3.5E-02	6.9E+00
Pu-239	2.1E+01	8.3E+01	7.6E-02	3.2E-02	1.0E+02
Pu-240	3.4E-02	---	1.2E-03	---	3.6E-02
Pu-241	5.4E-03	7.3E-01	3.7E-02	---	7.7E-01
Pu-242	1.2E-04	3.1E-07	2.0E-06	---	1.2E-04
PU52	---	7.5E+01	5.7E-02	---	7.6E+01
PU54	---	2.0E-08	---	---	2.0E-08
Ra-226	1.0E-01	2.5E+00	7.8E-01	8.4E-05	3.4E+00
Sn-126	---	---	2.4E-02	---	2.4E-02
Sr-90	1.1E+00	9.5E-02	8.7E+01	1.8E+00	9.0E+01
Tc-99	---	---	1.2E-05	---	1.2E-05
Th-228	---	---	6.9E-04	3.2E-03	3.9E-03
Th-229	---	---	5.4E-08	---	5.4E-08
Th-230	5.7E-04	---	1.6E-08	---	5.7E-04
Th-232	1.7E-05	1.5E-02	1.9E-01	6.0E-02	2.7E-01
Th-88	---	4.0E-03	---	---	4.0E-03
Ti-44	---	---	2.0E-02	9.0E-02	1.1E-01
U(DEP)	---	---	4.4E-05	2.0E-04	2.5E-04
U(NAT)	---	---	1.8E-01	8.3E-01	1.0E+00
U10	---	3.0E-03	---	---	3.0E-03
U12	---	1.7E+00	---	---	1.7E+00

Source: Shuman, 2008, Table 35

--- = None

Table 2-8 (Continued)
Radionuclide, Activation Product, Fission Product, and Material Type Inventories for Waste Included in the Composite Analysis, Disposal Shafts

Constituent	Activity (Ci)				
	Pre-1971 Waste	1971–September 26, 1988 Waste	September 27, 1988-2007 Waste	2008–2044 Waste	Total
U-232	---	2.1E-01	2.0E-04	---	2.1E-01
U-233	1.5E+00	4.0E+00	5.8E-04	---	5.5E+00
U-234	7.8E-06	4.9E-06	5.0E-01	2.3E+00	2.8E+00
U-235	1.3E-02	9.8E-01	2.8E-02	1.3E-01	1.1E+00
U-236	1.2E-07	2.5E-05	3.8E-06	1.8E-05	4.7E-05
U-238	1.3E-06	9.5E+00	4.5E-01	1.1E+00	1.1E+01
U38	---	3.9E-02	---	---	3.9E-02
U81	---	2.3E-02	---	---	2.3E-02

Source: Shuman, 2008, Table 35

--- = None

3.0 Technical Approach to Closure

This section discusses specific activities that are, or will be, undertaken to close Area G in accordance with DOE Order 435.1 (DOE, 2001a), DOE M 435.1-1 (DOE, 2001b), and other applicable requirements. Section 3.1 discusses the requirements that the closure plan is subject to and identifies important closure activities and facility design features that, when implemented, will ensure these requirements are met. A detailed description of the identified closure activities and design features is provided in Section 3.2. Finally, Section 3.3 discusses the monitoring activities related to facility closure that will be conducted over the remainder of the disposal facility's lifetime.

3.1 Compliance with Performance Objectives and Other Requirements

A variety of waste types have been disposed of at Area G since operations began in 1957. Consequently, the disposal facility is subject to a range of regulations and guidelines, many of which govern and/or impact site stabilization and closure. These requirements include various DOE orders as well as regulations issued by the New Mexico Environment Department (NMED) and the U.S. Environmental Protection Agency (EPA).

The requirements for the management of radioactive waste generated, treated, stored, or disposed of at DOE facilities are set forth in DOE Order 435.1 (DOE, 2001a); specific requirements and responsibilities associated with the implementation of this order are provided in DOE M 435.1-1 (DOE, 2001b). In terms of LLW disposal, compliance with the order is demonstrated, in part, by satisfying a series of performance objectives. These performance objectives specify the maximum permissible doses for human receptors who are exposed to waste radionuclides and the maximum permissible radon fluxes from the surface of the disposal facility. The performance objectives that apply to the performance assessment and composite analysis and the exposure scenarios evaluated to demonstrate compliance with these criteria are summarized in Tables 3-1 and 3-2.

Sections 3.1.1 through 3.1.3 discuss important design features of the operational covers included in the Revision 4 performance assessment and composite analysis and the recently developed final cover design, and evaluate these features in terms of their impact on the ability of the disposal facility to satisfy the DOE M 435.1-1 performance objectives. Section 3.1.1 addresses the protection of groundwater resources, while Sections 3.1.2 and 3.1.3 consider all-pathways and air-pathway exposures, respectively. Protection of the inadvertent intruder and releases of radon from the disposal site are considered in Sections 3.1.4 and 3.1.5. As indicated above, Area G is subject to requirements in addition to the performance objectives found in DOE Order 435.1. The potential impacts of these additional requirements and the manner in which these requirements will be addressed through facility closure are discussed in Section 3.1.6.

Table 3-1
Summary of Performance Objectives Adopted for the Area G Performance Assessment

Phase of Facility Life Cycle	Performance Objective	Exposure Scenario	Compliance Point
Operational, Closure, and Active Institutional Control Periods	All pathways (25 mrem/yr)	All Pathways–Groundwater	Point of maximum exposure outside LANL boundary
		All Pathways–Cañada del Buey	Cañada del Buey
	Air pathway (10 mrem/yr)	Atmospheric	Point of maximum exposure outside LANL boundary
	Radon flux (20 pCi/m²/s)	---	Area G
	Water resources impacts (40 CFR 141 limits)	Groundwater Resource Protection	100 m downgradient of Area G
Passive Institutional Control Period	All pathways (25 mrem/yr)	All Pathways–Groundwater	Point of maximum exposure outside Area G fence line
		All Pathways–Cañada del Buey	Cañada del Buey
		All Pathways–Pajarito Canyon	Pajarito Canyon
	Air pathway (10 mrem/yr)	Atmospheric	Point of maximum exposure outside Area G fence line
	Radon flux (20 pCi/m²/s)	---	Area G
	Water resources impacts (40 CFR 141 limits)	Groundwater Resource Protection	100 m downgradient of Area G
	Inadvertent intruder (500 mrem/yr acute exposure)	Intruder-Construction	Area G
	Inadvertent intruder (100 mrem/yr chronic exposure)	Intruder-Agriculture	Area G
		Intruder–Post-Drilling	Area G

Source: LANL, 2008b, Table 1-1.

--- = Radon fluxes are projected in conjunction with the air pathway modeling.

Table 3-2
Summary of Performance Objectives Adopted for the Area G Composite Analysis

Phase of Facility Life Cycle	Performance Objective	Exposure Scenario	Compliance Point
Operational, Closure, and Active Institutional Control Periods	All pathways (100/30 mrem/yr) [a]	All Pathways–Groundwater	Point of maximum exposure outside LANL boundary
		All Pathways–Cañada del Buey	Cañada del Buey
	Air pathway (10 mrem/yr)	Atmospheric	Point of maximum exposure outside LANL boundary
Passive Institutional Control Period	All pathways (100/30 mrem/yr)[a]	All Pathways–Groundwater	Point of maximum exposure outside Area G fence line
		All Pathways–Cañada del Buey	Cañada del Buey
		All Pathways–Pajarito Canyon	Pajarito Canyon
	Air pathway (10 mrem/yr)	Atmospheric	Point of maximum exposure outside Area G fence line

Source: LANL, 2008b, Table 1-2.

[a] *The first performance objective(100 mrem/yr) is the DOE's primary limit for the protection of the public; the second performance objective (30 mrem/yr) is the dose constraint imposed on the composite analysis to ensure the disposal facility does not constitute an extraordinary portion of the primary dose limit.*

3.1.1 Groundwater Resource Protection

Revision 4 of the Area G performance assessment evaluated the potential impacts to groundwater resources using the Groundwater Resource Protection Scenario. This scenario evaluates the potential impacts of Area G on drinking water supplies in the vicinity of the disposal facility by evaluating potential exposures to persons who consume drinking water at a rate of 2 L/d (0.5 gal/d); projected doses are compared to groundwater standards published in the Code of Federal Regulations (40 CFR 141) (EPA, 2000). Doses were projected for receptors located 100 m (330 ft) downgradient of the disposal facility.

No radionuclides were projected to reach the regional aquifer during the 1,000-year compliance period by the probabilistic modeling; deterministic modeling indicated that only C-14 would discharge to the aquifer within 100,000 years of facility closure. The very low risk posed by the use of contaminated groundwater downplays the importance of adopting a strategy for closing Area G that is focused on limiting groundwater pathway exposures. Nevertheless, a discussion of the closure activities and design features that will provide assurance that groundwater pathways exposures will remain negligible is appropriate.

A number of disposal site, facility, and radionuclide-specific properties or features are responsible for any exposures that may be received by a groundwater user. Important site features include the low annual precipitation at Area G and the great distance between the disposal units and the regional aquifer. The majority of on-site precipitation either runs off into the adjacent canyons or undergoes evapotranspiration, thereby limiting the amount of water that percolates through the waste. Low rates of infiltration, in conjunction with the sorption properties of the radionuclides, limit contaminant release rates within the pits and shafts, and result in long contaminant migration times to the aquifer. As a result, mobile radionuclides that are discharged to the aquifer tend to be present at low concentrations. The performance assessment and composite analysis modeling estimated contaminant travel times to the aquifer that are far in excess of the 1,000-year compliance period.

The preceding discussion indicates that an effective Area G closure strategy for limiting groundwater pathway exposures should minimize the rate of water infiltration through the disposed-of waste. An effective means of accomplishing this goal is to maximize rates of water loss due to evaporation and transpiration. Nyhan et al. (1990) found that evapotranspiration accounted for the removal of almost 90 percent of the precipitation from two control plots over a 3-year period; information cited in a LANL report (LANL, 2003b) indicates that the ratio of potential evapotranspiration to precipitation is greater than 6:1. The effects of evapotranspiration on infiltration rates are also apparent from work done by Newman et al. (2005), who estimated long-term moisture fluxes in piñon-juniper woodland just west of Area G on the basis of pore-water chloride concentrations. Samples were collected from 1 to 2 m (3.3 to 6.6 ft) deep boreholes underneath tree canopies and in intercanopy spaces. The fluxes estimated for these areas were generally around 0.1 to 0.4 mm/yr (3.9×10^{-4} to 0.016 in./yr), a small fraction of current-day rates of precipitation.

The final cover proposed for Area G is designed to function as an evapotranspiration cover system, employing vegetated soil layers to retain the water until it is removed through evaporation or plant transpiration. The top layers of the cover are to be installed at relatively low compaction levels, which will help plants become established. The bulk of the cover consists of crushed tuff with a 6 percent bentonite admixture. The clay helps increase the compactibility of the soil and is also expected to play a role in reducing rates of water infiltration. Levitt estimated infiltration rates for the final cover using HYDRUS; the infiltration rates projected using the model ranged from 1×10^{-4} to 0.61 mm/yr (3.9×10^{-6} to 0.024 in./yr) under vegetated conditions.

3.1.2 All-Pathways Exposures

Revision 4 of the Area G performance assessment and composite analysis projected doses for several receptors to demonstrate compliance with the all-pathways performance objective. These receptors include an individual residing downgradient of the disposal facility and persons living at several locations within Cañada del Buey and Pajarito Canyon, adjacent to Area G. The downgradient receptor was projected to receive exposures from radionuclides that are leached from the waste by infiltrating water and subsequently transported through the unsaturated and saturated zones to locations east of Area G; potential exposures for this individual were projected using the All Pathways–Groundwater Scenario. Exposure pathways include the inhalation of airborne contaminants; ingestion of contaminated water, soil, crops, and animal products; and direct radiation from contaminated soils and suspended dust. Exposures received by the canyon residents were estimated using the All Pathways–Canyon Scenario. These individuals were assumed to be exposed to contamination that is deposited on the surface of Mesita del Buey by plants and animals intruding into the buried waste, and transported into the canyons with surface runoff. The canyon residents were assumed to inhale airborne radioactivity; ingest contaminated soil, crops, and animal products; and receive direct radiation from soils and suspended dust.

No doses were projected to occur during the 1,000-year compliance period for the All Pathways–Groundwater Scenario, reflecting the long contaminant travel times to the regional aquifer. The lack of exposure projected for this period is due, in part, to the ability of the final cover to limit the amount of water that infiltrates through the disposal units. Features of the cover design that have the greatest impact on rates of infiltration were discussed in Section 3.1.1.

Peak mean doses were projected for nine exposure locations in Cañada del Buey and Pajarito Canyon under the All Pathways–Canyon Scenario. In terms of the performance assessment, the largest peak mean dose among these locations was 2.3 mrem/yr; the maximally exposed composite analysis receptor was projected to receive a peak mean dose of 4.4 mrem/yr. The dose projected for the performance assessment is about 9 percent of the 25 mrem/yr performance objective; the projected exposure for the composite analysis is about 15 percent of the 30-mrem/yr dose constraint.

Several characteristics of the disposal site and facility, as well as properties of the radionuclides found in the waste, will affect the magnitude of the doses estimated for the All Pathways–Canyon Scenario. The rooting and burrowing characteristics of the plants and animals that inhabit Area G, in conjunction with the design features of the cover system, will determine the potential for biotic intrusion into the waste. An effectively designed cover may largely exclude biota from the waste and thus minimize radionuclide releases to the surface environment. If contamination is deposited on the surface by plants and animals, the rate at which the radionuclides are transported into the adjacent canyons will have an important effect on the exposures received by the receptor. This rate of transport is a function of the surface erosion rate at Area G, which is a complex function of site topography, meteorological conditions, and cover configuration. The mesa-canyon topography that is characteristic of TA-54 also affects the manner in which mesa-top contamination is distributed in Cañada del Buey and Pajarito Canyon and the resultant radionuclide concentrations in canyon soils. Finally, radionuclide plant uptake factors will influence how much contamination is deposited on the surface of the disposal facility by plants that penetrate into the waste.

The preceding discussion indicates that an effective closure strategy for Area G in terms of the All Pathways–Canyon Scenario will focus on excluding biota from the waste. Although a number of cover designs exist that incorporate biobarriers for this purpose, the final cover design evaluated by Revision 4 of the performance assessment and composite analysis does not rely on engineered barriers of this type. Rather, the degree to which plants and animals may penetrate into the waste is controlled, primarily, by the overall thickness of the cover placed over the waste units. The proposed final design calls for a minimum of 2.5 m (8.2 ft) of cover over all disposal units; actual cover depths tend to be much greater than this over most of the pits and shafts. Based on the modeling results, this approach effectively limits the impacts of biotic intrusion.

Rates of surface erosion at Area G may have significant impacts on the doses projected for the All Pathways–Canyon Scenario. Erosion will reduce the thickness of the covers placed over the pits and shafts, thereby permitting greater access to the waste. Greater penetration into the waste by the plants and animals at the site will cause radionuclide releases to the surface of Area G to increase, resulting in greater exposures to the canyon resident. The mesa-top erosion rate will also determine how much contaminated soil is transported into the canyon with runoff. As rates of transport into the canyon increase, so will the doses received by the receptor.

As discussed in Section 2.2.2, the potential impacts of surface erosion on long-term cover performance were explicitly considered in the cover design process. The degradation of the final cover due to surface erosion was modeled throughout the 1,000-year compliance period, taking into account spatial variations in erosion pressures across the disposal facility. Rates of cover loss were taken into account when estimating rates of biotic intrusion into the waste and when projecting rates of sediment transport from the mesa top to Cañada del Buey and Pajarito Canyon.

