Remediation Program

RRES

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Corrective Measures Study Report for Material Disposal Area H, Solid Waste Management Unit 54-004, at Technical Area 54

Los Alamos
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Produced by the Risk Reduction and Environmental Stewardship Division–Remediation Program

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EXECUTIVE SUMMARY

This report documents the corrective measures study (CMS) conducted for Material Disposal Area (MDA) H, Solid Waste Management Unit (SWMU) 54-004, located at Los Alamos National Laboratory's (the Laboratory's) Technical Area (TA) 54. TA-54 is located in the east-central portion of the Laboratory on Mesita del Buey with Pajarito Canyon to the south and Cañada del Buey to the north. During the late 1950s, the Laboratory, with the approval of the US Atomic Energy Commission and upon recommendation of the US Geological Survey, selected TA-54 for the disposal of Laboratory waste.

MDA H is a 0.3-acre fenced area consisting of nine 60-ft deep shafts used between 1960 and 1986 for the disposal of security-classified solid-form waste generated by the Laboratory. Disposal events were recorded in a single logbook, which contains brief, unclassified descriptions of the waste, including the approximate weight of disposed objects. The waste descriptions include information sufficient to identify the types of potential hazardous waste and radionuclides waste in the inventory at MDA H. Although exact inventory quantities are unknown, there is sufficient information to evaluate alternatives in the CMS.

The Laboratory's Risk Reduction and Environmental Stewardship Division–Remediation (RRES–R) Program, formerly the Environmental Restoration (ER) Project, implements the Resource Conservation and Recovery Act (RCRA)/Hazardous and Solid Waste Amendments (HSWA) corrective action program pursuant to the conditions of Module VIII of the Laboratory's Hazardous Waste Facility Permit, hereinafter referred to as Module VIII. MDA H, however, contains radioactive materials in addition to hazardous waste. Therefore, the corrective measure alternatives analyses in this CMS do not simply analyze and compare the corrective measure alternatives that would address only potential impacts from hazardous waste or constituents, as required by RCRA and the New Mexico Hazardous Waste Act (NMHWA). The CMS is also intended to ensure that the proposed corrective measure will protect human health and the environment against impacts of potential future releases of radioactive materials at the site.

The MDA H RCRA Facility Investigation (RFI) results are the basis for identifying corrective measure alternatives that will be effective in reducing potential impacts to human health and the environment to acceptable levels. The MDA H RFI report and addendum describe the nature and extent of contaminant releases at MDA H and demonstrate that hazardous waste or constituents and radionuclide releases from MDA H pose no potential unacceptable current risks to human and ecological receptors. However, a CMS was requested by the New Mexico Environment Department Hazardous Waste Bureau (NMED-HWB) to ensure that risks from future releases from the site are also acceptable. Eight of MDA H's nine shafts (Shafts 1–8) are listed in Module VIII. One shaft (Shaft 9) received hazardous waste after July 26, 1982, and is considered to be a "regulated unit" under RCRA and subject to closure requirements specified in Section 20.4.1.500 of the New Mexico Administrative Code (NMAC). However, NMED directed the Laboratory to address all nine disposal shafts under corrective action, in accordance with 20.4.1.500 NMAC. Therefore, the corrective measure selected by the CMS process must also substantively meet applicable closure and post-closure requirements for MDA H Shaft 9. In March 2001, the RRES-R Program submitted a CMS plan describing the regulatory basis and technical approaches for the MDA H CMS. The CMS plan was approved by NMED in December 2001. A demonstration that corrective action requirements for MDA H would comply with RCRA closure requirements for Shaft 9 was submitted to NMED in April 2002.

The objective of this CMS is to provide stakeholders and regulators with an evaluation of corrective measure alternatives in order to (1) determine what corrective action is required at MDA H, and (2) ensure that human health and the environment will remain protected into the future. To meet this objective, the long-term performance of various containment and excavation alternatives was assessed in accordance with EPA, NMED, and DOE risk and dose assessment guidance for containment and excavation alternatives. These assessments assume that DOE will maintain institutional control of MDA H

for the next 100 yr. Therefore, the assessments also considered the potential for human and ecological receptors to be exposed on or near MDA H after 100 yr have elapsed. Consistent with DOE Order 435.1, “Radioactive Waste Management,” the assessments assumed that institutional controls would not be maintained after 100 yr.

In accordance with Module VIII, site-specific corrective action objectives were developed for MDA H. These objectives, which must be satisfied by any corrective measure alternative considered for implementation at MDA H, are as follows:

- Protect human health
- Protect the environment
- Attain action levels
- Control the source
- Comply with all applicable waste management requirements

In addition, the above objectives will satisfy the conditions for use of alternative requirements for groundwater monitoring, corrective action for releases to groundwater, and closure and post-closure care for Shaft 9 that are contained in 40 CFR 264.90(f) and 40 CFR 264.110(c) and incorporated into 20.4.1.500 NMAC.

Technologies were first screened for applicability to MDA H and then combined into corrective measure alternatives. Potential technologies were screened to eliminate any technology that (1) would not be feasible to implement, (2) is unlikely to perform satisfactorily or reliably, or (3) does not achieve the corrective action objectives within a reasonable time frame. The technology screening included a review of site data to identify conditions that limit or promote the use of certain technologies; identification of waste characteristics that limit the effectiveness or feasibility of technologies; and identification of the level of technology development, performance record and inherent construction, operation and maintenance requirements for each technology considered. The general types of technologies that may be appropriate for MDA H are evaluated in this report and include containment, in situ treatment, source removal, and ex situ treatment.

Eight preliminary corrective measure alternatives were developed and presented in the MDA H CMS Plan prior to the evaluation of technologies. Five corrective measure alternatives were developed for MDA H by combining the best elements of the eight preliminary alternatives presented in the CMS Plan with the results of the technology screening process. Each corrective measure alternative was evaluated based on overall site conditions at MDA H, disposal shaft design, environmental setting, corrective action objectives, and the viability of the technologies. The final alternatives meet the corrective action objectives and consist of a combination of technologies, including three containment alternatives and two removal alternatives. The five final corrective measure alternatives evaluated during the CMS include (1) upgrade existing surface layer; (2) construct an engineered evapotranspiration (ET) cover; (3) encapsulate source and install an engineered ET cover; (4) complete excavation and off-site disposal; and (5) complete excavation and on-site disposal.

The corrective measure alternatives that satisfy the corrective action objectives were screened against criteria specified in Module VIII. These criteria include technical (performance, reliability, implementability and safety), environmental, human health, institutional, and cost. The results of the screening process were used to select and justify the corrective measure alternative recommended for MDA H. The recommended corrective measure alternative is construction of an engineered ET cover along with long-term maintenance and monitoring.

Should the recommended alternative be selected by NMED, the engineered ET cover will be designed, constructed, monitored, and maintained to ensure that the corrective action objectives are met.

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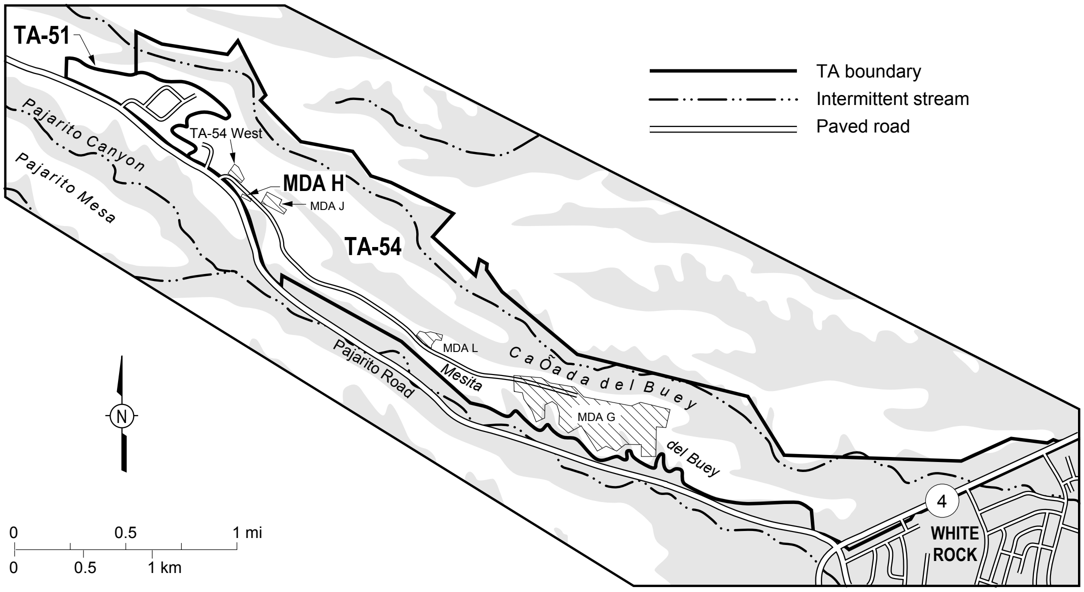
1.0 INTRODUCTION

This report documents the corrective measures study (CMS) conducted for Material Disposal Area (MDA) H, Solid Waste Management Unit (SWMU) 54-004, located at Los Alamos National Laboratory's (the Laboratory's) Technical Area (TA) 54. TA-54 is situated in the east-central portion of the Laboratory on Mesita del Buey with Pajarito Canyon to the south and Cañada del Buey to the north (Figure 1.0-1). MDA H is a 0.3-acre site consisting of nine 60-ft-deep shafts used between 1960 and 1986 for the disposal of security-classified solid-form waste generated by the Laboratory (Figure 1.0-2).

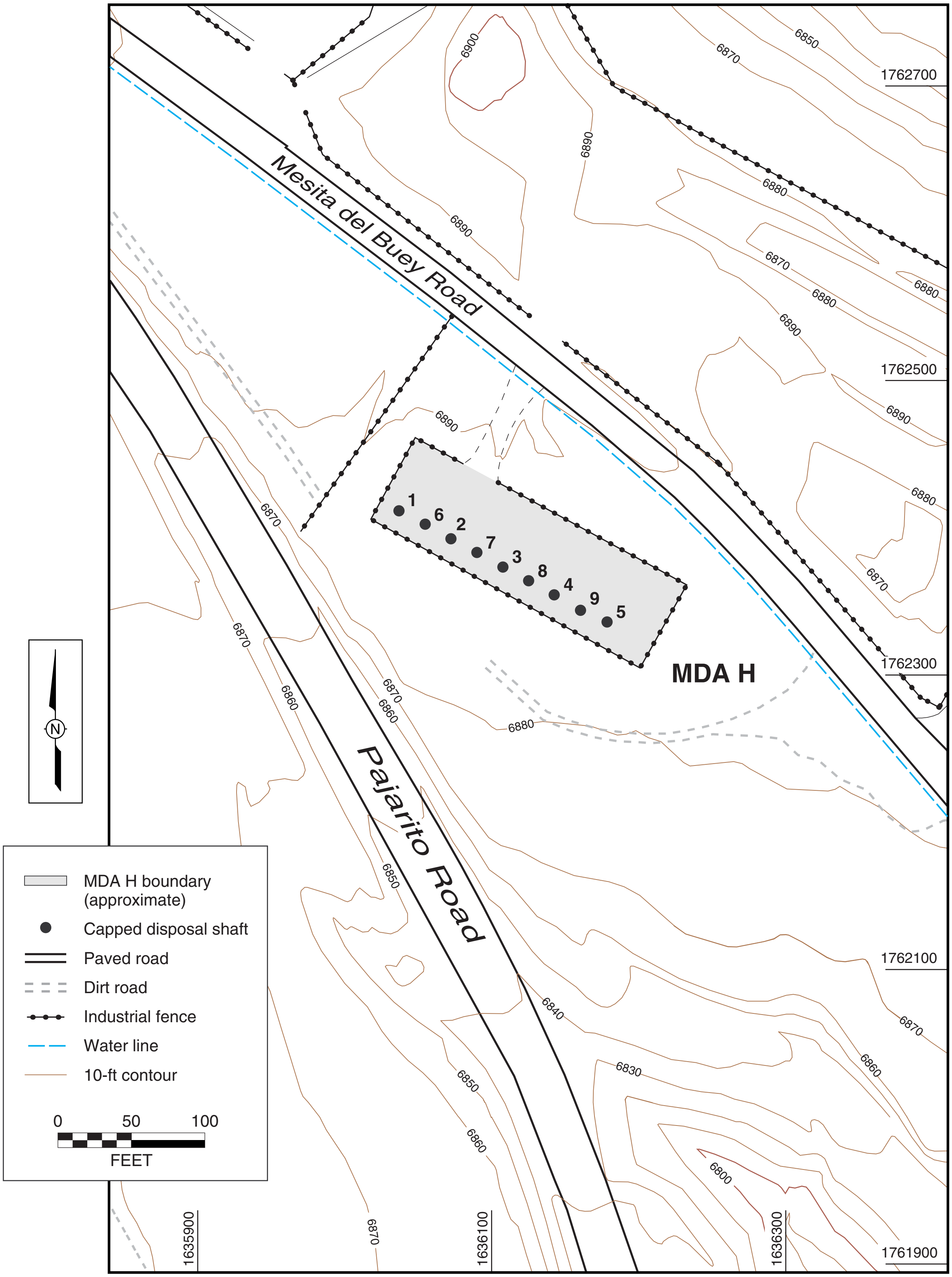


F1.0-1/mdahcms/022503/RLM

Figure 1.0-1. Location of MDA H in TA-54

1.1 Regulatory Basis of the CMS

The Laboratory's Risk Reduction and Environmental Stewardship Division–Remediation (RRES-R) Program, formerly the Environmental Restoration (ER) Project, implements the Resource Conservation and Recovery Act (RCRA)/Hazardous and Solid Waste Amendments (HSWA) corrective action program pursuant to the conditions of Module VIII of the Laboratory's Hazardous Waste Facility Permit (EPA 1990, 1585; EPA 1994, 44146), hereinafter referred to as Module VIII. MDA H contains both radioactive materials and potential hazardous waste or constituents. Therefore, the corrective measure alternatives analyses in this CMS do not simply analyze and compare the corrective measure alternatives that would address only potential impacts from hazardous waste or constituents, as required by RCRA and the New Mexico Hazardous Waste Act (NMHWA). The CMS also ensures that the proposed corrective measure will protect human health and the environment against potential future releases of radioactive materials at the site. The basis for analyzing and addressing the impacts of radioactive materials is contained in Department of Energy (DOE) Orders 5400.5, "Radiation Protection of the Public and the Environment" and 435.1, "Radioactive Waste Management" and in the National Nuclear Security Administration (NNSA) Service Center/Albuquerque's "Procedure for the Release of Residual Radioactive Material from Real Property" (DOE/AL 2000, 67153). The management of radioactive waste is regulated under the Atomic Energy Act and management of waste consisting of source, special nuclear, or byproduct materials is specifically excluded from regulation under RCRA. The radioactive waste data and dose assessments in this CMS report are provided to the New Mexico Environment Department (NMED) for informational purposes only.



F1.0-2, MDA H CMS, 052003, cf

Figure 1.0-2. **Location of inactive disposal shafts at MDA H**

The CMS is the third step in the four-step RCRA corrective action process for MDA H:

1. RCRA facility assessment (RFA) (conducted for MDA H in 1989)
2. RCRA facility investigation (RFI) (conducted for MDA H in 1994, 1995, 2001, and 2002)
3. CMS (conducted for MDA H from 2001 to 2003)
4. Corrective measure implementation (CMI) (design expected during 2004)

The MDA H RFI results are the basis for identifying corrective measure alternatives that will be effective in reducing potential impacts to human health and the environment to acceptable levels. The MDA H RFI report and addendum describe the nature and extent of contaminant releases at MDA H, and demonstrate that hazardous waste or constituents and radionuclide releases from MDA H pose no potential unacceptable current risks to human and ecological receptors (LANL 2001, 70158; LANL 2002, 73270). However, a CMS was requested by the NMED-HWB (NMED 2000, 68569) to ensure that risks from future impacts from the site are also acceptable. Eight of MDA H's nine shafts (Shafts 1–8) are listed in Module VIII. One shaft (Shaft 9) received hazardous waste after July 26, 1982, and is considered a "regulated unit" under RCRA and subject to closure requirements specified in Section 20.4.1.500 of the New Mexico Administrative Code (NMAC). However, NMED directed the Laboratory to address all nine disposal shafts under corrective action, as per 20.4.1.500 NMAC (NMED 2000, 68569). Therefore, the corrective measure selected in the CMS process must also satisfy applicable closure and post-closure requirements for MDA H Shaft 9. In March 2001, the ER Project submitted a CMS plan describing the regulatory basis and technical approaches for the MDA H CMS (LANL 2001, 70319). The CMS Plan was approved by NMED in December 2001 (NMED 2001, 71292).

1.2 Decision Basis of CMS

The CMS for MDA H incorporates aspects of the risk-based decision-making process for corrective measures as endorsed by EPA Region 6 (EPA 2000, 70145), the DOE (DOE 1998, 70146) and NMED (NMED 1998, 57897). The objective of risk-based corrective action is to streamline the RFI/CMS process by

- determining the specific objectives of the corrective measure early in the process;
- conducting a risk/dose assessment of the site to identify what potential contaminant releases, exposures and subsequent impacts might occur in the future;
- identifying significant uncertainties in the risk/dose assessments that could affect the expected effectiveness of the corrective measure alternative;
- identifying alternative corrective measures that, given the projected baseline performance, are likely to meet the corrective action objectives;
- determining what information is necessary to evaluate the performance of those corrective measure alternatives (and the effect of significant uncertainties) in the context of the corrective action objectives;
- collecting only information that is necessary to demonstrate the likely performance of corrective measure alternatives;
- evaluating the likely performance of each corrective measure alternative in the context of the corrective action objectives;

- comparing the relative cost and performance (effectiveness) of those alternatives that are demonstrated to meet the corrective action objectives; and
- implementing the optimal corrective measure.

1.3 Purpose and Scope of the CMS

The purpose of the CMS is to evaluate the potential future adverse human health and environmental impacts of contaminants at MDA H. The site conceptual model for MDA H was presented in the MDA H RFI report (LANL 2001, 70158). Future impacts may result from

- the release of potentially harmful amounts of specific contaminants and the resulting accessibility of those contaminants to human or ecological receptors, and
- direct contact of humans, plants, or animals with harmful amounts of contaminants by means of intrusion into the shafts.

Alternative corrective measures that address any natural and/or engineered feature(s), event(s) or process(es) that may, in time, change the site's ability to control contaminant releases, exposures, and human-health or environmental impacts in the future have been evaluated, and a corrective measure is recommended that meets or exceeds the corrective action objectives using the evaluation criteria specified in Module VIII. In addition, the recommended corrective action satisfies the conditions for use of alternative requirements for groundwater monitoring, corrective action for releases to groundwater, and closure and post-closure care for Shaft 9 that are contained in 40 CFR 264.90(f) and 40 CFR 264.110(c) (LANL 2002, 75886) and incorporated into 20.4.1.500 NMAC.

2.0 IDENTIFICATION AND DEVELOPMENT OF THE CORRECTIVE MEASURE ALTERNATIVES

The current conditions at MDA H are described in the MDA H RFI report (LANL 2001, 70158). The RFI report describes the site, including disposal units, wastes, characterization activities that have been conducted, analytical results of sampling, and assessments of potential current-day risks to human health and the environment. Data gaps requiring additional sampling were identified in the RFI report. The information obtained from this additional sampling was reported in an addendum to the RFI report provided to NMED in October 2002 (LANL 2002, 73270). NMED approved the RFI Report and Addendum in April 2003 (NMED 2003, 75936)

2.1 Description of Current Site Conditions

MDA H is a 70-ft by 200-ft (0.3-acre) fenced area located on Mesita del Buey, a small mesa that lies between Pajarito Canyon and Cañada del Buey. The MDA consists of nine inactive vertical disposal shafts arranged in a line approximately 15 ft inside the southern fence (Figure 1.0-2). Each shaft is cylindrical with a diameter of 6 ft and a depth of 60 ft. When filled to within 6 ft of the surface, the space above the waste in Shafts 1 through 8 was filled with 3 ft of concrete, over which an additional 3 ft of crushed tuff was placed; the space above the waste in Shaft 9 was filled with 6 ft of concrete.

To protect against the possible impacts of mesa-edge instability, all MDA H disposal shafts were located a minimum of 90 ft from the mesa edge. The surface of MDA H is vegetated with native grasses that stabilize the soil against erosion. In addition, the surface is contoured to redirect stormwater runoff around the site and into a single drainage to Pajarito Canyon. The deepest borehole adjacent to MDA H is 300 ft and no saturated conditions were encountered during its installation (LANL 2001, 70158).

2.1.1 Operating History

From May 1960 until August 1986, MDA H was the Laboratory's primary disposal area for classified, solid-form waste. Disposal of solid-form waste materials at MDA H was restricted to items or materials that were determined by authorized personnel to be both classified and no longer required for their intended use. This determination was recorded on disposal forms, which accompanied the waste to MDA H. Liquids were prohibited from disposal (Clayton 1960, 11515 and LASL 1960, 11514).

Material disposed of at MDA H required double packaging with an opaque outer material, such as plastic bags or drums. Lightweight wastes were dropped into the shafts, while heavier materials were lowered in by heavy equipment. Many of the solid-form classified materials disposed of at MDA H contained residues of liquids or gases. Based on early shaft disposal records, the density of waste materials varied from 5 to over 400 lb per cubic foot. Between waste disposal events, shafts were covered with a locked steel plate to prevent unauthorized access to classified materials.

Disposal events were recorded in a single logbook (LASL 1960, 70034), which contains brief, unclassified descriptions of the waste, including approximate weight. The logbook was transcribed into a spreadsheet, which is reproduced in Appendix B. The waste descriptions include information sufficient to identify the types of potential hazardous and radioactive waste in the inventory at MDA H and assist in evaluating alternatives in the CMS.

2.1.2 Waste Characteristics

2.1.2.1 Estimated Inventory

The RFI Report (LANL 2001, 70158) and CMS Plan (LANL 2001, 70319) for MDA H included preliminary estimates of the waste inventory at MDA H based on limited information in the disposal logbook. Appendix B includes a detailed list of the waste inventory by shaft. The total mass of all waste in the MDA H disposal shafts is recorded to be approximately 391,229 lb[1] (Omicron 2003, 75940). During the CMS, a significant effort was undertaken to improve the accuracy of the waste inventory estimates. Logbook descriptions (LASL 1960, 70034) include sufficient information to identify many of the potential hazardous wastes or constituents and radionuclides in the inventory. However, the quantities of the materials disposed can only be estimated because of insufficient details noted in the logbook, and restrictions on descriptions based on the still-classified nature of some of the materials disposed at MDA H. Therefore, the documented logbook information was supplemented by a review of waste disposal records, process knowledge of current and former site operations, and best professional and engineering judgment from subject matter experts. In addition, the quantities and metal composition of components excavated and recovered from the similar Classified Waste Landfill at Sandia National Laboratories/New Mexico (SNL/NM or Sandia) were reviewed to support the estimates of the MDA H metals inventory. These efforts resulted in the refined estimate of the waste inventory at MDA H (Omicron 2003, 75940) discussed in this section.

The percentages by weight of material disposed in the shafts at MDA H as recorded in the logbook are shown in Figure 2.1-1. The largest component of the MDA H waste inventory, 57%, is metal, both radioactive and non-radioactive (24% depleted uranium (DU) and 33% other metals). Potentially reactive materials, such as lithium compounds, represent approximately 1% of the inventory. Graphite represents about 9% of the inventory, and radioactive materials other than DU account for approximately 24% of the inventory. Plastics account for approximately 9% of the inventory and paper and HE each constitute less than 1% of the inventory (LASL 1960, 70034).

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[1] Weights provided within the logbook are missing for approximately 2% of the entries.

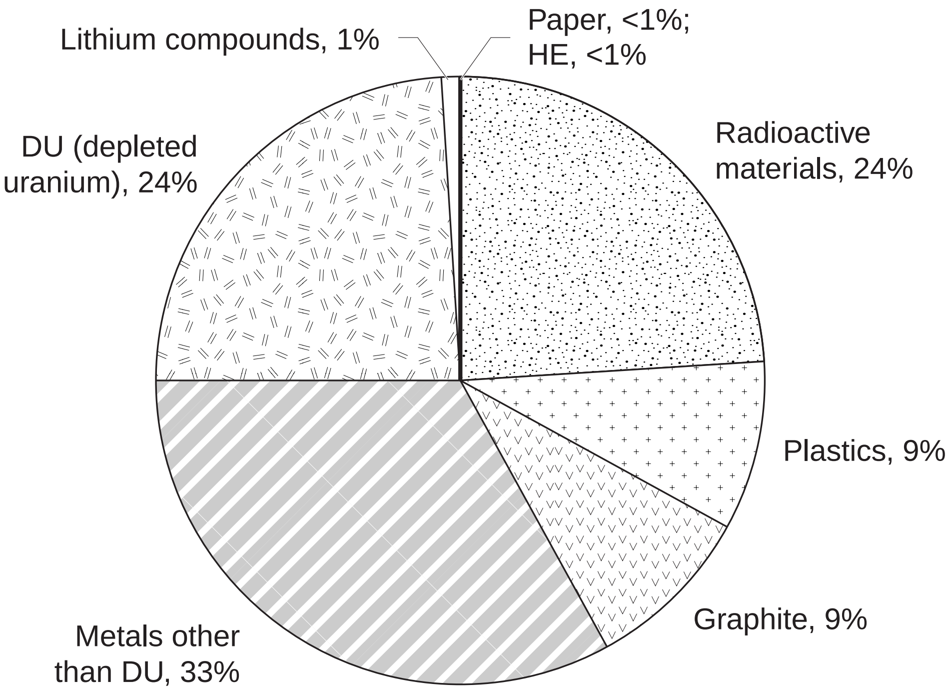


Figure 2.1-1. Breakdown of logbook entries of identified waste materials disposed in shafts (percentages by wt)

Logbook entries include waste that potentially meets the RCRA definition of characteristic hazardous waste, such as lithium hydride and high explosives (HE). Additional potential hazardous wastes or constituents not listed in logbook entries are anticipated to be present based on process knowledge. These materials (barium, cadmium, chromium, lead, mercury, and silver) were used for shielding, solders, parts, or coatings. Other hazardous constituents, such as beryllium and copper, are listed in logbook entries. Volatile organics compounds (VOCs) were not listed in the logbook entries but were detected in trace amounts in vapor phase sampling in the MDA H RFI boreholes. Radionuclides listed in or identified from the logbook entries include tritium; uranium-234, -235, -236, and -238; and plutonium-238, -239, -240, -241, and -242.

One of the assumptions made to estimate the inventory is that strategic materials (e.g., beryllium) would only have been used in the final stages of the research and development process. In initial phases, the parts would have been constructed of cardboard or wood; in the second phase they would have been constructed of metals, such as aluminum or steel; in the final phase they would have been constructed of DU or other strategic materials. The wood or cardboard would have been destroyed (burned) and non-radioactive materials would have been recycled, leaving only the materials that were not easily recycled.

There is uncertainty regarding the total amount of uranium disposed at MDA H because descriptions of the individual isotopes are limited due to classification and because disposed items listed as “shapes and parts” may be DU. Therefore, both upper-bound and best-estimate values were developed for the uranium inventory. The upper-bound value is the maximum quantity of uranium that could have been disposed at MDA H and the best-estimate value is the quantity of uranium that is believed to have been disposed at MDA H.

The results of the inventory analysis for the CMS are summarized in the following paragraphs and in Table 2.1-1.

Table 2.1-1
Summary of Wastes in MDA H Disposal Shafts

Inventory Waste Description	Mass (wt) of Material Reported in Logbook	Estimated Weight or Activity of Waste	Assumptions/Comments
Metals			
Aluminum (Al)	4976	58,700[a]	Not applicable
Barium (Ba)	Not reported	5300 lb	Barium is estimated to be 40% of mock/inert HE.
Beryllium (Be)	238 lb	6534 lb	Beryllium was in solid form as part of shapes and weapon components. Material considered strategic and recycled when possible. An additional quantity of Be was added based on process knowledge of LANL operations.
Cadmium (Cd)	Not reported	20 lb[a]	Cadmium was in solid form as part of shapes and weapon components.
Chromium (Cr)	Not reported	1960 lb	Chromium used in chrome-plated parts. The available Cr in the environment is only from non-stainless steel Cr. Cr was estimated based on process knowledge of LANL operations.
Copper (Cu)	230 lb	2350 lb[a]	Copper was in solid form as part of shapes and weapon components.
Lead (Pb)	Not reported	78,250 lb[a]	Lead was in solid form as part of shapes and weapon components. Material recycled when possible.
Lithium (Li) and Lithium Compounds:	4959 lb (total)	4341 lb (total)	Solid form and potentially reactive/toxic. 4408 lb LiF PBX[b] contains 86% LiF (3790 lb). Lithium samples are assumed to be in the form of LiH.
Lithium	75 lb	75 lb	
Lithium hydride (LiH)	466 lb	466 lb	
Lithium fluoride (LiF)	4408 lb	3790 lb	
Lithium boride	10 lb	10 lb	
Mercury (Hg)	Not reported	1300 lb[a]	Mercury was part of electrical components.
Silver (Ag):			Processed film disposed at MDA H contains silver that is unavailable for biological uptake and not included in the total available silver. Silver in film is based on a maximum of 45 troy ounces per 100 lb of waste processed industrial X-ray film (0.0686 lb per troy ounce). Non-film silver is assumed to be present either as plating or electrical parts.
Silver in developed film	(listed under plastic)	1310 lb[c]	
Non-film silver	Not reported	39 lb[a]	
Steels	Steel listed as one of many materials (not broken out)	156,490 lb[a]	Steel was in solid form as part of shapes and weapon components. Includes stainless steels.
Tungsten	11,500 lb	11,500 lb	Not applicable

Table 2.1-1 (continued)

Inventory Waste Description	Mass (wt) of Material Reported in Logbook	Estimated Weight or Activity of Waste	Assumptions/Comments
Specific Types of Waste			
Graphite	47,162 lb	47,162 lb	Not applicable
High explosives (HE): HE (RDX)[d] HE contaminated (RDX)	51,958 lb (total) 4,783 lb 47,175 lb	1275 lb (total) 992 lb 283 lb	Unless otherwise specified, HE assumed to be RDX based on mobility and toxicity; 4,408 lb LiF PBX[b] contains 14% RDX (617 lb) +375 lb = 992 lb. HE contaminated assumes invisible surface contamination, ≤0.6% of the total waste mass (47,175 x 0.006 = 283 lb)
Mock/inert HE	13,260 lb	13,260 lb	Cyanuric acid is estimated to be 40% of Mock/inert HE.
Paper	755 lb	755 lb	Not applicable
Plastics: Film Magnetic media Plastic (non-specific) Slides	54,461 lb (total) 42,346 lb 4337 lb 6555 lb 1223 lb	53,151 lb (total) 41,036 lb 4337 lb 6555 lb 1223 lb	Film weight less silver weight. (54,461 – 1310 = 53,151 lb)
Radioactive Wastes			
Uranium, Depleted Uranium Enriched Uranium Fuel Elements	67,055 lb (total) — — —	265,300/(104,800)[e] lb (total) 284.5/(94.2) Ci 233,000/(93,000) lb 14,600/(1100) lb 17,700/(10,700) lb	Standard ratios apply for converting depleted uranium, "units", and fuel elements[f] (enriched uranium and highly enriched uranium) masses to isotopic abundances.
Plutonium	300 lb (total)	300 lb (total)/0.014 Ci	Plutonium is surface contamination. For bounding purposes, assumed maximum concentration of 100 nCi/g; assumed volume contamination is "Pu 52" based on process knowledge.
Tritium	80 lb	3.5-106 Ci	Residual radioactivity in stainless steel canisters of known mass; estimated activity based on FY1995 and 2002 measured tritium values (Appendix I).
Shapes and Parts Without Material Description[f]	134,295 lb	Not applicable	
Total	391,229 lb	709,297/(548,797)[e] lb	

[a] Waste metal estimates were generated after review of waste generated from a similar operation at Sandia National Laboratories/NM and then adjusting for operational and programmatic differences.

[b] PBX = plastic-bonded explosives.

[c] Silver is not leachable based on knowledge of the waste form.

[d] RDX = 1,3,5-trinitro-1,3,5-triazacyclohexane (cyclotrimethylenetrinitramine).

[e] The first number represents the maximum (upper-bound) amount of material present in the waste. The number in parenthesis is the best-estimate of material present in the shafts.

[f] Based on the classified nature of these objects, specific information is not recorded in the logbooks.

Metals

The estimate of the amount of metals disposed of at MDA H is based on logbook entries, interviews with site workers from MDA H and the facilities generating the wastes disposed at MDA H, and information on material excavated from the Classified Waste Landfill at SNL/NM. The logbook information indicates that the classified objects disposed of at MDA H contained specific types of metals but the logbook information does not list the actual quantities of metals or the composition of the disposed objects. Therefore, metal quantities and the composition of metal-containing components excavated and recovered from the Classified Waste Landfill at SNL/NM were reviewed in order to estimate metal quantities for aluminum, beryllium, cadmium, chromium, copper, lead, mercury, silver, and steel (Galloway 2001, 71343; Omicron 2003, 75940). A percentage of the total mass of waste placed in the disposal shafts (based on programmatic differences between the two laboratories) was used to estimate a reasonable maximum mass of these specific metals disposed at MDA H, described below:

- Aluminum is listed in the MDA H inventory. It was used in large quantities for Laboratory operations based on weight, cost, and ease of casting/machining. These same properties made aluminum easy to declassify and recycle. Most classified aluminum parts would not have been disposed of at MDA H, with the exception of parts that were contaminated. The mass of aluminum was increased to 15% of the total MDA H inventory (58,700 lb) based on the Sandia inventory.
- Barium is not listed in the MDA H inventory. Based on process knowledge of Laboratory operations, barium is estimated to be present as 40% (5300 lb) of the mock/inert HE listed in the logbook.
- Beryllium is listed in the MDA H inventory. Beryllium was used in some classified shapes, even though it is not listed as a component of the shapes in the MDA H inventory. Beryllium or beryllium alloys were recycled whenever possible and were thus estimated to have been disposed of in limited quantities. The mass of beryllium was increased to 1.7% of the total MDA H inventory (6534 lb) based on process knowledge of Laboratory operations.
- Cadmium is not listed in the MDA H inventory. Based on process knowledge of Laboratory operations, cadmium was used in the form of coatings. Based on programmatic differences between the Laboratory and Sandia operations, the mass of cadmium in the MDA H inventory was estimated to be 0.00005% (20 lb) (SNL/NM 2002, 73709).
- Chromium is not listed in the MDA H inventory. Based on process knowledge of Laboratory operations, chromium was used as plating on certain parts. The chromium/nickel mass in stainless steel was not included in the inventory since it is unavailable for environmental transport. The mass of chromium was estimated to be 0.5% (1960 lb) of the total MDA H inventory based on process knowledge of Laboratory operations.
- Copper is listed in the MDA H inventory. Copper was present in shapes, electrical components and batteries based on process knowledge of Laboratory operations. Based on programmatic differences between the Laboratory and Sandia operations, the mass of copper was increased to 0.6% (2350 lb) of the MDA H inventory (SNL/NM 2002, 73709).
- Lithium and lithium compounds are listed in the MDA H inventory. The mass of lithium and lithium compounds identified in logbook entries is 4340 lb of the total MDA H inventory. Lithium compounds identified include lithium hydride (LiH), lithium fluoride (LiF), and lithium boride. The bulk of the lithium compounds are from a disposal of 4408 lb of “Lithium fluoride (LiF) plastic bonded explosive (PBX) containing 86% LiF.” Based on process knowledge of Laboratory operations, lithium and lithium compounds could have been present in some of the parts as well

as in samples. An additional 15 lb of LiH was added to the disposal made on 12/18/81 based on the memorandum dated March 6, 1986.

- Steel is listed in the MDA H inventory. Steel in all forms, like aluminum, was used in large quantities for Laboratory operations based on cost, availability, and ease of machining. These same properties made non-contaminated steel parts easy to declassify and recycle. Most classified steel parts would not have been disposed of at MDA H, only those parts that were contaminated. The mass of steel was estimated to be 40% of the total MDA H inventory (156,490 lb) based on the Sandia inventory.
- Lead is not listed in the MDA H inventory. Based on process knowledge of Laboratory operations, lead was used in solders as well as in models to give density without the radioactive component. Lead also would have been used for shielding of high-energy particles. Non-contaminated classified lead parts would have been recycled whenever possible. The mass of lead in the MDA H inventory is estimated to be 20% (78,250 lb) of the total MDA H inventory, based on the Sandia inventory.
- Mercury is not listed in the MDA H inventory. Based on process knowledge of Laboratory operations, mercury would have been present in electrical components and batteries. Based on programmatic differences between Laboratory and Sandia operations, the mass of mercury is estimated to be 0.33 % (1300 lb) (SNL/NM 2002, 73709) of the total MDA H inventory.
- Silver is not listed in the MDA H inventory; however, developed film is listed. Based on process knowledge of Laboratory operations, silver would also have been present in electrical or plated wastes items disposed at MDA H and is estimated to be 0.01% (39 lb) of the total MDA H inventory in these items. Silver present in developed film is not readily available for release and environmental transport and would represent up to 3.1 weight percent (1310 lb) of the film weight based on the assumption of use of industrial type X-ray films.
- Tungsten is listed in the MDA H inventory. The mass of tungsten is identified in the logbook entries as 11,500 lb. Based on process knowledge of Laboratory operations, tungsten was used for tools and high-strength applications and is included as part of the steel/iron estimate above.

High Explosives

The estimate of HE is based entirely on logbook entries. It was assumed that any HE-contaminated material in the logbook entries is residual contamination, representing no more than one weight-percent of the HE-contaminated discarded object prior to the “flashing” of the object (LANL 2001, 71344). The common Laboratory practice then (and now) was to flash (burn) objects to remove unreacted explosives before they were disposed (LASL 1961, 30561). All HE-contaminated material recorded in the logbook has been assumed to be contaminated with residual cyclotrimethylenetrinitramine (RDX) because RDX was the most commonly used explosive during the operational history of MDA H. In addition, the assumption of RDX is protective based on the relative mobility, persistence, and toxicity of RDX compared with other conventional HE. The quantity of RDX estimated to exist in the inventory due to HE-contaminated material is approximately 283 lb.

Only two logbook disposal entries (Appendix B) record the disposal of large quantities of HE at MDA H. Both disposals occurred in Shaft 3. The first entry recorded is the disposal of 4,408 lb of “Lithium fluoride (LiF) PBX containing 14% RDX in powder form” (LANL 2002, 73218). The second logbook entry reported 375 lb of “1 lot H.E.” classified waste was disposed in Shaft 3. The second disposal is assumed to be 100% RDX. The total RDX for these two disposals is 992 lb. This results in an estimated total of 1275 lb of RDX disposed within the MDA H shafts.

Plutonium

Three logbook entries (Appendix B) describe disposal of “shapes” (weapon molds/components) contained in drums contaminated with residual amounts of plutonium. A total of 300 lb of waste was listed in the MDA H logbook as “Pu contaminated.” Inventory estimates of the amount and isotopic composition of the residual plutonium (in the inventory) were based on the assumptions that (1) the plutonium contamination existed in the form of plutonium oxide (because plutonium readily oxidizes), (2) the amount of plutonium contamination was detectable by instruments in use at the time of disposal (with an assumed detection limit of 100 nCi/g), and (3) the isotopic ratio (Pu-52) was that of the most common plutonium-contaminated waste disposed of at MDA G (MDA G and MDA H received waste from the same technical areas and this was the most prevalent plutonium material disposed of at MDA G for which accurate records exist). Based on these assumptions, the maximum calculated total activity of plutonium at MDA H is approximately 0.014 Ci.

Tritium

There is insufficient information in the logbook entries to accurately estimate the tritium inventory. Therefore, the tritium inventory was estimated to range between 3.5 and 106 Ci [based on analytical data for tritium gathered during RFI activities (Appendix I)]. Tritium disposed at MDA H is most likely present as a gas based on knowledge of its uses at the Laboratory and site operators’ knowledge that tritiated wastewater at the Laboratory was absorbed onto a solid matrix and disposed of at MDA G (LASL 1960, 11514; LASL 1961, 30561). It is not anticipated that tritium is present as a solid (such as lithium tritide) at MDA H because of the value of the material and ease of recovery when in solid form.

Uranium

Logbook entries describe DU in the form of shapes, molds, modules, mockups, and scrap. Most entries do not specify uranium mass or composition. Based on process knowledge of Laboratory operations, uranium-contaminated waste in the MDA H inventory includes the following isotopes: uranium-234, -235, -236, and -238. Each radioisotope has different characteristics that are important in the context of potential long-term impacts. Most important are uranium-234, which (over very long time periods) decays into radium and radon gas, and uranium-235. The presence of uranium-238 and -235 are distinguished from naturally occurring uranium: enriched uranium (EU) has more uranium-235 than naturally-occurring uranium and DU has less uranium-235. Enriched uranium is used in nuclear applications (e.g., fuel elements), while DU (<0.72% U-235) is used for non-nuclear applications (e.g., weapon mockups).

Logbook entries list 93,000 lb of DU present in the MDA H inventory (24% of the total mass recorded [391,229 lb] at MDA H). Based on past disposal practices and engineering judgment, an upper-bound estimate was developed for DU because many of the entries for shapes and parts in the logbook could have been made from DU; however, material was not always specified in the logbook entry. Therefore, the estimated mass of DU was increased to 233,000 lb as an upper-bound estimate (80% of the mass associated with “shapes, molds, modules, mockups and scrap” [291,250 lb]).

Logbook entries are not specific on the mass or composition of enriched uranium disposed at MDA H. The three categories of enriched uranium that may have been disposed at MDA H include (EU), highly-enriched uranium (HEU), and fuel elements. Based on process knowledge of Laboratory operations and the total mass listed in the logbook entries that may have contained EU/HEU, the best estimate for the quantity of EU/HEU was restricted to a maximum of 20 kg per disposal, based on the pre-1964 quantities of HEU used per test in Appendix D of the Nuclear Weapons Databook, Volume II, 1987, National

Resources Defense Council Inc. (NRDC 1987, 75921). This assumption is reasonable since criticality would have become a major concern at higher masses. The best estimate of EU/HEU is 1100 lb.

An upper-bound mass of EU/HEU was calculated to be 14,600 lb, based on the total mass of logbook entries that may have contained EU/HEU. The documented mass of these categories of waste was converted directly into activity of constituent uranium isotopes, using standard mass ratios for the different uranium material types. EU isotopic activity percentages were calculated to be 91.1% U-238, 8.7% U-235, 0.075% U-234, and 0.09% U-236 using mass percentage conversions in Taggart (1992, 70212). HEU isotopic activity percentages were found to represent a maximum of 93.3% U-235, 1.1% U-234, 0.2% U-236, and 5.4% U-238 (LANL 1995, 70214). For the EU and HEU, a ratio of 95:5 EU to HEU was used to determine isotopic properties. This ratio is considered to be bounding because accountable HEU was significantly more valuable than EU and was easily recoverable.

Based on logbook entries, the upper-bound mass of fuel elements was estimated to be 17,700 lb with the entire mass in the logbook entries assumed to be uranium. The composition of the fuel elements was assumed to be the same as EU for the upper-bound value. The best-estimate of uranium mass in the fuel elements was based on the following assumptions: fuel elements listed as “unloaded” were considered to have been emptied of uranium, thereby reducing the mass of fuel elements by 3400 lb; it was also estimated that the cladding and associated hardware were 25% of the mass, thereby reducing the mass of the fuel elements by an additional 3600 lb. The resulting best-estimate of uranium mass of fuel elements is 10,700 lb. The best-estimate and upper-bound values for the uranium inventory are listed in Table 2.1-1.

Based on the information provided in the MDA H disposal logbook (LASL 1960, 70034), uranium fuel elements may have been irradiated in a neutron flux. However, due to restrictions placed on the MDA H operations by the Laboratory’s SP-2 Group Office (the Laboratory Security Group responsible at the time for MDA H), the rules for acceptance of these materials at MDA H prohibited gram quantities of fissile materials. SP-2 worked with the Health Physics Group, H-1, to ensure that this requirement was met. Based on this restriction, only short-term irradiation could have been done without allowing the fuel elements to generate gram quantities of fissile material within the fuel elements.

Other Types of Waste

Graphite

Logbook entries (Appendix B) describe disposal of “graphite” shapes and scrap material. A total of 47,162 lb of waste was listed in the MDA H logbook as containing graphite.

Mock/Inert HE

Logbook entries (Appendix B) describe disposal of “Mock/inert HE” shapes and scrap material. A total of 13,260 lb of waste was listed in the MDA H logbook.

Paper

Logbook entries (Appendix B) describe disposal of “documents” because of either classification or due to contamination by radioactive materials. A total of 755 lb of waste was listed in the MDA H logbook as document or paper.

Plastic

Logbook entries describe plastic in the form of shapes and scrap. Most entries do not specify mass or composition of the plastics. Plastics include materials such as film, magnetic media, slides, and other non-specific plastic (to include polymers, foams, glues, epoxy resins, elastomers, rubber, etc.). A total of 54,461 lb of waste was listed in the MDA H logbook as plastic. This breaks down further to film (42,346 lb), magnetic media (4337 lb), slides (1223 lb), and other non-specific plastic (6555 lb).

Table 2.1-1 summarizes the inventory of potential hazardous, radioactive and other constituents of concern disposed of at MDA H. Details are provided in Appendix B.

2.1.3 Site Characteristics

A complete description of the natural characteristics of the MDA H setting is provided in Appendix B of the MDA H RFI report (LANL 2001, 70158). For completeness and convenience, this section summarizes those features and processes that contribute to the site's natural ability to control the release of buried contaminants. The information presented herein provides the basis for conceptual and simulation models developed to assess the remedial alternatives in Section 3. The site-specific aspects of the natural setting of MDA H that are important to assessing the potential future impacts posed by releases of contamination to surface and subsurface media include the following:

- A very thick, relatively dry unsaturated zone, which restricts or prevents downward migration of contaminants in the liquid phase through the vadose zone to the regional aquifer (Section 2.1.3.2). The deepest borehole adjacent to MDA H is 300 ft and no saturated conditions have been encountered (LANL 2001, 70158). The regional aquifer is approximately 1000 ft below MDA H based on data from regional well R-22, located approximately 2 mi southwest of MDA H (LANL 2002, 71471).
- A semiarid climate with low precipitation and a high evapotranspiration rate, which limits the amount of moisture percolating into the disposal units, subsequently limiting the amount of water available to leach radionuclides or hazardous constituents.
- Infrequent soaking rains and episodic rainfall events.

2.1.3.1 Climate and Ecology

The semi-arid climate and associated ecosystem(s) of the Pajarito Plateau play an important role in the area's natural ability to control the release of chemicals of potential concern (COPC). (Bowen 1990, 6899).

The average annual precipitation measured at TA-54 over a period of 10 yr is 14 in., with a range between 6.8 and 30.3 in. Generally, intense rainfall occurs periodically during the two-month summer monsoon season, but is offset by very high evapotranspiration rates. Potential evapotranspiration (PET) is an index that represents the climatic demand for water and is calculated using Penman's equation (Jensen et al. 1990, 71430). The average annual calculated PET for the Laboratory climate station at TA-54 (located approximately 4 km [2.4 mi] east of MDA H) from 1992 to 2001 was 78.6 inches while the actual average precipitation during this period was only 14.1 inches. This equates to a greater than 6:1 PET-to-precipitation ratio; i.e., there is a much greater demand for water by the atmosphere and plants than can be supplied to the soil by precipitation events. The monthly comparison of PET versus precipitation for 1992 to 2001 is graphically shown in Figure 2.1-2.

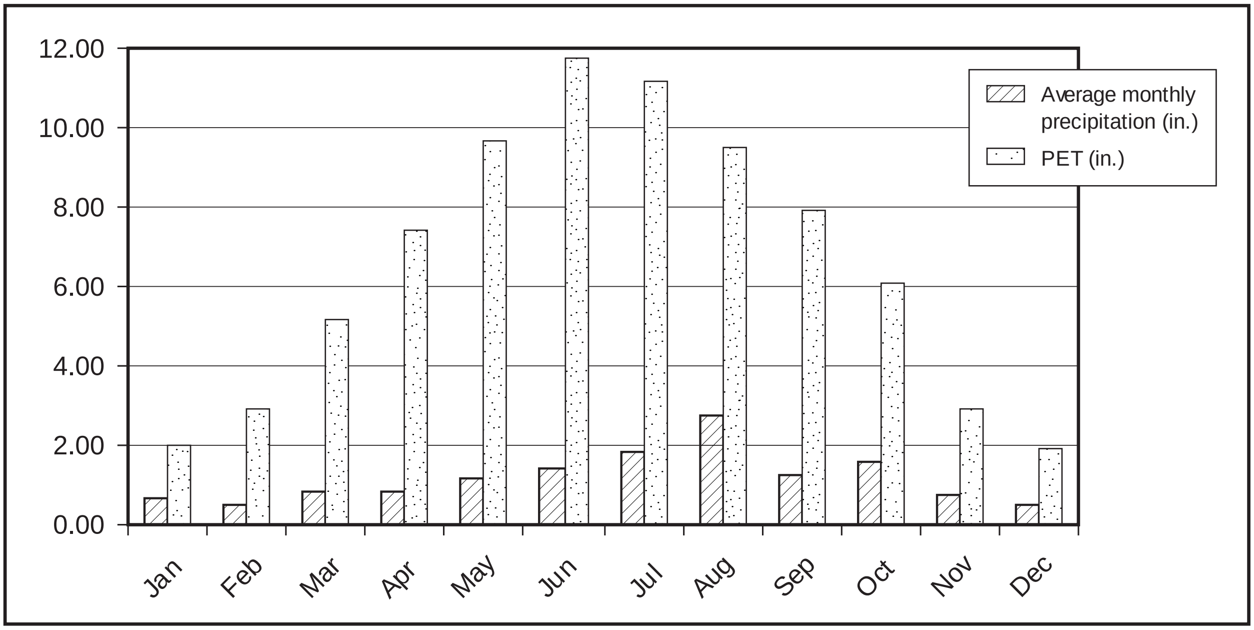


Figure 2.1-2. Actual precipitation vs. PET at Station TA-54 (1992–2001)

Plants adapted to this environment are very efficient in their ability to extract what moisture does infiltrate into the ground, and transpiration rates (removal of water from the near-surface via root uptake and redistribution to the atmosphere through plant leaves and stems) are high. For example, at TA-54, measured average transpiration equaled the measured annual average precipitation (14 in.) over a 10-yr period (LANL 1995, 73672).

Therefore, low precipitation and high evapotranspiration rates minimize the quantity of water that percolates through the vadose zone across the Pajarito Plateau, especially on mesa tops, including Mesita del Buey. The mesa geometry also enhances exposure of the subsurface to evaporative processes such as high solar radiation, strong winds, and enhanced air circulation.

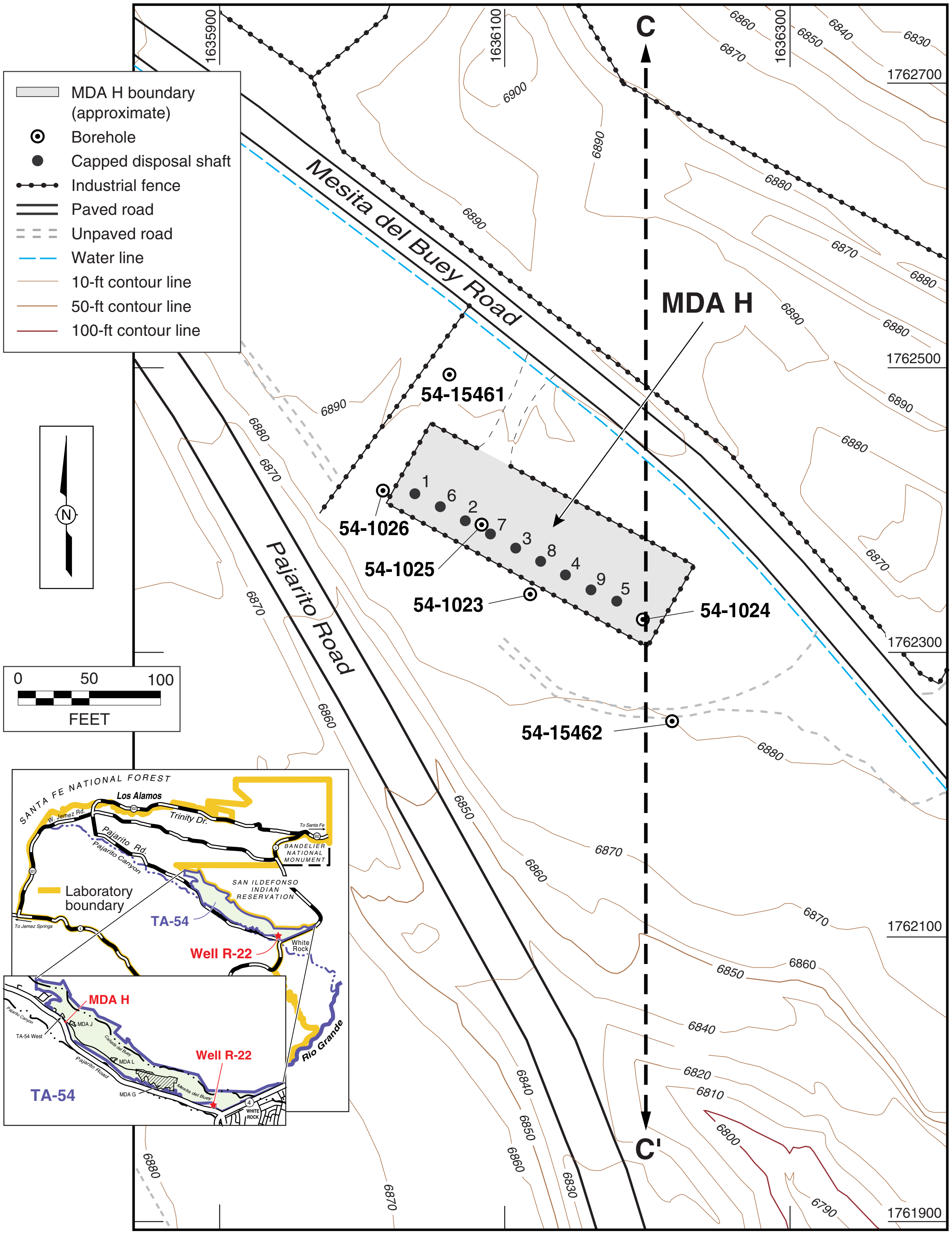
2.1.3.2 Geology, Hydrology and Tectonics

Geology

The stratigraphy beneath MDA H is based on RFI boreholes (54-1023 and -15462) located near MDA H (Figure 2.1-3), and geologic information from regional well R-22 located approximately 2 miles east of MDA H on Mesita del Buey (Figure 2.1-3 inset). A cross-section of the stratigraphy beneath MDA H is presented in Figure 2.1-4.

