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Title: PERFORMANCE ASSESSMENT CLOSURE PLAN FOR AREA G

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Submitted to:

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1.0 EXECUTIVE SUMMARY

Technical Area 54 (TA-54) Material Disposal Area (MDA) G has been used for the disposal of radioactive waste generated at the Los Alamos National Laboratory (LANL) since 1957. The facility is the only active low-level waste (LLW) disposal facility at the Laboratory today, and is expected to remain so until operations at LANL cease. Consistent with DOE Order 435.1 (DOE, 1999a) and DOE M 435.1-1 (DOE, 1999b), disposal units at MDA G must undergo interim or operational closure as 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 effect interim and final closure at MDA G. It complies with guidance on the format and content of LLW disposal facility closure plans issued by the DOE (DOE, 2001).

MDA G has been used for the disposal of LANL's solid radioactive waste since 1957. Since that time, routine operations at the Laboratory have generated about 4,000 m^3 (140,000 ft^3) of solid LLW annually. The majority of the waste is buried in large rectangular pits, waste is also disposed 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 dumped directly in the disposal units, and may be used to fill void spaces between waste containers. Waste is lowered into the shafts from above, using remote-handled procedures as necessary. In the past, crushed tuff was added to the shafts between waste packages for shielding purposes. While this practice was discontinued in recent years, it was resumed in 2001.

Waste disposal operations at MDA G are presently assumed to extend through the year 2044. Future expansion of the facility will be necessary in order to dispose of LLW generated at the Laboratory over that period. Expansion of the disposal facility into the area immediately west of the current disposal area was considered in the LANL Site Wide

Environmental Impact Statement (DOE, 1999c) and was approved under the National Environmental Policy Act (NEPA). Expansion into this area is expected to occur after the existing disposal capacity is exhausted.

Operational closure of the pits and shafts used to dispose of waste at MDA G is conducted as the disposal units are filled. Crushed tuff is used to fill the pits from the top of the waste to the ground surface, topsoil is applied over the tuff, and vegetation is established. Tuff is used to fill the headspace in the filled shafts and mounded over the holes. Following subsidence determination, a portion of the crushed tuff is removed. Until recently, concrete caps were placed over the filled shafts.

The final closure strategy for MDA G has not been decided upon. The performance assessment and composite analysis are based on the assumption that the existing operational covers serve as the final covers as well. This strategy is expected to be successful as long as DOE restricts access to the site and maintains the cover over the 1,000-yr compliance period adopted by these analyses. While it is still considered likely that DOE will maintain control over MDA G for at least 1,000 years, no commitment to that period of control has been made. Consequently, a final closure configuration was identified on the basis that DOE will exercise control over the site for a minimum of 100 years. This design calls for a total of 3.4 m (11.2 ft) of cover over all new and existing disposal units.

Based on the results of the performance assessment and composite analysis, the most important role of the cover system is to minimize biotic intrusion into the waste. The operational covers placed over the pits and shafts relied on their overall thickness to limit intrusion into the waste, and performed satisfactorily under the conditions of low erosion and moderate biotic impact adopted for the performance assessment and composite analysis. Questions about the ability of this cover to achieve these objectives in the face of potentially higher rates of erosion and limited maintenance of the disposal site following closure were partly responsible for the adoption of the more robust cover design presented in this plan.

The final cover presented in this plan is 1.4 to 2.4 m (4.6 to 7.9 ft) thicker than the interim covers included in the performance assessment and composite analysis. The placement of additional material over the waste should allow the disposal facility to satisfy the long-term performance objectives found in DOE M 435.1-1 in the face of more extensive biotic intrusion pressures, higher rates of erosion, and as little as 100 years of institutional control. These expectations will be formally verified in the next revision of the performance assessment and composite analysis.

Disposal pits and shafts undergo interim closure at MDA G as they are filled. The schedule for interim closure, then, depends upon the rate at which waste requiring disposal at MDA G is generated, the types of waste sent for burial, and the capacities of the disposal pits and shafts receiving the material. While the majority of the waste sent to MDA G is disposed of in pits, the capacities of these units are large. Most pits are filled within two to four years, although some of these units have remained active for longer periods of time. Smaller quantities of waste are disposed of in shafts, but these smaller-capacity units typically remain active for two years or less before being closed.

MDA G is the only active LLW disposal facility at LANL, and is expected to remain so until the Laboratory ceases operations. The future inventory projections developed for the performance assessment and composite analysis are based on the assumption that waste disposal will end at MDA G in the year 2044. Final closure activities are expected to start immediately after disposal operations cease, and are expected to require two years to complete. Institutional control of the site is expected to begin in 2046, after final closure is complete.

2.0 INTRODUCTION

Technical Area 54 (TA-54) Material Disposal Area (MDA) G 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 until operations at LANL cease. Consistent with DOE Order 435.1 (DOE, 1999a) and DOE M 435.1-1 (DOE, 1999b), disposal units at MDA G must undergo interim or operational closure as 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 effect interim and final closure at MDA G. It complies with guidance on the format and content of LLW disposal facility closure plans issued by the DOE (DOE, 2001).

This section summarizes the information and activities associated with the closure of MDA G. Section 2.1 briefly describes the disposal facility, discusses the types of waste that have been disposed of, and summarizes land use patterns in the vicinity of MDA G. The general approach used to conduct interim closure of disposal units at MDA G is discussed in Section 2.2, and issues pertinent to final closure are considered. Section 2.3 provides the anticipated schedule of closure activities, while Section 2.4 discusses other Laboratory activities and programs related to facility closure. Key assumptions upon which the closure plan for MDA G is based are provided in Section 2.5.

2.1 GENERAL FACILITY DESCRIPTION

LANL is located in northwestern New Mexico, about 45 km (29 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 (48 mi^2) of land. MDA G is located within TA-54 atop Mesita del Buey, in the east-southeast portion of the Laboratory. The north and east borders of TA-54 coincide with the LANL property boundary, while the west and south borders lie within Laboratory lands. The closest population centers to MDA G are the communities of Los Alamos and White Rock.

Los Alamos is located 8 km (5 mi) northwest of the disposal facility, while White Rock borders the LANL boundary to the east, approximately 2 km (1.3 mi) to the east of MDA G.

MDA G has been used for the disposal of LANL's solid radioactive waste since 1957. Since that time, routine operations at the Laboratory have generated about 4,000 m^3 (140,000 ft^3) of solid LLW annually. Annual rates of generation of operational waste have been declining in recent years. In contrast, increased quantities of waste generated by the Environmental Restoration (ER) Project will probably require disposal in the next 10 to 15 years as sites at the Laboratory undergo remediation. Rates of waste disposal at MDA G will decrease after this period as ER Project activities wind down.

The waste disposed of at MDA G is placed in pits and shafts. The vast majority of the waste is buried in large rectangular pits. Disposal pits are set back at least 15 m (50 ft) from the nearest canyon rim. They are dug to within 3 m (10 ft) of the adjacent canyon floor, which has resulted in pits with a maximum depth of about 20 m (65 ft). In the past, LLW was placed in lifts in the disposal pits. Each layer of LLW was covered by crushed tuff and compacted in-situ by driving heavy equipment over the crushed tuff. Current operational procedures require that waste, with the exception of bulk soils and debris, be packaged prior to placement in the pits. Compactible waste placed in containers is compacted to minimize void space. Bulk materials are dumped directly in the disposal units, and may be used to fill void spaces between waste containers.

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 of the waste using remote handling techniques, and to accommodate special packaging requirements. The shafts are drilled into the Bandelier Tuff using augers. Disposal shafts 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. The diameters of the shafts generally range from 0.3 to 6 m (1 to 20 ft). Waste is lowered into the shafts from above, using remote-handled procedures as necessary. In the past, crushed tuff was added to the shafts between waste packages for shielding purposes. While this practice was discontinued in recent years, it was resumed in 2001. Shafts are covered with metal lids in between disposals.

A variety of waste types have been disposed of at MDA G since it began operations. Waste that, under current definitions, is considered to be transuranic (TRU) waste was disposed of at the facility through the mid-1970's. 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 disposed of at MDA G between 1971 and 1988. Some of the LLW and TRU waste disposed of prior to 1986 would meet the current regulatory definition of mixed waste. Since that time, 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 MDA G since 1990. MDA G is also authorized for the disposal of low-level Toxic Substances Control Act (TSCA) waste (i.e., polychlorinated biphenyls). Finally, a small portion of the waste disposed of at MDA G is contaminated with asbestos. Asbestos management is consistent with state regulations.

Several waste management functions are conducted at MDA 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). The portion of this waste that was generated after 1985 is stored in aboveground configurations. All stored TRU waste will be sent to WIPP prior to final closure of MDA G. MLLW generated at the Laboratory is sent to MDA G for storage; however, this waste is sent off-site for treatment or disposal.

Waste disposal operations at MDA G are presently assumed to extend through the year 2044. Future expansion of the facility will be necessary in order to dispose of LLW generated at the Laboratory over that period. Expansion of the disposal facility to include the area immediately west of the current disposal area was considered in the LANL Site Wide Environmental Impact Statement (DOE, 1999c) and was approved under the National Environmental Policy Act (NEPA). Expansion into this area is expected to occur after the existing disposal capacity is exhausted.

The types and quantities of waste that have been disposed of at MDA G, and that are expected to require disposal in the future, were estimated for the MDA G Performance Assessment and Composite Analysis (LANL, 1997). Inventory projections for these analyses divided the waste into four waste forms, including surface-contaminated waste, soils, concrete and sludges, and bulk-contaminated waste. All told, inventory projections for MDA G estimate that approximately 300,000 m^3 (11 million ft^3) of waste will have been disposed at MDA G by the time operations end in 2044.

2.2 GENERAL CLOSURE CONCEPT

Operational closure of the pits and shafts used to dispose of waste at MDA G is conducted as the disposal units are filled. Crushed tuff is used to fill the pits from the top of the waste to the ground surface, topsoil is applied over the tuff, and vegetation is established. Tuff is used to fill the headspace in the filled shafts and mounded over the holes. Following subsidence determination, a portion of the crushed tuff is removed. Until recently, concrete caps were placed over the filled shafts.

While the final closure strategy for MDA G has not been decided upon, the performance assessment and composite analysis are based on the assumption that the existing operational covers serve as the final covers as well. This strategy is expected to be successful as long as DOE restricts access to the site and maintains the cover over the 1,000-yr compliance period adopted by these analyses. Although it is considered likely that DOE will maintain control of the site for at least 1,000 years, no formal commitment has yet been made. Consequently, a more robust cover design has been identified and is presented in this plan as the final cover configuration. This design calls for a total of 3.4 m (11.2 ft) of cover over all new and existing disposal units.

The results of the MDA G Performance Assessment and Composite Analysis (LANL, 1997) indicate that the existing operational covers placed over the pits and shafts provide adequate protection of human health and safety, and the environment. Best estimates of the doses received by all receptors were less than the limits prescribed by the performance objectives, projected fluxes of radon from the site were also less than the acceptable limits. While rates of radionuclide release to groundwater were negligible, the deposition of contamination on the surface of the facility by plants and animals intruding into the waste may lead to unacceptable doses under worst-case conditions.

Based on the results of the performance assessment and composite analysis, the most important role of the cover system is to minimize biotic intrusion into the waste. The operational covers placed over the pits and shafts rely on their overall thickness to limit intrusion into the waste, and perform satisfactorily under the conditions of low erosion and moderate biotic impact adopted for the performance assessment and composite analysis. Questions about the ability of this cover to achieve these objectives in the face of potentially higher rates of erosion and limited maintenance of the disposal site following closure were partly responsible for the adoption of the more robust cover design presented in this plan.

The final cover presented in this plan is 1.4 to 2.4 m (4.6 to 7.9 ft) thicker than the interim covers included in the performance assessment and composite analysis. The placement of additional material over the waste should allow the disposal facility to satisfy the long-term performance objectives found in DOE M 435.1-1 in the face of more extensive biotic intrusion, higher rates of erosion, and as little as 100 years of institutional control. Furthermore, the closure configuration is expected to be protective of human health and safety even if the site is released for unrestricted use at the end of 100 years of institutional control. These expectations will be formally verified in the next revision of the performance assessment and composite analysis.

2.3 CLOSURE SCHEDULE

As indicated above, disposal pits and shafts undergo operational or interim closure at MDA G as they are filled. The schedule for interim closure, then, depends upon the rate at which waste requiring disposal at MDA G is generated, the types of waste sent for burial, and the capacities of the disposal pits and shafts receiving the material. While the majority of the waste sent to MDA G is disposed of in pits, the capacities of these units are large. Historically, most pits have been filled within two to four years, although some of these units have remained active for longer periods of time. Smaller quantities of waste are disposed of in shafts, but these smaller-capacity units typically remain active for two years or less before being closed.

A total of five pits are either active or ready to undergo interim closure. Waste is being disposed of in Pits 31, 38, and 39, while Pits 15 and 37 are awaiting closure. Current expectations call for Pit 15 to be closed by the end of 2002; the times of closure for the other pits are unclear. Four to six shafts have undergone interim closure in the past two years. Interim closure of shafts is usually conducted within a month of filling the units.

MDA G is the only active LLW disposal facility at LANL, and is expected to remain so until the Laboratory ceases operations. The future inventory projections developed for the performance assessment and composite analysis are based on the assumption that waste disposal will end at MDA G in the year 2044. Final closure activities are expected to start immediately after disposal operations cease, and are expected to require two years to complete. Institutional control of the site is expected to begin in 2046, after final closure is complete.

2.4 RELATED ACTIVITIES

The closure plan for MDA G is, or will be, related to several other activities or programs at LANL. As such, the plan and those activities and programs must be coordinated with one another to ensure an effective, consistent approach to facility closure is identified and implemented. These related activities and programs are discussed below.

2.4.1 ER Project Closure Activities

The effective date of DOE Order 5820.2A was September 26, 1988; this order has since been superceded by DOE Order 435.1. The disposal units at MDA G that were used to dispose of waste prior to this date may contain hazardous constituents that are regulated under the Resource Conservation and Recovery Act (RCRA). Additionally, small amounts of MLLW were inadvertently placed in one pit and one shaft between 1986 and 1990. The closure of all units containing hazardous constituents is regulated under RCRA (RCRA, 1976) and is the responsibility of the ER Project. Closure of LLW disposal units placed into operation after the effective date of DOE Order 435.1 is the responsibility of the Facility Waste Operations–Waste Facility Management Group (FWO-WFM).

The fact that MDA G closure is subject to two sets of regulations and involves two organizations makes it apparent that a coordinated effort on the part of the ER Project and FWO-WFM will be necessary if the facility is to be closed in an efficient, safe manner. However, the timeline under which the ER Project will address MDA G closure and the timeline associated with the demonstration of compliance with DOE Order 435.1 are sufficiently different that achieving this level of coordination is difficult at this time. Specifically, while the ER Project has conducted preliminary evaluations of the risk posed by MDA G (LANL, 2000a), the assessments needed to identify a suitable final closure configuration for the portion of the site for which they are responsible have not begun. In contrast, the Laboratory is required to update the closure plan as needed to maintain consistency with anticipated closure configurations. The operational and final closure concepts for MDA G have recently changed, calling for an update to the closure plan at this time.

Given the situation discussed above, this closure plan was developed solely from the perspective of complying with DOE Order 435.1 and DOE guidance on closure. Specifically, the final closure concept was developed to provide reasonable assurance that the performance-based requirements found in DOE M 435.1-1 would be satisfied. In all likelihood, the closure concept adopted under this approach will also prove adequate for the closure of disposal units under the ER Project. Nevertheless, the closure plan presented here will be re-evaluated when the ER Project conducts its evaluations and develops a closure strategy for the portion of the site for which it is responsible. Ultimately, the ER Project and FWO–WFM will work together to identify a single effective method for closing MDA G.

2.4.2 MDA G Performance Assessment and Composite Analysis

The MDA G Performance Assessment and Composite Analysis (LANL, 1997) projects the potential risk posed by waste disposed of at the facility to members of the public. The ability of the disposal facility to satisfy the DOE performance objectives depends, in part, on the final closure configuration of MDA G. As such, the closure plan and the performance assessment and composite analysis must be responsive to one another. If the performance assessment and/or composite analysis demonstrate an inability to comply with the performance objectives then changes to the closure configuration of the facility may be necessary. Conversely, changes to the closure concept for MDA G may require that the performance assessment and/or composite analysis be revised.

The final closure concept presented in this plan has not undergone a formal evaluation using the performance assessment and composite analysis models. The concept has, however, undergone a preliminary evaluation and is expected to provide reasonable assurance that all performance objectives will be satisfied. A complete evaluation of the adequacy of the closure concept will be conducted in conjunction with the next revision of the performance assessment and composite analysis. Modifications to the closure plan, performance assessment, and composite analysis will be made where appropriate, based on the outcome of that evaluation.

2.4.3 MDA G Monitoring

Routine environmental monitoring is conducted at MDA G to determine compliance with appropriate standards and to identify potentially undesirable trends. 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. As such, much of this information has little bearing on how interim or operational covers are performing. Monitoring conducted during the 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 consistent with one another. The monitoring program should collect data that will benefit the evaluation of 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.

2.4.4 Site Stewardship

The closure concept adopted for this plan was heavily influenced by long-range site stewardship considerations. The performance assessment and composite analysis assumed DOE would retain control over the closed site for at least 1,000 years. While it is still considered likely that DOE will maintain control over MDA G for at least 1,000 years, no commitment to that period of control has been made. Consequently, a final closure configuration was identified on the basis that DOE will exercise control over the site for a minimum of 100 years. This period of control is consistent with DOE M 435.1-1 (DOE, 1999b), which states that institutional controls shall be assumed to be effective in deterring human intrusion into the waste for 100 years.

The final closure configuration presented in this plan is expected to be capable of meeting DOE performance objectives as long as the period of institutional control is 100 years or more. As stated above, it is considered likely that DOE will, in fact, maintain control over MDA G for at least 1,000 years after facility closure. If a commitment is made to this period of institutional control, it may be possible to implement a cover design that is less robust than that presented in this plan. Consequently, the closure plan will be re-evaluated when decisions about long-term site stewardship are reached and formalized through Laboratory land use plans and the like.

2.5 SUMMARY OF KEY ASSUMPTIONS

Key assumptions about operational aspects of MDA G and the performance assessment and composite analysis modeling have been made in order to prepare the closure plan presented here. Perhaps most importantly, it has been assumed that DOE will maintain active institutional control over the closed disposal facility for a minimum of 100 years. While it is expected that DOE control over the site will last 1,000 years or more, the actual period of control that will be exercised is unknown at this time because stewardship decisions have not been made. Modifications to the closure configuration of the facility will be made as appropriate once long-term land use plans have been finalized.

The final cover design presented in this plan is significantly different than that evaluated in the MDA G Performance Assessment and Composite Analysis (LANL, 1997). Consequently, the ability of this closure concept to meet performance-based standards has not been formally confirmed. Preliminary calculations were, however, conducted to determine key design specifications such as cover thickness. These calculations are considered to be preliminary in nature, in part, because they are based on model processes and input parameters that are being evaluated under the performance assessment and composite analysis maintenance program. This research is expected to result in changes in how some of the processes are simulated and in the input data used to conduct this modeling. Given this, additional assessments of cover adequacy will be necessary once the maintenance activities are completed. The viability of the proposed closure configuration will, of course, be fully evaluated in the next revision of the performance assessment and composite analysis.

3.0 DISPOSAL SITE, FACILITY, AND WASTE CHARACTERISTICS

The long-term performance of MDA 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. The following sections summarize important MDA G site and facility characteristics.

3.1 SITE CHARACTERISTICS

The characteristics of the disposal site will interact with the facility characteristics to 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 modes of release and the media through which contaminant transport dominates. Demographic characteristics and predominant land use patterns in the vicinity of MDA G will influence the likelihood that persons will be exposed to radionuclides that are transported off-site. These and other important features of the disposal site are described below. The majority of this discussion has been taken from the MDA G Performance Assessment and Composite Analysis report (LANL, 1997), additional information was taken from the 1979 Final Environmental Impact Statement (DOE, 1979). References for the information summarized below and additional details about the site may be found in those documents.

3.1.1 Geography and Demography

This section establishes the geographic and demographic settings of MDA G. This information serves as an introduction to subsequent information about the physical characteristics of the disposal site, and provides perspective on the likelihood of human interaction with the closed facility.

3.1.1.1 Disposal Site Location

The Laboratory is located in northwestern New Mexico, about 45 km (29 mi) northwest of the state capitol, 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 (48 mi^2) of land. A regional map showing the location of LANL is provided in Figure 3-1.

MDA G is located within TA-54 atop Mesita del Buey, in the east-southeast portion of the Laboratory (Figure 3-1). The north and east borders of TA-54 are coincident with the LANL property boundary, while the west and south borders lie within Laboratory lands. The closest population centers to MDA G are the towns of Los Alamos and White Rock. Los Alamos is located 8 km (5 mi) northwest of the disposal facility, while White Rock borders the LANL boundary to the east, approximately 2 km (1.3 mi) to the east of MDA G.

3.1.1.2 Disposal Site Description

Mesita del Buey was identified in 1956 by the U.S. Geological Survey for radioactive waste disposal due to its favorable hydrogeologic properties and relative isolation from population centers. Figure 3-2 shows the site superimposed on the mesa-canyon topography common to the area; the present-day boundary of TA-54, and the anticipated future boundary of MDA G during the institutional control period are included in the figure. Mesita del Buey is approximately 50 ha (130 acres) in extent, the majority of which was identified in the initial site survey as suitable for radioactive waste disposal. Approximately 25 ha (60 acres) of this area have been used for disposal operations to date.

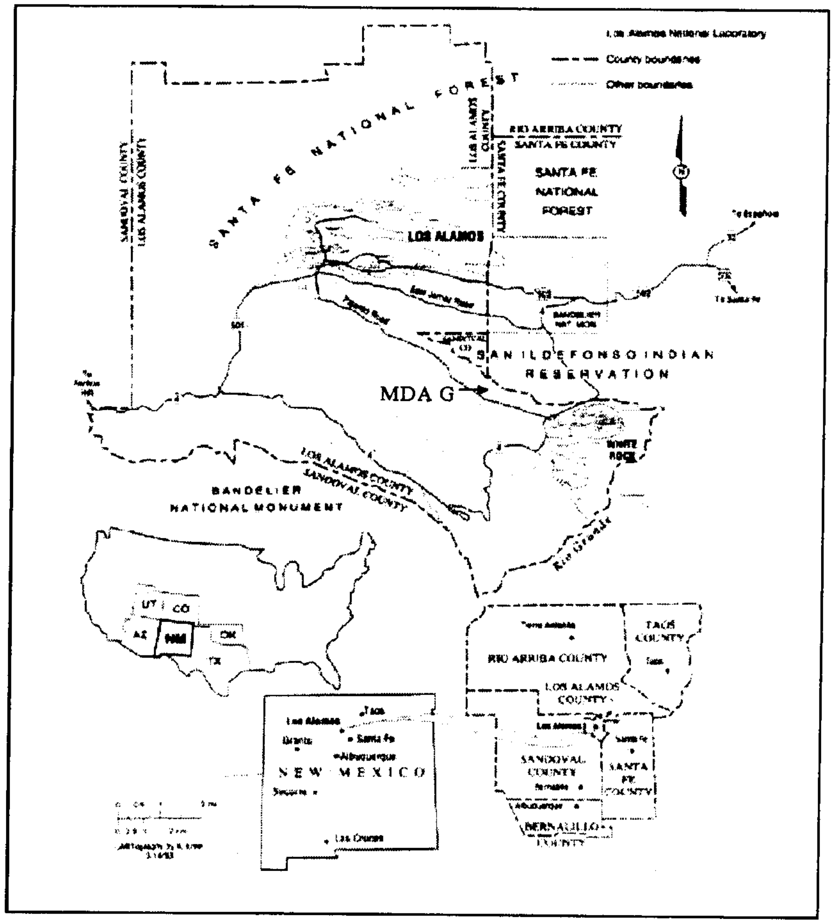

Figure 3-1. Location of LANL

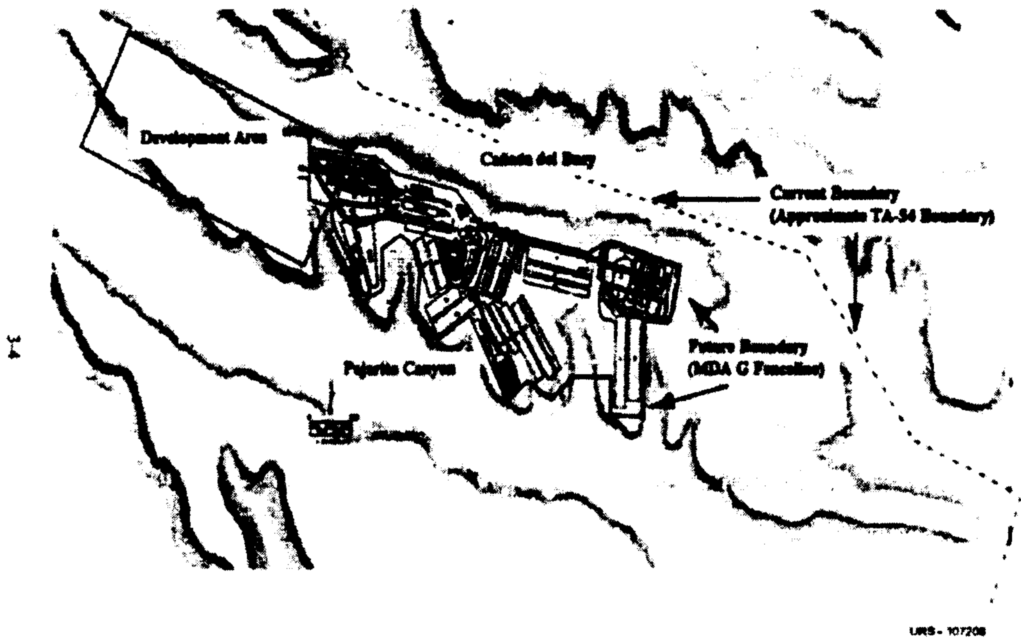

Figure 3-2. Map of MDA G illustrating mesa-canyon topography and current and future land-use boundaries

The mesa slopes gently from an altitude of about 2,100 m (6,900 ft) near its western boundary to about 2,000 m (6,600 ft) near its eastern end. It is bounded to the north by Canada del Buey, and by Pajarito Canyon to the south. The canyon floors are 15 to 30 m (50 to 100 ft) below the mesa-top. The northern side of the mesa is more gently sloping than the south side. The south faces of Mesita del Buey are almost vertical near the rim, becoming more sloped toward the canyon floor. Perennial water flows in Pajarito Canyon, while water flows in the much drier Canada del Buey only a few days out of the year.