The long-term ability to limit plant and animal intrusion and to minimize rates of cover loss due to erosion will depend upon the long-term stability of the covers placed over the pits and shafts. Perhaps the greatest threat to the stability of the covers is subsidence, which occurs as soils settle or collapse to fill void spaces within the disposal units. Actual impacts on the facility will, of course, depend upon which disposal units are impacted and the degree to which the integrity of the affected pits and shafts is undermined. In general, however, subsidence could lead to increased access to the waste by plants and animals inhabiting the site and, conceivably, to more severe rates of cover loss due to erosion.

Isolated incidences of subsidence have been observed at Area G. Most of these have consisted of small holes developing next to several disposal shafts. However, more significant subsidence events have been also been observed. In 2004, a 1 to 1.5 m (3.3 to 5 ft) diameter hole of unknown depth developed in a portion of pit 15. Pit 15 was dedicated to the disposal of waste packaged in metal and wood containers of various proportions; comparisons of the volumes of waste placed in these containers and the capacities of the packages suggest that many of these containers were incompletely filled. Also in 2004, a 1 to 1.5 m (3.3 to 5 ft) diameter hole of unknown depth developed between pits 32 and 33; these pits received mostly uncontainerized waste in the mid-1980s. In 2005, subsidence occurred over an area of approximately 46 m^2 (500 ft^2) within pit 9; the maximum depth of the depression was about 0.6 m (2 ft). This pit contains retrievably stored TRU waste that was packaged in wooden boxes and metal drums to facilitate its retrieval. Finally, a 1 to 1.5 m (3.3 to 5 ft) diameter hole of unknown depth developed in pit 31 in 2005. This pit received both containerized and bulk (uncontainerized) waste (French, 2005b).

Subsidence of incompletely filled disposal units was not explicitly modeled in Revision 4 of the performance assessment and composite analysis nor was it assumed to impact the long-term performance of the disposal facility. Instead, it was assumed that efforts will be taken to minimize or eliminate subsidence potential by the time the facility undergoes final closure. Obviously, the effectiveness of these efforts will have a significant impact on the long-term viability of the final cover design presented in this report.

Historically, uncontaminated crushed tuff was added to the disposal shafts after each waste disposal to fill void spaces between the waste and the shaft walls. This fill aided in shielding personnel from direct radiation emitted by the waste and improved the stability of the disposal unit. Waste was not compacted after placement in the disposal shafts because of practical considerations, "as low as reasonably achievable" (ALARA) principles, and safety requirements. The practice of backfilling shafts with crushed tuff was stopped for several years in the mid-to-late 1990s.

The lack of compaction in the older shafts and the cessation of backfilling in the units used in the mid-to-late 1990s may increase the potential for subsidence of the covers placed over these units. In recognition of this, the draft shaft disposal procedure issued in 1998 (LANL, 1998b) called for a 5-year delay between the time a shaft was filled and the placement of the operational cover. This delay was intended to allow for the correction of subsidence due to settlement in the shaft. During the 5-year period, crushed tuff was to be mounded over the top of the shafts and allowed to fill any void spaces created during settlement of the waste. At the end of the 5-year period, any remaining mounded tuff was to be removed and the operational cover applied. More recently, changes were adopted to reinstitute the practice of using crushed tuff to backfill shafts as they are filled with waste.

3.1.3 Atmospheric Scenario Exposures

The Atmospheric Scenario considers potential doses received by receptors living downwind of Area G. Volatile radionuclides may diffuse upward from the waste and enter the air over the disposal facility, while contaminated soils may be resuspended. Transport of these releases by the prevailing winds at the site may result in exposures to individuals living near the site. Revision 4 of the performance assessment and composite analysis projects atmospheric pathway doses for receptors located at the points of maximum exposure along the LANL boundary and the Area G fence line. Exposures to these individuals result from the inhalation of airborne radionuclides, the ingestion of soil and crops contaminated by atmospheric deposition, and direct radiation from soil and airborne contamination.

The performance assessment modeling projected peak mean doses of 0.18 and 0.014 mrem/yr for the receptors at the LANL boundary and Area G fence line, respectively; the composite analysis modeling projected peak mean doses of 0.23 and 0.64 mrem/yr for the receptors at the Laboratory boundary and Area G fence line, respectively. The peak doses projected for the LANL boundary receptor result from the inhalation of tritiated water vapor diffusing from the disposal facility, while the exposures projected for the fence line resident result from particulate releases.

Exposures from vapors and gases diffusing from Area G are influenced by several site, facility, and radionuclide-specific characteristics. Meteorological conditions at the site affect the rates of diffusion of volatile radionuclides from the disposal shafts through changes in barometric pressure, and determine the degree to which releases are dispersed before they reach the receptor locations. Characteristics of the waste and cover soil (e.g., porosity and moisture content) influence rates of gaseous diffusion from the site, as do facility characteristics such as the thickness of the waste and overlying cover. Radioactive gas is generated from only a portion of the inventory. For example, C-14 gas is generated through biodegradation of organic waste; such waste represents only a portion of the material disposed of at Area G. Thus, the distribution of the inventory among waste forms is an important factor. Finally, rates of diffusion from the disposal site will depend, in part, upon radionuclide-specific diffusivities.

The peak mean doses projected for the LANL boundary exposure locations are low relative to the 10-mrem/yr Laboratory-wide performance objective. Steps could be taken to further reduce diffusive releases from the surface of the disposal facility, including the addition of more cover over the waste and packaging of the waste to slow releases within the waste itself. However, the results of the dose assessment suggest that such efforts would not be cost effective.

The peak mean exposures projected for the Area G fence line receptor ultimately depend upon the rate at which contamination is deposited on the surface of Area G by plants and animals intruding into the waste. Consequently, it is not surprising that many of the influential site, facility, and radionuclide-specific characteristics discussed earlier with respect to the All Pathways–Canyon Scenario play important roles for this pathway. The meteorological conditions at Area G also influence how contaminated soils are resuspended from Area G and dispersed prior to reaching the receptor locations.

The importance of biotic intrusion in the atmospheric pathway for the composite analysis indicates that an effective closure strategy for the facility will focus on minimizing or preventing penetration of the waste by roots and burrows. Instead of engineered biointrusion barriers, the proposed cover design relies on the thickness of the cover material to limit biotic intrusion. The low exposures projected to occur as a result of particulate resuspension suggest that the final cover design keeps biotic intrusion pressures in check. Of course, this conclusion depends, in part, on the effectiveness of measures taken to limit or prevent subsidence of the final cover.

3.1.4 Intruder Protection

The Revision 4 performance assessment projects exposures for persons who inadvertently intrude into the waste disposed of at Area G since September 26, 1988. Separate exposures were projected for waste placed in pits from September 27, 1988 through 2010 and from 2011 through 2044, and in shafts from September 27, 1988 through 2015 and from 2016 through 2044. The projected exposures were compared to the chronic and acute performance objectives of 100 and 500 mrem/yr, respectively. Additional intruder analyses were conducted to establish radionuclide concentration limits for waste placed in the 1988–2010 pits and 1988–2015 shafts.

Dose projections were prepared for three intruder scenarios—the Intruder-Construction, Intruder-Agricultural, and Intruder–Post-Drilling Scenarios. Peak mean exposures for the three scenarios ranged from about 0.53 to 4.1 mrem/yr for the 1988–2010 pits and from 0.028 to 0.69 mrem/yr for the 2011-2044 pits. The intruder analysis projected peak mean exposures ranging from 5.1 to

89 mrem/yr for the 1988–2015 disposal shafts; for the 2016–2044 shafts, the peak mean doses for the construction, agricultural, and postdrilling scenarios were 2.5, 49, and 3.1 mrem/yr, respectively. All construction worker exposures are less than the 500 mrem/yr acute dose limit; all of the peak mean doses projected for the agricultural and postdrilling intruders fall below the 100 mrem/yr chronic dose objective.

The primary design feature that determines the magnitude of the projected exposures for the construction and agricultural intruders is the depth of the cover placed over the waste. In general, as the thickness of the cover increases, the projected intruder doses decrease. This is seen in the results of the intruder analysis, where the greater average thickness of the cover placed over the disposal pits, in conjunction with the smaller radionuclide inventories in these units, results in construction and agricultural intruder exposures that are much lower than those projected for disposal shafts. In contrast, the postdrilling intruder is exposed to contamination regardless of the depth of disposal, thus the thickness of the cover is much less important in this scenario.

The intruder analysis was used to develop WAC, which limit the quantities of waste that may be disposed of at Area G. These limits were developed on the basis of the final cover design and its projected performance over the 1,000-year compliance period.

3.1.5 Radon Flux

The radon flux analysis conducted in support of Revision 4 of the performance assessment estimated rates of diffusion of Rn-220 and Rn-222 from the surface of the disposal facility. These isotopes are members of the Th-232 and Th-230 decay chains, respectively. Once generated, they diffuse upward from the waste and enter the air over Area G. Projected fluxes for different segments of the disposal facility were used to estimate an average site-wide flux; this flux must be less than or equal to 20 pCi/m^2/s or result in an incremental increase in the air concentration of radon of 0.5 pCi/L at the boundary of the disposal facility in order to demonstrate compliance with DOE M 435.1-1.

The radon fluxes projected for the performance assessment range from about 1.8×10^{-6} pCi/m^2/s to 14 pCi/m^2/s for different segments of the disposal facility; a site-wide average peak flux of 0.43 pCi/m^2/s was estimated. All projected peak mean fluxes comply with the flux objective.

The magnitude of radon fluxes from disposal units at Area G will depend upon several site, facility, and radionuclide-specific characteristics. Meteorological conditions at the site affect the rates of diffusion of volatile radionuclides from the disposal shafts through changes in barometric pressure. Characteristics of the soils at Area G (e.g., porosity and moisture content) influence rates of radon emanation from the waste and the rates of diffusion in the waste and cover soils. Facility characteristics such as the thickness of the waste and overlying cover affect rates of radon discharge from the site surface. Finally, rates of diffusion from the disposal site will depend upon radionuclide-specific diffusivities.

In terms of Area G, the primary design feature used to maintain radon fluxes at acceptable levels is the total thickness of the cover placed over the waste. The proposed cover design appears to perform adequately, given the results of the performance assessment modeling.

3.1.6 Other Requirements

The activities undertaken and the design features used to close Area G will be influenced by factors in addition to those related to satisfying the DOE M 435.1-1 performance objectives. These additional requirements take into account the effects of releasing Area G for unrestricted use and the need to comply with regulations that govern the disposal of mixed wastes. The impacts of these additional requirements on the closure of Area G are discussed in the following sections.

3.1.6.1 Release of Area G for Unrestricted Use

In accordance with DOE M 435.1-1 (2001b), LLW disposal sites should eventually be released for unrestricted use pursuant to DOE Order 5400.5 (DOE, 1993). In the event that release of the site for unrestricted use cannot be safely accomplished, the DOE may choose to maintain control over sites indefinitely, as long as this action is consistent with land use and stewardship plans and programs. Revision 4 of the Area G performance assessment and composite analysis assumes the DOE will maintain active institutional control over the disposal site for a period of 100 years after facility closure. Passive institutional control is assumed to continue after the initial 100-year period until a time when the disposal facility no longer poses an unacceptable risk to human health and safety and the environment. It is unclear when passive institutional control will cease.

Once a site is released from DOE control, on-site activities are no longer restricted. Access to the site will likely result in exposure to higher environmental concentrations of waste radionuclides, leading to doses that are significantly greater than those projected for off-site receptors. Under DOE Order 5400.5, doses to on- and off-site receptors are limited to 100 mrem/yr from all DOE activities and all exposure modes. This order also specifies limits for exposures to airborne emissions (10 mrem/yr), exposures to contaminated drinking water, and radon fluxes (20 pCi/m^2/s).

The design of the final cover will play an important role in minimizing doses to on-site receptors and thus is likely to be a key element in the decision to release Area G for unrestricted use. To enable such release, the cover will need to prevent or minimize biotic intrusion into the waste, resist severe erosion, and limit human intrusion, as discussed previously.

Although the evaluation of exposures to members of the public did not include on-site residents, the results of the performance assessment and composite analysis suggest the final closure configuration can satisfy the performance objectives for on-site receptors during the 1,000-year compliance period. However, additional modeling would be required to confirm this expectation. It is not clear that members of the public who reside at the disposal site well beyond the compliance period will be adequately protected. Thus, it is reasonable to expect that active maintenance of the site will be necessary to maintain on-site exposures within acceptable limits for many thousands or tens of thousands of years in the future.

The release of Area G for unrestricted use increases the opportunities for human intrusion into the waste. The intruder analysis conducted in support of the performance assessment addressed only the waste disposed of since September 26, 1988, consistent with DOE regulations. However, if Area G is released for unrestricted use, it is reasonable to assume that human intrusion into any portion of the inventory may occur. Consequently, intruder exposures resulting from disturbance of the waste disposed of prior to September 27, 1988 need to be considered. Exposures from some of the older waste disposed of at Area G may be significantly greater than the intruder performance objectives.

3.1.6.2 Other Waste Regulations

As discussed in Section 1.1 of this report, Area G has been, and continues to be, used for a variety of waste management functions. Consequently, the facility is subject to requirements that do not normally apply at LLW disposal facilities. Some of these requirements will affect the manner in which the disposal facility is closed.

Low-level waste disposed of at Area G prior to September 27, 1986 may include hazardous materials as defined by RCRA (1976, as amended) and thus is subject to RCRA requirements. Most of the pits and shafts containing MLLW are subject to the corrective action requirements found in 40 CFR 264 Subpart S, which invokes the closure requirements found in Subpart G. Pit 29 and shaft 124, which inadvertently received hazardous waste after 1980, are subject to the closure requirements found in 40 CFR 264 Subpart N. Under an agreement with the EPA, RCRA requirements are enforced by the NMED.

The RCRA requirements pertaining to closure are based on technical design, rather than the performance-based standards found in the DOE orders discussed above. General requirements found in 40 CFR 264 Subparts G and N call for owners and operators to close hazardous waste facilities in a manner that:

- Minimizes the need for future maintenance
- Controls, minimizes, or eliminates postclosure escape of hazardous constituents, leachate, contaminated runoff, or decomposition products to groundwater, surface water, and the atmosphere

- Promotes drainage and minimizes erosion or abrasion of the cover
- Accommodates settling and subsidence to maintain the cover's integrity

Many of the cover design features discussed with respect to satisfying the DOE requirements also help satisfy the standards set by RCRA. Minimizing water infiltration through the waste to limit groundwater pathway doses will address the RCRA requirement calling for the control of contaminant releases to groundwater. Limiting plant and animal intrusion into the waste to minimize Atmospheric and All Pathways–Canyon Scenario exposures will help control contaminant releases to surface soils, surface water, and the atmosphere. The ability of Area G to satisfy the DOE requirements over long periods of time requires that the cover maintain its integrity and, therefore, that subsidence of disposal units be minimized. Achieving this objective will help satisfy the technical requirements found in RCRA.

Closure of MDA G is the responsibility of the CAP; as discussed earlier, current plans call for closure of this area to be completed by about 2015. The CAP will evaluate the final cover design presented in this plan to determine if it satisfies the requirements governing the closure of this portion of Area G.