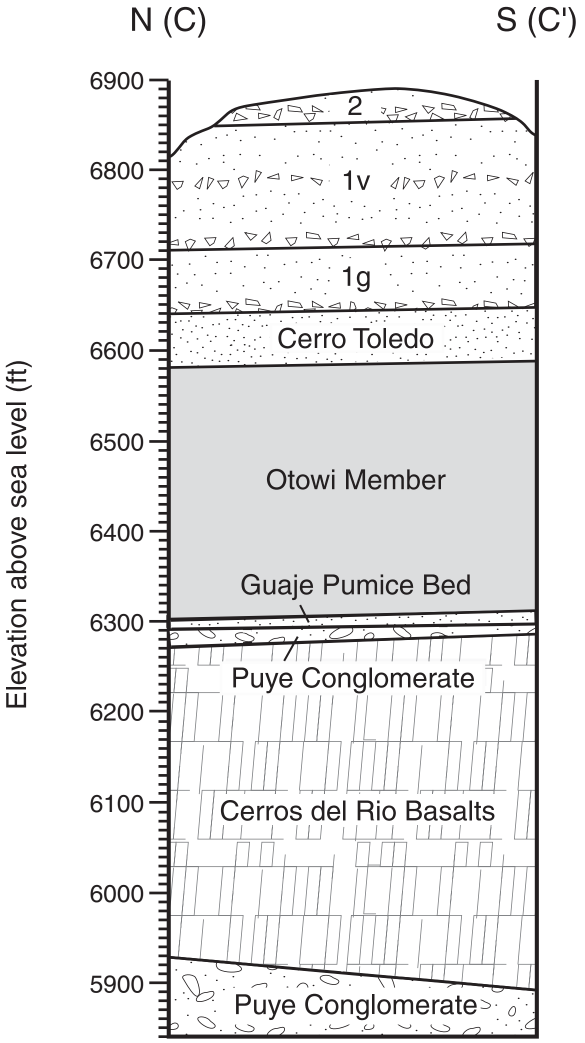
The most important geologic characteristics of the rock layers beneath MDA H are those that affect the hydrology (or movement of water) beneath the site by effectively minimizing the rate of percolation of infiltrating moisture. These characteristics include

- porosity between approximately 45% and 50%, which under unsaturated conditions creates a capillary suction that holds liquid water; and
- discontinuous open fractures in the more welded units, which under unsaturated conditions enhance the evaporation of moisture from deep within the subsurface (Krier et al. 1997, 56834).



F2.1-3, mdah, 071502, RLM_MDA H CMS, 052003, cf

Figure 2.1-3. **Locations of inactive disposal shafts and RFI boreholes at MDA H (C–C line is the north-south cross section shown on Figure 2.1-4)**



F2.1-4/mdahcms/041002/RLM

Figure 2.1-4. North-south cross section of Mesita del Buey at MDA H as presented in Figure 2.1-3

Erosion and Cliff Retreat

Because Mesita del Buey is an erosional landform, continued erosion must be considered as a potential contaminant release mechanism at MDA H. Erosional processes at Mesita del Buey include sheet erosion, rill and runnel erosion, and cliff retreat. At MDA H, erosion has not resulted in observable loss of surface soils or of wastes within the shafts, but it may become important in the future.

The unique topographical features of TA-54 make it susceptible to cliff retreat, involving the collapse of portions of the mesa walls into Pajarito Canyon and Cañada del Buey. However, based on the reasons described below, cliff retreat is not likely to affect the integrity of the MDA H shaft.

There is an existing 90-ft minimum setback of the disposal shafts from the edge of the mesa at MDA H. Cliff retreat could eventually result in the exposure of waste in disposal shafts close to the edges of the mesa. Field observations and examination of aerial photographs indicate that cliff retreat at Mesita del

Buey occurs by the dislodgment of fracture-bounded blocks of tuff, producing discrete rockfalls. No evidence has been found for larger landslides at Mesita del Buey (Reneau 1991, 74014). While no estimate of cliff-retreat rate is available for Mesita del Buey, the absence of large land sliding as an erosional process indicates that the cliff-retreat rate in this area is slow. Because the nine shafts at MDA H were set back a minimum of 90 ft from the cliff edge, multiple rockfall events would have to occur before shaft walls would be breached. Investigations at TA-21 and TA-67 have indicated that a 50-ft-minimum setback from short canyon walls dominated by rockfalls should be adequate to insure the integrity of disposal pits for periods exceeding 10,000 yr (Reneau 1995, 50143; Reneau 1995, 58031). While TA-54, including MDA H, was not included in the study, its geology is similar to TA-21 and TA-67. Therefore, it is assumed that the minimum 90-ft setback of the disposal shafts from the edge of the mesa at MDA H is sufficient distance to maintain the integrity of the shafts from cliff retreat for at least 10,000 yr.

Hydrology

The amount of water present in the Bandelier Tuff surrounding the disposal shafts at MDA H is generally less than 5% by volume due to the low infiltration of water from the surface (Figure 2.1-5). The rate of liquid water percolation has been investigated in field experiments at the Laboratory and by using models. These studies indicate that the natural capillary suction of the tuff and the relatively high permeability of air through pores and fractures interact to maintain very low moisture content, which translates into an extremely low moisture percolation rate in unsaturated rock (Purtymun et al. 1989, 6889). For example, under prevailing unsaturated conditions, liquid water moves downward very slowly, on the order of a few millimeters per yr (Bergfeld and Newman 2001, 71246). The hydrogeologic environment used to assess the corrective measure alternatives for MDA H is described by the models discussed in Section 3.1 and Appendices F and J.

No streams are located on Mesita del Buey. Water flows only as a result of stormwater and snowmelt runoff. The runoff causes surface erosion in the form of shallow sheet erosion on the flat parts of the mesa and as channel erosion in the major drainages from the mesa top. Runoff from summer storms results in rapid water discharge, lasting less than 24 hours and potentially reaching a maximum flow in less than two hours. In contrast, runoff from spring snowmelt occurs at a slow discharge rate. Thus, the amount of eroded material transported in runoff waters is generally higher during summer rainfall events than during snowmelt events (LANL 1997, 63131). The surface of MDA H is contoured to direct storm water runoff around MDA H and into a single drainage toward Pajarito Canyon (LANL 2001, 70158).

Tectonics

A seismic hazard evaluation was conducted at several sites around the Laboratory to estimate ground motion from possible earthquakes (tectonics) (Wong et al. 1995, 70097). The objective was to determine the seismic hazard criteria for designing new nuclear facilities. The evaluation led to the following conclusion:

- Within 100 yr, an earthquake with a magnitude of 6 or greater is considered likely to occur in the Pajarito fault system.

While TA-54, including MDA H, was not included in the study, its geology is similar to two of the sites evaluated in the study (TA-18 and TA-46). Results of the study were applied in the safety analysis report (SAR) for Area G, which includes the Laboratory’s radioactive waste disposal facility (LANL 1995, 63300). Such an earthquake was determined not to pose a hazard in terms of waste buried below the surface at Area G. Therefore, it is assumed that an earthquake would not cause a surface rupture at MDA H because MDA H and Area G are on the same mesa within a mile of each other.

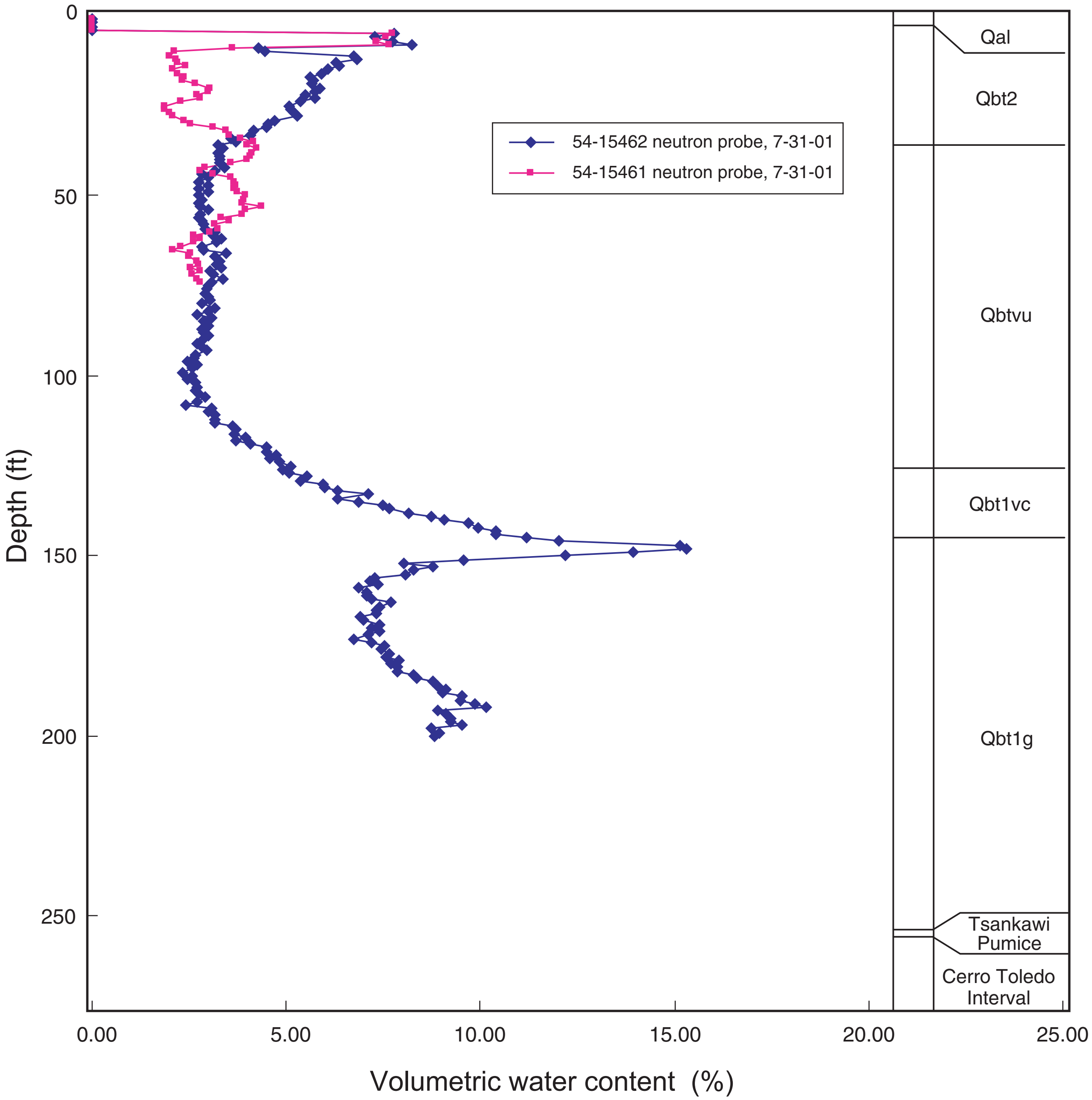


Figure 2.1-5. Volumetric water content (%) of tuff beneath MDA H

2.1.3.3 Additional Site Characteristics

In addition to the natural characteristics described above, MDA H currently has several features that have enhanced the effectiveness of the existing natural containment system to date and are key considerations for evaluating appropriate corrective measure alternatives.

The existing MDA H cover includes the following engineered features:

- ***Concrete caps***. The top 6 ft of eight of the nine disposal shafts at MDA H are filled with 3 ft of concrete beneath 3 ft of crushed tuff, and one shaft (Shaft 9) is filled with 6 ft of concrete only. The concrete provides protection against erosion, moisture infiltration, and intrusion by deep-rooting plants, burrowing animals, and humans.
- ***Surface drainage contouring***. The surface of MDA H has been contoured to direct surface runoff away from the shafts and off site.

The following institutional controls are used as appropriate to supplement the existing engineered controls for short- and long-term site management to prevent or limit exposure to hazardous or radioactive waste and/or to enhance the effectiveness of the following additional corrective actions:

- ***Fencing and posting***. MDA H is posted as a radiological control area and is surrounded by an 8-ft chain link fence.
- ***Land use and access restrictions***. MDA H is under the control of the DOE and the Laboratory, which plan, control, and restrict all land usage at TA-54. Access is gained through a locked gate only. No on-site activity may be conducted without prior review and approval of the activity by the Facility Manager. There is also restricted access to Pajarito Road.

2.2 Establishment of Corrective Action Objectives

The objective of this CMS is to provide the regulators and stakeholders with an evaluation of corrective measure alternatives in order to (1) determine what corrective action is proposed at MDA H, and (2) ensure that human health and the environment remain protected into the future. To meet this objective, the long-term performance of various containment and excavation alternatives were assessed in accordance with EPA, NMED, and DOE risk and dose assessment guidance.

The MDA H CMS Plan (LANL 2001, 70319) presented target corrective action objectives for the MDA H CMS. These objectives were based on the EPA RCRA Corrective Action Plan (EPA 1994, 73488) and the DOE RCRA Corrective Action Program Guide (DOE 1993, 73487).

In accordance with Module VIII (EPA 1990, 1585; EPA 1994, 44146), site-specific corrective action objectives were developed for MDA H. These objectives, which must be satisfied by any corrective measure alternative considered for implementation at MDA H, are to

- protect human health,
- protect the environment,
- attain action levels,
- control the source, and
- comply with all applicable waste management requirements.

In addition, the above objectives will satisfy the conditions for use of alternative requirements for groundwater monitoring, corrective action for releases to groundwater, and closure and post-closure care for Shaft 9 that are contained in 40 CFR 264.90(f) and 40 CFR 264.110(c) and incorporated into 20.4.1.500 NMAC.

A 1000-yr performance period was evaluated for corrective measure alternatives consistent with the performance assessment requirements for low-level waste disposal sites contained in DOE Order 435.1. The risk/dose assessments in this CMS also assume that DOE will maintain institutional control of MDA H for the next 100 yr, thereby limiting potential exposures to people living outside of DOE's controlled area. A second assumption is made that DOE will not maintain institutional control beyond a timeframe of 100 yr. Therefore, the MDA H human health risk assessment also considers the potential for people to be exposed on or near MDA H once 100 yr has elapsed. The assumption of loss of institutional controls after 100 yr is consistent with performance assessment requirements for low-level waste disposal sites contained in DOE Order 435.1.

The criteria specified in the corrective action objectives are intended to ensure the protection of human health and the environment. The objectives provided in the CMS plan are provided in **boldface** type below, and the Laboratory's proposed approach for meeting each objective presented in normal font.

1. ***Protect human health*.**

    - **For hazardous waste constituents, the selected corrective measure will provide reasonable assurance that (1) the excess incremental cancer risk (ICR) estimated according to EPA's reasonable maximum exposure (RME) approach does not exceed a range of 10^{-6} to 10^{-4} for the design life of the selected corrective measure, and (2) the noncancer hazard does not exceed a hazard index of 1.**

      To determine whether a corrective measure alternative meets this objective, impacts resulting from potential releases of hazardous constituents at MDA H were assessed for hypothetical human receptors working within the fenced area during the 100-yr institutional control period and living or recreating within the fenced area following the institutional control period.

    - **For radionuclides, the selected corrective measure will provide reasonable assurance that the total calculated RME dose does not exceed 15 mrem/yr.**

      To determine if a corrective measure alternative meets this objective, the radiological dose resulting from potential releases of radionuclides was evaluated for hypothetical human receptors working within the fenced area during the 100-yr institutional control period and living or recreating within the fenced area following the institutional control period.

    - **For radon, the selected corrective measure will provide reasonable assurance that the radon-222 emission rate to ambient air from DOE storage or disposal facilities for radium-containing materials will not exceed 20 picocuries per square meter per second.**

      To determine if a corrective measure alternative meets this objective, the radioactive decay of radium was modeled over a 1000-yr period (the first 100 yr of which is the institutional control period) to estimate radon-222 emission rates.

2. ***Protect the environment*. The selected corrective measure will provide reasonable assurance of protection of the environment as determined by ecological assessment guidance available at the time of the selection of the alternative.**

    The environmental impacts of corrective measure alternatives for MDA H were evaluated in terms of the potential biological and cultural resource damage that would be incurred during the implementation of each alternative. DOE requires the CMS process to comply with the National Environmental Policy Act (NEPA) and an Environmental Assessment for MDA H corrective measure alternatives is currently being prepared.

3. ***Attain action levels*. The selected corrective measure will provide reasonable assurance that migration of contaminants during the design life of the measure will not result in contaminant concentrations above action levels at the points of compliance.**

   A contaminant transport model was developed to evaluate the effectiveness of each containment alternative. The model evaluated whether hazardous wastes or constituents at levels above maximum contaminant levels (MCLs) and/or radionuclides at concentrations above dose limits can reach the saturated zone within a timeframe of 1000 yr following implementation of the corrective measure. Data collected by the TA-54 mesa-wide groundwater-monitoring program will be used to verify the transport model.

   For containment alternatives, action levels and points of compliance for moisture monitoring in the vadose zone would be negotiated with NMED to insure against exceedances at compliance points. Action levels will be based on the need to protect human health and the environment at the compliance points. Exceedance of action levels will trigger a contingency plan developed as part of the containment alternative.

4. ***Source control*. Provide source control to reduce or eliminate releases that may pose a threat.**

   The contaminant transport model will be used during the corrective measure design phase to provide reasonable assurance that future releases will be minimized and that the impact of any potential release is within the risk/dose levels specified above.

5. ***Waste management compliance*. Comply with standards for management of waste generated by the CMS.**

   A waste characterization strategy plan will be developed during the corrective measure design phase to ensure that any material removed from MDA H will not result in the creation of undue risk/dose or the creation of another corrective action unit. This objective applies most explicitly to the excavation alternative, but is also relevant to (and is therefore ensured for) remedies that may require disturbance of the surface (such as grading) or invasive procedures (such as installation of monitoring equipment or stabilization).

2.2.1 Evaluation Criteria

Each corrective measure alternative demonstrated to meet the corrective action objectives was also assessed to meet the evaluation criteria specified in Module VIII (EPA 1990, 1585; EPA 1994, 44146) and the MDA H CMS Plan (LANL 2001, 70319). The evaluation criteria (in **bold type**) and discussions of how each criterion is addressed in the assessment of alternative corrective measures for MDA H are presented below.

Criterion 1:

***Technical*. The Permittee (LANL) shall evaluate each corrective measure alternative based on performance, reliability, implementability and safety.** These four technical criteria provide additional assurance that the corrective measure alternative being assessed is capable of achieving its intended purpose of protecting human health and the environment. Each alternative was evaluated in the CMS against each of the technical criteria, as follows.

- ***Performance*. The Permittee shall evaluate performance based on effectiveness and useful life of the corrective measure. Effectiveness shall be evaluated in terms of the ability to**

perform intended functions. Useful life is defined as the length of time the level of effectiveness can be maintained.

Alternatives were evaluated for performance for a 1000-yr evaluation period with respect to the potential risk/dose remaining at the site after the alternative is implemented.

- ***Reliability*. The Permittee shall provide information on the reliability of each corrective measure including their operation and maintenance requirements and their demonstrated reliability**.

  The operation and maintenance aspects of each corrective measure alternative were evaluated in the alternatives assessment based on demonstrated technologies that have been successful (or unsuccessful) under similar conditions, to the extent that this information is available.

- ***Implementability*. The Permittee shall describe the implementability of each corrective measure including the relative ease of installation (constructibility) and the total time required to achieve a given level of response.**

  Three requirements must be considered when assessing the implementability of a corrective measure alternative:

  1. Technical implementability, which consists of the ability to implement and construct the technology, the reliability of the technology, and the ability to monitor the effectiveness of the remedy.
  2. Administrative feasibility, which consists of the effort and resources required to obtain approval from regulatory agencies.
  3. The availability of services and materials.

- ***Safety*. The Permittee shall evaluate each corrective measure alternative with regard to safety.**

  This evaluation will include threats to the safety of nearby communities and environments as well as those to workers during implementation.

Criterion 2:

***Environmental*. The Permittee shall perform an environmental assessment for each alternative.**

The intent of environmental assessments is met by the alternatives assessment insofar as it describes the potential environmental benefits and adverse effects associated with each alternative. In addition, an Environmental Assessment is being performed to meet DOE requirements for NEPA implementation.

Criterion 3:

***Human Health*. The Permittee shall assess each corrective measure alternative in terms of the extent to which it mitigates short- and long-term potential exposure to any residual contamination and protects human health both during and after implementation of the corrective measure.**

The relative reduction of long-term impact has been determined by comparing residual levels of each alternative with existing criteria, standards, or regulations acceptable to the administrative authority. Impacts to site workers and the community were evaluated for the implementation phase of each alternative.

Criterion 4:

***Institutional*. The Permittee shall assess relevant institutional needs for each alternative. Specifically, the effects of Federal, State, and local environmental and public health standards, regulations, guidance, advisories, ordinances, or community relations on the design, operation, and timing of each alternative.**

The major institutional need affecting the containment alternatives is restricting site access to the public by the maintenance of control over MDA H. For this document, it has been conservatively assumed that DOE will maintain control of this site for the next 100 yr.

RCRA requires a facility to obtain and address input from the public during the CMS process. For the Laboratory, the public includes anyone who resides in the communities surrounding the Laboratory or who has an interest in the activities of the Laboratory's corrective action process; organizations representing or protecting specific groups or interests in the region; and government agencies including local, state, federal and tribal governments. Surrounding communities include Los Alamos County, San Ildefonso Pueblo, Santa Clara Pueblo, Santa Fe, and Española.

To meet this public input requirement, a Public Outreach Plan (POP) specific to MDA H was prepared and implemented in 2001 (http://erproject.lanl.gov/, LANL 2001, 70319). The objectives of the plan are to

- provide the public with objective information to assist them in understanding the problem, remediation alternatives, and solutions;
- provide interpretations of data;
- ensure that public concerns are consistently understood and considered in the decision-making process;
- provide the surrounding communities with public access to RRES-R Program technical staff; and
- increase contact with the public in ways that encourage interaction and involve them in the CMS.

The POP for the MDA H CMS includes ongoing efforts to involve the community, mailing of informational material, online access to MDA H information found at http://erproject.lanl.gov/, a series of formal briefings and open houses, and the formation of a focus group of key individuals and organizations from various segments of the public. POP public outreach activities completed through April 2003 are described in Appendix C.

Criterion 5:

***Cost Estimate*. The Permittee shall develop an estimate of the cost of each corrective measure alternative. The cost estimate shall include capital, and operation and maintenance costs.** Cost is considered only when more than one alternative meets all the corrective action objectives and evaluation criteria. Comparative costs, including potential costs associated with uncertainties and assumptions, are provided for each corrective measure alternative meeting these criteria (Section 3).

2.3 Screening of Corrective Measure Technologies

EPA and DOE corrective action guidance (EPA 1994, 73488; DOE 1993, 73487) and Module VIII require that potential corrective measure technologies be screened to eliminate those that prove infeasible to implement, that rely on technologies unlikely to perform satisfactorily or reliably, or that do not achieve the corrective action objectives within a reasonable time frame. For the MDA H CMS, the screening of technologies included

- a review of site data and the site conceptual model described in the RFI report (LANL 2001, 70158) to identify conditions that may limit or promote the use of certain technologies,
- identification of waste characteristics that limit the effectiveness or feasibility of technologies, and
- identification of the level of technology development, performance record and inherent construction, operation and maintenance problems for each technology considered.

General types of corrective measure technologies potentially appropriate to MDA H site conditions and waste types were taken from the comprehensive technology list developed by the Federal Remediation Technologies Roundtable (http://www.frtr.gov/matrix2/top_page.html) (See Appendix D). For wastes disposed at MDA H, potentially appropriate technologies fall into the four general categories listed below and shown in the left-most column of Figure 2.3-1:

- containment
- in situ treatment
- excavation/removal
- ex situ treatment

The screening conducted in Section 2.3 is summarized in Figure 2.3-1. The list of candidate corrective measure technologies within each general technology subcategory is shown in the third column of Figure 2.3-1. Each candidate technology described briefly in column four of the figure was reviewed for applicability to MDA H site conditions, waste characteristics and technology limitations. Column five of the figure presents the results of the review. Twenty-six candidate technologies are evaluated in the initial candidate list.

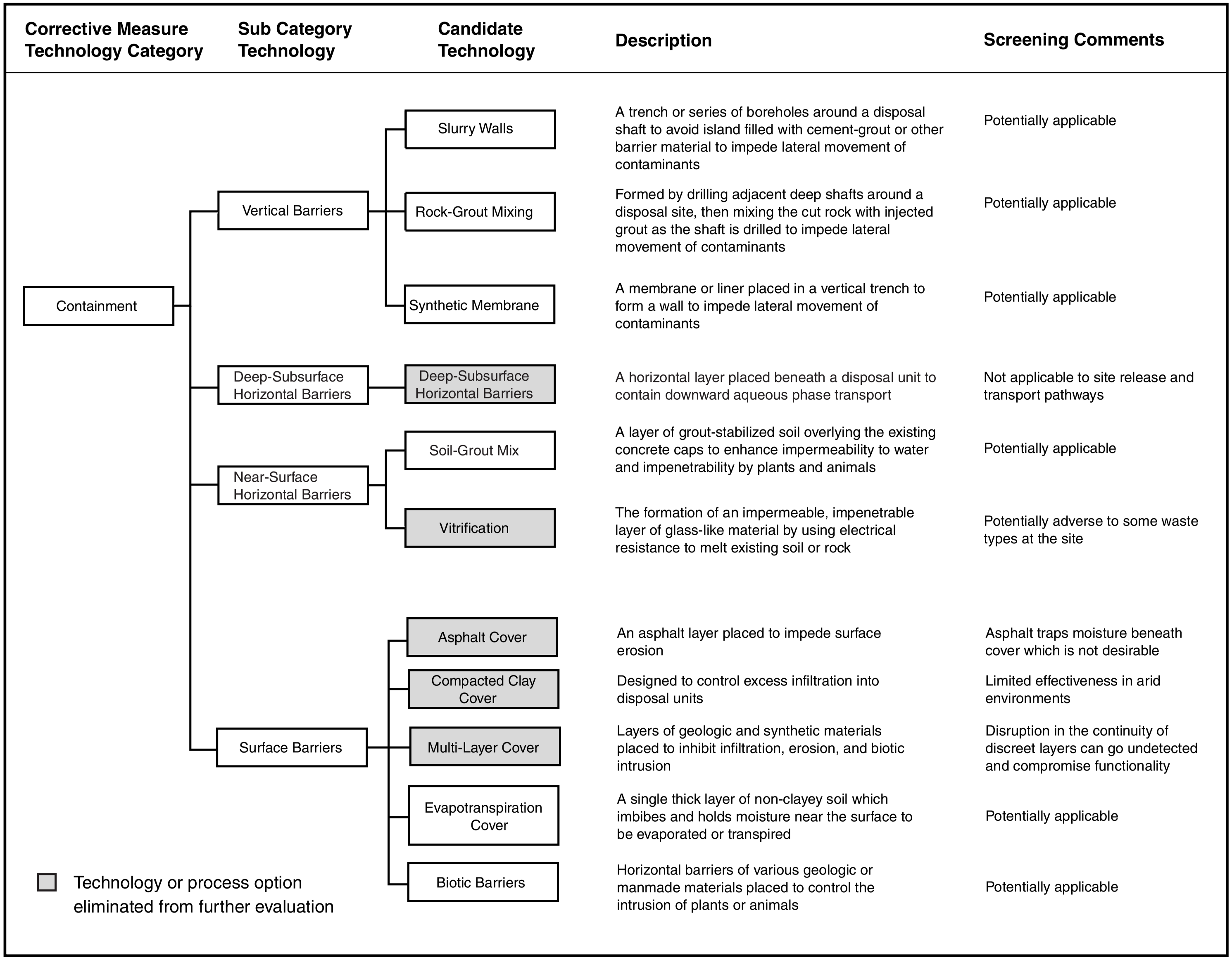
2.3.1 Containment Technologies

Containment technologies include surface and subsurface barriers. Various orientations and compositions of barriers can be used. The general functionality and potential MDA H-specific utility is discussed for each containment technology considered.

2.3.1.1 Vertical Barriers

Vertical barrier technologies could be designed to prevent biointrusion into the MDA H shafts and to prevent lateral movement of contaminants from the shafts. Vertical barriers installed in combination with an evapotranspiration cover could also reduce infiltration of moisture/water through the shafts. To minimize access to the shafts by humans, animals, or plants and to prevent water from entering the shafts laterally, the following vertical barrier technologies are retained for further consideration in Section 3.

Slurry wall. Slurry walls are formed using cement-grout, or barrier materials, placed in narrow, deep trenches or in a series of adjacent open boreholes surrounding the perimeter of a disposal site. Slurry walls are commonly used to intercept contaminants that migrate laterally.

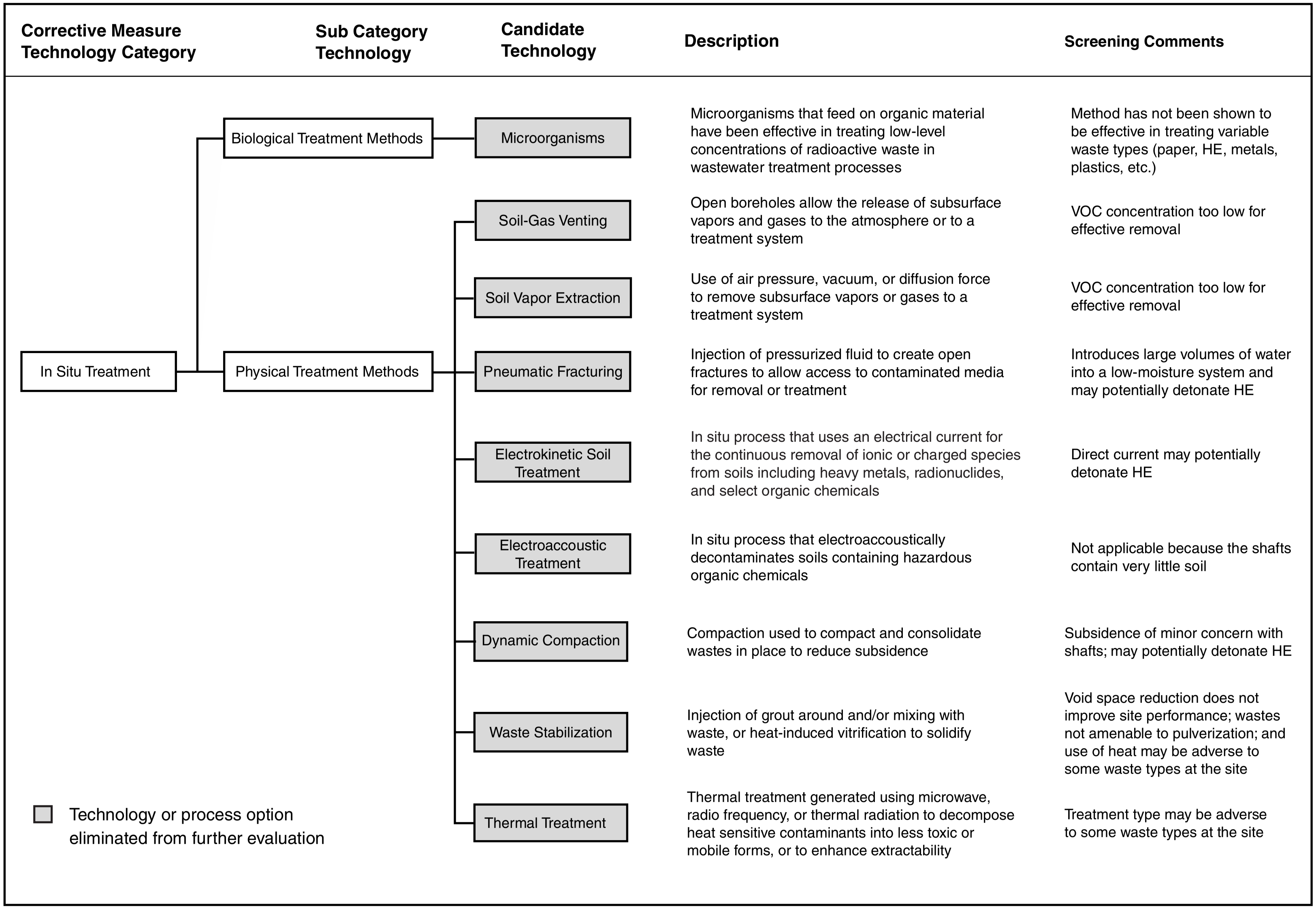


Corrective Measure Technology Category	Sub Category Technology	Candidate Technology	Description	Screening Comments
Containment	Vertical Barriers	Slurry Walls	A trench or series of boreholes around a disposal shaft to avoid island filled with cement-grout or other barrier material to impede lateral movement of contaminants	Potentially applicable
		Rock-Grout Mixing	Formed by drilling adjacent deep shafts around a disposal site, then mixing the cut rock with injected grout as the shaft is drilled to impede lateral movement of contaminants	Potentially applicable
		Synthetic Membrane	A membrane or liner placed in a vertical trench to form a wall to impede lateral movement of contaminants	Potentially applicable
	Deep-Subsurface Horizontal Barriers	▨ Deep-Subsurface Horizontal Barriers	A horizontal layer placed beneath a disposal unit to contain downward aqueous phase transport	Not applicable to site release and transport pathways
	Near-Surface Horizontal Barriers	Soil-Grout Mix	A layer of grout-stabilized soil overlying the existing concrete caps to enhance impermeability to water and impenetrability by plants and animals	Potentially applicable
		▨ Vitrification	The formation of an impermeable, impenetrable layer of glass-like material by using electrical resistance to melt existing soil or rock	Potentially adverse to some waste types at the site
	Surface Barriers	▨ Asphalt Cover	An asphalt layer placed to impede surface erosion	Asphalt traps moisture beneath cover which is not desirable
		▨ Compacted Clay Cover	Designed to control excess infiltration into disposal units	Limited effectiveness in arid environments
		▨ Multi-Layer Cover	Layers of geologic and synthetic materials placed to inhibit infiltration, erosion, and biotic intrusion	Disruption in the continuity of discreet layers can go undetected and compromise functionality
		Evapotranspiration Cover	A single thick layer of non-clayey soil which imbibes and holds moisture near the surface to be evaporated or transpired	Potentially applicable
		Biotic Barriers	Horizontal barriers of various geologic or manmade materials placed to control the intrusion of plants or animals	Potentially applicable

▨ Technology or process option eliminated from further evaluation

F2.3-1 pg1, mdahcms, 022603, rlm_F2.3-1 p. 1 of 3, MDA H CMS, 052203, cf

Figure 2.3-1. Screening of corrective measure technologies (page 1 of 3)

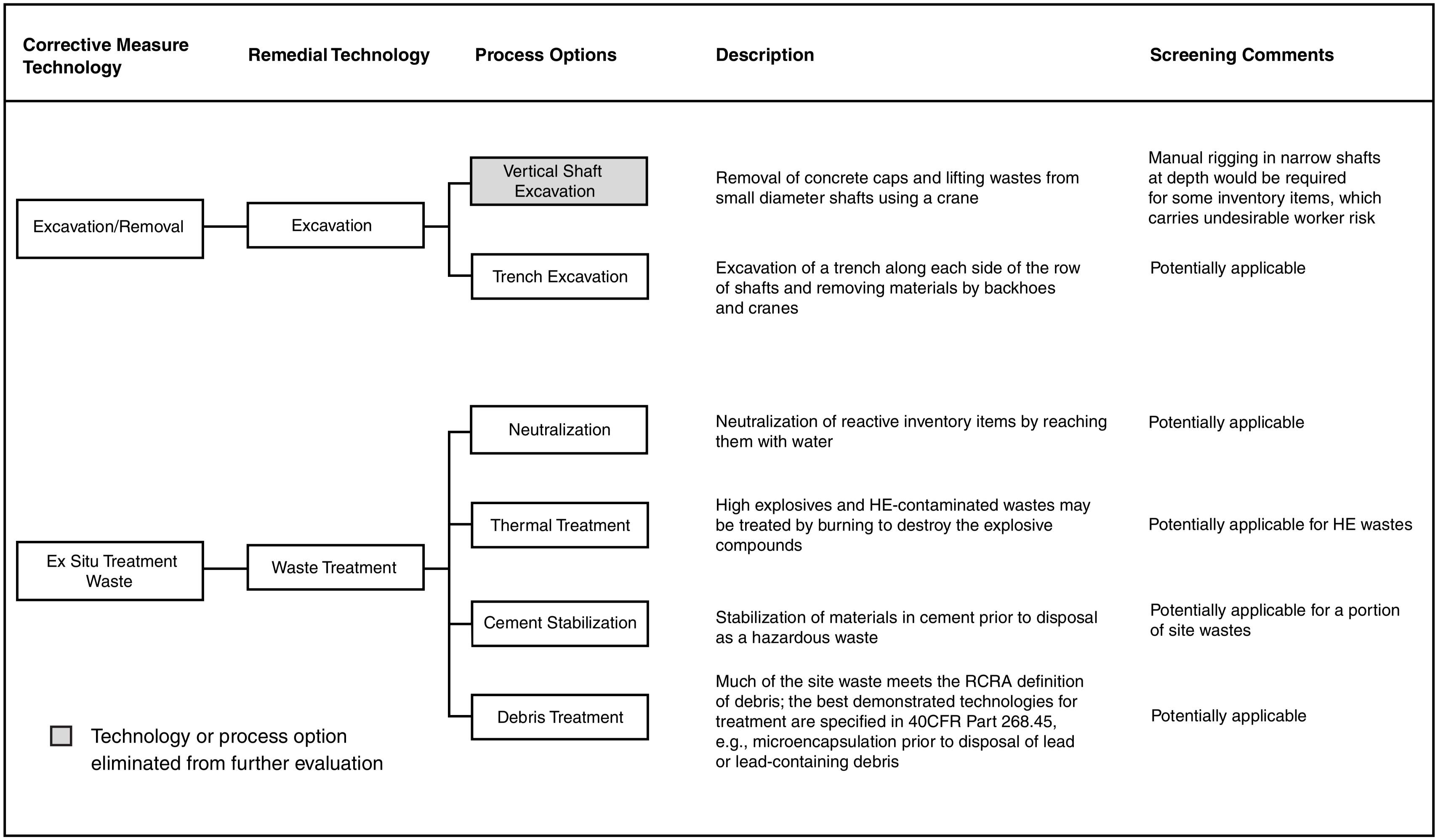


Corrective Measure Technology Category	Sub Category Technology	Candidate Technology	Description	Screening Comments
In Situ Treatment	Biological Treatment Methods	Microorganisms	Microorganisms that feed on organic material have been effective in treating low-level concentrations of radioactive waste in wastewater treatment processes	Method has not been shown to be effective in treating variable waste types (paper, HE, metals, plastics, etc.)
	Physical Treatment Methods	Soil-Gas Venting	Open boreholes allow the release of subsurface vapors and gases to the atmosphere or to a treatment system	VOC concentration too low for effective removal
		Soil Vapor Extraction	Use of air pressure, vacuum, or diffusion force to remove subsurface vapors or gases to a treatment system	VOC concentration too low for effective removal
		Pneumatic Fracturing	Injection of pressurized fluid to create open fractures to allow access to contaminated media for removal or treatment	Introduces large volumes of water into a low-moisture system and may potentially detonate HE
		Electrokinetic Soil Treatment	In situ process that uses an electrical current for the continuous removal of ionic or charged species from soils including heavy metals, radionuclides, and select organic chemicals	Direct current may potentially detonate HE
		Electroaccoustic Treatment	In situ process that electroaccoustically decontaminates soils containing hazardous organic chemicals	Not applicable because the shafts contain very little soil
		Dynamic Compaction	Compaction used to compact and consolidate wastes in place to reduce subsidence	Subsidence of minor concern with shafts; may potentially detonate HE
		Waste Stabilization	Injection of grout around and/or mixing with waste, or heat-induced vitrification to solidify waste	Void space reduction does not improve site performance; wastes not amenable to pulverization; and use of heat may be adverse to some waste types at the site
		Thermal Treatment	Thermal treatment generated using microwave, radio frequency, or thermal radiation to decompose heat sensitive contaminants into less toxic or mobile forms, or to enhance extractability	Treatment type may be adverse to some waste types at the site

▨ Technology or process option eliminated from further evaluation

F2.3-1 pg2, mdahcms, 022603, rlm_F2.3-1 p. 2 of 3, MDA H CMS, 052203, cf

Figure 2.3-1. Screening of corrective measure technologies (page 2 of 3)



Corrective Measure Technology	Remedial Technology	Process Options	Description	Screening Comments
Excavation/Removal	Excavation	Vertical Shaft Excavation	Removal of concrete caps and lifting wastes from small diameter shafts using a crane	Manual rigging in narrow shafts at depth would be required for some inventory items, which carries undesirable worker risk
		Trench Excavation	Excavation of a trench along each side of the row of shafts and removing materials by backhoes and cranes	Potentially applicable
Ex Situ Treatment Waste	Waste Treatment	Neutralization	Neutralization of reactive inventory items by reaching them with water	Potentially applicable
		Thermal Treatment	High explosives and HE-contaminated wastes may be treated by burning to destroy the explosive compounds	Potentially applicable for HE wastes
		Cement Stabilization	Stabilization of materials in cement prior to disposal as a hazardous waste	Potentially applicable for a portion of site wastes
		Debris Treatment	Much of the site waste meets the RCRA definition of debris; the best demonstrated technologies for treatment are specified in 40CFR Part 268.45, e.g., microencapsulation prior to disposal of lead or lead-containing debris	Potentially applicable

▨ Technology or process option eliminated from further evaluation

F2.3-1 pg3, mdahcms, 022603, rlm_F2.3-1 p. 3 of 3, MDA H CMS, 052203, cf

Figure 2.3-1. Screening of corrective measure technologies (page 3 of 3)

Rock-grout mixing. Rock-grout barriers are formed by drilling adjacent deep shafts around the perimeter of a site, and then mixing the cut rock with injected grout as the shaft is drilled. Like slurry walls, rock-grout mixing is used to intercept contaminants that migrate laterally.

Synthetic membrane. A synthetic membrane, such as a geosynthetic liner, can be placed in a vertical trench. The membrane forms a barrier that impedes/restricts the lateral migration of contaminants.

2.3.1.2 Deep-Subsurface Horizontal Barriers

The purpose of a horizontal barrier is to contain downward aqueous-phase contaminant transport and act as a biotic barrier. Such a barrier is suitable for sites with known aqueous-phase releases. These conditions do not exist at MDA H. Therefore, a deep horizontal barrier would not be appropriate for addressing the release and transport pathways of potential concern at MDA H and is not considered further in this CMS.

2.3.1.3 Near-Surface Horizontal Barriers

Near-surface horizontal barriers created by a soil-grout mixture or vitrification could enhance MDA H's existing shaft covers by controlling intrusion into the waste by plants, animals, or people, and by reducing infiltration of water. Therefore, this technology is retained for further consideration. Additional engineering or modeling studies are required to determine whether and to what extent the physical and hydrological properties of the existing cover can be improved over the short and long term by implementation of this technology.

Soil-grout mix. A concrete/grout mixture containing soil or crushed tuff could replace the 3-ft crushed tuff above the concrete plugs in eight of the nine MDA H disposal shafts. This barrier could be safely constructed and has the potential to decrease permeability to water and/or penetrability by plants and animals in the existing 3-ft concrete plugs (caps) of Shafts 1 through 8. This technology is retained for further evaluation in Section 3.

Vitrification. In situ vitrification is the process of using electrical resistance to heat soil or rock to temperatures high enough to melt them. When the melted materials cool, a glass-like material is formed. Although in situ vitrification produces an impermeable, impenetrable horizontal barrier, it is not practical for MDA H. Vitrification has only been demonstrated to a depth of 30 ft (the MDA H shafts are 60 ft deep) and the potentially adverse effects of high heat levels on certain wastes residing in the shafts at MDA H (e.g., HE and potentially reactive wastes) are of concern. Because soil-grout mixing can provide the same type of barrier without these concerns, vitrification is eliminated as a feasible technology for MDA H.

2.3.1.4 Surface Barriers

Barriers placed on the surface of disposal sites provide protection against the infiltration of water, erosion, and disruption by plants or animals, act as a deterrent to inadvertent human intrusion and limit radon flux. The existing surface barriers at MDA H (crushed tuff and concrete caps) have been effective protection against these types of intrusions for over 40 yr. In addition, several alternative surface barriers are currently available:

- ***Asphalt cover***. Asphalt provides a substantial barrier to surface erosion processes, but has been shown at another Laboratory site (MDA AB, Area 2 [LANL 1999, 63918]) to trap moisture that would otherwise be evapotranspired from the subsurface. Because maintaining a low moisture content is a desirable feature for MDA H, an asphalt cover would not be suitable for this site. Therefore, use of an asphalt cover is eliminated from further consideration.

- ***Compacted clay cover***. Compacted clay covers have successfully controlled excess infiltration at RCRA-regulated landfills located in humid environments. However, clay liners are far less effective in arid and semi-arid climates because the clay tends to dry out and crack, allowing moisture to flow directly into disposal units (Mulder and Haven 1995, 71297). Hence, compacted clay covers are not suitable for MDA H and are not a viable alternative.
- ***Multi-layer cover***. Multi-layer covers consist of layers of different geologic and synthetic materials placed in specific order to control various potentially detrimental processes and conditions at a site (e.g., infiltration, erosion, and biotic intrusion). The use of multi-layer covers at RCRA-regulated landfills has been compromised by settlement, which has disrupted the continuity of the discrete layers of the cover (Mulder and Haven 1995, 71297). The clay barrier is usually breached at the worst point, the bottom of the differentially settled area, serving as a funnel for infiltration. The geomembrane will tear if enough settlement occurs, due to tensile forces in the membrane. The drainage layer above the barrier layer will also serve as a funnel to feed water to this newly breached barrier. A capillary barrier will have similar problems due to differential settlement. Because such a disruption can go undetected, multi-layer covers are considered unreliable, in general, and are therefore not suitable at MDA H.
- ***Evapotranspiration cover***. Evapotranspiration (ET) covers consist of a single, vegetated soil layer constructed to represent an optimum mix of soil texture, soil thickness, and vegetation cover. ET covers consist of a monolithic soil layer designed to enhance soil water storage capacity to retain any infiltrated water until it can be evaporated by solar radiation and transpired by shallow-rooting plants. The vegetated ET cover was developed explicitly for landfills located in arid and semi-arid environments like Los Alamos (Barnes et al. 1990, 70209). The earliest research in this area was conducted at Los Alamos, at a test site within 1 mile of MDA H (Nyhan et al. 1984, 8797; Nyhan et al. 1989, 6874; Nyhan 1989, 6876). An engineered ET cover could enhance the existing crushed tuff and concrete cover. Capping Shafts 1–8 and the concrete cover capping Shaft 9 at MDA H, is therefore retained for consideration.
- ***Biotic barriers***. Various materials have been used to control the intrusion of plants and/or animals into RCRA-regulated landfills. Installation of horizontal barriers constructed of cobble-sized rocks or pea gravel inhibits deep-rooting plants and discourages burrowing animals. Chain-link fencing laid on the surface of a cover has been successfully used at a Laboratory site to discourage burrowing animals, while having no observable impact on vegetation (LANL 1999, 63919). Either of these biotic barriers could be effective at MDA H and are therefore retained for consideration.

2.3.2 In Situ Treatment Technologies

In situ waste treatment technologies are used to reduce the mobility and/or toxicity of wastes, or to increase their stability without removing the wastes from their disposal location. The different in situ methods (biological and physical) discussed in this section are appropriate for different contaminants and disposal environments (see Appendix D).

2.3.2.1 Biological Treatment Technologies

Biological methods, using various microorganisms that feed on organic material, have been effective in treating low-level concentrations of radioactive waste in wastewater treatment processes. However, biological treatment technologies have not been shown to be effective in treating the types of wastes specific to the inventory at MDA H (i.e., paper, HE, metals, plastics, etc.). Therefore, biological treatment is not viable at MDA H.

2.3.2.2 Physical Treatment Technologies

- Soil-gas venting. Soil-gas venting consists of open boreholes that allow the release of subsurface vapors and gases to the atmosphere or to a treatment system. This technology is used to remove an underground source of VOCs or to reduce VOC migration. Measured concentrations of VOCs at MDA H are too low (part-per-billion range) for venting to be effective, and tritium is not a dose driver. Therefore, soil venting is eliminated from further consideration.
- Soil vapor extraction. Soil-vapor extraction introduces the use of a force to accelerate the removal of the subsurface gases or vapors. The force may be in the form of air pressure injected into one or more wells, a vacuum that pulls the vapor from one or more wells, or the establishment of a steep diffusion force that removes the gas or vapor from an area. This technology commonly requires a treatment system for the vapor that is extracted from the subsurface. Measured concentrations of VOCs at MDA H are too low (part-per-billion range) for soil vapor extraction to be effective, and tritium is not a dose driver. Therefore, soil-vapor extraction is eliminated from further consideration.
- Pneumatic fracturing. Pneumatic fracturing uses the injection of a fluid under pressure to create open fractures in an area in which a contaminant plume exists. Opening flow paths allows access to the contaminated media for removal or treatment. Pneumatic fracturing has the potential for detonating the explosive material disposed at MDA H. In addition, the introduction of large amounts of water into a system that has optimal low moisture is not desirable. Therefore, pneumatic fracturing is not a viable technology for MDA H.
- Electrokinetic soil treatment. Electrokinetic soil treatment is an in situ process for the continuous removal of ionic or charged species from soils including heavy metals, radionuclides, and select organic chemicals. The technology is implemented by passing a direct current through the soil. Because use of a direct current might detonate explosives disposed at MDA H, this technology is not feasible at MDA H.
- Electroacoustic treatment. In situ electroacoustic soil decontamination is an emerging technology used for decontaminating soils containing organic chemicals. Because there is no soil in the shafts at MDA H and because the low concentrations of VOC contamination at MDA H are in the vapor phase, this technology is not applicable.
- Dynamic compaction. Dynamic compaction is used to compact and consolidate wastes in place to reduce the potential for settling or sinking over time. The technology has been successfully demonstrated on landfills where subsidence (settling) over large areas is possible, leading to potentially significant run-on and infiltration of surface water. Such catastrophic settling is not a concern with the small circumference disposal shafts at MDA H. In addition, dynamic compaction is not an appropriate technology for MDA H because it has the potential to detonate explosives in the inventory.
- Waste stabilization. The infiltration and movement of water through the shafts and the potential for subsidence might be reduced by injecting grout into/around waste to reduce the porosity within and between objects. In one method, grout is injected into holes drilled through the waste, while simultaneously pulverizing the waste and mixing it with the grout. The bulky, dense metal components comprising a large fraction of the wastes within MDA H are not amenable to the pulverization and mixing process. A second waste stabilization method involves the direct injection of grout into void spaces surrounding waste. Because there is no way to identify void

areas in the MDA H shafts, direct injection of grout is not appropriate. Therefore, waste stabilization of shafts is not feasible at MDA H.

- Thermal treatment. Several methods of thermal treatment have been developed and implemented to decompose heat sensitive contaminants into less toxic or less mobile forms, or to enhance the extractability of a contaminant by heating it into a vapor phase. Heat is generated using microwave, radio frequency, or thermal radiation. Due to the presence of potentially reactive and explosive materials disposed at MDA H, thermal treatment is not a viable technology at MDA H.

2.3.3 Excavation/Removal

Excavating wastes from MDA H would require the use of remotely operated or robotic excavators to control potential worker-safety hazards from HE and reactive components. Similarly, pyrophoric uranium hydride is expected to be present and engineering controls would be needed to prevent hydride fires during excavation. In addition, because of the classified nature of some of the waste inventory, excavation would have to be performed under a dome or tent for security purposes.

- Vertical shaft excavation. Although access to the MDA H disposal shafts can be gained by removing the concrete caps from the tops of the shafts, the small diameter of the shafts provides a limited space for manipulating the shaft contents. A remotely operated backhoe would not be able to access and remove objects located deeper than 10–12 ft. Deep removal could only be accomplished by using a crane. However, a crane requires manual rigging of each lift (rigging cannot be done remotely). While not impossible, this type of excavation is not desirable because of potential worker risks. Use of grappling devices or magnetic lifts would be possible for certain inventory items; however, due to size or shape, many items could be removed by means of manual rigging only. Therefore, the safety hazards of working in the narrow shafts at depths greater than 12 ft eliminate vertical shaft excavation as a viable technology for MDA H.
- Trench excavation. Removal of the wastes from the MDA H shafts by excavating a trench along both sides of the row of shafts and then removing materials by backhoe and crane is viable. This technology is routinely used at MDA G to excavate trenches to a depth of up to 65 ft in Unit 2 of the Bandelier Tuff. The shafts at Area H are similarly located in Unit 2 of the Bandelier Tuff at a depth of 60 ft. Therefore, this technology is retained for consideration in Section 3.

2.3.4 Ex Situ Waste Treatment Technologies

Once excavated and removed, MDA H waste materials would require characterization in order to be recycled or to make a determination as to whether the waste material would meet the waste acceptance criteria of both on-site and off-site treatment, storage, and disposal (TSD) facilities. Additionally, some of the waste may require treatment prior to recycling or emplacement in an approved on- or off-site facility. General treatment technologies include neutralization, thermal treatment, cement stabilization, and debris treatment.

- Neutralization. Reactive materials in the MDA H inventory, particularly lithium compounds, could be neutralized by reacting them with water. This technology has been demonstrated at Area L and is a suitable treatment technology for lithium wastes at MDA H.
- Thermal treatment. HE and HE-contaminated wastes could be treated by burning to destroy the explosive compounds. This technology is well demonstrated at the Laboratory and could be a suitable technology for HE wastes at MDA H.

- Cement stabilization. Some materials may require stabilization in cement prior to disposal as a hazardous or mixed waste. This technology is well demonstrated throughout the waste management industry and could be a suitable technology for particular wastes at MDA H.
- Debris treatment. Much of the waste that would be generated from excavation of the shafts at MDA H meets the RCRA definition of debris. The alternative treatment standards for hazardous debris are specified in 20.4.1.800 NMAC, which adopts 40 CFR Part 268.45. For example, macroencapsulation is one of the immobilization technologies that may be used to reduce potential for leaching of lead or lead-containing debris. This technology could be a suitable technology for MDA H debris.

All four ex-situ waste treatment technologies are retained for consideration in Section 3.

2.3.5 Summary

Of the 26 candidate corrective measure technologies evaluated in Section 2.3, 11 were retained and 15 were eliminated based on site conditions, waste characteristics, and/or technology limitations.

2.4 Identification of Corrective Measure Alternatives

The technologies retained after the screening evaluation were combined into corrective measure alternatives. RCRA guidance and Module VIII require that corrective measure alternatives be developed based on site conditions (including contaminant inventory), design of the disposal units, environmental setting, corrective measure objectives (Section 2.2), and the viability of the corrective measure technologies (Section 2.3).

Eight preliminary corrective measure alternatives were developed and presented in the MDA H CMS plan (LANL 2001, 70319) prior to the evaluation of technologies in Section 2.3. The eight preliminary alternatives identified in the MDA H CMS Plan are listed below.

Preliminary Alternative 1	Monitoring only, no action
Preliminary Alternative 2	Maintenance of existing cover and monitoring
Preliminary Alternative 3	Control of tritium vapors
Preliminary Alternative 4	Near-surface stabilization
Preliminary Alternative 5	Engineered ET Cover
Preliminary Alternative 6	Partial excavation, wastes replaced in MDA H
Preliminary Alternative 7	Complete excavation, wastes disposed of off site/on site
Preliminary Alternative 8	Combination of alternatives

Because the MDA H RFI report identifies no unacceptable present-day risks to human health or the environment and no unacceptable dose levels from radiological contaminants at MDA H, the potential need for corrective action at MDA H is based on future potential for releases that might create unacceptable risks/doses to human health or the environment. Thus, the alternatives below emphasize confirmation of continuing absence of releases, controlling the sources that could contribute to releases, and providing containment that will ensure the magnitude of potential future releases is within acceptable risk/dose levels.