The portion of Mesita del Buey that has not been disturbed by disposal operations is characterized by pinon-juniper woodland, while grasses dominate the disposal area. A number of surface structures are found within the operational area in addition to the disposal units. Erosion controls are used at the site to divert water away from waste management activities, and include drainage channels, culverts, riprap, silt fences, asphalt and concrete channels and curbing, earthen berms, and weirs.

3.1.1.3 Population Distribution

The estimated population of Los Alamos County, the county in which the Laboratory is located, was approximately 18,200 in 1991. 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. Other major residential population centers within 80 km (50 mi) of LANL include Espanola to the northeast and Santa Fe to the southeast. Santa Fe, with a population of about 80,000, is expected to remain the major urban center of the region. In all, approximately 224,000 people live within 80 km (50 mi) of the Laboratory.

3.1.1.4 Uses of Adjacent Lands

State and federal government agencies and local Indian tribes own much of the land surrounding the Laboratory. Three federal agencies (i.e., the Bureau of Indian Affairs, U.S. Forest Service, and Bureau of Land Management) control the majority of land in the area. The Santa Fe National Forest comprises 634,000 ha (1,600,000 acres) of land in several counties. The Espanola District of the Santa Fe National Forest includes 142,000 ha (352,000 acres) that border the Laboratory to the northwest and southeast. The Bandelier National Monument borders the southwest portion of LANL and is managed by the National Park Service. The monument includes 13,000 ha (32,000 acres) of land, approximately 9,300 ha (23,000 acres) of which are designated wilderness. All access routes to the monument pass through or along the boundaries of the Laboratory's property.

Thirteen Native American Pueblos are located within 80 km (50 mi) of LANL. The San Ildefonso Pueblo owns a triangular piece of land that directly borders MDA G within Canada del Buey, to the north of TA-54. The total area owned by the Pueblo is 10,600 ha (26,000 acres). The people of San Ildefonso Pueblo regard a portion of the land adjacent to

LANL as sacred hunting grounds. In addition to hunting wildlife for food, Pueblo people also harvest the fruit of pinon and juniper trees indigenous to the area. Hunting and gathering activities occur on the land directly adjacent to Mesita del Buey.

Agricultural activities in the vicinity of LANL have been declining for the past several decades and are no longer considered an important economic activity in terms of cash income to area residents. Livestock (primarily cattle) provide nearly 75 percent of the cash revenue from farm commodities in the region; crops (including hay, corn, chile, and apples) provide the remaining 25 percent.

Small farms remain an important means of providing supplemental income and domestic food in northern New Mexico. For example, the San Ildefonso Pueblo grows crops such as corn, chile, squash, beans, and tomatoes for domestic consumption and some marketing. All told, one to two percent of the land in the vicinity of the Laboratory is used for growing crops. Hay, corn, and chile are the most common crops grown in Los Alamos, Rio Arriba, and Santa Fe counties. Most of the agricultural acreage is irrigated; surface water irrigation is much more common than groundwater irrigation in Sandoval and Rio Arriba counties, while the opposite is true in Santa Fe County.

The density of livestock in the vicinity of LANL is low, approximately one animal per 120 ha (300 acres). All cattle are range-fed in northern New Mexico, where livestock forage is primarily native short-grass species. Much of the land now occupied by the Laboratory was historically used for grazing. The people of the Pueblos in the region graze livestock on their lands near LANL; numerous private landowners keep small numbers of livestock on land that surrounds Los Alamos County.

3.1.2 Meteorology and Climatology

The Los Alamos region has a semi-arid, temperate mountain climate. Annual precipitation is on the order of 46 cm (18 in.), but varies with elevation. Approximately 75 percent of the precipitation falls between May and October, primarily as thunderstorms.

There is an average of 62 thunderstorm-days per year. Showers tend to develop in early afternoon, and are accompanied by lightning, gusty surface winds, and occasional hail. Precipitation during the winter months occurs primarily as snow, with annual accumulations of about 1.3 m (4.3 ft).

Surface winds at the Laboratory show considerable variation in direction and velocity due to the complex terrain characteristic of the region. Winds are channeled by the terrain under moderate and strong atmospheric pressure gradients; a diurnal slope wind cycle exists under weak pressure gradients. The interaction of these effects gives rise to a predominantly westerly flow on the western part of the Laboratory and a southerly flow at the east end of the mesas. Near-calm conditions exist 10 to 15 percent of the time over most of the Laboratory; 80 percent of the wind speeds are less than 3 m/s (10 ft/s), and less than 1 percent of the 10-minute-averaged winds exceed 16 m/s (52 ft/s).

Four permanent meteorological towers are maintained at LANL, one of which has been located at TA-54 since 1989. The data from these stations indicate annual precipitation in the amount of 36 cm (14 in.). Approximately 40 percent of this total occurs during July and August. Annual variations in precipitation can be quite large. For example, totals ranged from 17 to 77 cm (6.7 to 30 in.) between 1989 and 1995. Evapotranspiration at MDA G is highest in the summer months, when vegetation is lush, temperatures are high, and the relative humidity is low.

Atmospheric conditions at MDA G are characterized using a combination of site-specific and Laboratory data. Table 3-1 summarizes atmospheric stability conditions near the disposal facility, and is based on 1995 meteorological tower data. Stability classes range from unstable (A) through stable (F), and characterize the dispersion conditions at the site. The data shown in the tables indicate that unstable conditions predominate, which promote dispersion of contaminant releases from the site. Atmospheric mixing heights at MDA G provide an indication of the height to which contaminants released from the site will disperse. These mixing heights average 710 m (2,300 ft) in January, 3,300 m (11,000 ft) in July, and 2,000 m (6,600 ft) over the entire year. Mixing heights are greatest in the summer months due to the strong daytime heating.

TABLE 3-1. ATMOSPHERIC STABILITY CLASS FREQUENCIES.

		Percent of Time Condition is Present	
Stability Class	Condition	Mesita del Buey	Pajarito Canyon
A through C	Unstable	48	48
D	Neutral	22	15
E and F	Stable	30	37

Wind patterns across the Pajarito Plateau are greatly influenced by the mesa-canyon topography discussed earlier. Data collected from six portable meteorological gauges that were installed to monitor wind conditions around MDA G are indicative of the strong channeling that occurs in the vicinity of the facility. The wind roses shown in Figures 3-3 and 3-4 indicate the wind speeds, frequencies, and directions for daytime and nighttime hours during 1995 for Mesita del Buey and Pajarito Canyon, respectively. Mesa top winds flow predominantly from the south-southwest during the day, while canyon winds flow almost exclusively up-canyon (i.e., to the north-northwest). The direction of canyon winds reverses during the nighttime hours, while mesa-top winds flow from the west. Wind speeds are typically less than 3 m/s (10 ft/s), and are lower in the canyons than across the mesa.

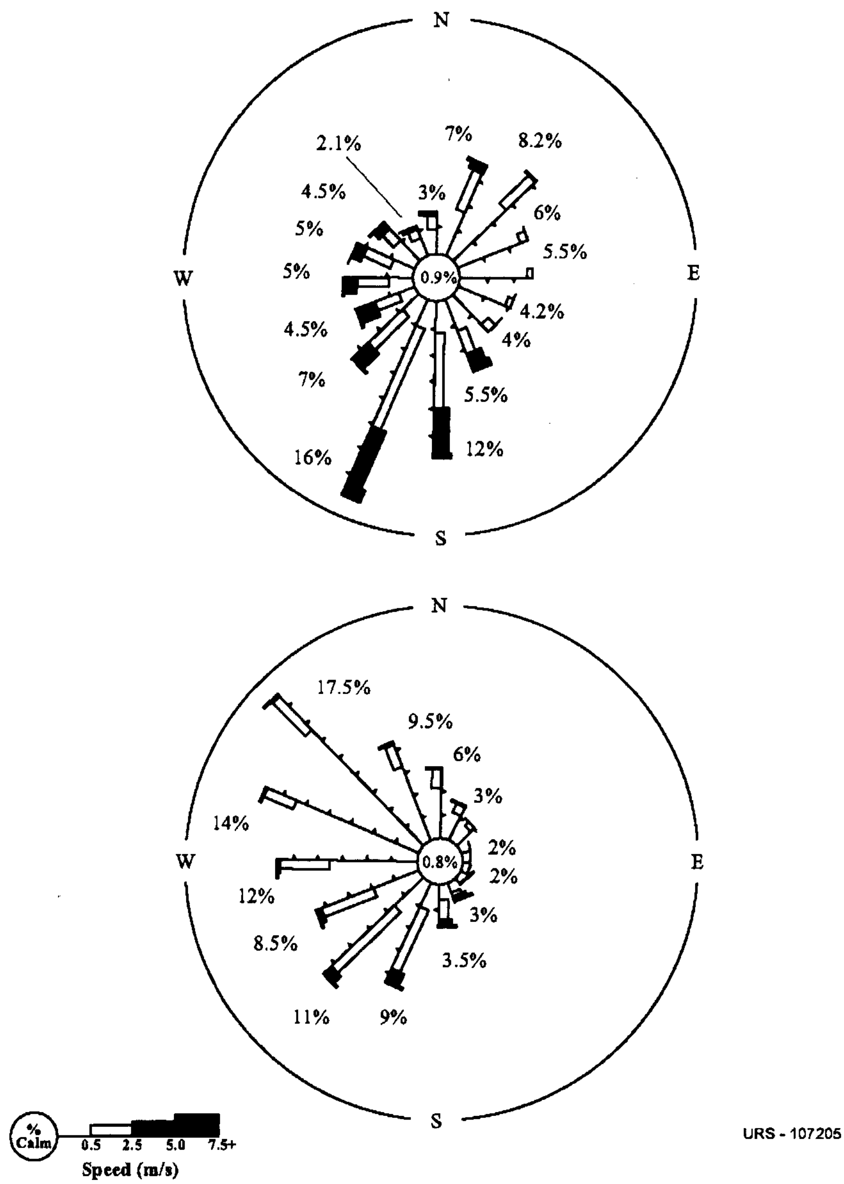

Figure 3-3. Daytime (top) and nighttime wind roses for Mesita del Buey

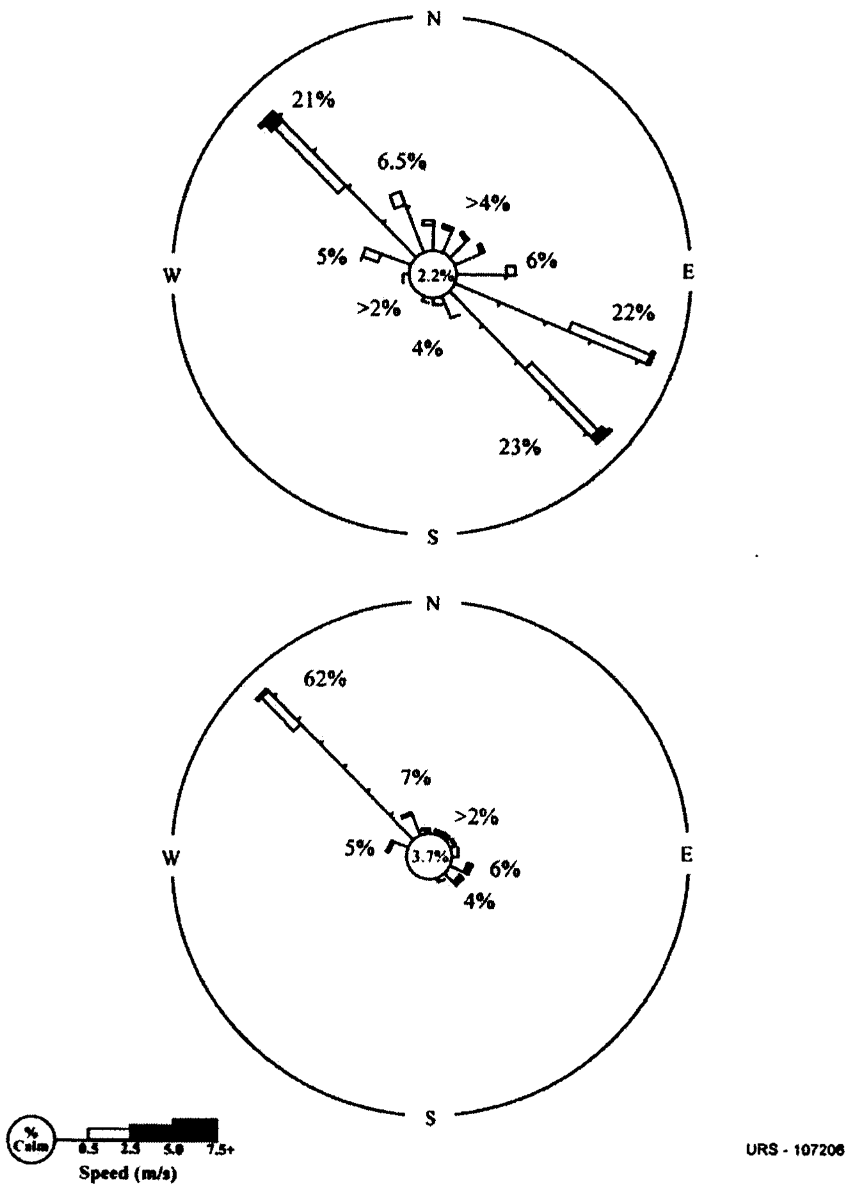

Figure 3-4. Daytime (top) and nighttime wind roses for Pajarito Canyon

3.1.3 Ecology

A diverse array of plants and animals is found in the Los Alamos region, owing to the large elevational gradient between the Rio Grande River (1,500 m [5,000 ft] above mean sea level) and the Jemez Mountains (2,700 m [9,000 ft] above mean sea level), and the canyon and mesa terrain. Six major vegetative community types are found in Los Alamos County including juniper-grassland, pinon-juniper, ponderosa pine, mixed conifer, spruce-fir, and subalpine grassland. The juniper-grassland, pinon-juniper, and ponderosa pine communities predominate, each of these communities occupies about one-third of the land area at the Laboratory.

Undisturbed areas on Mesita del Buey, the mesa upon which MDA G is located, are dominated by pinon-juniper woodland. Pinon pines (*Pinus edulis*) and one-seed juniper (*Juniperus monosperma*) are the dominant tree species, while common shrub species include big sagebrush (*Artemisia tridentata*), four-wing salt-bush (*Atriplex canescens*), currant (*Ribes cereum*), and mountain mahogany (*Cercocarpus montanus*). Blue grama grass (*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*), pinque (*Hymenoxys richardsonii*), wild chrysanthemum (*Bahia dissecta*), leafy golden aster (*Chrysopsis filiosa*), purple horned-toothed moss (*Ceratadon purpureus*), several lichen species, three-awn grass (*Aristida* spp.), bottlebrush squirreltail (*Sitanion hystrix*), bluegrass (*Poa* spp.), and false tarragon (*Artemisia dracunculus*). Waste management operations at MDA 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, buffalo grass (*Buchloe dactyloides*), western wheatgrass (*Agropyron smithii*), and dropseed (*Sporobolus* spp.), and forbs such as alfalfa (*Medicago sativa*).

Based on the information provided above, the disposal units at MDA G are expected to undergo ecological succession from their disturbed state shortly after closure to a pinon-juniper woodland climax, 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, a condition approximating the climax pinon-juniper woodland will most likely be attained.

The wide range of plant communities at the Laboratory provides a diversity of habitats for animal species. Harvester ants (*Pogonomyrmex* spp.) are the most abundant insects at MDA G, while common reptiles include fence lizards (*Scleoporous undulates*), Plateau striped whiptails (*Cnemidophorus velux*), gopher snakes (*Pituophis melanoleucus*), and garter snakes (*Thamnophilis elegans*). Many mammals inhabit the Pajarito Plateau, including a variety of rodents, mule deer (*Odocoileus hemionus*), elk (*Cervus canadensis*), black bear (*Ursus americanus*), mountain lion (*Felis concolor*), bobcat (*Lynx rufus*), gray fox (*Urocyon cinereoargenteus*), and coyote (*Canis latrans*), all of which occur in the vicinity of MDA G at least occasionally. Pajarito Canyon and Canada del Buey also support a wide range of bird species. In addition to several species of songbirds, a variety of nesting and migrating raptors have been identified in less disturbed portions of the canyons.

Several animal species that construct burrows for cover and foraging are present in the vicinity of MDA G. Species inhabiting the disturbed and grassland-dominated portions of the site include the previously mentioned harvester ants, deer mice (*Peromyscus maniculatus*), western harvest mice (*Reithrodontomys megalotis*), and pocket gophers (*Thomomys* spp.). Harvester ants and deer mice also occur in pinon-juniper woodlands, as do pinon mice (*Peromyscus truei*), western harvest mice, brush mice (*Peromyscus boylii*), and silky pocket mice (*Perognathus flavus*). Distribution maps for pinon-juniper woodland at the Laboratory also suggest the presence of chipmunks (*Eutamias quadrivittatus*), woodrats (*Neotoma* spp.), and mountain cottontails (*Sylvilagus nuttalli*).

3.1.4 Geology

The geologic setting of MDA G has a profound impact on the potential for the release and transport of radionuclides. Geologic characteristics of the Laboratory in general and the disposal site in particular are summarized below. The following discussion is a summary of the information presented in the MDA G Performance Assessment and Composite Analysis report (LANL, 1997). The reader is referred to that document for additional details.

3.1.4.1 Regional and Site-Specific Geology/Topography

The Laboratory resides at an average elevation of 2,100 m (7,000 ft) on the Pajarito Plateau, east of the Jemez Mountains. The Pajarito Plateau consists of a series of fingerlike mesas separated by deep erosional canyons that generally run from west to east. The tops of the mesas range in elevation from 2,400 m (7,800 ft) on the flank of the Jemez Mountains to approximately 1,900 m (6,200 ft) at their eastern ends. The eastern end of the Pajarito Plateau rises between 90 and 275 m (300 and 900 ft) above the Rio Grande Valley.

The Pajarito Plateau is formed of consolidated ash (or tuff) resulting from two major volcanic eruptions in the Jemez Mountains about 1.61 and 1.22 million years ago (Ma). These eruptions produced widespread, massive deposits 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 (or rhyolitic) tuffs and sediments that occur commonly but not uniformly between the Otowi and Tshirege Members.

The Bandelier Tuff is underlain by interstratified sedimentary and volcanic rock. 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. With the exception of the basalt, pre-Bandelier rock units are widely distributed across the Pajarito Plateau; the basalt is limited to the eastern and southeastern portions of the plateau. The Puye Formation (formed 1.6 to 4 Ma) is a fan-shaped sedimentary deposit (or alluvial fan) consisting of boulders, cobbles, coarse sands, and tuff beds, sloping eastward from the Tschicoma volcanic highlands. The Cerros del Rio Basalt (formed 2.3 to 2.8 Ma) originates from a volcanic ridge east of the Rio Grande River, dipping westward from the crest towards the river. Evidence of basaltic vents on trend with the same ridge have been encountered in recent boreholes west of the Rio Grande River, suggesting that the entire volcanic ridge from which the Cerros del Rio Basalt originated was completely buried by the Bandelier Tuff deposits.

The Otowi Member deposit partially filled in and flattened the pre-Bandelier valley that dips to the south-southwest. The deposit is at least 142 m (465 ft) thick in the northern part of the Laboratory and thins to the east against the basaltic ridge. The Otowi Member may have buried the basaltic ridge discussed above, but, if so, the ridge apparently eroded before the eruption that formed the Tshirege Member. Eruption of the Tshirege Member ashflow again largely erased the former topography. Erosion of the Tshirege Member forms modern drainages, including the steep-sided east-trending erosional canyons. The thickness of the Tshirege Member varies greatly across the Pajarito Plateau, and is partly controlled by the landscape of the partially eroded Otowi surface beneath it. Over most of the central and northern Pajarito Plateau, the Tshirege Member is between 30 and 122 m (100 and 400 ft) thick, but it exceeds 260 m (850 ft) in thickness in some places. The thickness of the member may be greater than 120 m (400 ft) to the southwest, and less than 30 m (100 ft) occur near the basaltic ridge. There is a general decrease in the thickness of the Tshirege Member to the north and to the east.

The current surface drainage pattern across the Plateau is generally southeast, oblique to 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. Geochemical and hydrologic characteristics of these buried soils may have an important, but not well-understood, impact on the potential for contaminant migration.

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 centerline of mesas, away from major drainages. In addition, mesas erode or "retreat" laterally as a result of mass wasting or cliff retreat. North-facing rims display large-scale mass movement (i.e., landslides) in zones determined by a threshold combination of slope gradient and canyon depth, while south-facing 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 and, while mass wasting on both north and south faces does occur, the effects are not nearly so dramatic as those observed along higher mesas across the Pajarito Plateau. The rate of cliff retreat is difficult to estimate insofar as it is a discontinuous process. Nonetheless, attempts have been made to quantify the process, largely for determining adequate set-back distances for facilities built on mesa tops. The most credible estimates of rates of cliff retreat made at locations across the Laboratory (not including Mesita del Buey) vary from 3.0×10^{-5} to 2.0×10^{-4} m/yr (1.0×10^{-4} ft/yr to 7.0×10^{-4} ft/yr).

Surface sediments across the Pajarito Plateau are composed of thin soils developed on the mesa top, alluvial (water deposits) and colluvial (slope deposits) residues on the mesa flanks, and alluvial deposition in the canyon bottoms. They consist of coarse-grained colluvium on steep hill slopes and fine-grained materials on the flatter mesa tops. Alluvial deposits in the canyons are composed of unconsolidated fine and coarse sands of quartz, sanidine crystal fragments, and broken pumice fragments weathered and transported from the mesa top and sides. The slopes between mesa tops and canyon bottoms often consist of rocky outcrops and patches of undeveloped colluvial soil. South-facing canyon walls are steep and may have no soils, while north-facing walls generally have areas of very shallow, dark soils.

Soils on the Pajarito Plateau are extremely variable in physical and chemical properties, including particle size, clay mineralogy, and trace elements. Glass is the major constituent of the regional soils, with iron being another important component. Thorium and uranium are naturally occurring, and are highly variable in their distribution across the Laboratory.

The stratigraphic beds underlying MDA G are shown in Figure 3-5. A fairly complete set of data and observations are available to characterize the uppermost 60 m (200 ft) of the Tshirege Member of the Bandelier Tuff. Far less information is available for the lower portion of the stratigraphy, particularly the Cerros del Rio Basalt. The majority of geologic, hydrologic, and geochemical information for MDA G is provided as an appendix to the performance assessment and composite analysis (LANL, 1997). The reader is referred to that report for additional information about the site's geology.

3.1.4.2 Seismology and Volcanology

The Laboratory is located within the northern Rio Grande rift, a seismically active region undergoing east-west extension. MDA G is located west of the Pajarito Fault system, which includes the Pajarito, Rendija Canyon, and Guaje Mountain faults. The main east-dipping Pajarito fault has had an average vertical slip rate of 0.07 mm/yr (2.7×10^{-4} in./yr) for the past 1.2 Ma, whereas the shorter west-dipping Rendija Canyon and Guaje Mountain faults have had average vertical slip rates of 0.02 and 0.01 mm/yr (7.8×10^{-4} and 3.9×10^{-4} in./yr), respectively. Given the proximity of MDA G to the Pajarito Fault system, a seismic hazard evaluation was performed to support the performance assessment and composite analysis.