3.2 Detailed Closure Activities

The objective of disposal facility closure is to achieve long-term stability of the waste in a manner that protects human health and safety, and the environment, while minimizing the need for active maintenance. Section 3.1 discussed the criteria against which the protection of human health and safety and the environment are measured, and identified the design features of the disposal facility that contribute to providing the needed level of protection. This section identifies a closure approach and closure design features that will provide the level of protection required while satisfying the stability and maintenance requirements of DOE M 435.1-1. Detailed information needed to implement the approach and design features is also discussed.

Disposal operations at Area G began in 1957 and are currently assumed to continue until the year 2044. Disposal pits and shafts undergo operational closure as they are filled with waste. Section 3.2.1 summarizes the approach and cover design features that have been used for operational closure in the past, and details the methods and features anticipated for future operational closures. Material Disposal Area G is scheduled to undergo final closure by 2015; the Zone 4 expansion area will be closed when disposal operations cease in 2044. The activities to be conducted in support of final closure and the configuration of the cover are discussed in Section 3.2.2. It is assumed that DOE will maintain control of the disposal site throughout the active institutional control period; the inspection and maintenance activities that will be conducted to ensure proper functioning of Area G during this period are discussed in Section

3.2.3. Finally, criteria for deciding when the disposal site can be released for unrestricted use and the activities associated with any such release are considered in Section 3.2.4.

3.2.1 Operational Closure

Operational closure of the disposal pits and shafts has been conducted at Area G since 1961, when pit 1 was backfilled to ground level. Operational closure of disposal units will continue until the last waste is disposed of at the facility. The operational closure activities and design features have evolved over time; both historical and future closure activities are discussed below.

3.2.1.1 Operational Closure Strategy and Cover Performance for Disposal Pits

Disposal pits 1 through 4 were constructed in accordance with Materials Waste Pits Standard Specifications Engineering Drawing ENG-C 18463, as referenced in Rogers (1977). This drawing, a copy of which is presented in Figure 3-1, shows a pit in plan view, in longitudinal cross section, and in cross section at right angles to the pit. Pits were specified to be no more than 183 m (600 ft) long, 30 m (100 ft) wide, and 7.6 m (25 ft) deep. As noted on the drawing, final pit depth was to be determined by field conditions. No minimum cover depth requirements were included in the drawing.

Formalized guidelines for disposal unit construction and closure were proposed by the USGS in 1965 (Koopman, 1965), and adopted by the Laboratory. Pit 5 was the first disposal unit constructed and closed using these guidelines and the new standard pit specifications (Figure 3-2). The 1965 guidelines relevant to the disposal of waste and closure of pits can be summarized as follows:

- Continue to dispose of waste in layers, separated by layers of tuff.
- Fill pits to within 0.6 m (2 ft) of the land surface.
- Ensure that the seal material, or tuff, that overlies the waste ranges from 1.8 to 2.4 m (6 to 8 ft) in thickness.
- Ensure that the surface of the seal material placed over the pits is slightly rounded.
- Provide adequate drainage on the mesa to remove runoff from precipitation.

A memorandum entitled *Guidelines for Construction and Use of Solid Waste Disposal Facilities* (LANL, 1975) formalized disposal operations further, modifying some of the 1965 guidelines discussed above. The 1975 guidelines address disposal unit siting, construction, operations, closure, and monitoring activities. The guidelines that pertain directly to the long-term stability of the disposed waste and closure of the filled pits include the following:

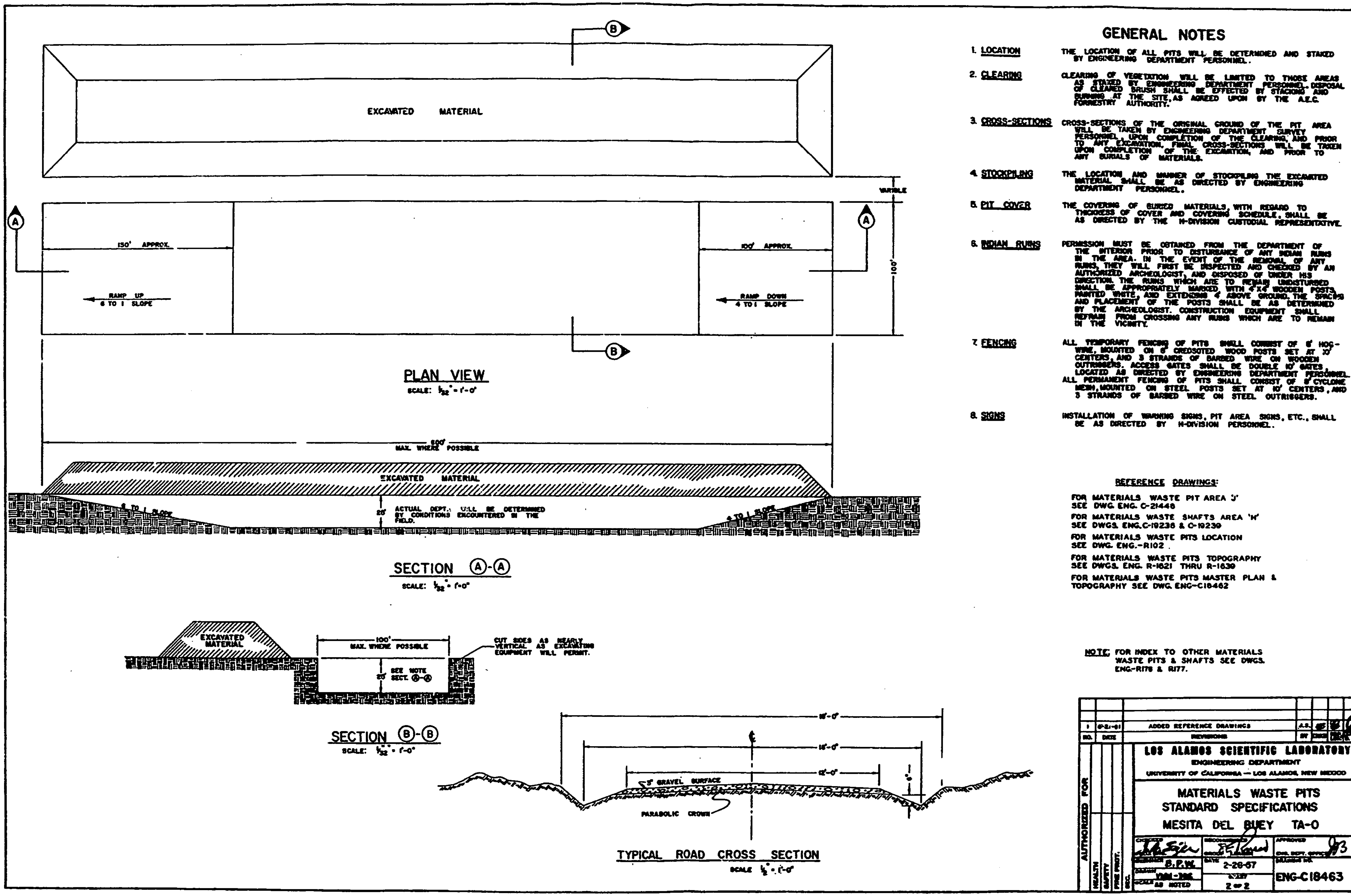


Figure 3-1
Standard Specifications for Waste Disposal Pits 1 through 4

(Drawing no. C25703 and R-3637)

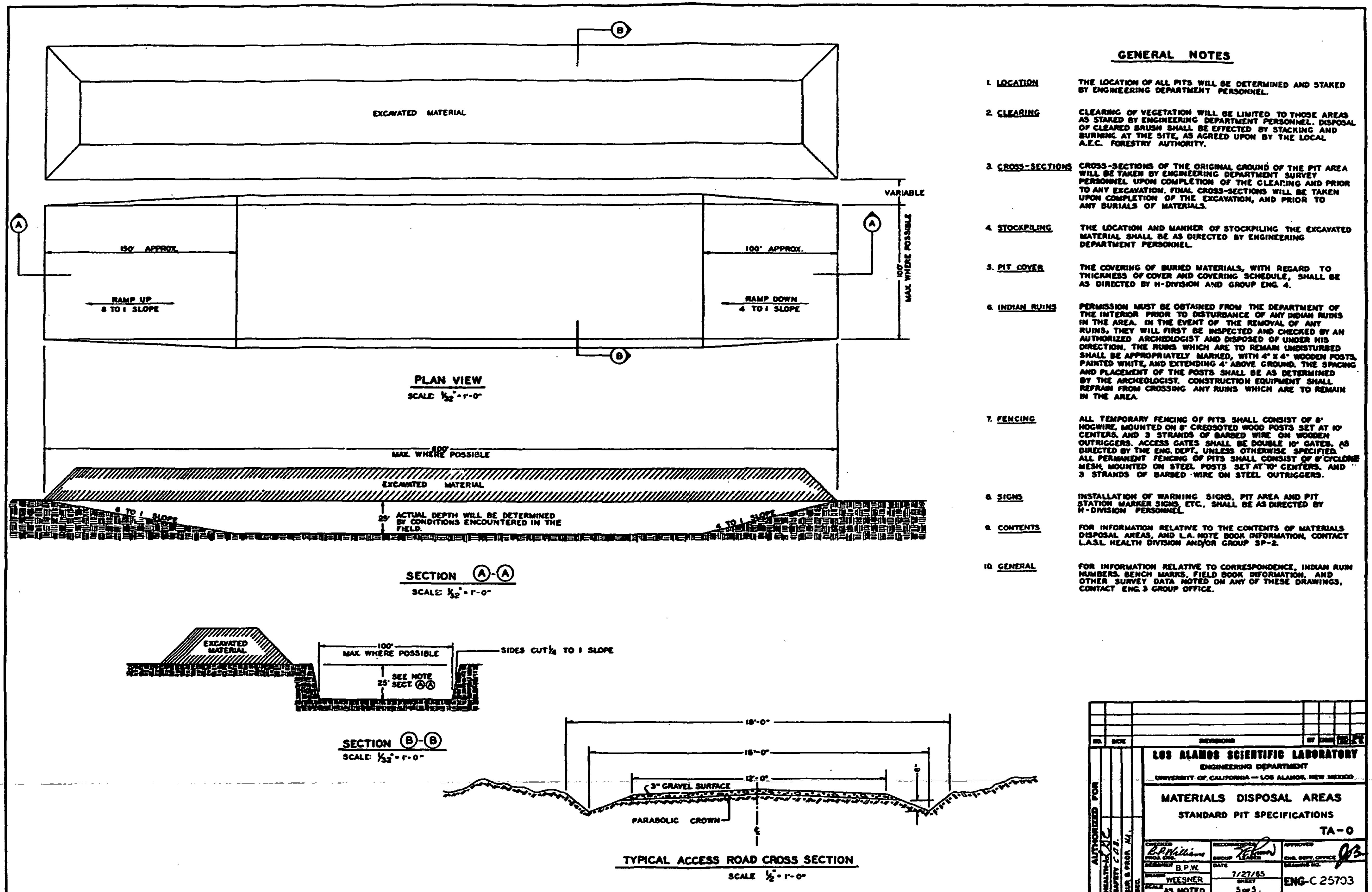


Figure 3-2
Standard Pit Specifications Adopted by the Laboratory in 1965

(Eng.–C25703)

- Crushed tuff 15 to 30 cm (0.5 to 1 ft) deep shall be compacted on the floors of pits prior to emplacement of wastes. Open joints and fractures in pit walls, access ramps, and floors that are open 5 cm (2 in.) or more shall be filled with sealing material.

- Drainage features shall be constructed and maintained so that surface runoff does not enter the pits.

- Roads shall be planned so that vehicles or equipment do not traverse rehabilitated areas.

- Waste shall be placed in layers; successive layers shall be separated by approximately 15 cm (0.5 ft) of compacted crushed tuff.

- Pits shall be filled with waste to a minimum depth of 0.9 m (3 ft) below the spill point, or the lowest point on the pit rim.

- The final cover of a pit shall be crushed tuff overlain by topsoil, and shall be a minimum of 0.6 m (2 ft) above the original land-surface at the edge of the pit. The cover will extend beyond the edges of the pit at least 0.9 m (3 ft).

- The surface of the final pit cover shall be slightly rounded to allow surface drainage without excessive erosion.

- Provisions shall be made to control runoff in the disposal area to minimize infiltration and erosion of the final pit covers.

- Benchmarks shall be placed at the corners of each pit. The benchmarks (at least 30 cm [12 in.] in diameter) shall be set into the bedrock and extend through the operational cover at the corners of each pit. The benchmark will be a single pour of cement with a standard brass cap that contains engineering data (cap number, LANL coordinates, and elevation and disposal data.) These benchmarks are to be tied into the disposal and engineering records so that if materials are to be retrieved, they can be found with a minimum of effort and disturbance to the final cover.

- Native vegetation shall be left in areas between pits.

- Turf-forming grasses and bunch grasses shall be planted in the final cover to prevent wind and sheet erosion.

LANL issued a procedure in 1996 that addresses the design, construction, use, and closure of disposal pits and shafts at Area G (LANL, 1996); the guidelines found in this procedure generally adhere to the 1975 memorandum. Revised guidelines were issued in draft form in 1998 (LANL, 1998b). Although these guidelines generally conform to those issued in 1975, some changes were implemented to address practical considerations and to implement procedural improvements. Most significantly, the requirement that waste be disposed of to a minimum depth of 0.9 m (3 ft) below the "spill point" of the pits was changed to 3 m (10 ft) below the disposal unit rim. Exceptions to this requirement were acceptable as long as the Area G WAC were satisfied and the waste was a minimum of 2 m (6.6 ft) below the rim of the disposal unit. Also, the requirement that no roads traverse closed disposal units was relaxed due to the limited area available at Area G for waste management activities. A disposal procedure issued in 2009 (LANL, 2009) prohibits the placement of waste within 3 m (10 ft) of the edges of the pits and shafts.

A revised procedure for the design, construction, and operational closure of Area G pits and shafts was issued in 2008 (LANL, 2008a). Under these requirements, operational covers are constructed of crushed tuff taken from approved stockpiles. With respect to the disposal pits, crushed tuff is placed in 20 cm (8 in.) thick lifts with earthmovers or scrapers, and then consolidated in place using standard earthmoving equipment. This process is continued until the level of the consolidated tuff has reached the ground surface. The operational covers are to conform to the surrounding grade, with slopes not to exceed 5 percent.

Benchmarks are placed at all four corners of the pit immediately after placement of the operational cover or as soon as facility operations permit; these benchmarks are linked with the disposal and engineering records to facilitate material recovery should it become necessary. The benchmark consists of a buried 30 cm (12 in.) diameter concrete column that extends at least 15 cm (6 in.) above the ground surface. A standard brass cap is placed into the top of the concrete benchmark with appropriate engineering records (e.g., disposal unit and disposal data). Finally, an easily identifiable fiberglass stake displaying the pit and corner identification number is placed next to each benchmark. Figure 3-3 shows a typical benchmark design.

The next step in the operational closure process depends upon the intended use of the disposal unit. In practice, if the surface of the disposal pit is not needed for temporary waste management operations, the completion of the operational cover is followed immediately by the placement of 1 m (3.3 ft) of crushed tuff surcharge. Taking care to prevent damage to the operational cover, this material may be placed in successive lifts or as a single layer. The surcharge material is consolidated in place using standard earthmoving equipment. The final bench of surcharge material is contoured to correspond with the existing grade with a maximum slope of 2 to 5 percent; slopes along the sides of the surcharge are not to exceed 3:1. Figure 3-4 shows a plan view and cross-sections of the operational pit cover with and without surcharge material. The surcharge material is not applied if the surface of the filled disposal pit will be used for the construction of temporary surface structures that are needed for waste management operations. The surcharge material is seeded with native grasses and forbs immediately after placement, if placement occurs between October 1 and July 31. Otherwise, the surcharge material is scarified and tracked perpendicular to the slope to minimize erosion, but seeding is delayed until October.