2.4.1 Preliminary Alternative 1: Monitoring Only, No Corrective Action

The existing containment features at MDA H have provided effective containment to date except for subsurface releases of tritium and VOCs, which do not pose a current risk to site workers. Thus, monitoring current containment performance using moisture-monitoring technology [neutron logging and/or time domain reflectometry (TDR) probes] is a viable preliminary alternative. Neutron logging has been successfully used to determine moisture content in two boreholes at MDA H (Figure 2.1-5). In considering this alternative, it is assumed that site access and administrative requirements for MDA H will continue as they are at present and the site will continue to remain under Laboratory control for the next 100 yr. No maintenance of any type will be performed on the MDA H containment system. A contingency plan will be developed in conjunction with NMED and implemented if new releases are identified.

2.4.2 Preliminary Alternative 2: Maintenance of Existing Cover and Monitoring

Alternative 2 includes the monitoring system described in Preliminary Alternative 1, and additionally provides for the upkeep of the existing containment systems during the assumed 100-yr institutional control period. Maintenance activities will be performed through the 100-yr institutional control period. Site access and administrative requirements for MDA H will continue as they are at present and the site will continue to remain under Laboratory control for the next 100 yr. A contingency plan will be developed in conjunction with NMED and implemented if new releases are identified.

2.4.3 Preliminary Alternative 3: Control of Tritium Vapors

Releases of tritium in water vapor have been identified at MDA H; the vapor moves from emplaced wastes into the tuff bedrock and migrates in the vapor phase through rock and soil. Based on 2002 and 2003 monitoring data, tritium releases to the environment are not sufficient to constitute a potential risk to human health or the environment.

2.4.4 Preliminary Alternative 4: Near-Surface Stabilization

Alternative 4 includes all the components of Alternative 2, with the addition of one or more stabilization methods. Site or waste stabilization methods, such as grout injection, could enhance the resistance of the MDA H shaft caps to subsidence or loss of their perimeter seals against the tuff and could enhance the performance of the caps to serve as barriers against erosion and intrusion (plant, animal, or human). In addition, stabilization methods would reduce contaminant mobility.

2.4.5 Preliminary Alternative 5: Engineered ET Cover

Alternative 5 includes all the components of Alternative 2, but with the addition of a site-specific engineered ET cover with run-on/run-off drainage controls. Engineered ET covers have been demonstrated to be effective in limiting percolation through landfills in semi-arid regions (Davenport et al. 1998, 69674; Dwyer et al. 2000, 69673). A well-designed engineered ET cover restricts infiltration of moisture through the cover and into the disposed waste, protects against erosion of the cover, deters plant and animal intrusion into the disposed waste, and inhibits human intrusion into the disposed waste. Various engineered ET cover designs could be incorporated to provide specific barriers. For example, erosion protection through use of gravel surface treatments; varying depths of enriched soil to enhance plant growth for evapotranspiration; varying depths of the main crushed-tuff evapotranspiration layer to increase evapotranspiration; and bio-intrusion barriers such as chain-link fencing or a layer of pea gravel.

2.4.6 Preliminary Alternative 6: Partial Excavation

Alternative 6 consists of excavating the top 17 ft of the waste in some or all of the disposal shafts and disposing of the wastes elsewhere at the Laboratory or at a permitted off-site facility.

Assessments of long-term risk/dose at Area G (at TA-54) demonstrated that the most likely future potential risk/dose is associated with the loss of containment at the ground surface (e.g., from bio-intrusion) (LANL 1997, 63131). To prevent loss of containment at the ground surface at MDA H, the wastes nearest the surface (upper 17 ft) would be removed and moved deeper into a new shaft at MDA H or placed at a greater depth (>17 ft) in a different permitted land fill or other permitted unit at the Laboratory that provides isolation of the buried materials from surface release processes or disposed off site at a permitted facility (Appendix L).

2.4.7 Preliminary Alternative 7: Complete Excavation/Removal, Waste Disposed of Off Site/On Site

Alternative 7 consists of the complete excavation of all MDA H waste. The removed waste would be disposed either at an off-site (non-Laboratory) facility (provided existing facilities will accept these wastes) or at a new permitted disposal facility at the Laboratory. Decontamination and recycling of some MDA H waste materials would be evaluated to meet waste minimization requirements of the NSWA Module. In addition, treatment of excavation waste could be required to meet waste acceptance criteria of disposal facilities and to comply with land disposal restriction requirements under 40 CFR 268 and 20.4.1.800 NMAC. Complete removal would eliminate all future potential risk/dose concerns at MDA H. Offsite disposal would transfer the potential risk/dose to the sites or communities where the waste would be disposed. On-site redisposal of all of the materials removed from MDA H would require permitting a new disposal unit at the Laboratory.

Implementing this alternative would involve an increased short-term risk/dose to excavation workers, environmental receptors, and the surrounding Los Alamos community during the excavation, handling and transportation process. No additional maintenance or monitoring activities would be required at MDA H if this corrective measure alternative were implemented.

2.4.8 Preliminary Alternative 8: Combination of Alternatives

Combinations of alternatives 1 through 7 will also be evaluated.

2.5 Final Corrective Measure Alternatives

Five corrective measure alternatives were developed for MDA H by combining the best elements of the eight preliminary alternatives presented in the CMS Plan with the results of the technology screening process presented in Section 2.3 of this document. The final alternatives meet the corrective action objectives presented in Section 2.2 and consist of a combination of technologies. Each alternative is summarized in Table 2.5-1 and references the CMS Plan preliminary corrective measure alternatives from which it was derived.

Table 2.5-1
Alternatives Proposed for MDA H

Alternative	Preliminary Alternatives Presented in the CMS Plan from which the Final Alternatives are Derived[a]
Final Containment Alternative	
Alt 1: Upgrade Existing Surface Layer	Combined Preliminary Alternatives 1 and 2: This alternative includes upgrades, maintenance and monitoring of the existing surface cover and the vadose zone.
Alt 2: Engineered ET Cover	Combined Preliminary Alternatives 1, 2, and 4: This alternative includes maintenance and monitoring of an engineered cover and the vadose zone.
Alt 3 a and b: Shaft Encapsulation and Engineered ET Cover	Combined Preliminary Alternatives 1, 2, 4, and 5: This alternative adds a vertical barrier around the shafts to Final Alternative 2.
Final Excavation/Removal Alternative	
Alt. 4: Complete Excavation and Off-site Disposal	Preliminary Alternative 7: This alternative involves complete excavation of the material disposed in the shafts and off-site disposal of the material.
Alt. 5: Complete Excavation and On-site Disposal	Preliminary Alternative 7: This alternative involves complete excavation of the material disposed in the shafts and on-site (Laboratory) disposal of the material.

[a] Preliminary Alternative 3, control of tritium vapors, was eliminated based on 2002 and 2003 sampling data that show that tritium concentrations do not pose a potential risk to human health or the environment. Preliminary Alternative 6, partial excavation and reburial at MDA H, was eliminated from further consideration based on the analysis in Appendix L.

Although current conditions are sufficient for preventing adverse impacts to human health or to the environment (LANL 2001, 70158), the Laboratory considers implementing certain site improvements to be necessary to reduce uncertainties associated with future risks. The following elements are features common to the three final containment alternatives (Alternatives 1, 2, and 3):

- The waste inventory remains in the shafts.
- The concrete/crushed-tuff caps are retained.
- The site remains fenced to provide protection against disturbance of the caps and vegetated surface for a period of at least 100 yr.
- The site has regular maintenance inspections that will include examination of the surface for any excessive erosion or gullying, ponding of water, and quality of the vegetative cover to continue to ensure against significant erosion.
- Pressure sensors and automatic shut-off valves would be installed in the two subsurface PVC water lines located east of MDA H along Mesita del Buey road to prevent potential infiltration of water through the vegetative cover from a breakage of the water line.

2.5.1 Corrective Measure Alternative 1: Upgrade Existing Surface Layer

Alternative 1 proposes upgrading the existing MDA H natural vegetative cover and implementing an appropriate monitoring and maintenance program. The upgrade will consist of regrading and recontouring the existing surface to optimize run-on/runoff control, covering the newly contoured surface with a 6-in.[2] gravel/soil mix, and revegetating the regraded soils with shallow-rooting native grasses and plants.

This alternative involves no additional corrective actions for the following reasons:

- The existing concrete shaft caps provide an adequate barrier to biointrusion;
- Regrading and revegetation of the surface provides adequate evapotranspiration of soil moisture (Figure 2.1-5 shows that moisture content in the 100-ft below ground surface (bgs) depth is below 5%);
- The fence surrounding the site and the access gate at the TA-54 entrance and Pajarito Road access restrictions provide a sufficient control against public access; and
- The monitoring and maintenance program includes measures to protect against severe erosion and detect any future subsurface releases from the disposal shafts.

2.5.2 Corrective Measure Alternative 2: Engineered ET Cover

Alternative 2 proposes construction of an engineered ET cover, including run-on/runoff controls, and implementing an appropriate monitoring and maintenance program.

Alternative 2 proposes that

- the concrete and concrete/crushed tuff shaft caps remain in place and an engineered ET cover is constructed over the shafts;
- the site remains fenced to provide protection against disturbance of the engineered ET cover for a period of at least 100 yr;
- the site has regular maintenance inspections that will include examination of the engineered ET cover for any excessive erosion, gullying, ponding of water, and to ensure that the vegetative cover is of sufficient quality to prevent erosion; and
- a monitoring program is implemented to determine if conditions change. Should conditions change, a site-specific contingency plan, agreed upon by NMED, will be implemented.

The objectives of an engineered ET cover are to (1) reduce or limit the amount of water that percolates into a shaft (minimizing the potential for subsurface contaminant transport); (2) reduce or limit erosion, preventing direct exposure of the waste and minimizing surface transport of contaminants; and 3) prevent intrusion of deep-rooting plants and burrowing animals.

The conceptual design of an engineered ET cover for MDA H is illustrated in Figure 2.5-1. The design is based on research on engineered ET covers conducted at the Laboratory and SNL/NM (LANL 1998, 71345; Dwyer 2001, 71298; Dwyer 2002, 71347). The proposed surface of the cover consists of a topsoil/gravel layer with dense, shallow-rooting vegetation that facilitates moisture removal by evapotranspiration. The thin layer of gravel/soil mix would control erosion without compromising the evapotranspiration features of the cover. The gravel/soil mix also promotes initial plant growth on the cover, further reducing runoff and erosion. Because the second layer of the cover consists of a thick layer of crushed tuff, the functionality of the cover is not compromised by differential settlement or localized erosion. Adding more soil to areas that have settled or eroded would easily maintain the cover. The third

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[2] The actual cover thickness will be determined during final design based on estimates of the water holding or storage capacity of the soil and the amount of infiltrated water that has to be stored (Dwyer 2002, 71347).

layer of the cover is a biobarrier. Biobarriers are constructed of various materials, including cobbles or metal chain-link fencing, as implemented at the Laboratory's MDA AB (LANL 1999, 63919). A cobble barrier is effective in inhibiting intrusion from both burrowing animals and deep-rooted plants, whereas metal fencing would be effective against burrowing animals only.

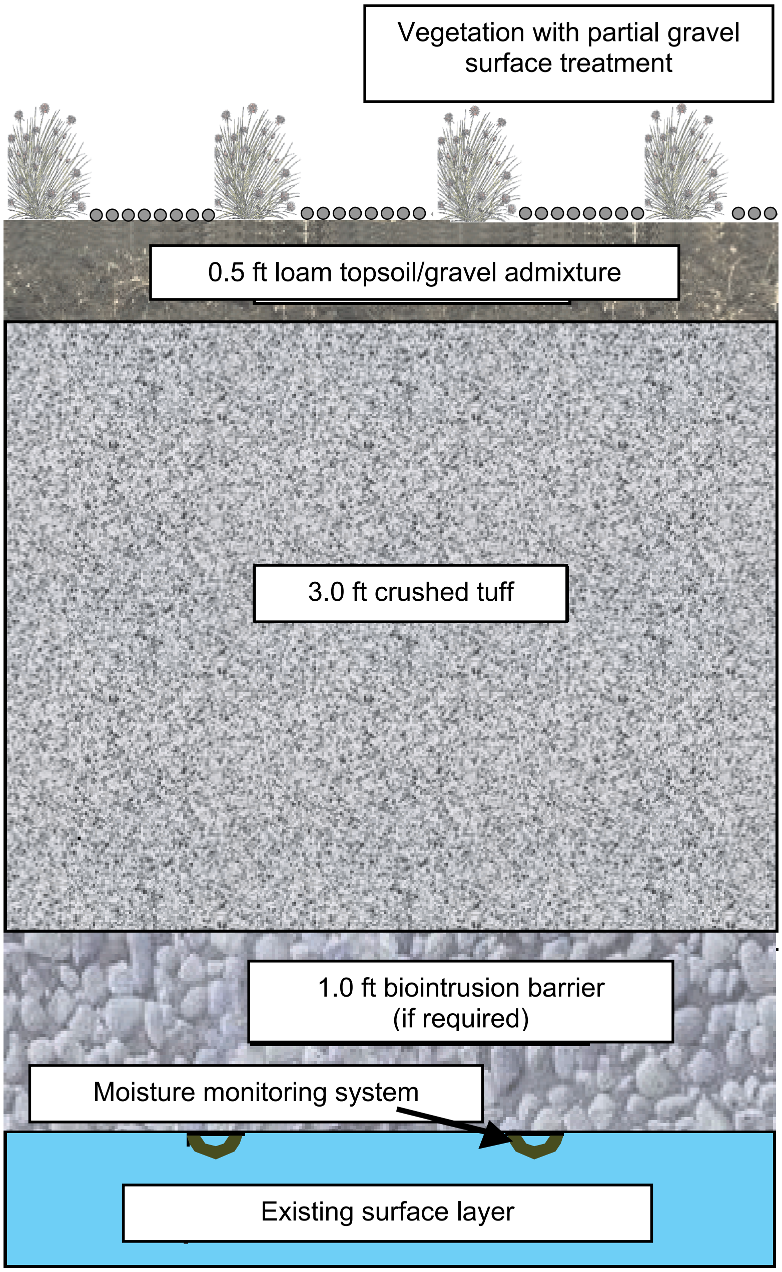


Figure 2.5-1. **Conceptual design of an engineered evapotranspiration cover with approximate dimensions**

2.5.3 Corrective Measure Alternatives 3a and 3b: Shaft Encapsulation and Engineered ET Cover

Alternatives 3a and 3b propose the use of currently available commercial encapsulation technologies combined with the construction of an engineered ET cover to prolong the ability of the existing shaft configurations to inhibit potential intrusion events, and to provide an additional barrier against the infiltration of moisture. Both partial encapsulation of the shafts and complete encapsulation of the shafts are evaluated. A more detailed description of encapsulation methods is provided in Appendix E. The four bullets listed for Alternative 2 also apply to Alternatives 3a and 3b.

The materials proposed for encapsulation of the MDA H shafts consist of a mixture of grout or micro-concrete incorporated into the native tuff present at the site. To be effective over a long period of time, the grout must remain chemically and physically stable. The mechanical properties of strength and stiffness are to be determined by bench-scale tests in order to maximize the structural integrity for the total system. Although existing climatic and geological conditions at MDA H will likely cause the surrounding soil to remain dry over the lifetime of the shafts, the grout will be designed for low permeability to water and minimization of leaching to remain optimally protective.

3a: Partial Shaft Encapsulation

The partial shaft encapsulation alternative proposes that an engineered vertical sidewall barrier be constructed at a predetermined depth and width around the entire perimeter of the MDA H shafts (Appendix E). The barrier would be formed by injecting a grout slurry mixed with ground native tuff into the subsurface. The primary intent of the barrier is to restrict plant roots and animals from migrating laterally along fractures in tuff and to discourage human intrusion.

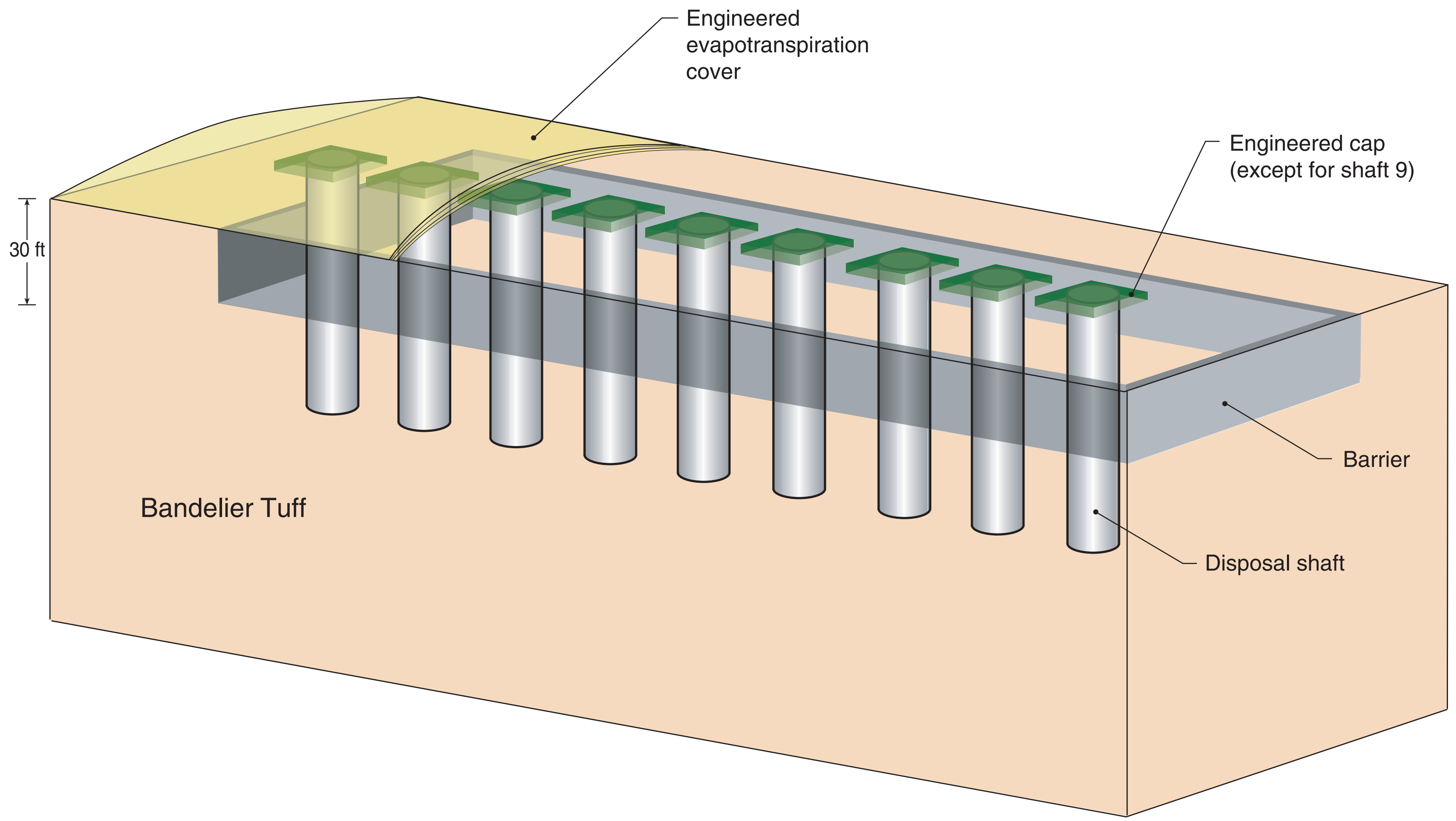
The thickness, permeability, and strength of the proposed vertical barrier would be engineered to meet the final requirements or objectives of the selected alternative, as discussed in Sections 2.2 and 3.0. Figure 2.5-2 is a conceptual view of the partial shaft encapsulation alternative for MDA H.

3b: Complete Shaft Encapsulation

The complete shaft encapsulation alternative proposes the construction of a perimeter wall around each shaft at MDA H to a depth of 60 ft. A predetermined area below each shaft would also be cemented/grouted to form a barrier. Figure 2.5-3 provides a conceptual view of the complete shaft encapsulation alternative for MDA H.

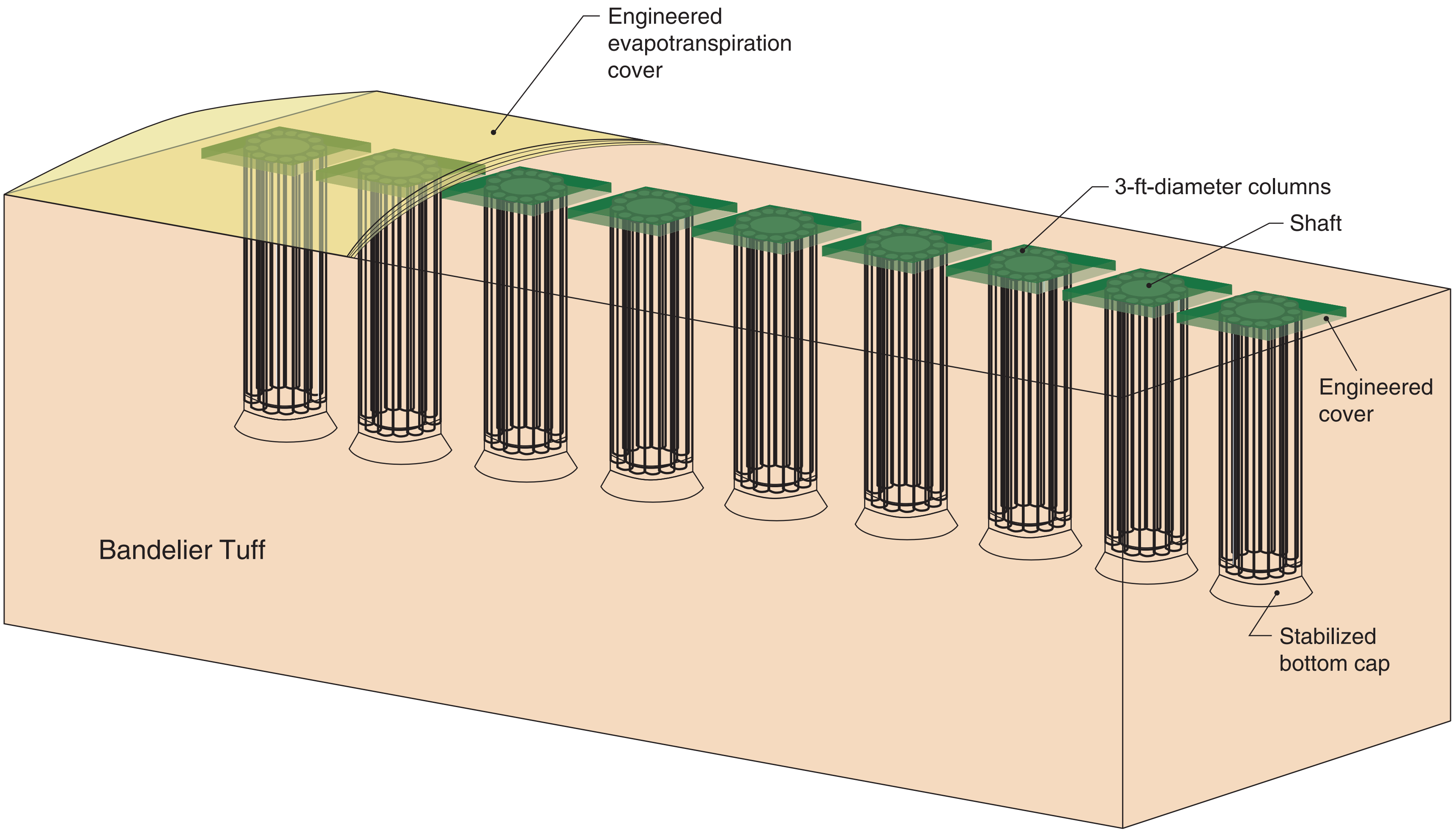
If this corrective measure alternative were selected, interlocking boreholes 2 to 3 ft in diameter would be constructed around the perimeter of each existing MDA H shaft by a rotary drilling rig, without actually drilling into or disturbing the contents of the shaft (Appendix E). As each new borehole is drilled around the perimeter of an existing MDA H shaft, a cement slurry, or other grout mixture, would be injected into the tuff around the existing shaft. A base or barrier would also be constructed under each shaft and would be connected to the perimeter wall to completely isolate each existing MDA H shaft from the surrounding tuff.

The complete shaft encapsulation alternative is the more robust of the two encapsulation alternatives because it offers the maximum protection against plant, animal, and human intrusion, and water infiltration. However, complete encapsulation may limit air circulation within the mesa top. This may in turn result in potentially higher in situ moisture levels, nullifying the benefits of the engineered ET cover and increasing the potential for uranium hydride formation (Appendix M).



F2.5-3, mdahcms, 022603, rlm_Rev. for MDA H CMS Rpt., 052203, cf

Figure 2.5-2. Partial encapsulation of shafts and engineered ET cover



F2.5-3/mdahcms/022603/rlm_Rev. for MDA H CMS Rpt., 052203, cf

Figure 2.5-3. Complete encapsulation of shafts and engineered ET cover

2.5.4 Corrective Measure Alternative 4: Complete Excavation and Off-Site Disposal

Alternative 4 proposes the complete removal and off-site disposal[3] of all waste at MDA H. Trenching would be conducted parallel to the line of the shafts and would take place in six-ft increments to expose the line of shafts. The tuff (overburden) adjacent to the shafts would be excavated to a depth of 62 ft bgs at a minimum slope of 1.5:1. The complete footprint of the excavation would measure approximately 260 ft x 120 ft x 62 ft (Figure 2.5-4).

For optimal worker safety, waste removal must be conducted using remote methods in the area immediately surrounding the existing shafts because of the HE inventory and potential pyrophoricity of the DU. Engineered controls, such as use of inert atmospheres, would be required to prevent ignition of uranium hydride during excavation. Excavated material containing uranium hydride would then be allowed to react under controlled conditions. The estimated volume to be removed by remote excavation is 4800 cubic yards (200 ft x 10 ft x 65 ft). Waste would be removed and transported to temporary structures for sorting, declassification, characterization, and packaging. Wherever practical, waste minimization techniques would be applied to the removed wastes (e.g., decontamination and recycling of metals). Excavated wastes that are determined to be hazardous or mixed wastes would require treatment to satisfy land disposal restriction requirements under 40 CFR 268 and 20.4.1.800 NMAC. Such treatment could be accomplished using existing Laboratory treatment facilities or at permitted off-site facilities. Due to security considerations, all excavation and declassification activities would be conducted under the cover of temporary surface structures. These structures might be considered nuclear facilities, which would impose additional requirements on design and operation.

The nearby roadways would require temporary closure during removal of HE and DU materials. In addition, sheet piling, shoring, and blast-proofing material would be used along approximately 200 ft of the Mesita del Buey Road right-of-way to protect road users and the integrity of the road structure. Piling would extend 15 ft above grade for security purposes and for potential blast shielding. Utilities along Mesita del Buey Road would have to be protected and/or relocated, including the water line supplying Areas G and L.

Waste shipped off site must meet Department of Transportation shipping requirements and TSD-specific waste acceptance criteria and permit conditions before shipment and disposal occurs. Most non-radioactive, hazardous wastes can be disposed of at a number of permitted hazardous waste disposal facilities. However, a portion of the hazardous waste at MDA H has the potential to be radioactively contaminated (i.e., mixed waste) and can therefore only be disposed of at facilities licensed to manage mixed radioactive/hazardous waste up to an authorized limit. Several TSD facilities may be appropriate for one or more categories of waste that can be anticipated in the MDA H inventory. These include

- Nevada Test Site,
- Duratek in Tennessee,
- Perma-Fix in Florida,
- Waste Control Specialists in Texas,
- Allied Technology Group in Washington, and
- Envirocare in Utah.

All waste requiring off-site disposal would be transported via Pajarito Road. It is estimated that a maximum of 1500 yd^3 of material would be transported on public roads[4].

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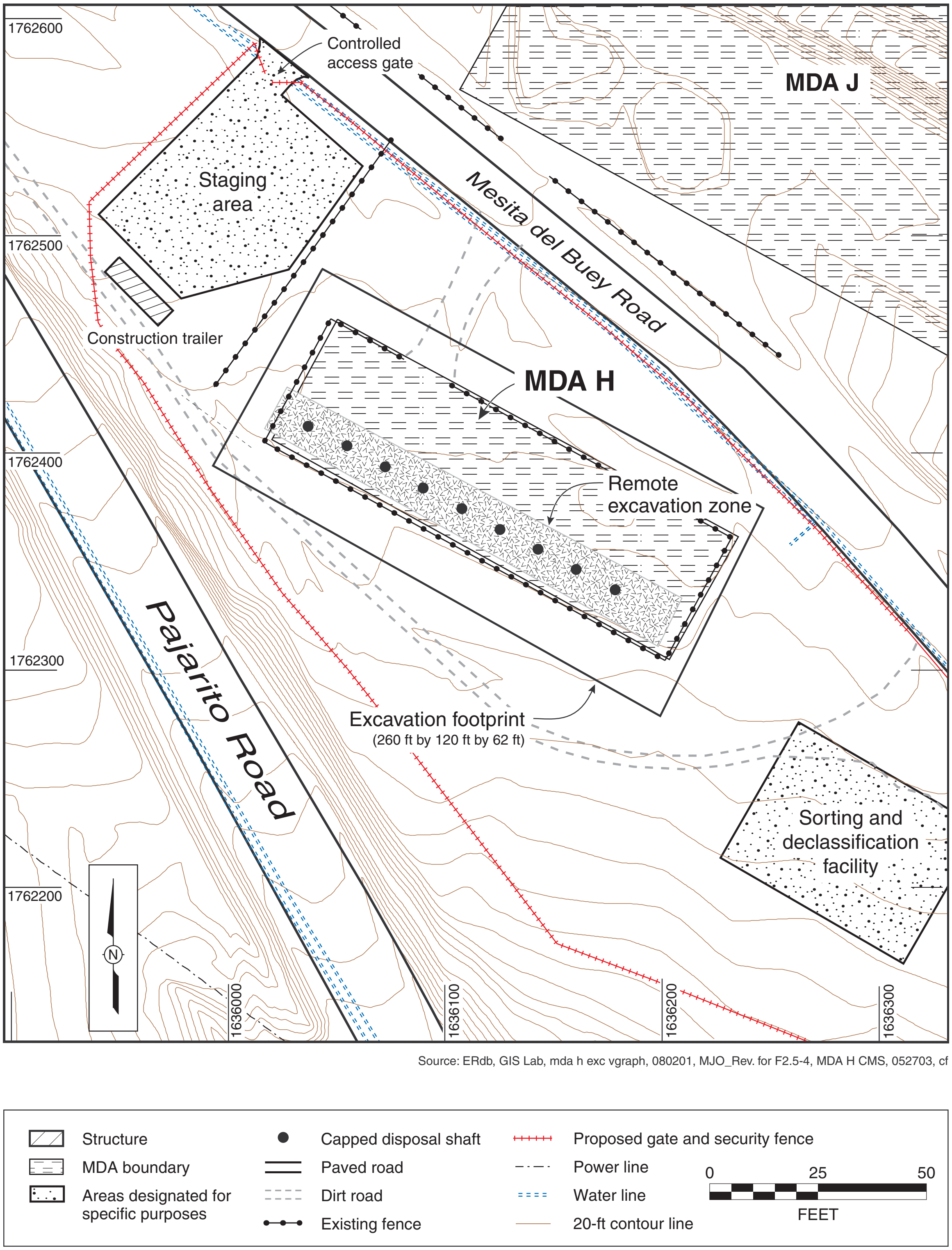
[3] Except any HE component that will be flashed at TA-16 or metal that can be recycled within the DOE Complex.

[4] Shaft volume = 9 shafts x 6-ft diameter x 60-ft depth = 720 yd^3 at 100% density. Assume the volume will double because of contamination in the tuff surrounding the shaft.



Source: ERdb, GIS Lab, mda h exc vgraph, 080201, MJO_Rev. for F2.5-4, MDA H CMS, 052703, cf

Figure 2.5-4. Site plan for corrective measure alternatives 4 and 5

All overburden materials removed under the excavation alternative would be placed on an approved site within 2000 ft of MDA H. A plastic liner to prevent cross contamination would be used to protect the site. Up to 40,000 cubic yards of overburden material would be removed from the excavation area (which will bulk up to approximately 50,000 cubic yards because of changes in density) resulting in approximately 5000 10-cubic-yard truckloads of overburden material. Any of the removed overburden materials that are characterized as industrial, hazardous, mixed waste or low-level waste (LLW) would be managed in accordance with applicable waste management and disposal requirements. Removed overburden materials determined to be contaminated would be replaced by clean fill. For the purpose of evaluating corrective measure alternatives, it is assumed that 10% of the removed overburden materials will be replaced with clean fill.

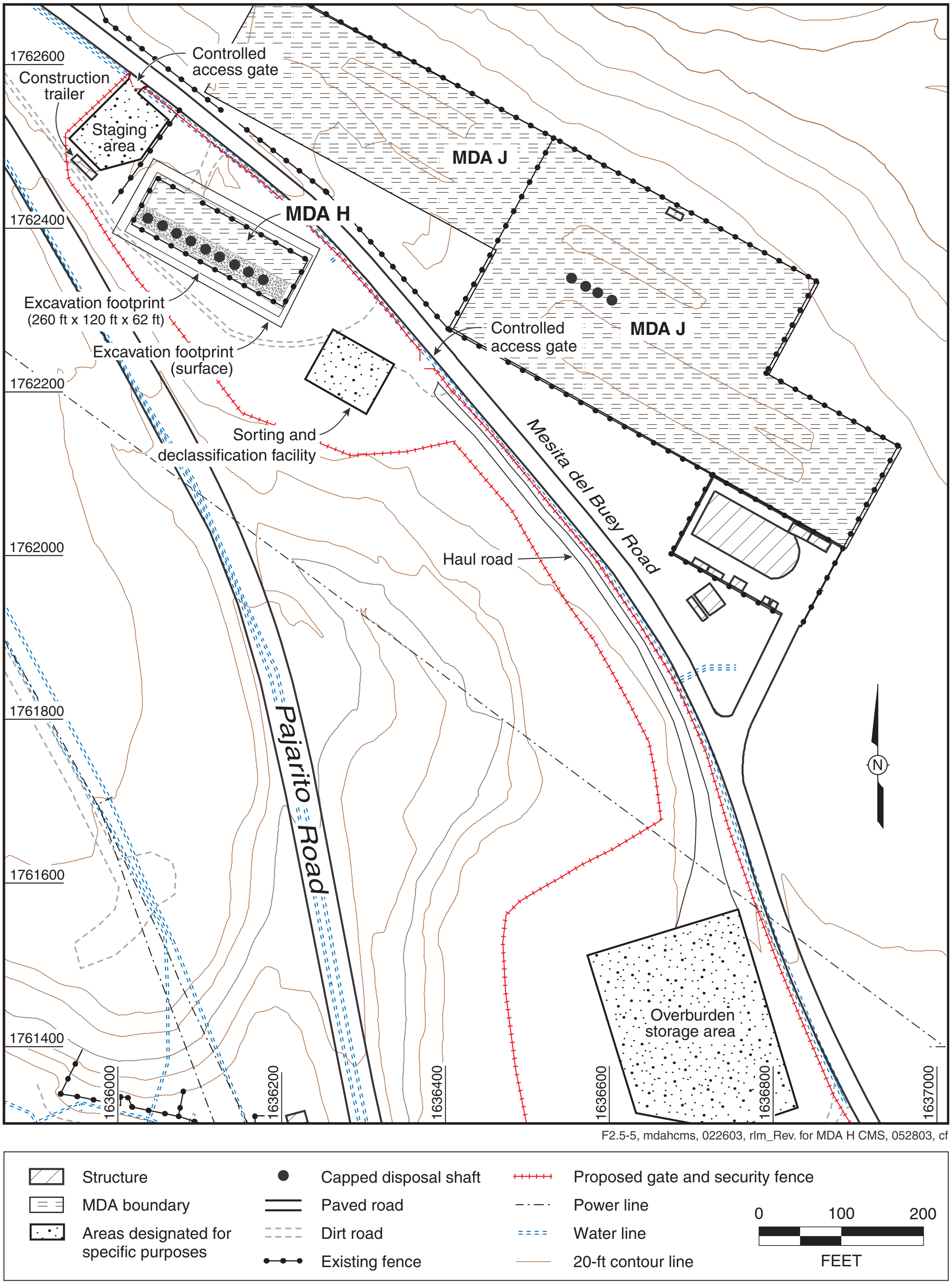
The facilities required for the excavation alternatives include a facility for waste sorting and controlled reaction of uranium hydride, a tent over the excavation for security purposes and protection from the elements, a waste declassification facility, a storage vault, and storage area for removed materials. Appropriate personal protective equipment (PPE) would be used in areas of material sorting, declassification, characterization, and packaging. Figure 2.5-5 illustrates a conceptual site design with the overburden storage area.

2.5.5 Corrective Measure Alternative 5: Complete Excavation and On-Site Disposal

The excavation component of Alternative 5 is the same as Alternative 4; however, the excavated wastes are disposed of on-site at the Laboratory, rather than off site. The declassified material removed from MDA H could be disposed of either in a Laboratory hazardous waste disposal unit that would have to be permitted and constructed, or as LLW at Area G at TA-54. Any non-hazardous, low-level radioactive waste excavated from MDA H, that meets the waste acceptance criteria for disposal at the Laboratory's Area G, could be disposed of there. The evaluation of disposal at Area G cannot be completed before waste has been excavated. Since mixed waste disposal is not permitted or allowed in any Laboratory area, the presence of mixed waste will negate full on-site disposal unless a new, permitted disposal unit that is suitable for mixed waste is constructed. Alternately, it may be possible that, following treatment to satisfy land disposal restrictions of 40 CFR 268 and 20.4.1.800 NMAC, treated wastes or residuals would not require disposal as hazardous or mixed waste.

Two options available for on-site hazardous waste disposal units are (1) a landfill permitted under RCRA, or (2) a Corrective Action Management Unit (CAMU). The latter would be less expensive and easier to construct and permit and is therefore the preferred approach.

The CAMU at SNL/NM provides an example of successful CAMU designation and provides for cost-effective, expedient cleanup of contaminated sites and management of hazardous remediation wastes. The SNL/NM CAMU includes multiple waste staging areas, a treatment area, and a containment cell capable of holding 1 million cubic feet of waste. The containment cell incorporates several innovative components, including a capillary barrier final cover and vadose zone monitoring system. The permit modification request and completion of a fully constructible design was completed by SNL/NM on an accelerated six-month schedule in 1996. The CAMU was designated through a permit modification to the HSWA module of SNL/NM's Hazardous Waste Facility Permit. Approval of the permit modification request was granted by EPA in October 1997, with CAMU construction beginning shortly after approval. Construction was completed in 1999.



F2.5-5, mdahcms, 022603, rlm_Rev. for MDA H CMS, 052803, cf

Figure 2.5-5. Conceptual design of corrective measure alternatives 4 and 5

The primary benefit of a CAMU is that it does not trigger land disposal restrictions (LDRs), minimum technological requirements (MTRs) for the cover, liner, and leachate collection and removal components; or Subtitle C permitting requirements. A CAMU may only be used for management of remediation wastes, not as-generated wastes. The CAMU regulations provide general performance criteria that are used by the regulatory authority in evaluating whether or not CAMU designation would be appropriate for a given facility. These criteria are summarized as follows:

- Facilitate implementation of reliable, effective, protective, and cost-effective remedies
- Minimize risks to humans or the environment during remediation
- Include use of uncontaminated areas only when shown to be more protective than use of a contaminated area
- Minimize future releases for wastes that remain in place after closure
- Expedite timing of remedy implementation
- Use treatment technologies (including innovative technologies), when appropriate, to enhance the long-term effectiveness of remedial actions
- Minimize land areas where waste will remain in place to promote future beneficial use.

Additionally, the CAMU regulations specify that the following four requirements will be addressed: define areal extent of the CAMU; describe design and operation; provide for groundwater monitoring; and address closure and post-closure requirements.

The assumptions pertaining to quantity and density of waste to be emplaced in a new Laboratory hazardous waste disposal unit (RCRA landfill or CAMU) are based on best professional judgment and knowledge of the MDA H inventory. This volume could be reduced by segregation, decontamination, treatment, and recycling of material in the inventory. Wherever practical, waste minimization techniques would be applied to the removed wastes (e.g., decontamination and recycling of metal). The estimated amount of material that can be recycled or disposed of in the DOE system is 129,000 lb. A total of 187,000 lb of DU (93,000 lb) and radioactive materials (94,000 lb) (assuming no mixed-waste classification) would be disposed at Area G. Excavated wastes that are determined to be hazardous or mixed wastes would require treatment to satisfy land disposal restriction requirements under 40 CFR 268 and 20.4.1.800 NMAC. Such treatment could be accomplished using existing Laboratory treatment facilities or portable treatment equipment. Following treatment, some treated wastes or residuals could still require disposal as hazardous or mixed waste. For estimating purposes, the size of the new hazardous waste disposal unit will be based on design of a cell that can hold 74,000 lb of waste from MDA H. Assuming a density of 2000 lb. per cubic yard, the hazardous waste disposal unit will be designed for a capacity of 40 cubic yards.

A hazardous waste disposal unit of this size is small; however, there are extensive regulatory and institutional requirements for siting, permitting, and constructing a new on-site disposal unit (e.g., NEPA requirements, the RCRA process for permitting a new land disposal unit, and the permit modification process for designating a CAMU). RCRA and the NMHWA require that a permitted landfill be equipped with a double composite liner system and an impermeable cap system on final closure, as well as a leachate collection and leak detection systems. The leachate collection and leak detection systems must have fluid monitoring sensors and provide for the removal of accumulated liquids. The criteria for designation of a CAMU are not as prescriptive as the requirements for a RCRA landfill; however, the design features must demonstrate protectiveness of human health and the environment. The size of the hazardous waste disposal unit would be large enough to accommodate MDA H hazardous wastes and would most likely be constructed as a larger facility than needed solely for MDA H due to the high fixed costs of obtaining an approved on-site disposal unit. If a CAMU were selected, waste acceptance from sites other than MDA H would be restricted to remediation wastes only.

The most likely outcome of an excavation alternative would be a combination of off-site and on-site disposal, decontamination, and recycling of waste.

Sections 2.5.5.1–2.5.5.7 provide details of each step of the excavation, handling, and transportation process for Alternatives 4 and 5. Many of the activities will have to be conducted outside the primary waste management area of MDA H. To ensure continued compliance with RCRA/NMHWA requirements, the specific design and operation of any waste handling/staging areas will require pre-approval by NMED.

2.5.5.1 Transporting Waste to Storage and Staging Areas

It is not possible to fully determine the most efficient and appropriate means of handling waste during removal operations before excavation is initiated at MDA H. Therefore, several waste handling methods were considered in the initial technology screening. For security purposes, wastes could only be moved a short distance from the point of excavation to a screening, sorting, and declassification area (Figure 2.5-5). Wastes would also have to be handled in a manner that would prevent uncontrolled ignition of uranium hydride.

A front-end loader would provide a suitable option for the conditions and waste types at MDA H. Remote operation of a front-end loader has been shown to be effective in removing HE wastes at MDA P (TA-16).

Once wastes have been screened and segregated, they must be transported to a staging or storage area. Bulk transport by dump truck is a viable and suitable option for the site conditions and waste types at MDA H.

Wastes that have been screened and segregated could also be placed in waste containers, such as rolloff boxes and drums that could be used both for transport and secure storage. Container transport, via truck, is a viable method and suitable to the site conditions and waste types at MDA H.

Although conveyors are useful for moving small waste materials, the majority of waste inventory items at MDA H are unsuitable for conveyor transport because they are too large and/or too heavy for a conveyor.

2.5.5.2 Waste Segregation/Sorting

To ensure safety and allow for required waste characterization and security, any materials excavated from MDA H would require segregation and sorting in a secure area located under cover of a tent or dome. Sorting activities would be conducted using manual, mechanical sieve, magnetic, and washing/flotation methods.

Manual

Manual inspection, identification, and sorting of waste items allow classified materials to be segregated from nonclassified materials. Manual sorting has been conducted at the Laboratory (MDA P) and at SNL/NM for excavated wastes similar to those at MDA H and is a viable technique for the wastes at MDA H.

Mechanical Sieve

Sieving separates waste objects from soil and gravel backfill. However, it cannot provide complete separation of waste from soil if very small objects are present. During excavation, efforts would be taken to avoid mixing surrounding clean soil or crushed tuff with excavated wastes. This technique is suitable for the wastes at MDA H.

Magnetic

Separation of ferrous and other magnetic metals by electromagnetic methods is useful in certain waste removal applications. However, many of the metals in the MDA H inventory are not magnetically susceptible. Therefore, this technique is not suitable for the wastes at MDA H.

Washing/Flotation

Soil washing or flotation of light waste components causes certain materials to be segregated from soil. At MDA H, little or no backfill is present in the disposal shafts, and it is expected that the majority of the wastes are identifiable discrete objects easily separated from adjacent materials. Therefore, this technique provides no benefit for separating the wastes at MDA H and is not suitable.

2.5.5.3 Declassification

All of the waste at MDA H was considered classified at the time of its disposal. Because security practices and requirements have changed since the time of disposal, certain objects in the MDA H inventory may no longer be considered classified. Therefore, if excavated, each item in the MDA H inventory will require a classification review.

Official Declassification

Items not meeting current classification criteria would be declassified and managed in accordance with applicable waste management requirements. Declassification is a well-established procedure and a suitable option for certain wastes in the MDA H inventory.

Physical Destruction

Classified shapes can be declassified by means of crushing, cutting, incinerating, melting, dissolving, or machining. The most appropriate means of destruction is dependent upon the particular characteristics of each classified shape. Therefore, all destruction methods are considered viable options.

2.5.5.4 Volume Reduction

The Department of Energy Pollution Plan (www.eh.doe.gov/p2/) requires the minimization of waste volumes at the point of generation prior to shipping to a TSD facility; therefore, volume reduction technologies must be considered.

Crushing

Crushing or compaction is a standard well-demonstrated volume reduction technique applicable to many types of waste. It is expected that a portion of the volume of removed MDA H wastes are compactable. Compaction and crushing are suitable techniques for non-explosive waste at MDA H.

Cutting

Very large metallic items are known to have been disposed of in the MDA H shafts. For purposes of handling, declassifying, storing, shipping, and disposing, size reduction is beneficial. This technology is well demonstrated and is suitable for non-explosive wastes at MDA H.

Incineration

Approximately 14% of the waste inventory at MDA H consists of paper, photographic film, plastic, and recording media (Figure 2.1-1). The paper, film, and recording media are suitable for incineration. This technology is well demonstrated and is a suitable option for the paper and recording media in the inventory at MDA H.

Thermal Treatment

Open burning of explosives in the MDA H inventory is also a suitable technology for deactivation and would be required to satisfy land disposal restriction requirements under 40 CFR 268 and 20.4.1.800 NMAC. If performed, the burning of explosives would be conducted only at permitted or interim-status Laboratory burn areas by trained explosives personnel.

2.5.5.5 Metal Decontamination and Recycling

The DOE Directive on release of materials from DOE facilities (www.energy.gov/HQPress/releases00/julpr/pr00182.htm) states that recyclable metals must remain within the DOE system and cannot be sent to commercial metal recyclers. Non-hazardous, non-radioactive metals may be recycled through a Laboratory-operated recycling facility when its acceptance criteria are met.

The following metals are suitable for recycling within the DOE system by metal melting even if they are radioactively contaminated: stainless steel, carbon steel, iron, galvanized metal, nickel alloys, chromium alloys, and ferrous alloys. This process is also suitable for small quantities of copper, aluminum, brass, and bronze.

The following metals are suitable for recycling within the DOE system following decontamination: lead, stainless steel, carbon steel, iron, copper, aluminum, nickel, chromium, galvanized metal, and brass.

In the past, there have been markets in the Department of Defense (DoD) for DU to be used for munitions, counter weights, or armor. DU not contaminated by other radioactive materials or hazardous wastes may be recycled.

Enriched uranium, such as the uranium fuel elements present in the MDA H shafts, is not likely to be recyclable within the DOE system. The fuel elements may be unusable in their current condition, and there is no market for a small quantity of this material in the nuclear fuel industry.

2.5.5.6 Deactivation Treatment

Water-reactive wastes, such as the lithium hydride present at MDA H, may be deactivated by reaction with water and/or alcohol. Deactivation of reactive wastes would be required to satisfy land disposal restrictions under 40 CFR 268 and 20.4.1.800 NMAC. One treatment method historically used at the Laboratory is batch treatment with water. Wastes containing uranium hydride would have to be reacted before further handling or disposal is possible. One alternative would be to allow the hydride and uranium to ignite under controlled and contained conditions that would prevent release of uranium oxide particulates produced during ignition.

2.5.5.7 Waste Transportation

Two alternatives are available for shipping and transporting waste to off-site TSD facilities: use of trucks and use of railcars (although the waste would have to leave the Laboratory by truck to be transported to a railcar). The best transportation method cannot be determined prior to characterizing the waste. Therefore, both options are considered equally viable for the purposes of assessing the excavation alternatives.

Transportation distances to off-site facilities greatly impact disposal cost, and the probability of an accident increases the greater the distance the waste is transported. Whenever possible, the closest site permitted to accept a given waste type would be chosen (Omicron 2001, 70229).

3.0 EVALUATION OF THE CORRECTIVE MEASURE ALTERNATIVES

This section evaluates each of the final corrective measure alternatives described in Section 2.5 based on the technical, environmental, human health, and institutional criteria specified in Module VIII (EPA 1990, 1585; EPA 1994, 44146) and the CMS Plan (LANL 2001, 70319) and summarized in Section 2.2. Cost estimates are also developed for each of the alternatives. The corrective measure alternatives evaluated are listed below.

- Containment Alternatives
  - Alternative 1: Upgrade Existing Surface Layer
  - Alternative 2: Engineered ET Cover
  - Alternatives 3a and 3b: Partial or Complete Encapsulation and Engineered ET Cover
- Excavation Alternatives
  - Alternative 4: Complete Excavation and Off-Site Disposal
  - Alternative 5: Complete Excavation and On-site Disposal

3.1 Analysis and Evaluation of Technical Issues Including Performance, Implementability, Reliability, and Safety

Each of the final corrective measure alternatives is evaluated based on four technical issues: performance, reliability, implementability, and safety.

3.1.1 Performance

The following issues are addressed when assessing the performance of an alternative:

1. Effectiveness—the ability to perform intended functions such as containment, diversion, removal, destruction, or treatment; and
2. Useful Life—the length of time the level of effectiveness can be maintained.

3.1.1.1 Performance of Alternatives 1, 2, and 3

The current native vegetative cover has proven effective in preventing releases (except for VOCs and tritium in the subsurface) from waste disposed in the shafts at MDA H with minimal maintenance (LANL 2001, 70319). If properly maintained, the existing cover or a new engineered ET cover would perform its intended containment function. Contaminant transport modeling of the effectiveness of the existing cover demonstrated that no contaminants would reach the regional groundwater table beneath MDA H during the 1000-yr evaluation period (Appendix J). The useful life of the existing or a new cover can be extended indefinitely if the cover is maintained properly and site access is restricted. Even with loss of institutional controls, the 3-ft thick concrete caps over each shaft will not erode over the 1000-yr evaluation period (Alternative 1) and the engineered ET cover will not completely erode over the 1000-yr evaluation period (Alternatives 2 and 3) (Appendix H).

The reactive materials (HE and DU) would not affect the performance of the covers. The HE disposed in Shaft 3 would require an initiator to detonate an explosion and oxygen in disposal shafts is insufficient to sustain a uranium hydride fire. The DU will all be converted to a stable oxide form in 200–1000 yr (Appendix M).

3.1.1.2 Performance of Alternatives 4 and 5

Excavation of the materials disposed in the MDA H shafts would result in removal of the source of contaminants, thus eliminating future transport of contaminants.

3.1.2 Implementability of Alternative Corrective Measures

The following issues are addressed when assessing the implementability of a remedial alternative:

1. Constructability—the complexity of installation, and
2. Time—the time it takes to implement a corrective measure alternative and the time it takes to actually see beneficial results.

3.1.2.1 Implementability of Alternative 1: Upgrade Existing Surface Layer

Implementation of this alternative would require upgrading the existing native vegetative cover. Upgrades to the existing cover are easily constructible. Re-grading the site is routine. The topsoil and gravel mulch that make up the upgraded vegetative cover are relatively easy to install. A vegetative cover would be established within 2 yr. The gravel/soil admixture would serve to control erosion of the cover while the vegetation is establishing itself in the topsoil beneath the gravel. Thereafter, the upgraded cover would provide additional erosion control and decrease infiltration of moisture through the cover by the process of transpiration. The topsoil would promote maximal plant coverage.

Moisture-monitoring equipment would be installed within and below the cover and a neutron probe would be used to monitor moisture levels in existing boreholes to verify that the cover was performing its design of losing moisture rather than gaining moisture. TDR moisture-monitoring probes, that can be tied into an automated data collection system, will be difficult, if not impossible, to install beneath the existing cover to proper depths due to interference of the existing concrete covers over the shafts.

The time to design and upgrade the existing native vegetative cover is six months and the vegetative cover will not be fully developed for two years.

The water line supplying TA-54 will be upgraded by adding pressure sensors and automatic shutoff valves within the six-month design and construction duration in order to prevent line breakage from causing large volumes of water infiltrating the disposal shafts. This upgrade is applicable to all alternatives.

The equipment and material required to implement Alternative 1 are readily available.

3.1.2.2 Implementability of Alternative 2: Engineered ET Cover

Implementation of this alternative would require construction of an engineered ET cover. Engineered ET covers have been determined to be effective throughout the Southwest (LANL 1998, 71345, Dwyer et al. 2000, 69673) and are relatively easy to install. It is estimated that the engineered ET cover for MDA H could be designed in three months while construction of the cover is estimated to take two months. As with Alternative 1, a vegetative cover would be established within 2 yr.

Moisture-monitoring equipment would be installed within and below the cover and a neutron probe would be used to monitor moisture levels in existing boreholes to verify that the cover was performing its design of losing moisture rather than gaining moisture.

The equipment and material required to construct the engineered ET cover are common construction material that are readily available.

3.1.2.3 Implementability of Alternative 3: Encapsulation and Engineered ET Cover

Implementation of this alternative would require construction of vertical barriers and an engineered ET cover. As discussed in Alternative 2, an engineered ET cover is easily constructible. Vertical barriers are also easily constructible. Existing commercial technologies can be used to place the engineered vertical barriers to a depth of 60 ft or greater. These technologies are well established, including specific worker health and safety protocols. The materials used in construction of the vertical barriers are not hazardous. Since the installation of the barriers requires no disturbance of the shafts, there are no safety issues associated with the hazardous materials in the MDA H inventory. Grout could also be injected into the tuff beneath the shafts from areas outside the shafts so that the material in the shafts is not disturbed. Bench-scale and/or pilot-scale studies are required to develop the correct grout mixture to meet specifications for construction of the barriers.

Moisture-monitoring equipment would be installed within and below the cover and a neutron probe would be used to monitor moisture levels in existing boreholes to verify that the cover was performing its design of losing moisture rather than gaining moisture. The total time required for design and implementation of this alternative, including bench and pilot tests, and construction is 1 yr. An additional 2 yr would be required to establish a vegetative cover. The implementability of the engineered ET cover would be the same as for Alternative 2.