Two potential seismic hazards were identified as having a possible impact on the ability of MDA G to contain and isolate waste: 1) small displacements or deformation of the disposal unit cover due to surface faulting on minor secondary faults; and 2) disturbance or deformation of the disposal unit cover due to ground shaking. Other potential earthquake hazards were not considered a risk at MDA G for a variety of reasons. Most importantly, the subsurface excavation of disposal units into bedrock precludes the potential for liquefaction of sediments or earthquake induced slope failures. While 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 MDA G. Should such events occur, the 15 m (50 ft) setback from the edge of the cliffs is expected to protect against the loss of integrity of disposal units

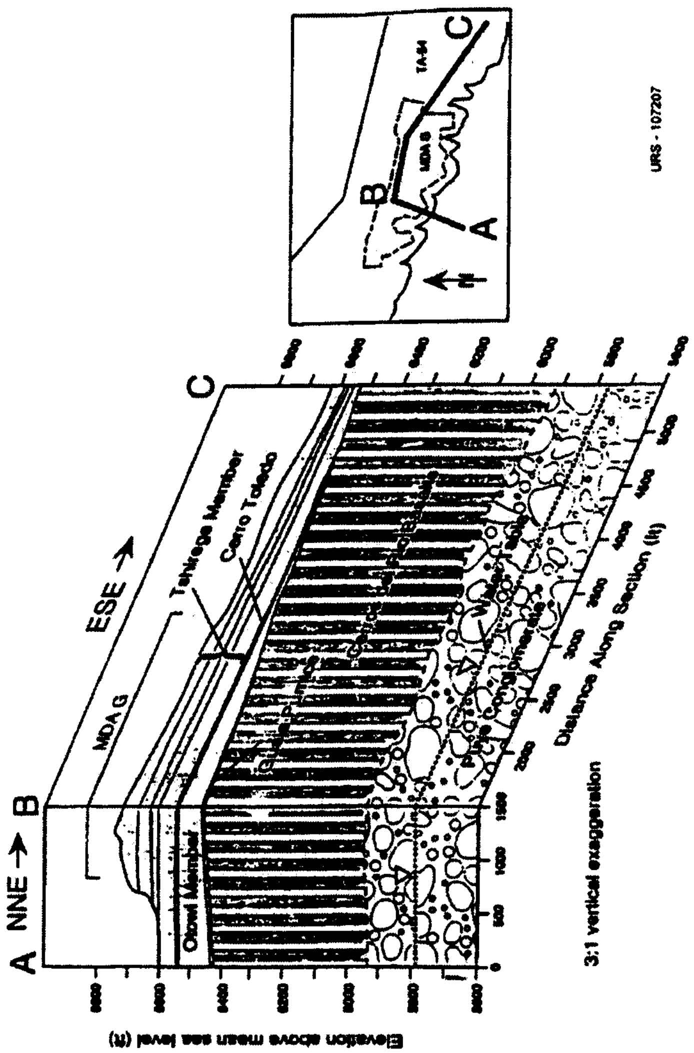

Figure 3-5. Stratigraphic cross-sections in the vicinity of MDA G

The Rendija Canyon fault is the portion of the Pajarito Fault system closest to MDA G, and is located more than 6 km (3.6 mi) west-southwest of the site. The most recent surface faulting event along this fault occurred at least 8,000 years ago, and possibly 23,000 years ago. This event did not rupture the southern end of the fault, which is the end closest to MDA G. Estimates of average recurrence intervals for surface-faulting earthquakes (i.e., earthquakes with a magnitude of more than 6.5 on the Richter scale) range from 33,000 to 60,000 years.

Previous investigations have not identified any geomorphic expressions of faults at MDA G. However, minor faults with small offsets within the Tshirege Member of the Bandelier Tuff have been observed in natural exposures in Pajarito Canyon south of MDA G. Due to the variety of orientations and very small total offsets in rock that is 1.2 Ma old, these faults are not likely seismogenic. It is thought that these displacements are either related to cooling of the tuff, or to secondary slippage triggered by earthquakes occurring in the Pajarito Fault system. In terms of slippage, total displacements of 40 to 65 cm (16 to 25 in.) over 1.2 Ma correspond to rates of slippage of about 4×10^{-4} mm/yr (1.6×10^{-6} in./yr). While the possibility exists that the observed displacements occurred during a single seismic event, the fact that such an event occurred only once in the past 1.2 Ma makes it unlikely that another will occur in the next 1,000 to 10,000 years.

A seismic hazard evaluation was conducted at LANL to estimate ground motion from possible earthquakes at several sites around the Laboratory. The objective of the study was to determine the design criteria for several nuclear facilities based on potential seismic hazards in accordance with DOE Order 5480.28, Natural Phenomena Hazards Mitigation. The evaluation concluded that a magnitude 6 background earthquake is likely within 100 years, and that a magnitude 7 Pajarito Fault system earthquake over the next 10,000 years is unlikely.

Peak horizontal accelerations ranging from 0.41 to 0.57 g were estimated for the sites included in the study. While TA-54 was not included in the study, its geology is similar enough to two sites that were considered (i.e., TA-18 and TA-46) that results of that study were applied in the Safety Analysis Report for MDA G (LANL, 1995a). In particular, the maximum design-basis earthquake considered in the Safety Analysis Report as a criterion to which facility structures must be shown to be capable of withstanding was 0.57 g. Such an earthquake was determined not to pose a risk in terms of waste buried below the surface.

The 16.5-million year volcanic history of the Pajarito Plateau has been extensively studied. Much of the information has already been discussed. Evidence suggests that eruptions like those depositing the upper and lower members of the Bandelier Tuff have recurred every 200,000 to 500,000 years. Small, localized eruptions occurred about 50,000 years ago and were contained within the Valles Caldera to the west of the Pajarito Plateau.

3.1.5 Hydrology

The hydrologic characteristics of the disposal site are important in terms of understanding the potential for release of radionuclides from the waste by leaching, and the mechanisms through which contamination may be distributed in the environment. Contaminants released to the surface of the facility may be transported via surface water, while leachate from the pits and shafts may be transported by groundwater. Regional and MDA G-specific characteristics of these waters are provided below.

3.1.5.1 Surface Water

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

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

2,400 and 2,700 m (7,900 and 8,900 ft) on the slopes of the Sierra de los Valles and supply water to the upper reaches of several major canyons, including Pajarito Canyon south of Mesita del Buey. The source of these springs is water perched in the Bandelier Tuff and Tschicoma Formation. These springs discharge at rates from 7 to 530 L/min (1.8 to 140 gpm), which is insufficient to maintain surface flow for more than the upper third of the canyons before it is depleted by evaporation and infiltration into the underlying alluvium.

There are no streams on Mesita del Buey; water flows on the mesa only as storm water and runoff following snowmelt. Surface erosion due to runoff occurs primarily as shallow sheet erosion on the relatively flat parts of the mesa, and by deeper erosion channels along the edges. Runoff from summer storms 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 low discharge rates. The amount of eroded material transported in runoff waters is generally higher in summer rainfall events than during snowmelt.

Flooding of the disposal facility is not a major concern due to the natural inclination for runoff from the mesa into the canyons; temporary ponding within the disposal pits, however, has occurred. Storm water flows at a number of points along the perimeter of MDA G, the perimeter of the facility includes nine distinct natural drainage channels. In addition, there are a number of areas over which water flows in sheets off the mesa edge after rains. Fieldwork at MDA G has demonstrated that disposal pit covers are subject to sheet erosion, with only small, localized rills occurring infrequently.

3.1.5.2 Groundwater

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

Canada del Buey periodically and is present in Pajarito Canyon. Observation wells and moisture-access holes were drilled in Canada del Buey and Pajarito Canyon to determine if perched water existed within canyon alluvium and, if present, if it extended beneath Mesita del Buey. Of the nine holes drilled in Canada del Buey, seven were dry. Two other holes delineate a small (0.8 km [0.5 mi] long) saturated segment in the alluvium, the apparent source of which is purge water from a nearby municipal supply well. Of the seven holes drilled in Pajarito Canyon, four were drilled in the alluvium near the Pajarito Canyon stream and found groundwater. The three remaining holes were drilled on the flank of the canyon near the mesa walls and were dry. It was concluded that perched water in Pajarito Canyon, adjacent to Mesita del Buey, is confined to the alluvium in the stream and does not extend to the flank of the canyon.

There have been 21 supply wells and 10 test wells drilled into the regional aquifer on or adjacent to the Pajarito Plateau. The hydrologic characteristics of the regional aquifer measured at each of the supply wells and at eight 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 MDA G) contains the most productive supply wells. The average saturated thickness of the aquifer penetrated by the Pajarito Field wells is 550 m (1,800 ft). The age of water in the regional aquifer ranges from a few thousand to more than 40,000 years, with the youngest water occurring to the west and the oldest to the east. A portion of the regional aquifer discharges into the Rio Grande River east of the Laboratory; the 18-km (11-mi) reach of the Rio Grande River in White Rock Canyon receives about 6.8×10^6 m^3 (5,500 acre-ft) of discharge annually.

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

The processes that drive flow and radionuclide transport in the vadose zone at MDA G are especially complex. Flow and transport may occur in two phases (liquid and gas) in the variably saturated media, and occur in the presence of open to filled fractures in some of the geologic strata underlying the site. Liquid flow is driven by energy gradients, and controlled by the hydraulic conductivity and structure of these strata. A summary of important hydrologic properties for the MDA G stratigraphy is provided in Table 3-2, detailed discussions of this information may be found in the performance assessment and composite analysis report (LANL, 1997).

The properties summarized in Table 3-2 ultimately determine the deep percolation rate of water through the mesa. This rate of recharge plays an important role in determining the minimum time required for contamination to be transported from the disposal units, through the vadose zone, to the regional aquifer. The recharge through the undisturbed vadose zone is complex and is complicated further at MDA G by man-made disturbances associated with waste management activities.

Measurements of moisture within the subsurface at MDA G consistently show three moisture content zones. In the top few meters, volumetric moisture content varies between about 3 and 12 percent, reflecting the seasonal effects of precipitation and evapotranspiration. At mid-mesa depths (i.e., from about 8 to 23 m [25 and 75 ft]), volumetric moisture content is quite low, ranging from 0.5 to 2.0 percent. At greater depths within the mesa, moisture content increases to between 9 and 19 percent. The dry zone consistently occurs near the surge beds at the base of Unit 2 of the Tshirege Member, while the deeper, moist zone is apparently associated with the vapor-phase notch at the interface between Units 1vc and 1g. Estimates of flux rates through the low moisture content region, based on unsaturated hydraulic conductivity estimates, are negligible. Water-pressure profiles estimated beneath the mesa using hydraulic properties from cores suggest liquid water moves towards the base of Tshirege Unit 2 from above and below. These observations are consistent with a hypothesis that the mesa is dried out to a significant extent by evaporation and air movement along surge beds and along fractures that are prevalent near this horizon.

TABLE 3-2. HYDRAULIC CHARACTERISTICS OF THE MDA G VADOSE ZONE.

Property	Tshirege Member Unit 2	Tshirege Member Unit 1vu	Tshirege Member Unit 1vc	Tshirege Member Unit 1g	Tsankawi/ Cerro Toledo Interval	Otowi Member	Guaje Pumice	Cerros del Rio Basalts	Puye Formation
Thickness (m)	12.2	13.7	7.6	15.2	1.8	36.6	3.7	>36.3	~200
Lithololgy Summary	Massive crystal-rich slightly welded tuff devitrified; vapor-phase altered; pumice swarms; basal surge	Massive, crystal rich nonwelded tuff; devitrified; pumiceous; crystal-rich lapilli	Massive, crystal-rich nonwelded tuff; pumiceous; pumice swarms; ash falls, crystal-rich lapilli	Massive, nonwelded, nonindurated tuff, vitric; pumiceous; crystal-rich lapilli	Massive air-fall tuff; large white-pumice lapilli; topical surge bed of crystals and ash	Massive, oderately crystal-rich, nonwelded, vitric tuff; ~30% pumice	Basalt nonwelded pumice lapilli bed; vitric	Dense fractured, basaltic tondesitic lava flows, with flow breccias and Puye interbeds	Fanglomerates and conglomerates, fluviatile and debris-flow deposits; interbedded ash and pumice falls, basalt flows
Fracture Spacing (m)	1.1-1.3	1.0-1.3	No data; few fractures	No data; some fractures	No data; rare fractures	No data; few fractures	No data; rare fractures	~0.3 (from observation)	No data; poorly developed in outcrop
Fracture Dip and Aperture	87 deg median; 3 mm median	84 deg median; 3 mm median	No data; assumed vertical	No data; assumed vertical	No data; assumed vertical	No data	No data	~5 mm (from observation)	No data
Fracture Fill	72% filled; 9% plated; 19% open	82% filled or plated; 18% open	No data	No data	No data	No data; some caliche observed	No data	None observed	No data
Mean Density (g/cm^3)	1.37	1.26	1.20	1.14	1.12	1.2	No data	No data; 2.4-3.1 estimated	No data
Mean Porosity (%)	45.7	48.7	49.3	46.2	47.3	43.5	No data	No data	No data
Mean Vol. Moisture (%)	2.57	1.89	10.88	8.94	14.00	11.5	No data	No data	No data
Saturation (%)	5.7	3.7	21.3	16.9	30.3	26.4	No data	No data	No data
Mean Ksat (cm/sec)	4.37E-7	1.48E-4	1.67E-4	1.88E-4	8.65E-4	2.49E-4	No data	No data	No data
van Genuchten									
θ	0.0	0.0	0.0	0.0	0.8	2.1	no data	no data	no data
α	0.0060	0.0030	0.0033	0.0053	0.0152	0.059	no data	no data	no data
η	1.890	1.932	1.647	1.745	1.506	1.713	no data	no data	no data

Several independent analyses have inferred different rates of recharge corresponding to the three moisture-content zones measured in boreholes at MDA G or determined using core recovered from the boreholes. These analyses invoke simplifying assumptions, but nonetheless, provide consistent qualitative evidence of variable recharge within and across Mesita del Buey. These inferred recharge zones are:

- A near-surface zone with an apparent recharge on the order of several mm/yr;

- An intermediate zone through the mid-depths of the mesa with rates of recharge on the order of tenths or hundredths of mm/yr; and

- A deeper zone in which apparent recharge rates may be several cm/yr.

The analyses corroborating these spatially-dependent recharge rates are summarized in the MDA G Performance Assessment and Composite Analysis (LANL, 1997).

The hydrologic characteristics of the canyons adjacent to Mesita del Buey may influence the hydrology beneath the mesa. To the north, Canada del Buey contains an intermittent stream. The alluvium is thin and contains no perennial saturation. Pajarito Canyon, to the south, also contains an intermittent stream, but the larger flow in this canyon supports a perennial groundwater body in the alluvium.

In Canada del Buey, the infiltration rate estimated using *in situ* moisture contents and hydrologic properties determined from cores is 0.44 cm/yr (0.17 in./yr). Data are not available to estimate fluxes beneath Pajarito Canyon. However, data are available from Mortandad Canyon, a canyon that is expected to be hydrologically similar to Pajarito Canyon. Estimates of rates of recharge for that canyon range from 2 to 10 cm/yr (0.8 to 4 in./yr).

3.1.6 Geochemistry

The geochemical characteristics of the pore water, groundwater, rocks, and soils beneath MDA G have important implications with respect to the rate at which radionuclides are transported by water away from the disposal units. In modeling subsurface "aqueous phase" transport, element-specific sorption coefficients are used to estimate partitioning between solids and pore water. These sorption coefficients depend on the chemical forms of the radionuclides, which are determined by the chemistry of the water in which the contaminants are dissolved and the concentrations of the radionuclides. Contaminants that do not sorb to solids may dissolve in the pore water in proportion to their solubilities. This section describes the geochemistry of the Bandelier Tuff in general, then reviews geochemical conditions specific to MDA G.

Certain minerals present in Bandelier Tuff have high sorptive capacity for many radionuclides present in the MDA G inventory; these minerals include hematite, kaolinite, smectite, and calcite. Although the mass concentration of these minerals is small in the Bandelier Tuff, they are found throughout the tuff, especially within fractures as coating and fill material. Consequently, they can have a significant effect on the retardation of several radionuclides in the MDA G inventory. Hematite (i.e., iron ore) fracture coatings are also found, but with less frequency than clay coatings. Hematite has a very large surface area for binding certain radionuclides (e.g., americium, plutonium, and uranium) and, as a result, is also important when considering transport in fractures lined with this material. 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 weight-percent.

Certain highly sorptive solid phases, including clay minerals, iron oxides, solid organic matter, and carbonate minerals, are known to be present in buried soils found across the Laboratory. While the occurrence of calcium carbonate and clay-rich horizons in the subsurface is not known beneath MDA G specifically, they may be important for sorbing radionuclides.

Bench-scale batch experiments were performed to estimate sorption coefficients for use in the MDA G Performance Assessment and Composite Analysis (LANL, 1997). Briefly, sorption experiments were performed using naturally occurring groundwater and a synthetic solution representative of the pore water within the vadose zone. The groundwater samples were obtained from the Water Canyon Gallery, which is considered to be chemically similar to the regional aquifer. The synthetic pore water matched the chemistry of water extracted from core samples and is considered to be representative of recharge moisture. Known amounts of radionuclides were added to both waters. The solutions were mixed with known amounts of crushed tuff onto which sorption was being measured. After three weeks, the liquids and solids were separated, and the quantities of radionuclides that were sorbed by the tuff were determined.

The solutions and tuff samples used in the batch sorption experiments were chosen to represent the sorption capacity of Bandelier Tuff within and beneath the disposal pits under saturated flow conditions, and beneath the pits under unsaturated conditions. The isotopes included in the analysis were either highly mobile radionuclides (i.e., Tc-99 and Np-237) or radionuclides that are abundant in the MDA G inventory (i.e., Am-241, Am-243, Pu-239, and U-233). Additional details about the experimental protocol may be found in the MDA G Performance Assessment and Composite Analysis report (LANL, 1997).

3.1.7 Natural Resources

The development of natural resources in the vicinity of MDA G could impact the site after closure of the disposal facility. Consequently, an understanding of these resources is necessary in order to ensure safe disposal of the radioactive waste. Distributions of geologic and water resources near MDA G are discussed below.

Several mines and quarries exist in Los Alamos County, but none are active. Small surface mines in Sandoval, Santa Fe, and Rio Arriba counties near Los Alamos extract pumice. The pumice mine that is closest to the Laboratory is about 10 km (6 mi) north of the MDA G. Other active surface mining operations in the region recover sand, gravel, crushed rock, and other fill materials. The nearest of these facilities is located in Santa Fe County, about 10 km (6 mi) east of MDA G. Surface mines for volcanic cinders operate approximately 8 km (5 mi) east and 25 km (15 mi) south of MDA G, and a surface mine for humate (a soil conditioner) operates approximately 55 km (33 mi) west of LANL. Gypsum is mined at a few locations south of the Laboratory.

Historically, metal deposits (primarily silver, copper, and gold) were mined in the Cochiti (Bland) mining district, about 16 km (10 mi) south of the Laboratory. 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 active metal mines closest to LANL are located in the San Pedro Mountains, approximately 45 km (27 mi) to the south. Turquoise is also mined approximately 45 km (27 mi) south of the Laboratory.

The natural gas field closest to LANL 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 the Laboratory. The U.S. Geological Survey considers the potential for oil and gas discoveries in Los Alamos County area to be poor. However, in the Espanola Basin, just a few kilometers northeast of the Laboratory, recent exploration wells have encountered oil and gas.

The coalfields closest to the Laboratory are in the San Juan Basin, and extend to within 40 km (25 mi) of LANL. Small fields south of Santa Fe, the Hagen and Cerrillos fields, are about the same distance to the south of Los Alamos. Relatively small uranium deposits occur in the Nacimiento-Jemez uranium area, about 35 km (20 mi) southwest of LANL. Also, relatively high concentrations of uranium sediments have been found on the southeast flank of the Jemez Mountains.

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

Under normal operating conditions, the majority of water from the Guaje and Otowi well fields serves only the town of Los Alamos. Approximately five percent of the water from the Otowi well serves LANL. Of the five wells in the Pajarito field, two serve the town of White Rock and three serve the Laboratory. If the need arises, water from any of these wells can be routed to any destination. Water from the Los Alamos well field was transferred to the San Ildefonso Pueblo in 1991. Currently, only two wells in this field are being used, and these serve as a source of non-potable water for irrigation. Non-potable industrial water is obtained from the spring gallery in Water Canyon.

The Cochiti Reservoir dam is located on the Rio Grande River, about 15 km (9.3 mi) from the southernmost point of the LANL boundary. It provides the area with flood control, sediment retention, recreation, and fishery development. The permanent pool of the reservoir extends upstream some 12 km (7.4 mi), reaching a point about 5 km (3.1 mi) from the Laboratory's boundary. The dam is estimated to trap at least 90 percent of the sediments carried by the Rio Grande River.

No municipal water supplies are taken directly from the Rio Grande River between the Laboratory and the Cochiti Dam. The river is used primarily for recreation. Irrigation water is taken from the river downstream of the Laboratory at numerous diversions starting at the Cochiti dam.

3.2 FACILITY CHARACTERISTICS

MDA G has been used for the disposal of the Laboratory's solid radioactive waste since 1957. Since that time, routine operations at LANL have generated about 4,000 m^3 (140,000 ft^3) of solid LLW annually. Annual rates of generation of operational waste have been declining in recent years, and this trend is expected to continue in the future as waste minimization programs are implemented at the Laboratory. In contrast, the volume of waste generated by the ER Project is expected to increase as contaminated sites and facilities undergo remediation or decontamination and decommissioning (D&D). Large quantities of this waste will be disposed of at MDA G. Rates of waste disposal at MDA G will decrease as ER Project activities wind down in the next 10 to 15 years.

The nature of the waste disposed of at MDA G has changed over the facility's lifetime. Waste that, under current definitions, is considered to be transuranic (TRU) waste was disposed of at the facility through the mid-1970's. Since that time, the vast majority of the TRU waste generated at LANL has been segregated and retrievably stored for permanent disposal at the Waste Isolation Pilot Plant (WIPP), although small amounts of TRU waste were disposed of at MDA G between 1971 and 1988.

MDA G is used for the storage of TRU waste destined for disposal at the WIPP. Waste generated after 1985 is stored in aboveground configurations. Some of the older TRU waste was stacked on asphalt pads and covered with earthen berms. This waste has been excavated and stored in aboveground structures. All of this stored TRU waste will be retrieved and sent to WIPP prior to final closure of MDA G. Some TRU waste was placed in below-grade retrievable arrays (i.e., pits 9 and 29, trenches A through D, and several shafts); the final disposition of this waste has yet to be determined.

Waste that, under current definitions, qualifies as MLLW was placed in pits and shafts through 1985, and 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/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 MDA G since 1990. In addition to LLW, MDA G is authorized to accept low-level TSCA waste (i.e., polychlorinated biphenyls). Solid LLW is the only type of waste disposed of at MDA G today.

Disposal operations at MDA G have led to the mesa top being cleared over most of the present site, or about 25 ha (60 acres). Disposal units that have been filled, covered, and reseeded with indigenous grasses occupy the majority of the surface area. Surface waste management operations have required the construction of waste storage domes; the domes are placed on asphalt pads that generally lie on top of closed disposal pits. Additionally, various buildings and dirt roads are present on the site, and some of these roads and buildings are located over closed disposal pits.

As previously stated, the two major types of disposal units used for waste disposal at MDA G are pits and shafts. Routine LLW (e.g., operational and ER Project waste) is placed in disposal pits. These units are 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, which has resulted in pits no deeper than 20 m (65 ft). In the past, LLW was placed in lifts in the disposal pits. Each layer of LLW was covered by crushed tuff and compacted *in situ* by driving heavy equipment over the crushed tuff. Current operational procedures require that waste, with the exception of bulk soils and debris, be packaged prior to placement in the pits. Compactible waste placed in containers is compacted to minimize void space. Bulk materials are placed directly in the disposal units, and may be used to fill void spaces between waste containers.

Waste is disposed of in shafts to provide additional shielding of material with high external radiation levels, to facilitate placement of the waste using remote handling techniques, and to accommodate special packaging requirements. The shafts are drilled into the Bandelier Tuff using augers. Disposal shafts 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. The diameters of the shafts generally range from 0.3 to 6 m (1 to 20 ft).

Waste disposal operations at MDA G are presently assumed to extend through the year 2044. Future expansion of the facility will be necessary in order to dispose of LLW generated at the Laboratory over that period. Expansion of the disposal facility to include the area immediately west of the current disposal area was considered in the LANL Site Wide Environmental Impact Statement (DOE, 1999c) and was approved under NEPA. Expansion into this area is expected to occur after the existing disposal capacity is exhausted.