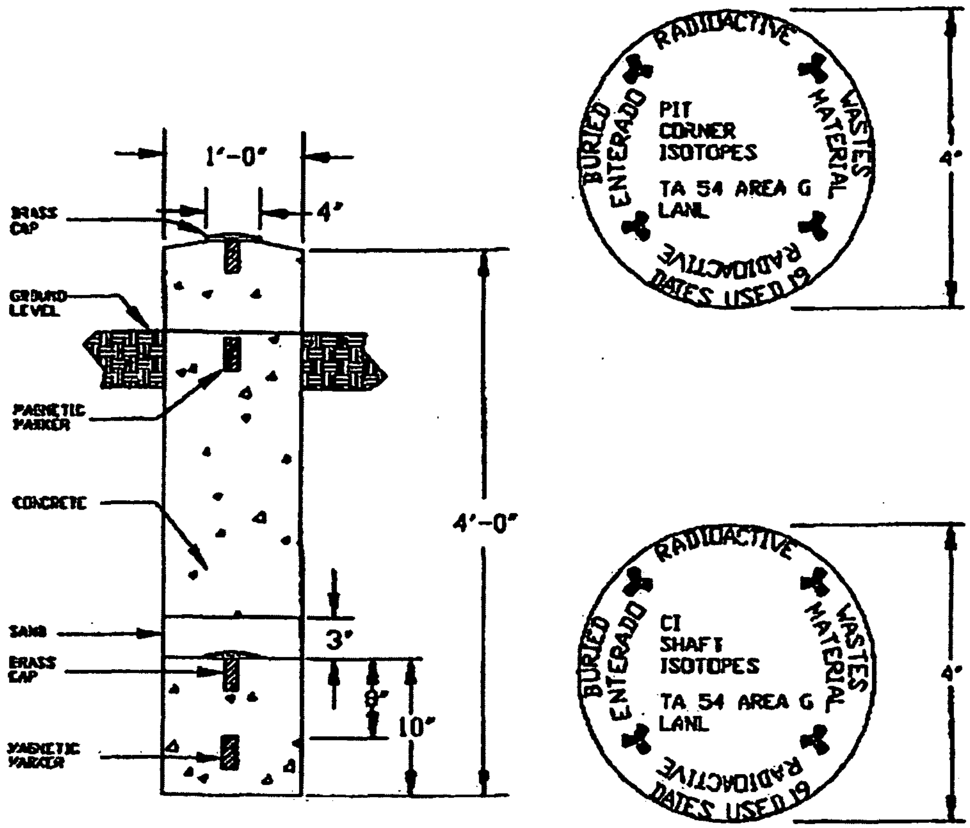


Figure 3-3
Typical Pit and Shaft Benchmark Designs

Figure 3-4a
Plan view of pit with operational cover

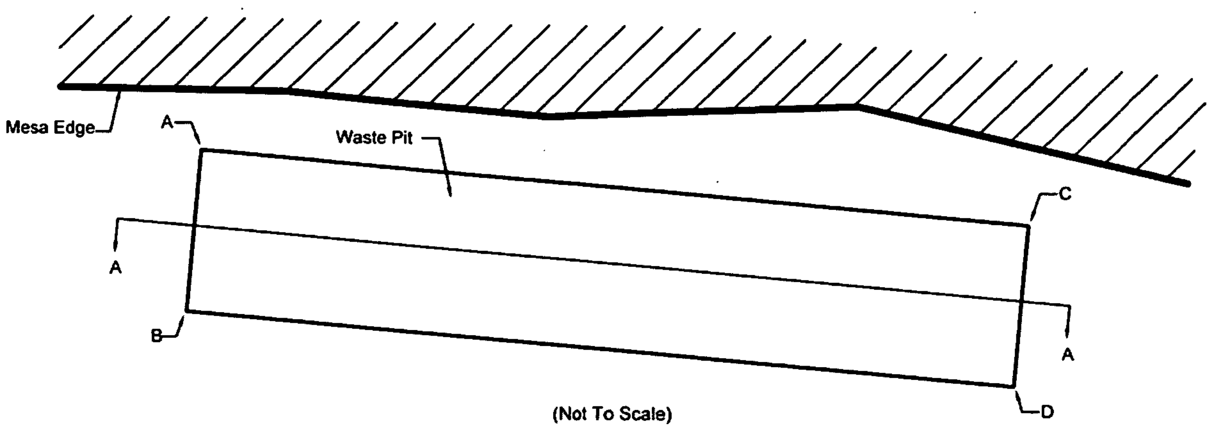


Figure 3-4b
Cross sections of pits with operational cover

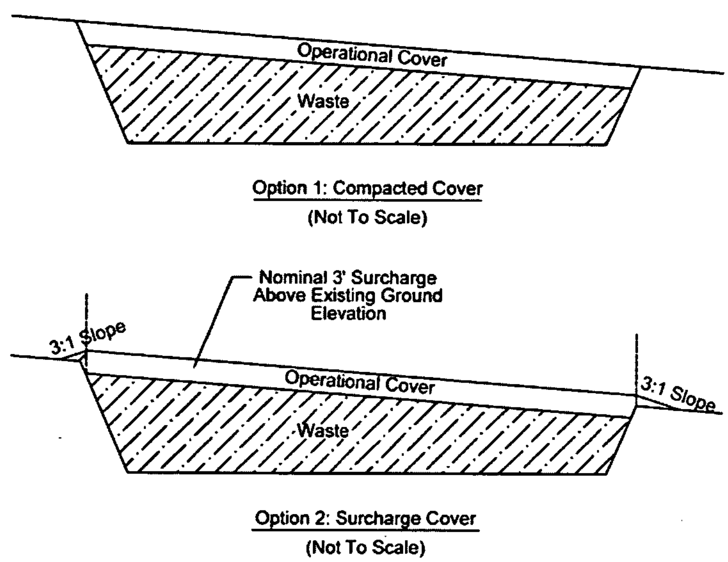


Figure 3-4
Operational Pit Cover

In general, the surcharge is left in place until the site undergoes final closure. However, the material may be removed prior to final closure if the area is needed for waste management operations. In this case, the surcharge material may be removed if conditions at the site indicate subsidence of the disposal unit is unlikely and the material has been in place for at least 1 year since the disposal unit underwent operational closure or the last significant subsidence event.

The operational closure process is fully documented and is subject to rigorous quality control. Drawings showing plan, profile, and section views of the disposal unit and operational cover are developed. The suitability of the materials used to construct the cover must be evaluated in terms of the material specifications prior to their use, and all surveying activities must conform to State of New Mexico standards for professional surveying. Actual construction of the cover must conform to construction quality assurance procedures and all records associated with cover construction must be maintained in accordance with LANL document control procedures.

Site operators monitor and maintain operational covers to ensure cover integrity. If significant or recurring problems are identified through monitoring activities, the closure plan will be modified to incorporate changes necessary to mitigate these problems. Inspection activities include the following (LANL, 2008c)

- Operational covers are inspected to ensure they contour to surrounding grade.
- Covers are inspected to ensure that native vegetation is planted and growing across them, without large barren areas.
- Brass caps are inspected.
- Drainage channels and culverts are inspected for obstructions.
- Covers are inspected for deep-rooting plants and signs of burrowing animals.
- Covers are inspected for signs of subsidence, water-driven erosion, and ponding.

Site operators record the results of operational cover inspections on forms and submit the results to records management. Any findings requiring corrective actions are reported on the form. The particular corrective action plan is agreed upon, and the completed action inspected by line management.

The operational covers placed over the disposal units are designed to minimize the potential for significant radionuclide releases to those portions of the environment accessible to human receptors and subsequent exposure of members of the general public during the operational period. The 1997 Area G performance assessment and composite analysis conducted by Hollis et al. demonstrated that rates of water infiltration through the operational covers are expected to be low and that no groundwater pathway exposures will occur until well after the disposal facility is closed. Revision 4 of these analyses (LANL, 2008b) did not evaluate the performance of the operational covers, however, the modeling results for the final cover indicated low rates of infiltration and long contaminant travel times to the regional aquifer. The recent modeling projects that the final cover will successfully limit the impacts of biotic intrusion and surface erosion on facility performance. In general, the less robust nature of the operational cover will provide less protection against these forces. Routine maintenance of the covers during the operational period, however, is expected to compensate for the less capable cover. Active portions of the disposal facility are regularly inspected for signs of animal intrusion into the disposal units and instances of severe erosion; any observed damage is repaired. The establishment of deep-rooting trees is also prevented, thereby reducing the impacts of plant intrusion.

The ability of the operational cover to safely isolate the waste from the environment may be undermined by settlement and subsidence. As discussed earlier, isolated incidences of subsidence have been observed at Area G and any damage to the disposal units repaired. Annual inspections of the entire disposal facility accompanied by the repair of any damage will minimize the impacts of increased infiltration, greater access to the waste by plants and animals, and elevated rates of surface erosion that may accompany subsidence events.

Operational closure of the disposal pits is performed in a manner that also promotes worker safety and the long-term stability of the waste. The tuff placed over the lifts of waste in the older pits and the application of crushed tuff during closure minimizes the potential for inhalation and direct radiation exposures.

3.2.1.2 Operational Closure Strategy and Cover Performance for Disposal Shafts

Waste was first disposed of in shafts at Area G in 1966, and the first shaft underwent operational closure in 1967. The design features of these units are provided in Figure 3-5, which illustrates the layout of adjacent units and shows profiles of typical shafts.

Shaft closure activities and cover designs have complied with the guidelines in effect at the time of closure. The disposal guidelines proposed by the USGS in 1965 (Koopman, 1965) did not address shafts because these units were not yet in use. Nevertheless, it is expected that pertinent parts of those guidelines were applied to shaft closure between 1966, the year in which shaft disposal began, and 1975, when specific guidelines for shafts were issued. Specifically, the waste in shafts is thought to have been placed to within 0.6 m (2 ft) of the ground surface. It is known that the shafts were covered with metal plates while they were active. Once filled, the space between the top of the waste and the ground surface was filled with tuff and concrete caps were placed over the units.

Figure 3-5a
Plan view of typical shaft layout

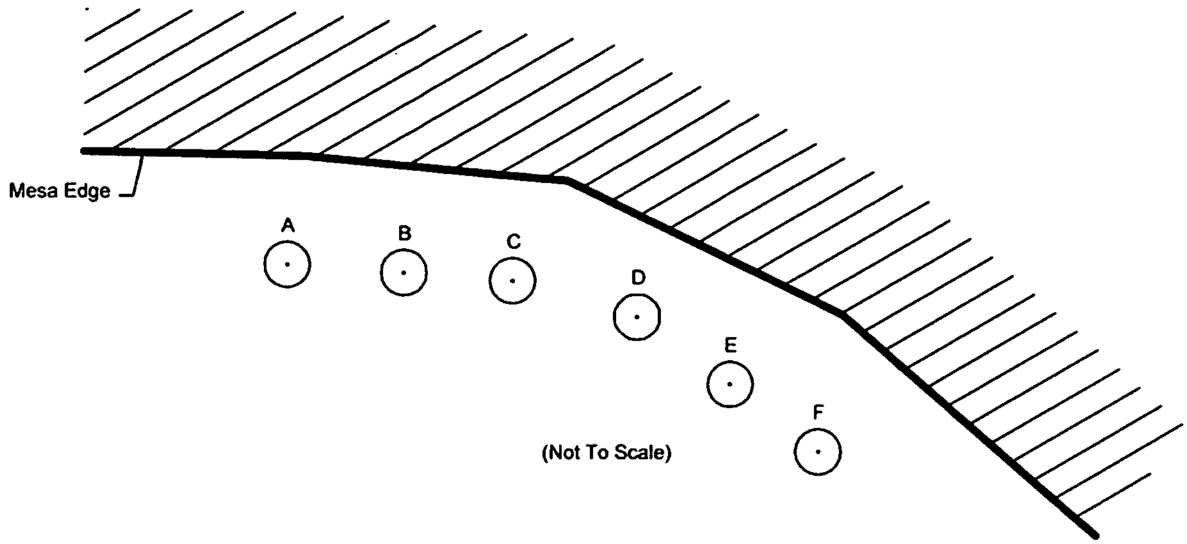
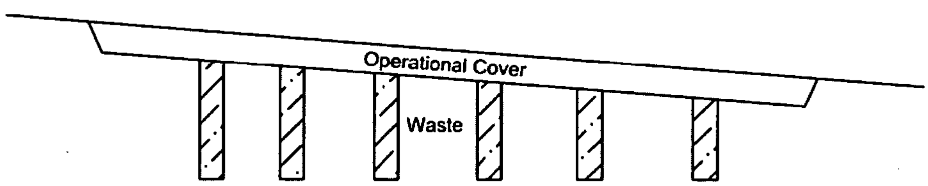
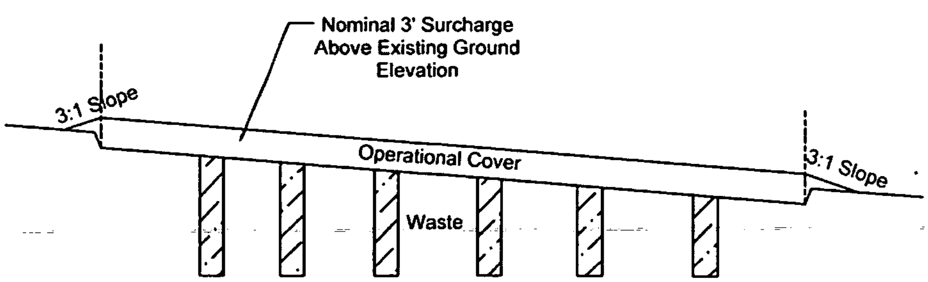


Figure 3-5b
Cross sections of shafts with operational cover



Option 1: Operational Cover
(Not To Scale)



Option 2: Surcharge Cover
(Not To Scale)

Figure 3-5
Standard Specifications for Waste Disposal Shafts
Source: Eng.–C25700 as revised in 1965, 1967, and 1970

The disposal guidelines issued in 1975 (LANL, 1975) addressed both pits and shafts. The following guidelines were specific to the shafts:

- Appropriate measures shall be taken to ensure containment of the waste in the disposal shafts (e.g., an asphalt coating on the walls of tritium disposal shafts). Prior to their use, shafts shall be inspected to ensure the absence of significant open joints or fractures, and steps shall be taken to seal any such fractures with material similar to that recommended for sealing joints and fractures in pit walls.

- Drainage features shall be constructed and maintained so that surface runoff does not enter the shafts.

- Shafts shall be filled with waste to a minimum depth of 0.9 m (3 ft) below the spill point, or to the lowest point on the shaft rim.

- The final cover of a shaft shall be noncontaminated cement, a minimum of 0.9 m (3 ft) thick, slightly rounded, and extending about 15 cm (0.5 ft) above the ground surface.

- The surface of the final shaft cover shall be slightly rounded to allow surface drainage without excessive erosion.

- Provisions shall be made to control runoff in the disposal area to minimize infiltration and erosion of the final shaft covers.

- Benchmarks shall be placed in the concrete used to construct the shaft caps. The benchmark will include a standard brass cap that contains pertinent engineering data (e.g., cap number, LANL coordinates, and elevation and disposal data.) The benchmarks are to be tied into the disposal and engineering records so that if materials are to be retrieved, they can be found with a minimum of effort and disturbance to the final cover.