3.1.2.4 Implementability of Alternatives 4 and 5: Source Removal and Off-Site Disposal/On-site Disposal

Implementation of these alternatives would require

- conducting a hazard categorization and hazard analysis to identify nuclear safety analysis requirements associated with excavation of HE and potentially pyrophoric radioactive materials;
- remote handling of high explosive and DU waste material and personal protective equipment (PPE) up to level B (supplied air) to reduce worker exposure;

- engineering controls to prevent uranium hydride fires during excavation;
- construction of temporary security enclosures over the removal area and in any area designed for sorting, declassification, and reshaping operations;
- controlled reaction of pyrophoric uranium objects removed from the shafts;
- sorting and declassification of shapes and related materials prior to disposal. Any classified waste removed from MDA H must undergo a declassification review and potential reshaping such as milling, crushing, shredding, or other methods before it can be recycled or disposed off site; and
- temporary closing of adjacent roads and possible relocation of utilities because overburden material removed from the excavation would need to be transported to an adjacent area.

Figure 2.5-5 illustrates the facilities required for implementing Alternatives 4 and 5 including a waste sorting facility, excavation tenting and moisture protection, a waste declassification facility, storage vault, and overburden storage area. Appropriate security measures would need to be developed, presented in a site-specific security plan, and approved. Safety measures would include remote excavation due to the presence of HE and other potentially reactive materials (e.g., lithium hydride and DU) in certain or possibly all of the waste disposal shafts. Appropriate PPE would be required in areas of material sorting and declassification.

The presence of pyrophoric uranium hydride in shafts raises implementability concerns. Controls would have to be implemented (e.g., inert atmospheres) to prevent spontaneous ignition of these materials during excavation. It would then be necessary to maintain these materials under stable conditions until transferred to a facility where they could be reacted/ignited under controlled conditions.

A number of implementability issues arise from the logistics of excavating and transporting waste. Utilities would have to be protected and/or relocated along Mesita del Buey Road. Sheet piling and shoring is required to be installed along approximately 200 ft of the Mesita del Buey Road right-of-way to protect the road structure and road users. Piling extending 15 ft above grade for security purposes and to act as potential blast shielding would need to be installed. It is estimated that at least 1500 cubic yards of material would require transportation on public roads to recycle facilities or off-site disposal sites. In addition, Mesita del Buey Road and Pajarito Road could require temporary closure during HE and DU material removal. This closure may impact TA-54 operations and/or regular traffic flow on Pajarito Road.

In addition, Alternatives 4 and 5 involve waste management requirements. Materials removed from the shafts would first be conveyed to a storage and sorting area, covered with a temporary structure where excavated waste materials would be evaluated for explosive and radiation properties. The wastes would then be sorted for classification, decontamination, disposal at a permitted on-site or off-site location, or recycled. HE materials would be transported to TA-16 for treatment. The selection of treatment or disposal location would depend on the waste characterization results for the hazardous and radioactive content of each waste.

Approximately 50,000 cubic yards of material (overburden) would be removed from the excavation and transported for temporary storage on the new haul road, shown on Figure 2.5-5, to a pre-approved site located within 2000 ft of the excavation site. The overburden material would be placed on a liner to prevent possible cross contamination. After completion of shaft excavation, the overburden material would be retransported back to the MDA H area and used as backfill. Additional clean fill would need to be hauled to the site to replace the volume of the removed waste. It is estimated that these activities would result in the transportation of approximately 5000 10-cubic-yard truckloads of material back and forth over the newly constructed haul road. It is believed that the majority of the overburden material would be able to be replaced in the excavation. It is possible that some of the overburden would be characterized as LLW, hazardous waste, and/or mixed waste. In this case, the existing overburden would need to be replaced by clean fill and would be subject to appropriate disposal laws and requirements. Once the excavated area has been backfilled, the site would be regraded and revegetated.

The time to design, implement, and complete Alternatives 4 and 5 is estimated to be 46 and 70–118 months, respectively. Alternative 4 requires 6 months design and 40 months construction. Alternative 5 requires an additional 24–72 months (12–60 months for permitting and 12 months for construction of the RCRA disposal unit).

3.1.3 Reliability Evaluation of Corrective Measure Alternative

The evaluation of reliability has two components: (1) the demonstrated and expected reliability of the technology being employed, and (2) the frequency and complexity of maintenance and operation.

3.1.3.1 Reliability Evaluation of Alternative 1: Upgrade Existing Surface Layer

The results of the RFI demonstrated that the MDA H native vegetative cover has been reliable and effective in preventing releases of material from the disposal shafts at MDA H (with the exception of subsurface releases of VOCs and tritium) for over 40 yr with minimal maintenance. Upgrading the cover and its maintenance would provide additional protective measures ensuring that no moisture would migrate through the waste materials disposed in the shafts. The cover would be inspected and maintained yearly (after the vegetative cover is established) to ensure that the vegetative cover provides an adequate barrier to plant and animal intrusion and prevents erosion of the cover. Even with loss of institutional controls, the 3-ft thick concrete caps over each shaft will not erode during the 1000-yr evaluation period (Appendix H).

Continuous monitoring of moisture levels within and below the cover would ensure that subsurface moisture levels remain below those specified in pre-established levels negotiated with NMED. The reliability of the monitoring equipment is based on existing proven technology that is being used routinely in industry and by the Laboratory for monitoring subsurface moisture at TA-49 and TA-54. The water line supplying TA-54 would be upgraded as discussed in Sections 3.1.2.1 to prevent future loss of water. Run-on/run-off controls would prevent erosion.

3.1.3.2 Reliability Evaluation of Alternative 2: Engineered ET Cover

Engineered ET covers have been demonstrated to be reliable because they use “natural” climatic and vegetation ET conditions at the site to minimize downward water movement; and engineered ET covers have been installed at several locations in the southwest where their performance has been documented, if properly maintained (Dwyer et al. 2001, 69673).

In order to ensure the continued performance of an engineered ET cover, regular maintenance and monitoring of the site would be required throughout the institutional control period once the vegetative cover has been established. Therefore, the site would (1) remain fenced to provide protection against unexpected disturbance of the cover; (2) have regular maintenance inspections to ensure the integrity of the vegetative cover and to assure the prevention of excessive erosion or gullying, ponding of water, and quality of the vegetative cover and; (3) be monitored to ensure that subsurface moisture levels are below those agreed upon with NMED. Even with loss of institutional controls, the engineered cover will not completely erode over the 1000-yr evaluation period (Appendix H).

The reliability of the monitoring equipment, run-on/run-off controls and water line replacement is similar to the reliability discussed for Alternative 1.

3.1.3.3 Reliability Evaluation of Alternative 3: Encapsulation and Engineered ET Cover

The encapsulation alternative at MDA H consists of the installation of an engineered ET cover plus the injection of grout mixtures to encase shafts with vertical barrier walls.

Bench and/or pilot scale studies would be conducted to determine the appropriate grout mixture for site-specific conditions to ensure the long-term reliability of encapsulation for the evaluation period. Various mixtures would be formulated and standard construction industry tests conducted to determine a formulation that would achieve design specifications.

In order to ensure the continued performance of an engineered ET cover and encapsulation, regular maintenance and monitoring of the cover would be conducted throughout the institutional control period. Therefore, the site would (1) remain fenced to provide protection against unexpected disturbance of the cover; (2) have regular maintenance inspections to ensure the integrity of the vegetative cover and to assure the prevention of excessive erosion or gullying, ponding of water, and quality of the vegetative cover and; (3) be monitored to ensure that subsurface moisture levels are below those agreed upon with NMED. Even with loss of institutional controls, the engineered cover will not completely erode over the 1000-yr evaluation period (Appendix H).

The reliability of the cover, monitoring equipment, run-on/run-off controls, and water line replacement is similar to the reliability discussed for Alternative 2.

3.1.3.4 Reliability Evaluation of Alternatives 4 and 5: Source Removal and Off-Site/On-site Disposal

Complete removal of all wastes disposed in the shafts MDA H and residual material in surrounding tuff imposes no requirements for long-term maintenance and/or monitoring because upon completion of excavation and disposal activities, no wastes would remain at MDA H. Field instrumentation that would be used to screen material to be excavated to determine the limits of the excavated area have been shown to be reliable in identifying excavation limits. The reliability of on-site and off-site permitted facilities is under the purview of the regulatory agency that oversees compliance at the site.

3.1.4 Safety Evaluation of Corrective Measure Alternatives

The evaluation of safety has two components: (1) assessment of threats to the safety of nearby communities and environments, and (2) assessment of threats to workers implementing the corrective measure.

Community risk involves the risk to nearby communities and to motorists traveling along Pajarito Road from potential fires and explosions during the implementation of remedial alternatives. These risks will be evaluated in a Safety Analysis for excavation alternatives and appropriate controls instituted.

Worker risk involves the risk incurred to workers both during the implementation of the corrective action for all five alternatives and during the 100-yr institutional control maintenance and monitoring period for the three alternatives that involve leaving waste in place.

3.1.4.1 Safety Evaluation of Corrective Measure Alternatives 1, 2, and 3

The evaluation of safety for implementing and monitoring Alternatives 1, 2, and 3 focuses on site-worker risks because of restricted access to Pajarito Road. There is no risk from HE detonation because an initiator would be required to detonate the HE. Insufficient oxygen is present in the shafts to sustain a uranium hydride fire (Appendix M).

Near-term exposures at MDA H are limited to Laboratory employees who may enter the fenced area for purposes such as final cover construction, environmental monitoring, or grounds/cover maintenance. During cover construction, the site worker's exposure will be evaluated in the site-specific health and safety plan and appropriate personnel protective equipment will be provided and engineered controls established to protect site workers. The site-worker scenario evaluates risk under the provision that for the first 100 yr after implementation of a containment alternative, institutional controls remain in place. These controls include site surveillance, maintenance, and monitoring activities designed to prevent the impacts of deep-rooting plants and burrowing animals on the transport of buried waste in the MDA H shafts to the surface.

During the 100-yr institutional control period, the site worker may be exposed via direct dermal absorption and incidental ingestion exposures to contaminated soil particles, external irradiation from radionuclides in soil, and inhalation exposure to vapor-phase contaminants or contaminants on suspended soil. Potential human health impacts include incremental cancer risk from chemicals, systemic hazard from chemicals, and radiation dose from radionuclides.

During the 100-yr period of institutional control, the worker-exposure scenario involves monitoring and site maintenance activities. The frequency of monitoring and maintenance activities was assumed to be 2 hr/week over a 50-week working year. This is likely to be an overestimate of actual exposure intensity and is intended to reflect reasonable maximum exposure conditions. The simulation models used in the safety assessments are the same as those used for the long-term assessments presented in Section 3.3.1 and Appendix F. Worker health impacts are modeled using the upper-bound value of uranium inventory at MDA H and the assumption of immediate availability of uranium for dissolution and transport to provide the most conservative dose estimate.

Calculated dose rates for the site worker over the 100-yr institutional control period are shown in Figure 3.1-1. The dose from radiation shown in the figure is the 50-yr whole-body effective dose equivalent.

The majority of the total dose to the worker is contributed by uranium-234 and uranium-238, especially at earlier times within the 100-yr period. Radium-226 increases in importance over the 100-yr institutional control period and at 100 yr contributes more to total dose than does uranium-238 and about equal dose as uranium-234. The external irradiation exposure pathway is also the predominant exposure route over the first 100 yr. The worker dose over the first 100 yr reaches a maximum of approximately 0.0003 mrem/yr at year 100, a value that is four to five orders of magnitude below the target dose limit of 15 mrem/yr (see Section 2.2).

The ICR for the site worker over the 100-yr institutional control period is shown in Figure 3.1-2. The ICR is calculated as the product of chemical intake and the chemical-specific slope factor, summed across exposure routes. Virtually all of the ICR for the site worker is due to exposure to RDX via incidental soil ingestion. The worker ICR over the first 100 yr reaches a maximum of approximately 4×10^{-11} at year 100, a value that is five orders of magnitude below the lower end of the 10^{-6} to 10^{-4} risk range used to evaluate potentially unacceptable cancer risk (see Section 2.2). The chemical hazard index (HI) for the site worker over the 100-yr institutional control period is shown in Figure 3.1-3. Approximately 75% of the site-worker risk from chemical hazard is related to inadvertent soil ingestion. The remaining 25% is due to inhalation of suspended soil (dust). The chemical hazard via both these exposure pathways is associated with exposure to barium and mercury in approximately equal proportions. The HI value of 0.0001 is five orders of magnitude below the target value of 1 (see Section 2.2).

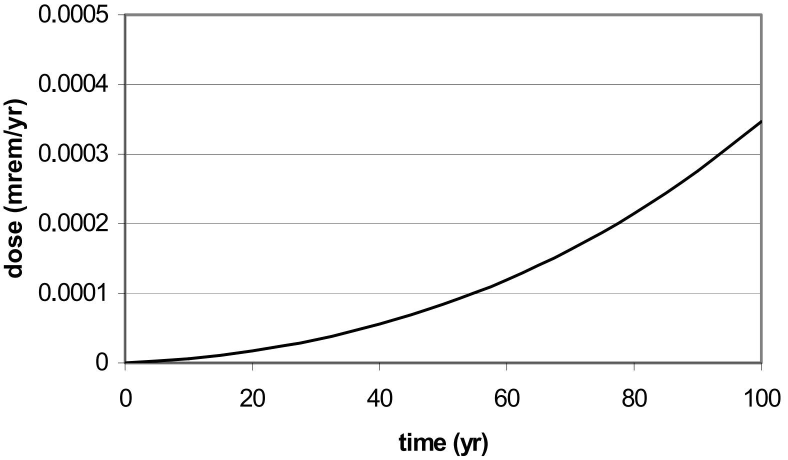


Figure 3.1-1. **Dose rate for the site worker exposure scenario; Alternatives 1, 2, and 3**

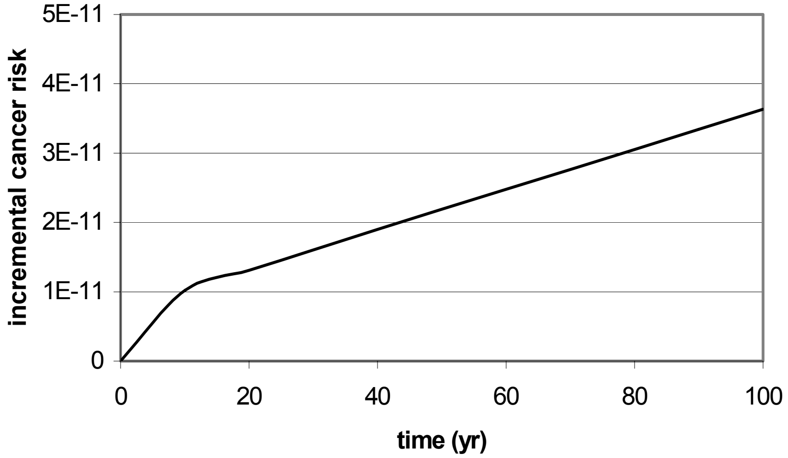


Figure 3.1-2. **Incremental cancer risks for the site-worker exposure scenario; Alternatives 1, 2, and 3**

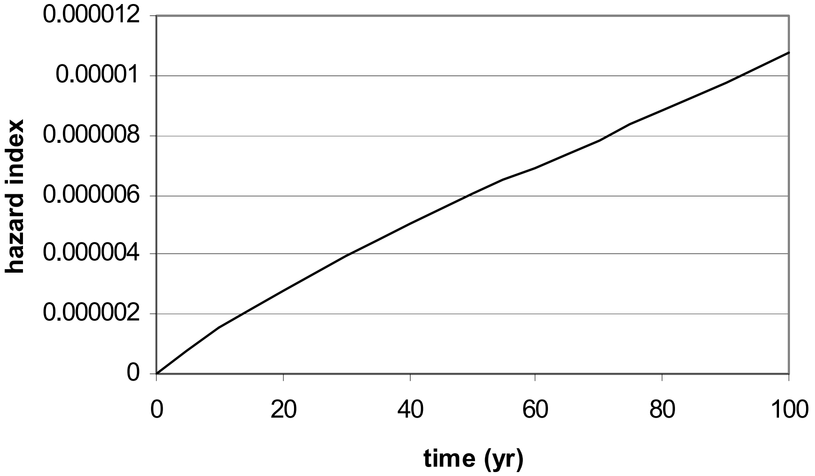


Figure 3.1-3. **Hazard index for the site-worker exposure scenario; Alternatives 1, 2, and 3**

Radiation dose, ICR, and HI for times following the 100-yr institutional control period are addressed in Section 3.3.1. A description of the conceptual model of constituent transport among environmental media, and the computer simulation models used to calculate transport and subsequent health effects, are also provided in Section 3.3.1. More detail on the constituent transport models is provided in the appendices to this CMS report. Details of the equations and parameter values used to calculate worker effects are provided in Appendix H.

3.1.4.2 Safety Evaluation of Alternative 4 and 5: Source Removal and Off-Site Disposal/On-Site Disposal

Worker risk associated with the implementation of Alternatives 4 and 5 was based on the requirement that all workers would adhere to rigorous DOE, state, and federal worker safety regulations and that engineered barriers would be designed to protect workers. During planning and implementation of Alternatives 4 and 5, engineering controls would be emplaced that are designed to ensure that no worker would be exposed to risks above the levels specified by DOE, state, and federal worker safety regulations. Alternatives 4 and 5 involve workers spending 286,000 worker hours on site versus a maximum of 10,800 worker hours for of Alternatives 1, 2, and 3.

Potential accidents due to extensive excavation and associated waste handling include industrial hazards/accidents, fires with release of radioactive/hazardous materials, explosions and associated releases of radioactive materials, spills of hazardous and radioactive materials, inadvertent exposures to penetrating radiation, and transport accidents. In addition, workers at off-site disposal locations would be exposed to hazards associated with the handling and disposal of these wastes.

Both unmitigated and mitigated worker and transportation risks associated with Alternatives 4 and 5 are assessed (Omicron 2001, 70229). Unmitigated risk refers to the risk from postulated accident scenarios for which no controls are credited in reducing either the likelihood or consequences of an accident, while mitigated risk is based on crediting the reduction of the likelihood or consequences of an accident to the implementation of controls pre-established for all remediation activities.

A risk assessment of all remediation activities was performed according to various accident categories (Omicron 2001, 70229). These remediation activities include (1) site preparation, (2) site excavation, (3) sort/segregation, (4) declassification, (5) packing/loading, (6) transportation, and (7) site restoration. Accident categories include industrial hazards/accidents, potential fires with release of radioactive/hazardous materials, potential explosions and associated releases of radioactive materials, spills of radioactive materials, and inadvertent exposures to penetrating radiation. The evaluation goals were to determine (1) the overall worker dominant risk remediation activity, (2) the dominant worker risk accident category for each of the remediation activities, (3) the risk to the public from remedial activities, and (4) the identification of major controls that could be instituted to prevent or mitigate the dominant risk.

Of the more than 150 accidents postulated from remedial activities, the total potential risk is dominated by standard or industrial types of accidents (58%). For most remedial activities, the second-most dominant risk is from explosions (27%), followed by excavation (26%) and transportation (7%).

Implementing a variety of administrative and engineered controls (i.e., mitigating risks) reduces the risk for non-standard industrial accidents by nearly 43%. Proposed controls include shaft/pit stabilization, blast shields/berms, remote excavation, remote waste removal techniques, remote video surveillance, explosives inerting, and radiation monitors.

The risk to the public from all activities, except potential fire and explosions and on-site/off-site transportation, is negligible. If Alternative 4 or 5 were selected, a safety analysis would be required to detail the risks from potential fires and explosions prior to designing administrative and engineering controls for Alternatives 4 and 5. Approximately 4800 lb of HE material (4,408 lb LiF PBX and 375 lb RDX) is buried in the shafts in addition to approximately 93,000 lb of DU. A small portion of the DU could be in the hydride form and pyrophoric, i.e., extremely reactive (Appendix M). DU in its hydride form requires minimum energy to ignite. The combination of pyrophoric uranium and HE material has the potential to create significant risk to workers from fires and explosions.

Removal activities would be performed as a remote operation due to the combination and configuration of the material in the shafts. Remote handling technology exists to extract shaft contents, but no known technology exists to stop the ignition of pyrophoric uranium unless removal can be completed in an inert atmosphere. Without full knowledge of the location, depth, quantity, or potential presence of pyrophoric uranium, all shafts in MDA H would be subject to the same removal safety restrictions. Depending on safety analysis results, this may include periodic closure of Pajarito Road and access to TA-54, which could impact the Laboratory's mission and add significant costs to the remediation of MDA H. Rerouting of traffic away from MDA H is constrained by the geography of the mesa in that location.

Modeling the risk to the public from a transportation accident was dominated by standard, industrial accidents type such as vehicle crashes and accidents associated with transportation activities in which serious or fatal consequences could occur to members of the public as a result of the vehicle accident alone. Drivers responsible for transporting the waste to off-site disposal locations would be at risk of having traffic accidents. The probability of a fatal crash involving a large truck would be 2.5 x 10^{-8}/mile. Assuming 150,000 truck miles, the probability of a fatal crash is 6 x 10^{-3} for the Alternative 4. Under Alternative 4, other members of the public (i.e., not nearby residents) would be exposed to the risk of transporting the wastes across the nation’s highways. The risk of a traffic fatality to a member of the public has been estimated to be about 1 x 10^{-4}/yr for this alternative. Implementing controls for vehicle accidents is difficult to achieve.

For all accident scenarios of concern, the total average (between the unmitigated and mitigated) risk to workers from all remediation activities is 22 times greater than risk to the public; in other words, the risk to the public is less than 5% of the risk to the worker.

Due to extensive excavation and waste handling, Alternatives 4 and 5 pose the highest exposure to workers and Alternative 4 poses the only exposure to the community from transportation of waste on public roads.

3.2 Analysis and Evaluation of Environmental Impacts

The environmental impacts of corrective measure alternatives 1 through 5 were evaluated in terms of the potential biological and cultural resource damage that would be incurred during their implementation. An environmental assessment is being prepared under separate cover to address NEPA issues.

Biological resource field surveys have been conducted for the TA-54 area (MDAs G, H, and L) for compliance with the Federal Endangered Species Act of 1973; the New Mexico Wildlife Conservation Act; the New Mexico Endangered Species Act; Executive Order 11990, “Protection of Wetlands”; Executive Order 11988, “Floodplain Management”; 10 CFR 1022, “Compliance with Floodplain/Wetlands Environmental Review Requirements”; and DOE Order 5400.1, “General Environmental Protection Program.”

No wetlands exist in the immediate vicinity of MDA H, but wetlands and floodplains exist in the lower portion of Pajarito Canyon. Possible threatened and endangered species for the area were identified, but no species or habitats were located. Further information is contained in “Biological Assessment of

Environmental Restoration Program, Operable Unit 1148, TA-54" (Banar 1996, 58192) and in Appendix B of the MDA H RFI Report.

A cultural resource survey was conducted during the summer of 1991 at TA-54, as required by the National Historic Preservation Act of 1966. A total of 68 archaeological sites were located within the boundary of the technical area. Of this number, 56 are eligible for inclusion on the National Register of Historic Places, and 12 have been declared ineligible. These sites are east of MDA H.

3.2.1 Environmental Impacts of Containment Alternatives 1, 2, and 3

Environmental damage to biological resources resulting from the three containment alternatives would be localized over a small area (the existing MDA H footprint of 0.3 acres plus a laydown area of approximately 0.3 acres). Once work was completed, the surface of the site will be re-vegetated. Noise associated with implementation would be of limited duration and of relatively low intensity. Thus, disturbances to local fauna would be limited. The depth to contaminated media in the shafts in Alternative 1 is 6 ft or greater and for Alternatives 2 and 3 is 10 ft or greater. Animal burrows are not predicted to reach wastes buried at depths greater than 10 ft. Plant roots could still bring material in the shafts to the surface and expose receptors under Alternatives 2 and 3 (a biobarrier would prevent this). This is consistent with the Ecological Screening Assessment in the RFI report (LANL 2001, 70158), which determined there was no present day risk to ecological receptors and this risk is not likely to change in the future. There would be no impact to cultural resources, as there are none within the MDA H footprint.

3.2.2 Environmental Impacts of Alternatives 4 and 5: Source Removal and Off-Site Disposal/On-Site Disposal

The excavation alternatives would result in much greater short-term environmental impacts to biological resources than Alternatives 1, 2, and 3. The area of physical impact would be much larger (Figure 2.5-5) due to the project requirements for hauling and storing overburden material and constructing a sorting and declassification facility. The auditory impact would be more widespread than for Alternatives 1, 2, and 3 due to the intensive use of heavy machinery, and the duration of the impact would be greater. Ultimately, the site would be restored to a relatively natural state; therefore, long-term environmental impacts to biological resources would be negligible.

There would be potential impact to cultural resources located north and east of MDA H along Mesita del Buey Road, because of the potential for fire and explosions during the excavation of high explosives in the Shaft 3 and also from construction of the haul road and overburden storage area. The RRES-R Program will work with the Laboratory Ecology Group (RRES-E) to determine the optimal location of the haul road and overburden storage area to minimize any impact on cultural sites in the area. A mitigation plan would be developed for any impacted sites.

3.3 Analysis and Evaluation of Potential Human Health Impacts

The purpose of Section 3.3 is to evaluate and compare the final corrective measure alternatives identified in Section 2.5 in terms of their ability to prevent potential future human exposure.

The evaluation of long-term impacts on human health for the containment alternatives necessitates use of mathematical simulations to project the control effects of site features, events and processes far into the future. The models used to analyze potential long-term impacts to human-health are described in Appendixes F, G, H, I, and J.

3.3.1 Analysis of Long-Term Human-Health Impacts of MDA H Containment Alternatives

The analysis of potential long-term human health impacts of the three containment alternatives begins with how the site might change over time as a result of natural environmental processes or human activities, and how these changes might result in the release of, and exposure to, contamination. This description is the conceptual model for MDA H (Figure 3.3-1). Once the conceptual model has been constructed, simulation models are applied to quantify the extent to which natural environmental processes and human activities might affect the potential release of, potential exposure to, and potential impacts from MDA H contaminants.

3.3.1.1 Conceptual Model of Long-Term Performance

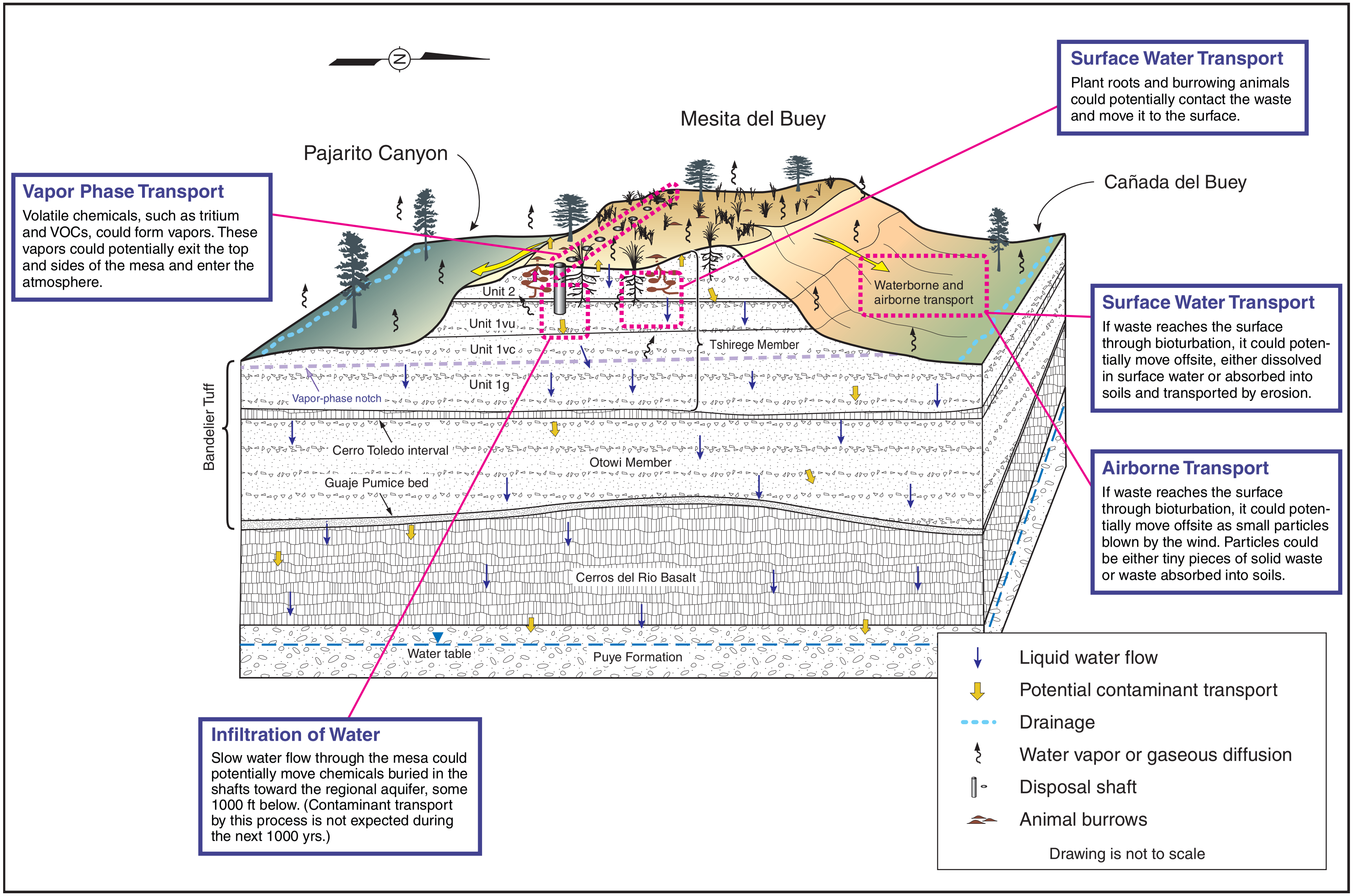
Each of the three containment alternatives shares the common conceptual model shown in Figure 3.3-1. The potential release of contaminants due to natural environmental processes at MDA H is illustrated by arrows in the conceptual site model. Conceptually, contaminants in MDA H shafts have the potential to be released and transported away from the disposal shafts in three ways:

- Volatilization, diffusion and dispersion in air—gas or vapor-phase contaminants diffuse from waste and mix with air in the shafts, then diffuse through the air-filled pores in the subsurface rock toward ambient air, then disperse in the atmosphere;
- Dissolution and advective transport via pore water in the rock beneath MDA H—rain or melting snow on the surface moves down through the shafts, dissolves contaminants, and slowly transports dissolved contaminants through the subsurface rock; and
- Biotic perturbation and translocation by dispersion of surface contamination in air, dissolution of surface contamination in water, and erosion of contaminated surface materials—plants grow into the waste or into releases and incorporate contaminants into their surface biomass (e.g., stems, petals and leaves), and deposit the incorporated contaminants onto the soil surface as biomass decays. In addition, burrowing animals excavate contaminants from the shafts and release these onto the soil surface. Surface contamination is then transported back into the subsurface by burrow collapse, by dissolution in surface water infiltrating the soil, or is transported away from the site by suspension in air or surface water runoff.

Over hundreds of yr, these release and transport processes could result in contaminants migrating into air, surface water, surface soil, subsurface rock, pore water, and biota. The potential impacts to long-term human health from exposure to the contaminated media depend on reasonable assumptions about how humans might be exposed to the media. Based on future human uses of MDA H land, the exposure model calculates human health impacts under RME conditions (EPA 1989, 8021). Three types of chronic human health impacts are evaluated over time: incremental cancer risk from chemicals, systemic hazard from chemicals, and radionuclide dose.

Land-use scenarios used in the long-term human-health impacts assessment for MDA H are based on the following assumptions of future site conditions:

- For the first 100 yr after implementation of a containment alternative, institutional controls limiting site access and managing the biotic community remain in place; and,
- For the 900 yr following the 100-yr institutional control period, no controls remain at the site, thus allowing hypothetical members of the public to be exposed to contamination released and transported away from the site in air, soil, or water, or to contamination remaining in environmental media on site (since access is no longer controlled).



Vapor Phase Transport
Volatile chemicals, such as tritium and VOCs, could form vapors. These vapors could potentially exit the top and sides of the mesa and enter the atmosphere.

Surface Water Transport
Plant roots and burrowing animals could potentially contact the waste and move it to the surface.

Surface Water Transport
If waste reaches the surface through bioturbation, it could potentially move offsite, either dissolved in surface water or absorbed into soils and transported by erosion.

Airborne Transport
If waste reaches the surface through bioturbation, it could potentially move offsite as small particles blown by the wind. Particles could be either tiny pieces of solid waste or waste absorbed into soils.

Infiltration of Water
Slow water flow through the mesa could potentially move chemicals buried in the shafts toward the regional aquifer, some 1000 ft below. (Contaminant transport by this process is not expected during the next 1000 yrs.)

J. Tauxe, 062101 after A. Kron_Rev. for F2.3-1, MDA H RS, 122001, RLM_Rev. for MDA H CMS Rpt., 051403, cf

Figure 3.3-1. Site conceptual model for MDA H at TA-54

Because land use of the MDA H site is not guaranteed to be restricted following the 100-yr institutional control period, the land-use scenarios selected to assess the long-term effectiveness of the containment alternatives for MDA H are the recreational and residential scenarios.

- During the 900-yr post-institutional control period, recreational users could be exposed through direct dermal absorption and incidental ingestion exposure to contaminated soil particles, external irradiation exposure from radionuclides in soil, and inhalation exposure to gas-phase contaminants or contaminants on suspended soil (dust).
- Future residents of the MDA H site during the 900-yr post-institutional control period could be exposed through direct dermal absorption and incidental ingestion exposure to contaminated soil particles; external irradiation from radionuclides in soil; inhalation exposure to gas-phase contaminants or contaminants on suspended soil; ingestion exposure from garden produce grown in contaminated soil; and (potentially) ingestion exposure from drinking contaminated groundwater.

3.3.1.2 Models Simulating Long-Term Performance

Process-level computer models were used to simulate some of the natural environmental contaminant release processes identified in the conceptual model. The computer models employ a detailed and complex set of mathematical equations to represent a particular process realistically. To evaluate potential human-health impacts from contaminants released over time by multiple coupled environmental processes, a system model is used. The system model developed for MDA H uses simple approximations of environmental processes, as described in Appendix H. The system model uses the outputs of the process models for a variety of purposes, as shown in Figure 3.3-2 and discussed in Appendix F. These models are described further in Appendices F, G, H, I, and J of this report.

3.3.1.3 Long-Term Impacts Assessment of Alternative 1

The site conditions evaluated for Alternative 1 reflect present conditions of the MDA H native vegetative cover with the addition of a gravel-mulch layer that will be placed on the existing cover as a best management practice. Potential long-term human health impacts are calculated over a time frame of 1000 yr (a 900-yr period beginning at the end of the assumed 100-yr institutional control period). Inputs to the risk, hazard, and dose calculations include soil contaminant concentrations over time, exposure equations and parameter values, and contaminant-specific toxicity values. Chemical and radionuclide concentrations in the disposed waste used as inputs to the fate and transport models are documented in Table H-2.0-1 in Appendix H and are derived from information presented in Appendix B. Concentrations of chemicals and radionuclides in surface soil over time (presented in Tables H-3.0-1 and H-3.0-2, respectively) are calculated from the initial waste concentrations according to the methods described in Section H-2.0 of Appendix H. Exposure model inputs and equations for residential and recreational scenarios are provided in Section H-3.0 of Appendix H. Contaminant-specific toxicity values used in the health effects assessment are presented in Table H-3.1-1 in Appendix H. Additional contaminant-specific parameter values used in the risk equations are provided in Table H-3.2-1 in Appendix H.

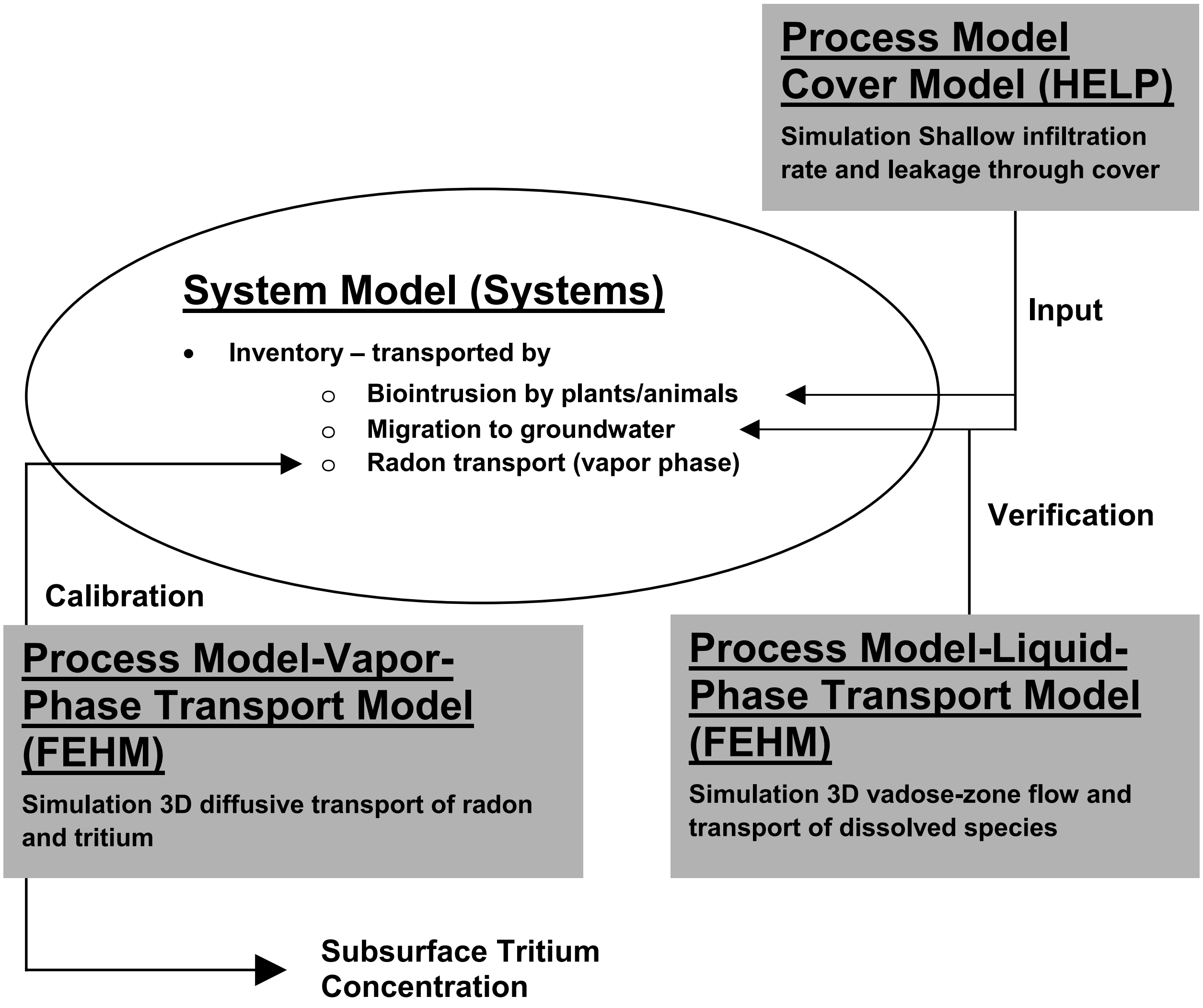


Figure 3.3-2. Links between the system model and the three process models

The dose rates for the recreational and residential receptors over the 1000-yr modeling period are shown in Figures 3.3-3 and 3.3-4, respectively. The radiation doses shown in the figures are 50-yr whole-body effective dose equivalents. The values for residential dose were calculated based on a best-estimate value of uranium inventory and the best estimate of uranium corrosion over time in the environment of the disposal shafts. Details of the uranium inventory and corrosion rate are provided in Appendices B and M, respectively. An evaluation of uncertainty in the residential dose estimate pertaining to uranium inventory and corrosion is provided in the “Interpretation of Results for the Long-Term Impacts Assessment” (Appendix H.4). The dose estimate for the recreational land-use scenario, shown in Figure 3.3-4, also uses a best-estimate value of uranium inventory and the best estimate of uranium corrosion over time in the environment of the disposal shafts. For the radon surface flux, both the upper-bound and best-estimate values of the uranium inventory were used for comparison to National Emission Standards for Hazardous Air Pollutants (NESHAP) standards.

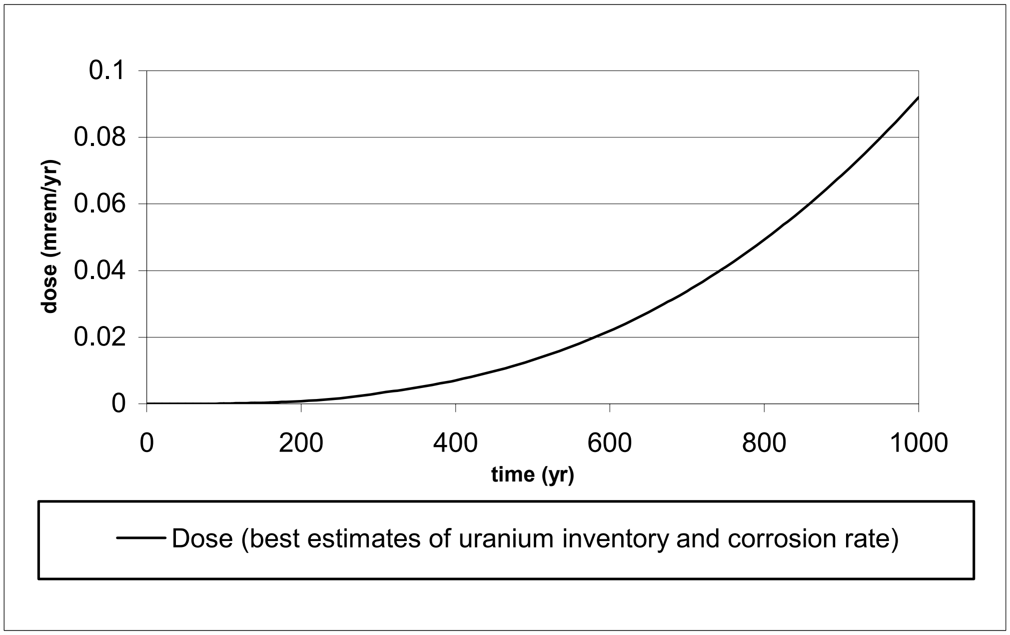


Figure 3.3-3. Dose rates for the long-term residential exposure scenario

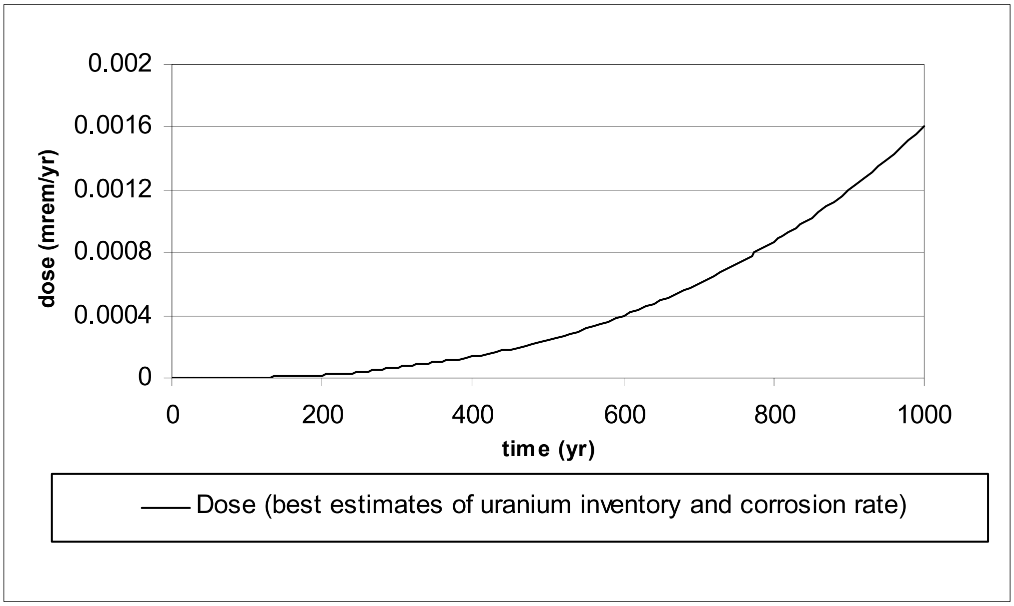


Figure 3.3-4. Dose rate for the long-term recreational exposure scenario

Approximately 99% of the upper-bound total resident dose at 1000 yr is due to external irradiation, of which 97% is related to radium-226, a decay product of uranium-234 as shown in Appendix F, Figure F-2.0-4. Early in the modeling period, other exposure routes are somewhat more important. For example, only about 85% of the total residential dose at 300 yr is due to external irradiation, although radium-226 is still responsible for 97% of the total dose. In the recreational scenario, about 90% of the total dose at 1000 yr is due to external irradiation from radium-226. However, other radionuclides are more important at early modeling times in the recreational scenario than under residential land use; radium-226 contributes 70% of the total dose at 300 yr. These other radionuclides include uranium-234, uranium-238, lead-210, and thorium-230. In decreasing order of importance, the other routes contributing to residential and recreational dose at earlier model times include soil ingestion, plant ingestion (residential only), and dust inhalation. Thus, in both residential and recreational scenarios, external irradiation increases in importance through the 1000-yr simulation period. The residential and recreational dose estimates at 1000 yr are approximately 0.09 and 0.0016 mrem/yr, respectively. Both residential and recreational dose rates are well below the dose limit of 15 mrem/yr.

The difference in dose between the residential and recreational scenarios is due primarily to the amount of time spent on site, which is far greater in the residential scenario. However, the soil ingestion rate is not dependent on time on site, while exposure via the external irradiation pathway is linearly related to exposure time. This accounts for the slightly greater influence of inadvertent soil ingestion at 1000 yr in the recreational scenario (about 10% of total dose, versus about 1% in the residential scenario), where time on site is only assumed to be two hours per day. The zero dose line between time 0 and 100 yr in Figures 3.3-3 and 3.3-4 reflects the 100-yr institutional control period when these receptors are assumed to be excluded from the site.

The ICR for the recreational and residential receptors over the 1000-yr modeling period are shown in Figures 3.3-5 and 3.3-6, respectively. The ICR is calculated as the product of chemical intake and the chemical-specific slope factor, summed across exposure routes and chemicals. Approximately 100% of the residential ICR is due to ingestion of the HE RDX via the garden produce exposure route.

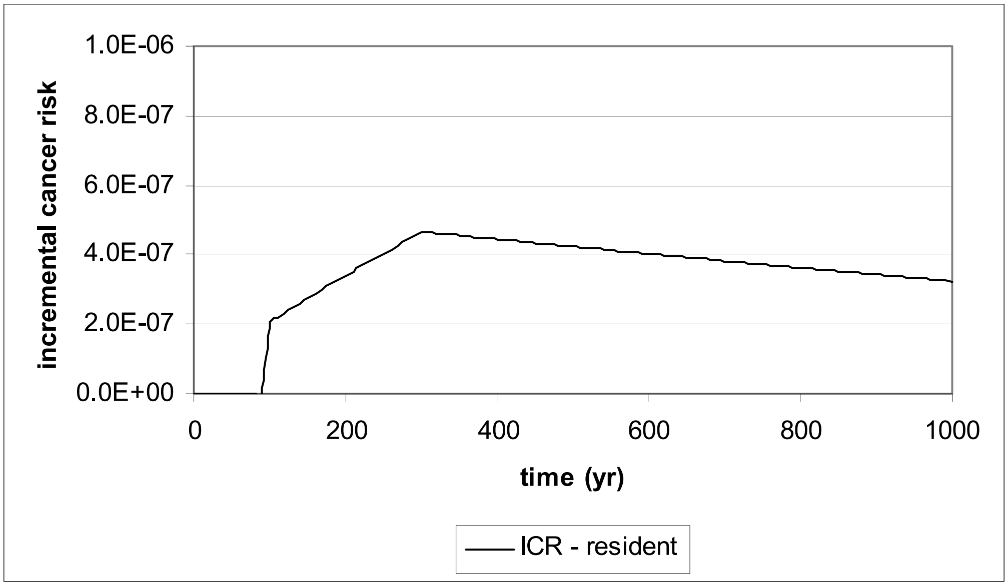


Figure 3.3-5. Incremental cancer risk for the long-term residential exposure scenarios

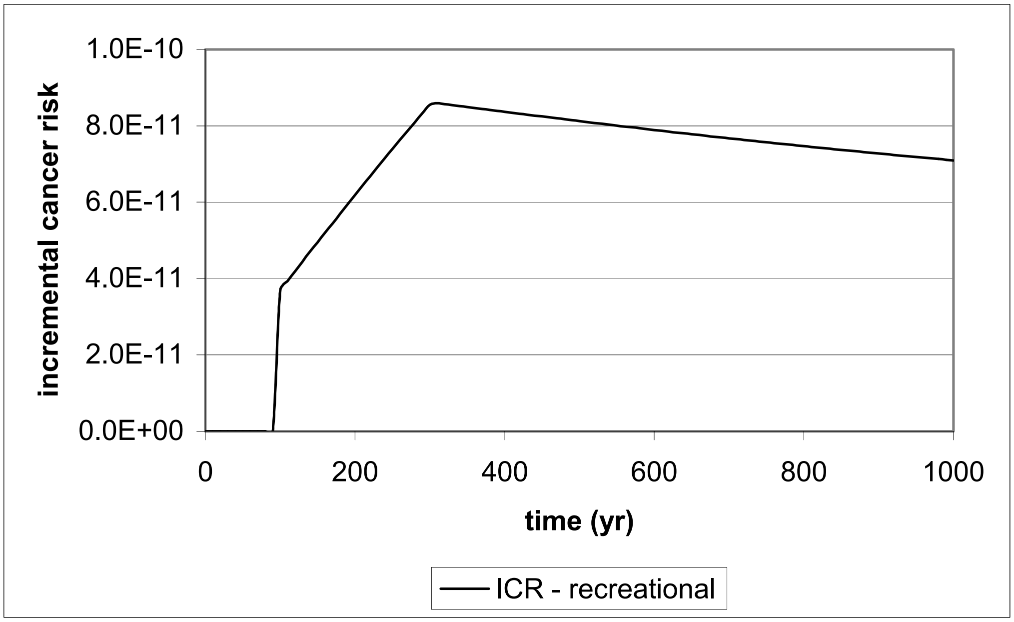


Figure 3.3-6. Incremental cancer risk for the long-term recreational exposure scenarios

In the recreational scenario, about 80–95% of the ICR between model times 300 and 1000 yr is due to exposure to RDX, primarily via inadvertent soil ingestion, with the remainder related to inhalation of beryllium dust. The relative importance of beryllium inhalation increases throughout the simulation. The discrepancy in the magnitude and nature of the ICR between residential and recreational exposure is due to the absence of a plant ingestion pathway in the recreational land use scenario. Both residential and recreational ICR are below the *National Contingency Plan* range of 1 x 10^{-4} to 1 x 10^{-6} and reach a maximum at about model time 300 yr. The recreational ICR value at 300 yr is 9 x 10^{-11} and the residential ICR value at this time is about 5 x 10^{-7} [5].

The chemical HIs for the residential and recreational scenarios over the 1000-yr modeling period are shown in Figure 3.3-7 and 3.3-8, respectively. The hazard index is the sum across chemicals of the chemical-specific hazard quotients. A hazard quotient, in turn, is the sum across exposure routes of the ratio of chemical intake and chemical reference dose.

Approximately 75% of adult and child residential HI at 1000 yr is associated with mercury. RDX is responsible for about another 15% of the HI, and barium and copper combined contribute virtually all of the remainder. At model times before approximately 500 yr, cyanuric acid (an atrazine-type herbicide that may be present in mock HE), also contributes up to about 10% of residential HI. Ingestion of garden produce is responsible for almost 98% of chemical hazard for the adult receptor, the remainder being due in equal part to inadvertent soil ingestion and dust inhalation. The main differences between child and adult receptors with regard to pathway and chemical influence in the residential scenario is that plant

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[5] The ICR values were calculated under model conditions of the best-estimate uranium dose (*i.e.*, the lower value of uranium inventory). ICR values would be slightly lower over time using the higher value of the uranium inventory because when the mass of waste is higher the concentrations of any individual constituents in the waste will be lower. In other words, the use of the higher uranium inventory results in a larger value for the denominator (mg constituent per kg waste) of chemical concentrations in the waste. The zero ICR lines between time 0 and 100 yr in Figures 3.3-5 and 3.3-6 reflect the 100-yr institutional control period when these receptors are assumed to be excluded from the site.

ingestion will be somewhat more important in adults (98%) than in children (about 85%) because the child soil ingestion rate used in the calculation is fourfold higher than the adult rate. The adult and child residential HI values at 1000 yr in Figures 3.3-7 are both approximately 0.02. Similar to the ICR values, HI values would be slightly lower over time using the upper-bound uranium inventory because the mass of waste is higher and this results in lower constituent waste concentrations.

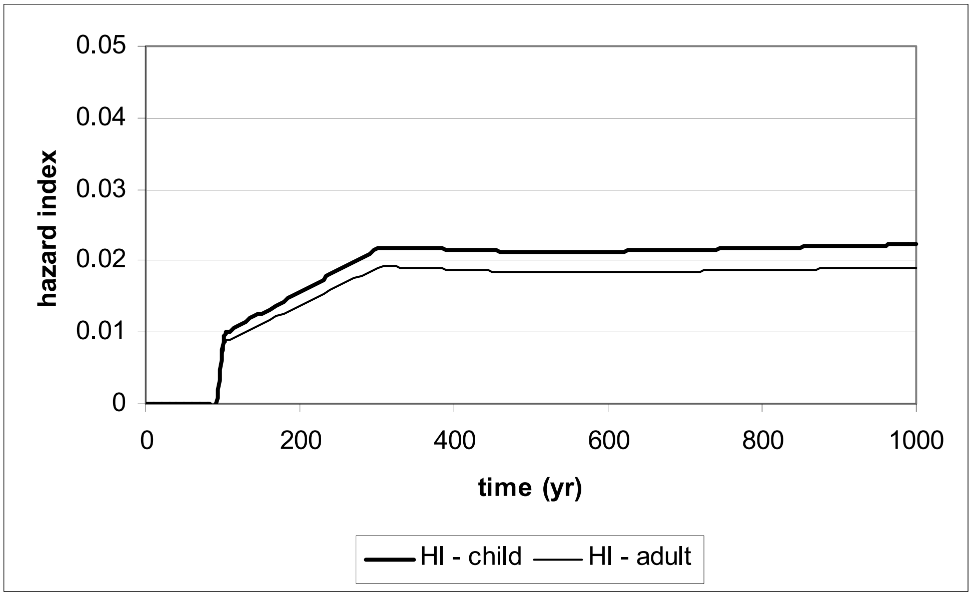

Figure 3.3-7. Hazard indices for the long-term residential exposure scenario

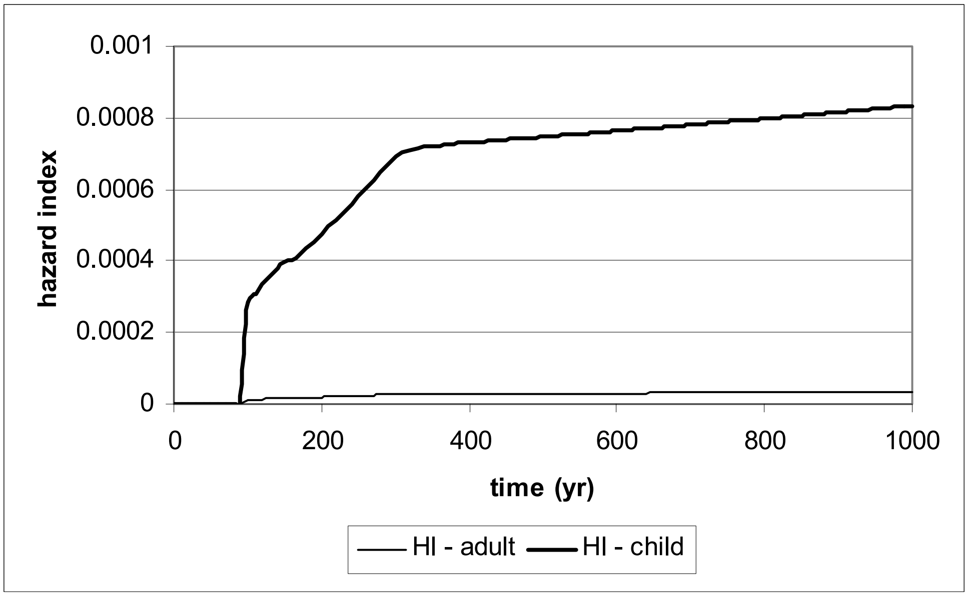

Figure 3.3-8. Hazard indices for the long-term recreational exposure scenario

The possible surface flux of radon associated with the buried wastes at MDA H (specifically, uranium-234) was also evaluated in the systems model using the conditions related to the upper-bound (higher uranium inventory value and 100% immediate availability) and best-estimate (best-estimate uranium inventory and low corrosion rate) of radiation dose, discussed previously. Radon flux from the disposed waste was simulated in a process-level model (Appendix I) and the results were used to calibrate this process. The projected flux of radon-222 (the principal radon isotope of concern) directly above the waste shafts is shown in Figure 3.3-9. The difference between upper-bound and best-estimate values at 1000 yr is approximately a factor of 20. The upper-bound value is well below the corrective action objective of meeting the NESHAP standard of 20 pCi/m^2-sec (40 CFR 61, Subpart Q).