3.2.1 Water Infiltration

Water infiltration is the portion of the precipitation (or snowmelt) that is left to percolate through the disposal unit cover after the effects of runoff, evaporation, and transpiration have been taken into account. The passage of water through the disposal units is potentially problematic, particularly if the infiltration is of sufficient quantity to leach radioactivity from the waste and transport the contamination to the regional aquifer. Several components of the water-balance system have been discussed on a regional scale earlier in this section. As mentioned, precipitation, evaporation, and transpiration vary throughout the year. Evaporation generally occurs within several centimeters of the surface, but may be effective over greater depths in fractured or very permeable rock. Transpiration occurs as plants take up moisture via their roots and release it to the atmosphere via their leaves, and is observed throughout the root zone. Due to the inter-relationships among the water-balance components, infiltration varies with climate, ecology, and topography.

Manmade disturbances at MDA G interact with the naturally variable water balance components, making rates of infiltration difficult to quantify with a high degree of certainty. Throughout much of the year, the moisture content of the disposal units is maintained at low levels due to the effects of evapotranspiration. Studies conducted at LANL using test plots equipped with covers resembling the existing operational pit covers at MDA G indicate that 87 percent of the annual precipitation is released to the atmosphere by evapotranspiration. Approximately 6 percent of the precipitation infiltrates below the plant root zone, while the remainder is retained in the soil. The data also indicate that percolation through a conventional vegetated crushed-tuff cover is greatest in the late winter and early spring when snowmelt occurs and evapotranspiration is low because the vegetation is dormant.

Efforts are made to maintain high rates of evapotranspiration potential at MDA G by maintaining vegetative covers over filled disposal pits. However, ongoing waste management operations require features such as roads, asphalt pads, fire-breaks, and storm water diversions that interfere with evapotranspiration. In addition, while pits are in use, they may retain additional moisture from rainfall or snowmelt because transpiration is absent.

Additional insight into rates of infiltration may be gained using field measurements of moisture within well-established covers at MDA G. In 1973, moisture content measurements were taken in holes augered into the covers over Pit 1 and Pit 2, which were closed in 1961 and 1963, respectively. Measured volumetric moisture contents were quite variable, ranging from 2 to 17 percent in Pit 1, and from 4 to 8 percent in Pit 2. Peak water concentrations occurred at a depth of about 2 m (6.6 ft), and decreased between 2 and 3 m (6.6 and 10 ft). The variation in moisture contents observed between the pits was tentatively attributed to variations in soil conductivity or differences in surface slope. A common approach to estimating infiltration rate (or moisture flux) is to equate the flux with the unsaturated hydraulic conductivity of the rock using the unit-gradient assumption. Using the moisture data for Pits 1 and 2, infiltration rates of several millimeters to several centimeters per year are calculated.

To better understand infiltration through disposal units at MDA G, the moisture content within Pit 37 has been measured periodically over a period of years. Pit 37 is expected to have moisture contents in excess of most pits at MDA G. While most pits are excavated, filled, and covered within two to four years, Pit 37 began receiving waste in 1990, and has still not received final cover. Pit 37 measurements indicate a maximum moisture content of about 11 percent by volume, with a mean of about 8 percent. Using these data and the unit gradient approach to estimating infiltration yields an average percolation rate through Pit 37 of 5 mm/yr (0.2 in./yr).

While moisture content data collected within pit fill have generally shown moisture levels higher than those in surrounding undisturbed tuff, the ultimate effect of this additional moisture on recharge beneath the pits is not known. In 1976, cores were collected from horizontal boreholes drilled to pass through Tshirege Unit 2 about 1 m (3.3 ft) beneath a pit that had been closed in 1966. Analysis of these cores indicated that concentrations of Sr-90, Cs-137, Pu-238, Pu-239, Pu-240, and Am-241 were below the minimum detection limits, suggesting that none of these radionuclides had migrated from the pits. The boreholes were re-entered in 1992 and moisture measurements were conducted using a neutron probe. Volumetric moisture content values beneath the pits were in the range of 1 to 4 percent, and were generally 1 to 2 percent higher beneath the pit than at locations away from the pit. These measurements suggest that pit excavation has had a small effect on moisture content beneath the pits.

This discussion has focused on infiltration through pit covers, to the relative exclusion of the covers placed over the shafts. This is largely because more data are available for pits. However, the infiltration conditions estimated for the pits are expected to bound those for the shafts. This is due to the fact that moisture contents are expected to be greater in the pits, which remain open for the period they are used for disposal. In contrast, shafts are covered between disposal events and, as a result, the amount of moisture entering the units while they are active is minimized.

3.2.2 Disposal Unit Cover Integrity

Considerable research has been conducted at LANL regarding the effectiveness of landfill covers in arid environments. While an engineered cover has been contemplated for final closure of MDA G, the operational or interim covers placed over the pits and shafts appear to perform adequately, and have some advantages over an engineered design. These advantages include ease of installation and maintenance, and cost-effectiveness. Another important consideration is that any uncertainties regarding the performance of the simple crushed-tuff cover are exacerbated in a multilayer barrier. The nominal 1 or 2 m (3 or 6 ft) operational cover was the basis for the MDA G Performance Assessment and Composite Analysis (LANL, 1997).

The operational closure cap for pits at MDA G consists of 1 to 3.3 m (3.3 to 10.8 ft) of consolidated crushed tuff, 10 cm (4 in.) topsoil, and native grass vegetation. Due to on-going operations, some of the covers contain a broken-up asphalt layer. Asphalt pads have been constructed over some closed disposal pits at MDA G. When operations requiring the asphalt pads are complete, the asphalt is broken up into pieces that are 4 inches or less.

These broken-up asphalt layers become part of the operational cover for some closed disposal pits. Tuff is placed over these asphalt layers. The covers placed over the pits are contoured to match the local topography, thereby minimizing ponding over the units and excessive erosion.

Covers placed over the disposal shafts in the past have consisted of crushed tuff and concrete caps placed over the augered holes, and the concrete caps are expected to maintain their integrity for extended periods of time. The use of concrete caps for closing the shafts is being phased out. In their absence, the units will be filled with crushed tuff to the ground surface and a vegetative cover will be established. Covers over the shafts will be contoured to match the local topography, minimizing the potential for ponding and excessive erosion.

3.2.3 Structural Stability

MDA G disposal methods were developed to minimize the potential for subsidence, promote consolidation within the disposal pits, and minimize the potential for shear failure. This has been achieved by layering and compacting waste. Historically, waste was emplaced in parallel horizontal layers or "lifts" using dump trucks, cranes, or forklifts. Sufficient crushed-tuff backfill was used to fill void spaces between waste, to cover waste in one lift, and to provide an even, consolidated surface for the next lift. Earthmovers and scrapers were used to emplace the backfill, and 50-ton bulldozers were used to consolidate the crushed-tuff layer and the emplaced waste. On a volume basis, about 60 percent of a typical disposal pit was consolidated, crushed tuff, the remainder was waste. Compression measurements of crushed tuff showed extremely fast consolidation; minimal settlement was observed because consolidation was immediate and occurred cumulatively during each loading. Field evidence indicates that these disposal methods were effective. There has been no significant subsidence since the facility began operations in 1957, only infrequent and minor local settlements, which have been filled with tuff.

While liberal use of large quantities of backfill is a good practice in terms of disposal unit stability, it is not an efficient use of limited disposal capacity. In an attempt to increase pit efficiency, disposal procedures now call for the use of large containers to package most LLW disposed of in pits at MDA G. Efforts are made to ensure that the boxes are full and that the contents are compacted to the extent possible, both to maximize efficiency and to minimize the potential for subsidence. To date, Pits 15, 38, and 39 have been used for the disposal of waste contained in large metal boxes. Pit 15 has been exclusively used for containerized disposal, while Pits 38 and 39 contain bulk and containerized waste. The disposal efficiencies of these pits are expected to be substantially higher than older pits, but the use of containers may increase the potential for subsidence. The continued success of this disposal method will depend upon the ability to minimize subsidence potential, and to remedy subsidence events should they occur.

In general, the structural stability of the disposal shafts has been less of an issue than that of the pits because of the units' much smaller size. Historically, waste was lowered into the shafts and crushed tuff added as necessary to fill void spaces between waste packages. The addition of crushed tuff as the units were being filled was discontinued for the past several years, but has been re-instituted. Crushed tuff is mounded over the top of filled shafts for a period of up to five years. This material is placed over the shafts to fill void spaces as the materials in the disposal units settle. Localized subsidence has been observed around the edges of some of the concrete caps placed over the older shafts, but no widespread subsidence of the waste in these units has occurred since the shafts were first put into use.

3.2.4 Inadvertent Intruder Barrier

The only structural barriers present at MDA G that may influence the likelihood of human intrusion into the waste are the concrete caps placed over filled disposal shafts. The use of these concrete caps is in the process of being discontinued. There are no structural barriers to prevent inadvertent intrusion into disposal pits at MDA G. Administrative controls over access to the site were assumed by the performance assessment and composite analysis to be in place throughout the 1,000-year compliance period. These controls were expected to prevent long-term intrusion from occurring at the site. However, it was assumed that a person could arrive at the site and inadvertently intrude into the waste for a few years due to a temporary lapse in site restrictions.

The final cover design presented in this closure plan relies on the overall thickness of the cover to prevent or minimize impacts to inadvertent intruders; no engineered intruder barriers are assumed to exist. If administrative controls over the site are maintained for 1,000 years then no long-term intrusion into the waste will occur during the DOE Order 435.1 compliance period. Long-term intrusion into the waste may occur during the compliance period if DOE releases the site for unrestricted use.

3.3 WASTE CHARACTERISTICS

The types and quantities of waste that have been disposed at MDA G, and that are expected to require disposal in the future, were estimated for the MDA G Performance Assessment and Composite Analysis (LANL, 1997). A detailed discussion of the methods used to develop these inventories may be found in that report, as well as the estimated inventories themselves. A brief summary of the approach taken to characterize the waste is provided below, along with summary tables of the performance assessment and composite analysis inventories.

Inventory projections were developed for four periods of time that comprise the operational lifetime of MDA G. These periods include 1957 through 1970; 1971 through September 26, 1988; September 27, 1988 through 1995; and 1996 through 2044. Separate inventories were estimated for these periods for three reasons. First, the amount of detailed data available for characterizing waste disposed of before and after the start of 1971 differs dramatically. Maintaining the identities of the pre- and post-1971 waste permits evaluation of the uncertainties inherent in each inventory. Second, DOE Order 435.1, and its predecessor Order 5820.2A, apply to waste disposed of after September 26, 1988. Consequently, separate inventories (i.e., waste disposed of through September 26, 1988 and waste disposed thereafter) must be developed to demonstrate compliance with these Orders. Finally, the MDA G inventory was developed in 1996. While the waste disposed of prior to 1996 could be characterized using disposal receipt data, the future waste inventory had to be estimated using an extrapolation approach. Given the need for different estimation techniques, it was logical to keep the pre- and post-1996 inventories separate.

The period-specific inventories discussed above were combined to arrive at the total performance assessment and composite analysis inventories. The performance assessment addresses the LLW disposed of after September 26, 1988 through the end of disposal operations at MDA G. Consequently, inventory projections for the September 27, 1988 through 1995, and 1996 through 2044 periods were combined to yield the total inventory for this analysis. Insofar as the composite analysis accounts for exposures from all waste disposed of at MDA G, inventories for all four periods were combined for this evaluation.

The physical and chemical forms of the waste disposed of in the pits and shafts play an important role in how radionuclides are released to the environment and the rates at which these releases occur. Source-term modeling conducted in support of the MDA G Performance Assessment and Composite Analysis accounts for releases from four waste forms including surface-contaminated waste, soils, concrete and sludges, and bulk-contaminated waste. In support of the source-term modeling, separate inventories were developed for these waste forms. To do this, waste streams were assigned to one of the four waste forms based on their anticipated release characteristics. Once these assignments were complete, waste volumes and activities were summed to yield waste form specific inventories. Separate inventories were developed for the disposal pits and shafts.

A variety of wastes have been disposed of at MDA G since its inception in 1957. Prior to 1971, waste now defined as TRU waste was routinely disposed of in pits and shafts. Since that time, the vast majority of the TRU waste generated at the Laboratory has been segregated and stored at MDA G. A portion of this stored waste is retrievably stored in pits, trenches, and shafts. The waste stored in these units was not included in the composite analysis inventory, based on the expectation that the waste will be retrieved and sent for off-site disposal. A small quantity of TRU waste was disposed of at MDA G after

1970, and this waste was included in the composite analysis inventory. A portion of the waste disposed of at MDA G prior to the late 1980s was mixed waste, and the radiological component of this waste is included in the composite analysis inventory.

A portion of the waste disposed of at MDA G is listed as mixed fission products (MFP) or mixed activation products (MAP). The listed activities for this waste were allocated to specific radionuclides as part of the inventory development process. Allocations of MFP were based on fission product yields for thermal and fast neutrons. Information about the radiological characteristics of the MAP from the facility responsible for most of this waste was used to assign activities to specific radionuclides. Some of the waste included in the disposal databases was referred to using material types, each of which corresponds to specific radionuclide compositions. These radionuclide abundances were used to develop isotope-specific activities.

The total volumes and activities of waste included in the MDA G Performance Assessment and Composite Analysis are summarized in Table 3-3. Separate inventories are provided for pits and shafts, and for the four waste forms discussed above. Radionuclide-specific inventories included in the performance assessment inventory are summarized in Tables 3-5 and 3-6, while their composite analysis counterparts are shown in Tables 3-7 and 3-8. The waste volumes listed in Tables 3-4 through 3-7 represent the quantity of waste contaminated with each radionuclide. Because several radionuclides may occur in a single waste package, the sum of these volumes is greater than the total volume of waste disposed of in the pits and shafts. The radionuclides included in the tables have half-lives greater than five years or have parents or daughters with half-lives greater than five years.

TABLE 3-3. TOTAL WASTE VOLUMES AND ACTIVITIES FOR THE PERFORMANCE ASSESSMENT AND COMPOSITE ANALYSIS INVENTORIES.

	Performance Assessment		**Composite Analysis**	
Disposal Unit and Waste Form	**Volume (m^3)**	**Activity (Ci)**	**Volume (m^3)**	**Activity (Ci)**
Pits				
Surface-contaminated waste	1.5E+05	1.6E+03	2.4E+05	5.9E+04
Soils	1.4E+04	4.0E+01	5.4E+04	1.0E+02
Concrete and sludges	6.8E+03	4.4E+01	2.0E+04	2.9E+03
Bulk-contaminated waste	3.5E+03	2.4E+01	4.4E+03	5.7E+02
Shafts				
Surface-contaminated waste	1.3E+03	6.6E+06	2.2E+03	7.4E+06
Soils	1.3E+01	2.7E-07	3.5E+01	1.0E+02
Concrete and sludges	2.2E+02	3.9E+00	2.2E+02	1.0E+02
Bulk-contaminated waste	1.4E+02	1.9E+04	2.6E+02	2.6E+04

TABLE 3-4. PIT RADIONUCLIDE INVENTORIES FOR THE MDA G PERFORMANCE ASSESSMENT

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Ac-227	1.4E+04	7.1E-02	4.4E+03	2.2E-02	4.4E+03	2.2E-02		
Ag-108m	1.0E+04	2.3E-01	6.8E+02	3.4E-06	7.2E+01	1.6E-06		
Al-26	2.6E-01	3.4E-07						
Am-241	3.5E+04	1.2E+00	4.9E+03	2.0E-02	5.7E+03	5.6E+00		
Am-243	3.9E+02	3.4E-04	1.6E+00	5.7E-05	1.6E+00	5.7E-05		
Ba-133	1.1E+04	8.3E+00	6.8E+02	1.2E-04	7.2E+01	5.8E-05		
Bi-207	6.8E+00	8.6E-04						
Bk-247	1.7E+02	5.1E-07						
C-14	1.9E+03	1.5E-01	9.0E+00	3.9E-05	8.8E+00	3.9E-05		
Cd-113m	1.0E+04	9.5E-01	6.8E+02	1.4E-05	7.2E+01	6.6E-06		
Cf-252	1.3E+00	1.3E-04						
Cl-36	1.3E+00	3.4E-03						
Co-60	3.5E+04	3.0E+01	4.8E+03	2.7E-01	4.6E+03	2.6E-01	3.5E+03	7.8E-01
Cs-135	1.0E+04	2.3E-04	6.8E+02	6.3E-10	7.2E+01	3.0E-10		
Cs-137	2.9E+04	4.3E+00	5.5E+03	5.9E-01	4.7E+03	5.0E-01		
Dy-154	1.0E+04	1.5E-06	6.8E+02	2.2E-11	7.2E+01	1.1E-11		
Eu-152	1.0E+04	5.6E-01	6.8E+02	8.0E-06	7.3E+01	3.7E-06		
Eu-154	1.0E+04	1.5E-01	6.8E+02	2.2E-06	7.2E+01	1.1E-06		
Gd-148	1.0E+04	4.0E-01	6.8E+02	5.9E-06	7.2E+01	2.8E-06		
Gd-150	1.0E+04	4.2E-06	6.8E+02	6.2E-11	7.2E+01	3.0E-11		
H-3	2.0E+04	7.1E+02	4.7E+03	3.5E+00	4.5E+03	6.5E+00		
Hf-182	3.9E+02	5.9E-02						
Ho-163	1.2E+02	3.2E-02						
I-129	1.0E+04	2.9E-06	6.8E+02	4.2E-11	7.2E+01	2.0E-11		
K-40	1.4E+04	8.3E-01	4.4E+03	2.6E-01	4.4E+03	2.6E-01		
Kr-81	1.0E+04	5.1E-05	6.8E+02	7.4E-10	7.2E+01	3.6E-10		
Kr-85	1.0E+04	2.5E+00	6.8E+02	3.6E-05	7.2E+01	1.8E-05		
La-137	1.0E+04	8.3E-04	6.8E+02	1.2E-08	7.2E+01	5.8E-09		
Mo-93	1.0E+04	1.6E-02	6.8E+02	2.4E-07	7.2E+01	1.2E-07		
Nb-92	1.0E+04	5.0E-06	6.8E+02	7.2E-11	7.2E+01	3.5E-11		
Nb-94	1.0E+04	2.3E-01	6.8E+02	1.0E-07	7.2E+01	6.5E-08		
Ni-59	1.7E+02	4.9E-02	3.8E-01	1.4E-03	3.8E-01	1.4E-03		

TABLE 3-4. PIT RADIONUCLIDE INVENTORIES FOR THE MDA G PERFORMANCE ASSESSMENT

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Np-237	5.8E+02	5.7E-03	1.7E+00	3.5E-08	1.7E+00	3.5E-08		
Pa-231	1.6E+02	8.3E-08						
Pb-210	1.4E+04	2.3E-01	4.4E+03	4.4E-02	4.4E+03	4.4E-02		
Pd-107	1.0E+04	7.0E-06	6.8E+02	1.0E-10	7.2E+01	4.9E-11		
Pm-145	1.6E+02	5.2E-03						
Pu-238	4.5E+04	4.2E-01	5.2E+03	1.6E+00	5.7E+03	2.1E+01		
Pu-239	8.1E+04	2.4E+01	5.2E+03	1.1E+00	5.8E+03	8.6E+00		
Pu-240	3.6E+04	5.4E+00	4.4E+03	9.7E-01	4.4E+03	9.7E-01		
Pu-241	2.2E+04	3.5E+01	1.1E+00	1.6E-07	1.1E+00	9.5E-13		
Pu-242	2.2E+04	2.4E-04	2.5E+00	5.7E-05	2.5E+00	5.7E-05		
Ra-226	1.4E+04	2.7E-01	4.4E+03	1.5E-02	4.4E+03	1.5E-02		
Se-79	1.0E+04	4.7E-06	6.8E+02	6.8E-11	7.2E+01	3.3E-11		
Si-32	1.9E+03	2.6E+00						
Sm-146	1.0E+04	3.8E-07	6.8E+02	5.6E-12	7.2E+01	2.7E-12		
Sm-147	1.1E+04	3.0E-10	6.8E+02	4.5E-15	7.2E+01	2.1E-15		
Sm-151	1.0E+04	1.3E-01	6.8E+02	1.9E-06	7.2E+01	9.0E-07		
Sr-90	2.6E+04	3.6E+00	5.2E+03	4.3E-02	4.5E+03	4.3E-02		
Tb-157	1.0E+04	4.7E-03	6.8E+02	6.9E-08	7.2E+01	3.3E-08		
Tb-158	1.0E+04	2.0E-03	6.8E+02	2.9E-08	7.2E+01	1.4E-08		
Tc-97	1.0E+04	3.8E-05	6.8E+02	5.6E-10	7.2E+01	2.7E-10		
Tc-99	2.7E+04	1.9E-01	5.1E+03	3.1E-03	4.5E+03	3.1E-03		
Th-229	1.2E+02	3.5E-04	1.7E-01	5.2E-07	1.7E-01	5.2E-07		
Th-230	1.4E+04	3.7E-02	4.4E+03	1.2E-02	4.4E+03	1.2E-02		
Th-232	1.7E+04	1.2E-01	4.4E+03	1.9E-02	4.4E+03	1.9E-02		
Ti-44	6.4E+01	2.8E-03						
U-232	2.0E+00	1.1E-04	1.0E-01	5.7E-05	1.0E-01	5.7E-05		
U-233	5.8E+01	7.7E-03	4.0E+00	3.4E-04	4.0E+00	3.4E-04		
U-234	1.9E+04	4.1E+00	7.4E+03	1.3E+01	4.7E+03	7.5E-02		
U-235	5.6E+04	4.9E+00	7.6E+03	3.7E-01	6.1E+03	6.8E-02		
U-236	2.1E+03	2.1E-02	2.2E+03	6.0E-01	9.0E+00	6.0E-05		
U-238	4.1E+04	3.4E+01	1.0E+04	1.8E+01	4.6E+03	1.0E-01		
Zr-93	1.0E+04	5.2E-05	6.8E+02	7.6E-10	7.2E+01	3.6E-10		

TABLE 3-5. SHAFT RADIONUCLIDE INVENTORIES FOR THE MDA G PERFORMANCE ASSESSMENT

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Ag-108m	6.2E+00	1.2E-01						
Am-241	8.1E+01	9.5E-03			3.3E+02	9.6E-01		
Ba-133	6.5E+00	4.5E+00						
Bi-207	3.5E-02	3.7E-05						
C-14	2.6E+01	8.9E-03						
Cd-113m	6.2E+00	5.1E-01						
Cf-252	3.5E-02	4.2E-07						
Co-60	4.8E+02	5.4E+03					1.4E+02	6.2E+02
Cs-135	3.1E+01	6.4E-05						
Cs-137	4.8E+01	7.5E+02						
Dy-154	6.2E+00	8.2E-07						
Eu-152	7.3E+00	3.0E-01						
Eu-154	9.4E+00	9.7E-01						
Gd-148	6.2E+00	2.2E-01						
Gd-150	6.2E+00	2.3E-06						
H-3	2.9E+02	6.6E+06	7.5E+00	1.5E-07				
I-129	6.2E+00	1.5E-06						
Kr-81	6.2E+00	2.7E-05						
Kr-85	6.2E+00	1.4E+00						
La-137	6.2E+00	4.4E-04						
Lu-172	1.1E+01	2.1E+00						
Mo-93	6.2E+00	8.8E-03						
Nb-92	7.2E+00	3.7E-02						
Nb-94	6.2E+00	2.7E-03						
Ni-63	3.5E-02	2.8E-04						
Pb-210	1.7E-01	2.2E-08						
Pd-107	6.2E+00	3.8E-06						
Pm-145	1.5E-01	3.2E-13						
Pu-238	1.4E+02	1.3E-02			3.3E+02	2.2E+00		
Pu-239	1.7E+02	1.2E-01			3.3E+02	7.1E-01		
Pu-240	3.8E+00	2.6E-02						
Pu-241	3.8E+00	3.9E-01						

TABLE 3-5. SHAFT RADIONUCLIDE INVENTORIES FOR THE MDA G PERFORMANCE ASSESSMENT

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Pu-242	3.8E+00	1.5E-06						
Ra-226	5.5E-01	1.7E-05						
Se-79	6.2E+00	2.5E-06						
Sm-146	6.2E+00	2.0E-07						
Sm-147	6.4E+00	1.6E-10						
Sm-151	6.2E+00	6.9E-02						
Sr-90	8.0E+00	4.1E+01						
Tb-157	6.2E+00	2.5E-03						
Tb-158	6.2E+00	1.1E-03						
Tc-97	6.2E+00	2.0E-05						
Tc-99	6.2E+00	2.5E-04						
Th-229	3.5E-02	5.0E-07						
Th-232	8.5E+00	3.7E-03						
U-234	1.2E+00	3.5E-03	1.8E-02	4.7E-08	1.8E-02	4.7E-08		
U-235	1.2E+02	1.0E-02	1.8E-02	1.1E-09	3.3E+02	2.0E-03		
U-236	1.1E+00	5.3E-05	1.8E-02	2.2E-09	1.8E-02	2.2E-09		
U-238	1.9E+02	1.8E+00	1.8E-02	6.1E-08	4.0E+00	3.5E-06		
Zr-93	6.2E+00	2.8E-05						