A procedure issued by LANL in 1996 addresses the design, construction, use, and closure of disposal pits and shafts at Area G (LANL, 1996). This procedure generally adheres to the 1975 memorandum. Draft guidelines issued in 1998 (LANL, 1998b) call for waste to be disposed of to a depth of 3 m (10 ft) below the disposal unit rim. Exceptions to this requirement were acceptable as long as the Area G WAC were satisfied and the waste was no less than 2 m (6.6 ft) below the rim of the disposal unit.

LANL issued a revised procedure for the design, construction, and operational closure of Area G pits and shafts in 2008 (LANL, 2008a). Under these requirements, disposal shafts are surveyed, and survey data are recorded and unit perimeters are marked. A 15 to 30 cm (0.5 to 1 ft) layer of tuff is placed in the bottom of excavated shafts to seal fractures in the floor of the disposal units. The disposal shafts are fitted with concrete collars that are designed to minimize the entry of runoff into the units and maintain the integrity of the tops of the shafts while they are active. Steel plates are placed over the concrete collars to control the entry of water and to provide easy access to the shafts during disposal operations. Waste is disposed of in the shaft until it reaches the specified depth from the rim of the unit, at which point the operational closure process begins.

Operational closure of a filled shaft begins with the removal of the steel lid from the unit. Crushed tuff taken from an approved stockpile is used to fill the disposal unit from the top of the waste to the ground surface. Fill is added until the surface of the cover conforms to the surrounding grade. The concrete collars are left in place during operational closure.

A benchmark is placed adjacent to each shaft immediately after placement of the cover or as soon as facility operations permit; all benchmarks are linked with the disposal and engineering records to facilitate material recovery should it become necessary in the future. A benchmark consists of a buried 30 cm (12 in.) diameter concrete column extending a minimum of 15 cm (6 in.) above the ground surface. A standard brass cap is placed into the top of the concrete benchmark with appropriate engineering records (e.g., disposal unit and disposal data). Finally, an easily identifiable fiberglass marker stake displaying the shaft number is placed next to each benchmark. A typical benchmark design is shown in Figure 3-3.

In practice, a 1 m (3.3 ft) thick layer of crushed tuff surcharge is applied over the disposal unit immediately following construction of the operational cover if the area occupied by the shaft is not needed for waste management operations. If more than three adjacent shafts are being closed simultaneously, surcharge material is also placed between the individual units and contoured to minimize ponding and the infiltration of storm water. The surcharge is to be left in place until the site undergoes final closure. If required by site conditions, the material may be removed if subsidence of the disposal unit is unlikely and the crushed tuff has been in place for at least 1 year since operational closure or the last significant subsidence event.

The operational closure process shall be fully documented and is subject to rigorous quality control. Requirements for the operational closure drawings, material specifications, surveys, construction quality assurance procedures, and record-keeping are provided in the procedure.

Site operators monitor and maintain operational covers emplaced over filled disposal units to ensure cover integrity. If significant or recurring problems are identified through monitoring activities, the closure plan will be modified to incorporate changes necessary to mitigate these problems. Inspection activities include the following (LANL, 2008c):

- Operational covers of shafts closed without concrete caps are inspected to ensure they contour to surrounding terrain.
- Covers of shafts are inspected to ensure that native vegetation is established across them.
- Brass caps are inspected.
- Drainage channels and culverts are inspected for obstructions.
- Shaft covers are inspected for deep-rooting plants and signs of burrowing animals.
- Shaft covers are inspected for signs of subsidence, water-driven erosion, and ponding.

Site operators record the results of operational cover inspections on forms and submit the results to records management. Any findings requiring corrective actions are reported on the form. The particular corrective action plan is agreed upon, and the completed action inspected, by line management.

For reasons discussed in Section 3.2.1.1, the operational covers placed over the shafts are expected to safely isolate the waste from the environment, thereby protecting human health and safety. Although less robust than the final cover, the operational covers are expected to limit the amount of water infiltrating through the waste, check biotic intrusion into the waste, and resist surface erosion for the short period of time the cover is in place prior to final closure of the site. Maintenance of the covers will provide added assurance that the waste will be safely contained. Finally, the covers will limit exposures of workers during the operational period to acceptable levels.

3.2.2 Final Closure

The objective of final closure of Area G is to achieve long-term stability of the waste in a manner that protects human health and safety and the environment while minimizing the need for active maintenance. This section specifies a final closure approach and design that will provide the level of protection required and satisfy the performance requirements of DOE M 435.1-1.

3.2.2.1 Final Cover Design

The conceptual design of the final cover for the Area G disposal facility is presented in Day et al. (2005). The information that follows is taken from that report.

The primary criterion that guided the design process was the maintenance of at least 1.5 m (4.9 ft) of cover over most of the disposal facility throughout the 1,000-year compliance period; this thickness was estimated on the basis of biotic intrusion modeling conducted by Shuman (1999). Other criteria that guided the design process for the final cover are provided below.

- *Gas emissions*—One of the principal objectives of the cover is to limit the escape of gases generated by the waste. The thickness and air permeability of the cover shall be such that gas flux performance objectives and doses arising from exposure to vapor- or gas-phase contaminants remain within allowable limits.

- *Water infiltration*—An important role of the cover is to limit the amount of water contacting the waste. The hydraulic properties of the materials used to construct the cover shall limit infiltration, thereby maintaining groundwater pathway exposures within allowable limits.

- *Design term*—The cover must be capable of fulfilling its design functions for a minimum of 1,000 years, the compliance period imposed by DOE Order 435.1. Active maintenance of the cover was assumed to occur for the first 100 years of this period.

- *Wind and water erosion resistance*—The cover must resist erosive impacts, thereby limiting biotic intrusion into the waste, minimizing rates of water percolation through the waste, and limiting the transport of contamination into adjacent canyons.

- *Slope*—All cover slopes shall range from 2 to 10 percent to limit generation of runoff and, hence, the potential for rill and gully formation.

- *Intruder control*—The cover must limit inadvertent human intrusion and biotic intrusion into the disposed waste.

- *Surface water control*—The profile, slope, and grading of the cover must be completed in a manner that limits rill and gully formation following rainfall and snowmelt events.

- *Vegetation support*—The cover shall be designed to support vegetation native to the semiarid environment of northern New Mexico. The vegetative cover will be relied upon to remove water through transpiration and to stabilize surface soils, thereby resisting erosive forces.

- *Settlement resistance*—The cover shall be installed to eliminate voids and areas of low density, thereby limiting the potential for settlement of the cover.

- *Engineering controls*—Engineering controls such as rock armor or slope stabilization techniques shall be used as necessary to maintain the integrity of the cover in critical portions of the site.

- *Rock hardness*—Rock incorporated into the cover design shall be capable of resisting weathering and other forces of nature during the design term.

- *Seismic event*—The cover design shall consider resistance to the effects of seismic events. Parameters of concern include, but are not limited to, seismic magnitude, on-site peak horizontal acceleration, the distances to and lengths of capable faults, and the types of capable faults and associated displacement.

- *Reactive materials*—The materials used in cover construction shall be limited to natural materials that support the longevity of the cover over the design term. Aggregates or other materials that are known to be reactive shall not be used.

- *Soil strength*—The cover must have the internal soil strength to remain in place for the entire design term. Weaker soils such as crushed tuff shall be amended with other materials to enhance internal strength and compactibility.

In general, the design process was undertaken with the goal of developing a cover with characteristics resembling those of natural landscapes in the vicinity of the disposal facility. This approach is expected to provide the greatest assurance that the facility will safely contain the waste over extended periods of time.

The conceptual cover for Area G was designed using an iterative approach. Each design was evaluated and the process was repeated until a design expected to be capable of meeting the minimum cover requirements was identified. The specific processes used for MDA G and the Zone 4 expansion area differed slightly. The initial design process for MDA G included the following procedures:

- *Identifying the completion year of each disposal unit.* The completion year shown on the record drawings was used to classify each pit and shaft by construction year. The freeboard distance (i.e., the distance from the top of the waste to the ground surface) pertaining to a specific unit could then be established by referring to the disposal guidelines in force at that time.

- *Determining the waste elevation within the disposal unit.* The pertinent freeboard distance, as determined above, was subtracted from the elevation of the spill point for each pit.

- *Designing the cover.* Once the waste elevations were established, geographical information system software was used to determine the cover location and establish initial lines and grades. The output was transferred to Autodesk® Land Desktop 2004 to establish the final surface of the cover using the basic steps outlined below.

1. Establish the edge line of the cover. This boundary was established by identifying the perimeters of the pits and shafts closest to the edges of the mesa and joining these points with a continuous line, as shown in Figure 3-6. A cover elevation of 2.5 m (8.2 ft) was placed along the edge line once it was located to ensure that the minimum cover requirement was satisfied along the outer extent of the waste.

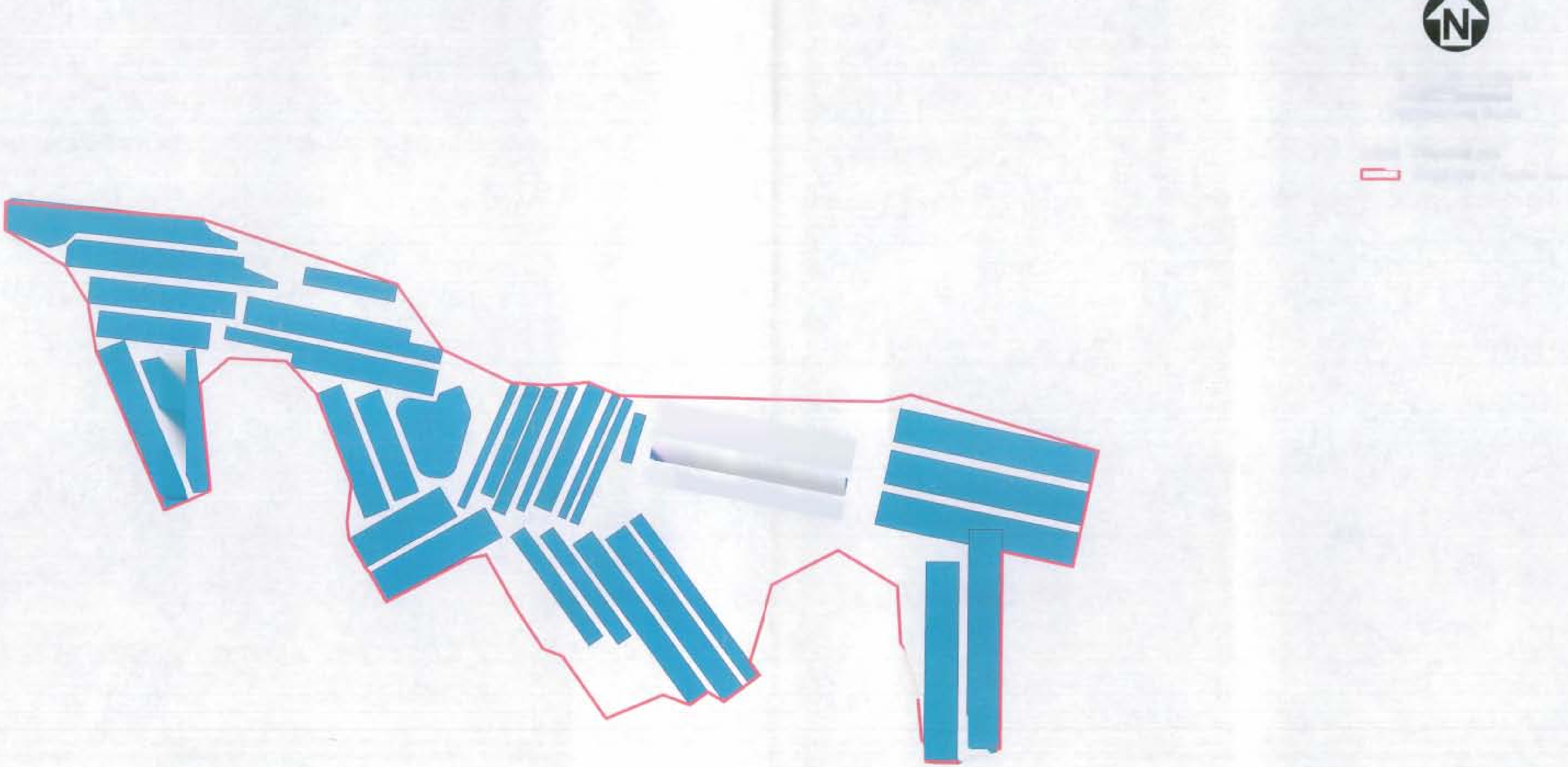
2. Set the ridgelines. The initial approximation of the surface of the cover was established as shown in Figure 3-7 by joining the ridgelines to the edge line. This allowed identification of the peaks, valleys, and slopes of the cover (Figure 3-8). The contours shown on these figures are the ultimate result of computer-modeling enhancements that occurred throughout the iterative design process.

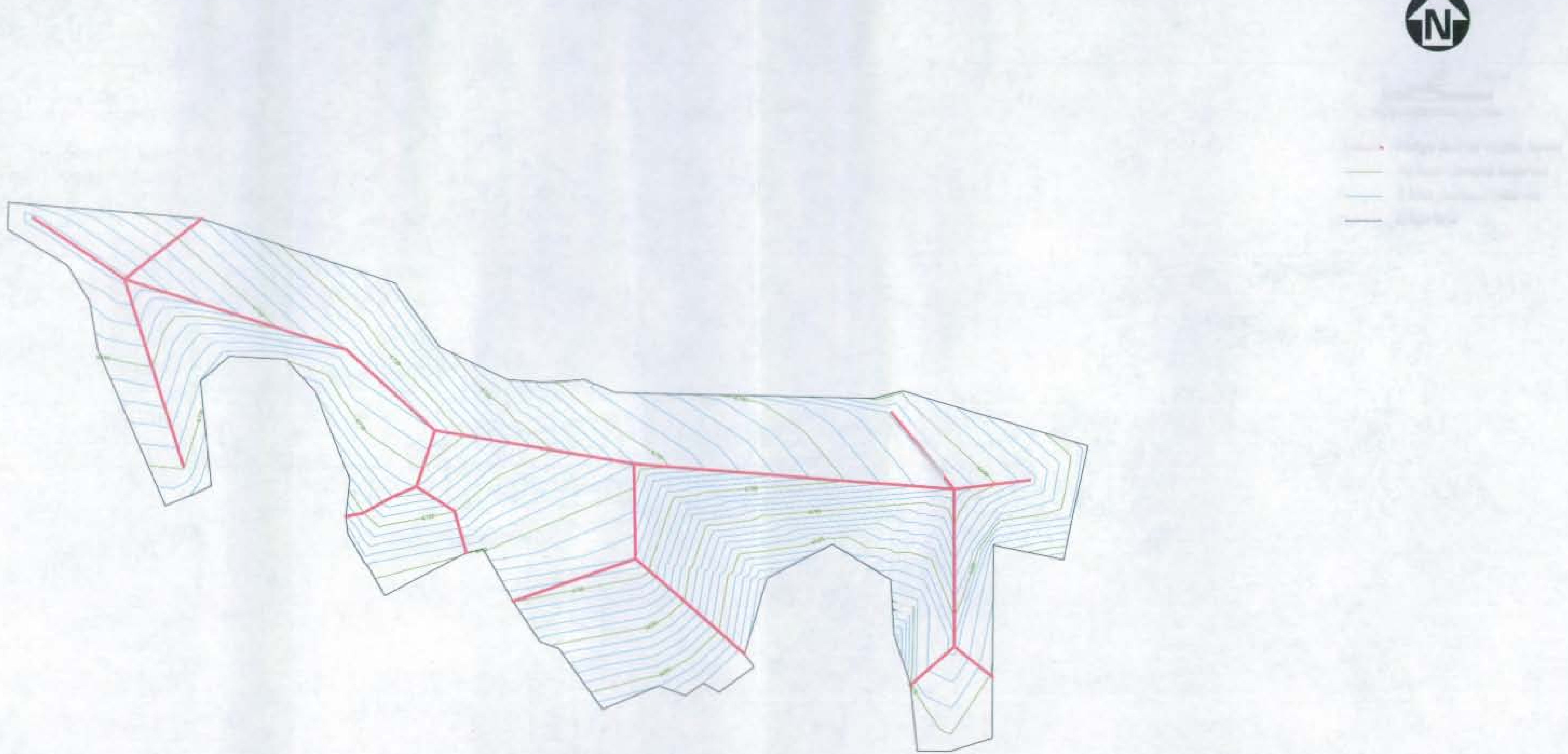
3. Examine the cover slopes for grade and flow concentrations. Slopes were maintained between 2 and 10 percent to promote moderate sheet flow and minimize flow concentration. Sheet flow was checked using a feature in the Land Desktop design software called "Water Drop." Figure 3-9 shows consistent uniform path lines indicating sheet flow. Dramatic convergence of flow lines would indicate concentrated flow, a condition that would require that the surface of the cover be recontoured or smoothed. Through an iterative process, areas of abrupt grade change were adjusted, and elevations were modified to approach the desired profile. The cover elevations over the waste were checked to ensure that a minimum of 2.5 m (8.2 ft) of cover material was present across the site.