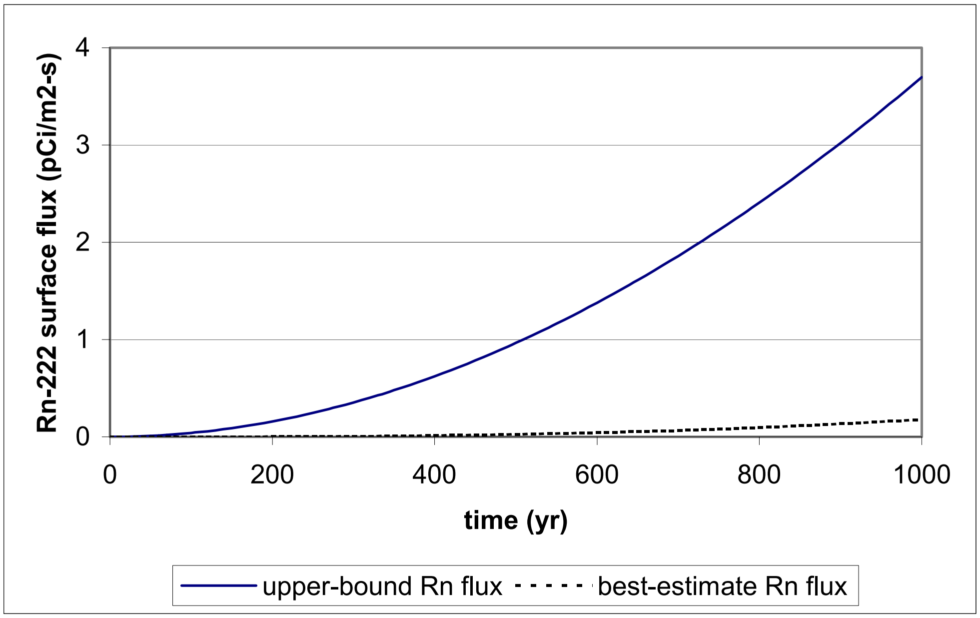

Figure 3.3-9. Radon surface flux above the disposal shafts for the long-term assessment

Transport of constituents from the waste to groundwater was modeled using the results of the process-level model described in Appendix J. The vadose transport model used a deep net infiltration rate of 1 mm per yr, the best-estimate value discussed in Appendix J. No breakthrough of any chemical or radionuclide to groundwater occurred within the 1000-yr evaluation period. Therefore, MCLs are not exceeded in the regional aquifer beneath MDA H.

3.3.1.4 Interpretation of Results for the Long-Term Impacts Assessment for Alternatives 1, 2, and 3

Uncertainties in the results for the long-term human health impacts assessment are discussed in Section H-4.0 of Appendix H. Aspects of the systems modeling discussed in Section H-4.0 of Appendix H include inventory and release models, biotic transport models, erosion, infiltration and vadose transport and diffusion models, exposure models, and health effects models.

3.3.1.5 Long-Term Impacts Assessment for Alternatives 2 and 3

Alternatives 2 and 3 are variations of Alternative 1 with additional controls designed to enhance system performance. The results of the impacts assessment of Alternative 1 incorporate protective assumptions designed to ensure that potential future human health impacts are not underestimated. Therefore, because Alternative 1 meets the human health corrective action objectives, Alternatives 2 and 3 also meet the corrective action objectives.

3.3.1.6 Conclusions of the Long-Term Impact Assessment for Alternatives 1, 2, and 3

Long-term potential human health impacts were evaluated over a period of 1000 yr from the present day. During the first 100 yr of this period, institutional controls are in place and land use remains as industrial/Laboratory use. Human health impacts during this 100-yr period have been evaluated in the context of worker safety in Section 3.1.4. The conclusions of the long-term effects assessment, from 100 to 1000 yr, are assessed with no institutional controls in place using residential and recreational scenarios.

The calculated radon flux of approximately 4 pCi/m^2-sec at 1000 yr, using upper-bound estimates of the uranium inventory and immediate availability of uranium for transport, and the best-estimate radon flux of approximately 0.2 pCi/m^2-sec are below the NESHAP standard of 20 pCi/m^2-sec (40 CFR 61, Subpart Q).

Potential human health impacts related to radiation dose, cancer risk, and systemic hazard were all below the corrective action objectives described in Section 2.2. MCLs are not exceeded in the regional aquifer beneath the site. Based on the results of the long-term impact assessments conducted at MDA H, the potential exposure to contaminants is minimal should institutional control be removed. The physical nature of the disposed material and the presence of a crushed tuff and gravel mulch cover provide substantial protection to human receptors under both a residential and recreational land use scenarios. Therefore, the implementation of a containment corrective measure will provide protection of human health over a 1000-yr time period.

3.3.1.7 Conclusion of the Long-Term Impact Assessment for Alternatives 4 and 5

No local long-term potential human health impacts are associated with excavation Alternatives 4 and 5 because the material in the MDA H shafts would be removed, decontaminated or treated as necessary, and disposed in either off-site or on-site permitted units or facilities or recycled, where appropriate.

3.4 Analysis and Evaluation of Institutional Concerns

Institutional concerns include the effects of Federal, State, and local environmental and public health standards, regulations, guidance, advisories, ordinances, or community relations on the design, operation, and timing of each alternative.

3.4.1 Institutional Concerns for Alternatives 1, 2, and 3 Upgrade Existing Surface Layer, Engineered ET Cover, and Encapsulation Alternatives

When appropriate, institutional controls, such as access and deed restrictions, can be used to supplement engineered controls. Short-term and long-term institutional controls assist in preventing or limiting exposure to hazardous constituents and radionuclides and/or ensuring the effectiveness of a corrective measure alternative. For Alternatives 1, 2, and 3, existing access restrictions (locked fence, restricted access to TA-54, and restricted access to Pajarito Road) would remain in place at MDA H for a minimum of 100 yr, limiting human and animal access.

A deed restriction or an environmental covenant, a recorded document kept on file at the county recorder's office would assure regulation of potential future activities such as foundation construction and domestic well installation. A deed restriction would be required to maintain institutional control of MDA H and the surrounding property should DOE transfer the property. The deed restriction would set forth maintenance and monitoring guidelines to assure continued protection of human health and the environment. An environmental covenant could also be pursued for MDA H should appropriate legislation be promulgated by the State of New Mexico.

Long-term stewardship would be a requirement for sites where persistent contamination (in the context of potential impact) is left in the environment. These stewardship activities (such as monitoring and contingencies) must be implemented to address the uncertainties inherent in the long-term performance of corrective action.

3.4.2 Institutional Concerns for Alternatives 4 and 5: Excavation and Off-Site Disposal/Excavation and On-Site Disposal

Institutional concerns for Alternatives 4 and 5 at MDA H include the mitigation of potential fire and explosion events during the excavation activities. Such events have the potential to spread contamination off site, impact environmental receptors, and disturb archeological sites to the south of MDA H and tribal lands to the north of MDA H. The archaeological sites would require mitigation prior to initiation of construction activities, including surveying and archaeological activities. Transport road re-routing may be required if sites are determined to be historically important.

Once excavation and transport activities related to Alternative 4 are completed, institutional controls would not be required for MDA H, assuming the no further action determination based on no potential unacceptable risk from residual contamination can be achieved. Institutional controls would be required for the disposal unit(s) used for Alternative 5.

3.5 Cost Estimate of Corrective Measure Alternatives

A cost estimate was developed for each of the final corrective measure alternatives. These costs may vary considerably depending on agreements with NMED and stakeholders. Cost considerations include estimations of

- capital costs (Section 3.5.1),
- operation and maintenance costs (Section 3.5.2), and
- monitoring costs for the three containment alternatives (Section 3.5.3).

3.5.1 Estimates for Capital Cost

Capital costs consist of direct costs (construction), indirect costs (non-construction and overhead), and uncertainty estimates (contingency allowances). Tables 3.5.1 through 3.5.6 summarize the capital cost for each alternative. Detailed estimates of capital cost are provided for each alternative in Appendix K and in Section 3.5.1.1 for moisture monitoring equipment. Cost estimates are expected to be within the accepted standard accuracy range of +100% to –50% established by EPA for remedial alternative estimates at the alternatives screening stage (EPA 2000, 71540).

Table 3.5.1
Capital Cost Estimate
Corrective Measure Alternative 1: Upgrade Existing Surface Layer

Preliminary Estimate	WBS Element
$3,000	WBS 1.1 – Mobilization, demobilization
$13,800	WBS 1.2 – Fence removal and site preparation
$9,000	WBS 1.3 – Regrading/BMPs/imported topsoil/gravel/revegetation
$31,500	WBS 1.4 – New fencing/gate installation
$50,000	WBS 1.5 – Utility work – installation of pressure sensors and automatic shut-off valves
$29,000	WBS 1.6 – Implementation of health and safety
$24,000	WBS 1.7 – Design and permitting
$18,000	WBS 1.8 – Project management
$35,700	Contingency @ 20%
$214,000	Total

Table 3.5.2
Capital Cost Estimate
Corrective Measure Alternative 2: Engineered ET Cover

Preliminary Estimate	WBS Element
$5,000	WBS 1.1 – Mobilization, demobilization
$13,800	WBS 1.2 – Fence removal and site preparation
$30,200	WBS 1.3 – Regrading ET cover installation/revegetation
$31,500	WBS 1.4 – New fencing/gate installation
$50,000	WBS 1.5 – Utility work – Installation of pressure sensors and automatic shut-off valves
$72,000	WBS 1.6 – Implementation of health and safety
$36,000	WBS 1.7 – Design & permitting
$40,000	WBS 1.8 – Project management
$69,000	Contingency @ 25%
$348,000	Total

Table 3.5.3
Capital Cost Estimate
Corrective Measure Alternative 3b: Complete Encapsulation and Engineered ET Cover

Preliminary Estimate	WBS Element
$40,000	WBS 1.1 – Mobilization, demobilization
$668,000	WBS 1.2 – Drilling
$295,000	WBS 1.3 – Grouting
$45,000	WBS 1.4 – Surface caps, 9 shafts
$230,000	WBS 1.5 – Implementation of health and safety
$145,000	WBS 1.6 – Design and permitting
$177,000	WBS 1.7 – Project management
$640,000	WBS 1.8 – Contingency @ 40%
$310,000	Installation of engineered ET cover
$2,550,000	Total

Table 3.5.4
Capital Cost Estimate
Corrective Measure Alternative 4: Excavation and Off-Site Disposal

Preliminary Estimate	WBS Element
$1,162,000	WBS 1.1 – Excavation/backfill
$5,724,000	WBS 1.2 – Removal and sorting of waste material from shafts[a]
$8,790,000	WBS 1.3 – Declassification, treatment, packaging, and disposal off site
$3,757,000	WBS 1.4 – Construction of support facilities
$3,880,000	WBS 1.5 – Implementation of security measures
$6,427,000	WBS 1.6 – Implementation of health and safety, including SAR
$1,730,000	WBS 1.7 – Design and permitting
$3,815,000	WBS 1.8 – Project management
$16,620,000	Contingency @ 47%
$51,906,000	Total

[a] Contingency does not include cost for excavation under an inert atmosphere.

Table 3.5.5
Capital Cost Estimate
Corrective Measure Alternative 5A:
Source Removal and On-Site Disposal in a RCRA Permitted Unit

Preliminary Estimate	WBS Element
$1,162,080	WBS 1.1 – Excavation/backfill
$5,724,400	WBS 1.2 – Removal and sorting of waste material from shafts[a]
$8,790,000	WBS 1.3 – Declassification, treatment, packaging, and disposal (off site)
$3,757,400	WBS 1.4 – Construction of support facilities
$3,879,600	WBS 1.5 – Implementation of security measures
$6,426,800	WBS 1.6 – Implementation health and safety, including SAR
$1,730,000	WBS 1.7 – Design and permitting
$3,815,400	WBS 1.8 – Project management
$16,620,000	Contingency @ 47%
51,906,000	**Total Preliminary Estimate for Alternative 4, MDA H Excavation & Removal**
	Alternative 5A Adjustments
($5,104,000)	WBS 1.3 – Remove off-site disposal costs, transportation, and contingency for this portion of WBS 1.3
$19,332,000	WBS 1.9 – Add RCRA landfill permit, design, construct, fill, cap & cover with contingency for this section (35%)
$66,134,800	**Total Preliminary Estimate for Alternative 5A**

[a] Contingency does not include cost for excavation under an inert atmosphere.

Table 3.5.6
Capital Cost Estimate
Corrective Measure Alternative 5B: Source Removal with On-Site Disposal in a CAMU

Preliminary Estimate	WBS Element
$1,162,080	WBS 1.1 – Excavation/backfill
$5,724,400	WBS 1.2 – Removal and sorting of waste material from shafts[a]
$8,790,000	WBS 1.3 – Declassification, treatment, packaging, and disposal (off site)
$3,757,400	WBS 1.4 – Construction of support facilities
$3,879,600	WBS 1.5 – Implementation of security measures
$6,426,800	WBS 1.6 – Implementation health and safety, including SAR
$1,730,000	WBS 1.7 –Design and permitting
$3,815,400	WBS 1.8 – Project management
$16,620,000	Contingency @ 47%
51,906,000	**Total Preliminary Estimate for Alternative 4, MDA H Excavation & Removal**
	Alternative 5B Adjustments
($5104,000)	WBS 1.3 – Remove off-site disposal costs, transportation, and contingency for this portion of WBS 1.3
$17,982,000	WBS 1.9 – Add CAMU permit, design, construct, fill, cap & cover with contingency for this section (35%)
$64,784,000	**Total Preliminary Estimate for Alternative 5B**

[a] Contingency does not include cost for excavation under an inert atmosphere.

Contingency cost estimates were developed based on past on-site removal actions (MDA P), other DOE site experience (Sandia, Hanford, Rocky Flats), and factors such as the MDA H site location near existing operating facilities.

Alternatives 1, 2, and 3 contain contingency that are primarily due to the preliminary status of the design. Alternatives 4 and 5 have additional contingency added due to the uncertainty of shaft contents and degradation of shaft material. Safety and security activities have been estimated but a high degree of cost uncertainty exists until site-specific health, safety, and security plans are established. See Appendix K, page K-19, for contingency considerations that were used for calculation of contingency in Alternatives 4 and 5.

3.5.1.1 Capital Cost Estimates for Monitoring Alternatives 1, 2, and 3

Installation of a moisture monitoring system is proposed for Alternatives 1, 2, and 3 to measure performance of the engineered ET cover.

The design phase of implementation of corrective action for Alternatives 1, 2, or 3 would include requirements for monitoring to be added to Module VIII.

Capital Cost Estimate for Moisture Monitoring System

The proposed system to monitor cover performance is to consist of (1) TDR probes installed in arrays and an associated data collection system; and (2) neutron logging of the three existing boreholes at MDA H. Three TDR arrays comprised of three probes each are proposed. Two arrays would be placed in the cover directly above disposal shafts, and one would be installed in the cover in an off-shaft location within the MDA H fence line. In each array, the TDR probes would be placed in a horizontal orientation at appropriate depths at and just below the soil/topsoil interface. The three arrays would be tied to one data collection center comprised of a data logger, remote data access (by cell phone), associated solar equipment to operate the data center, and a tipping bucket rain gauge to monitor precipitation events. The remote access instrumentation would allow for data collection remotely with a modem connection.

The three existing boreholes will be neutron logged every foot monthly for two years to establish time series trends for developing a depth profile of moisture to confirm the conceptual model. After the first two years, neutron logging will be conducted annually. Review of the depth profile of moisture will be included in a five-yr review with NMED.

The capital cost estimate for the TDR equipment is outlined in Table 3.5-7.

Table 3.5-7
Capital Cost Estimate for TDR Moisture Monitoring Equipment for Alternatives 1, 2, and 3

Instrumentation	Quantity	Unit Cost	Total Cost
TDR Probes	9	$300	$2700
Rain Gauge	1	$400	$400
Datalogger	1	$2500	$2500
Software	1	$300	$300
Remote access system, solar panel, and charger unit	1	$6700	$6700
Calibration of probes and hardware in order to connect probes and weather station to data logger	1		$3400
Total			**$16000**

Two cost estimates have been provided for installing the monitoring equipment. The first provides an estimate for installing the instrumentation into the existing cover (Alternative 1). The second provides an estimate for installation of the equipment into an engineered cover (Alternatives 2 and 3). The primary difference is the additional excavation required to install the TDR probes into the existing cover. Installation of the probes into a new cover would occur during cover installation and would not require additional excavation. Tables 3.5-8 and 3.5-9 summarize these cost estimates.

Neutron logging is estimated at $3500/month for the first two years for an annual cost of $42,000. The annual cost after the first two years is estimated at $9400: $3500 for neutron logging plus $5,900 for moisture monitoring (16 hr), health and safety support (24 hr), and annual data analysis (40 hr).

Table 3.5-8
TDR Installation Cost in Existing Cover

	Cost	Hours	Total Cost
Instrument assemble and checkout	$65/hr	60	$3900
Excavate array trenches	$100/hr	10	$1000
Instrument installation	$65/hr	100	$6500
Programming data logger	$65/hr	80	$5200
Technical oversight	$90/hr	16	$1400
H&S support	$70/hr	50	$3500
Total			**$21,500**

Table 3.5-9
TDR Installation Cost in New Cover

	Cost	Hours	Total Cost
Instrument assemble and checkout	$65/hr	60	$3900
Instrument installation	$65/hr	80	$5200
Programming data logger	$65/hr	80	$5200
Technical oversight	$90/hr	16	$1400
H&S support	$70/hr	40	$2800
Total			**$18500**

3.5.2 Operation and Maintenance (O&M) Costs

Annual costs for cover surveillance and maintenance for Alternatives 1, 2, and 3 is estimated to be $18,000 based on $2000/yr for materials and equipment to maintain the cover and cell phone charges, $4000/yr (80 hours) for personnel performing cover maintenance, and $12,000/yr (160 hours) for maintenance of the monitoring system and data analysis. There would be no annual costs for Alternative 4. Annual costs for operation, maintenance and monitoring of the Alternative 5 RCRA-permitted unit are estimated at $170,000, based on 1 staff at 0.50 FTE plus sampling and disposal.

3.5.3 Present Value Analysis

Remedial action projects involve construction costs that are expended at the beginning of a project (e.g., capital costs) and annual operation and maintenance and monitoring costs that are required to maintain the remedy after the initial construction period. Present value analysis is recommended in EPA guidance to compare costs for corrective measure alternatives whose expenditures occur over different time periods. Present-value analysis allows cost comparisons of different remedial alternatives on the basis of a single cost figure for each alternative. By discounting all costs to a common base year, the costs for different remedial alternatives were compared on the basis of a single figure for each alternative as recommended in “A Guide to Developing and Documenting Cost Estimates during the Feasibility Study” (EPA 2000, 71540).

Present value was calculated according to the following formula:

$$PV_{total} = 1/\mathrm{i}\,\frac{(1+\mathrm{i})^{n}-1}{(1+\mathrm{i})}$$

where PV = present single sum of money

i = 0.07; a discounted interest rate per interest period (i.e., a total interest less inflation)

n = total yr

A discounted interest rate of 7% was used (EPA 2000, 71540) and present value was calculated for 30-yr and 1000-yr periods to provide a range of values. The multi-yr discount factor for a discounted interest rate of 7% over a 30-yr period is 12.409 and for a 1000-yr period is 14.286. The present value analysis is presented in Table 3.5-10.

Table 3.5-10
Present Value Analysis

Alternative	Item	Total Cost
1) Upgrade Existing Cover	Capital Cost	$214,000
	Monitoring equipment	$37,500
	Total capital cost	$251,500
	Annual cost after 2 yr for moisture monitoring only	$9400
	Annual maintenance cost	$18,000
	Subtotal annual O&M cost	$27,400
	Present value 30 yr	$592,000
	Present value 1000 yr	$643,000
2) Engineered Cover		
	Capital cost	$348,000
	Monitoring equipment	$34,500
	Total capital cost	$382,500
	Annual cost after 2 yr for moisture monitoring	$9400
	Annual maintenance cost	$18,000
	Subtotal annual O&M cost	$27,400
	Present value 30 yr	$723,000
	Present value 1000 yr	$774,000
3) Encapsulation and Engineered Cover		
	Capital cost	$2,550,000
	Monitoring equipment	$34,500
	Total capital cost	$2,584,500
	Annual cost after 2 yr for moisture monitoring	$9400
	Annual maintenance cost	$18,000
	Subtotal annual O&M cost	$27,400
	Present value 30 yr	$2,925,000
	Present value 1000 yr	$2,976,000

Table 3.5-10 (continued)

Alternative	Item	Total Cost
4) Excavation and Off-site Disposal		
	Capital cost	$51,906,000
	Monitoring equipment	0
	Total Capital cost	$51,906,000
	Annual Maintenance cost	0
	Subtotal annual O&M cost	0
	Present value 30 yr	$51,906,000
	Present value 1000 yr	$51,906,000
5A) Excavation and On-site Disposal in a RCRA Permitted Unit		
	Capital cost	$66,134,000
	Monitoring equipment	0
	Total capital cost	$66,134,000
	Annual Maintenance cost	0
	Subtotal annual O&M cost	$170,000
	Present value 30 yr	$68,244,000
	Present value 1000 yr	$68,563,000
5B) Excavation and On-site Disposal in a CAMU		
	Capital cost	$64,784,000
	Monitoring equipment	0
	Total capital cost	$64,784,000
	Annual Maintenance cost	0
	Subtotal annual O&M cost	$170,000
	Present value 30 yr	$66,894,000
	Present value 1000 yr	$67,213,000

4.0 JUSTIFICATION AND RECOMMENDATION OF THE CORRECTIVE MEASURE

EPA RCRA Corrective Action Plan and DOE RCRA Corrective Action guidance; Module VIII, Task VII of the Laboratory's Hazardous Waste Facility Permit; and the MDA H CMS Plan require that a comparison of alternatives be prepared with respect to technical criteria, human health and environmental criteria, and other pertinent factors outlined in Section 3.2.

As per EPA guidance (EPA 1994, 44146), the preferred corrective measure was selected based on the following criteria:

Technical

1. Performance—corrective measure or measures that are most effective at performing their intended functions and maintaining the performance over extended periods of time will be given preference;

2. Reliability—corrective measure or measures that do not require frequent or complex operation and maintenance activities and have proven effective under waste and facility conditions similar to those anticipated will be given preference;
3. Implement ability—corrective measure or measures that can be constructed and operated to reduce levels of contamination to attain or exceed applicable standards in the shortest period of time will be given preference; and
4. Safety—corrective measure or measures that pose the least threat to the safety of nearby residents and environments as well as workers during implementation will be given preference.

Human Health

The corrective measure or measures must comply with existing federal and state criteria, standards, or regulations for the protection of human health. Corrective measures that provide the minimum level of exposure to contaminants and the maximum reduction in exposure over time will be given preference.

Environmental

The corrective measure or measures posing the least adverse impact (or greatest improvement) on the environment over the shortest period of time will be given preference.

Other Pertinent Factors

Other pertinent factors to be evaluated in the selection process include institutional needs and cost.

4.1 Technical

4.1.1 Performance

The risk/dose assessments presented in Section 3.3 determined that MDA H wastes left in place under Alternative 1 would pose no unacceptable risk to human health over the 1000-yr time period evaluated. In addition, the fate and transport modeling in Appendix H predicted that MCLs would not be exceeded in the regional groundwater beneath MDA H for these periods. Alternative 2 proposes to add depth and engineering features to the existing cover and improve the performance over time. Alternative 3 also proposes to add depth and engineering features to the existing cover and prevent intrusion into the shafts by construction of a grout barrier around the shafts. Maintaining the covers past the initial 100-yr institutional control period would increase the effectiveness of the covers but the evaluation of performance assumed no maintenance past 100 yr.

Excavation of the waste in the shafts at MDA H (Alternatives 4 and 5) would ensure that waste disposed at MDA H would be of no further risk if the disposal unit is maintained.

Therefore, all alternatives would perform their intended function equally and maintain the performance over the 1000-yr evaluation period.

4.1.2 Reliability

The current MDA H native vegetative cover (including the 3-ft and 6-ft concrete shaft covers) has proven effective in preventing releases from waste disposed in the shafts at MDA H (except for subsurface VOC and tritium releases) with minimal maintenance. Upgrading the native vegetative cover (Alternative 1), constructing an engineered ET cover (Alternative 2), or constructing an engineered cover and encapsulating the shafts (Alternative 3) would all require additional monitoring and maintenance to ensure the cover reliability over the 1000-yr evaluation period. Engineered ET covers constructed in the southwestern United States have been demonstrated to be effective under waste and facility conditions similar to those at MDA H if properly maintained (Dwyer 2001, 71298).

Excavation and off-site disposal or disposal in an authorized/permitted unit at the Laboratory of the waste in the shafts at MDA H (Alternatives 4 and 5) would require no further operation and maintenance requirements for waste disposed at MDA H. The monitoring requirements would be specified by the operating conditions of the disposal unit(s).

Alternatives 4 and 5 would be more reliable because long-term maintenance of Alternatives 1–3 cannot be assured after the 100-yr institutional control period.

4.1.3 Implementability

It will be difficult to install moisture-monitoring probes to the correct depth under Alternative 1 because of the existing concrete covers over the shafts. This may limit the ability to properly monitor the performance of Alternative 1. The ability to construct and install monitoring equipment for a new engineered ET cover has been demonstrated at landfill sites throughout the southwest (Alternative 2) and encapsulation is a demonstrated technology (Alternative 3). Alternatives 1 and 2 could be constructed in less than six months and are expected to attain performance standards in the vadose zone immediately based on use of annual grasses to provide evapotranspiration in the first growing season. It is expected to take an additional two years to fully establish the vegetative cover with perennial grasses and plants as successors to the annual grasses. It is estimated that Alternative 3 would take approximately six months longer to construct than Alternative 2.

The ability to use remote excavation to remove and sort HE contaminated material with the use of engineered barriers was proven at MDA P at the Laboratory. It is estimated that Alternative 4 would require 46 months to complete: 6 months for design and 40 months for construction. Alternative 5 would take approximately 70–110 months to complete [removal: 6 months design, 38 months construction; onsite disposal: 12–60 months permitting (CAMU/RCRA-permitted unit), 6 months construction].

Therefore, Alternatives 1 and 2 would be constructed and operated in the shortest period of time. However, there is the potential that monitoring equipment may not be able to be properly installed to required depths for Alternative 1. Permitting for on-site disposal of RCRA hazardous and/or mixed wastes would add 1–5 yr to the project schedule.

4.1.4 Safety

Potential risks to workers and the surrounding community arise from the actions to be taken in implementing all of the corrective measure alternatives. The types of hazards faced by workers from Alternatives 1, 2, and 3 include industrial accidents. The types of hazards faced by workers and the community from Alternatives 4 and 5 include industrial accidents, transportation accidents, exposure to hazardous materials, and the potential for detonation of HE and fires during excavation and removal.

During implementation of Alternatives 1, 2, or 3, the short-term impact to workers and the surrounding community is minimal. Experience during construction and monitoring of covers at TA-49 and TA-54 indicates that workers are adequately protected by adhering to regulatory health and safety practices required by the Occupational Safety and Health Administration (OSHA) (29 CFR 1910.120), and DOE Orders. Through adherence to OSHA requirements and DOE Orders, off-site air emissions will not exceed regulatory levels. Over the long term, the DU will all be converted to a stable oxide form in 200–1000 yr, or less

Implementation of Alternatives 4 or 5 has the potential to pose significant short-term risk to workers and the community. Potential hazards/accidents from implementation of Alternatives 4 and 5 include industrial hazards/accidents, potential fires and explosions that might release radioactive/hazardous materials, and transportation accidents. Engineering controls to reduce the potential for fires and explosions will increase the difficulty of implementing Alternatives 4 and 5.

Implementation of Alternatives 1, 2, or 3 poses substantially fewer short-term risks than Alternatives 4 and 5.

4.2 Human Health

Results of the RFI for MDA H (LANL 2001, 70158; LANL 2002, 73270) demonstrated that the only contaminant releases at MDA H over the past 40 yr have been subsurface releases of tritium and trace amounts of VOCs. Although there are no unacceptable present-day risks, the need to evaluate corrective measure alternatives for MDA H arises because contaminants at the site have the potential to present a risk to human health and the environment over the lifetime of the waste (NMED 2000, 68569).

A risk/dose assessment was conducted for Alternative 1 by evaluating both recreational and residential scenarios for potential future risk to human health and site worker risk/dose for the 100-yr period of institutional control (Section 3.3). The risk/dose assessments determined that leaving MDA H wastes in place poses no unacceptable risk to human health and the environment over the 100-yr institutional control period for workers, the 1000-yr evaluation period, and MCLs and radionuclide dose would not be exceeded in the regional groundwater beneath MDA H (Appendix J). The risk/dose calculations (the simulated risk, dose, radon flux, and hazard index) all fall below the CAOs listed in Tables 4.2-1 and 4.2-2.

Table 4.2-1
Summary of Results of Worker Risk/Dose Assessment
(100-yr Institutional Control Period) for Alternatives 1, 2, and 3

Corrective Action Objective	Worker Scenario
RCRA hazardous constituents ICR within or below 10^{-6} to 10^{-4}	4×10^{-11}
Hazard Index < 1	1×10^{-5}
Radionuclide dose < 15 mrem/yr	0.0004

Table 4.2-2
Summary of Results of Long-Term Risk/Dose Assessment
(1000-yr Duration Period) for Alternatives 1, 2, and 3

Corrective Action Objective	Recreational Use	Residential Use
RCRA hazardous constituents ICR within or below 10^{-6} to 10^{-4}	9×10^{-11} [a]	5×10^{-7} [a]
Hazard Index <1	0.0008[b]	0.02[b]
Radionuclide Dose <15 mrem/yr	0.006	2.4 / 0.09[c]
Radon Flux <20 pCi/m^2-sec	4.0/0.2[c,d]	4.0/0.2[c,d]

[a] Maximum value at approximately 300 yr.

[b] Child receptor.

[c] Value using upper-bound and best-estimate uranium inventory, respectively.

[d] Radon flux estimate is independent of land use scenario.

Alternatives 2 and 3 are similar to Alternative 1, differing only by including features to improve the performance of Alternative 1. The improvement in protection of human health afforded by Alternatives 2 and 3 was not quantified because of the conservative, bounding type of analysis used for Alternative 1 (i.e., the certainty that these enhancements would only serve to reduce the risk/dose calculated for Alternative 1). Therefore, if a risk/dose assessment were specifically conducted on Alternatives 2 and 3, this assessment would result in lower estimates of risk/dose, which would also be below all existing federal and state criteria, standards, or regulations for the protection of human health and CAOs.

Under Alternative 4, the waste in MDA H would be removed and sent to a permitted off-site disposal facility. Any such facility is required to meet the appropriate human health criteria of dose, risk, radon flux, and hazard index that have been demonstrated as met by Alternative 1. Thus, Alternative 4 would provide the same or greater level of protection for human health as Alternative 1 and comply with all standards for protection of human health but to a different community.

Under Alternative 5, the waste in MDA H would be removed and transported to recycle facilities, Area G, and, if necessary, a permitted hazardous waste disposal unit at the Laboratory. All disposal facilities would be required to meet the appropriate human health criteria of dose, risk, radon flux, and hazard index that have been demonstrated to be met by Alternative 1. Thus, Alternative 5 would provide the same or greater level of protection for human health as Alternative 1 and comply with all standards for protection of human health.

Alternatives 1, 2, and 3 result in minimum exposure to contaminants. Alternatives 4 and 5 result in the maximum exposure to workers during waste excavation, sorting and declassification activities and the maximum reduction (Alternative 4) in exposure to the community after completion of waste excavation, sorting and declassification activities.

4.3 Environmental

4.3.1 Environmental Considerations for Alternatives 1, 2, and 3

The implementation of Alternatives 1, 2, and 3 would involve small-area (0.3 acres) short-term disturbances to the surface soil, plants, and animals within and around MDA H. The activities associated with these alternatives are expected to last 6–12 months. An additional two years is estimated for full establishment of the vegetative cover. Alternatives 1, 2, and 3 would cause relatively minimal damage to the biological resources in and around MDA H. Implementation of Alternatives 1, 2, and 3 would have no effect on cultural resources.

4.3.2 Environmental Considerations for Alternatives 4 and 5

Implementation of Alternatives 4 and 5 would involve disturbance of approximately 3 acres to the soil, plants, and animals within and around MDA H. The activities associated with Alternative 4 are expected to last approximately 40 months and approximately 50 months for Alternative 5. An additional two years is estimated for full establishment of the vegetative cover. Thus, there would be no long-term impacts on the MDA H plant and animal species.

Cultural resources in the area of MDA H may potentially be impacted by fire or explosions occurring during excavation and by construction of an overburden storage area.

4.4 Cost

Implementation of Alternative 5 (on-site disposal) versus Alternative 4 (off-site disposal) would add approximately $14 million in capital cost for on-site disposal of approximately 40 cubic yards of hazardous waste. Alternative 5 is not cost effective versus Alternative 4 and is recommended for elimination from further consideration. In addition, this material may be able to be treated on site to remove the RCRA characteristics prior to disposal. Alternative 5 could also require an additional 5 yr for permitting.

4.5 Summary Comparison of Alternatives

The evaluation of alternatives summarized in Table 4.4-1 shows the following:

- Performance—The technical performance of all five alternatives is equal.
- Reliability—All five alternatives are technically reliable.
- Implementability—Alternatives 1 and 2 would be implemented and operational in the shortest timeframe. It may not be possible to install moisture-monitoring equipment to the proper depth for Alternative 1. Alternative 5 would take up to 5 yr to permit versus no permitting time for Alternative 4.
- Safety—Under Alternatives 1, 2, and 3, the DU is converted to a stable oxide form in 200–1000 yr, or less. Implementation of Alternatives 4 and 5 pose potentially substantial risk to workers and the community from potential fires promoting the release of radioactive/hazardous materials, potential explosions promoting the release of radioactive materials, and transportation accidents.
- Human Health—All five alternatives are expected to meet the corrective action objectives for human health (Section 2.2). If any of the alternatives were implemented, breakthrough of either hazardous waste or constituents or radionuclides to the regional groundwater beneath MDA H is not expected within the 1000-yr evaluation period
- Environmental—Alternatives 1, 2, and 3 would have minimal short-term impact on biological resources and no impact on cultural resources. Alternatives 4 and 5 have substantial short-term impacts on biological resources and potential impacts on cultural resources, but no long-term impacts.
- Cost—Alternatives 1 and 2 had substantially lower present-value cost than Alternatives 3, 4, and 5. Alternative 5 is not cost effective compared with Alternative 4.

5.0 RECOMMENDED CORRECTIVE MEASURE

This section describes the rationale for the selection of the corrective measure, the design approach for the Corrective Measure Implementation, design and implementation precautions, and cost estimates and schedules for implementation of the recommended alternative (LANL 2001, 70319).

Table 4.4-1
Comparative Analysis of Corrective Measure Alternatives

Alternative	Technical Performance	Technical Reliability	Implementability	Safety
1. Upgrade Existing surface layer	The cover would be expected to be effective for the 1000-yr evaluation period. MCLs would not be exceeded in groundwater over the 1000-yr evaluation period. CAOs for radon flux would be met.	RFI demonstrated the current cover has been reliable and effective in preventing releases of most contaminants.	Designed and constructed in less than 6 months with normal construction equipment. Monitoring equipment may not be able to be installed to required depths.	Minimal threat to community, workers and the environment.
2. Engineered ET Cover	The cover would be expected to be effective for the 1000-yr evaluation period. MCLs would not be exceeded in groundwater over the 1000-yr evaluation period. CAOs for radon flux would be met.	The reliability of the existing cover would be increased by increasing the cover depth.	Designed and constructed in less than 6 months with normal construction equipment.	Minimal threat to community, workers and the environment.
3. Encapsulation with Engineered ET Cover	The cover would be expected to be effective for the 1000-yr evaluation period. MCLs would not be exceeded in groundwater over the 1000-yr evaluation period. CAOs for radon flux would be met. Bench scale tests would be required to determine the effectiveness of barriers.	The addition of vertical barrier walls could reduce human and biotic intrusion in the future.	Designed and constructed in approximately 12 months with normal construction equipment.	Minimal threat to community, workers, and the environment.
4. Excavation, Off-Site Disposal	Excavation and off-site disposal would remove the disposed material from MDA H.	Use of a remote excavator to remove HE from subsurface units has been demonstrated at MDA P. Removal of depleted uranium may require engineering controls and an inert atmosphere to prevent ignition.	Designed and constructed in approximately 46 months. Requires remote excavator and engineered barriers for blast shielding.	Potential significant threats to nearby community, workers and the environment from fire and explosions during excavation. A Safety Analysis will be required.
5A, B. Excavation, On-Site Disposal	The material disposed at MDA H would be removed and recycled or disposed in a RCRA permitted unit on Laboratory property and/or at Area G.	Use of a remote excavator to remove HE from subsurface units has been demonstrated at MDA P. Removal of depleted uranium may require engineering controls and an inert atmosphere to prevent ignition.	Designed and constructed in approximately 70–118 months. Requires remote excavator and engineered barriers for blast shielding.	Potential significant threats to nearby community, workers and the environment from potential fire and explosions during excavation. A Safety Analysis will be required.

Table 4.4-1 (continued)

Alternative	Human Health Long-term Risk	Environmental Impacts	Cost Estimate Present Value 30-yr	Cost Estimate Present Value 1000-yr
1. Upgrade Existing surface layer	ICR, HI, dose and radon levels less than CAOs[a] over the 1000-yr evaluation period and for workers during the 100-yr institutional control period. MCLs not exceeded in groundwater over the 1000-yr evaluation period.	Minimal effect on biological resources. No effect on cultural resources.	$592,000	$643,000
2. Engineered ET Cover	ICR, HI, dose and radon levels less than CAOs over the 1000-yr evaluation period and for workers during the 100-yr institutional control period. MCLs not exceeded in groundwater over the 1000 yr evaluation period.	Minimal effect on biological resources. No effect on cultural resources.	$723,000	$774,000
3. Encapsulation with Engineered ET Cover	ICR, HI, dose and radon levels less than CAOs over the 1000- yr evaluation period and for workers during the 100-yr institutional control period. MCLs not exceeded in groundwater over the 1000-yr evaluation period.	Minimal effect on biological resources. No effect on cultural resources.	$2,925,000	$2,976,000
4. Excavation, Off-Site Disposal	ICR, HI, dose and radon levels less than CAOs over the 1000-yr evaluation period. MCLs not exceeded in groundwater over the 1000-yr evaluation period.	Short-term effect to biological resources greater than Alternatives 1, 2, and 3. Potential impact to cultural resources.	$51,906,000	$51,906,000
5A, B. Excavation, On-Site Disposal	ICR, HI, dose and radon levels less than CAOs over the 1000-yr evaluation period. MCLs not exceeded in groundwater over the 1000-yr evaluation period.	Short-term effect to biological resources greater than Alternatives 1, 2, and 3. Potential impact to cultural resources.	$68,244,000 (5A)[b] $66,894,000 (5B)[c]	$68,563,000 (5A)[b] $67,213,000 (5B)[c]

[a] CAO = Corrective action objectives.

[b] 5A = On-site disposal of hazardous/mixed waste in RCRA-permitted landfill.

[c] 5B = On-site disposal of hazardous/mixed waste in CAMU.

The recommended corrective measure alternative is Alternative 2, which includes construction of an engineered ET cover along with long-term maintenance and monitoring and proposed contingency plan implementation requirements if the cover does not function as designed. Alternative 2 is preferred to the other alternatives for the following reasons:

- Alternative 2 provides equal protection to human health and the environment compared to the other alternatives.
- Performance monitoring equipment can be readily installed at appropriate depths below the Alternative 2 evapotranspiration cover and in the subsurface at depth. Existing concrete shaft covers in Alternative 1 may interfere with placement of performance-monitoring equipment to correct depths. Therefore, performance monitoring may be less reliable for Alternative 1.
- Alternative 2 requires less time to implement than Alternatives 3, 4, and 5.
- Alternative 2 poses substantially less risk to workers during implementation than Alternatives 4 and 5.
- Alternative 2 provides the same benefits as Alternatives 3, 4, and 5 at markedly reduced cost.

5.1 Design Approach

Should Alternative 2 be selected by NMED, an engineered ET cover would be designed during the Corrective Measures Implementation (CMI) phase for MDA H. The design process would include the following activities:

1. Identification of critical infiltration events, which includes identification of the design precipitation event (maximum precipitation event that the design is based upon) or series of events.
2. Determination of the minimum required water-storage capacity of MDA H soil based on design infiltration events identified in step 1.
3. Determination of the minimum soil thickness required.
4. Identification of the seed mixture to be used, the surface treatment to be employed prior to seeding, and the frequency of watering required to establish the vegetative cover.
5. Determination of whether a biointrusion barrier is required.
6. Verification that this design will have performance equivalency with the requirements of 20 NMAC 9.1 for alternative cover design.
7. Design of a moisture-monitoring system using TDR probes and neutron logging in existing boreholes.
8. Development of an operation and maintenance manual based on design and monitoring requirements. The operation and maintenance manual would be reviewed during final design meetings and submitted to NMED for approval.

5.1.1 Performance Expectations

The engineered ET cover (Alternative 2) for MDA H would be designed and maintained to ensure that the following corrective action objectives (discussed in Section 2.2) are met:

1. ***Protect human health.***

   For hazardous wastes or constituents, the selected corrective measure will provide reasonable assurance that (1) the excess incremental cancer risk estimated according to EPA's RME approach does not exceed a range of 10^{-6} to 10^{-4} for the design life of the cover and (2) the noncancer hazard evaluated for the cover does not exceed a hazard index of 1. For radionuclides, the selected corrective measure will provide reasonable assurance that the total calculated RME dose does not exceed the DOE dose limit of 15 mrem/yr. For radon, the cover will provide reasonable assurance that the radon emission rate to ambient air will not exceed 20 picocuries per square meter per second (40 CFR 61, Subpart Q). The fate and transport modeling discussed in Appendix H predicts that these metrics will be achieved for Alternative 2.

2. ***Protect the environment.***

   The cover will provide reasonable assurance of protection of the environment as determined in the environmental assessment being prepared in parallel with the CMS.

3. ***Attain action levels.***

   The cover will provide reasonable assurance that migration of contaminants during the design life of the corrective measure will not result in contaminant concentrations above action levels at the points of compliance to be negotiated with NMED. A monitoring system will be designed to monitor cover performance. A contingency plan is proposed in Section 5.3.4 to respond to increased moisture levels if the cover fails.

4. ***Source control.***

   This objective ensures that the cover will be designed to provide reasonable assurance that future releases will be minimized and that the impact of any potential release is within the risk/dose levels specified above. A monitoring system will be designed to monitor cover performance. A contingency plan is proposed in Section 5.3.4 to respond to detections if the cover fails.

5. ***Waste management compliance.***

   Activities involved with placement of the cover and installation of performance monitoring equipment will comply with Federal, State, and Laboratory requirements for management of wastes generated during these activities.

5.1.2 Preliminary Design Criteria and Rationale

During the initial phase of the CMI, design calculations and documentation will be provided to NMED that show the following:

- There is sufficient storage capacity within the cover to store the "maximum" infiltration quantity resulting from the worst-case precipitation event until it can be removed via evapotranspiration.
- The cover design will have performance equivalency with the requirements of 20 NMAC 9.1 for alternative cover design (Appendix G).

- The proposed seed mixture that will be used to stabilize the cover with vegetation comprising plant communities that closely emulate the local plant community and ensure that the vegetative cover remains viable.
- The proposed surface treatment method that will encourage native vegetation establishment and growth and reduce erosion.
- The proposed moisture-monitoring system will verify that volumetric water content levels below the shafts do not exceed 11%. This monitoring criterion is applicable to unit Qbt 1vu from depths of 60 to 100 ft in boreholes 54-15462, 54-15461, and/or 54-1023. This assures that aqueous-phase transport to the regional aquifer is sufficiently slow to inhibit migration to the regional aquifer so MCLs are not exceeded (Appendix J, Section J-5.0).

5.1.3 General Operation and Maintenance Requirements

The Laboratory Ecology Group (RRES-E) will review the MDA H cover design and develop requirements for irrigating the cover sufficiently during the two years after construction to aid in germination and establishment of a vegetative cover. The Laboratory will implement the irrigation plan.

During the first two years after construction, the Laboratory will inspect the cover quarterly and after significant rain events to identify any area of the cover that is eroding. Any eroded areas of the cover will be repaired. After the cover is established, it will be inspected in the fall (after the monsoon season has ended) and any erosion to the cover will be repaired.

During the design phase of the CMI, an area will be designated within the MDA H fence to store the gravel mulch mixture to be used for cover maintenance. A small shed will be placed in this area for storage of tools and grass seed.

Moisture-monitoring equipment for the cover will be inspected regularly and repaired as necessary.

5.1.4 Long-Term Monitoring Requirements

Groundwater monitoring of the regional aquifer beneath MDA H will be consolidated with the TA-54 mesa-wide groundwater-monitoring program.

TDR probes will be installed within and beneath the MDA H cover for vadose-zone moisture monitoring as described in Section 3.5.3. Moisture levels will be recorded twice daily on a data logger. The data will be analyzed and reported quarterly for the first two years to verify that the cover is performing at the pre-established rate of moisture loss or better. Thereafter, the data will be analyzed and reported annually. A five-yr review will be conducted with NMED to review cover performance.

The three existing boreholes will be neutron logged every foot monthly for two years to establish time series trends for developing a depth profile of moisture to confirm the conceptual model. After the first two years, neutron logging will be conducted annually. Review of the depth profile of moisture will be included in the five-yr review.

5.2 Design and Implementation Precautions

5.2.1 Special Technical Problems

The following technical issues will be evaluated during CMI conceptual design:

Cover Thickness

The performance of the engineered ET cover relies on its thickness. The engineered ET cover for MDA H will be of sufficient thickness to ensure that the storage capacity of the cover is sufficient to store the maximum infiltration quantity resulting from the design precipitation event until it could be removed via evapotranspiration.

Surface Treatment

In the dry climate at the Laboratory, surface treatments, such as the addition of soil nutrients, a surface gravel layer, or gravel admixture may be warranted to assist native vegetation establishment and reduce erosion. The addition of a one- or two-inch thick layer of 0.5- to 2-in. diameter rounded gravel on the surface of the cover offers the following advantages for the MDA H cover:

- A gravel layer will reduce surface erosion due to runoff and wind erosion and serve to hold seed in place until germination.
- Moisture will be retained in the upper-most layer of soil allowing vegetation such as native grasses to be established, thereby increasing the transpirational capacity available to remove moisture and thus prevent drainage after a significant rainfall event. The difference between a gravel layer and a rock or riprap covering is that the moisture is retained in soil near the surface, apart from the waste, where water-seeking roots will not intrude into the shafts.

The disadvantages of a gravel layer include a reduced evaporation rate. Fine-grained soil generally has a higher evaporation rate than coarse-grained soil. After the surface (gravel) dries, the lower portions of the soil profile will tend to remain moist because this coarse-grained gravel layer is non-conductive. This reduced evaporation may become a large enough factor to discredit the use of a surface gravel layer on the MDA H cover. There is no hard evidence revealing whether the added vegetation resulting from the gravel layer, and consequently the additional transpiration will outweigh the reduced evaporation.

An alternative to a gravel layer is a gravel admixture. Erosion and water balance studies at the Laboratory indicate that moderate amounts of gravel mixed into the cover topsoil will control both water and wind erosion with little effect on the vegetation or the soil-water balance. As wind and water pass over the landfill cover surface, some winnowing of fines from the admixture is expected, creating a vegetated erosion-resistant surface sometimes referred to as a "desert pavement."

The design of a gravel admixture layer is based primarily on the need to protect the soil cover from water and wind erosion. A gravel admixture generally protects a cover from long-term wind erosion. The protection from water erosion is dependent on the depth, velocity, and duration of water flowing across the MDA H cover. Flow values can be established from the physical properties of the cover (slope, convex or concave grading, slope uniformity, and length of flow paths) and the intensity of the precipitation (precipitation rates, infiltration vs. runoff relationships, snowmelt, and off-site flows).

The decision on surface treatment will be based on review of site specific conditions at MDA H and Laboratory data from cover experiments at TA-51 (Nyhan et al. 1997, 63111) during the CMI design phase and discussions with NMED

Vegetative Mix

During the CMI design phase, the Laboratory Ecology Group (RRES-E) will be consulted to provide a seed mix that will stabilize the cover with vegetation comprising plant communities that closely emulate plant communities found in the MDA H area that have long been undisturbed and in equilibrium with all other environmental parameters.

Compaction Requirements

Evapotranspiration covers are designed to function under unsaturated conditions; consequently obtaining very low saturated hydraulic conductivity is not a priority. Compaction density requirements will be based on the design criteria used, but will generally be geared toward achieving a density in the upper soil layer that approximately equals that of the surrounding, in situ, undisturbed soil. Uniformity of compaction will be critical.

Use of Biobarriers

When the cover depth is established, an evaluation will be performed to determine what type of biointrusion barrier required to prevent plants and animals penetrating through the cover system, creating conduits for water to move downward into the shaft waste and/or to transport shaft waste to the surface.

5.2.2 Additional Engineering Data Required

Prior to initiating CMI design, existing plans and specifications for the water line that parallels MDA H along Mesita del Buey Road will be reviewed to determine the best method for installing pressure sensors and automatic shut-off valves in order to shut down the water line should a water line break occur. These upgrades will be completed prior to start of cover construction.

5.2.3 Permits and Regulatory Requirements

A permit modification request will be submitted to NMED upon their approval of a corrective measure for MDA H. The modification request will propose the scope and schedule to implement the corrective measure by means of the CMI process.

5.2.4 Access, Easements, Right-of-Way

A facility tenant agreement will be required between the Laboratory RRES-R Program and Facility Management that would specify the specific roles and responsibilities of the Facility Owner and the group constructing the cover.

5.2.5 Health and Safety Requirements

A site-specific health and safety plan (SSHASP) will be prepared that will include health and safety requirements to be followed during construction of the MDA H cover, during construction of the monitoring system, during operation and maintenance activities, and during monitoring activities.

5.2.6 Community Relations Activities

Public Outreach Plan activities were summarized in Section 2.2.1. In addition, an independent peer reviewer will provide comments on the CMS report and a fifth and sixth Focus Group meeting is planned to review the selected alternative. NMED will also schedule a formal public comment period on the MDA H CMS report during the permit modification review period.

5.3 Cost Estimates and Schedules

5.3.1 Capital Cost Estimate

The estimated capital cost for design and construction of Alternative 2 is $382,500 (Section 3.5, Table 3.5-10)

5.3.2 Operation and Maintenance Cost Estimate

The estimated annual operation and maintenance cost of Alternative 2 is $65,900 for the first two years based on the following:

Cover maintenance	$18,000
Neutron Logging	$42,000
Moisture monitoring	$ 5,900
Total	$65,900

Assuming that neutron logging is conducted annually after two years, the annual operation and maintenance costs is reduced to $27,400 based on the following:

Cover maintenance	$18,000
Neutron Logging	$ 3,500
Moisture monitoring	$ 5,900
Total	$27,400

5.3.3 Project Schedule (Design, Construction, Operation)

The current FY 2003 Laboratory RRES-R Program baseline shows the following schedule for MDA H:

- Permit Modification, August 21, 2003–August 23, 2004
- CMS Design, August 24, 2004–April 22, 2005
- CMS Construction, April 25, 2005–October 13, 2005

5.3.4 Contingency Plan

If vadose-zone moisture-monitoring indicates the volumetric water content in unit Qbt 1vu from depths of 60 to 100 ft in boreholes 54-15462, 54-15461, and/or 54-1023 rise above 11%, the Laboratory will inspect the condition of the MDA H vegetative cover and have RRES-E personnel determine if a proper vegetative cover is being established. If the vegetative cover is definitely established, the Laboratory will reevaluate cover thickness requirements and upgrade the cover as appropriate by adding additional cover material and re-establishing the vegetative cover.

6.0 REFERENCES

The following list includes all references cited in this document. Parenthetical information following each reference provides the author, publication date, and the ER identification (ID) number. This information also is included in the citations in the text. ER ID numbers are assigned by the Laboratory's RRES-R Program to track records associated with the Program. These numbers can be used to locate copies of the actual documents at the RRES-R Program's Records Processing Facility and, where applicable, with the RRES-R Program's reference library titled "Reference Set for Material Disposal Areas, Technical Area 54."

Copies of the reference library are maintained at the NMED Hazardous Waste Bureau; the DOE Los Alamos Site Office; and EPA, Region 6. This library is a living collection of documents that was developed to ensure that the administrative authority has all the necessary material to review the decisions and actions proposed in this document. However, documents previously submitted to the administrative authority are not included.