TABLE 3-6. PIT RADIONUCLIDE INVENTORIES FOR THE MDA G COMPOSITE ANALYSIS

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Ac-227	1.4E+04	1.0E+00	4.4E+03	2.2E-02	4.4E+03	2.2E-02		
Ag-108m	1.7E+04	3.7E+00	8.1E+02	2.6E-05	3.0E+02	1.2E-03		
Al-26	2.6E-01	3.4E-07						
Am-241	3.6E+04	4.6E+01	5.4E+03	1.2E+00	1.1E+04	2.2E+03		
Am-243	3.9E+02	3.4E-04	1.6E+00	5.7E-05	1.6E+00	5.7E-05		
Ba-133	1.7E+04	1.3E+02	8.1E+02	9.5E-04	3.0E+02	4.2E-02		
Bi-207	6.8E+00	8.6E-04						
Bk-247	1.7E+02	5.1E-07						
C-14	1.9E+03	3.8E-01	9.0E+00	3.9E-05	8.8E+00	3.9E-05		
Cd-109	3.2E+03	3.7E+01						
Cd-113m	1.7E+04	1.5E+01	8.1E+02	1.1E-04	3.0E+02	4.8E-03		
Cf-249	1.9E+00	2.8E-03						
Cf-251	2.3E-01	4.3E-03						
Cf-252	2.1E+00	2.3E-02						
Cl-36	1.3E+00	3.4E-03						
Cm-244	3.6E-01	1.7E-03						
Co-60	3.8E+04	1.3E+03	5.0E+03	6.0E-01	4.7E+03	2.6E-01	4.4E+03	1.9E+01
Cs-135	1.7E+04	8.7E-04	8.1E+02	4.9E-09	3.0E+02	2.2E-07		
Cs-137	3.6E+04	1.1E+03	6.6E+03	6.0E-01	5.0E+03	5.1E-01		
Dy-154	1.7E+04	2.4E-05	8.1E+02	1.7E-10	3.0E+02	7.7E-09		
Eu-152	1.7E+04	8.4E+00	8.1E+02	6.0E-05	3.0E+02	2.7E-03		
Eu-154	1.7E+04	2.4E+00	8.1E+02	1.7E-05	3.0E+02	7.6E-04		
Gd-148	1.7E+04	6.4E+00	8.1E+02	4.6E-05	3.0E+02	2.0E-03		
Gd-150	1.7E+04	6.7E-05	8.1E+02	4.8E-10	3.0E+02	2.1E-08		
H-3	2.3E+04	8.2E+03	4.7E+03	4.7E+00	4.7E+03	7.7E+00		
Hf-182	3.9E+02	5.9E-02						
Ho-163	1.2E+02	3.2E-02						
I-129	1.7E+04	4.6E-05	8.1E+02	3.2E-10	3.0E+02	1.4E-08		
K-40	1.4E+04	8.3E-01	4.4E+03	2.6E-01	4.4E+03	2.6E-01		
Kr-81	1.7E+04	8.1E-04	8.1E+02	5.8E-09	3.0E+02	2.6E-07		
Kr-85	1.7E+04	4.0E+01	8.1E+02	2.8E-04	3.0E+02	1.3E-02		
La-137	1.7E+04	1.3E-02	8.1E+02	9.4E-08	3.0E+02	4.2E-06		

TABLE 3-6. PIT RADIONUCLIDE INVENTORIES FOR THE MDA G COMPOSITE ANALYSIS

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Mo-93	1.7E+04	2.6E-01	8.1E+02	1.9E-06	3.0E+02	8.3E-05		
Nb-92	1.7E+04	5.2E-05	8.0E+02	5.6E-10	3.0E+02	2.5E-08		
Nb-94	1.7E+04	3.1E-01	8.1E+02	5.9E-07	3.0E+02	2.5E-05		
Ni-59	1.7E+02	4.9E-02	3.8E-01	1.4E-03	3.8E-01	1.4E-03		
Ni-63	2.6E+00	1.5E-03						
Np-237	5.9E+02	9.6E-03	1.7E+00	3.5E-08	1.7E+00	3.5E-08		
Pa-231	1.6E+02	8.3E-08						
Pb-210	1.4E+04	2.3E-01	4.4E+03	4.4E-02	4.4E+03	4.4E-02		
Pd-107	1.7E+04	1.1E-04	8.1E+02	8.0E-10	3.0E+02	3.6E-08		
Pm-145	1.6E+02	5.2E-03						
Pu-238	6.4E+04	4.2E+03	9.6E+03	3.4E+00	1.1E+04	6.4E+02		
Pu-239	1.2E+05	1.8E+03	1.7E+04	4.1E+01	1.6E+04	1.0E+02		
Pu-240	4.2E+04	4.6E+02	4.8E+03	1.0E+00	4.6E+03	9.7E-01		
Pu-241	2.8E+04	8.2E+03	3.2E+02	6.5E-01	1.5E+02	6.7E-02		
Pu-242	2.8E+04	4.9E-02	3.2E+02	6.7E-05	1.5E+02	5.7E-05		
Ra-226	1.4E+04	4.6E-01	4.4E+03	1.5E-02	4.4E+03	1.5E-02		
Se-79	1.7E+04	7.5E-05	8.1E+02	5.3E-10	3.0E+02	2.4E-08		
Si-32	2.0E+03	2.6E+00						
Sm-146	1.7E+04	6.1E-06	8.1E+02	4.3E-11	3.0E+02	1.9E-09		
Sm-147	1.7E+04	2.7E-02	8.1E+02	3.4E-14	3.0E+02	1.5E-12		
Sm-151	1.7E+04	2.1E+00	8.1E+02	1.5E-05	3.0E+02	6.5E-04		
Sr-90	3.4E+04	1.4E+03	6.8E+03	2.3E-01	4.9E+03	6.1E-02		
Tb-157	1.7E+04	7.5E-02	8.1E+02	5.4E-07	3.0E+02	2.4E-05		
Tb-158	1.7E+04	3.2E-02	8.1E+02	2.3E-07	3.0E+02	1.0E-05		
Tc-97	1.7E+04	6.1E-04	8.1E+02	4.3E-09	3.0E+02	1.9E-07		
Tc-99	3.3E+04	2.0E-01	5.3E+03	3.1E-03	4.7E+03	3.1E-03		
Th-229	1.2E+02	3.5E-04	1.7E-01	5.2E-07	1.7E-01	5.2E-07		
Th-230	1.4E+04	2.6E+01	4.4E+03	1.2E-02	4.4E+03	1.2E-02		
Th-232	1.7E+04	1.5E-01	4.4E+03	1.9E-02	4.4E+03	1.9E-02		
Ti-44	6.4E+01	2.8E-03						
U-232	2.0E+00	1.1E-04	1.0E-01	5.7E-05	1.0E-01	5.7E-05		
U-233	6.3E+01	2.7E-02	4.0E+00	3.4E-04	2.5E+03	6.2E+00		
U-234	2.0E+04	7.8E+00	7.4E+03	1.4E+01	4.7E+03	7.5E-02		

TABLE 3-6. PIT RADIONUCLIDE INVENTORIES FOR THE MDA G COMPOSITE ANALYSIS

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
U-235	8.7E+04	6.1E+00	1.0E+04	4.0E-01	9.0E+03	7.9E-02		
U-236	2.2E+03	2.1E-02	2.2E+03	6.0E-01	9.0E+00	6.0E-05		
U-238	6.5E+04	5.5E+01	1.9E+04	2.3E+01	4.7E+03	1.0E-01		
Zr-93	1.7E+04	8.3E-04	8.1E+02	5.9E-09	3.0E+02	2.6E-07		

TABLE 3-7. SHAFT RADIOLNUCLIDE INVENTORIES FOR THE MDA G COMPOSITE ANALYSIS

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Ag-108m	4.2E+01	1.9E+01						
Am-241	8.8E+01	4.9E-02			3.3E+02	9.6E-01		
Am-243	2.6E-02	1.1E-05						
Ba-133	4.2E+01	6.8E+02						
Bi-207	3.5E-02	3.7E-05						
C-14	3.2E+01	1.1E+00						
Cd-113m	4.2E+01	7.7E+01						
Cf-252	5.9E-01	1.1E+02						
Cm-244	7.7E-01	3.7E-01						
Co-60	6.4E+02	8.5E+03					2.6E+02	8.4E+02
Cs-135	6.7E+01	3.6E-03						
Cs-137	8.6E+01	9.2E+02						
Dy-154	4.2E+01	1.2E-04						
Eu-152	4.3E+01	4.3E+01						
Eu-154	4.5E+01	1.3E+01						
Gd-148	4.2E+01	3.3E+01						
Gd-150	4.2E+01	3.4E-04						
H-3	4.8E+02	7.5E+06	7.6E+00	1.0E+02	5.3E-01	1.0E+02		
Hf-182	2.8E-02	3.1E+01						
I-129	4.2E+01	2.3E-04						
Kr-81	4.2E+01	4.1E-03						
Kr-85	4.5E+01	2.0E+02						
La-137	4.2E+01	6.7E-02						
Lu-172	1.1E+01	2.1E+00						
Mo-93	4.2E+01	1.3E+00						
Nb-92	4.1E+01	3.7E-02						
Nb-94	4.2E+01	4.0E-01						
Ni-63	3.9E+00	4.6E-03						
Np-237	1.4E-01	1.5E-04						
Pb-210	1.7E-01	2.2E-08						
Pd-107	4.2E+01	5.7E-04						
Pm-145	1.5E-01	3.2E-13						
Pu-238	2.7E+02	2.5E+00			3.3E+02	2.2E+00		
Pu-239	3.9E+02	1.5E+02			3.3E+02	7.1E-01		
Pu-240	1.7E+01	4.7E+00						

TABLE 3-7. SHAFT RADIOLNUCLIDE INVENTORIES FOR THE MDA G COMPOSITE ANALYSIS

	Waste Form							
	Surface-Contaminated Waste		Soils		Concrete and Sludges		Bulk-Contaminated Waste	
Radionuclide	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)	Volume (m^3)	Activity (Ci)
Pu-241	1.7E+01	7.3E+01						
Pu-242	1.7E+01	2.7E-04						
Ra-226	1.9E+00	2.5E+00						
Se-79	4.2E+01	3.8E-04						
Sm-146	4.2E+01	3.1E-05						
Sm-147	4.4E+01	2.4E-08						
Sm-151	4.2E+01	1.1E+01						
Sr-90	4.5E+01	3.0E+02						
Tb-157	4.2E+01	3.9E-01						
Tb-158	4.2E+01	1.6E-01						
Tc-97	4.2E+01	3.1E-03						
Tc-99	4.2E+01	3.8E-02						
Th-229	3.5E-02	5.0E-07						
Th-232	2.1E+01	3.4E-02						
U-232	7.6E-03	4.3E-01						
U-233	7.7E-01	8.0E+00						
U-234	2.9E+01	5.2E-01	6.2E+00	2.8E-02	1.8E-02	4.7E-08		
U-235	2.7E+02	1.0E+00	6.2E+00	1.1E-03	3.3E+02	2.0E-03		
U-236	2.5E+00	4.1E-04	1.8E-02	2.2E-09	1.8E-02	2.2E-09		
U-238	3.9E+02	1.7E+01	8.0E+00	1.8E-01	4.0E+00	3.5E-06		
Zr-93	4.2E+01	4.3E-03						

The inventories listed in Tables 3-4 through 3-7 are those that were developed in 1996 for the latest draft of the MDA G Performance Assessment and Composite Analysis (LANL, 1997). Since that time, efforts have been made under the performance assessment and composite analysis maintenance program to evaluate the accuracy some of these estimates. A detailed review of MDA G disposal records from 1957 through 1970 was conducted to try to better define the pre-1971 waste inventory. While the disposal records proved helpful in generally confirming inventory estimates for some waste streams, the lack of data for other types of waste thwarted efforts to more accurately characterize the disposed activities. Since 1998, annual reviews of MDA G LLW disposal receipts have been conducted to evaluate the accuracy of the future waste inventory projections developed in 1996. The reviews have indicated that actual inventories of critical radionuclides are similar to and, in some cases, less than, the activity projections included in the performance assessment and composite analysis inventories. Annual reviews of disposal receipts will continue until the end of disposal facility operations. At that time, a final review of the waste disposal records will be conducted and used to estimate final inventories for MDA G.

4.0 TECHNICAL APPROACH TO CLOSURE

Specific activities that are, or will be, undertaken to close MDA G in accordance with DOE Order 435.1, DOE M 435.1-1, and other applicable requirements are discussed in this section. The requirements that the closure plan is subject to are discussed in Section 4.1, and are used to identify important closure activities and facility design features that, when implemented, will ensure these requirements are met. A detailed description of the activities and design features so identified is provided in Section 4.2. Finally, Section 4.3 discusses the monitoring activities related to facility closure that will be conducted over the remainder of the disposal facility's lifetime.

4.1 COMPLIANCE WITH PERFORMANCE OBJECTIVES AND OTHER REQUIREMENTS

As discussed in Section 3.3, a variety of waste types have been disposed of at MDA G since it began operations 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).

DOE Order 435.1 (DOE 1999a) sets forth the requirements for the management of radioactive waste generated, treated, stored, or disposed of at DOE facilities; specific requirements and responsibilities associated with the implementation of this Order are provided in DOE M 435.1-1 (DOE, 1999b). In terms of LLW disposal, compliance with the Order is demonstrated, in part, by satisfying a series of performance objectives. These performance objectives specify maximum permissible doses for human receptors that are exposed to waste radionuclides and maximum radon fluxes from the surface of the disposal facility.

The ability of a disposal facility to satisfy the performance objectives listed in DOE M 435.1-1 will depend, in part, upon the configuration of the cover placed over the closed disposal units and the long-term performance of that cover. The MDA G Performance Assessment and Composite Analysis (LANL, 1997) were based on the assumption that the final covers placed over the disposal pits and shafts will be the same as the interim or operational covers used for these disposal units. The ability of MDA G to satisfy the performance objectives using these interim covers was due, in part, to the fact that the performance assessment and composite analysis were based on the assumption that DOE will maintain control over the disposal facility throughout the 1,000-year compliance period. It was expected that DOE will take steps during this period to ensure the interim covers meet performance standards, as witnessed by the fact that the performance of the covers was not assumed to falter during the compliance period.

Since the performance assessment and composite analysis were prepared, it has become less certain that a period of control and maintenance equal to the compliance period can be assured. In response to this, a final cover design different than the interim covers has been identified that will provide assurance that the performance objectives will be met with a moderate level of institutional control over the closed disposal facility. This cover design differs from the covers evaluated by the performance assessment and composite analysis, most notably in its total thickness. Because this new design has only recently been identified, the long-term performance of this final cover was not evaluated in the performance assessment and composite analysis. However, the results of those analyses can be used, in conjunction with an understanding of the impacts of the new cover design features, to provide reasonable assurance that the revised final cover design will allow the site to satisfy the performance objectives and other regulations. A formal evaluation of the long-term effectiveness of the final cover design will be conducted in the next revision to the performance assessment and composite analysis.

Sections 4.1.1 through 4.1.3 discuss important design features of the interim covers included in the 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 4.1.1 addresses all pathways exposures, while Sections 4.1.2 and 4.1.3 consider air pathway exposures and releases of radon from the disposal site, respectively. As indicated above, MDA 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 4.1.4.

4.1.1 All-Pathways Performance Objective

The MDA G Performance Assessment and Composite Analysis projected doses for two receptors to demonstrate compliance with the All Pathways performance objective. These receptors include an individual residing down-gradient (i.e., east) of the disposal facility, and an individual living in Pajarito Canyon adjacent to MDA G. Exposures were projected for these receptors using the All Pathways – Groundwater and All Pathways – Pajarito Canyon scenarios, respectively. The receptor down-gradient of the disposal facility is projected to receive exposures from radionuclides that are leached from the waste by water infiltrating through the disposal units and subsequently transported through the unsaturated and saturated zones to locations east of MDA G. The resident in Pajarito Canyon is exposed to contamination that is deposited on the surface of Mesita del Buey by plants and animals intruding into the buried waste. The radionuclides brought to the surface are transported into the canyon with surface runoff, where they are assumed to contaminate canyon soils where the individual is living. Secondary exposures result from the use of contaminated groundwater entering the canyon from the sides of the mesa. Both receptors are assumed to undertake activities that lead to exposure (i.e., the inhalation of airborne particulates, the ingestion of soil, drinking water, and crops, and direct radiation from contaminated soils and suspended dust).

The peak performance assessment dose estimated for the All Pathways – Groundwater Scenario was $2.3x10^{-7}$ mrem/yr during the 1,000-year compliance period, and the peak dose for this scenario under the composite analysis was $1.2x10^{-5}$ mrem/yr. Both of these doses are much less than the corresponding performance objectives (i.e., 25 mrem/yr for the performance assessment and 100 mrem/yr for the composite analysis). A number of disposal site, facility, and radionuclide-specific properties or features are responsible for the small peak doses projected for this receptor. Important site features include the low annual precipitation at MDA G and the long distance from the bottom of the disposal pits and shafts to the regional aquifer. The majority of the water that falls on the site either runs off into the adjacent canyons or undergoes evapotranspiration, thereby limiting the amount of water that percolates through the waste. These features, 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. Most contaminants either decay to negligible levels before they reach the aquifer or discharge to the saturated zone long after the end of the 1,000-year compliance period.

As stated above, the peak doses projected for the All Pathways – Groundwater Scenario are very small relative to the applicable performance objectives. While the projected exposures for the scenario are subject to uncertainty, conservative analyses of the impacts of this uncertainty indicated that worst-case doses would still be less than one percent of the dose limits. These results downplay the importance of adopting a strategy for closing MDA G that strives to limit 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.

An effective closure strategy for MDA G in terms of groundwater pathway exposures will be one in which rates of water infiltration through the disposed waste are minimized. Studies conducted at the Laboratory (e.g., Nyhan et al., 1990) and modeling conducted in support of the performance assessment and composite analysis (Springer, 1996) have indicated the importance of evapotranspiration at the site. Under the conditions studied and modeled, evapotranspiration was responsible for removing more than 85 percent of the water applied to the soil surface. Consistent with these observations, sensitivity analyses conducted by Springer (1996) indicate that rates of infiltration are sensitive to the rooting depth of plants and the leaf area index. The leaf area index is defined as the area of plant leaves relative to soil surface, and is a surrogate for transpiration potential. These results highlight the importance of establishing and maintaining a viable plant community over the closed disposal units.

Rates of infiltration are also sensitive to the antecedent moisture condition of the cover soil as this affects the amount of water that can be stored by the cover material. Once the storage capacity of the soil is reached, water can no longer infiltrate into the cover and becomes runoff. The moisture condition of the soil is a complex function of soil characteristics, cover design, and land use.

The final cover design selected for the closure of MDA G is expected to perform as well as, or better than, the interim covers that it replaces in terms of the groundwater pathways. The cover is constructed of the same materials used for the interim covers and, as such, is expected to have the same hydraulic properties. The fact that the final cover is thicker than the interim covers provides greater opportunity for removal of water from the cover through evaporation and transpiration, before the water percolates through the waste and leaches radionuclides from the waste. Given these factors, doses projected for the All Pathways – Groundwater Scenario under the final closure configuration are expected to be similar to, or less than, those projected for the performance assessment and composite analysis.

The peak performance assessment dose projected for the All Pathways – Pajarito Canyon Scenario was 1.3×10^{-4} mrem/yr, while the peak composite analysis dose was 7.2×10^{-3} mrem/yr. These doses are small compared to the 25 mrem/yr All Pathways performance objective for the performance assessment and the 100 mrem/yr all-pathways dose limit for the composite analysis. 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 this scenario. The rooting and burrowing characteristics of the plants and animals that inhabit MDA 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 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 Pajarito Canyon 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 MDA G which, itself, 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 Pajarito Canyon and, as a result, 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.

It is apparent from the preceding discussion that an effective closure strategy for MDA G in terms of the All Pathways – Pajarito Canyon Scenario is one that focuses on excluding biota from the waste. While a number of cover designs exist that incorporate bio-barriers for this purpose, the interim covers that were included in the performance assessment and composite analysis do not take advantage of 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 interim or operational covers in use at MDA G today are approximately 1.2 to 3.3 m (4 to 10.8 ft) thick. Covers over the disposal pits were conservatively assumed to be 1 to 2 m (3.3 to 6.6 ft) thick for the performance assessment and composite analysis, while the covers placed over shafts were assumed to range from 1.4 to 2 m (4.5 to 6.6 ft). Given the very small doses projected for the All Pathways – Pajarito Canyon Scenario, the modeled cover depths appear to adequately protect the waste from plant and animal intrusion.

As indicated earlier, the MDA G Performance Assessment and Composite Analysis assumed DOE will maintain control over the disposal facility throughout the 1,000-year compliance period. One of the benefits of maintaining control over the site for extended periods of time is that it provides the opportunity to limit plant and animal intrusion into the waste. Consistent with this line of reasoning, the biotic intrusion modeling conducted for the performance assessment and composite analysis was based on moderate plant rooting depths and limited intrusion pressure from animals. Reliance on long-term site maintenance activities to confine disturbance of the waste to moderate levels is appropriate to the extent that the maintenance program can effectively rid the site of deep rooting plants and animals that construct deep burrows. However, if the maintenance program is ineffective or is not implemented properly, the results of the biotic intrusion modeling conducted for the performance assessment and composite analysis may be invalidated.

Recognizing the limitations of relying on long-term institutional control and maintenance to mediate the impacts of biotic intrusion, a more comprehensive evaluation of the potential impacts of biotic intrusion was undertaken under the MDA G Performance Assessment and Composite Analysis Maintenance Program (Shuman, 1998). In this update, biotic intrusion was assumed to be feasible at various times following facility closure, one of which coincided with the end of a 100-yr institutional control period. Intrusion effects were evaluated for a complete suite of plant species, comprising four plant growth forms, rather than the single plant species used in the existing performance assessment and composite analysis modeling; four species of burrowing animals were used to estimate animal impacts on the facility instead of the one species used earlier. The impacts of changes in plant and animal communities due to succession of the disposal site to pinon-juniper woodland were also evaluated.

The results of the updated biotic intrusion modeling indicate that shortening the period of control over MDA G will result in only modest increases in the rates at which radionuclides are deposited on the surface of MDA G by plants and animals. Exposures for the All Pathways – Pajarito Canyon Scenario are projected to increase less than 20 percent, assuming the scenario is first feasible after 100 years of institutional control. Despite this increase, doses for the performance assessment and composite analysis are still much less than the performance objectives. These results suggest the cover evaluated in the performance assessment and composite analysis is capable of adequately protecting the waste from biotic intrusion when limited controls over plant and animal establishment at the disposal site are in place.

Rates of surface erosion at MDA G may have significant impacts on the doses projected for the All Pathways – Pajarito 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 living at the site will cause radionuclide releases to the surface of MDA 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 too will the doses received by the receptor.

The biotic intrusion modeling conducted in support of the performance assessment and composite analysis considered the impacts of surface erosion. However, the rates of erosion developed for those analyses was negligible and may not accurately reflect conditions at MDA G over the 1,000-year compliance period. Since updating the biotic intrusion modeling, expert elicitation techniques have been used in an attempt to improve upon erosion rate estimates. In addition, the erosion modeling conducted for the performance assessment and composite analysis is being updated under the MDA G Performance Assessment and Composite Analysis Maintenance Program. The results of these efforts will be used to formally evaluate the impacts of erosion on biotic intrusion potential and the projected exposures for the All Pathways – Pajarito Canyon Scenario.

As discussed earlier, the covers included in the performance assessment and composite analysis relied upon their total thickness to limit the impacts of biotic intrusion. Given this, and the fact that the recently updated final cover design is thicker than the covers included in these analyses, the impacts of biotic intrusion will be significantly reduced under the new closure regime. The increased thickness of cover will reduce plant root and animal burrow penetration into the waste, decreasing rates of radionuclide release to the surface of MDA G. Preliminary calculations have indicated that the increased thickness of the final cover will be capable of protecting the waste in the face of higher rates of surface erosion. All told, then, any doses resulting from the transport of contamination into Pajarito Canyon with surface runoff are expected to fall well within acceptable limits.