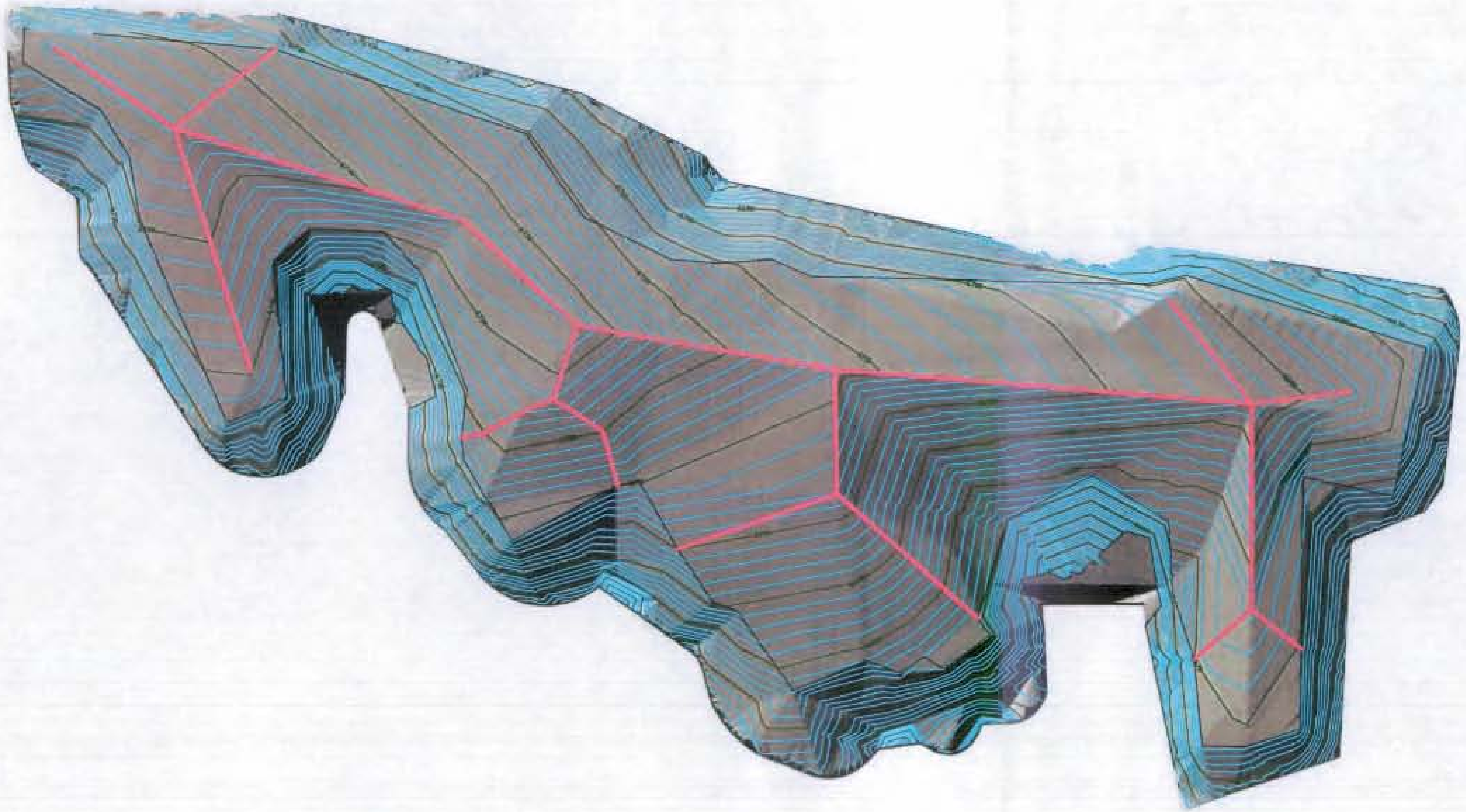
4. Establish the slopes from the cover edge line to the existing ground surface at the edge of the mesa. These edge slopes, shown in Figure 3-10, were kept to a minimum where physically possible. Once the edge slopes were established, the contours were examined for areas marked by sharp valleys or ridges and these areas were smoothed and adjusted as necessary.

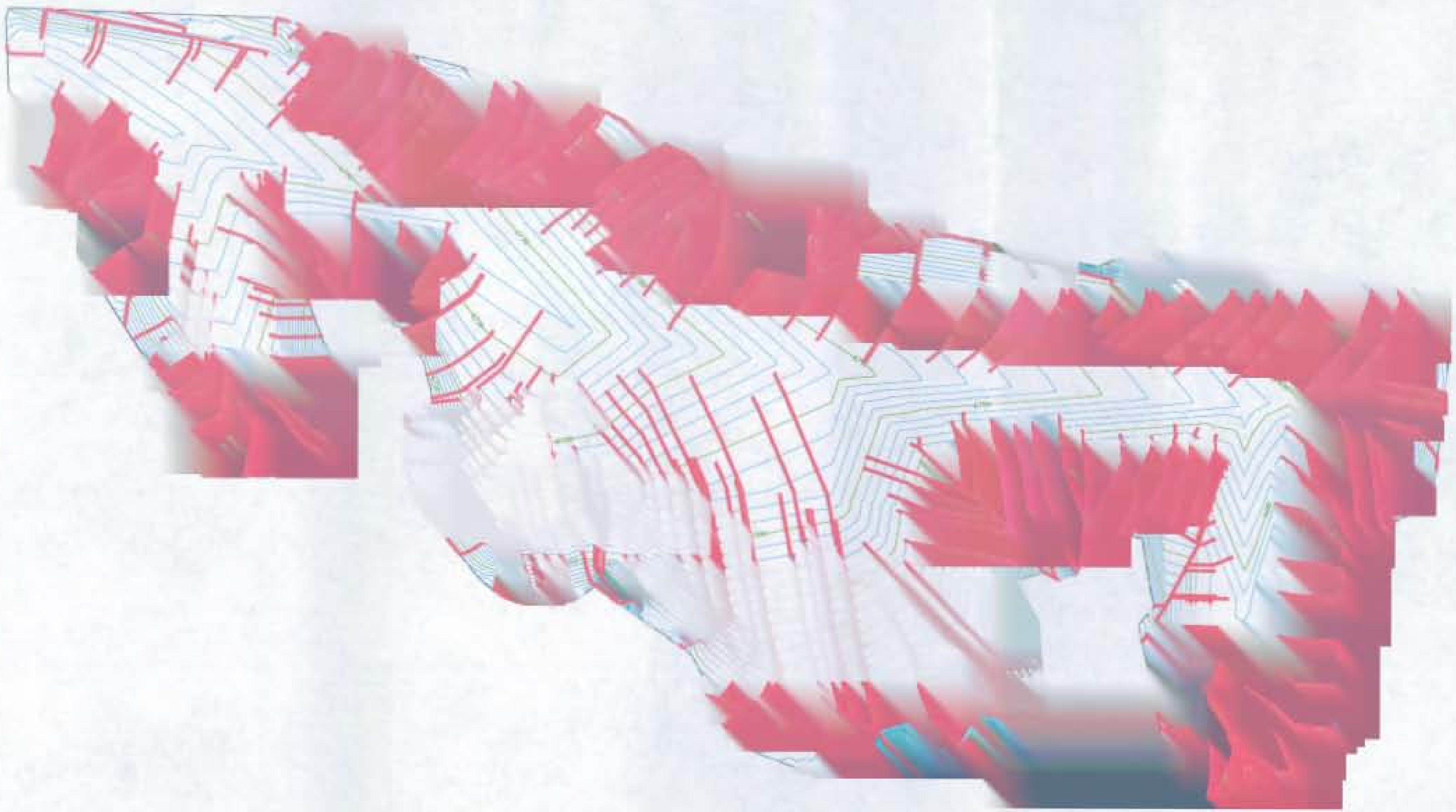
The cover design process for the Zone 4 expansion area took advantage of the fact that disposal unit construction had not yet begun. Restrictions were placed on waste placement and elevation, specifying that waste would be placed at least 3 m (10 ft) below the ground surface in all pits and shafts. This restriction exceeds the 2.5 m (8.2 ft) minimum cover thickness required for the disposal units.

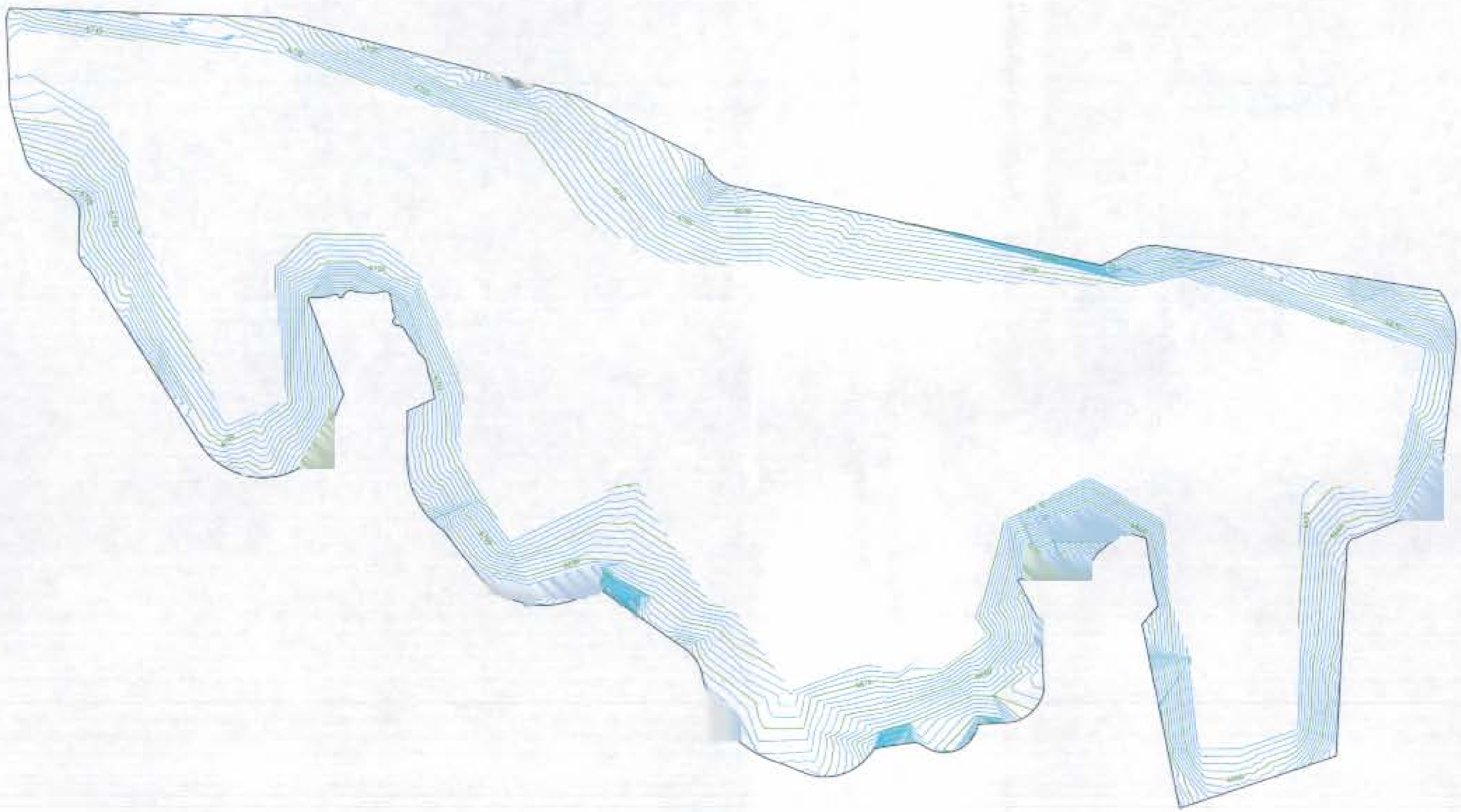
With the waste elevations in Zone 4 established, the remainder of the design process was similar to that described for MDA G. The final surface of the cover was established using points around the perimeter of the expansion area and points along a centerline that represented the ridgeline of the cover. The elevation of the ridgeline was established using slopes of 2 to 5 percent. Finally, the cover over Zone 4 was graded so it matched the contour lines of the cover over MDA G.











After the initial design for the entire disposal facility was completed, the cover elevations were used to create a three-dimensional grid of the surface of the disposal facility using Land Desktop 2004. Elevations were assigned using a 9.3 m^2 (100 ft^2) grid and these data were used in the SIBERIA surface erosion modeling (Wilson et al., 2005).

The SIBERIA modeling software was used to project remaining cover depths across the disposal facility after a 1,000-year period. These simulations indicated that the minimum cover requirements were generally satisfied over much of the site throughout the 1,000-year compliance period. Nevertheless, higher rates of erosion were observed over small portions of the site; these areas generally occurred where the cover and the original grade met along the edges of the mesa and adjacent to drainages. The cover was redesigned and enhanced as necessary to address these critical areas. The design considerations and modifications that went into this process included the following:

- Various engineering controls were considered in the development of the cover design. One such control was an increase in the footprint of the cover to achieve gentler slopes along the edges of the mesa and to provide greater quantities of sacrificial material that could be eroded without compromising the minimum cover requirement.

- The use of earth-filled dams was considered as a means for increasing the footprint of the cover. This technique was used in initial iterations but was later discarded because of concerns about subsurface water collection in the areas behind these dams. This subsurface water could contact the waste in nearby disposal units and leach radionuclides from the pits and shafts.

- Rock armor was applied along edge slopes to limit erosion along the edges of the mesa. Other engineering controls, such as retaining walls and rock bolt reinforcements, were found to be less effective than rock armor.

- The peaks and valleys and some of the rough edges shown on the contour of the cover design were smoothed digitally in order to more accurately represent the constructed cover. This smoothing reduced the tendency of the erosion model to artificially initiate erosion at the valleys, ridges, and some edges.