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Appendix A

Acronyms, Glossary, and Metric Conversion Tables

APPENDIX A ACRONYMS, GLOSSARY, AND METRIC CONVERSION TABLES

A-1.0 ACRONYMS

bgs	below ground surface
CMI	corrective measures implementation
CAMU	corrective action management unit
CAO	corrective measures objective
CMS	corrective measures study
COPC	chemical of potential concern
DCF	dose conversion factor
DoD	Department of Defense
DOE	US Department of Energy
DU	depleted uranium
EPA	US Environmental Protection Agency
ER	environmental restoration
ET	evapotranspiration
EU	enriched uranium
HE	high explosives
HEU	highly enriched uranium
HI	hazard index
HWB	Hazardous Waste Bureau (NMED)
HSWA	Hazardous and Solid Waste Amendments of 1984
ICR	incremental cancer risk
ID	identification
Laboratory	Los Alamos National Laboratory
LANL	Los Alamos National Laboratory
LDR	land disposal restrictions
LLW	low-level waste
MCL	maximum contaminant level
MDA	material disposal area
MDL	method detection limit
MTR	minimum technological requirement

NEPA	National Environment Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NMAC	New Mexico Administrative Code
NMED	New Mexico Environment Department
NMHWA	New Mexico Hazardous Waste Act
NNSA	National Nuclear Security Administration
O&M	operation and maintenance
OSHA	Occupational Safety and Health Administration
PBX	plastic bonded explosives
PET	potential evapotranspiration
POP	Public Outreach Plan
PPE	personal protective equipment
RCRA	Resource Conservation and Recovery Act
RDX	cyclotrimethylenetrinitramine
RFA	RCRA Facility Assessment
RFI	RCRA Facility Investigation
RME	reasonable maximum exposure
RRES-E	Laboratory Ecology Group
RRES-R	Risk Reduction and Environmental Stewardship–Remediation Program
Sandia	Sandia National Laboratories/New Mexico
SAR	safety analysis report
SNL/NM	Sandia National Laboratories/New Mexico
SSHASP	site-specific health and safety plan
SWMU	solid waste management unit
TA	technical area
TDR	time-domain reflectometry
TSD	treatment, storage, and disposal
VOC	volatile organic compound

A-2.0 GLOSSARY

Alluvium. Clay, silt, sand, and gravel transported by water and deposited on streambeds, flood plains, and alluvial fans.

Baseline risk assessment (also known as risk assessment). A site-specific analysis of the potential adverse effects of hazardous substances that are released from a site in the absence of any control or mitigation actions. A baseline risk assessment consists of four steps: data collection and analysis, exposure assessment, toxicity assessment, and risk characterization.

Calibration. Process used to identify the relationship between the true (reference) analyte concentration or other variable and the response of a measurement instrument, chemical analysis method, or other measurement system.

Chemical of potential concern (COPC). Chemical, detected at a site, that has the potential to adversely affect human and/or ecological receptors due to its concentration, distribution, and mechanism of toxicity. A COPC remains a concern until exposure pathways and receptors are evaluated in a site-specific risk assessment.

Department of Energy (DOE). Federal agency that sponsors energy research and regulates nuclear materials for weapons production.

Detection limit. Minimum concentration that can be determined by a single measurement by an instrument; implies a specified statistical confidence that the analytical concentration is greater than zero.

Dose. Quantity of radiation that is absorbed, per unit of mass, by the body or by any portion of the body.

Environmental Protection Agency (EPA). Federal agency responsible for enforcing environmental laws. While state regulatory agencies may be authorized to administer some of this responsibility, the EPA retains oversight authority to ensure protection of human health and the environment.

Evapotranspiration. The combined discharge of water from the earth's surface to the atmosphere by evaporation from lakes, streams, and soil surfaces, and by transpiration from plants.

Exposure pathway. Mode by which a receptor may be exposed to contaminants in environmental media (e.g., drinking water, ingesting food, or inhaling dust).

Fault. A fracture, or zone of fractures, in rock along which there has been vertical or horizontal movement; adjacent rock surfaces are displaced.

Groundwater. Water in a subsurface saturated zone; water beneath the regional water table.

Hazard quotient (HQ). The ratio of a calculated exposure (E) to or dose (D) from a given contaminant (I) to a given receptor (j) over a reference value (TRV) for contaminant (I) determined to be protective of receptor (j), i.e., $HQ_{ij} = E_{ij}$ [or D_{ij}]TRV_{ij}.

Hazardous and Solid Waste Amendments (HSWA). The Hazardous and Solid Waste Amendments of 1984 (Public Law No. 98-616, 98 Stat. 3221), which amended the Resource Conservation and Recovery Act of 1976, 42 U.S.C. § 6901 et seq.

HSWA module. A portion of the Laboratory's permit to operate under RCRA that contains requirements specific to Los Alamos National Laboratory. It is this portion of the permit that contains the list of solid waste management units that must be cleaned up in accordance with RCRA procedures.

Hydraulic conductivity. The rate at which water moves through a medium in a unit of time under a unit hydraulic gradient through a unit area measured perpendicular to the direction of flow.

Hydrogeology. The science that applies geologic methods to the understanding of hydrologic phenomena.

Model. A mathematical approximation of a physical, biological, or social system.

Operable unit (OU). At the Laboratory, one of 24 areas originally established for administering the ER Project. Set up as groups of potential release sites, the OUs were aggregated based on geographic proximity for the purpose of planning and conducting RCRA facility assessments and RCRA facility investigations. As the project matured, it became apparent that 24 were too many to allow efficient communication and to ensure consistency in approach. Therefore, in 1994, the 24 OUs were reduced to six administrative "field units."

Radionuclide. A nuclide (species of atom) that exhibits radioactivity.

RCRA facility investigation (RFI). The investigation that determines if a release has occurred and the nature and extent of the contamination at a hazardous waste facility. The RFI is generally equivalent to the remedial investigation portion of the Comprehensive Environment Response, Compensation, and Liability Act (CERCLA) process.

Receptor. A person, plant, animal, or geographical location that is exposed to a chemical or physical agent released to the environment by human activities.

Recharge. The process by which water is added to the zone of saturation, either directly from the overlying unsaturated zone or indirectly by way of another material in the saturated zone.

Regional aquifer. Geologic material(s) or unit(s) of regional extent whose saturated portion yields significant quantities of water to wells, contains the regional zone of saturation, and is characterized by the regional water table or potentiometric surface.

Release. Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of hazardous waste or hazardous constituents into the environment (including the abandonment or discarding of barrels, containers, and other closed receptacles that contain any hazardous wastes or hazardous constituents).

Resource Conservation and Recovery Act (RCRA). The Solid Waste Disposal Act as amended by the Resource Conservation and Recovery Act of 1976. (40 CFR 270.2)

Runoff. The portion of the precipitation on a drainage area that is discharged from the area either by sheet flow or adjacent stream channels.

Run-on. Surface water flowing onto an area as a result of runoff occurring higher up the slope.

Sample. A portion of a material (e.g., rock, soil, water, air), which, alone or in combination with other samples, is expected to be representative of the material or area from which it is taken. Samples are typically sent to a laboratory for analysis or inspection or are analyzed in the field. When referring to samples of environmental media, the term field sample may be used.

Sample matrix. In chemical analysis, that portion of a sample which is exclusive of the analytes of interest. Together, the matrix and analytes of interest form the sample.

Sediment. (1) A mass of fragmented inorganic solid that comes from the weathering of rock and is carried or dropped by air, water, gravity, or ice; or a mass that is accumulated by any other natural agent and that forms in layers on the earth's surface such as sand, gravel, silt, mud, fill, or loess. (2) A solid material that is not in solution and either is distributed through the liquid or has settled out of the liquid.

Site characterization. Defining the pathways and methods of migration of the hazardous waste or constituents, including the media affected, the extent, direction and speed of the contaminants, complicating factors influencing movement, concentration profiles, etc. (U.S. Environmental Protection Agency, May 1994. “RCRA Corrective Action Plan, Final,” Publication EPA-520/R-94/004, Office of Solid Waste and Emergency Response, Washington, DC)

Site conceptual model. A qualitative or quantitative description of sources of contamination, environmental transport pathways for contamination, and biota that may be impacted by contamination (called receptors) and whose relationships describe qualitatively or quantitatively the release of contamination from the sources, the movement of contamination along the pathways to the exposure points, and the uptake of contaminant by the receptors.

Solid waste management unit (SWMU). Any discernible unit at which solid wastes have been placed at any time, irrespective of whether the unit was intended for the management of solid or hazardous waste. Such units include any area at a facility at which solid wastes have been routinely and systematically released. This definition includes regulated units (i.e., landfills, surface impoundments, waste piles, and land treatment units) but does not include passive leakage or one-time spills from production areas and units in which wastes have not been managed (e.g., product storage areas).

Spring. The site where groundwater discharges to the ground surface.

Standard operating procedure (SOP). A document that details the method for an operation, analysis, or action with thoroughly prescribed techniques and steps, and is officially approved as the method for performing certain routine or repetitive tasks.

Stratigraphy. The science dealing with the succession, age, composition, and history of strata.

Target analyte. An element, chemical, or parameter, the concentration, mass, or magnitude of which is designed to be quantified by use of a particular test method.

Technical area (TA). The Laboratory established technical areas as administrative units for all its operations. There are currently 49 active TAs spread over 43 square miles.

Topography. The physical configuration of the land surface in an area.

Tuff. A compacted deposit of volcanic ash and dust that contains rock and mineral fragments accumulated during an eruption.

Vadose zone. The unsaturated zone. Portion of the subsurface above the regional water table in which pores are not fully saturated.

Welded tuff. A volcanic deposit hardened by the action of heat, pressures from overlying material, and hot gases.

A-3.0 METRIC CONVERSION TABLES

Metric to English Conversions

Multiply SI (Metric) Unit	by	To Obtain US Customary Unit
kilometers (km)	0.622	miles (mi)
kilometers (km)	3281	feet (ft)
meters (m)	3.281	feet (ft)
meters (m)	39.37	inches (in.)

centimeters (cm)	0.03281	feet (ft)
centimeters (cm)	0.394	inches (in.)
millimeters (mm)	0.0394	inches (in.)
micrometers or microns (µm)	0.0000394	inches (in.)
square kilometers (km^2)	0.3861	square miles (mi^2)
hectares (ha)	2.5	acres
square meters (m^2)	10.764	square feet (ft^2)
cubic meters (m^3)	35.31	cubic feet (ft^3)
kilograms (kg)	2.2046	pounds (lb)
grams (g)	0.0353	ounces (oz)
grams per cubic centimeter (g/cm^3)	62.422	pounds per cubic foot (lb/ft^3)
milligrams per kilogram (mg/kg)	1	parts per million (ppm)
micrograms per gram (µg/g)	1	parts per million (ppm)
liters (l)	0.26	gallons (gal.)
milligrams per liter (mg/l)	1	parts per million (ppm)
degrees Celsius (°C)	9/5 + 32	degrees Fahrenheit (°F)

Metric Prefixes

Term	Power of 10	Symbol
mega-	10^6	M
kilo-	10^3	k
deci-	10^{-1}	d
centi-	10^{-2}	c
milli-	10^{-3}	m
micro-	10^{-6}	µ
nano-	10^{-9}	n
pico-	10^{-12}	p

Appendix B

MDA H Disposal Inventory

APPENDIX B MDA H DISPOSAL INVENTORY

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
1	5-3-60	1344	Tungsten carbide	Tungsten carbide			1	1' X 1' X 1'	100	60.0	From storage in CMB-6
1	5-4-60	1345	SM		2	Truck load	1024	16'X8'X4'	12,575	58.8	From storage in Ice House.
1	5-9-60	1346	Sleeve				1	1' X 1' X 1'	10	58.8	
1	5-23-60	1347	SM				1	1' X 1' X 1'	100	58.8	
1	5-27-60	1348	1 case, 2 carriers		1	Case	18	3' X 2' X 3'	300	58.1	
1	5-27-60	1348	1 case, 2 carriers		2	Carriers	18	3' X 2' X 3'	300		
1	6-14-60	1578	SP				0.125	6" X 6" X 6"	50	58.1	
1	6-21-60	none	S	Contamination (unknown type)			Negligible		Negligible	58.1	
1	6-22-60	1579	SM	Al, graphite, plaster, phenolic, rubber			56	2' X 2' X 14'	1,875	56.1	
1	7-7-60	1580	Scrap	Tungsten carbide and tungsten alloy	8	Boxes	21.875	12 1/2" X 10 1/2" X 36"	11,400	55.0	8 ea boxes large size from SM-30 carpenter shop
1	7-7-60	1580	Scrap	Tungsten carbide and tungsten alloy	1	Box	12.7	21 1/2" X 20" X 7'1"	11,400		8 ea boxes large size from SM-30 carpenter shop
1	8-1-60	1582	Film, X-ray	Film			60	5' X 4' X 3'	300	54.8	
1	8-2-60	1583	Film, X-ray	Film	33	Boxes	33(2.625)	18" X 18" X 14"	6,900	49.8	
1	8-2-60	1583	Film, X-ray	Film	33	Boxes	86.6	18" X 18" X 14"	6,900		
1	8-2-60	1584	SM	Aluminum & steel			4.4	20" x 16" X 24"	100	49.7	
1	8-3-60		α Sources		2	Each				50.0	
1	8-8-60	1590	Inert objects		26	Boxes	26(1.7778)	16"X12"X16"	700	48.4	
1	8-8-60	1590	Inert objects		26	Boxes	46.2	16"X12"X16"	700		
1	8-16-60	1592	SM						20	48.3	
1	8-17-60	1594	Cones						100	48.2	
1	8-17-60	1594	SM						100		
1	8-17-60	1594	SM						100		
1	8-17-60	1595	SP		300	Grams			0.7	48.2	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft³)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
1	8-29-60	1596	SM	Copper					5	48.2	
1	9-9-60	1586	SM				27		1,000	47.2	
1	9-27-60	1352	SM		27	pcs.			975	45.9	
1	10-7-60	1354B	Cones						1	45.8	
1	10-7-60	1354B	Cylinders						1		
1	10-7-60	1354B	SM						1		
1	10-26-60	1361B	Film, radiographic	Film			25		1,000	45.0	
1	12-15-60	1372B	SM						100	44.8	
1	1-16-61	1375B	Scrap pieces	D-38					69	44.7	
1	1-20-61	1375B	Scrap pieces	D-38					69		
1	1-23-61	1606B	Scrap	D-38					50	44.7	
1	1-24-61	1608B	SM						250	44.3	
1	2-21-61	1617B	Scrap pieces	D-38					50	44.2	
1	2-24-61	1619B	Scrap pieces	D-38					150	44.0	
1	2-24-61	1620B	Scrap pieces	D-38					75	43.9	
1	3-10-61	1876B	SP							43.9	
1	3-15-61	1878B	Cable harness assemblies						251	43.6	
1	3-17-61	1877B	SP						200	43.3	
1	3-20-61	1879B	Inert objects						350	42.8	
1	3-21-61	None	Film	Film					2,000	39.9	
1	3-29-61	1628B	Unit						1,016	38.5	
1	4-4-61	1629B	SP				27		1,000	37.5	
1	6-14-61	1708B	Film, X-Ray	Film			8		325	37.3	
1	6-19-61	1709B	SP						5	37.3	
1	6-28-61	1891B	SP		19	Units			190	36.0	
1	7-25-61	2036B	Radioactive solid waste, (from Silas Mason on RR-34182F, 7/24/61)	Radioactive solid waste	7	Drums			638	35.4	
1	8-2-61	---	S	Film			1		35	35.4	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
1	8-17-61	1893B	Radioactive solid waste, (from Silas Mason on RR-36734, 8/22/61)	Radioactive solid waste	2	Drums			90	35.3	
1	9-19-61	1894B	Film, X-Ray	Film			20		900	34.4	
1	9-27-61	2061B	SM						29,580	6.0	
2	10-17-61	2068B	SM						2,655	55.8	
2	11-1-61	2040B	SM	D-38					240	55.5	
2	11-7-61	2041B	Scrap pieces	D-38					100	55.3	
2	11-17-61	2044B	Container	SS					20	55.3	
2	11-28-61	2076B	SM						10	55.3	
2	11-28-61	2080B	SM						25	55.2	
2	12-21-61	2081B	Assorted plastic parts	Plastic					4,500	48.2	
2	2-20-62	2091B	Scrap pieces	D-38					300	47.7	
2	2-21-62	2095B	SM						200	47.4	
2	3-2-62	2100B	SM	D-38					100	47.3	
2	3-26-62	1856B	SM						50	47.2	
2	3-28-62	1861B	SM		1	Lot			3,725	45.0	
2	3-28-62	1861B	X-ray film	Film	14	Boxes	35		1,400	39.2	
2	3-28-62	1865B	Film, 16MM	Film					10	39.2	
2	5-31-62	3078B	SM	D-38					400	38.5	
2	6-6-62	3082B	Module, support blocks						15	38.5	
2	6-8-62	3083B	Scrap pieces	D-38					100	38.3	
2	6-27-62	3088B	SM						500	37.6	
2	6-27-62	3089B	Various components	Graphite					1,000	36.0	
2	7-5-62	3094B	SM	D-38			4		175	35.8	
2	7-17-62	3097B	SM,		1	Lot	160		3,075	33.0	
2	7-17-62	3097B	X-ray film	Film	10	Box	160		3,075		
2	8-3-62	3030B	SM	D-38	3	Barrels	6		225	32.8	
2	8-9-62	3033B	SM		5	Boxes			280	32.5	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
2	8-17-62	3035B	X-ray film	Film	21	Boxes			2,100	30.6	
2	8-22-62	3037B	Air masks, oxygen, not classified		4	Each				30.6	
2	9-4-62	3038B	SM	Graphite	1	Pkg			100	30.5	
2	9-5-62	3040B	SM		2	pcs.			1,000	29.6	
2	9-12-62	3053B	SM		2	pcs.			150	29.5	
2	9-13-62	3054B	SM	Graphite	5	Barrels, packing			400	29.1	
2	9-20-62	3055B	Reflector cylinder	Graphite	1	Each			500	28.6	
2	9-25-62	3056B	Support disc		1	Each			1,500	27.3	
2	9-28-62	3058B	SM		18	Each			200	27.1	TA-16-27
2	9-28-62	3058B	SM		4	Each			200	27.1	TA-16-10
2	10-12-62	3046B	SM		1	Box			100	27.0	
2	10-25-62	3061B	SM	D-38	3	Barrels, packing			400	26.6	
2	10-31-62	3063	SM	D-38	6	Barrels, packing			600	26.1	
2	11-16-62	3047B	Various components	Graphite	60	pcs.			3,074	23.2	
2	11-16-62	3047B	Various components	Graphite	3	Boxes			3,074	0.0	
2	11-29-62	3050B	SM		8	Drums			2,099	21.3	
2	11-29-62	3050B	SM		3	Boxes			2,099	0.0	
2	12-4-62	3067B	Carriers,		1	Lot			1,575	19.9	TA-16, S-Site
2	12-4-62	3067B	SM		1	Lot			1,575		TA-16, S-Site
2	12-4-62	3067B	Molds,		1	Lot			1,575		TA-16, S-Site
2	1-2-63	3068B	Carrying case		1	Each			1	19.8	
2	1-4-63	3069B	Film, X-ray	Film			50		1,080	18.9	
2	1-22-63	2705B	SM	D-38 & Scrap	2	Boxes			50	18.8	
2	2-5-63	2715B	Foils & prints		4	Boxes			200	18.6	
2	2-8-63	2718B	SM	Graphite	1	Box			5	18.6	
2	2-14-63	2720B	SM	Styrofoam	5	Boxes			20	18.6	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft³)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
2	2-19-63	2780B	SM	D-38	6	Barrels, packing			400	18.2	
2	3-6-63	2777B	SP	Rubber	1	Each			5	18.2	
2	3-14-63	2779B	SM		1	Lot			7,950	10.9	
2	3-22-63	2781B	SM	Cold & D-38	4	Boxes			150	10.8	
2	3-29-63	2784B	SM	D-38	2	Boxes			80	10.7	
2	3-29-63	2785B	SM	D-38	4	Drums			250	10.5	
2	3-29-63	2785B	SM	Aluminum	1	Drums			250		
2	4-2-63	2786B	Tubes	Aluminum	6	Tubes	0.153	56" X 1",	5	10.5	
2	4-2-63	2786B	SM	Graphite					5		
2	4-4-63	2787B	SP		1	Lot			15	10.5	
2	4-5-63	2789B	SM	D-38	4	Drums			225	10.2	
2	4-16-63	2792B	SP	Graphite	5	Boxes			200	10.1	
2	5-9-63	2151B	X-Ray film	Film	1	Lot			4,350	6.1	
2	5-9-63	2151B	SM		1	Lot			4,350		
2	5-15-63	2155B	D-38 and cold stock	D-38 and cold stock	2	Boxes			68	6.0	
3	6-4-63	2156B	1 Unit		1	Drums			250	59.7	55 gal
3	6-5-63	2157B	Lithium fluoride PBX	Lithium fluoride PBX					4,408	53.6	
3	6-10-63	2158B	D-38	D-38	4	Pkg			185	53.3	
3	6-24-63	2162B	S/N Units		13	Each			100	53.2	
3	7-1-63	2164B	SM	D-38 graphite					400	52.6	
3	7-1-63	2165B	SM	D-38 graphite	3	Boxes			100	52.5	
3	7-3-63	2166B	SM	D-38	18	Barrels, packing			2,125	49.6	
3	7-16-63	2816B	SM		1	Box			25	49.5	
3	7-16-63	2817B	SM		38	Each			1,475	47.5	
3	7-17-63	2712B	Tank, "Cambridge Corp.", Model A S/N-B-30116		1	Each			2,500	44.1	
3	7-24-63	2102B	Slides	Glass	92(total)	Each			10	44.1	
3	7-24-63	2102B	Slides	Glass	67	Each		3 1/4 X 4"	10		

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft³)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
3	7-24-63	2102B	Slides	Glass	25	Each		4 X 5"	10		
3	7-31-63	2819B	SM		2	Cans			250	43.7	
3	8-1-63	2103B	Film, X-ray (60 ea cartons)	Film	2	Lots			3,300	39.2	
3	8-23-63	2105B	Film, X-ray (56 ea cartons)	Film	2	Lots			2,800	35.3	
3	8-23-63	2821B	SM						400	34.8	
3	8-23-63	2822B	SM						35	34.7	
3	8-27-63	2107B	SM	Aluminum & SS	1	Unit			1,200	33.1	
3	8-27-63	2107B	SM	D-38	1	Unit			1,200		
3	8-28-63	2823B	SM	D-38	2	Boxes			95	32.9	
3	9-6-63	2824B	SM	Beryllium	1	Box			13	32.9	
3	9-16-63	2108B	Modules, unfinished, tie rod	D-38					195	32.7	
3	9-17-63	2825B	S/N units -		6	Each			100	32.5	
3	9-17-63	2825B	SP		1	Box			100		
3	9-18-63	2177B	SP	Graphite	1	Lot			150	32.3	
3	9-20-63	2110B	SM	Beryllium	1	Lot			25	32.3	
3	9-20-63	2178B	SM	Graphite and metal	1	Box			10	32.3	
3	9-26-63	2126B	SM		2	Boxes			25	32.2	
3	9-27-63	2179B	SM	Metal	1				350	31.8	
3	9-30-63	2180B	SP	H.E.	1	Lot			375	31.2	
3	10-1-63	2181	SP		14	Each			1	31.2	
3	10-2-63	2127B	Film X-ray	Film	31	Box			1,500	29.2	
3	10-17-63	2128	SM		41	Each			250	28.8	
3	11-13-63	2184	SM		1	Box			150	28.6	
3	11-13-63	2187	SM		1	Pkg			125	28.4	
3	11-13-63	2187	SM		2	Boxes			125		
3	12-4-63	2190	SM	Metal	1	Lot			900	27.2	
3	12-4-63	2190	SP	Film	6	Boxes			900		
3	1-10-64	2194	SM		3	Boxes			207	26.9	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
3	1-16-64	2197	SM		2	Each			7	26.9	
3	1-29-64	2129	SP	Film	9	Cartons			300	26.5	
3	2-11-64	2143	SM	D-38	15	Drums			1,400	24.6	
3	2-11-64	2182	Y tubes		1	Lot			75	24.5	
3	2-11-64	2182	S/N'd Items and		19				75		
3	2-14-64	2146	SM	D-38	6	Drums			342	24.0	
3	3-6-64	2150	SM	D-38	41	Each			2,000	21.2	
3	3-23-64	2119	SM	Titanium + steel	10	Each			25	21.2	
3	3-24-64	2120	SP	Graphite	3	Boxes			200	20.9	
3	5-7-64	2135	SP	HE contaminated	1	Lot			600	20.1	
3	5-14-64	2476	SM	D-38 & cold stock	2	Pkg			200	19.8	
3	5-14-64	2476	SM	D-38 & cold stock	2	Boxes			200		
3	5-15-64	2174	SP	Graphite	3	Boxes			75	19.7	
3	5-21-64	2478	SP		1	Box			25	19.7	
3	5-27-64	2479	SP	Graphite	13	Boxes			400	19.1	
3	6-11-64	2352	SP	Alum.	1	Lot			150	18.9	
3	6-15-64	2353	SP	Graphite	l	Lot			1,000	17.6	
3	6-23-64	2134	SM		7	Each			465	16.9	
3	7-13-64	2482	SM		1	Pkg			10	16.9	
3	7-21-64	2483	SM		2	Boxes			400	16.4	
3	7-24-64	2487	SM	(Steel & Alum)	6	Boxes			300	15.9	
3	7-27-64	2357	SP	Film	6	Boxes			700	15.0	
3	7-27-64	2488	SP		4	Drums			300	14.6	
3	8-4-64	2490	SP		2	Drums			200	14.3	
3	8-4-64	2491	SP		1	Lot			250	13.9	
3	10-14-64	2533	Fuel elements	Fuel elements	2	Pkg			75	13.8	
3	10-23-64	2537	Unloaded fuel elements	Fuel elements, unloaded	1	Box			30	13.8	
3	10-30-64	2538	Scrap	Graphite	l	Lot			200	13.5	
3	11-5-64	2542	SP	Graphite	1	Pkg			5	13.5	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
3	11-6-64	2541	SP		1	Each			400	13.0	
3	11-11&12-64	2545	SP	Graphite					3,500	8.2	
3	11-12-64	2544	SM	D-38					200	7.9	
3	11-16-64	2547	SP	HE contaminated					1,200	6.2	
3	11-19-64	2550	Fuel elements	Fuel elements					150	6.0	
4	12-23-64	2557	SP		1	Box			15	60.0	
4	1-6-65	2560	SP		2	Lots			350	59.4	
4	1-19-65	2563	SP	Graphite	9	Drums			1,000	57.9	
4	1-20-65	2564	Cold stock & D-38	Cold stock & D-38	5	Containers			250	57.6	
4	1-27-65	2567	SP	D-38, lithium etc	1	Lot			75	57.4	
4	2-18-65	2367	X-ray film, 15 cartons	Film	1	Lot			500	56.7	
4	3-1-65	2583	SP		1	Lot			10	56.7	
4	3-5-65	2587	Hedghog train units & detonators	Detonators	1	Lot			600	55.8	
4	3-23-65	2593	SP		1	Lot			350	55.2	
4	4-6-65	2597	SP	Graphite	4	Drums			350	54.7	
4	4-6-65	2599	Cold stock & D-38	Cold stock & D-38	1	Lot			400	54.1	
4	4-16-65	3352	SP		1	Box			75	54.0	
4	5-4-65	3362	SP		1	Lot			250	53.6	
4	5-5-65	3364	Fuel elements	Fuel elements	8	Bundles			100	53.4	
4	5-20-65	3356	X-ray film	Film	31	Boxes			1,700	50.9	
4	5-29-65	3357	SP	Graphite	1	Lot			200	50.6	
4	7-14-65	3372	SP	Graphite	3	Boxes	6		120	50.4	Trash boxes
4	7-14-65	3375	SP		5	Drums			380	49.8	
4	7-15-65	3374	-Ring & Slug Ass'ys		1	Drums	7.35		750	48.7	55-gallon drum
4	7-20-65	3377	SP		1	Lot			2,000	45.6	
4	7-21-65	3359	Graph & D-38	Graph & D-38	8	Boxes			50	45.6	
4	8-10-65	3378	SP	Contains U235	2	Boxes	1		250	45.2	
4	8-18-65	3382	Tr. cont	Tritium cont	1	Unit	0.5		15	45.2	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
4	8-25-65	3360	SP		6	Units			50	45.1	
4	9-3-65	3384	Cold scrap & D-38	Cold scrap & D-38	6	Boxes			250	44.7	
4	9-20-65	3386	Photos	Film	5	Boxes			100	44.6	
4	9-20-65	3386	Fuel elements	Fuel Elements	5	Boxes			100		
4	9-23-65	3388	SP		1	Lot			150	44.3	
4	9-30-65	3391	SP	Tritium cont	2		0.5		20	44.3	
4	10-1-65	3392	SP		11	Boxes			175	44.0	
4	10-14-65	3393	SP	HE contaminated	1	Load			3,850	38.2	
4	10-25-65	3394	Fuel elements (unloaded & D-38)	Fuel elements (unloaded & D-38)	1	Lot			850	36.9	
4	10-26-65	3502	SM	SS- Be	2	Drums	7.35		100	36.8	2- 5 gallon drums
4	11-4-65	3395	SP		1	Truck load			2,500	33.0	
4	11-17-65	3397	SP	Magnesium	2	Each			3	33.0	
4	11-23-65	3398	Unload fuel elements (scrap)	Fuel elements, unload	9	Containers			100	32.8	
4	11-23-65	3399	SP		4	Boxes			250	32.5	
4	11-23-65	3503	SM	D-38	2	Drums			175	32.2	
4	1-5-66	3504	SM		2	Drums			100	32.0	
4	1-5-66	3504	SM		1	Box			100		
4	1-28-66	3426	Cold stock & D-38	Cold stock & D-38	4	Boxes			150	31.8	
4	1-28-66	3427	Fuel elements	Fuel elements	5	Boxes			250	31.4	
4	1-28-66	3428	S	Contaminated	3	Boxes	1.5		75	31.3	
4	1-28-66	3430	SM	Tritium	2 1	Boxes box			30	31.3	from TA-41
4	2-4-66	3433	Unloaded fuel elements	Fuel elements, unloaded	3	Boxes			100	31.1	
4	2-18-66	3435	SP	HE cont.	1	Truck load			2,900	26.7	
4	2-25-66	3436	Fuel elements (unloaded) & scrap	Fuel elements, unloaded	5	Boxes			225	26.4	
4	2-25-66	3437	SP		2	Boxes			75	26.3	
4	3-1-66	3438	SP	Graphite	4	Drums			400	25.7	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
4	3-10-66	3441	Fuel elements - unloaded	Fuel elements, unloaded	9	Each			20	25.6	
4	4-4-66	3509	Keys		1	Box			100	25.5	
4	4-6-66	3446	S	Paper	5	Plastic bag					
4	4-12-66	3448	SP		15	Boxes			450	24.8	
4	4-13-66	3508	Radiographic film	Film	12	Cartons	96		3,000	20.3	
4	4-21-66	3447	SP	Graphite	15	Drums			1,500	18.0	
4	5-2-66	3449	Fuel elements - scrap	Fuel elements	9	Boxes			750	16.9	
4	5-4-66	3450	SM		2	Drums			75	16.7	
4	5-5-66	3451	Miscellaneous scrap		5	Boxes			250	16.4	
4	5-31-66	3453	SM	Tritium cont.	1	Each	0.1		15	16.3	
4	5-31-66	3455	SM		10	Drums			500	15.6	
4	6-2-66	3454	SM		2	Drums			100	15.4	
4	6-15-66	3510	Scrap	D-38	9	Bundles			250	15.0	
4	6-15-66	3510	Scrap	D-38	4	Boxes			250		
4	6-22-66	3457	Radiographic film	Film	118	Boxes			4,120	8.8	
4	6-22-66	3458	SM	Al + D-38	1	Drums			25	8.8	
4	6-24-66	3459	SM		2	Boxes			650	7.8	
4	7-28-66	3513	Module Clamps		1	Box			75	7.7	
4	8-9-66	3462	SM	Lithium Hydride	8	Boxes			400	7.1	
4	8-16-66	3463	Cold Stock & D-38	Cold Stock & D-38	3	Boxes			200	6.8	
4	8-16-66	3464	SM		7	Boxes			250	6.4	
4	8-29-66	3407	SM		11	Boxes			255	6.0	
5	10-7-66	3467	SM	Graphite	6	Drums			620	59.4	
5	10-13-66	3468	Unloaded fuel elements	Fuel elements, unloaded	5	Boxes			200	59.2	
5	10-13-66	3470	SM	D-38, SS & Al	3	Drums			80	59.1	
5	10-13-66	3869	Unloaded fuel elements & scrap	Fuel elements, unloaded	14	Boxes			525	58.6	
5	11/66	3533	Glass-mounted slides		1	Lot			700	57.9	
5	11-9-66	3473	SP		1	Lot			600	57.3	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
5	12-1-66	3497	SP	Graphite					1,000	56.3	Conf. R.D.
5	12-2-66	3474	SM	D-38					25,925	30.7	
5	12-6-66	3521	SM						350	30.3	
5	12-14-66	2499	SM						75	30.2	
5	12-14-66	3500	SM	D-38					10	30.2	
5	12-15-66	3527	SM						360	29.9	
5	12-19-66	3475	SM		1	Box			175	29.7	
5	12-19-66	3528	D-38 impregnated fuel elements	Fuel elements, D-38 impregnated	10	Boxes			200	29.5	
5	12-19-66	3529	Unloaded fuel elements	Fuel elements, unloaded	3	Boxes			150	29.4	
5	1-12-67	3532	Fuel elements	Fuel elements	1	Box			30	29.3	
5	1-16-67	3585	Unloaded fuel elements	Fuel elements, unloaded	3	Each			5	29.3	
5	1-26-67	3524	SM	HE contaminated					400	28.9	
5	1-27-67	3587	SM	Graphite					3	28.9	
5	1-30-67	3538	SM						15	28.9	
5	2-3-67	3540	SM	S/N's					174	28.7	
5	2-27-67	3525	SM	Graphite					3,300	25.5	
5	2-28-67	3544	Records	Pu contaminated					25	25.5	
5	4-12-67	3547	Cold scrap & D-38	Cold scrap & D-38	9	Boxes			325	25.1	
5	4-19-67	3551	SM	Al, stainless, titanium	1	Lot			400	24.7	
5	4-24-67	3552	Fuel elements - unloaded & 38	Fuel elements	6	Each			10	24.7	
5	4-28-67	3591	Scrap fuel elements	Fuel elements	13	Cartons			410	24.3	
5	5-5-67	3592	Unloaded fuel elements	Fuel elements, unloaded	4	Cartons			160	24.2	
5	5-10-67	3553	SM		1	Lot			150	24.0	
5	5-15-67	3554	SM	D-38	4	Drums			180	23.8	
5	5-19-67 thru 6-8-67	3566	Obsolete reactor parts & hardware						10,655	13.3	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
5	6-15-67	3560	SM	Fuel elements	7	Boxes			225	13.1	
5	7-18-67	3562	SM		1	Lot			600	12.5	
5	9-6-67	3567	SM	Graphite	8	Boxes			400	12.1	
5	9-7-67	3568	SM	Depleted uranium	1	Lot			250	11.8	
5	9-20-67	3570	Unloaded fuel elements	Fuel elements, unloaded	11	Boxes			660	11.2	
5	9-27-67	3572	SM	HE contaminated	1	Lot			5,200	6.0	
5	11-11-67	3531	Fuel elements & modules, unloaded & D-38	Fuel elements, unloaded & D-38	1	Lot			35	6.0	
6	7-12-67	6550B	SM		1	Lot			2,575	56.2	
6	10-9-67	6478	SM	HE cont.	2	Loads			18,425	28.6	
6	10-17-67	6477	Mounted slides	Glass	4	Boxes			50	28.5	
6	10-26-67	3573	SM		2	Drums			250	28.2	
6	11-10-67	6481	SM		8	Boxes			175	27.9	
6	11-10-67	6482	SM		1	Lot			150	27.7	
6	11-16-67	3574	Scrap	Graphite	4	Drums			400	27.1	
6	12-1-67	3575	Graphite fuel elements	Fuel elements, graphite	6	Boxes			275	26.7	
6	1-16-68	2524	Cold scrap & D-38	Cold scrap & D-38	9	Bundles			600	25.8	
6	1-16-68	2524	Cold scrap & D-38	Cold scrap & D-38	5	Boxes			600		
6	1-16-68	6530	Scrap	D-38 graphite	6	Drums			450	25.1	
6	1-18-68	6582	SM		1	Garbage can			100	25.0	
6	2-7-68	None	SM		3	Boxes			80	24.8	
6	2-20-68	6535	SM		12	Drums			1,500	22.6	
6	2-20-68	6536	SM		13	Boxes			550	21.8	
6	2-27-68	6537	SM	HE cont.	1	Box			25	21.7	
6	2-27-68	6538	SM	he cont	1	Truck load			2,425	18.1	
6	3-8-68	6542	SM		6	Drums			200	17.8	
6	4-17-68	6545	SM		3	Boxes			125	17.6	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
6	5-7-68	6492	Fuel elements, 500 ea	Fuel elements	18	Boxes			1,000	16.1	
6	5-8-68	6546	SM	D-38	4	Drums			75	16.0	
6	5-8-68	6546	SM	D-38	2	Cans			75		
6	5-23-68	6495	Shells - expended - mortar		4	Each			20	16.0	
6	5-24-68	6551	SM	Alum.	42				225	15.7	
6	7-10-68	6549	Unloaded fuel elements	Fuel elements, unloaded	9	Boxes			475	14.9	
6	7-16-68	6301	SM						40	14.9	
6	7-22-68	2525	Cold scrap & D-38	Cold scrap & D-38	12	Bundles			1,000	13.4	
6	7-22-68	2525	Cold scrap & D-38	Cold scrap & D-38	6	Boxes			1,000		
6	8-1-68	6554	Depleted uranium	Depleted uranium	11	Drums			513	12.6	
6	8-1-68	6551A	SP		1	Box			30	12.6	
6	8-8-68	6555B	SP		1	Box			30	12.5	
6	8-29-68	6304	SP	Containing D-38	4	Drums			500	11.8	
6	9-23-68	6305	SP		1	Lot			100	11.6	
6	12-3-68	6307	SM	Metal	2	Each			500	10.9	
6	12-17-68	6308	SM	Alum., stainless steele, tuballoy					225	10.6	
6	12-17-68	6309	SM	Stainless, copper, beryllium					75	10.4	
6	1-13-69	6564	Fuel elements	Fuel elements	15	Boxes			900	9.1	
6	1-31-69	6566B	Documents		1	Box			35	9.0	
6	2-5-69	6567B	SM		3	Drums			750	7.9	
6	2-12-69	6311	SM	HE cont.,					1,000	6.4	
6	2-25-69	6312	Scrap fuel elements	Fuel elements	1	Lot			75	6.3	
6	2-25-69	6313	SM						200	6.0	
6	3-6-69	6314	S	Glass					10	6.0	
7	3-20-69	6316	SM	D-38					10	60.0	
7	3-21-69	6317	SM	D-38 & cold stock & D-38					325	59.5	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
7	3-21-69	6318	Obsolete parts						200	59.3	Part of GMX-7 Mat'l disposed of in Hot Dump
7	3-27-69	6319	Cold stock & D-38	Cold stock & D-38		Can			500	58.6	
7	4-4-69	6320	Miscellaneous scrap	60 kg D-38					250	58.2	
7	4-7-69	6321	SM						150	58.0	
7	4-29-69	6570	Fuel elements	Fuel elements					500	57.3	
7	6-13-69	6876	S	Film	8	ft				57.3	
7	6-18-69	6322	Scrap	D-38					750	56.3	
7	7-3-69	None	Obsolete, damaged, etc., seals (Gov't security)						125	56.1	
7	8-5-69	6881	SP						6,575	46.9	
7	8-19-69	None	Obsolete, damaged, etc., seals (Gov't security)						25	46.9	
7	8-29-69	6325	SM		3	Drums			150	46.7	
7	9-19-69	6885	SP	Fuel elements, graphite	7	Boxes			500	46.0	
7	9-19-69	6886	SP	Fuel elements, Graphite	1	Pkg			35	45.9	
7	9-25-69	6887	Machine gun, spare barrels, and other components						25	45.9	
7	9-30-69	6858	S						20	45.9	
7	10-1-69	6883	SM	Beryllium					25	45.8	
7	10-3-69	6889	SP	Plastic	3	Boxes			150	45.6	
7	10-9-69	6888	Samples	D-38 etc.					1,753	43.2	
7	10-23-69	6891	SM		1	Lot			1,000	41.8	
7	10-26-69	6894	SM	Pu contaminated	4	Drums			100	41.7	
7	11-14-69	6895	GBV		8	Units			5	41.7	
7	11-26-69	6897	SM	Pu contaminated	7	Drums			175	41.4	
7	12-18-69	6899	SM	Graphite D-38	1	Lot			400	40.9	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
7	12-24-69	6900B	Slides - #635262, 65, 68, & 70		1	Box			5	40.9	
7	1-9-70	6926B	Data processing sheets		1	Box			20	40.8	
7	1-9-70	6927B	SP	Graphite	2	Boxes			200	40.5	
7	1-9-70	6928B	S		1	Box			20	40.5	
7	1-9-70	6929B	SM	D-38 and other	5	Drums			200	40.2	
7	1-19-70	6930B	Shredded drawings		1	Lot			150	40.0	
7	1-19-70	6931B	SP		1	Each			150	39.8	
7	1-19-70	6932B	Tubes		8	Each			5	39.8	
7	2-3-70	6862B	SP	Graphite					1,000	38.4	
7	2-10-70	6934B	SP		2	Boxes			40	38.4	
7	2-18-70	6936B	SP	Steel and copper	4	Boxes			150	38.2	
7	2-18-70	6936B	SP		4	Boxes			150		
7	2-19-70	6454	SP		1	Lot			3,000	34.0	
7	2-19-70	6454	Vessels		13	Each			3,000		
7	3-6-70	6942	SP	Fuel elements, graphite	3	Lots			7,675	23.3	
7	3-12-70	6865	SP	HE contaminated					500	22.6	
7	3-16-70	6939	SM	D-35	6	Boxes			150	22.4	
7	3-19-70	6941	Slides - mounted	Glass	5	Each			5	22.4	
7	3-19-70	6943	SP		1	Lot			600	21.6	
7	4-6-70	6945	Lantern slides		35	Each			5	21.5	
7	4-7-70	6946	SP	Fuel elements, graphite	20	Boxes			800	20.4	
7	4-7-70	6947	SP		3	Drums			150	20.2	
7	4-7-70	6947	SP		1	Box			150		
7	4-15-70	---	Mounted slides etc.	Glass					25	20.2	
7	4-20-70	6948	SP						350	19.7	
7	5-8-70	6820	SP		1	Each				19.7	
7	5-8-70	6869	SP		2	Barrels			1,000	18.3	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
7	5-11-70	6870	Keys & cores	Keys & cores	1	Lot			275	17.9	
7	5-20-70	6906	SP		1	Each			1,377	16.0	
7	5-25-70	6457	SP		5	Each			35	16.0	
7	7-8-70	6907	SP		1	Each			10	15.9	
7	7-22-70	6909	SP	Lithium hydride	2	Containers			1	15.9	
7	8-4-70	6954	Magnetic tape recordings		8	C/B boxes			200	15.7	
7	8-5-70	6913	SP	HE contaminated	1	Lot			2,075	12.8	
7	9-17-70	6957	X-Units w/load coil assemblies		86	Each			2,150	9.8	
7	9-29-70	6458	SP		3	Boxes			100	9.6	
7	10-23-70	6459	Transmitters, receivers, covers and miscellaneous items						150	9.4	
7	11-10-70	6917	Klystrons		3	Each			5	9.4	
7	12-11-70	6964	SP		1	Garbage can			100	9.3	
7	1-29-71	6965B	Slides and signs		1	Lot			5	9.3	
7	1-29-71	6966B	Slides and negatives		1	Lot			25	9.3	
7	2-17-71	3183B	SP						25	9.2	
7	2-19-71	6976B	Scrap fuel elements (unloaded) and	Fuel elements, (unloaded)					50	9.1	
7	2-19-71	6976B	Radiographic plates						50		
7	4-1-71	3412B	SP	Inert HE	1	Lot			1,600	6.9	
7	5-10-71	3414B	SP		1	Box			75	6.8	
7	5-11-71	3413B	Test Sets		18	Each			25	6.8	
7	6-4-71	3418B	Slides (Jane Hall collection)		1	Lot			40	6.7	
7	8-24-71	6464B	Squibs and miscellaneous items		1	Lot			500	6.0	
7	9-8-71	5804B	SP		1	Lot			20	6.0	
8	10-4-71	5810B	SM	Steel	1	Box			40	59.9	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft³)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
8	11-22-71	6467	SM		7	Each			100	59.8	
8	11-22-71	5814B	Source, dummy deutron		3	Each				59.8	
8	12-3-71	5816	SP	HE	1	Load			5,475	52.1	
8	12-6-71	5815	SP		2	Garbage can			75	52.0	
8	3-22-72	5857	SP		1	Box			20	52.0	
8	3-24-72	5858	S	Paper	1	Box			50	51.9	
8	4-7-72	5859	Recorder charts & paper		3	Boxes			50	51.9	
8	5-12-72	5864	SP		3	Garbage can			200	51.6	
8	5-31-72	5865	S		1	Box			50	51.5	Cont. by Assoc. w/U235
8	7-13-72	5875	S		36	Each			3	51.5	
8	8-7-72	5655	SP		1	Lot			75	51.4	
8	8-15-72	5656	SP		1	Lot			2,060	48.5	possible Declassified
8	8-15-72	5656	Load rings & components		1	Lot			2,060		possible Declassified
8	8-30-72	5657	Mylar tape	Mylar	1	Box			10	48.5	
8	8-30-72	5658	SP		2	Boxes			15	48.5	
8	9-25-72	5662	SP		5	Boxes			150	48.3	
8	11-9-72	5666	SM		3	Cans	14.0		400	47.7	35 gal.
8	11-15-72	5670	Voice tapes (recordings)		64	Rolls			75	47.6	
8	1-29-73	6256	Slides (Negatives)	Film	11	Each		4 X 3 1/4"	1	47.6	
8	2-21-73	3189	Miscellaneous metal parts		1	Lot			500	46.9	
8	3-2-73	6992	Analogue computer tapes	Computer tape	1	Lot			1,200	45.2	
8	3-6-73	7260	SP		11	Boxes			300	44.8	
8	3-14-73	7264	SP		1	Lot			150	44.6	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
8	3-28-73	7265	SP.		1	Lot			150	44.4	
8	4-13-73	3190	Silos, remnants of silo program		16	Each			15	44.4	
8	4-13-73	7267	S		1	Lot			60	44.3	
8	4-24-73	3191	SP		9	Each			300	43.8	
8	4-24-73	3191	Silo parts display		1	Each			300		
8	4-24-73	3191	SP		1	Container			300		
8	7-20-73	7357	SP		1	Lot			150	43.6	
8	7-26-73	7355	SP		1	Lot			50	43.6	
8	8-10-73	7358	Classified neg. slides (S-RD) per CD #61		8	Each			1	43.6	
8	10-18-73	7366	S		22	Each				43.6	
8	11-2-73	7362	Lithium boride material	Lithium boride	3	Cans	0.40		10	43.6	1-Gallon, Metal
8	11-14-73	7367	Dies, pressing, LASL dwg. # Y-4187-D		2	Units			80	43.4	
8	2-28-74	6473	1A and 1J valves (uncl.)		63	Each			300	43.0	
8	2-28-74	6473	SP		16	Each			300		
8	3-26-74	7372	SP		1	Lot			250	42.7	
8	5-10-74	7375	SP	Metal	1	Lot			20	42.6	
8	6-27-74	7333	SP		1	Lot			4,175	36.8	
8	7-12-74	7331	S		3	Each			1	36.8	
8	7-16-74	7335	S		1	Lot			15	36.8	
8	7-16-74	7335	S		1	Lot			15		
8	8-8-74	6580	SP		1	Each			50	36.7	
8	9-11-74	6584	Part S/N 874A13-002		1	Each			5	36.7	
8	9-11-74	6584	Miscellaneous parts		1	Box			5		
8	9-24-74	7000	SP		3	Each			25	36.7	
8	9-30-74	7341	SP		1	Lot			10	36.6	
8	2-7-75	7285	SP	Lithium samples	74	Each			50	36.6	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
8	4-24-75	7287	SP		6	Boxes			430	36.0	
8	5-16-75	7293	SP		56	Each			15	35.9	
8	9-23-75	8130	SP		1	Load			3,000	31.7	
8	8-3-76	8149	SP		1	Lot			30	31.7	
8	8-23-76	7307	SP		1	Lot			1,500	29.6	
8	10-1-76	7310	SP		1	Lot			5,800	21.5	
8	11-16-76	7308	SP		1	Lot			2,600	17.8	
8	11-16-76	7309	SP		1	Lot			3,700	12.6	
8	11-16-76	7309	File safe, CL, 04D Legal, (LASL P/N 139515) containing	File safe	1	Each			3,700		
8	12-14-76	7314	SP		2	Boxes			65	12.6	
8	9-29-77	8989	SP		1	Lot			2,575	8.9	
8	7-10-79	9305	SP		5 ea.	Drums, metal			2,000	6.1	
8	7-10-79	9305	SP		5 ea.	Drums, metal			2,000		
8	7-16-79	9306	Part No. 422212		5	Each			100	6.0	
8	7-16-79	9306	Part No: 422213		5	Each			100		
9	7-23-80	9310	SP						70	59.9	
9	7-23-80	9311	SP						150	59.7	
9	7-23-80	9314	SP						300	59.2	
9	7-21-81	9036	SP						200	58.9	
9	12-8-81	9309B	SP						100	58.8	
9	12-8-81	9318B	SP	LiH- 10g (+), Be – unk amount, D-38 – unk amount					15	58.7	From C&D information, 15 lb of LiH added based on Memorandum HSE7-86-78
9	12-8-81	9321B	SP	File system cartridges						58.7	From C&D information
9	1-19-82	9051B	SP						200	58.5	
9	1-21-82	9322B	SP						1,000	56.9	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
9	1-25-82	9052	SP						5,810	48.1	
9	4-13-82	9023	SP								
9	4-13-82	9324B	SP						4,000	42.1	
9	4-13-82	9325B	SP						4,000	36.0	
9	8-17-82	9056B	SP						250	35.6	
9	1-5-83	9337B	SP	From C&D information –unk from TA41-#W30					500	34.8	
9	6-8-83	9341B	SP	From C&D information Be							
9	6-17-83	9343B	SP	From C&D information Be sample							
9	10-16-84	12532	SP						5,000	27.3	
9	1-8-85	12378	Computer tape - degaussed [3]	Computer tape			60		300	26.8	
9	1-31-85		6 drawer file with combo locks	File safe	1	Box			250	26.4	
9	1-31-85		Combination locks		1	Box			250		
9	2-28-85		Keys and cores	Keys/cores			2	~1 or 2 ft^3	75	26.3	
9	3-18-85	11707, 13290	Computer tape degaussed - 3 tapes/sack (50 lb per sack)	Computer tape	21	Sacks		15" x 7"	1,000	24.8	
9	3-20-85	11882	Al_20_3 and stainless steel parts - in sack	Al_20_3 and stainless steel			1.337		40	24.7	10-gallon drum
9	9-24-85	9170B	S		7	Envelopes			141	24.5	
9	10-17-85	13375B	Computer disk packs - digital RPO6	Computer disk pack	16				80	24.4	
9	12-24-85	---	Keys, Cores, Locks	Keys & cores			6		400	23.8	
9	1-15-86	---	3 drawers (file) with boxes of combo locks	File & locks			10		200	23.5	~ 8-10 ft^3
9	3-25-86	12383B	Graphite w/motor oil	Graphite w/motor oil	3	Drums	1.47		40	23.4	11 gallons
9	4-7-86	13310	Computer disk packs, dishpack platters	Computer disk pack						21.9	

Shaft No.	Date	Form 252-R	Nomenclature and/or Description	Materials	Quantity	UOM	Volume (ft^3)	Dimensions	Weight (lb)	Depth in Shaft*	Remarks
9	4-7-86	13311	Computer disk packs, dishpack platters	Computer disk pack					1,000		
9	5-8-86	12382	Computer disk pack	Computer disk pack			1		7	21.9	
9	7-22-86	10087	Computer disks pack, disk pack platters	Computer disk pack			90		200	21.6	
9	8-29-86	10088	Computer disk pack	Computer disk pack	4	Bags	8		200	21.3	

Note: S = scrap, SM = scrap metal, SP = scrap pieces, SS = stainless steel, D-38 = depleted uranium, cold stock = non-radioactive materials, S/N = serial number/ part number.

*Depth is based on average densities. Location within shafts is approximate based on mass except when known (measured) depths have been included for shafts 1 and 2.

Appendix C

Project-Specific Outreach Plan

APPENDIX C PROJECT-SPECIFIC OUTREACH PLAN

Public outreach activities completed through March 2003 include the following:

- February 8, 2001: John Hopkins presented an overview of the 10 mesa-top material disposal areas, including MDA H, and of the RCRA corrective action process to San Ildefonso, Santa Clara, Jemez, and Cochiti pueblos.
- February 12, 2001: John Hopkins, Woody Woodworth, and Eliza Frank presented an overview of MDA H and the RCRA corrective action process to the Northern New Mexico Citizens Advisory Board ER subcommittee (subsequent briefings occurred during March, April, and May 2001).
- March 1, 2001: John Hopkins presented an overview of MDA H and the RCRA corrective action process to San Ildefonso Pueblo.
- June 13, 2001: The Laboratory and DOE sent a mailer to 1200 individuals and public interest organizations on Laboratory's mailing list. The mailer introduced the ER Project, the MDA HPT, the RCRA corrective action process, and the history of MDA H.
- June 27, 2001: DOE and the Laboratory held a workshop for stakeholders and discussed the potential corrective action alternatives for MDA H. The workshop was cosponsored by the NNMCAB and was held at DOE LAAO.
- August 14, September 25, November 13, 2001 and February 25, 2002: Focus group meetings were convened to enlist a broad spectrum of individuals and public interest organizations in reviewing the MDA H site background and proposed corrective action alternatives for MDA H.
- July 20, 2002: George Rice was contracted to perform an independent peer review of the MDA H Corrective Measures Study Report.
- November 1, 2002: A status report for the MDA H CMS Report was mailed to focus group members.