The ability to exclude plants and animals from the waste for long periods of time will depend upon the long-term stability and performance of the covers placed over the pits and shafts. The greatest threat to the stability of the covers is subsidence, which occurs as soils settle or collapse to fill void spaces in the disposal pit. Subsidence of the covers over the disposal pits at MDA G has been minimized over the first 40 years of the facility's lifetime by the manner in which waste is placed in these units. Historically, pit waste was disposed of in lifts and covered with lifts of clean crushed tuff. Heavy equipment was used to compact the waste and tuff, and the process was repeated until the disposal units were full. Recent changes in disposal procedures require that most waste be packaged prior to placement of the material in pits. Exceptions to this requirement include bulk soils and debris such as that generated by ER and D&D activities and large pieces of equipment. Waste containers are stacked in the pits; successive layers of containers are covered with crushed tuff, which is applied using heavy equipment. When the final layer of containers is in place, crushed tuff is added and compacted to grade.

The disposal of uncontainerized waste in lifts was effective in minimizing subsidence at MDA G in that only limited instances of subsidence were observed over the first 40 years of the facility's lifetime. The extensive use of containers increases the potential for subsidence due to the difficulty of completely filling the waste packages to minimize void spaces. Preliminary analyses of the subsidence potential for pits dedicated to the disposal of containerized waste have been conducted (Shuman, 1999). While that study indicated an increased risk of subsidence, the response to any subsidence will ultimately determine the long-term stability of the disposal facility. To the extent that necessary actions are taken to fill void spaces in the disposal pits, no long-term impacts on site stability are anticipated.

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, ALARA principles, and safety requirements. More recently, backfilling with crushed tuff has not been performed. The lack of compaction in the older shafts and the cessation of backfilling in the newer units may increase the potential for subsidence of the covers placed over these units. Recognizing this potential, changes to the disposal procedure (LANL, 1998) have been made which call for a five-year delay between filling the shafts and placing the final operational covers over them. The purpose of this period is to allow for subsidence due to settlement in the shaft to be corrected. During this period, crushed tuff is mounded on top of the shafts; the mounded tuff replaces void spaces as they are created during settlement of the waste. At the end of the five-year period, the mounded tuff is removed and operational covers are applied. More recently, changes were adopted to re-institute the practice of using crushed tuff to backfill shafts as they are filled with waste.

As discussed above, once biotic intrusion into the waste has occurred, the contamination brought to the surface is transported into Pajarito Canyon at a rate determined by the surface erosion rate. The rate at which the cover erodes will be a function of its design and its long-term performance. For example, analyses conducted in support of the MDA G Performance Assessment and Composite Analysis (LANL, 1997) indicate that the application of a gravel mulch layer on top of the covers placed over the pits may reduce rates of erosion to negligible levels. The effectiveness of design features, however, will tend to be compromised over extended periods of time as covers undergo gradual degradation or subsidence. Under these conditions, two primary approaches may be used to assure adequate protection of the waste by the cover system. First, the cover design may be made more robust to withstand the anticipated impacts of erosion. For example, the total thickness of the cover may be increased to offset the effects of erosion, thereby assuring that the minimum cover depth needed for satisfactory isolation of the waste is present throughout the compliance period. Second, periodic maintenance of the cover may be performed to restore the cover to its as-designed condition and, as a result, assure it's continued effectiveness.

Long-term maintenance of the cover to minimize the impacts of erosion was implied by the performance assessment and composite analysis, which assume that cover performance does not degrade over the 1,000-year compliance period. As indicated earlier, it is unclear if this level of control and maintenance over MDA G can be relied upon over the duration of the compliance period. Consequently, the final cover design for the disposal facility has been updated and is now expected to be capable of withstanding projected rates of surface erosion in the absence of maintenance beyond a 100-yr institutional control period. The added level of protection is provided by substantially increasing the thickness of the cover relative to the covers included in the performance assessment and composite analysis.

4.1.2 Atmospheric Scenario Performance Objective

The atmospheric pathway considers potential doses received by receptors living down-wind of MDA 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. The MDA G Performance Assessment and Composite Analysis estimated Atmospheric Scenario doses for receptors located at the point of maximum exposure (i.e., in Canada del Buey) and in the town of White Rock, the population center closest to the disposal facility. Exposures to these individuals resulted from the inhalation of airborne radionuclides, ingestion of soil and crops contaminated by atmospheric deposition, and direct radiation from soil and airborne contamination.

The peak performance assessment dose estimated for the Atmospheric Scenario was $6.6x10^{-2}$ mrem/yr during the 1,000-year compliance period, while the peak dose for the composite analysis was 5.8 mrem/yr. The peak dose projected for the performance assessment is due to tritiated water vapor diffusing from the disposal facility, and is small compared to the 10 mrem/yr performance objective (Note: this performance objective applies to all sources of radioactivity at LANL, not just MDA G. However, projected exposures are still below this limit even when contributions from other facilities at the Laboratory are taken into account.) The peak exposure estimated for the composite analysis is caused by radionuclides resuspended from MDA G following their deposition on the surface of the facility by plants and animals intruding into the waste. At the time it was conducted, the composite analysis was subject to a 100-mrem/yr performance objective and an administratively limited dose constraint of 30 mrem/yr. The dose of 5.8 mrem/yr is about 6 to 20 percent of these limits. The performance objective for the atmospheric pathway under DOE Order 435.1 is 10 mrem/yr, and the projected peak dose is less than this limit as well.

Exposures from vapors and gases diffusing from MDA 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. In these cases, 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 magnitude of the peak dose projected for the performance assessment is small relative to the 10-mrem/yr performance objective. Based on a conservative analysis of the uncertainty associated with this exposure estimate, a worst-case dose for the Atmospheric Scenario is about 10 times larger than the 6.6×10^{-2} mrem/yr peak dose. This dose, in combination with the dose that was estimated for other facilities at the Laboratory (i.e., 3.5 mrem/yr), is still small compared to the performance objective. Using the newly defined final cover design rather than the interim covers included in the performance assessment and composite analysis is expected to result in similar, or slightly lower, dose contributions from MDA G. These results suggest that it would not be cost-effective to conduct closure activities or incorporate cover design features in response to risks posed by MDA G via the atmospheric pathway under the performance assessment.

The peak Atmospheric Scenario dose projected for the composite analysis ultimately depends upon the rate at which contamination is deposited on the surface of MDA 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 – Pajarito Canyon scenario also play important roles for this pathway. In addition to aspects that affect the nature and extent of biotic intrusion into the waste, meteorological conditions at MDA G will play an important role, as they will determine how surface soils are resuspended from MDA G and dispersed prior to reaching the receptor locations.

Given the role of biotic intrusion in the atmospheric pathway for the composite analysis, an effective closure strategy for the facility will focus on minimizing or preventing penetration of the waste by roots and burrows. In the absence of engineered biointrusion barriers, the thickness of the cover material placed over the waste is used to limit biotic intrusion. As discussed earlier, the MDA G Performance Assessment and Composite Analysis used conservative estimates of interim cover thickness over the disposal pits and shafts. These modeled cover depths limited biotic intrusion to the degree necessary to maintain base-case doses well below the 30 and 100-mrem/yr performance objectives in effect at the time. However, uncertainty analyses conducted in support of the composite analysis indicate that Atmospheric Scenario doses could exceed these dose limits under worst-case conditions. Obviously, it is even more likely that the 10-mrem/yr dose limit implied by DOE Order 435.1 will be exceeded when uncertainties are taken into account.

The composite analysis dose projections for the Atmospheric Scenario are based on the assumption that the performance of the covers placed over the pits and shafts is not seriously compromised over the 1,000-yr compliance period. The final cover design that was recently identified to replace the interim covers evaluated by the performance assessment and composite analysis will significantly reduce the degree to which plant roots and animal burrows penetrate into the buried waste. Releases of radionuclides to the surface of MDA G will decrease, causing exposures to the receptor living downwind of the disposal facility to fall. These benefits will be realized under the updated biotic intrusion modeling approach and in the face of significantly higher surface erosion rates. Furthermore, projected exposures are expected to remain below acceptable limits even under conditions approaching worst-case.

As discussed earlier, the ability to minimize the impacts of intruding plants and animals will depend, in part, on the long-term stability and performance of the covers placed over the pits and shafts. The potential for subsidence of disposal unit covers has been discussed in Section 4.1.1.

4.1.3 Radon Flux Performance Objective

The radon flux analysis conducted in support 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 MDA G. Projected fluxes for the two radionuclides are summed to yield a total radon flux, and this flux must be less than or equal to 20 pCi/m2/s in order to demonstrate compliance with DOE M 435.1-1. The fluxes estimated for the MDA G Performance Assessment satisfied this limit, ranging from 0.11 pCi/m2/s for the disposal pits used between September 27, 1988 and 1995 to 3.1 pCi/m2/s for the shafts used during this same period.

The magnitude of radon fluxes from disposal units at MDA 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 MDA 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.

The interim or operational cover designs are effective barriers to radon diffusion, insofar as the projected fluxes are much less than the 20 pCi/m^{2}-s performance objective. Based on these results, no closure activities or cover design features above and beyond those used for interim closure of the disposal units at MDA G are expected to be necessary. While fluxes may increase in the future as the cover degrades, the scale of any such degradation would need to be large in order for the projected fluxes to exceed the limit. Increasing the radon diffusion coefficient used for the pits to the free air diffusion coefficient would fail to elevate fluxes to unacceptable limits. Increases in the diffusion coefficient used for the shafts would have little or no impact as well. While reductions in the total cover thickness due to erosion may result in increased fluxes, cover depths over the pits and shafts would need to decrease by more than 80 percent for the fluxes to exceed the 20 pCi/m^2-s limit. The rates of surface erosion that would be needed to effect such reductions are not anticipated over the 1,000-year compliance period.

The application of the final cover design over MDA G will only increase the level of assurance that radon fluxes from the site will not exceed 20 pCi/m^2-s. The additional thickness of the cover is expected to reduce fluxes of Rn-220 from the site, while leaving Rn-222 fluxes relatively unchanged. The additional cover also provides greater protection against the effects of surface erosion over the compliance period. Insofar as the interim covers are expected to be adequate in this regard, the final cover design will have the effect of increasing the margin of safety with respect to the release of radon.

4.1.4 Other Requirements

The activities undertaken and the design features used to close MDA G will be influenced by a number of factors in addition to those related to satisfying the DOE M 435.1-1 performance objectives. These requirements take into account the effects of:

- Protecting groundwater resources,
- Complying with radionuclide concentration and inventory limits included in the disposal facility's Waste Acceptance Criteria (WAC),
- Releasing MDA G for unrestricted use, and
- Complying with regulations imposed upon MDA G because material other than LLW has been disposed at the facility.

The impacts of these additional requirements on the closure of MDA G are discussed in the following sections.

4.1.4.1 Protection of Groundwater Resources

In addition to the All Pathways – Groundwater Scenario discussed earlier, the MDA G Performance Assessment also evaluated potential doses for the Groundwater Resource Protection Scenario. This scenario evaluates the potential impacts of MDA G on drinking water supplies in the vicinity of the disposal facility. It estimates doses to receptors from the consumption of drinking water only, these exposures were compared to a performance objective of 4 mrem/yr. Doses were projected for receptors located east of MDA G and in Pajarito Canyon adjacent to the disposal facility.

The peak 1,000-yr compliance period doses projected for the Groundwater Resource Protection Scenario were 8.3×10^{-8} and 4.5×10^{-5} mrem/yr for the receptors located east of MDA G and in Pajarito Canyon, respectively. The peak dose projected for the receptor east of MDA G under worst-case conditions is 3.0×10^{-5} mrem/yr, while the corresponding dose for the individual in the canyon is 8.1×10^{-4} mrem/yr. All of these doses are much smaller than the 4 mrem/yr performance objective.

The conclusions reached earlier with respect to the All Pathways – Groundwater Scenario apply to the Groundwater Resource Protection Scenario as well. The very small doses projected for the scenario downplay the importance of optimizing the strategy used to close MDA G with respect to groundwater pathway exposures. Nevertheless, an effective closure strategy for MDA G in terms of groundwater resource protection will be one in which rates of water infiltration through the disposed waste are minimized. Features of the cover design that have the greatest impact on rates of infiltration were discussed in Section 4.1.1.

4.1.4.2 WAC Compliance

LLW disposed of at MDA G must comply with the disposal facility's WAC which, among other things, specify the maximum radionuclide concentrations and total inventories that may be safely placed in the pits and shafts. These concentration and inventory limits are based on the modeling conducted for the MDA G Performance Assessment. As such, these limits take into account the environmental conditions at Mesita del Buey and the design features of the disposal facility, including the characteristics of the covers placed over the waste and the long-term performance of these covers.

Radionuclide concentration limits were estimated using two inadvertent intruder exposure scenarios. Limits for waste disposed of at depths less than 3 m (3.3 ft) were calculated using the Intruder Agriculture Scenario, which assumes that an individual lives in a house that is built on the closed disposal site. Contaminated material is brought to the surface when the basement for the house is excavated, and spread over the resident's lot. Concentration limits for waste disposed of at depths greater than 3 m (3.3 ft) were estimated using the Intruder Post-Drilling Scenario. The on-site resident in this scenario is assumed to be exposed to waste brought to the surface during establishment of a well; excavation of a basement is either not undertaken or fails to bring contamination to the surface because of the depth of disposal of the waste. Both receptors inhale airborne radionuclides, ingest contaminated soil and foodstuffs, and receive direct radiation from contaminated media.

The primary design feature of the disposal pits that determines the magnitude of the projected intruder exposures and, hence, the allowable waste concentration limits, is the depth of the cover placed over the waste. In general, as the thickness of the cover increases the projected intruder doses decrease, allowing disposal of waste with higher radionuclide concentrations. The MDA G Performance Assessment used an interim cover depth of 2 m (6.6 ft) to estimate radionuclide concentration limits for the pits. Calculation of these limits is based on the assumption that this cover depth is maintained throughout the 1,000-year compliance period. While the thickness of the cover has a significant impact on the magnitude of the radionuclide concentration limits for the disposal shafts, those limits also took into consideration the presence of the concrete caps placed over these units during operational closure. These concrete caps were assumed to prevent basement excavation for a period of 300 years after facility closure. Hence, no doses were projected to occur for the Intruder Agriculture Scenario during this period. The concrete caps were not expected to prevent establishment of a well. Consequently, drilling through the waste was assumed to be feasible at the end of a 100-yr institutional control period.

The final cover design for the pits and shafts is sufficiently different from the interim covers used in the MDA G Performance Assessment that the applicability of the radionuclide concentration limits is in question. However, similar or higher limits are anticipated when the final cover design is used in place of the interim covers. An increase in the total thickness of the cover placed over the pits to 3.4 m (11.2 ft) significantly reduces the amount of waste contacted during basement excavation, even when the effects of surface erosion are taken into account. As a result, pit concentration limits based on the Intruder Agriculture Scenario will increase dramatically. Radionuclide concentration limits based on the post-drilling scenario will also increase, though only slightly, due to the application of additional cover.

The interim covers for the disposal shafts include concrete caps placed over the units which, as discussed above, were assumed to prevent the Intruder Agriculture Scenario for 300 years post-closure. The lack of these caps in the final cover design will allow this scenario to occur as soon as the 100-yr institutional control period ends. However, the increase in the cover thickness from 2 to 3.4 m (6.6 to 11.2 ft) ensures that little or no contact with the waste will occur during basement excavation over the time the concrete caps were assumed to prevent intrusion. Consequently, the concentration limits based on this scenario are not expected to change appreciably, and may increase. The shaft concentration limits calculated on the basis of the Intruder Post-Drilling Scenario, which are unaffected by the presence of the concrete caps, will increase modestly because the final cover design is thicker than the interim cover.

The radionuclide inventory limits included in the WAC are also based on the performance assessment modeling and the specific design features of the disposal facility at MDA G. To the extent that the configurations of the covers placed over the pits and shafts affect the magnitude of these inventory limits, the approach adopted for closure of MDA G needs to coincide with the modeling used to develop the limits. Given that the inventory limits developed for the facility are based on groundwater pathway doses, design features that need to be taken into account are those concerned with limiting rates of water infiltration through the waste over the course of the 1,000-year compliance period. Features of the cover that affect infiltration were discussed with respect to the All Pathways performance objective in Section 4.1.1.1. As mentioned in that section, the final cover design is expected to be as effective as the interim covers, and possibly more effective, in terms of minimizing infiltration through the waste.

4.1.4.3 Release of MDA G for Unrestricted Use

DOE M 435.1-1 (1999b) requires that LLW disposal sites 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, DOE may choose to maintain control over the sites indefinitely as long as these plans are integrated into land use and stewardship plans and programs. In essence, the MDA G Performance Assessment and Composite Analysis (LANL, 1997) adopted the latter approach when it was assumed that DOE would maintain control over the disposal facility throughout the 1,000-yr compliance period. The final cover design presented in this plan is capable of providing adequate protection in the event that all restrictions on site access cease 100 years after the facility is closed.

While exposures to members of the general public are limited to off-site locations as long as DOE maintains control over a site, on-site activities are feasible after the site is released. Access to the site will generally provide the opportunity to access higher environmental concentrations of waste radionuclides, leading to doses that are significantly greater than those projected for off-site receptors. Under Order 5400.5, doses to on and off-site receptors are limited to 100 mrem/yr from all DOE activities and all exposure modes. The Order also specifies limits for exposures to airborne emissions (10 mrem/yr), exposures to contaminated drinking water (4 mrem/yr), and radon decay product concentrations (0.02 WL in habitable structures).

The design of the final cover will play an important role in terms of minimizing doses to on-site receptors and, therefore, in allowing MDA G to be released for unrestricted use. Specifically, the cover will need to prevent or minimize biotic intrusion into the waste, and will need to limit human intrusion as well. The features of the cover that play an important role in minimizing biotic intrusion into the waste have been discussed previously.

As discussed in the preceding section, the MDA G Performance Assessment and Composite Analysis assumed the concrete caps placed over the shafts prevented some types of human intrusion for 300 years after facility closure. The use of these caps has been discontinued, and the existing caps will be retrieved during final closure of MDA G. In the absence of engineered barriers, the thickness of the cover is the only design feature used to limit or prevent human intrusion into the buried waste. Contact with the waste can be prevented for some types of intrusion if the cover is sufficiently thick. An example of this is the excavation of a basement for a house. If the cover is thicker than the basement is deep, no waste will be disturbed. In other cases, however, the thickness of the cover will not prevent intrusion from occurring. For example, a well drilled to provide water will pass through the waste regardless of the cover thickness as long as the well is located over the disposal unit.

Intruder analyses conducted in support of the MDA Performance Assessment indicated that intruder pressures could be adequately limited using 1 to 2 m of cover (3.3 to 6.6 ft) over the pits; 1.4 to 2 m (4.5 to 6.6 ft) of cover over the shafts was adequate when it was assumed the concrete caps prevented intrusion for a period of 300 years. These analyses, however, considered intrusion into the waste included in the performance assessment only, the impacts of intrusion into the waste disposed of prior to September 27, 1988 was not evaluated. Exclusion of the earlier waste from the intruder analysis was consistent with the fact that intruder analyses were conducted primarily to establish WAC for future waste disposal.

The release of MDA G for unrestricted use places fewer limitations on the conditions under which human intrusion into the waste may occur. Given unlimited access to the site, it is reasonable to assume people may intrude into any portion of the inventory. Consequently, intruder exposures resulting from disturbance of the waste disposed of prior to September 27, 1988 need to be considered. In terms of the shafts, the absence of concrete caps from units closed in the future will provide the opportunity for intrusion to start at the end of the active institutional control period. Removal of the existing concrete caps at the time of facility closure will allow intrusion into those units at the end of the institutional control period as well.

The interim covers addressed by the performance assessment and composite analysis are not expected to adequately protect intruders if the site is released for unrestricted use before the end of 1000 years of institutional control. The final cover design presented in this closure plan responds to this expected shortcoming. The increased thickness of the material placed over all waste units will either prevent intrusion into the waste or limit exposures of the intruder to acceptable limits.

4.1.4.4 Other Waste Regulations

As discussed in Section 2.1 of this report, MDA G has been, and continues to be, used for a variety of waste management functions. Consequently, the facility is subject to requirements that are normally not implicated at LLW disposal facilities. Some of these requirements will have an impact on the manner in which the disposal facility is closed.

LLW disposed of at MDA G prior to September 27, 1986 may include hazardous materials as defined in the RCRA of 1976, as amended (RCRA, 1976). Most of the pits and shafts containing MLLW are subject to the corrective action requirements found in Subpart S of 40 CFR 264, 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 Subpart N. RCRA requirements are enforced by the NMED under an agreement with the EPA.

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 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 post-closure 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; and
- Accommodates settling and subsidence to maintain the cover's integrity.

Many of the cover design features discussed with respect to satisfying the DOE requirements address the standards set by RCRA as well. Minimization of water infiltration through the waste to limit groundwater pathway doses will also 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 – Pajarito Canyon scenario doses will also control contaminant releases to surface soils, surface water, and the atmosphere. The ability of MDA 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 also help satisfy the technical requirements found in RCRA.

The ER Project is responsible for identifying a suitable closure configuration for the disposal units containing hazardous constituents regulated under RCRA. While preliminary evaluations of the risk posed by MDA G have been performed by that organization (LANL, 2000a), the assessments necessary to define suitable closure alternatives are not expected to be undertaken for some time. Consequently, the closure plan presented here focuses on compliance with the requirements laid out in DOE Orders. While the plan so developed is expected to address most, if not all, of the needs of the ER Project, it will be necessary to re-evaluate this plan when a final closure plan for the older disposal units at MDA G has been developed. ER Project and FWO-WFM personnel will continue to interact closely in order to define a single suitable closure strategy.

4.2 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, and that minimizes the need for active maintenance. The criteria against which the protection of human health and safety and the environment are measured have been discussed, and the characteristics of the disposal site and facility that may undermine the ability to achieve this level of protection have been identified. This section uses that information to identify 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. The detailed information required to implement the approach and design features is subsequently provided.

Disposal operations at MDA G began in 1957 and are currently assumed to continue until the year 2044. Operational or interim closure of the disposal pits and shafts is conducted as the disposal units are filled with waste. Section 4.2.1 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 interim closure in the future. At the end of its operational lifetime, MDA G will undergo final closure. The activities to be conducted in support of final closure and the configuration of the cover are discussed in Section 4.2.2. DOE will maintain control of the disposal site throughout the institutional control period, the inspection and maintenance activities that will be conducted to ensure proper functioning of MDA G during this period are discussed in Section 4.2.3. 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 4.2.4.

4.2.1 Operational/Interim Closure

Operational closure of the disposal pits and shafts has been conducted at MDA G since 1961, when Pit 1 was backfilled to ground level. Interim closure of disposal units will continue until the last waste is disposed of at the facility. The closure activities undertaken and the design features used for operational closure of the pits and shafts have evolved over time. The activities and design features used to close the pits and shafts in the past, and those planned for closure of active disposal units in the future, are discussed in the following sections.

4.2.1.1 Operational Closure Strategy And Cover Performance For Disposal Pits

Disposal pits 1 through 4 were constructed using Materials Waste Pits Standard Specifications, Engineering Drawing ENG-C 18463 (Rogers, 1977). A copy of this drawing is presented as Figure 4-1. The drawing shows a pit in plan view, in longitudinal cross-section, and in cross-section at right angles to the pit. Pits were to be a maximum of 180 m (600 ft) long, 30 m wide, and 7.6 m (25 ft) deep. With respect to the depth, however, a note on the drawing indicates that final pit depth will 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 U.S. Geological Survey in 1965 (Koopman, 1965) and were adopted by the Laboratory. Pit 5 was the first disposal unit constructed and closed using these guidelines and the new standard pit specifications (Figure 4-2). Portions of these guidelines relevant to the disposal of waste and closure of pits are summarized below:

- Continue disposing of waste in layers, separated by layers of tuff;
- Fill pits to within 0.6 m (2 ft) of the land surface;

- Seal material, or tuff, overlying the waste should range in thickness from 1.8 to 2.4 m (6 to 8 ft);
- Ensure that the surface of the seal material placed over the pits should be slightly rounded;
- Ensure that adequate drainage is provided to remove runoff from precipitation on the mesa;
- Locate drainage ways so that they do not cross the surface of sealed pits;
- Where appropriate, plant native vegetation on the surfaces of sealed pits;
- Biannually inspects the sealed pits, as appropriate, to determine if any unusual settling or gullying has occurred.