- Pea gravel was mixed into the upper 7.5 cm (3 in.) of topsoil to promote the establishment and growth of vegetation over the site. Angular rock with a diameter of 10 cm (4 in.) was randomly placed on the surface of the cover; these rocks help trap nutrients and provide a stable growth surface, thus promoting the development of a vigorous plant community.

The predominant soil available for cover construction at TA-54 consists of the crushed tuff borrow from excavations and available "bank-run" sources. Crushed tuff is a friable, low-strength material that is difficult to form into an earthen embankment without admixtures. Clay was combined with the crushed tuff to increase the compactibility of the soil, thereby enhancing cover stability; rock was included to increase the strength of the cover.

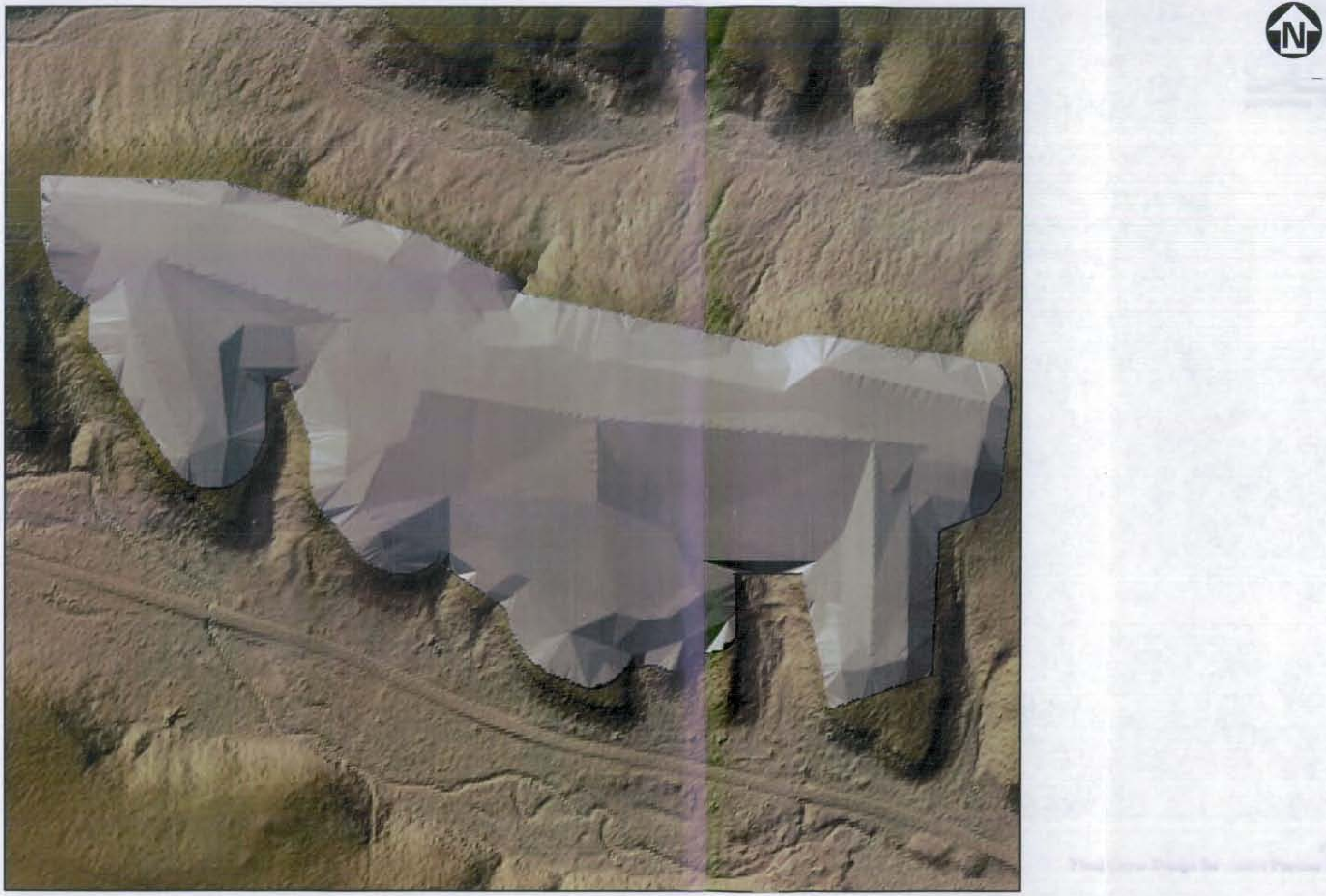
The conceptual design of the final cover for MDA G is depicted in Figures 3-11 and 3-12. The three-dimensional perspective of the cover shown in Figure 3-11 accentuates the ridges, slopes, and valleys to highlight their locations. During construction, transitional areas such as edges, ridges, and valleys will be smoothed to minimize erosion potential. The final contours of the cover are displayed in Figure 3-12. The gentle slopes characteristic of the majority of the cover contrast with the relatively steep slopes required to transition from the cover to the edges of the mesa.

The final cover configuration for the Zone 4 expansion area (not shown) is generally less complex than the cover over MDA G. As discussed earlier, the minimum cover requirements for the units in Zone 4 will be met because all waste will be placed at least 3 m (10 ft) beneath the ground surface. Consequently, development of the final cover consists primarily of contouring the land surface so the cover transitions smoothly with the edges of the mesa and the cover over MDA G.

The cross section of the final cover design provided in Figure 1-4 shows the general configuration of the cover, including the gravel mulch and topsoil layers at the surface and the crushed tuff/clay layer that forms the bulk of the cover. The top layers of the cover are to be installed at relatively low compaction levels, which will help promote the establishment of plants. The optional layer shown above the operational cover is designed to serve as a capillary break. This layer enhances the water-carrying capacity of the soil above and therefore promotes and sustains vegetation growth.

Figure 3-13 shows the location of the rock armor along the edges of the mesa. The thickness of the rock armor will be specified to be at least six times the average diameter of the rock material. In other words, if material with a diameter of 10 cm (4 in.) is used, the rock armor layer will be designed to be at least 60 cm (2 ft) thick. The actual diameter of the rock will be determined during the final design.

Prior to final closure of Area G, all structures built at the site in support of waste management activities must undergo decontamination and decommissioning (D&D). While no final plans exist for the D&D of surface structures at this time, current objectives call for decontaminating and salvaging as much material as possible for reuse. A formal program and procedure will be developed for Area G, which will be consistent with the *LANL Decommissioning Summary Site Plan* (LANL, 1995). Contaminated items with little or no potential residual value may be disposed of as LLW rather than decontaminated for disposal in a sanitary landfill. Concrete and asphalt pads will be either crushed into pieces not greater than 10 cm (4 in.) or removed and disposed of, probably on site.



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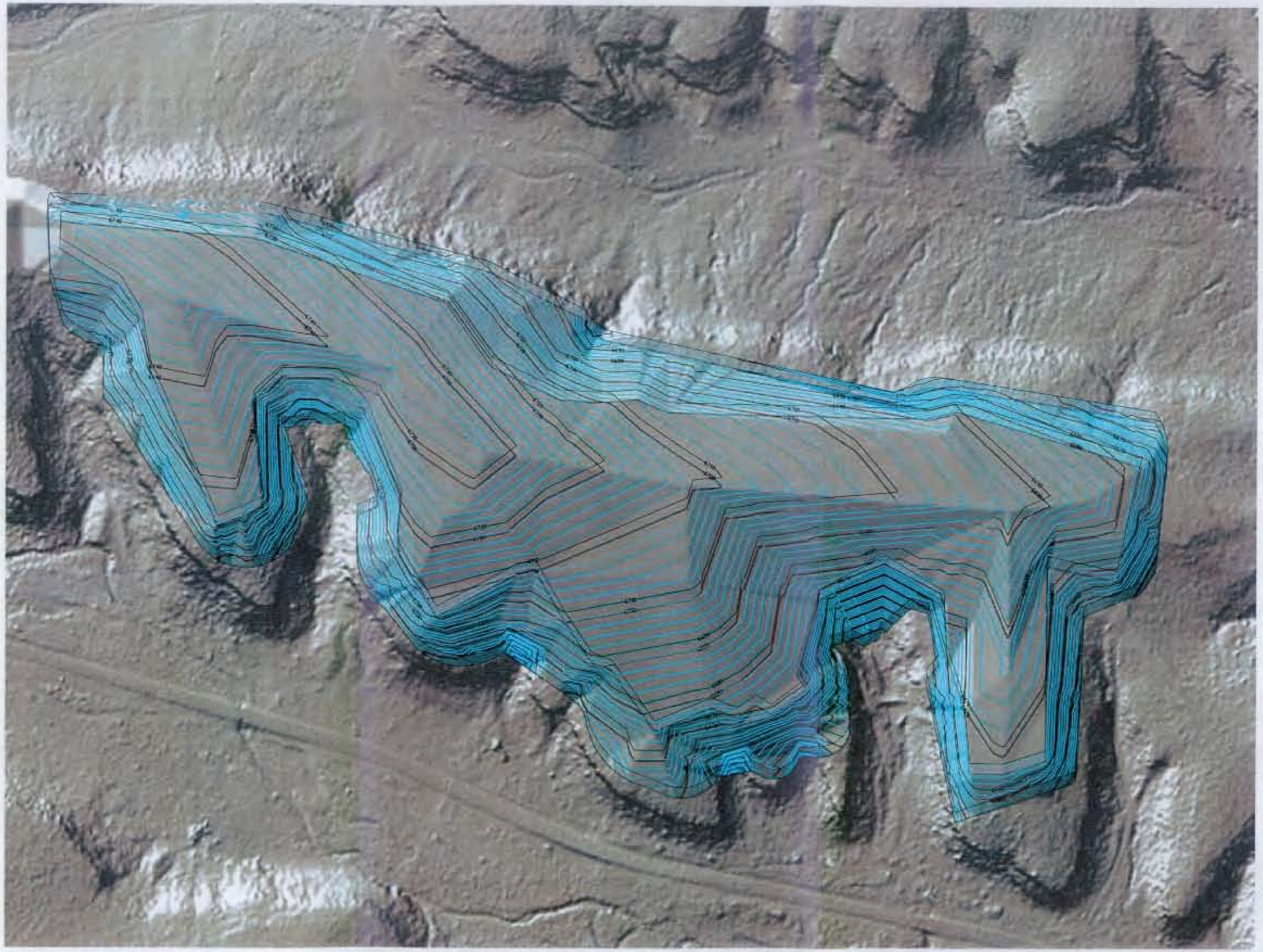

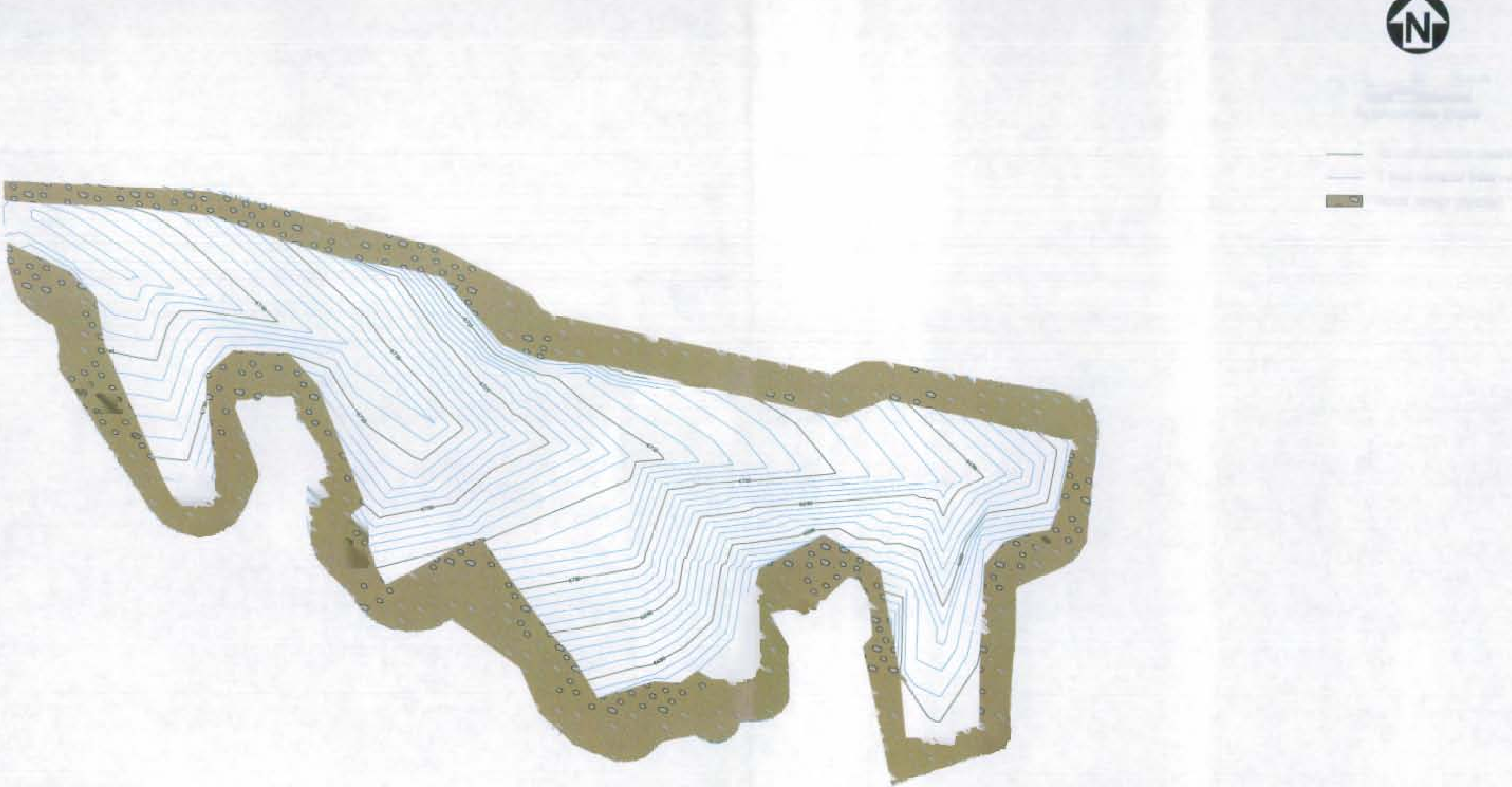
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The final D&D and closure plans for Area G must be consistent with each other with respect to several issues, including:

- The closure plan must (1) recognize the extent of D&D that must be completed prior to site closure and (2) allow for the amount of waste generated by D&D activities that will require disposal within the facility prior to final closure

- The D&D plan must (1) present a schedule of completion that can be accommodated in the overall schedule for final closure and (2) ensure that D&D activities will not interfere with, or disrupt, existing covers and other closure activities

In addition to LLW disposal, Area G is used for the storage of TRU waste that, upon certification, will be sent to WIPP for final disposal. This waste is expected to be shipped off site before the time the disposal facility undergoes final closure. However, in the event that any of this waste is still present at Area G, it will be retrieved and removed from the site during final closure. Any soils contaminated during removal operations will be disposed of appropriately.

Area G is also used for storing and characterizing MLLW prior to shipment off site for treatment and disposal. All MLLW management operations will cease prior to the implementation of the final closure strategy.

3.2.2.2 Final Cover Performance

The final cover design presented above was evaluated in Revision 4 of the Area G performance assessment and composite analysis (LANL, 2008b). As discussed in Section 3.1, these analyses indicated that the disposal facility is capable of satisfying the DOE Order 435.1 performance objectives. To summarize, no groundwater pathway exposures were projected to occur during the 1,000-year compliance period; peak mean atmospheric pathway exposures were 6.4 percent or less of the 10 mrem/yr performance objective that applies to all airborne releases from the Laboratory; peak mean doses projected for persons living in Cañada del Buey and Pajarito Canyon were about 9.2 to 15 percent of the allowable limits; and the peak facility-wide radon flux was 2.2 percent of the 20 pCi/m^2/s limit. All projected intruder exposures were less than the 500 and 100 mrem/yr dose limits that apply to acute and chronic exposures, respectively.