Active members of the MDA H Focus Group include the following:

- New Mexico Toxics Coalition
- Pojoaque Pueblo
- Los Alamos County Council
- NNMCAB
- CCNS (Concerned Citizens for Nuclear Safety)
- Los Alamos CDC (Community Development Corporation)
- San Ildefonso Pueblo
- Private Citizens
- Los Alamos League of Women Voters
- State Emergency Management Bureau
- Office of Senator Bingaman

Appendix D

DOE Site Remediation Technologies by Waste Contaminant

APPENDIX D DOE SITE REMEDIATION TECHNOLOGIES BY WASTE CONTAMINANT

Technology	Media	Waste Contaminant	Description
Arc Melter Vitrification	Soil	Toxic metals	Vitrification
Bio-Immobilization of Heavy Metals	Ground water, surface water, aqueous streams	Toxic metals	Uses bacteria to transform heavy metal ions to an insoluble, less toxic form
Biological Destruction of Tank Waste	Supernatants, aqueous streams	Toxic metals	Biosorption
Electrokinetic Remediation of Heavy Metals and Radionuclides	Soil	Heavy metals	Electrical current is supplied between two electrodes, ions of contaminant will be attracted to one of the electrodes
Encapsulation of Hazardous Wastes	Liquid, slurry, solid waste	Metals, inorganics	Encapsulation of wastes
In Situ Ground Water Remediation Using Colloid Technology	Ground water	Heavy metals absorbed on clay and silica	In situ colloid immobilization of contaminants
In Situ Vitrification of Contaminated Soils	Soil	Heavy metals	Immobilization
Mitigation Barrier Covers	Arid soils	Soluble metals	Containment/ Treatment
Polyethylene Encapsulation of Radionuclides and Heavy Metals	Aqueous salt and concentrate, saltcake, sludge, ash, ion exchange resin in tanks	Toxic metals (e.g., Cr, Pb, Cd)	Encapsulation
Remediation of Metals Contaminated Soils Using Ligand-Based Extraction Technology	Soil	Pb, Hg, Cr	Density classification followed by extraction to remove metals from soil
Dynamic Underground Stripping of VOCs	Soil, ground water	Mixed waste	Enhanced Removal
Electrokinetic Remediation of Heavy Metals and Radionuclides	Soil	Heavy metals and Radionuclides	Electrical current is supplied between two electrodes, ions of contaminant will be attracted to one of the electrodes
In Situ Ground Water Remediation Using Colloid Technology	Ground water	Mixed waste	In situ colloid immobilization of contaminants
In Situ Vitrification of Contaminated Soils	Soil	Mixed waste	Destruction/ Immobilization
Plasma Hearth Process	Soil, stored waste	Mixed waste	Waste Form Enhancement
Adsorption of BTEX Using Organozeolites	Ground water, Surface Water	Single-ring aromatics, BTEX	Adsorption of aromatic compounds
Arc Melter Vitrification	Soil	Organics	Vitrification
Biological Destruction of Tank Waste	Supernatants, aqueous streams	Organics	Biosorption

Technology	Media	Waste Contaminant	Description
Bioreactors for Bioremediation	Ground water	TCE, PCE, Vinyl Chloride, DCE, TCA, and BTEX	Uses a bioreactor to biodegrade unwanted chlorinated chemicals
Bioremediation of High Explosives by Plants	Soil	Nitroaromatic compounds, TNT	Bioremediation
Dry Barriers for Containment and Remediation at Waste Sites	Soil	VOCs, volatile solvents, petroleum fuels	Drying of horizontal soil layer to create a barrier
Dynamic Underground Stripping of VOCs	Soil, ground water	VOCs	Enhanced Removal
Engineered System for In Situ Bioremediation of Ground Water	Ground water	CCl4	Micro-organisms biodegrade CCl4 to harmless chemicals
High-Energy Corona	Gas, aqueous and non-aqueous liquids	VOCs, halogenated solvents (e.g., TCE, PCE, carbon tetrachloride, chloroform, diesel fuel, gasoline)	Destruction of VOCs at room temperature
In Situ Air Stripping of VOCs Using Horizontal Wells	Permeable soils, ground water	VOCs, light hydrocarbons, chlorinated solvents, TCE, PCE	Enhanced Removal
In Situ Ground Water Remediation Using Colloid Technology	Ground water	Pesticides	In situ colloid immobilization of contaminants
In Situ Vitrification of Contaminated Soils	Soil	VOCs	Destruction/ Immobilization
In Well Vapor Stripping	Ground water	VOCs	Gas is bubbled through contaminated ground water to liberate contaminants
Methane-Enhanced Bioremediation for the Destruction of TCE Using Horizontal Wells	Soil, ground water	Halogenated aliphatic organics, TCA, TCE, PCE	Co-metabolic Destruction
Mitigation Barrier Covers	Arid soils	VOCs, organics	Containment/ Treatment
Plasma Hearth Process	Soil, stored waste	Organics	Waste Form Enhancement
Six-Phase Soil Heating	Soil	VOCs, SVOCs	Extraction
Thermal Enhanced Vapor Extraction System	Arid soils	VOCs, SVOCs, VOC-oil mixtures, chemicals with vapor pressures <0.002atm @20°C	Extraction
Tunable Hybrid Plasma	Air	VOCs	Organic compounds are destroyed or oxidized with an electron beam
VOC Off-Gas Membrane Separation	Gas stream	VOCs, halogenated solvents, carbon tetrachloride, chloroform	Membrane Separation

Technology	Media	Waste Contaminant	Description
VOC Recovery and Recycle	Air	VOCs	A Brayton cycle heat pump condenses an air stream and VOCs can be captured and re-used or disposed
Biological Destruction of Tank Waste	Supernatant aqueous streams	Various radionuclides, TRU	Biosorption
Chelators for Application In Radioactive Actinide Waste Remediation	Soil, Process waste streams	Pu	Selective removal of radioactive and highly toxic actinides with organic chelators
Compact Processing Units for Radioactive Waste Treatment	Liquids, sludges, slurries	High-level, low-level, TRU	Biosorption
Cryogenic Retrieval of Buried Waste	Soil, buried waste	TRU	Freezing/ Retrieval Containment
Electrokinetic Remediation of Heavy Metals and Radionuclides	Soil	Radionuclides	Electrical current is supplied between two electrodes, ions of contaminant will be attracted to one of the electrodes
In Situ Ground Water Remediation Using Colloid Technology	Ground water	Pu	In situ colloid immobilization of contaminants
In Situ Vitrification of Contaminated Soils	Soil	Various radionuclides, TRU	Immobilization
Polyethylene Encapsulation of Radionuclides and Heavy Metals	Aqueous salt and concentrate, saltcake, sludge, ash, ion exchange resin in tanks	Various radionuclides, TRU	Encapsulation
Remediation of Metals Contaminated Soils Using Ligand-Based Extraction Technology	Soil	U	Density classification followed by extraction to remove metals from soil
Resorcinol-Formaldehyde Ion Exchange Resin for Cesium Removal	Cs supernatant salt streams	Cs	Ion Exchange
Selective Extraction/Leaching of Uranium from Soil	Soil, sediment	U	Attrition scrubbing and carbonate leaching remove uranium from soil
Biological Destruction of Tank Wastes	Supernatants, aqueous streams	Nitrate	Biosorption
Cryogenic Retrieval of Buried Waste	Soil, buried waste	Hazardous waste	Freezing/ Retrieval Containment
Decision Support System to Select Migration Barrier Cover Systems	Arid and humid soils	Waste Independent	Multi-Objective Decision Making Software System
Hydraulic Impact End Effector	Hard waste forms in tanks	N/A	Fracturing of solid waste forms

Technology	Media	Waste Contaminant	Description
Medium-Pressure Waterjet Dislodging and Conveyance End Effector Using Confined Sluicing	Supernatant, sludge, saltcake in tanks	Waste Independent	Confined Sluicing
Polymer Gel as a Barrier for Ground Spill Contaminants	Soil	Applicable to many chemicals and radioactive contaminants (depending on the polymer barrier material selected).	Injection of a wall-forming fluid that gels in situ
Remote Excavation System	Soil	Waste Independent	Retrieval
Subsurface Barrier Emplacement Development	Soil	Waste Independent	An impermeable grout barrier is placed beneath the waste to prevent further contamination

Appendix E

In Situ Stabilization Alternatives Analysis Evaluated for the MDA H Corrective Measures Study

APPENDIX E IN SITU STABILIZATION ALTERNATIVES ANALYSIS EVALUATED FOR THE MDA H CORRECTIVE MEASURES STUDY

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Date: 10/19/01

1.0 GOALS AND OBJECTIVES

The final remedial strategy for the closure of Material Disposal Area (MDA) H will be based on the conclusions presented in the Corrective Measures Study (CMS). This paper supplements the CMS in its evaluation of the application of in situ stabilization technologies and associated grout formulations as a potential remedial strategy for the closure of the disposal shafts in MDA-H.

Two in situ stabilization remedial approaches are discussed: complete encapsulation of the disposal shafts in MDA H, and the construction of an in situ barrier around the perimeter and engineered cap over the MDA H site. Each of these approaches is evaluated against the overall goals of the CMS to ensure future protection of human health and the environment. Specific goals evaluated for in situ stabilization include the ability of this approach to

- reduce mobility of contaminants in shafts;
- prevent biointrusion of plants and animals; and
- reduce potential for future human intrusion.

In addition to the specific goals outlined above, each approach is further evaluated relative to potential security and safeguards issues.

This technology evaluation supplement to the CMS also discusses implementation issues associated with the in situ stabilization remedial strategy. Topics covered include the following:

- Construction
- Projected costs
- Long-term stewardship
- Evaluation of stabilization technologies

2.0 DESIGN ALTERNATIVES

The LANL MDA Focus Area Team has performed an initial evaluation of two specific in-situ remedial alternatives for potential implementation in the closure of MDA-H: (1) in situ barrier and engineered cap, and (2) complete encapsulation of shafts. This section provides generalized descriptions of these alternatives. The two alternatives may use different construction technologies and/or different grout or stabilization formulations.

2.1 In Situ Barrier and Engineered Cap (Partial Top and Sides)

The in situ barrier and engineered cap alternative is considered a partial stabilization approach. For this alternative, an engineered barrier would be constructed at a predetermined depth and width around the perimeter of the MDA H site. Existing commercial technologies can be used to place the barrier to a depth of up to 30 ft. The thickness of the barrier can also be varied from 2 to 3 ft. The engineered barrier can be constructed of cement, pozzolanic, or bentonite-based materials, and may be reinforced with steel. The native tuff can be incorporated into the final barrier mix design. Each of these materials has different performance characteristics.

Under this alternative, an engineered cap made of cement-based or pozzolanic materials would be constructed over the MDA H site. This cap would be tied into the engineered barrier. The thickness, permeability, and strength of the cap would be engineered to meet the final requirements or objectives of the project. An evapotranspirative cover would be placed over the engineered cap.

Figure-1 provides a conceptual view of MDA H utilizing the in situ barrier and engineered cap alternative for final closure.

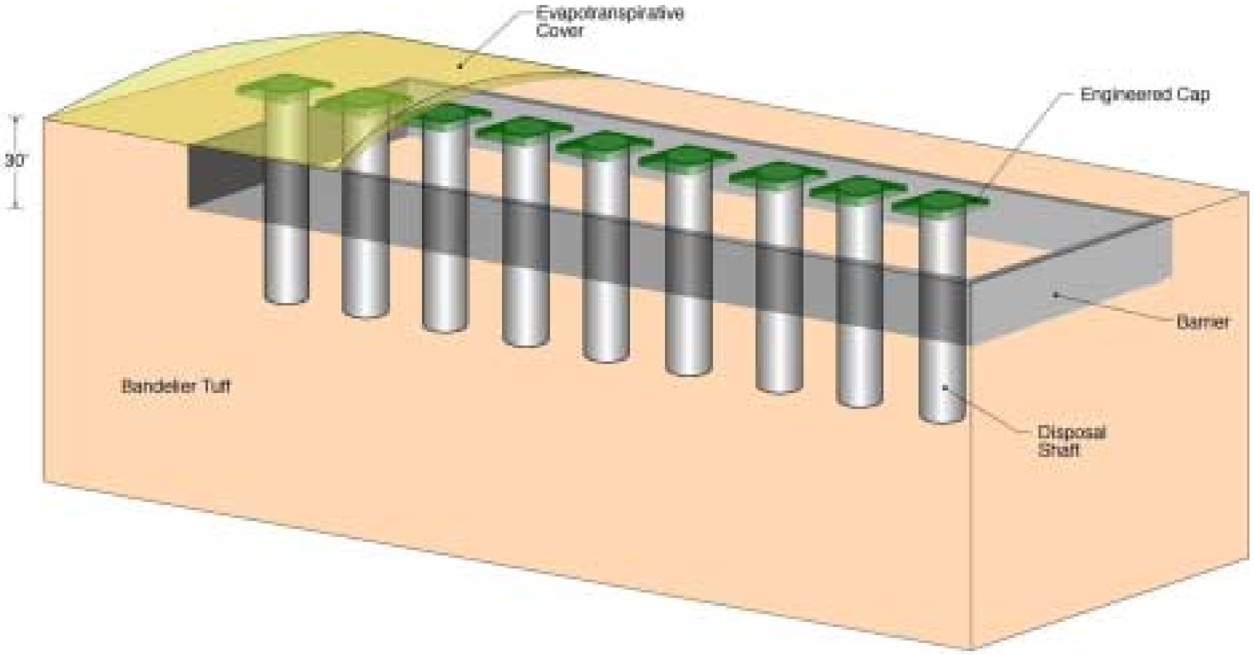

Figure 1
In-situ Barrier and Engineered Cap
Remedial Alternative

2.1.1 Ability to Reduce Mobility of Contaminants in Shafts

The in situ barrier and engineered cap alternative would prevent water from entering the shafts, thus minimizing the potential for contaminant transport into the surrounding tuff. The cap would have to be monitored and maintained to insure that its structural integrity is not breached. If the cap is not maintained the potential exists for water infiltration to the shafts.

2.1.2 Ability to Prevent Biointrusion of Plants and Animals

This alternative would be effective in minimizing access to the shafts by either animals or plants. The in situ barrier would be constructed to a depth that would help reduce access by animals. The materials of construction for both the in situ barrier and engineered cap would be designed to preclude access or degradation by plants or animals.

2.1.3 Ability to Reduce Potential for Future Human Intrusion

The materials of construction for both the in situ barrier and the engineered cap could be selected to make entry into the shafts difficult. Cement incorporated into the stabilization matrix and engineered cap design would make human intrusion difficult, even by using conventional construction equipment. Incorporation of pigment into the grout formulation would provide an additional means of warning people not to breach the engineered barriers.

2.2 Complete Encapsulation of Shafts

The complete encapsulation alternative would involve the construction of a perimeter wall around each shaft to a depth of 60 ft (Figure 2). An area below each shaft would also be stabilized to form a secure barrier. The top of each shaft would be covered with an engineered cap. The entire surface of the MDA H area would then be covered with an evapotranspirative cover. An alternative to building individual covers over each shaft would be to place an engineered cover over the entire surface of the MDA H area, followed by an evapotranspirative cover.

Figure-2 provides a conceptual view of MDA H utilizing the Complete Encapsulation of Shafts alternative for final closure.

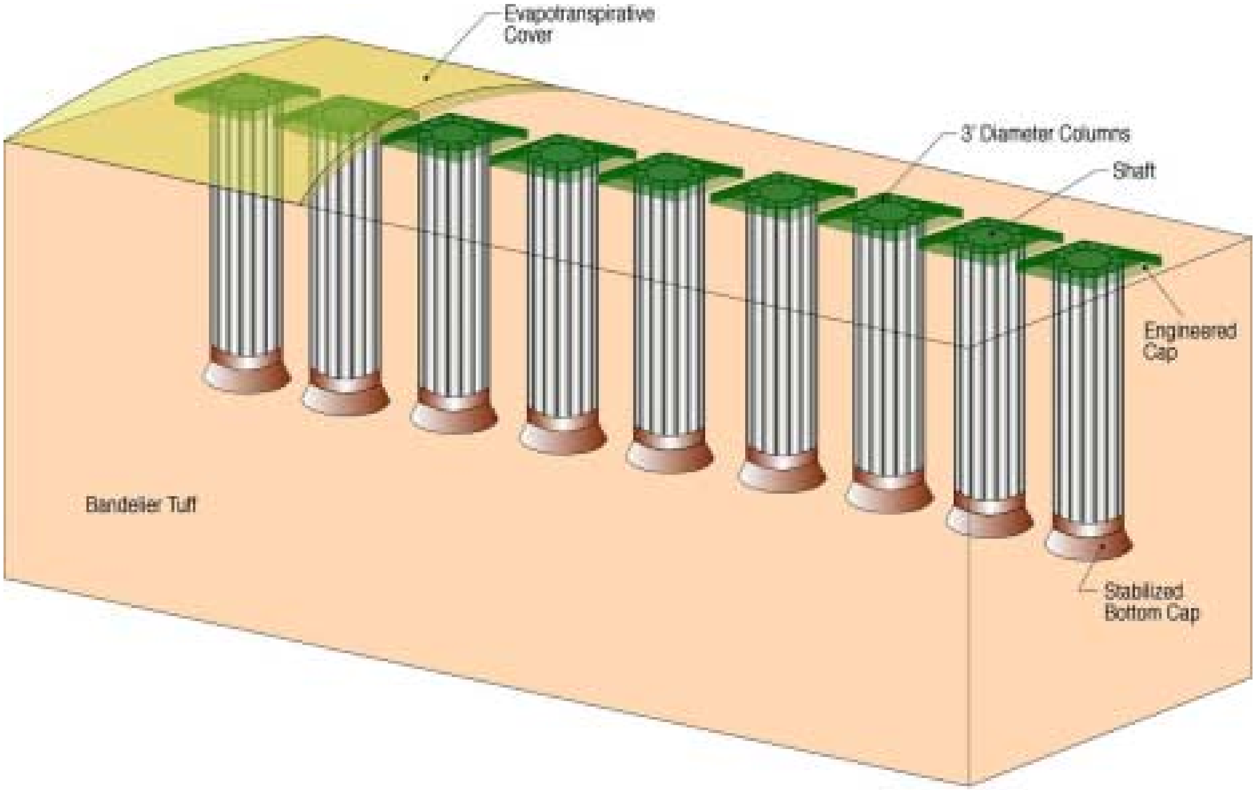

Figure 2
Complete Encapsulation of Shafts Remedial Alternative

Under this alternative, a rotary drilling rig would be used to place interlocking shafts of 2 to 3 ft in diameter around each MDA H shaft. This would be accomplished without drilling into or disturbing the contents of the shaft. As each shaft was drilled, a grout or microconcrete would be injected into the cuttings (tuff). Commercial jet grouting or soil mixing technology currently exists to complete this construction. A base or barrier would be constructed under each disposal shaft and would be connected to the wall to completely isolate the MDA H shaft from the surrounding tuff.

2.2.1 Ability to Reduce Mobility of Contaminants in Shafts

The complete encapsulation alternative would prevent water from entering the shafts. The grout formulation would produce a barrier with a low permeability. This design would minimize the potential for contaminant migration into the surrounding tuff.

2.2.2 Ability To Prevent Biointrusion of Plants and Animals

This alternative would offer the maximum protection in limiting access to the shafts by either animals or plants. The encapsulated shaft would be constructed to a thickness that would preclude access by animals. The grout formulation for both the construction of the wall around each MDA-H shaft and the materials of construction for the engineered cap would be designed to limit access or degradation by plants or animals.

2.2.3 Ability to Reduce Potential for Future Human Intrusion

The materials of construction for both the in situ perimeter wall and engineered cap for each MDA H shaft could be selected to make future entry into the shafts difficult. Cement incorporated into the grout matrix and engineered cap design would make human intrusion difficult with current conventional construction equipment. Incorporation of pigment into the grout formulation would provide an additional warning against breaching the engineered barrier.

3.0 CONSTRUCTION

The construction technologies needed to implement the remedial strategies identified in Section 2 are currently in use throughout the world. This section defines the approach, sequence, and grout formulation development, and identifies potential technologies that could be used to implement either a partial or complete encapsulation remedial strategy for MDA H.

3.1 In Situ Barrier and Engineered Cap (Partial: Top and Sides)

The main design component of the in situ barrier and engineered cap remedial alternative for MDA H is the construction of a barrier wall around a predetermined perimeter of the MDA H site. This barrier wall would be integrated into an engineered cap constructed over the entire enclosed area. The materials of construction for the engineered cap could consist of some combination of Portland cement and supplementary cementing materials, or it could be constructed as a composite cap consisting of soils, clays, and/or synthetic materials.

3.2 In Situ Barrier Construction Method

Under the in situ barrier remedial strategy, a barrier or wall would be constructed around the perimeter of the MDA H site to discourage human and biointrusion. The depth and width of the barrier would be determined during the remedial design phase of the MDA H closure project. Many proven methods for the installation of in situ barriers are commercially available. The methods described in this section can be considered for the construction of an in situ barrier at the MDA H site. These construction methods usually fall within the following categories:

- Slurry walls
- Diaphragm walls
- Soil mixed walls

3.2.1 Slurry Walls

Slurry walls are constructed by continuous trenching and displacement of soils with a bentonite or a Portland cement-bentonite slurry mixture. The trench is kept full of an engineered fluid or slurry such that as soil is removed from the trench, an equal volume of slurry replaces it. The slurry is also used to exert hydraulic pressure against the trench wall, which prevents it from collapsing.

The infrastructure needed to implement a slurry wall construction includes trenching equipment, slurry batch plant, and soil handling equipment. The construction sequence starts with the removal of soil from the trench and the immediate backfilling of the excavated area with the engineered fluid or slurry. The slurry is pumped from the batch plant, which is located near the trenching operations. Soils removed from the trench are transported via end dump to another part of the site for temporary storage.

Typical equipment used for trenching includes long-reach hydraulic excavators, continuous trenching machines, and cable-hung clamshell buckets.

3.2.2 Diaphragm Walls

Diaphragm walls are constructed by the basic slurry wall construction method described in the previous section. The two variations to diaphragm wall construction are cast-in-place and pre-cast.

Cast-in-place diaphragm walls are usually excavated and constructed under a bentonite slurry. The same excavation equipment used for typical slurry wall construction can be used. The construction sequence usually begins with the excavation of discontinuous or alternating primary panels. Stop-end pipes are placed vertically in each end of the primary panels to form joints for adjacent secondary panels. As with the slurry trench, the width and depth can vary, based on equipment capability. The panel sections typically vary in lengths of to 20 ft.

Once the excavation (through the bentonite slurry) of a panel is complete, a support structure, such as reinforced steel, is placed in the center of the panel section. In a continuous operation, cement grout or microconcrete is then pumped, via tremie pipes, from the bottom of each panel, displacing the bentonite slurry until each panel is filled. The displaced bentonite slurry is recovered and pumped to a holding area and subsequently reused for the construction of the next panel. Once the concrete has gained sufficient strength in the primary panels, the end pipes are removed. The sequence continues with the excavation of the adjacent secondary panels until a continuous interlocking wall is completed.

Pre-cast diaphragm wall construction is one variation of this method. The pre-cast diaphragm technique differs in two ways from the cast-in-place method. First, the slurry used in the excavation is a self-hardening, cement-bentonite slurry. Secondly, pre-cast wall sections are placed through the cement-bentonite slurry and positioned in the trench by cranes. The cement-bentonite slurry eventually hardens to form a seal between adjacent panels.

3.2.3 Soil Mixed Walls

Construction of barriers utilizing soil mixing technologies has been an accepted practice for decades. Soil mixing is a technique that utilizes the introduction of a pozzolanic grout or engineered fluid into soil at depth in order to change its physical or chemical characteristics. The soil is incorporated as a part of the engineered matrix; therefore, unlike slurry wall and diaphragm wall construction, the soils remain in place. Generally, the soil mixing technologies, which can be used to construct in situ barriers or walls, fall within two categories:

- Mechanical mixing with multiple- or single-shaft augers
- Jet grouting

Mechanical soil mixing technologies typically use multiple- or single-shaft augers or mixing blades to create one or more columns of modified soils mixed with pozzolanic grout or an engineered fluid. These columns are overlapped to form an interlocked continuous wall. The diameters of these columns can range from as little as 1 foot to more than 18 ft. Many of these technologies can be used to create a stabilized column of soil to a depth of 200 ft or more. The equipment used for mechanical soil mixing include the following:

- a drill rig or crane with a rotary table
- single- or multiple-shaft augers and mixing blades
- a grout batch/mixing plant
- a pump system

The construction sequence starts with the augers and/or mixing blades advancing into the soils at a predetermined rate. As the augers and mixing blades move through the soil, grout or an engineered fluid is pumped through the shaft to the end of the auger, and in some cases, the grout is pumped through ports in the mixing blades. The action of both the auger and mixing blades allows for the proper mixing of the grout within the soil to form a column. A continuous barrier is formed by overlapping adjacent columns.

Jet grouting utilizing a mono-fluid system is another in situ soil mixing method that is used to modify soils by mixing a grout or engineered fluids with soils. In the mono-fluid system, grout or an engineered fluid is pumped at high pressure (4,000 to 5,000 psi) through horizontal ports (injectors) in the shaft above the auger or drill bit. This high-pressure stream of grout serves to cut and mix the soil. This technology creates the same soil column and continuous barrier as the mechanical soil mixing technology.

The main equipment required for this system includes a drill rig or crane with a rotary table, a high-pressure pump, and a batch/mixing plant.

3.3 Complete Encapsulation of Shafts

The main design component of the complete encapsulation of shafts remedial strategy for MDA H includes the construction of a wall around each shaft to a depth of 60 ft. An area below each disposal shaft would also be stabilized to form a secure barrier. Under this alternative, interlocking shafts of 2 to 3 ft in diameter would be constructed around the perimeter of each MDA H shaft with a rotary drilling rig. This would be accomplished without drilling into or disturbing the contents of the disposal shaft. As each soil column is drilled around the perimeter of the MDA H shaft, a cement slurry, or other engineered fluid, would be injected into the cuttings (tuff).

Complete encapsulation of the shafts would be achieved by the construction of overlapping columns to form a wall around each disposal shaft. In addition, an area of tuff immediately below each shaft would be modified with cement grout or other engineered fluid to serve as a bottom seal. This bottom seal would be constructed to be integral to the bottom columns of the perimeter wall surrounding each disposal shaft. The wall columns surrounding the disposal shafts could be constructed by either mechanical soil mixing or mono-fluid jet grouting as described in the previous section.

For the construction of the bottom seal of each shaft, a second jet grouting method, the three-fluid, or "Kajima" system, may also be considered. The three-fluid system differs from the mono-fluid system in that the high-pressure grout used in the mono-fluid system is replaced by a high-energy jet of water. This water jet is further augmented by an aureole of compressed air concentric about the jet. At the same time, the cement grout or engineered fluid is injected into the soil under pressure through a second nozzle located just below the air/water nozzle. The effect of the three-fluid system is to increase the effective radius of mixing to over 6 ft.

The main equipment required for this system includes the following:

- Drill rig or crane with a rotary table
- High-pressure, high-flow pump (for the water jet)
- Compressor (for air injection)
- Low-pressure pump for grout injection
- Three-way coaxial drill string with drill bit, injector assembly to house cement grout nozzles, and coaxial air/water nozzles

The procedure used for stabilizing the soil is the same as in the mono-fluid system. Once the required depth is reached, water and air are injected through their respective lines to the coaxial injectors, which cut the soils surrounding the drill string. At the same time, the cement grout or engineered fluid is injected into the soil. The rotating drill string is then slowly withdrawn.

This method may have to be used to ensure that a complete bottom seal has been constructed for the width of the perimeter wall under each disposal shaft.

3.4 Material Considerations

The materials used in the stabilization of the shafts in MDA H will consist of some mixture of grout or microconcrete incorporating the native tuff. Use of the native material will limit the amount of material that must be removed and transported elsewhere. Depending on the exact chemical and mineralogical composition of the tuff, it may have some pozzolanic properties. Pozzolans are siliceous materials that, in finely divided form, react with calcium hydroxide and water to form cementitious compounds. If the native soils do have pozzolanic properties, the pozzolanic reaction could be highly beneficial rendering the resulting concrete or grout more chemically stable and less permeable.

The considerations for the materials used in stabilization can be related to the installation, the development of properties, and the long-term performance. For the installation, the main considerations have to do with the flow characteristics of the grout or microconcrete. It must be able to be pumped into place, perhaps mixed by jet grouting or other means with the native tuff; it may need to consolidate on its own to some degree; and it must not segregate or bleed to any significant extent. (That is, it must remain intact without settlement of the heavier components to the bottom, leaving the lighter components near the top.)

Once the grout is in place, the cementitious materials react with water to produce the desired final properties. The presence of certain organic materials, lead, or other trace heavy metals can adversely affect these reactions, or even prevent them altogether. The setting time under the conditions to be encountered in the field must be verified. Since hydration reactions generate heat, the thermal behavior of the grout must be verified, and the formulation modified as necessary to ensure that it will not crack from thermal stress. The use of pozzolans and/or ground granulated blast furnace slag would reduce both the amount and rate of heat generation, thus reducing the potential for thermally-induced cracking. In addition, the products of hydration have somewhat smaller volume than the cementitious materials from which they form, resulting in autogenous shrinkage. Water lost to the surrounding medium (in this case, the soil) results in additional shrinkage. These volume changes may cause cracking. To prevent cracking, the strength of the grout must exceed the stresses generated at any given time. The early-age properties of the grout are thus vital to its long-term performance.

In the long term, the grout must remain stable both chemically and physically. Assuming no significant changes in temperature, it is expected that a properly designed grout will be dimensionally stable after the heat of hydration has dissipated. The mechanical properties of strength and stiffness must be determined for the purposes of structural analysis of the total system. As mentioned above, the native tuff may have some pozzolanic properties. These properties must be determined and the long-term behavior evaluated to ensure that no adverse reactions occur.

Some of the materials present in the material disposal area that could be used in soil mixing may require physicochemical stabilization to minimize their solubility in water. For example, hexavalent plutonium tends to be more soluble and more difficult to stabilize in cement hydration products than tetravalent plutonium. Thus the grout should have some chemically reducing capability (E_h). The incorporation of ground granulated blast furnace slag into the grout can provide this capability at reasonable cost. In addition, a high pH is desirable because most radionuclides are more soluble at low pH. It is anticipated that the surrounding soil will remain dry. However, because of the extremely long design life, the grout should be designed for a low permeability to water and minimization of leaching.

3.5 Design and Development

Proper design and verification of an encapsulation structure requires the integration of several disciplines. The behavior of the structure in place will depend on a complex interaction among the structural configuration; the materials from which the structure is constructed; the waste material contained in the shafts; the surrounding tuff; and any external influences, such as seismic activity or flooding. These interactions must be examined on the macro scale (e.g., the effect of a seismic event on the integrity of the structure) and the micro scale (e.g., the deterioration of the grout or microconcrete over time). In addition, changes on the micro scale affect the macro properties of the material and thus the long-term behavior of the structure. For example, if the grout becomes more porous over time due to leaching, its strength and stiffness will be reduced, and the response of the structure as a whole to external loading will deteriorate. If cracks form in the structure due to external loading, the rate of deterioration of the material will increase.

3.6 Structural Modeling

Whether designed as a cap or complete enclosure, the barrier must remain intact to mitigate the flow of groundwater to and from the shafts. It is anticipated that the main loading on the structure will be earth pressure in combination with groundwater pressure and seismic loading. At MDA H, the water table is located hundreds of feet below the shafts. However, the area may be subject to intermittent flooding under extreme conditions. The 10,000-year flood will determine the maximum water pressure that will be exerted on these structures. The earthquake hazard will be evaluated and its potential effect on the structure will be assessed.

Three-dimensional models using ADINA numerical modeling software will be developed to assess the performance of these structures in response to the critical loading as well as to the loading during construction. The elastic properties of the concrete or grout and its compressive and tensile strength will be used to model the barrier system properties. The geological setting of the site will be considered in modeling the barrier. The strength and elastic properties of the tuff will be used to model the surrounding environment with 8-node and 16-node elements. The model extends far enough from the structure to minimize the effects of boundaries and wave reflection. Degradation of the barrier strength with time due to aging and environmental effects can be taken into account. These effects will be estimated by the materials model described in the following section. The structural model will be used to determine the stresses and deformation in the barrier system, and the results will be used to design the system against excessive loading, deformation, and fracture.

Because of the complexity of the interactions among structure, materials, and environment, the process of design and development will be an iterative one. That is, the structural analysis may dictate a certain set of material properties for a given structural configuration. The selected construction method will dictate additional requirements for the grout or microconcrete. Laboratory testing will determine which properties can be obtained. These measured values will then be used as input parameters in the structural model, and the configuration of the structure will be modified as needed. The materials model projects the nature and extent of changes in the microstructure and chemistry of the materials due to the influence of the surrounding tuff and the waste material in the shafts over the useful life of the structure. These changes result in changes in the structural properties of the material and, in turn, in the response of the structure as a whole to environmental forces.

3.7 Materials and Structure Service Life Modeling

As discussed above, the grout or microconcrete plays an active role in stabilizing the waste materials; it is not simply a physical barrier. Over time, the components of the grout may undergo various changes which, may include the following:

- Chemical reactions with each other (hydration, pozzolanic reaction) and/or with substances in the environment (the soil or any waste materials that may leach from the shafts);
- Changes to the microstructure as a result of the chemical reactions
- Physical changes (thermally induced volume changes or shrinkage due to drying)

The nature and extent of these changes will depend on the initial formulation and properties of the grout and the nature of the environment including; moisture, temperature, chemicals. The arid climate and low elevation of the water table will keep the exposure to moisture to a minimum, contributing to the longevity of the grout.

The behavior of the materials over time will be predicted by using two models, 4SIGHT and the NIST Microstructural Model.

The 4SIGHT model was developed specifically for the purpose of predicting the performance of underground vaults for the storage of radioactive wastes. Clifton, Pommersheim, and Snyder[1] identified the major degradation processes of underground concrete as sulfate attack, corrosion of reinforcement, alkali-aggregate reactions, and leaching by ground water. The 4SIGHT model includes all of these mechanisms, as well as their synergistic effects. Mechanisms that could cause early cracking, such as plastic and drying shrinkage, settlement, and thermal effects are not included in the model. Clifton, Pommersheim, and Snyder considered that defects due to these mechanisms would be visible before the vaults were buried. For the construction techniques described in this white paper, the bench-scale material testing combined with the structural modeling would ensure that cracks due to these causes and/or to external loading would not develop. The non-destructive testing techniques would verify the absence of cracking. Dr. Snyder is continuing to work with scientists at the Nuclear Regulatory Commission to refine this model to include the condition of unsaturated flow through the grout/microconcrete. NRC hydrologists have separate models for moisture transport in the surrounding soils to provide the hydraulic boundary conditions for the 4SIGHT model.

The NIST Microstructural Model numerically simulates the development of the microstructure and properties of cement-based materials. It will be used in conjunction with 4SIGHT for a more complete picture of the behavior of the material over time. Laboratory measurements of such properties as the permeability to water at a given age will be used to ensure the accuracy of the model. Dr. Detwiler has worked closely with the developers of the microstructural model in this capacity.

It should be noted that any model is an extrapolation of existing data. In this case we would be using data collected in the first days, months, and (in some cases) years after placement of the grout or microconcrete to project its behavior over 10,000 years. In addition, the grout or microconcrete is affected by the surrounding environment, the behavior of which must also be extrapolated over the same period. Long-term monitoring of the site provides essential information about the actual behavior, which can then be used to obtain more accurate projections of the future behavior, as well as indications of interventions that may be necessary.

The models provide a probabilistic estimation of the service life on the basis of a randomization of the input parameters within their respective ranges of experimental uncertainty. The input parameters for the materials modeling would include a complete characterization of each individual cementitious material (cement, the tuff if used as a pozzolan, and any additional supplementary cementing materials, such as ground granulated blast furnace slag, fly ash, silica fume, or calcined clay). Cementitious materials are characterized by chemistry, particle size distribution, and mineralogy. The mix proportions of the grout or microconcrete as well as its capillary porosity and permeability are also required. The ionic species present in the environment (either from the tuff or from the waste materials contained in the shafts) must also be identified.

The durability of the structure would also depend on the depth of cover over the reinforcing steel. In addition, if cracks are present, they will provide the most efficient route of ingress for any harmful species in the environment. Thus the depth, width, and spacing of cracks must be determined by the structural model, or sufficient insurance against the formation of cracks must be provided by the structural design.

3.8 Field Pilot Study

For the remediation project to be successful, it is essential to ensure that the structure as installed and the grout or microconcrete as placed conform to the design specifications. The individual ingredients of the grout, the mix proportions of the grout, the dimensions and alignment of the encapsulation structure, the placement of the reinforcement, and the degree of consolidation of the grout must all be verified. A field pilot installation will be used to verify all aspects of the construction process and quality control procedures. Parameters such as mix proportions and pumping pressures may be varied to determine the optimum values, as well as the sensitivity of the results to variations in the parameters. Nondestructive testing will verify the alignment of the structure and ensure that the grout is fully consolidated. Selective coring of the grout as placed will be used to verify and supplement the information obtained by nondestructive testing.

The encapsulation structure would consist of some arrangement of secant jet–grouted or soil mixed vertical columns and cement-grout slurry trench (diaphragm) walls. The jet grout structure can be extended under the containment unit to form a continuous base. Quality control of such grout and concrete structures is normally achieved by using techniques and approaches described in the Deep Foundations Institute's *Manual for Drilled Shaft Inspectors*. Cross-hole sonic logging, a proven nondestructive test method for this purpose, is fully described in ACI 228.2R. The relative advantages of the method are discussed by Davis and Hertlein and an application of the method to concrete nuclear waste repository structures is described by Davis et al.

The principle of the sonic logging method is to use low frequency (~35 kHz), direct transmission ultrasound stress waves between transmitter and receiver in vertical 37-mm internal diameter steel tubes pre-placed in the piles or walls at fixed intervals. These steel tubes can be incorporated into the structural reinforcing cage if used. The ultrasound pulses can be transmitted at regular vertical intervals. In most commercial applications, these intervals are set between 10 and 50 mm; however, the interval can be as small as desired for complete coverage of the vertical tested profile. Typical tube spacing is between 600 mm and 1.8 m. In the case of diaphragm walls, tube spacing is usually set at 1.5 m, and tubes are set in a Z-pattern in the wall in order to cover as much wall volume as possible. For secant piles, two tubes per pile are set on either side of the pile in the wall axis in order to transmit pulses across the joint between piles, as well as across each pile axis.

Vertical profiles of time of flight are presented in graphical form, and any anomalous zones in the grout are readily seen. Poor quality grout (cracking, poor compaction) is recorded as a reduction in ultrasonic pulse time of flight between tubes. To this effect, the horizontal distance between tubes must be measured before testing. When discontinuities are encountered, the ultrasonic signal disappears completely.

When this test method is combined with procedures outlined in the *Manual for Drilled Shaft Inspectors*, anomalous zones in the grout are easily detected at the time of construction. The level of confidence in this procedural approach is very high. Additionally, the tubes in the grout, if properly sealed and protected, can serve for retesting the grout at any time after construction to evaluate any changes in grout integrity. It is recommended that periodic retesting of the grout be performed at intervals not exceeding 7 years. In the case of jet-grouted bases, it would be possible to adapt the method to test these bases immediately after construction upon excavation of the container.

4.0 PROJECTED COSTS

4.1 Design and Development

The design criteria for the grout or microconcrete are determined by construction considerations (desired flow characteristics, pumping pressures, weather at the site, and logistics of construction) and the requirements for stabilization of the encapsulated wastes (permeability, E_h, pH). The values of the input parameters for both the materials model and the structural model must be determined experimentally. For the structural model, these parameters include the mechanical properties of compressive strength, tensile strength, and modulus of elasticity. For the materials model, the individual component materials must be characterized by chemical analysis, mineralogy, and particle-size distribution. Once the mix proportions of the grout are established by test, the resulting grout must be tested for capillary porosity and permeability. Most of this testing is bench-scale laboratory work. However, the pumping and flow characteristics must be tested on a larger scale in the laboratory to ensure that the materials and mix design will work in the field. The total cost of all laboratory testing is estimated at $250,000.

The characteristics of the native tuff must also be determined. For the structural model, the relevant characteristics are the compressive strength and the modulus of elasticity. For the materials model, the chemistry and mineralogy of the tuff must be characterized, and its permeability to water measured. The chemistry of the waste material must be determined as accurately as possible to ensure that no trace heavy metals or organics that could prevent the setting of the grout are present. Also, the potential for leaching of any materials that may be harmful to the hardened grout must be evaluated.

The use of the materials model to project the service life and estimate the deterioration of the material properties over time is estimated to cost $50,000.

The total cost for the structural modeling is estimated at $60,000.

A field pilot test, utilizing full-scale technologies that would be used to implement the complete encapsulation approach, would be performed in a non-contaminated area of MDA H. The goal of the pilot test would be to create the side and bottom plug/barrier structures that would be used to entomb a disposal shaft that has a diameter of 6 ft and a depth of 60 ft. The pilot would create a double row of secant soil mixed columns extending to 70 ft. A jet grouted plug structure would then be constructed under the columns. Cores of the columns and bottom plug will be taken to confirm the effectiveness of mixing. The cores will also confirm that the completed the structure has met the design specifications (length and width) for the columns and bottom plug.

The total cost for the field pilot test, including the cross-hole sonic logging, coring, and examination of the cores in the laboratory, is estimated at $350,000.

4.2 Implementation

The in situ soil modification technologies, which would be considered, to implement the full-scale design of either the in situ barrier and engineered cap or the complete encapsulation of shafts remedial alternative, have demonstrated track records in terms of performance and cost. There are many variables which could affect the cost to implement these remedial alternatives. These variables include, but are not limited to

- mobilization,
- depth of treatment,
- width of treatment,
- length,
- characteristics of soil or lithology,
- composition of grout,
- health and safety requirements (PPE, monitoring),
- decontamination requirements, and
- demobilization.

For purposes of developing costs on a unit basis for each of the technologies discussed in section 3.0, we have eliminated some of the variables identified above. The variables not included in the unit cost estimate are

- mobilization,
- health and safety requirements,
- decontamination requirements, and
- demobilization.

The unit costs presented in Table 1, represent a "battery limit" operation, which includes all the equipment and materials needed to implement each technology at MDA H. In addition, specific boundary conditions or design criteria were developed for each remedial alternative. The boundary conditions for the in situ barrier construction remedial alternative included the construction of a barrier wall with the following dimensions:

Length:	700 linear ft
Depth:	30 ft
Width:	3 ft
Grout/Slurry:	Cement-Bentonite

The boundary conditions for the complete encapsulation of shafts remedial alternative include the following dimensions:

Parameter Shaft Length:	70 ft
Parameter Shaft Width:	3 ft
Overlap:	Secant Shafts with 18-20% overlap
Grout/Slurry:	Cement

Table 1

Technology	Unit Cost $	Comments
Slurry Walls		
Excavator		
Soil-Bentonite Cement-Bentonite	2.50–8.00/sf 8.00–15.00/sf	Slurry wall construction quoted in vertical square feet.
Trenching Equipment		
Cement-Bentonite	20.00–30.00/sf	
Diaphragm Walls		
Cast/Poured In Place	45.00–80.00/sf	Diaphragm Wall construction quoted in vertical square feet
In situ Jet Grouting		
Cement Grout	180.00–250.00/cy	This technology is quoted in cubic yards when treating a volume or entombing a structure.
In situ Soil Mixing		
Cement Grout	180.00–200.00/cy	This technology is quoted in cubic yards when treating a volume or entombing a structure

5.0 LONG-TERM STEWARDSHIP

The cornerstone of long-term environmental stewardship is the development of mechanisms or strategies for monitoring the performance of a site that has undergone closure. Long-term monitoring of the structure in place could take the form of active or passive systems. Active systems could entail permanently installed instrumentation, which cannot be expected to be usable for many decades, either because the instruments deteriorate or because they become incompatible with new software or instrumentation. Passive systems include settlement plates and benchmarks that allow measurements of location and/or tilt to be compared using the instrumentation that is available at the time. Records of previous measurements must be available for comparison. Hollow tubes cast into the shafts at the time of construction will allow access for instrumentation.

Instrumentation will be installed to measure geometric deformations of the deep shafts and surrounding soil/rock, as well as changes in local environmental conditions, such as temperature, humidity, and seismic activity. Geometric deformations of the deep shafts could be the result of breaching of the shafts from unexpected changes in interior or exterior conditions. Interior conditions could change from storage material activity or reactivity with shaft material. Exterior conditions could change from seismic events or erosion.

All instrumentation should be redundant with external serviceable “controls” for long-term stability checks. The controls (or standards) would be replicas of the instrumentation used in the shafts that are not accessible after installation. These controls would be used to monitor potential long-term drift of sensors to properly interpret data accuracy.

All instruments would require manual readout devices to obtain data from the sensors during installation. All readout devices should be duplicated, serialized, and dedicated to the site without exception. All instruments (starting with the controls) would be read with duplicate readout devices for the first year to establish baseline data. After the first year, one set of manual readout devices would be removed from the site to a local storage for backup.

Instrumentation installed during construction would include inclinometers, tiltmeters, extensometers, survey monumentation, accelerometers, and temperature and humidity sensors.

Inclinometers are manually read removable instruments that would measure horizontal movement at 2-ft spacing in a vertical tube through the depth of the shafts. It is proposed that each of the nine shafts incorporate three inclinometers equally spaced about the circumference of the shaft. As a redundancy measurement, in-place tiltmeters would be placed in three vertical lines equally spaced about the circumference of each shaft at depths 30, 60, and 90 ft. The overall site area would also incorporate four inclinometers about the perimeter to depths of 150 ft. This would allow measurement of horizontal (relative and overall) movements of shafts and surrounding soil/rock conditions. A total of 31 inclinometer installations, 81 tiltmeter installations, and redundant transducers and readout devices would cost approximately $300,000.

Extensometers are sleeved carbon fiber rods that would be anchored into the soil/rock at considerable depth to monitor longitudinal length change and/or settlement of the shafts. It is proposed that each of the nine shafts incorporate one two-position extensometer. One of the positions would measure length change, the other settlement. As a redundancy measurement for settlement, a survey network should be established, including a deep benchmark. A total of 9 two-position extensometers, transducers, readout devices, deep benchmark and survey instrumentation would cost approximately $100,000.

Accelerometers would measure seismic activity at the site. Temperature and humidity would be measured at various depths inside the shaft walls, on the exterior of the shaft walls, in the surrounding soil/rock strata, and at ambient surface locations. Two tri-axial accelerometers and 60 installed temperature and humidity sensors and readout devices would cost approximately $50,000.

An automated monitoring system could be used to read the majority of the instruments. The automated monitoring system could have response values set for each of the installed instruments. If any of the response values were exceeded, relays would activate dial-out modems or satellite communication to alert personnel to abnormal conditions. The automated monitoring system should have duplicate hardware in storage for immediate replacement and redundant power backup, such as solar panels and batteries. The use of an automated monitoring system would not obviate the need for annual (minimum) readings of sensors with manual readout devices. The cost for this system to read 300 channels would be approximately $50,000.

Long-term performance of sensors cannot be guaranteed, although current applications have sensors functioning beyond 50 years. Every attempt will be made to utilize rugged, proven technology for no recoverable and/or embedded sensors. Instruments that are recoverable (e.g., inclinometers) or externally placed (e.g., extensometer transducers, seismographs, and survey monuments), will be of stainless steel construction and could be replaced with similar or newer technology without jeopardizing data integrity.

Cross-hole sonic logging should be performed at regular intervals, not exceeding 7 years, to ensure that the grout has maintained its integrity. Since only the hollow tubes used in the sonic logging would be left in place, the longevity of the instruments is not an issue.

6.0 EVALUATION OF ALTERNATIVES

The specific criteria for evaluating the design alternatives include reduction of the mobility of the contaminants in the shafts, the prevention of intrusion by plants and animals, and the prevention of intrusion by humans. In addition, the practicality of construction and the total costs must be considered.

Both alternatives include covering the shafts with an engineered and an evapotranspirative barrier. This system would prevent groundwater from percolating into the shafts.

Intrusion by plants and animals would be prevented by the system of cap plus evapotranspirative barrier on the top and either the barrier wall (partial encapsulation) around the perimeter or the full encapsulation of each individual shaft. Full encapsulation would prevent intrusion by both plants and animals so long as the material and structure remained intact.

Intrusion by humans would be the most difficult system compromise to prevent, since drilling equipment is capable of penetrating any of the materials that would be used to construct either of the design alternatives. The presence of grout or other artificial materials and the regularity of the structures would indicate the presence of man-made barriers. Incorporation of pigment in the grout could provide a stronger warning of danger. However, potential human intruders must be counted on to understand the warning and stop drilling or digging of their own volition.

Both alternatives use existing proven technology for formulation of the grouts and for all phases of construction. The monitoring techniques for both construction and long-term stewardship are also well established.

7.0 CONCLUSIONS

The "in situ barrier with engineered cap" and "complete encapsulation of shafts" remedial alternatives were evaluated as potential remedial strategies for the closure of MDA H.

The construction technologies and equipment that would be used to implement either of these alternatives are commercially available. Considerable documentation exists for successfully completed projects that have used these technologies. The use and performance of cement and other grout formulations have also been well documented. Models have been developed, in collaboration with the Nuclear Regulatory Commission that can predict the long-term performance of grout formulations.

Either remedial alternative, if implemented at MDA H, will meet the stated goals in the Corrective Measures Study. However, the "complete encapsulation of shafts" remedial alternative, due to its design, will offer a higher degree of long-term protection against bio-intrusion of plants and animals. This alternative will also provide greater security and long-term protection against human access.

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Appendix F

Models Simulating Long-Term Performance

APPENDIX F MODELS SIMULATING LONG-TERM PERFORMANCE

F-1.0 INTRODUCTION

This appendix summarizes the overall approach used to analyze long-term performance at MDA H. In particular is outlines the linkage between the various models that are presented in Appendices G through J, summarizes the main assumptions and approach used for the various models, and presents some of the results from the process-level models (Appendices G, I, and J) that feed the system-level environmental transport and health-effects model (Appendix H). The outcome of the system-level model is not included in this appendix; rather it is presented in the main body of the report and in Appendix H.

Individual "process-level" computer models are used to simulate natural environmental processes identified in the conceptual model that may result in contaminant releases, as shown in Figure 3.3-1. A "process-level" model employs a detailed and complex set of mathematical equations to represent the physical mechanisms associated with a particular process. To integrate multiple coupled environmental processes, and evaluate the potential human-health impacts from contaminants released over time, a "system-level" model is used. The "system-level" model developed for MDA H uses simple approximations of environmental processes, as described in Appendix H. The system-level model uses the outputs of the process-level models for a variety of purposes, as shown in Figure F-1.0-1. First, shallow infiltration and leakage through the surface cover, as calculated by the surface-cover model in Appendix G, are input parameters to the system-level model. The system-level model is calibrated to match the results for diffusive transport of radon gas calculated by the process-level, vapor-transport model discussed in Appendix I. Finally, the process-level, liquid transport model presented in Appendix J is used to verify that the simpler, liquid transport model incorporated in the system-level model adequately captures the more complex process of unsaturated-zone liquid transport that may occur at the site. These models are all described further in the following sections and in the appropriate Appendices of this report.

The process-level models and the system-level model share a common technical approach of incorporating intentional bias to overestimate rates of contaminant release and transport that could result in human or ecological impacts. The use of intentional bias arises from the requirement to produce models that are as usable and defensible as possible in the face of uncertainties in the model equations and parameter values, and to ensure that the ultimate output of the models are reasonably protective of human health and the environment. The consequences of this approach are that modeling efforts are often iterative and the results may be inherently conservative (i.e., biased). For example, for the sake of modeling simplicity it was assumed in the MDA H simulations that all contaminants in the disposed wastes except uranium were immediately available for release and transport regardless of their physical form or packaging. Because this is not the case, calculated health impacts in the earlier times within the modeling period are likely overestimated and should be interpreted as such. If calculated health impacts exceeded one or more decision criteria, it is possible that this assumption would be modified to be more accurate in an iteration of the original (simpler) modeling effort. For uranium, two end-member release mechanisms representing immediate availability and a corrosion-limited release were modeled. These calculations demonstrate the sensitivity of the predicted health effects on the release mechanism, as described in Section 3.3.1.3 and in Appendix H.

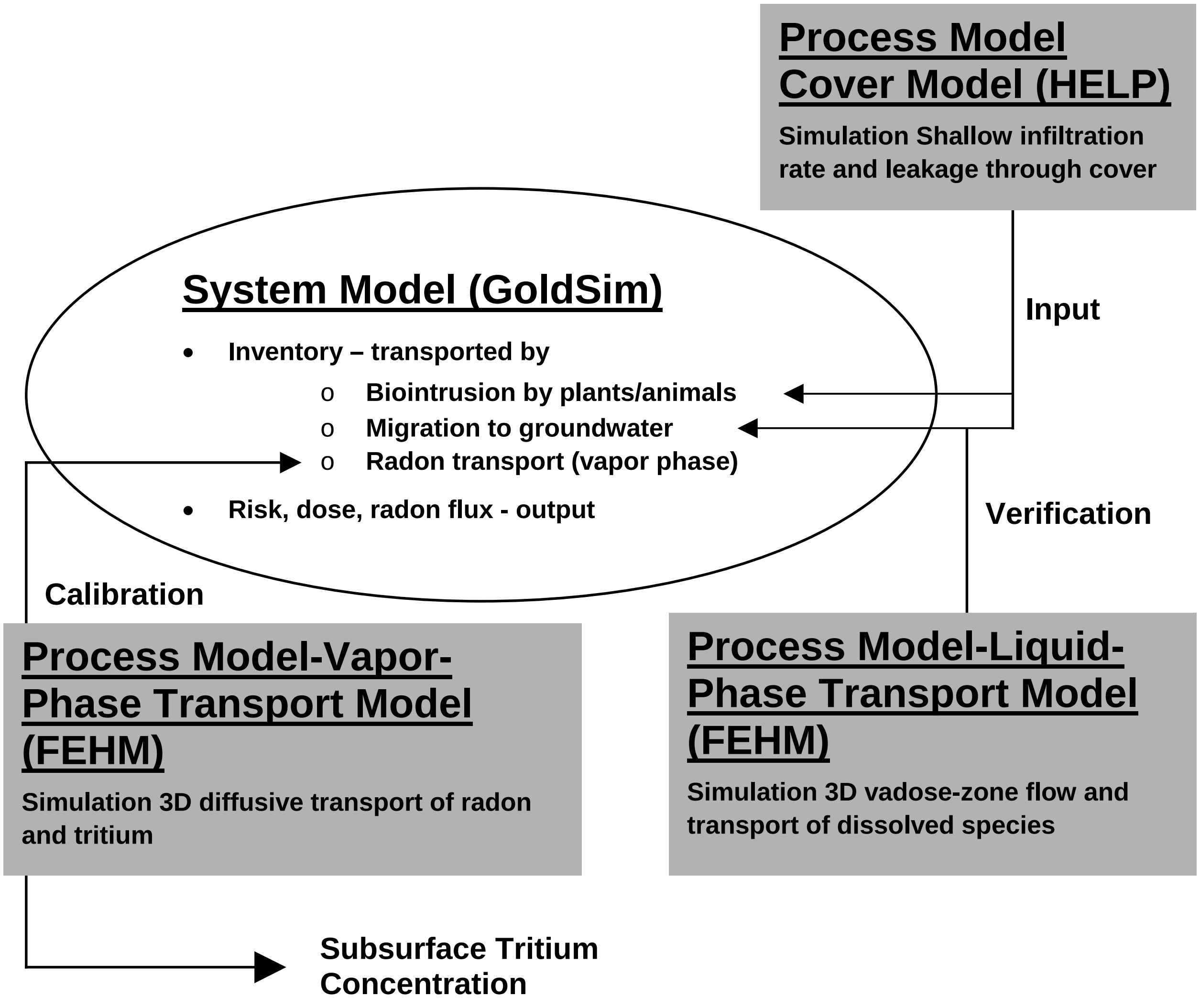


Figure F-1.0-1. Links between the system-level model and the three process-level models

F-2.0 PROCESS-LEVEL MODELS

A process-level model was run to evaluate the performance of the surface cover (Appendix G). The results of this study were used to define two key water-flow rates, the infiltration rate and leakage through the cover, required by the system-level model for the site. These affect both the biointrusion pathway and the liquid-phase transport pathway as shown in Figure F-1.0-1. The two pathways compete for the available inventory near the surface, with the water flow affecting the rate that contaminants are leached downward out of the surface soil as well as the rate at which contaminants move downward through the vadose zone.