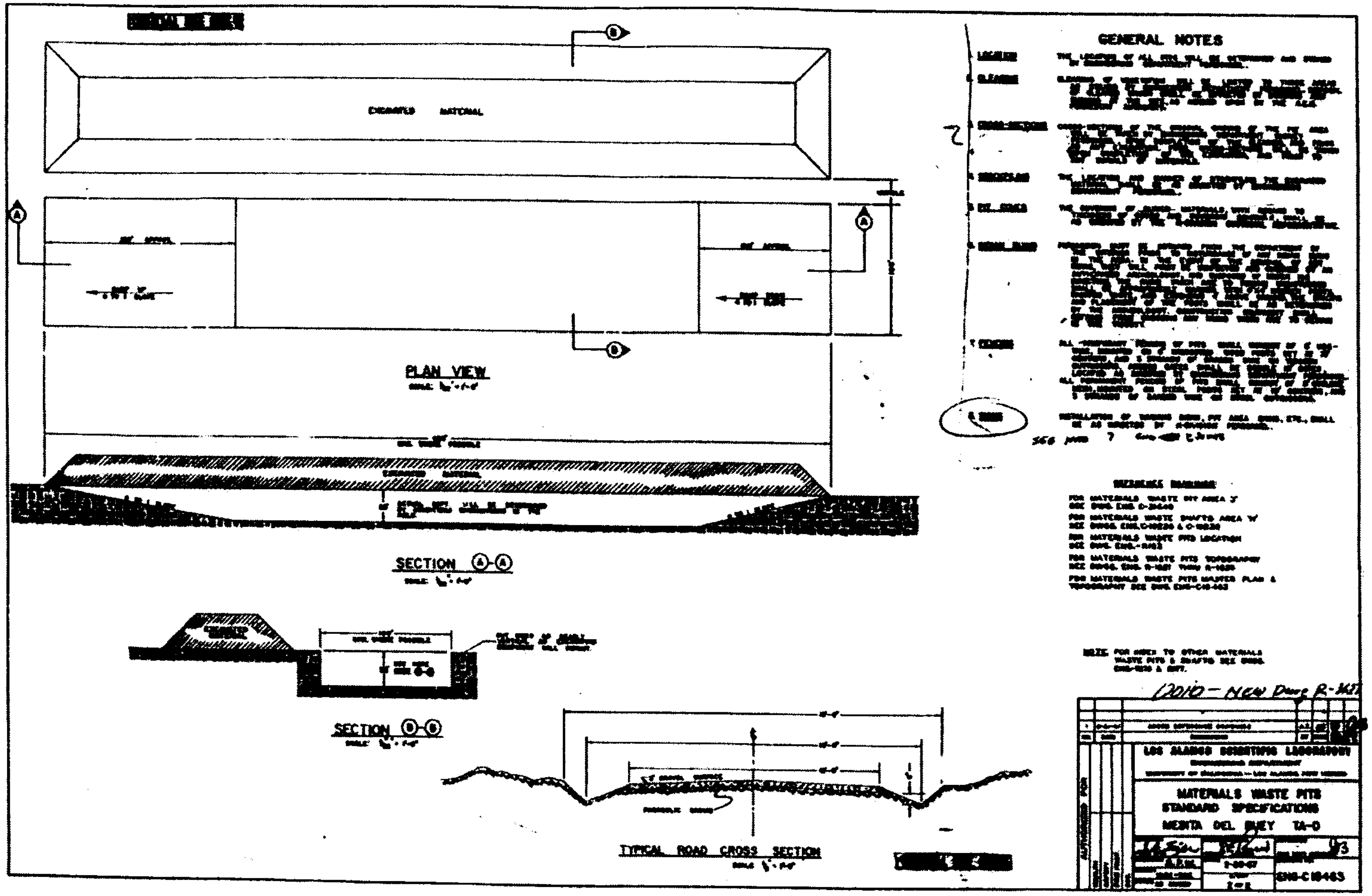

Figure 4-1. Standard specifications for waste disposal pits 1 through 4.

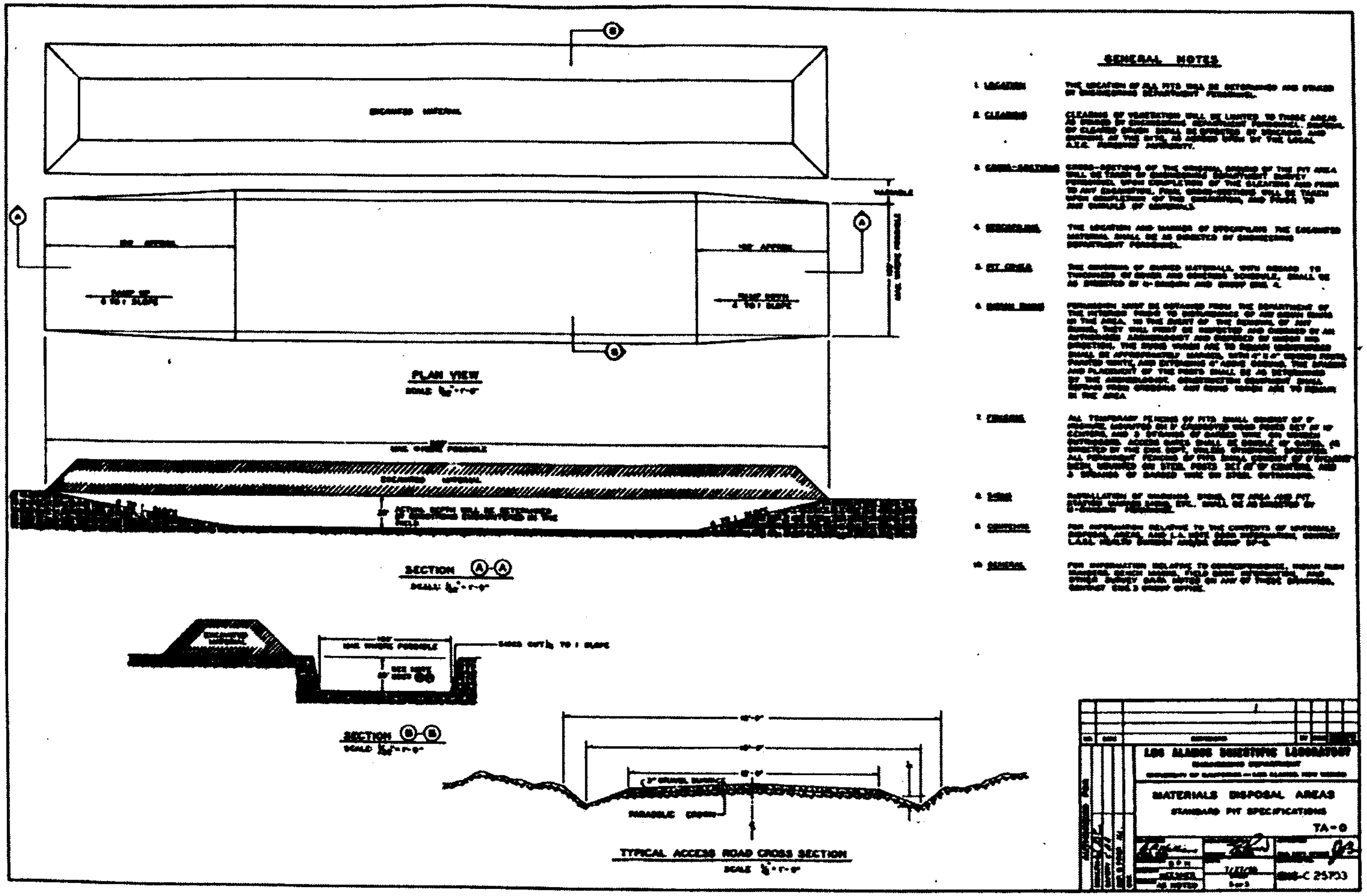

Figure 4-2. Standard pit specifications adopted by the Laboratory in 1965.

A memorandum issued in 1975, Guidelines for Construction and Use of Solid Waste Disposal Facilities (LANL, 1975), formalized disposal operations further, modifying some of the guidelines proposed by the U.S. Geological Survey in the process. These guidelines address disposal unit siting, construction, disposal 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:

- 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.

The guidelines for the design, construction, and closure of disposal units at MDA G were updated in 1998 (LANL, 1998). In general, these guidelines adhere to the 1975 memorandum. However, some changes to the design 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 (9.8 ft) below the disposal unit rim. Exceptions to this requirement were acceptable as long as the MDA 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 MDA G for waste management activities.

Design, construction, and closure procedures for disposal units at MDA G were undergoing revision as this closure plan was developed. While similar to the 1998 guidelines in most respects, the amount of cover to be placed over the waste was increased. The revised guidelines require that waste be disposed of to a minimum depth of 3.3 m (10.8 ft) below the disposal unit rim.

Additional information about the operational closure of disposal pits is provided here, and is based on the revision of the closure procedure that was in progress when this plan was being developed. Pits are surveyed according to procedure at the time of establishment, and survey data are recorded and unit perimeters are marked. Once a pit is excavated, a 15 to 30 cm (0.5 to 1 ft) layer of tuff is placed in the bottom of the unit to seal fractures in the pit floor and to provide a level surface for the waste. Waste is disposed of in the pit to within 3.3 m (10.8 ft) of the rim of the unit. Once a disposal pit is full, the operational closure process is begun. Crushed tuff is emplaced in 30 cm (12 in.) thick lifts with earthmovers or scrapers, and then consolidated in place using a 50-ton bulldozer. This process is continued until the level of the consolidated tuff has reached the ground surface.

The operational closure activities that follow depend upon the intended use of the disposal unit. If the surface of the disposal pit is not needed for temporary operations, a small lift of crushed tuff is placed over the surface of the pit (Figure 4-3). This lift is slightly mounded along the longitudinal centerline of the pit and extends 1 m (3.3 ft) beyond the sides of the pit. A minimum of 10 cm (4 in.) of topsoil is placed over the crushed tuff. The cover is graded to correspond with surface contours in the area surrounding the pit, thereby decreasing the potential for runoff into other disposal units. The topsoil is then planted with shallow rooting, native, turf-forming grass over the entire surface. If the filled disposal pit is going to be used to support temporary surface structures (e.g., those used for treating or storing mixed and/or TRU waste), the consolidated tuff is covered with an asphalt pad. The pad is either crushed into 4 in. or smaller pieces or removed prior to final closure. Tuff and topsoil are applied as discussed above.

Once a disposal pit is closed, benchmarks are placed in opposite pit corners immediately after placement of the 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 in the future. The 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 then placed into the top of the concrete benchmark with appropriate engineering records (e.g., disposal unit and disposal data). A typical design for the benchmarks is shown in Figure 4-4. Finally, an easily identifiable fiberglass marker stake displaying the pit and corner identification number is placed next to each benchmark.

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 are conducted under the Detailed Operating Procedure titled "TA-54 TSDF Inspections" (LANL, 2000b). The following types of

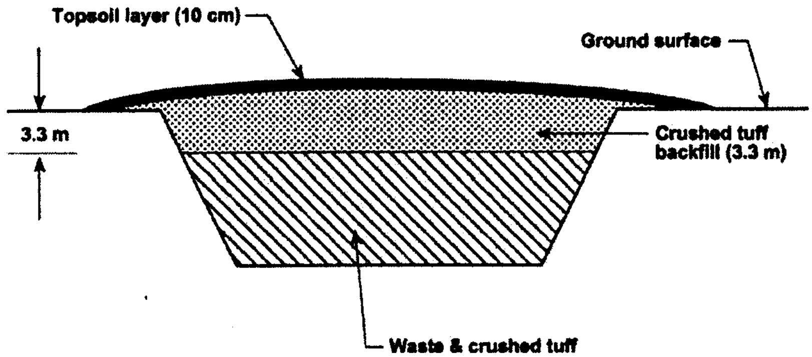

Figure 4-3. Operational cover design for disposal pits at MDA G.

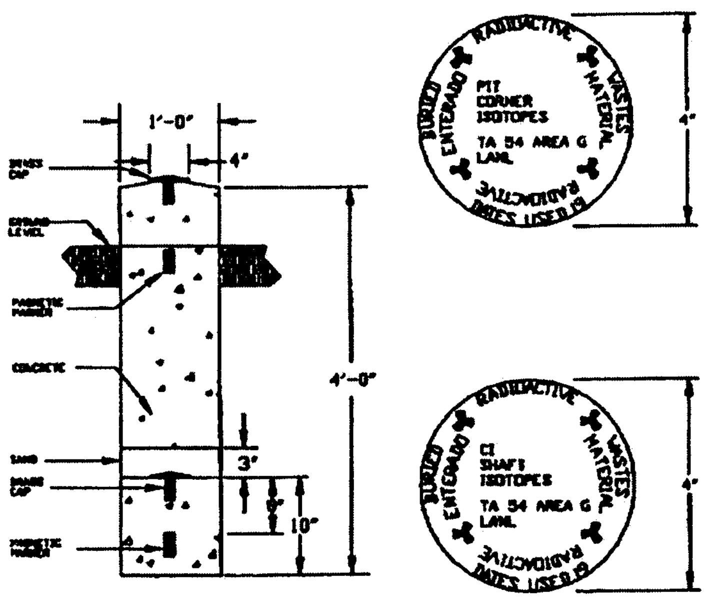

Figure 4-4. Typical pit and shaft benchmark designs.

inspections are performed:

- Operational covers are inspected to ensure they contour to surrounding terrain and extend 1 m (3 ft) beyond the edges of the pits.

- 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.

- Pit covers are inspected for deep-rooting plants and signs of burrowing animals.

- Pit covers are inspected for signs of subsidence and water-driven erosion.

Site operators record the results of operational cover inspections on forms and submit the results to records management on the first business day following completion of the inspection. 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.

DOE guidance (DOE, 2001) requires the development of detailed engineering plans and specifications for interim closure. Types of information that are to be presented include:

- Engineering drawings, including grading plans, cross sections, drainage plans;

- Specifications for materials and placement of materials (e.g., permeability, lift height, compaction, and moisture content);

- Specifications for final survey of disposal cell location;

- Construction quality control plans; and

- Records management plan for documents and records generated during interim closure.

While numerous disposal units have undergone closure at MDA G, the majority of this information has not been formally documented. Recognizing this shortcoming, plans are being made to develop the information needed to support interim closure activities.

The interim or operational covers placed over the disposal pits are designed to isolate the waste from the accessible environment, thereby minimizing exposures received by the general public and on-site personnel, and to promote stability of the closed pits. The degree of waste isolation provided by the covers is such that there is little potential for significant radionuclide releases to the accessible environment and subsequent exposure of members of the general public during the operational period. The MDA G Performance Assessment and Composite Analysis (LANL, 1997) have demonstrated that rates of water infiltration through the interim covers are expected to be small and that any groundwater pathway exposures will be realized well after the disposal facility is closed. While biotic intrusion into the waste may result in releases of radionuclides to the surface, these releases are expected to be much smaller than those projected for the performance assessment and composite analysis because of the maintenance activities undertaken during the operational period. Consequently, any exposures resulting from such releases are expected to be negligible relative to those projected for the performance assessment and composite analysis. Finally, releases of tritiated water vapor or radioactive gases could occur during the operational period and, following their dispersal down-wind of MDA G, result in exposures to the general public. However, the exposures projected by the performance assessment and composite analysis to result from these releases were small. The magnitude of any such releases and exposures during the operational period are expected to be even less than these projections because of differences in the exposure conditions and the fact that the entire inventory of tritium and gaseous radionuclides has not yet been placed at MDA G.

Interim 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. Periodic compaction of disposed waste and of the interim cover was effective in maximizing the stability of the waste prior to the extensive use of waste containers. This conclusion is based on the fact that only limited subsidence of the pits has been noticed in the first 40 years of the facility's life. Current use of containers to dispose of most waste will all but prevent worker exposures to airborne contaminants and direct radiation from the waste after the pits are closed. The use of containers may result in a greater potential for subsidence that may, in turn, undermine the long-term stability of the disposal units. However, problems with waste stability are not expected to be an issue during the operational period. Inspections for subsidence and settlement will be conducted under the MDA G Environmental Monitoring Program; the results of the inspections will be used to determine if any corrective actions are necessary.

4.2.1.2 Operational Closure Strategy and Cover Performance for Disposal Shafts

Waste was first disposed of in shafts at MDA G in 1966, the first shaft underwent interim closure in 1967. The design features of these units are shown in Figure 4-5. This drawing shows vertical cross-sections of typical shafts and illustrates the layout of adjacent units. Shafts may be unlined or lined by pouring concrete between a centered metal tube and the walls of the shafts. The depths of the shafts were to be specified or determined on the basis of field conditions.

Shaft closure activities and cover designs have complied with the guidelines in effect at the time units have been closed. The disposal guidelines proposed by the U.S. Geological Survey in 1965 (Koopman, 1965) did not address shafts because the use of these units had not yet started. Nevertheless, it is expected that pertinent parts of those guidelines were applied to these units between 1966, the year in which shaft disposal began, and 1975, when specific guidelines for shafts were issued. Specifically, it is expected that waste was disposed of in layers, separated by layers of tuff, 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 head-space remaining in the shafts was filled with tuff and concrete caps were placed over the units.

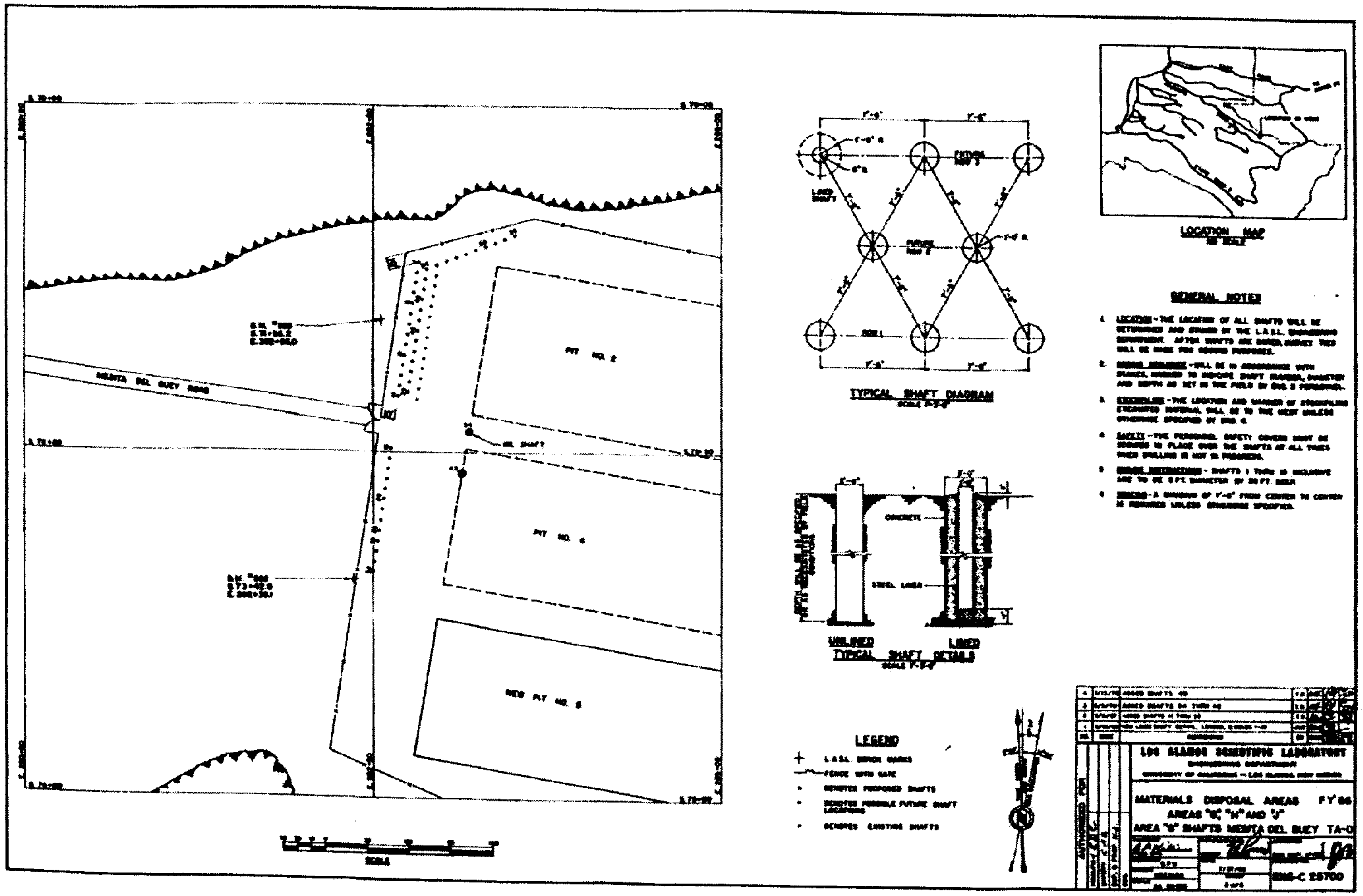

Figure 4-5. Standard specifications for waste disposal shafts.

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

- Appropriate measures shall be taken to insure 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 insure the absence of significant open joints or fractures, 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 the lowest point on the shaft rim.

- The final cover of a shaft shall be non-contaminated 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.

Guidelines for the design, construction, and closure of disposal units at MDA G were updated in 1998 (LANL, 1998). These guidelines called for waste to be disposed of to a depth of 3 m (9.8 ft) below the disposal unit rim. Exceptions to this requirement were acceptable as long as the MDA G WAC were satisfied and the waste was no less than 2 m (6.6 ft) below the rim of the disposal unit.

Changes in the manner in which shafts undergo interim closure were underway when this closure plan was developed. The revised guidelines call for the disposal of waste to a depth of 3.3 m (10.8 ft) below the rim of the disposal unit, with no exceptions. The entire head space above the waste is to be filled with crushed tuff, eliminating the concrete caps discussed above. The use of crushed tuff instead of the concrete caps allows an easier transition to the final closure configuration, while providing adequate isolation of the waste from disposal facility personnel. Additional requirements included in this procedure are discussed below.

Under current procedures, disposal shafts are surveyed according to procedure at the time of establishment, 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 prevent 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 minimize the entry of water and to provide easy access to the shafts during disposal operations. Waste is disposed of in the shaft to within 3.3 m (10.8 ft) of the rim of the unit; crushed tuff is added to fill void spaces between the waste containers. When a disposal shaft is full the steel lid is removed, the head-space in the shaft is filled with tuff, and tuff is mounded over the top of the disposal unit. The shaft is left in this configuration for up to five years to allow for subsidence due to waste settlement in the shaft to be corrected. At the end of this period, the concrete collar and the mounded material are removed to ground level, and the disposal unit is considered closed.

Benchmarks are placed near the shafts immediately after placement of the 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 in the future. The benchmarks are placed in opposite corners of shaft fields, or groups of shafts, rather than establishing a benchmark for each shaft. The 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 then placed into the top of the concrete benchmark with appropriate engineering records (e.g., disposal unit and disposal data). A typical design for the benchmarks is shown in Figure 4-4. Finally, an easily identifiable fiberglass marker stake displaying the shaft number is placed next to each shaft.

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 are conducted under the Detailed Operating Procedure titled "TA-54 TSDF Inspections" (LANL, 2000b). The following types of inspections are performed:

- Operational covers of shafts closed without concrete caps are inspected to ensure they contour to surrounding terrain and extend 1 m (3 ft) beyond the edges of the pits.
- Covers of shafts that are closed with crushed tuff caps (i.e., without concrete caps) are inspected to ensure that native vegetation is planted and growing 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 water infiltration.

Site operators record the results of operational cover inspections on forms and submit the results to records management on the first business day following completion of the inspection. 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.

DOE guidance (DOE, 2001) requires the development of detailed engineering plans and specifications for interim closure. Types of information that are to be presented include:

- Engineering drawings, including grading plans, cross sections, drainage plans;

- Specifications for materials and placement of materials (e.g., permeability, lift height, compaction, and moisture content);

- Specifications for final survey of disposal cell location;

- Construction quality control plans; and

- Records management plan for documents and records generated during interim closure.

While numerous disposal units have undergone closure at MDA G, the majority of this information has not been formally documented. Plans are being made to develop the information needed to support interim closure activities.

The interim cover placed over the shafts is an effective means for isolating the waste from the accessible environment during operations. While the MDA G Performance Assessment and Composite Analysis did not address operational period exposures, they did indicate that the interim cover designs used to date at MDA G limit releases to the environment and, consequently, maintain doses to members of the public to levels less than the performance objectives. While uncertainties are associated with these doses and, hence, the ability of the disposal facility to satisfy these performance objectives, the level of site maintenance in effect during the operational period is such that any necessary corrective actions can be taken in short order. Consequently, the probability that radiation doses to members of the public in excess of acceptable levels will occur is virtually zero.

Disposal and interim closure procedures for the shafts also promote worker safety and long-term stability of the waste. Covering waste with clean tuff while the units are active, placing metal lids over the shafts between disposals, and filling the head-space of the filled shafts with tuff minimizes the potential for the inhalation of airborne radionuclides and direct radiation from waste and suspended particulates. The crushed tuff added between and around waste containers fills void spaces in the shafts, thereby reducing subsidence potential. If problems with waste stability do arise, however, they are not expected to be significant insofar as corrective actions will be taken as soon as they are needed.