The results of the performance assessment and composite analysis are consistent with the design features of the final cover. The application of a minimum of 2.5 m (8.2 ft) of cover over the disposal units effectively limits the degree to which plants and animals inhabiting the closed site can penetrate into the disposed waste. The result is small amounts of contamination deposited on the surface of the facility and low subsequent exposures for persons living downwind of Area G or in the canyons adjacent to the facility. The depth of cover placed over the disposal units and the engineered aspects of the final cover (e.g., rock armor around the edge of the facility) resist the effects of surface erosion in a manner that limits the impacts of biotic intrusion throughout the 1,000-year compliance period. Rates of diffusion of vapor- and gas-phase radionuclides from the disposal facility are maintained at low levels largely because of the thickness of the cover. Finally, the hydraulic properties of the cover limit the amount of water that percolates through the waste, thereby minimizing exposures received by persons living downgradient of the disposal facility.

3.2.3 Institutional Control

The final closure strategy assumes the DOE will maintain active institutional control over Area G for at least 100 years after the final cover has been applied. During the active institutional control period access to the site by members of the public will be prevented, the site will be periodically inspected and maintained, and site monitoring will be conducted. This section discusses the actions that will be taken in terms of inspection and maintenance of the facility.

The ability of Area G to satisfy the performance objectives in DOE M 435.1-1 requires that the integrity of the final cover persist throughout the 1,000-year compliance period. Perhaps the two greatest threats to the integrity of the cover are subsidence and severe erosion. In addition to activities conducted during final closure, which are expected to minimize any subsidence potential, inspections of the pits and shafts for signs of subsidence will be conducted throughout the active institutional control period. Inspections will be conducted at least annually and after significant rain events at the site. If subsidence or settlement of the units is noted, corrective actions will be taken. Crushed tuff will be added and graded when appropriate. Large-scale additions of crushed tuff will be compacted using heavy equipment, and care will be taken to minimize the disturbance of areas where the cover remains intact. Topsoil will be added over the repaired areas and seeded with turf-forming native grasses.

Surface erosion will reduce the thickness of the cover over time, resulting in greater access to the waste by plants and burrowing animals inhabiting the site. If erosion is severe enough, it may also allow an increased rate of water percolation through the waste. The proposed final cover has been designed to counteract the effects of erosion anticipated for Area G over the 1,000-year compliance period and, as such, is expected to provide an adequate level of protection for the site. However, inspections for signs of excessive rates of erosion will be conducted during the active institutional control period. All cover systems will be examined for damage, and all drainage features at the site will be checked. Inspections will be conducted at least annually and after all significant rain events. The inspections will allow early identification of the need for corrective actions and will provide information that will be useful in validating projected rates of erosion at the site.

Biotic intrusion into the waste by plants and burrowing animals inhabiting Area G may lead to the release of radionuclides to the ground surface. Although the thickness of the final cover is expected to limit these releases to acceptable levels, actions taken during the active institutional control period will help limit the intrusion potential. Steps will also be taken to prevent the establishment of deep-rooting trees throughout the active control period. Even though it will be virtually impossible to control populations of burrowing animals at the site, the covers will be inspected for extensive disturbance by these species and corrective actions will be taken as deemed appropriate.

Monitoring of the disposal facility will occur throughout the active institutional control period. Inspections of the monitoring equipment will be conducted and maintenance activities performed as needed. Visual inspections will be performed whenever monitoring stations are visited, and complete tests of equipment will be conducted annually. Additional inspections and maintenance will be conducted if the data collected from the monitoring stations indicate that problems may exist.

Maintenance during the active institutional control period will include the upkeep of disposal unit benchmarks, site markers, and fences. Benchmarks not covered by surcharge material will be inspected annually for any damage and to ensure readability of the disposal information on the brass caps. Damaged benchmarks or caps will be repaired or replaced as necessary. The 2.4 m (8 ft) industrial chain-link fence topped with razor wire that defines the present property protection area at Area G will remain in place throughout the active institutional control period. This fence, which lies outside of all disposal units, will be inspected monthly and repaired as needed.

Passive institutional control over the closed disposal facility will begin at the end of the 100-year active institutional control period and continue until Area G no longer poses an unacceptable risk to members of the public. The modeling conducted in support of Revision 4 of the performance assessment and composite analysis (LANL, 2008b) assumes only that people are prevented from establishing residences on the closed site during this period; no other active maintenance of the site (e.g., repair of damage caused by subsidence or erosion or prevention of the establishment of deep-rooting trees) is assumed.

Long-range land use and stewardship plans have yet to be developed for LANL, but will include provisions that apply during the adopted period of passive institutional control over Area G. Land use plans for the disposal facility will be evaluated with respect to other plans for the site to ensure that long-term care requirements are satisfied.

3.2.4 Unrestricted Release of Site

Requirements set forth in DOE M 435.1-1 (2001b) indicate that LLW disposal sites should eventually be released for unrestricted use pursuant to DOE Order 5400.5 (DOE, 1993). In the event that safe release of the site is not possible, the DOE may choose to maintain control over the sites indefinitely, as long as this action is consistent with land use and stewardship plans and programs.

It is not clear at this time if, or when, Area G will be released for unrestricted use. If unrestricted use is allowed, the approach for release will be detailed in a revised closure plan. Key elements of a conceptual approach to site release include the following actions:

- Characterize the property proposed for release.
- Identify the type(s) of release criteria that apply to the site.
- Develop site-specific doses and radionuclide concentration limits.
- Perform an ALARA analysis.
- Obtain approvals for the use of the proposed release criteria.
- Conduct site measurements of residual radioactivity and evaluate compliance.
- Take appropriate action based on the comparison of release criteria and measured radionuclide concentration.

3.3 Monitoring

Routine environmental surveillance is conducted at the Laboratory, including TA-54, to determine compliance with appropriate standards and to identify potentially undesirable trends. The results of these efforts are used to assess the potential for adverse environmental impacts associated with the mission of the Laboratory, thereby providing the opportunity to take corrective actions as the need arises. Specific to Area G, the environmental surveillance efforts provide information needed to assess the impacts of waste management operations on the environment and facility personnel.

This section discusses radiological monitoring activities relevant to the closure of Area G. Section 3.3.1 addresses the current monitoring activities that will continue through the end of operations. Section 3.3.2 briefly discusses the postclosure monitoring program.

3.3.1 Operational Closure Period

Environmental surveillance activities include the monitoring of air and meteorological conditions, direct radiation, storm water and sediments, soils, small mammals, vegetation, and groundwater (e.g., LANL, 2007b). A discussion of the data quality objectives (DQO) process used to structure the surveillance program, and summaries of the sampling and analysis plan, the data management procedures, and quality assurance and quality control procedures may be found in the annual surveillance reports.

Most of the surveillance activities are designed to monitor the impacts of waste management operations, including disposal, at Area G. Little, if any, of the contamination detected in the past has been connected to releases from the buried waste. In general, then, most of the surveillance data is of limited use for monitoring the performance of operational closure measures. Exceptions to this statement are summarized below.

Air monitoring activities include the measurement of tritiated water vapor and particulate loadings of several radionuclides, and the collection of meteorological information. A total of eight sampling locations are monitored at Area G on a biweekly or quarterly basis (LANL, 2005b); these stations are situated along the perimeter of the site. Although particulate monitoring results have little to offer in terms of evaluating the performance of closure measures, the tritium data may be useful in this regard. Tritium routinely diffuses upward from the waste disposed of in pits and shafts, and exits from the surface of Area G. The monitoring of tritium releases provides insight into the ability of the operational covers to contain this vapor-phase contaminant.

Groundwater sampling locations at the Laboratory are used to monitor the regional aquifer, alluvial groundwater in canyons, and intermediate-depth perched groundwater. Five observation wells located near Area G, two in Cañada del Buey and three in Pajarito Canyon, are used to monitor alluvial waters in those canyons. Five regional characterization wells surrounding Area G have been monitored on a quarterly or annual basis for a range of radioactive and chemical contaminants; additional wells are in the process of being drilled and will be sampled in the future.

Groundwater surveillance data are expected to prove useful in terms of quantifying releases of radionuclides in the buried waste due to leaching. This information is directly relevant to the role of the cover in minimizing water infiltration through the waste and, hence, the potential for doses via the groundwater pathway. Consequently, groundwater monitoring plays a significant role in evaluating the performance of operational closure measures.

Operational closure monitoring data are, and will continue to be, used to evaluate the adequacy of the Area G performance assessment and composite analysis on an annual basis. These adequacy reviews are directly relevant to the evaluation of the effectiveness of operational closure measures. As discussed above, however, the value of these evaluations is limited at this time because the monitoring data generally reflect operational releases rather than releases from the buried waste.

Two methods are used to evaluate disposal facility performance using the surveillance data. First, where appropriate, monitoring results are compared to performance assessment and composite analysis model projections. Second, monitoring program measurements of parameters used to model Area G are compared to the input data used in the performance assessment and composite models. These comparisons provide an opportunity to refine the input values to more accurately represent actual conditions.

Separate from the surveillance activities, soil moisture content is monitored at Area G. Near-surface sampling is conducted using boreholes, neutron probe access ports, and characterization wells in the vicinity of the pits and shafts and within the operational covers.

3.3.2 Final Closure and Institutional Control Periods

The postclosure environmental surveillance program for Area G will be a modified version of the operational environmental surveillance program. It will include vadose-zone monitoring; radiological surveillance measurements; cover performance monitoring, including settlement and subsidence monitoring; surface erosion monitoring; monitoring for the presence of burrowing animals; and inspections to prevent the establishment of undesirable, deep-rooting vegetation. Many of these monitoring activities will remain in effect throughout the active and passive institutional control periods; others, such as efforts to monitor and exclude deep-rooting plants from the site, are assumed to occur during the active institutional control period only. The specifications of and implementation procedures for the postclosure monitoring program will be developed as the period of closure for Area G nears. A detailed description of the program will be provided in the final closure plan.

4.0 Closure Schedule

The anticipated schedules for operational closure of the disposal units at Area G and final closure of the entire facility are discussed in this section. Section 4.1 addresses the activities associated with the operational closure of active pits and shafts. A general discussion of the schedule associated with final closure of the facility is provided in Section 4.2

4.1 Operational Closure Schedule

At Area G, several disposal pits and shafts are typically open and ready to receive waste at a given time. Four pits and approximately 20 shafts were open and capable of receiving waste in early 2008. Efforts are made to minimize the number of shafts open at any given time, while providing the disposal capacity required for the different types of waste disposed of in these units.

The operational closure schedule is closely tied to the quantities and types of waste received for disposal at Area G. Though general trends in the volumes of waste may be estimated, this information is difficult to translate into accurate estimates of waste volumes by disposal unit. Furthermore, reasonably long-term estimates of waste disposal needs cannot readily account for changes in the schedules of projects that generate the waste or for facility downtime and maintenance activities. Closure schedules for disposal shafts are especially unpredictable because of the small amounts of waste these units accommodate. For example, rapid generation of a given type of waste (e.g., tritium waste) could cause several shafts to be filled in a matter of months. Under different circumstances, extended periods of time may pass between waste shipments.

Given the preceding discussion, development of an operational closure schedule is difficult at best and prone to a high degree of uncertainty. For this reason, no schedule for operational closure currently exists.

4.2 Final Closure Schedule

Phased final closure of MDA G is scheduled to begin as early as 2010 and to be complete by 2015. Pit disposal operations in this portion of the facility are currently expected to cease in 2010, moving into the Zone 4 expansion area; the disposal of waste in shafts is expected to shift from MDA G to Zone 4 in 2016. The expansion area is assumed to receive waste until the year 2044, at which time this portion of the site will undergo final closure. Final closure of the expansion area is assumed to require 2 years once the last disposal unit has undergone operational closure. A number of site preparations need to be completed in conjunction with the closure process, including the removal of any remaining surface structures, preparation of the pits and shafts for the final cover, application of the final cover(s) over the units, and the final cleanup of equipment and materials once closure has been completed. Operational period monitoring systems may be removed, if they are no longer necessary, or converted for use during the closure and institutional control periods.

A number of documents will be needed in support of final closure of MDA G and Zone 4. For each portion of the disposal facility, the final waste inventory must be developed and used to prepare a final closure plan for the disposal units. This plan will detail the final cover design for the site and identify a period of institutional control that is compatible with LANL land use and stewardship plans and programs. At the same time, the performance assessment and composite analysis will be updated. The results of these analyses will provide estimates of the long-term performance of Area G and its ability to satisfy all appropriate performance objectives. A safety analysis report will be prepared in conjunction with the start of the final closure activities to ensure personnel involved in the closure activities and subsequent care of the facility receive adequate protection. Lastly, a number of permits and approvals will be required before the facility can undergo closure and enter into institutional control.

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C-9.10 SWMU 39-007(a)

Locations 39-604857 and 39-604858 were beneath the concrete pad east of the building. Location 39-604857 was moved 3 ft northeast, and location 39-604858 was moved 0.5 ft south to accommodate collection without removal of the concrete.

C-9.11 SWMU 39-004(d)

Dioxins/furans samples were not collected at this SWMU. The radiological activity present with these samples exceeded the criteria for acceptance by the off-site laboratory conducting dioxins/furans analysis.

C-9.12 Extended Drainages

Location 259 was located under the parking lot asphalt outside the entry gate to Technical Area 39. Parking lot construction obscured the drainage location and made collecting a sample at the correct elevation impracticable.

Samples in the extended drainages were collected according to the approved work plan. As a result, actual locations varied from the proposed locations in the work plan figures. However, figures were used as a guide for general sample location requirements.

C-9.13 SWMU 39-005

Two locations, 39-604838 and 39-604839, were moved as a result of their proximity to the building awning, which impeded collecting samples because of the height of the auger. Location 39-604838 was moved 7 ft northwest. Refusal in the form of welded tuff was encountered and the bottom two depths were not collected. Location 39-604839 was moved 27.5 ft west to the opposite side of the SWMU and was still within the footprint of the seepage pit.

C-10.0 REFERENCE

The following list includes all documents cited in this appendix. Parenthetical information following each reference provides the author(s), publication date, and ER ID. This information is also included in text citations. ER IDs are assigned by the Environmental Programs Directorate's Records Processing Facility (RPF) and are used to locate the document at the RPF and, where applicable, in the master reference set.

Copies of the master reference set are maintained at the New Mexico Environment Department Hazardous Waste Bureau and the Directorate. The set was developed to ensure that the administrative authority has all material needed to review this document, and it is updated with every document submitted to the administrative authority. Documents previously submitted to the administrative authority are not included.

LANL (Los Alamos National Laboratory), September 2007. "Investigation Work Plan for North Ancho Canyon Aggregate Area," Los Alamos National Laboratory document LA-UR-07-5947, Los Alamos, New Mexico. (LANL 2007, 098280)

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Closure Plan for Los Alamos National Laboratory Technical Area 54, Area G	Paper (letter)	03/01/2009	R. Shuman	LA-UR-09-02012	122	106860
Radiation Risk Estimation from Total Effective Dose Equivalents (TEDEs) [and attachments], U.S. Department of Energy memorandum, Office of Environmental Policy and Guidance	Paper (letter)	08/09/2002	A. Lawrence		8	106861
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