4.2.2 Final Closure

It is currently assumed that disposal operations will continue at MDA G until the year 2044. At that time, the facility is expected to undergo final closure over a two-year period, entering into institutional control in 2046. While considerable thought has been given to the closure configuration of MDA G, the activities that will be implemented to bring about closure and the detailed design features of the final covers have not been decided upon. Consequently, the final closure plan for the disposal facility is discussed on a conceptual basis.

A major portion of the waste at MDA G was disposed of prior to September 26, 1988, and may contain hazardous components regulated under RCRA. MLLW was inadvertently placed in two disposal units between 1986 and 1990. Final closure of the disposal units containing hazardous waste is the responsibility of the ER Project; closure of the disposal units that began receiving waste after September 26, 1988 and that do not contain hazardous constituents is the responsibility of the FWO-WFM. While the shared responsibility complicates site closure, both organizations recognize that they need to work together to develop and implement an effective closure strategy for MDA G.

As discussed earlier, the ER Project has not yet begun the assessments needed to identify a suitable final closure strategy for the portion of MDA G for which they are responsible. In order to comply with DOE Orders, it was necessary for the FWO-WFM to develop a final closure strategy for MDA G that could be used as the basis for future revisions of the performance assessment and composite analysis, and for other activities conducted at TA-54. It is clear that this plan will need to be re-evaluated once the ER Project has conducted the assessments necessary to define a final closure strategy for the older disposal units.

The discussion of the final closure configuration for MDA G is organized into two sections. The final closure strategy itself is described in Section 4.2.2.1, once again on a conceptual basis. Section 4.2.2.2 discusses the level of performance expected of the final cover.

4.2.2.1 Final Closure Strategy

The MDA G Performance Assessment and Composite Analysis evaluated the performance of the disposal facility based on the assumption that the final cover designs were the same as the interim or operational covers placed over the pits and shafts. Furthermore, it was assumed that the disposal facility would remain under the care of DOE for the 1,000-year compliance period, thereby allowing any maintenance activities necessary to ensure these covers would continue to meet their design specifications. Under these conditions, MDA G was expected to safely isolate the waste from the accessible environment and satisfy all pertinent performance objectives.

The performance assessment and composite analysis assumed the final covers were the same as the interim covers because it was unclear at the time what closure strategy would be applied to the facility. While a final closure strategy still does not exist, it has become less certain that a period of control and maintenance equal to the compliance period can be relied upon. Consequently, a final cover design different than the existing operational covers was identified. This design will provide reasonable assurance that the performance objectives will be met with no more than 100 years of institutional control following facility closure. In the event that a longer institutional control period prevails, the closure configuration discussed below should perform even better than expected.

The conceptual design of the final cover for MDA G is shown in Figure 4-6. It consists of a total of 3.3 m (10.8 ft) of compacted crushed tuff overlain by a minimum of 10 cm (4 in.) of topsoil. The topsoil placed over the crushed tuff is vegetated with turf-forming, native grasses.

The amount of crushed tuff applied during final closure will depend upon the thickness of the interim covers placed over the disposal pits and shafts at the time they were filled and closed. While no specifications of the cover thickness are available for the earliest pits (i.e. Pits 1 through 4), the amount of crushed tuff placed over the waste in these units during interim closure is expected to be on the order of 1 m (3.3 ft).

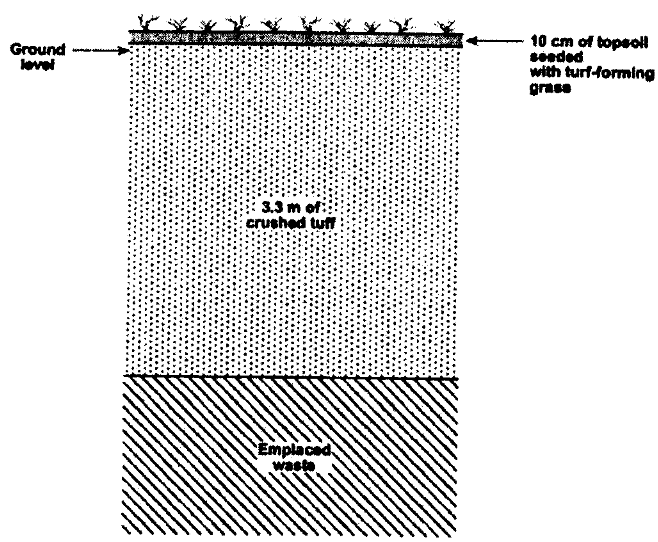

Figure 4-6. Final cover design for pits and shafts at MDA G.

The interim cover thickness for the remaining pits and the disposal shafts ranges from approximately 1.5 to 3 m (5 to 10 ft), based on the disposal guidelines in effect at the time. Based on the estimated depths of existing cover, 0.3 to 2.3 m (1 to 7.5 ft) of crushed tuff will need to be applied at the time of final closure.

Any crushed tuff that needs to be applied will be placed over the disposal pits using procedures similar to those described for operational closure. The material will be applied in 30 cm (12 in.) lifts with earthmovers or scrapers, and consolidated in place using a 50-ton bulldozer. The process is continued until the desired cover thickness is achieved. Cover material applied over the pits and shafts will be contoured to match the surrounding topography, to control drainage patterns at the site and to minimize the potential for erosion of the pit and shaft covers.

In some cases, pit surfaces have been used for waste management operations. In these instances, the compacted crushed tuff put in place during interim closure is level with the surrounding ground surface and overlain by an asphalt pad. During final closure, the asphalt pad will be crushed into pieces not greater than 4 in. or removed in a manner that minimizes disturbance of the underlying compacted crush tuff. Crushed tuff will then be placed and compacted as described above to bring the cover into conformance with the final cover design. The compacted crushed tuff will be overlain with a minimum of 10 cm (4 in.) of topsoil and planted with shallow rooting, turf-forming grasses.

Until mid-2001, interim closure of the disposal shafts included the placement of concrete caps over the filled units. As discussed in Section 4.2.1.2, the entire head-space above the waste is now filled with crushed tuff, and no concrete caps are placed over the closed units. Concrete caps that are already in use at MDA G may or may not be retrieved prior to final closure. Regardless, all concrete caps remaining at the site at the time of final closure will be removed prior to the application of the final cover. Caps found to be contaminated with radionuclides will be disposed of in pits at MDA G as LLW. The portion of each shaft occupied by the stalk of the cap will be filled with crushed tuff and compacted. Crushed tuff will be added as required to bring the total thickness of the material over the shafts to 3.3 m (10.8 ft).

The disposal shafts are typically arranged in groups or shaft-fields at various locations across MDA G. Given the small surface area of the shafts and the fact that the units are grouped, it is anticipated that the final cover will be placed over entire shaft-fields rather than over individual shafts. This approach will simplify the process of contouring the cover to match the surrounding topography and should result in a more stable site. The cover placed over the shaft fields will be applied in 30-cm (12-in.) lifts and compacted using a 50-ton bulldozer. Cover material will be applied until the required thickness of crushed tuff total has been achieved, at which point the topsoil layer will be applied.

Prior to final closure of MDA G, all structures built at the site in support of waste management activities must undergo 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 MDA G, which will be consistent with the LANL Decommissioning Summary Site Plan (LANL, 1995b). 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 4 in. or removed and disposed of, probably on site. The final D&D and closure plans for MDA G must be consistent with each other with respect to several issues, including:

- The closure plan must recognize the extent of D&D that must be completed prior to site closure;

- The D&D plan must present a schedule of completion that can be accommodated in the overall schedule for final closure;

- The closure plan must allow for the amount of waste generated by D&D activities that will require disposal within the facility prior to final closure; and

- The D&D plan must ensure that D&D activities will not interfere with, or disrupt, existing covers and other closure activities.

MDA 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 MDA G, it will be retrieved and removed from the site during final closure. Any soils contaminated during removal operations will be disposed of appropriately.

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

At the time of final closure, the interim covers over which final cover material will be applied will be inspected with respect to their integrity. The covers over all pits will be inspected for subsidence and erosion. If subsidence or significant erosion is noted, the affected area(s) will be filled with crushed tuff and regraded as necessary. Large-scale additions of crushed tuff will be compacted using heavy equipment, taking care to minimize the disturbance of areas where the cover remains intact. Inspections will be conducted for subsidence of the shafts, and crushed tuff will be added and compacted to fix any problems prior to application of the final cover.

The integrity of the benchmarks and brass caps marking the corners of the disposal pits and the shafts will be verified at the time of final closure. Benchmarks for the pits will be re-positioned as necessary to ensure their continued visibility after the application of the final cover. Free-standing benchmarks and brass caps will be established for the shafts that were previously identified using brass caps placed in the concrete caps. The readability of the information on all brass caps will be ensured and the information cross-checked against the waste disposal documentation.

A decision about the extent of the final cover at MDA G has not been made. While the cover may be applied over the entire disposal facility, including areas between disposal units, the possibility exists that areas between pits and shafts will remain uncovered. As discussed earlier, it is anticipated that cover material will, at a minimum, be applied across entire shaft fields. Regardless of how cover application is approached, grading will be conducted to ensure orderly runoff of precipitation and to prevent ponding of surface water.

All portions of the site that lack suitable vegetative cover will be planted with native turf-forming grasses to minimize erosion. Finally, the perimeter of the disposal area will be surveyed and marked with concrete benchmarks and standard brass caps.

4.2.2.2 Final Cover Performance

The final cover design presented above was selected after the MDA G Performance Assessment and Composite Analysis (LANL, 1997) were complete. Consequently, the long-term effectiveness of this design has not yet been formally evaluated by these analyses. Nevertheless, the doses and radon fluxes projected by the performance assessment and composite analysis on the basis of the less robust interim covers and the results of additional preliminary calculations indicate that the disposal facility will be fully capable of satisfying the performance objectives found in M 435.1-1. These results will be verified in the next versions of the performance assessment and composite analysis.

The most important function of the covers placed over the pits and shafts at MDA G is to prevent or minimize plant and animal intrusion into the buried waste, and to limit human intrusion into the waste after the site is released for unrestricted use. The interim covers included in the performance assessment and composite analysis relied on their overall thickness to limit the impacts of biotic intrusion. Given that the peak doses projected by these analyses were all less than the performance objectives, these covers appear to limit biotic intrusion to acceptable levels. Updated biotic intrusion modeling based on a full suite of deep-rooting plants and burrowing animals supports this conclusion, even in the absence of long-term control over the disposal facility (Shuman, 1999).

The final cover design described above is 1.4 to 2.4 m (4.6 to 7.9 ft) thicker than the interim covers included in the MDA G Performance Assessment and Composite Analysis. The additional cover material over the waste will significantly decrease the impacts of biotic intrusion at the site. Radionuclide releases to the surface will decrease, resulting in doses to off-site receptors that are small, relative to the performance objectives. These benefits will be realized even in the absence of long-term control over the closed facility.

Erosion of the cover may exacerbate the long-term effects of biotic intrusion insofar as the opportunity for plants and animals to penetrate further into the waste increases as the cover erodes. The effect of surface erosion on biotic intrusion potential was evaluated in the original performance assessment and composite analysis, and in the revised biotic intrusion modeling conducted under the maintenance program. However, these analyses used a very small rate of erosion, which was based on the assumption that a gravel mulch layer applied over the site would remain intact throughout the compliance period. This assumption is critical to the performance assessment and composite analysis as rates of erosion may increase if the gravel mulch deteriorates and is no longer effective. Given this, the impact of surface erosion on biotic intrusion potential merits additional discussion.

Preliminary analyses indicate that even large increases in the surface erosion rate at MDA G will have limited impacts on doses to Atmospheric Scenario receptors during the 1,000-yr compliance period. Approximately 3.3 m (10.8 ft) of cover will remain over the pits and shafts after 1,000 years if the average erosion rate is increased 250 times over that used in the performance assessment and composite analysis. This cover thickness exceeds that used in the performance assessment and composite analysis for all segments of the inventory. Given that the best estimate of the peak Atmospheric Scenario doses projected by the performance assessment and composite analysis were less than the performance objective, the final cover design is expected to be protective even in the face of high rates of erosion.

The impacts of higher surface erosion rates at MDA G may be more critical in terms of the All Pathway – Pajarito Canyon Scenario receptor. For this receptor, higher erosion rates translate into greater rates of release due to biotic intrusion, as seen for the atmospheric pathway, but also into greater rates of contaminant transport from the mesa-top to the canyon floor. Having said this, the greater thickness of the final cover relative to the interim covers evaluated in the performance assessment and composite analysis is expected to limit the effects of higher rates of erosion. That is, the increased cover thickness will significantly reduce rates of radionuclide release to the surface of MDA G even if erosion rates 250 times greater than those used in the performance assessment and composite analysis are adopted. As a result, even with much higher rates of soil transport into the canyon, doses to the canyon resident are expected to fall well within acceptable limits.

As discussed earlier, it is expected that DOE will retain control over MDA G for at least 1,000 years after facility closure. However, given that no formal land use plans exist that specify this level of control, this closure plan was developed based on the assumption that institutional control over the closed site lasts for a minimum of 100 years. The release of MDA G for unrestricted use after 100 years will provide the opportunity for receptors to move on-site, come in contact with higher levels of environmental contamination, and receive exposures in excess of those projected for off-site individuals. Persons choosing to reside at the site may be exposed to radionuclides deposited on the surface by plants and animals intruding into the waste. Greater exposures may result if a person intrudes into the buried waste in the process of building a house or establishing a well for drinking water. Exposures to on-site receptors were not considered in the composite analysis because it was assumed that DOE would retain control over the site for the 1,000-yr compliance period. Exposures to inadvertent intruders were estimated for the performance assessment primarily for the purpose of developing radionuclide concentration limits for the WAC.

The final cover will play a key role in terms of limiting exposures to on-site receptors. The sheer thickness of the cover will limit biotic intrusion into the waste to the extent that radionuclide concentrations at the surface of MDA G will not result in unacceptable exposures to an on-site receptor. In terms of human intrusion, the thickness of the final cover is such that no contact with the waste is anticipated during the construction of a house throughout the 1,000-yr compliance period. While establishment of a drinking water well will contact the waste, exposures from the excavated waste are expected to remain below acceptable dose limits. The ability of the cover to limit the impacts of human intrusion will be realized even in the face of high rates of surface erosion.

The final cover will also limit the amount of water infiltrating through the waste and will contribute to the long-term stability of the site. As discussed earlier, the final cover design presented above is expected to function as well as, if not better than, the interim covers in terms of excluding water from the buried waste. While significant rates of erosion could undermine the ability of the cover to exclude water, rates of erosion in excess of what is considered likely would be needed to cause the final cover to fail in a hydrologic sense.

The ability of MDA G to minimize releases of radionuclides to the accessible environment depends upon the maintenance of the long-term stability of the facility. The chief threat to long-term stability is subsidence of the cover material in response to void spaces in the disposed waste. As discussed earlier, the recent use of containers to dispose of the majority of the pit waste may result in more void space in the affected pits and a greater potential for subsidence. Recognizing this potential problem, alternatives for correcting already-filled pits and for minimizing the potential for failure in future pits are being evaluated.

4.2.3 Institutional Control

The final closure strategy assumes DOE will maintain institutional control over MDA G for at least 100 years after the final cover has been applied; in all likelihood control over the site will persist for 1,000 years or more. During the institutional control period, access to the site by members of the public is prevented, the site is periodically inspected and maintained, and site monitoring is conducted. This section discusses the actions that will be taken in terms of inspection and maintenance of the facility. The discussion is conceptual in nature; detailed procedures for conducting the activities described below will be developed once the closure strategy is finalized.

The ability of MDA G to satisfy the performance objectives in DOE M 435.1-1 requires that the integrity of the final cover be maintained throughout the 1,000-yr compliance period. Perhaps the two greatest threats to cover integrity are subsidence and severe erosion of the cover. While activities conducted during final closure are expected to minimize any subsidence potential, inspections of the pits and shafts for signs of subsidence will be conducted throughout the institutional control period. Inspections will be conducted at least once 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, taking care 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 and, if severe enough, allowing greater rates of water percolation through the waste. The final cover described above has been designed to counteract the reasonable maximum rates of erosion anticipated for MDA G over the 1,000-yr 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 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 once 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 MDA G may lead to the release of radionuclides to the ground surface. While the thickness of the final cover is expected to limit these releases to acceptable levels, actions taken during the institutional control period will help limit the intrusion potential. All vegetation over the final covers will be mowed annually, thereby controlling the establishment of the deep-rooting shrubs and trees. While 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 be conducted throughout the institutional control period. Inspections of the equipment used to conduct this monitoring will be conducted and maintenance activities performed as needed. Visual inspections will be conducted 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 institutional control period will include the upkeep of disposal unit benchmarks and site markers and fences. Benchmarks for the pits and shafts will be inspected annually for any damage and the readability of the disposal information on the brass caps. Damaged benchmarks or caps will be repaired or replaced as necessary. The eight-foot high industrial chain link fence topped with razor wire that defines the present Property Protection Area at MDA G will remain in place throughout the institutional control period. This fence, which lies outside of all disposal units, will be inspected on a monthly basis and repaired if the need arises.

Long-range land use and stewardship plans have yet to be developed for LANL. As these plans are developed, the provisions for the adopted period of institutional control over MDA G will be included. Land use plans for the disposal facility will be evaluated with respect to other plans for the site to ensure the long-term care requirements are satisfied.

4.2.4 Unrestricted Release of Site

DOE M 435.1-1 (1999b) requires that LLW disposal sites eventually be released for unrestricted use pursuant to DOE Order 5400.5 (DOE, 1993). In the event that release of the site cannot be safely accomplished, DOE may choose to maintain control over the sites indefinitely as long as these plans are integrated into land use and stewardship plans and programs.

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

- 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, and
- Take appropriate action based on the comparison of release criteria and measured radionuclide concentration

4.3 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 MDA G, the environmental surveillance efforts provide information needed to assess the impacts of waste management operations on the environment and facility personnel. Disposal unit and vadose zone monitoring are conducted in addition to these surveillance activities to better understand the impacts of disposal operations at the disposal facility.

This section discusses radiological monitoring activities relevant to the closure of MDA G. Section 4.3.1 addresses the monitoring activities that are currently in place and that will continue through the end of operations. Section 4.3.2 briefly discusses the configuration of the monitoring program once the facility closes and enters into institutional control.

4.3.1 Operational Closure Period

Operational monitoring at MDA G includes disposal unit and vadose zone monitoring and environmental surveillance. In terms of the former, moisture monitoring is conducted within disposal units and the surrounding vadose zone to detect significant trends in soil moisture. Two pit locations and five vadose zone locations are monitored bi-monthly, while four pit locations and eight vadose zone locations are monitored annually. Moisture monitoring is conducted at 0.3-m (1-ft) increments to a depth of about 40 m (140 ft) below ground surface. In terms of closure, the results of this monitoring provide insight into rates of water movement through the operational covers.

Environmental surveillance activities include the monitoring of air and meteorological conditions, direct radiation, storm-water and sediments, soils, small mammals, vegetation, and groundwater. Most of these activities are designed to monitor the impacts of waste management operations, including disposal, at MDA 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 interim 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 nine sampling locations were monitored at MDA G during 1999, the majority of these stations are situated along the perimeter of the site, downwind from active waste management locations. While 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, exiting from the surface of MDA G. Monitoring of these releases provides insight into the ability of the interim 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. Four observation wells are located near MDA G, two each in Canada del Buey and Pajarito Canyon, and are used to monitor alluvial waters in those canyons. The deep well closest to MDA G prior to 2001 was located in Pajarito Canyon. This well is expected to be slightly up-gradient of the site and, therefore, unaffected by releases from the facility. Recently, a deep well was established at the east end of the disposal site; additional wells may be drilled in the immediate vicinity of the facility in the future. Water from the regional aquifer is discharged to the Rio Grande River via several springs located in White Rock Canyon. These springs are sampled as part of the groundwater surveillance efforts. Several of these springs are located down-gradient of MDA G where water contaminated by the facility may discharge.

Groundwater surveillance data are expected to prove useful in terms of quantifying releases of radionuclides in the disposed waste due to leaching. This information is directly relevant to the discussion earlier about the role of the cover in minimizing water infiltration through the waste and, hence, doses via the groundwater pathway. As such, groundwater monitoring plays a significant role in evaluating the performance of interim closure measures.

The discussion above highlights the operational focus of most of the environmental surveillance activities. Recognizing the limited usefulness of the monitoring program in terms of evaluating the effectiveness of operational closure measures, steps are being taken to expand the monitoring activities. Specifically, uncertainty and sensitivity analyses are being performed to identify processes and parameters that can be monitored and used to evaluate the performance of the facility in its operational closure configuration.

Operational period monitoring data are, and will continue to be, used to evaluate the adequacy of the MDA G Performance Assessment and Composite Analysis on an annual basis. Insofar as these analyses represent the site in its operational closure configuration, these adequacy reviews are directly relevant to the evaluation of the effectiveness of interim closure measures. For reasons discussed above, the value of these evaluations is limited at this time due to fact that the monitoring data upon which they are based reflect operational aspects rather than long-term, post-closure facility performance.

Two methods are used to evaluate disposal facility performance using the surveillance information. First, where appropriate, monitored concentrations will be compared to concentrations projected by the performance assessment and composite analysis models. Second, monitoring program measurements of parameters used to model MDA G will be compared to the input data used in the performance assessment and composite models. These comparisons will provide an opportunity to verify that the model data are correct or to refine the input values to more accurately represent the disposal system.

DOE closure plan guidance (DOE, 2001) requires additional details about monitoring activities conducted in support of operational closure. The items to be addressed include the following:

- The application of the data quality objectives (DQO) process to identify the specific data that should be collected during monitoring;
- A summary of the sampling and analysis plan developed using the DQO process (e.g., types of samples, sample locations, sampling frequency, sampling methods, and analytical methods);
- A summary of data management procedures;
- A description of data evaluation procedures (i.e., how disposal facility performance will be evaluated using the monitoring data); and
- A summary of quality assurance and quality control procedures.

At LANL, the responsible ESH Group or ER Program conducting the individual monitoring activities have complete quality assurance programs in place. These programs address the above items in detail.

4.3.2 Final Closure and Institutional Control Periods

The post-closure environmental surveillance program for MDA G will be a modified version of the operational environmental surveillance program. It will include vadose zone monitoring, radiological surveillance measurements; cap performance monitoring, including settlement and subsidence monitoring; surface erosion monitoring; monitoring for the presence of burrowing animals; and inspections to prevent the succession of undesirable, deep-rooting vegetation. This plan will remain in effect throughout the institutional control period adopted for MDA G. The specifications of and implementation procedures for the post-closure monitoring program will be developed as the period of closure for MDA G nears. A detailed description of the program will be provided in the final closure plan.

5.0 CLOSURE SCHEDULE

The anticipated schedules for interim closure of the disposal units at MDA G and final closure of the entire facility are discussed in this section. Section 5.1 addresses the activities associated with the operational closure of active pits and shafts. The schedule associated with final closure of the facility is discussed in a generic sense in Section 5.2.

5.1 INTERIM/OPERATIONAL CLOSURE SCHEDULE

Several disposal pits and shafts are typically open and ready to receive waste at a given time. Three pits were open and receiving waste at the time this closure plan was developed. 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.

While exceptions exist, operational closure of the disposal pits and shafts at MDA G is performed as the units are filled with waste. An example of this is Pit 15, which is full of waste and will most likely be closed by the end of calendar year 2002. In contrast, while waste is no longer being disposed in Pit 37, the unit will not be closed until Pit 38 is closed. Closing Pit 37 first may result in wall collapse and lead to runoff from the operational cover into Pit 38. Efforts are made to place operational caps on shafts within a month of filling the units.

The operational closure schedule is closely tied to the quantities and types of waste received for disposal at MDA G. While 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 schedules for projects responsible for the waste or for facility down-time 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 interim closure currently exists.

5.2 FINAL CLOSURE SCHEDULE

The MDA G Performance Assessment and Composite Analysis are based on the assumption that the disposal facility will continue to receive waste through the year 2044. This period of time was selected to provide what is expected to be a conservative estimate of the inventory that will reside in the pits and shafts by the time final closure takes place. It is not clear at this point in time if the facility will be open in 2044 or, for that matter, if the Laboratory will still be generating LLW. Consequently, the discussion of the final closure schedule that follows is tentative at best.

Overall, the final closure process is expected to require two years to complete once the last disposal unit has undergone interim closure. A number of site preparations need to be completed during this period, including the removal of any remaining surface structures, preparation of the pits and shafts for the final cover, applying the final cover(s) over the units, and performing a 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 must be developed in support of final closure. The final waste inventory must be developed and used to prepare a final closure plan for the disposal facility. This plan will be based on the final cover design identified for the site and the period of institutional control reflected in LANL land use and stewardship plans and programs. At the same time, the final performance assessment and composite analysis will be prepared. The results of these analyses will provide estimates of the long-term performance of MDA G and, hence, the facility's 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 in the care of the facility thereafter receive adequate protection. Lastly, a number of permits and approvals will be required before the facility can undergo closure and enter into institutional control.

6.0 REFERENCES

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