Process-level models were also developed and used to calculate contaminant release and transport by

- volatilization, vapor-phase diffusion in a porous solid medium, and vapor dispersion in ambient air (vapor-phase release and transport), and
- dissolution and contaminant transport in pore water in unsaturated, porous, fractured rock (liquid-phase release and transport).

The conceptual representation of the vapor- and liquid-phase release and transport processes are illustrated in Figure F-2.0-1 and Figure F-2.0-2, respectively.

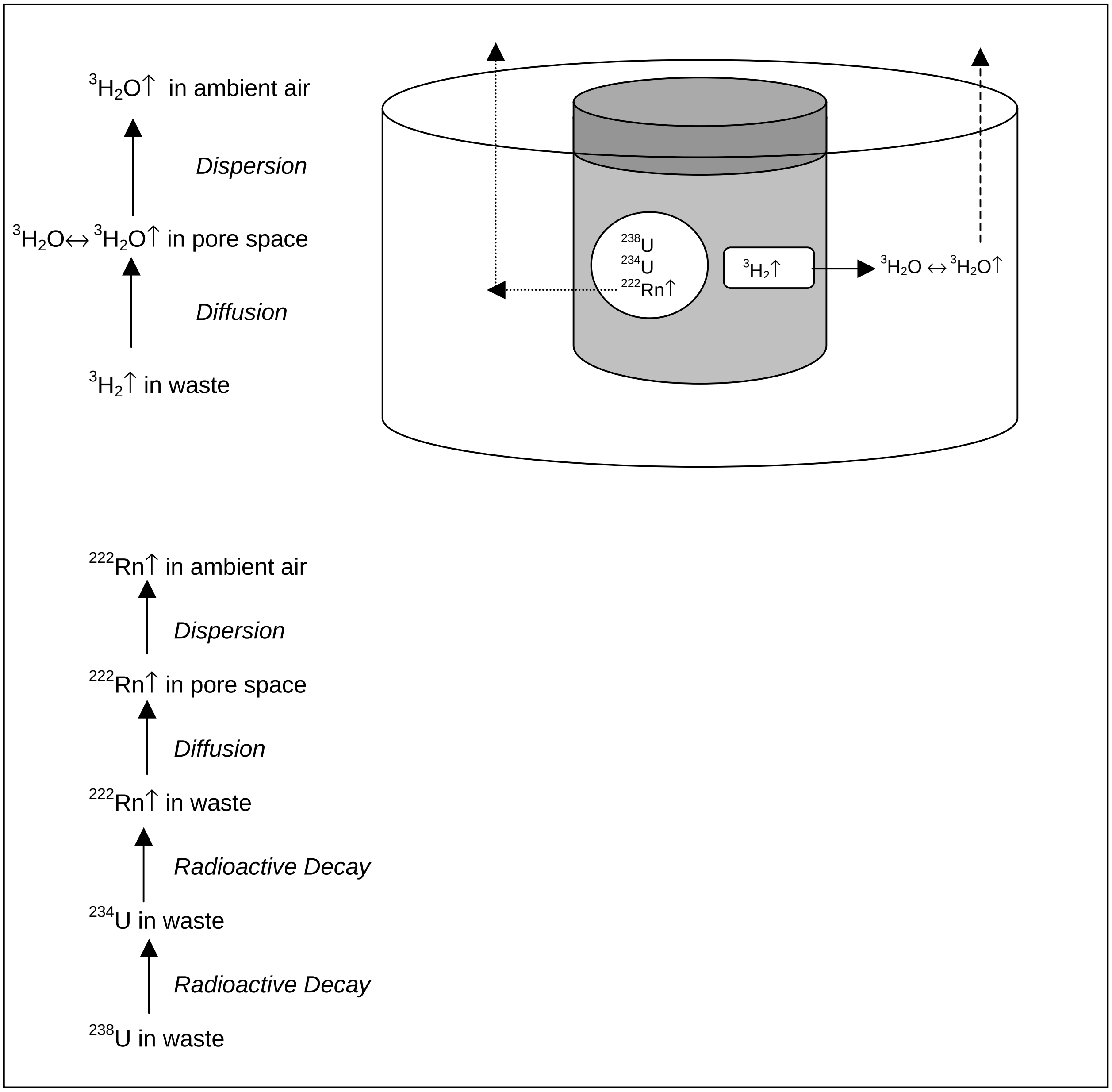


Figure F-2.0-1. Illustration of the vapor-phase transport process model

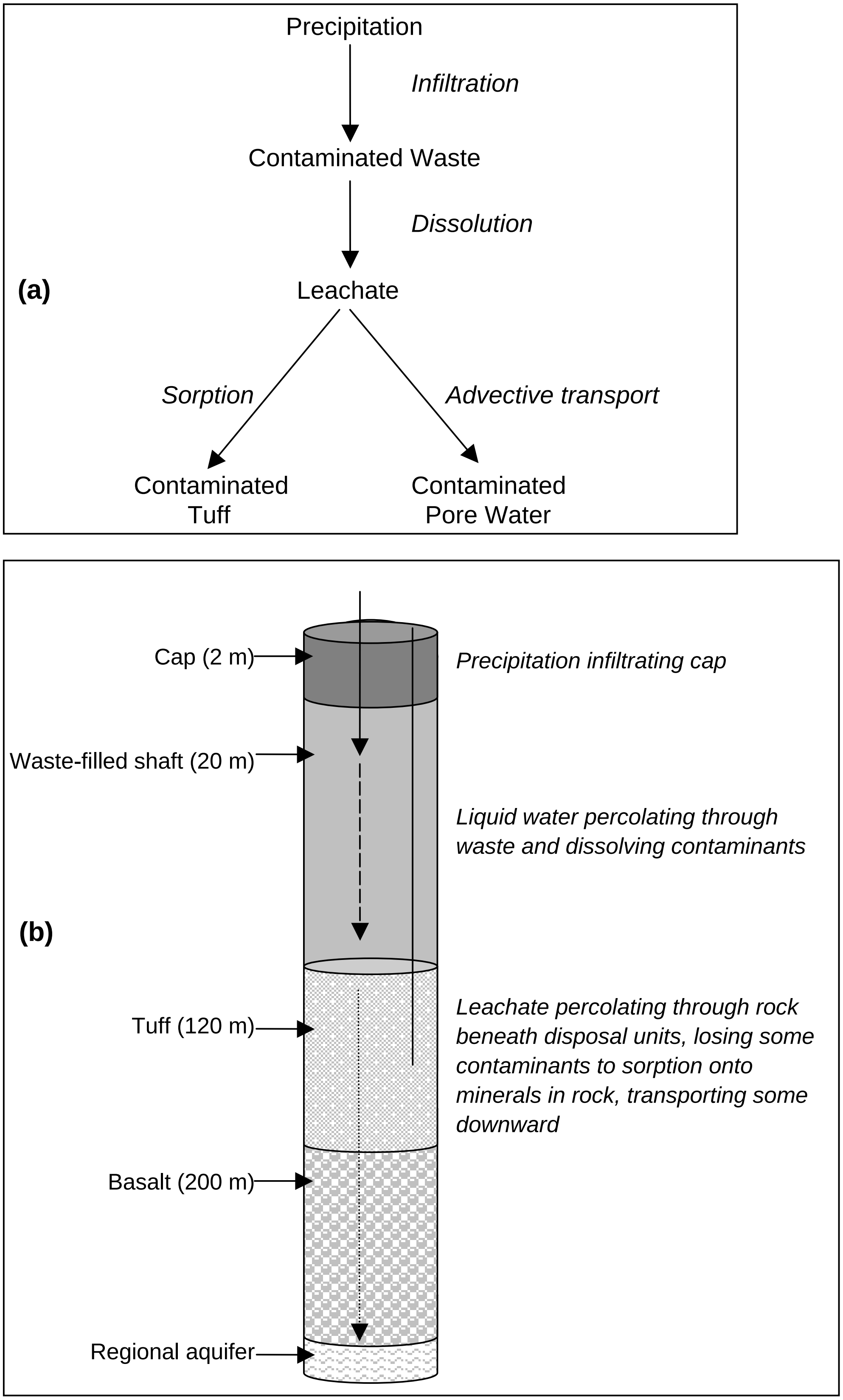


Figure F-2.0-2. Illustration of the liquid-phase transport process model

The complexity of three-dimensional, two-phase (i.e., air and water) fluid flow and contaminant transport in unsaturated porous, fractured media (like the rock surrounding the shafts at MDA H) is the subject of long-standing theoretical and empirical investigation (Freeze and Cherry 1979, 64057). (Understanding of these processes is essential in environmental and economic applications, e.g., to protect water resources and identify extractable petroleum reserves and potable water.) While the development of computer models that accurately portray complex natural systems has proven to be extremely difficult, credible models of specific individual processes within natural systems are available.

Despite their limitations, computer models are the only method available for assessing the future potential impacts of processes that occur over very long time periods, such as contaminant transport in the environment. To compensate for their limitations in impact-assessment applications, models are developed that effectively simplify the complex natural processes in a manner that overestimates the impact of the process. Under DOE sponsorship and NRC and EPA regulatory oversight, the Laboratory has developed the multi-phase fluid flow and chemical transport computer program FEHM (Finite Element Heat and Mass), Version 2.10 to assess the Yucca Mountain site proposed for the Nation's high-level radioactive waste repository (Zyvoloski et al. 1997, 70147). The same computer program was used to evaluate vapor- and liquid-phase contaminant transport in the MDA H subsurface. To assess the long-term potential human-health impacts of the containment alternatives at MDA H, FEHM was used to estimate releases of contaminants to both air and subsurface pore-water. The natural processes modeled in FEHM are realistic, but the calculated rate of movement and amount of contaminant released are (purposefully) unrealistically high for MDA H based on assumptions and parameters that are used to describe the system within the computer model.

Vapor-Phase Contaminant Release and Transport

The vapor-phase transport model was used to simulate the release of tritium and radon from the disposal shafts at MDA H based on the Alternative 1 cover. Waste containing tritium was disposed of at MDA H, and tritium has been measured in the subsurface in water vapor. While no radon was disposed of per se at MDA H, radon's radioactive "precursors" (the 234 and 238 isotopes of uranium) are present in the MDA H inventory. No simulations for vapor-phase transport of volatile organic chemicals were run because these chemicals have only been detected in trace amounts.

Tritium. The MDA H disposal records indicate that a number of tritium-contaminated "units" were disposed of. Tritium is a radioactive isotope of hydrogen (H^3). Based on recorded descriptions and process knowledge, it is most likely that small amounts of tritium were disposed of in the form of elemental hydrogen gas contained in metal canisters. (The assumption of "small amounts" is justified by the knowledge that tritium was expensive to produce and therefore not willingly disposed of). Eventually, hydrogen gas diffuses through every material and readily oxidizes to form water. The 1995 RFI measurements of tritium taken in boreholes at MDA H indicate that the tritiated hydrogen gas has diffused from the canisters to the surrounding subsurface tuff and has oxidized to form water molecules, which are moving through the subsurface as water vapor, not as liquid water. (This phenomenon is elaborated in Appendix I). These measurements were used to estimate the maximum amount of tritium in the 1995 plume by using the FEHM model to simulate the vapor-diffusion processes at MDA H. The maximum calculated inventory of tritium in 1995 is 168 Ci (Appendix I). FEHM was then used to calculate the diffusion of 167 Ci of tritiated water vapor from the shafts through the surrounding tuff.

Figure F-2.0-3 shows the FEHM-calculated tritium concentrations in the subsurface pore water in tuff surrounding the disposal shafts. Vapor-phase concentrations in equilibrium with these pore-water concentrations are lower by a factor of 10^5. Because tritium is a short-lived radionuclide with a half-life of only 12.4 years, tritium concentrations will continue to decrease from their current levels. Therefore, dose by tritium will continue to decrease. The present-day dose to a site worker at MDA H caused by inhalation of tritium was estimated in the MDA H RFI report (LANL 2001, 70158) to be acceptable, at less than 0.19 mrem/yr. Therefore, dose to site workers over the next 100 years will continue to be in the acceptable range. Figure F-2.0-3 shows that after 100 years, subsurface tritium concentrations drop by approximately six orders of magnitude. Hence, future dose from tritium to recreational or residential users after the institutional control period will be negligible. Projected tritium concentrations are only plotted for 175 years (through year 2170) because at that time the simulated subsurface concentrations are below the pre-bomb pulse precipitation background value (20 pCi/L in the aqueous phase) (Adams et al. 1995, 59066.1) and no further transport should occur.

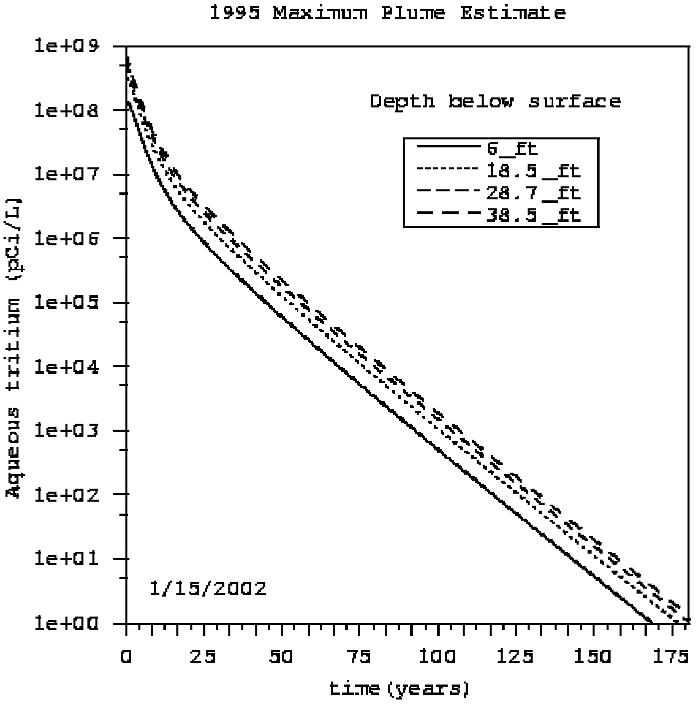
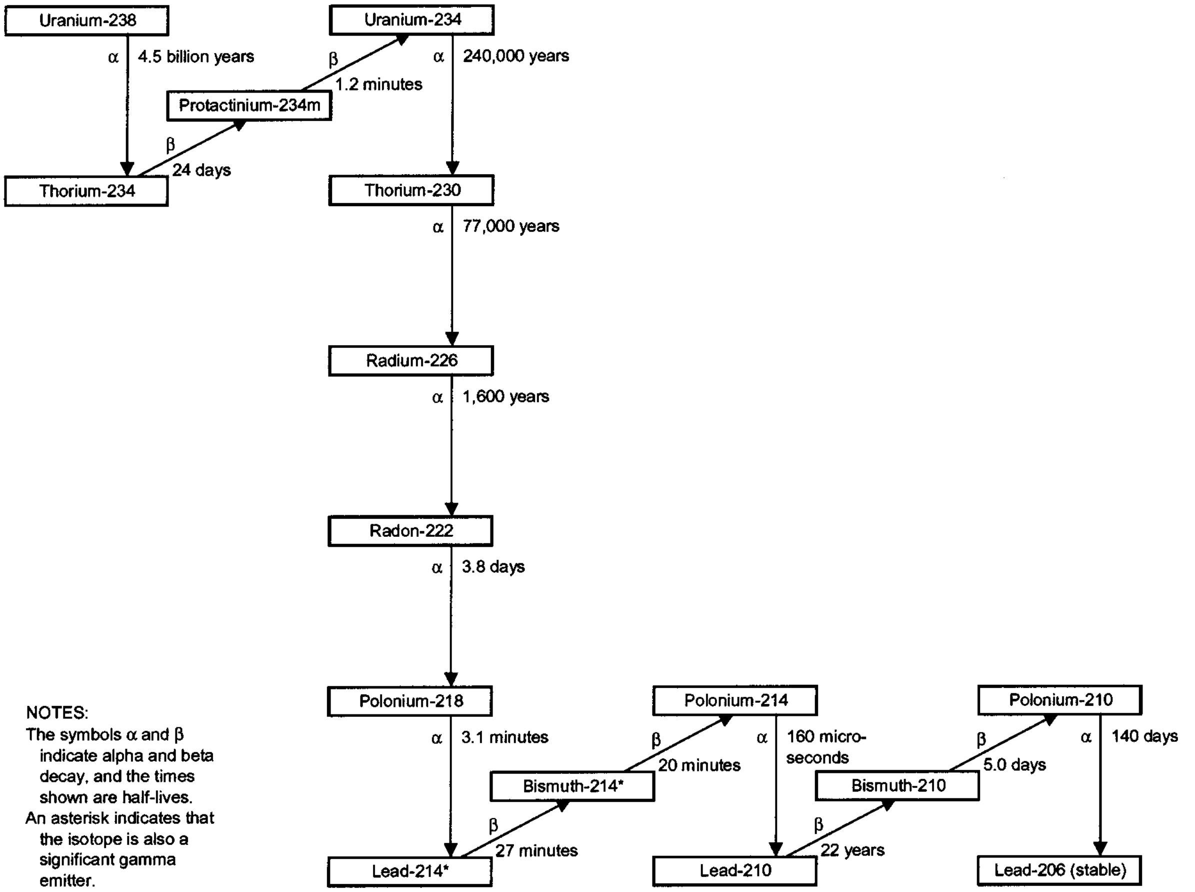


Figure F-2.0-3. Simulated aqueous-phase tritium concentrations in pore water as a function of time in the MDA H subsurface (time = 0 occurs in 1995)

The FEHM transport calculations were not reproduced with the GoldSim system model because GoldSim is unable to realistically capture the complex nature of diffusive vapor-phase tritium transport.

Radon. Radon-222 (which is the most harmful of the radon isotopes) will “grow into” the MDA H inventory over time, primarily from the radioactive decay of uranium-238 and -234 present in the MDA H inventory. Figure F-2.0-4 shows the decay chains resulting in the eventual generation of radon gas (radon will also be produced as naturally-occurring uranium-238 and radium, which are present in tuff, decay over time).



F3.1-5/mdahcms/071502/RLM

Figure F-2.0-4. Decay chains leading to in-growth of radon-222 in the MDA H inventory

The uranium present in the MDA H inventory is in the form of solid metal. As the radon-producing uranium isotopes decay, radon gas will slowly diffuse out of the solid metal, then through the air-filled pore spaces and fractures in the tuff surrounding the disposal shafts. Given its short half-life (less than 4 days) much of the radon will decay to less harmful elements before it reaches the surface. FEHM was used to calculate gaseous diffusion of radon from its uranium sources in the disposal shafts to the surface, as described in Appendix I.

The radon surface flux calculated using FEHM was closely reproduced in the system-level model to calculate potential human-health impacts. The FEHM simulation predicts that the maximum radon flux occurs after 1000 years. Maximum fluxes of approximately 1.82 and 0.17 pCi/m^{2}s were calculated, based on the upper-bound and best-estimate uranium inventory estimates presented in Table 2.1-1. Both flux values are lower than the 20 pCi/m^{2}s threshold value. This result was used to calibrate the system-level model discussed in Appendix H and Section F-3.0. The radon diffusion to the surface will decrease with increasing cover thickness.

Liquid-Phase Contaminant Release and Transport

FEHM was also used to simulate release and transport of contaminants dissolved in the small amount of rain water and snow-melt that moves from the surface through the disposal shafts and surrounding tuff. MDA H RFI data indicate that small amounts of liquid water move very slowly downward through the mesa. The potential (but unexpected) impacts of future releases of contaminants from MDA H into the groundwater were estimated using the FEHM model to simulate two cases, a realistic case and an unrealistically large amount of water moving continuously through the disposal shafts coming into contact with all contamination in the shafts. In reality, very little liquid water moves through the shafts, and at variable rates, and most of the contaminants are bound within solid masses of waste, conditions that would produce a much smaller release. For example, uranium isotopes contained in depleted uranium “shapes” are distributed throughout the volume of the shape and would be dissolved at a very slow rate over a very long time period as the metal shapes corrode, as discussed in Appendix M. Similarly, uranium isotopes in “unloaded fuel elements” would also be dissolved very slowly over a very long time, depending on the corrosion rate of any “cladding” material (usually ceramic) encapsulating the metal and the corrosion rate of the metal itself.

The FEHM model of liquid-phase contaminant transport from the disposal shafts through the Bandelier tuff toward the regional aquifer applied a continuous base-case water flow rate of 1 mm/year and a continuous high water flow rate of 10 mm/yr through the disposal shafts and the mesa. Fluxes through the Bandelier Tuff have been estimated using a variety of field, laboratory, and computational techniques. Interpretation of the available data indicates that moisture percolation under today’s climate is generally slow to non-existent deep within the mesa and that the base-case water flow rate of 1 mm/yr is a realistic, yet high, estimate. However, seasonal wetting and drying cycles maintain moisture contents (up to 20% by volume) in the top few meters of the mesa that are higher than those found at greater depths (less than 5% by volume). Also, percolation through fractures near the mesa surface may occasionally occur. Nevertheless, fracture flow does not appear to result in increased percolation within or below the mesa, as described in Section 2.1.3.2. Surface disturbances associated with waste management activities may also increase the moisture content near the top of the mesa, but a lasting effect of this increased moisture on deeper percolation has not been observed. Extremely low moisture contents (1 to 5% by volume) are found 10 to 38 m (33 to 125 ft) below the mesa surface at MDA H, as shown in Figure 2.1-5. These values are likely to be the result of evaporation caused by air flow through fractures and surge beds, a concept that is supported by moisture content, suction, chloride and stable isotope data. In fact, Bergfeld and Newman (2001, 71246) estimate fluxes of 0.2 mm/yr through the upper 139 ft of the mesa and 3.3 mm/yr below that, producing a travel time of nearly 12,000 years from the surface to the base of the Otowi Member at MDA H. The 10 mm/yr rate represents an upper bound based on analysis of leakage through the surface cover, as presented in Appendix G. Leakage through the cover does not include evaporation within the mesa and thus overestimates the net quantity of water expected to percolate through the disposal shafts.

Several simplifying assumptions were used in developing and exercising the computer model. These include a uniform rate of infiltration through the mesa, porous media flow, and no evaporation from the sides of the mesa. In order to provide assurance that the model used was defensible, a number of ancillary studies were done (Birdsell et al. 1995, 70012; Soll and Birdsell 1998, 70011). These included studies on the following:

- Alternative percolation rates
- Transient percolation
- Evaporation in fractures and surge beds on moisture below the mesa tops.

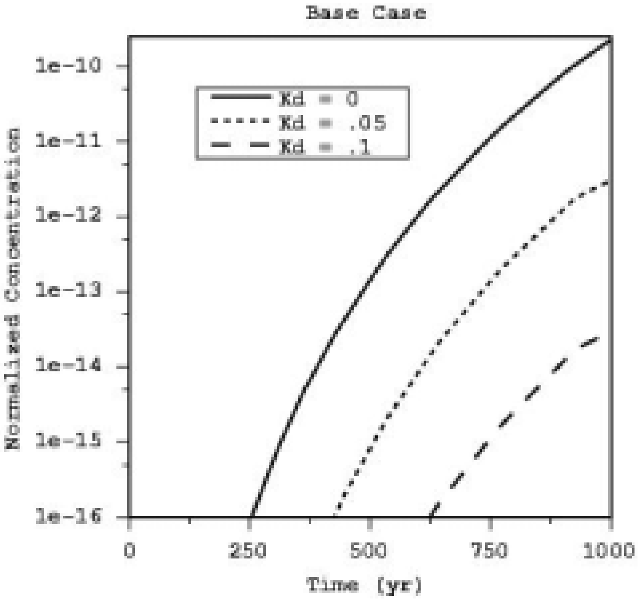
- Uncertainty in material properties.
- Fracture flow
- Fracture fillings and coatings

All of these studies indicate that the steady-state porous media model used for the aqueous phase transport is appropriate and conservative (i.e., it overestimates releases to the regional aquifer).

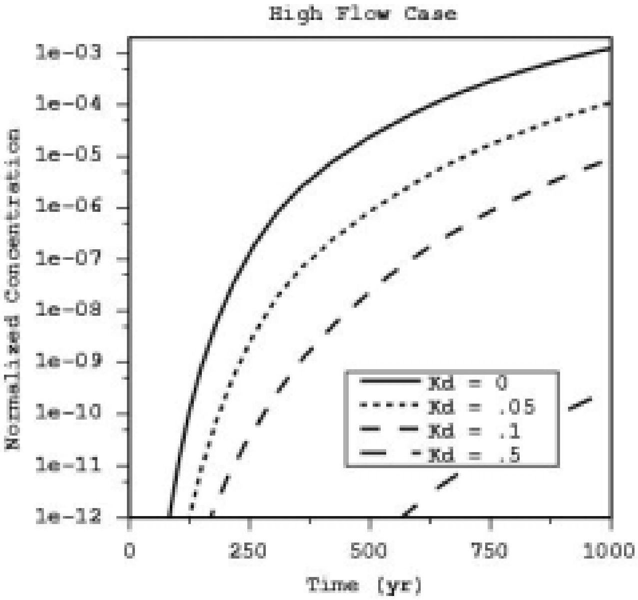
In the FEHM liquid-phase transport model, contaminants in the MDA H inventory were assumed to dissolve into water that was assumed to flow through the shafts, resulting in contaminant concentrations equal to the solubility limit of each contaminant within the shaft volume. The water was then assumed to carry the dissolved contaminants down through and out of the disposal shafts, then through the unsaturated rock beneath the shafts toward the regional aquifer some 1000 ft below. The FEHM model included the physical-chemical interactions between dissolved contaminants and minerals in tuff that result in contaminants being pulled from water and bound to minerals in the process known as adsorption. Certain contaminants (including uranium) adsorb strongly enough to minerals in tuff that they are effectively immobile in tuff, while other contaminants (including HE and tritium) do not adsorb and travel at the same rate as water.

Figures F-2.0-5 (a) and (b) plot the calculated maximum concentrations of generic solutes emanating at the base of the unsaturated zone as a function of time and distribution coefficient (Kd) for both the base-case flow field and the high flow field, respectively. These curves are for an idealized source that has a constant concentration of 1 mole/L throughout the simulation. To estimate maximum constituent-specific concentrations exiting the unsaturated zone, the appropriate curve is chosen based on the constituent's adsorption coefficient, and then that curve is scaled by that constituent's solubility limit. Calculated concentrations exiting the unsaturated zone fall several orders of magnitude below a constituent's solubility limit (assumed to be 1 mole/L in these calculations). For example, at 1000 years, releases for constituents with Kd>0 migrating under the base-case flow field and for constituents with Kd>0.5 mL/g for the high flow case are less than 10^{-10} times their solubility limit. Figures F-2.0-5 (a) and (b) show that releases drop off rapidly with only a slight increase in Kd ($\leq$0.5 mL/g in these figures). In fact, most of the Kd values for constituents in the MDA H inventory are much larger than 0.5 mL/g, as shown in Appendix J, Table J-2.0-2.

Constituent-specific releases based on these FEHM simulations are given in Appendix J for uranium, RDX and plutonium. These species were found to produce dose (uranium and plutonium) or cancer (RDX) risks that fall well below the 15 mrem/yr dose for uranium and plutonium (Table J-5.1-1 and Section J-5.0). These contaminant transport results were used to verify the liquid-phase transport model within the system-level model correctly captures this transport process. The system model includes all water-soluble components in the MDA H inventory and estimates the potential human-health impacts associated with contaminants released over time into the regional aquifer. Neither the FEHM simulations nor the system-level model includes transport within the regional aquifer, where further dilution would occur before reaching a potential receptor.



(a) Maximum breakthrough concentration exiting the unsaturated zone as a function of Kd (mL/g)—generic source concentration of 1 mole/L, base-case flow field (1mm/yr)



(b) Maximum breakthrough concentration exiting the unsaturated zone as a function of Kd (mL/g)—generic source concentration of 1 mole/L, high flow field (10 mm/yr)

Figure F-2.0-5. Calculated contaminant concentrations exiting the base of the unsaturated zone as a function of Kd (mL/g)—generic source concentration of 1 mole/L

F-3.0 SYSTEM-LEVEL MODEL

Since the physics of vapor-phase and liquid-phase flow and transport are both complex and different, the two processes are not easily modeled together. And while both the vapor- and liquid-phase FEHM models are simplified approximations of the natural system, the models themselves are still quite complex. FEHM cannot be used to estimate potential human-health impacts. FEHM calculates contaminant concentrations as a function of space and time. Also, the FEHM program does not support modeling of the complicated interplay between surface processes (in particular, water balance and biotic effects). To couple the subsurface vapor-phase and liquid-phase processes and surface/near-subsurface water balance and bioturbation processes, and to calculate the environmental distribution and associated potential human-health impact of all of the processes operating simultaneously, the GoldSim (Golder Simulation) version 7.21 modeling program was used (Kossik and Miller 2002, 71467). Like FEHM, GoldSim was developed initially for Yucca Mountain applications (under the previous name, Repository Integration Program), but it was developed independently and not at the Laboratory.

The MDA H GoldSim system-level model was developed to evaluate the combined effect of several environmental processes on contaminant concentrations over time in possible exposure media. The model is also used to estimate potential human health impacts over time for various land-use scenarios related to potential exposure to contaminants in air and surface soil. The GoldSim model was parameterized to reproduce the results of FEHM calculations of gas-phase radon transport and liquid-phase contaminant release and transport, the details of which are included as Appendix I and Appendix J, respectively. The bioturbation processes were modeled directly using GoldSim. Figure F-3.0-1 is a visual representation of the GoldSim system-level model.

In a systematic process, contamination is brought from the upper waste cell to the surface soil by plant roots and burrowing animals. Contaminants may be returned to the waste cells by infiltration and burrow collapse. Contamination in the soil, tuff, cap, and waste are all potentially susceptible to mobilization with infiltrating surface water. Contaminants that “break through” the tuff cell or lower waste cell are further evaluated for potential transport to the regional aquifer (represented in Figure F-3.0-1 as the groundwater sink). There are three “sinks” in the GoldSim model of MDA H where contaminants may leave the modeling environment. These are the groundwater sink, the erosion sink, and an atmospheric sink for radon gas. Details of the GoldSim model of MDA H are provided in Appendix H. A summary of the transport and exposure components of the GoldSim model is presented in the following paragraphs.

The MDA H GoldSim model incorporates three solid media (waste, crushed tuff, and solid tuff) and two fluid media (water and air). In GoldSim parlance, these media are distributed among the “cell pathways”: the two waste cells, the cap cell, the solid tuff cell, and the soil cell. The waste cells (i.e., disposal shafts) consist of waste, water and air. The cap cell and soil cell are modeled as consisting of crushed tuff, water, and air, and the solid tuff cell consists of solid tuff, water, and air. Chemicals are transported among the environmental media and cells over time as a function of the mathematical equations and parameters that constitute the “model.” The majority of connections between these cells and media are advective connections, which means that contaminants are transported as a function of the movement of environmental media in which they are dissolved (liquids) or adsorbed (solids). The exceptions to this rule are contaminant transport via plants and gaseous diffusion of radon.

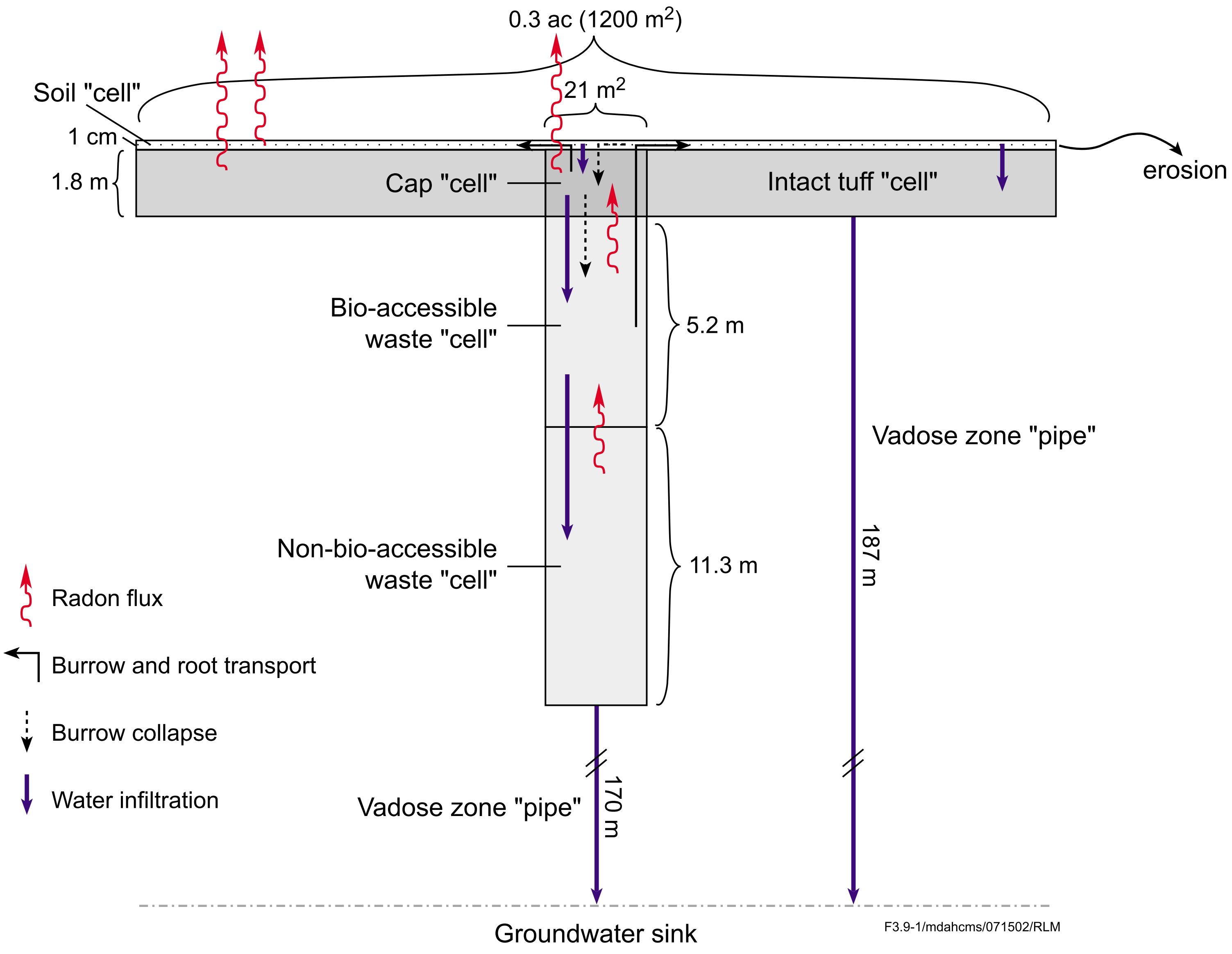


Figure F-3.0-1. Schematic of the GoldSim system-level model

Contaminant Source and Release

The inventory, or mass, of chemicals and radionuclides present in the disposal shafts was discussed in Section 2. In order for these chemicals and radionuclides to pose a risk to humans or the environment, they must first be released from the disposal shafts. The three natural physical processes for movement of contaminants away from the disposal shafts at MDA H include dissolution of contaminants into liquid water moving through the shafts, movement of gas-phase contaminants in air, and biotically-mediated transport of waste via plant roots or excavation by burrowing animals. Once chemicals and radionuclides are released to environmental media beyond the disposal shafts they become available for incidental exposure via the land-use scenarios described in Section 3.3.1.1. The chemical and radionuclide inventory used as input to the GoldSim system-level model is presented in Table H-2.0-1 in Appendix H.

One of the greatest sources of protective bias in the GoldSim model is that the entire inventory of chemicals and radionuclides described in Section 2, except uranium, is assumed to be immediately available for transport at the beginning of the model simulation. In fact, it is obvious from the waste records that much of the chemical inventory exists in metallic form or is packaged in such a manner that release via dissolution or biotic uptake would occur only very gradually. Release of contaminants from within packaged waste items would be essentially zero until the packaging was compromised. For uranium, both immediate availability and corrosion-limited releases were considered.

As indicated in Figure F-3.0-1, the waste inventory present in the nine disposal shafts is represented in the GoldSim model as existing in a single shaft (with dimensions equivalent to the nine actual shafts) that is divided into two waste cells. The depth of the upper waste cell was set such that all plant roots and animal burrows exist between the ground surface and the bottom of the upper waste cell. Thus, this upper cell contains all the waste that is biotically accessible. Chemicals in the lower waste cell can only migrate downwards with infiltrating water or (in the case of radon gas) upwards via gaseous diffusion.

The waste in each of the two cells is modeled as a homogenous solid medium with a density calculated as the total mass of chemicals and radionuclides divided by the volume of the waste shafts. This “homogenous waste” is a theoretical construct to simplify the modeling effort. Other physical attributes of the waste, such as moisture content and porosity, were defined as equivalent to that of crushed tuff (see Appendix H). Each cell within GoldSim is completely mixed such that contaminant concentrations do not change over space within a cell. When contaminants are redistributed among cells at each time step according to the mathematical equations of the model, they achieve equilibrium among solid and liquid phases and are mixed throughout the entire volume of the cell instantaneously.

Biotic Perturbation Processes

The GoldSim biotic transport model developed for MDA H is based on the models used for the MDA G Performance Assessment/Composite Analysis (PA/CA) (Hollis et al. 1997, 63131). The MDA G PA/CA models are in a continual state of refinement under the performance assessment maintenance program required by DOE. Hence, the MDA H biotic transport modeling incorporates revisions to the models originally published in the PA/CA and is consistent with the current state of understanding of these processes on Mesita del Buey. The basis of the animal burrowing and plant root uptake models used for the MDA H CMS is documented in *An Evaluation of the Potential Impacts of Plant and Animal Intrusion into Disposed Waste at TA-54, MDA G* (Shuman 1999, 66804). The biotic transport model is presented in greater detail in Appendix H.

Burrowing Animals. Burrowing by animals is a potentially significant process in the transport of materials in the near surface. It is assumed that in the long term the principal effects of burrowing are to bring potentially contaminated materials from depth to the surface through active excavation and to cause downward transport through burrow collapse. Lateral movement of materials is ignored in this one-dimensional model. Four burrowing animals were selected based on site surveys and available data. These representative animals are harvester ants, chipmunks, mice, and pocket gophers (Shuman 1999, 66804). For each of the four animals, a connection is established from the upper waste cell to the soil cell and from the cap cell to the soil cell, in accordance with the conservative assumption that excavated materials are brought directly to the surface. The density of burrows at any given depth is modeled with a simple mathematical function fitted to the burrow data. Using this information, as well as data on the density of animals and rate of burrow formation, the total amount of material excavated from the waste cell and the cap cell is calculated.

The relative density of the four animals changes over time as the biotic community transitions from a disturbed state characterized by human management to a climax state (Shuman 1999, 66804). The best estimate of this transition period is 200 yr, and transition is modeled as a linear change beginning at the end of the 100-year institutional control period.

Burrow collapse is modeled as a series of advective connections. Crushed tuff and water migrate downward at the same rate that waste and water are excavated upward, thereby conserving mass. Materials from each cell “collapse” into the abandoned burrows in the layer below, and the cycle of bioturbation is completed. This is the case even for the connections between the cap and soil cells, although their relative areas are quite different.

Because the upper region of the waste is modeled as a single well-mixed cell, the chemical concentrations in waste nearer the surface do not decrease faster with time than concentrations nearer the bottom of the cell. This introduces a conservative bias to the burrowing animal model because the density of burrows is greater near the top of the upper waste cell and decreases with depth. However, the total mass of waste transported by burrowing animals over the 1000-year modeling period was only about three kg. The burrows of gophers (which excavate relatively large quantities of material during burrowing) are not deep enough to reach the buried wastes.

Plant Roots. By assimilation of nutrients and other constituents in the root tissues, and subsequent transport within the plant to the aboveground biomass, plants are known to bring subsurface contamination to the surface. The contaminated leaves and other above-ground plant parts die off and fall as litter, which as it decays becomes mixed with the surface soils, completing the link between subsurface materials and surface soils. This mechanism and the parameters of the plant uptake model are developed and documented in Shuman (1999, 66804) and are outlined here.

Four representative plant types were selected based on site surveys and available data. These plant types are grasses, forbs, shrubs, and trees (Shuman 1999, 66804). Their relative densities on the mesa top change over time in a manner similar to that described above for the animal community. A connection for transporting chemicals via plants is established in GoldSim independent of any solid or liquid medium. The inputs to the plant transport model include the percentage of root mass with depth; the thickness of the soil, cap, and upper waste cells; the plant-specific litter production rates; and the plant-soil chemical concentration ratios for each contaminant.

It is assumed that contaminants are brought directly from the roots to the aboveground parts of the plant. As in the animal burrow model, the density of plant roots at any given depth is modeled with mathematical functions fitted to the root-depth data. Using the plant root depth information, the fraction of root mass that exists in the upper waste cell is calculated for each plant type. The quantity of chemicals brought to the surface over time from the roots in the waste cell depends on the plant-specific litter production rates and chemical-specific plant-soil concentration ratios. The amount of chemical moved from the cap cell and upper waste cell is scaled by the fraction of root mass existing in that cell. The amount of contaminants brought to surface soil over time from each subsurface cell also depends upon the plant uptake efficiency for each contaminant, which is expressed by a plant-soil concentration ratio obtained from the literature. Plant-soil ratios, as well as contaminant-specific plant transport quantities, are provided in Appendix H.

Erosion, Infiltration and Vadose Transport Processes

Once contaminants in the upper waste cell are transported to the soil cell via plant or animal activity, the only mechanisms other than burrow collapse by which they may leave soil are erosion and infiltration. Soil erosion is modeled as a sheet erosion process. Aeolian processes resulting in suspended soils are considered in the exposure model but are not applied as a mechanism for potential off-site transport. Infiltration is governed by the water infiltration rates for the near-surface and subsurface, as well as the chemical properties of the individual contaminants. Contaminant transport via dissolution and infiltration can occur in each of the cells in the model.

Infiltration of water through the model cells is sequential. Thus, water flows from the cap to the upper waste cell, and from the upper to the lower waste cell. Similarly, water flows from the soil cell to the intact tuff cell (see Figure F-3.0-1 for a schematic of these relationships). Shallow and deep rates of water infiltration are described in Appendix H. The infiltration rate of water through the intact tuff and lower waste cells serves as the inflow into two GoldSim “pipe pathways” that model transport of contaminants in the vadose zone to groundwater. Fluid flow in the pipe pathways is modeled as one-dimensional advective transport. No breakthrough of contaminants to groundwater was observed during the 1000-year simulation period. The results of the vadose-zone modeling of contaminant transport in GoldSim are supported by more detailed analyses of vadose phenomena presented in Appendix J.

The amount of any chemical lost via infiltration is a function of its solubility and soil-water partition coefficient. Among the inventory contaminants, cyanuric acid is the most quickly lost from soil due to infiltration because it has the highest solubility (excepting tritium, which has infinite solubility since it exists as tritiated water in the environment). However, most other contaminants are also lost from soil predominantly due to infiltration. The only contaminants that are lost from soil in appreciably greater quantities via erosion rather than infiltration are cadmium and silver, a reflection of the low solubilities of these metals.

The soil erosion rate is modeled to vary through time. During the 100-yr institutional control period, it is assumed that a gravel mulch cap will be maintained. The erosion rate used during this period was obtained from the MDA G PA/CA (Table 3-4 in Hollis et al. 1997, 63131). This value is 0.45 g/m^2-yr, and corresponds to 3.5 x 10^{-7} m/yr given an average crushed tuff density of 1400 kg/m^3 (Appendix 2a, 3.2.3.1.2 in Hollis et al. 1997, 63131). To assess the likely consequences of erosion on Mesita del Buey at MDA H under uncontrolled conditions, a team of local hydrologists was assembled two years ago in order to perform an expert elicitation (Neptune and Company 2000, 71455). These experts concluded that a likely life span for a gravel mulch cap was approximately 50 yr, after which two types of erosion would ensue: erosion under normal climatic conditions and erosion following severe drought conditions. Their best estimate was that erosion under normal climatic conditions would occur at twice the rate (7 x 10^{-7} m/yr) as when gravel mulch existed on the site. Drought-induced erosion rates were expected to be much higher, with a best-estimate value of 1 x 10^{-3} m/yr. The panel’s best estimate of the fraction of time spent in severe drought conditions was 10%. These estimates form the basis of the sheet erosion model used in the MDA H GoldSim model. Over the course of 1000 yr, cumulative soil erosion is calculated to be approximately 8.5 cm.

Radon Diffusion

Diffusion of radon-222 in air from the buried waste was modeled by using a series of links from the lower to the upper waste cell, the upper waste cell to the cap, and the cap to the atmosphere. Diffusion links from the 1-cm thick soil layer and the underlying intact tuff to the atmosphere were also established to account for radon that may be generated from the decay of uranium in these cells. Diffusion of tritium as tritiated water vapor was not included in the GoldSim model because the tritium is primarily present in subsurface tuff rather than in the disposed waste. Tritium diffusion over time is discussed in Section F-2.0 and in Appendix I.

Radioactive decay of a radionuclide during the diffusion process is not accounted for in the diffusion links that exist in the GoldSim modeling program. In the case of radon-222 (half-life of 3.8 days) diffusing through a cap with a thickness of 6 ft, the diffusive flux at the surface is overestimated by approximately 40% relative to the output of the process-level diffusion model described in Appendix I. To account for this discrepancy, the air-phase diffusion coefficient for radon-222 was defined in GoldSim as 60% of the value employed in the process-level model. These calculations were verified by using the Radiation Attenuation Effectiveness and Cover Optimization with Moisture Effects (RAECOM) model (See Appendix I for calculation and model details). A radon emanation coefficient of 1% was employed in the GoldSim model, consistent with the information described in Appendix I.

The surface radon flux over time calculated above the disposal shafts in the GoldSim model reaches a maximum of approximately 3.7 and 0.2 pCi/m^2-sec at 1,000 years, for the upper-bound and best-estimate uranium inventories respectively, in close agreement with the radon flux calculated with FEHM (Appendix I). The radon surface flux from the soil and intact tuff cells is negligible compared to flux above the shafts (less than 0.01%).

Exposure Models

Institutional controls were assumed to be absent after 100 years at MDA H as a condition of the long-term human health impacts assessment. Uncertainty in future land-use scenarios and exposure pathways will increase with time during the 1,000-year modeling period because assumptions governing human behavior based on current observations are less credible when applied to the distant future. Because future land use is subject to a high degree of uncertainty, the possible intensity of future human exposure was bounded by developing two exposure scenarios representative of relatively low and high intensity land use. These scenarios employ reasonably conservative values of the input parameters for media contact rates, site utilization, etc. Exposure parameters and equations are documented in Section H-3.0 in Appendix H of this report.

The most likely land-use scenario (recreational use) is used to analyze the impacts of low-intensity use of MDA H after institutional access controls are assumed to be lost. Recreational land use is assumed to consist of casual activities pertaining to undeveloped land such as hiking or bird watching, rather than activities related to more developed recreational uses such as ball fields or parks. Potential exposure pathways associated with recreational land use were described in Section 3.3.1.1.

A residential land-use scenario is used to bound the impacts of high-intensity use of MDA H after institutional access controls are no longer effective. The residential exposure model assumes that a hypothetical future resident may be exposed to contaminants through all of the pathways that are viable for the recreational scenario, with the additional exposure pathway of ingestion of garden produce grown in contaminated soils. The potential for exposure via drinking groundwater contaminated by constituents infiltrating from MDA H is discussed in Section 3.1.1.1. The amount of time spent within the area presently occupied by MDA H is assumed to be significantly greater in the residential scenario.

Atmospheric dispersion of suspended soils was not included in the GoldSim model as a mechanism of off-site contaminant transport. Instead, all suspended soil (dust) above the site was assumed to be generated from the site itself in a closed system. This assumption results in higher site soil and dust contaminant concentrations than would be the case if off-site wind dispersion occurred. As shown in Table H-3.1-1 in Appendix H, a particulate emission factor of 5×10^7 m^3/kg (corresponding to an ambient dust concentration of 2×10^{-8} kg/m^3) is used in the exposure assessment, based on air measurements of 10-micron diameter particulates made within the Laboratory boundaries and recorded in several Environmental Surveillance reports in the 1990s (LANL 1998, 59904).

The exposure area associated with both residential and recreational exposure scenarios is 0.3 acres. This is the area in which contaminants brought to the surface via biotic processes are mixed to calculate exposure point concentrations in surface soil. With respect to the exposure assessment, it is immaterial whether one assumes that the soil in this area is truly well mixed or perhaps heterogeneous, so long as one accepts that the 0.3-acre area is a single entity with respect to a health-based assessment. In other words, exposure is the same whether soil concentrations are averaged mathematically over the 0.3-acre site or whether several concentrations are calculated and then averaged by a receptor, who is assumed to be exposed randomly over the site.

F-4.0 LONG-TERM IMPACTS ASSESSMENT

Long-term human health impacts are calculated based on output from the system-level model described above. Details of the GoldSim risk, hazard, and dose calculations are included in Appendix H, and the results of the assessment are summarized in Section 3.3 of the main body of this CMS report.

F-5.0 REFERENCES

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Appendix G

Modeling of the Surface Cover

APPENDIX G MODELING OF THE SURFACE COVER

G-1.0 INTRODUCTION

The hydrologic response of the surface cover for MDA H is important because of the potential to reduce the life of the cap through soil erosion and because groundwater impacts depend on drainage or leakage through the surface cover. Evaluating the hydrologic response of waste site covers is typically conducted using a numerical modeling approach.

Two models were used in the assessment of MDA H surface cover hydrology. The Hydrologic Evaluation of Landfill Performance (HELP) model, which is recommended by the U.S. Environmental Protection Agency (EPA) and the New Mexico Environmental Department (NMED), was used to simulate the surface cover hydrology. HELP is available from the following website: http://www.wes.army.mil/el/elmodels/. The second model called Weather GENerator (WGEN, Richardson and Wright 1984, 71247) was used to generate different sequences of daily precipitation, maximum and minimum temperatures, and solar radiation values as input to HELP. This is particularly important for precipitation because it is a sensitive input term to the HELP model (Lane and Ferria 1980, 70238).

HELP was selected to model MDA H because of the recommendations by EPA and NMED. Based on the NMED “Guidance Document for Performance Demonstration for an Alternate Cover Design under Section 502.A.2 of the New Mexico Solid Waste Management Regulations (20 NMAC 9.1) Using HELP Modeling” (NMED 1998, 71299), cover modeling of MDA H is not required. Cover modeling is not required because MDA H meets the requirements that the saturated hydraulic conductivity of the infiltration layer be the same as the natural subsoils and that the infiltration layer be at least 18 in. thick. In the case of MDA H, the crushed tuff infiltration layer over the waste is over 18 in. thick and has the same hydraulic conductivity as the *in situ* tuff below the cover [i.e., saturated hydraulic conductivity values from Rogers and Gallaher (1995, 49824) show that the range of saturated conductivity measurements of crushed tuff is within the range of measurements from unit 2 of the Tshirege member of the Bandelier Tuff that occurs at MDA H]. Even though HELP modeling is not required for MDA H, LANL has performed a series of HELP simulations to provide quantitative estimates of cover performance over a range of precipitation conditions. In addition, the surface runoff and leakage results from HELP can be used as a way of comparing cover performance for different cover designs.

To examine uncertainty in predictions of surface runoff and leakage a Monte Carlo approach was used. Three scenarios were considered. The first scenario was termed background, and it looked at site conditions of a thin topsoil layer overlying a tuff layer. The concrete shaft is the second scenario, and this used a 91-cm layer of tuff over a 91-cm concrete shaft layer. The evapotranspiration (ET) cover design was the final scenario, and this used a 15-cm topsoil layer over a 101-cm tuff layer. For each scenario, a total of 1000 simulations of 1000 years were used to assess runoff and leakage at MDA H. The results from HELP (runoff and leakage) are presented as statistical estimates rather than deterministic values because the weather variables driving the HELP simulations were uncertain, and this uncertainty is propagated through the HELP simulations. The statistics and distributions of the key response variables are a better representation of the future behavior of the site than a single value generated by a deterministic analysis.

In addition to the Monte Carlo simulations, a HELP simulation was performed for the prescriptive cover discussed in the NMED Guidance Document for Alternate Cover Design Using HELP Modeling (NMED, 1998, 71299). The prescriptive cover simulation is used as a basis for comparison to the MDA H cover scenarios, and is used for modeling comparisons only (i.e., it is not an actual cover design for MDA H). In order to be deemed an adequate alternative, the HELP results for the MDA H proposed covers must show an equivalent or smaller amount of leakage as compared to the prescriptive cover. The comparison is discussed later in this document. The prescriptive cover case includes an 18-in. infiltration layer with a saturated hydraulic conductivity of 1 x 10^{-5} cm/sec and a 6-in. topsoil layer. As an extension of the prescriptive cover case, a simulation using the same parameters as the original prescriptive case was run, except a saturated hydraulic conductivity of 3.53 x 10^{-4} cm/s was used, which is consistent with the crushed tuff used in the background, concrete shaft, and ET cases.

G-1.1 WGEN Model

WGEN described by Richardson and Wright (1984, 71247) uses a Markov Chain to determine daily precipitation occurrence and a gamma distribution to estimate the amount of daily precipitation. WGEN generates maximum and minimum daily temperatures and total daily solar radiation, and parameters are entered to modify the maximum temperature and solar radiation for days when precipitation occurs. Temperatures and solar radiation use a Fourier series to describe annual variations in the mean and standard deviation and daily values are estimated using stochastic residuals. WGEN also has the capability to generate daily wind speed, but wind speeds generated by WGEN were not used in this analysis.

The parameters required for WGEN are

- the probability of a wet day given a wet day by month,
- the probability of a wet day given a dry day by month,
- the alpha parameter of the gamma distribution for daily rainfall by month,
- the beta parameter of the gamma distribution for daily rainfall by month,
- Fourier coefficients for maximum temperature (TXMD, ATX, CVTX, ACVTX),
- Fourier coefficients for maximum temperature on wet day (TXMW),
- Fourier coefficients for minimum temperature (TN, ATN, CVTN, ACVTN),
- Fourier coefficients for solar radiation (RMD, AR),
- Fourier coefficients for solar radiation on a wet day (RMW),
- Mean and standard deviation of annual wind velocity, and
- Mean wind velocity for the 9th day of each month.

The parameters for WGEN were estimated from observed data from Los Alamos weather stations (Los Alamos townsite, TA-6 and TA-59) from 1951 to 2000. The Los Alamos station has higher precipitation than MDA H (TA-54 weather station), but the longer record at Los Alamos site allows for more stable parameter estimates. WGEN will produce statistics that will appear similar to those for the site (Los Alamos) from which the parameters were estimated. This means that the precipitation does not increase or decrease as the result of climatic variations that may be present in a long-term record. Bowen (1990, 6899) analyzed existing weather records for the Los Alamos National Laboratory and found that the annual average precipitation near TA-54 was 35.6 cm, which is approximately 10.1 cm lower than the Los Alamos weather station mean which is 45.29 cm. By using the higher Los Alamos mean annual precipitation, these analyses are biased towards a wetter condition enhancing runoff and groundwater response over current conditions at MDA H.

The parameters used for simulating precipitation are presented in Table G-1.1-1. The Fourier coefficients for maximum temperature (°F) on a dry day are TXMD = 62.3, ATX = 20.7, CVTX = 0.129, and ACVTX = -0.073. The maximum temperature on a wet day is TXMW = 54.63. Minimum temperature parameters are

TN = 35.97, ATN = 18.08, CVTN = 0.216, and ACVTN = -0.167. Minimum temperatures were found to be unaffected by wet or dry conditions. The solar radiation parameters for a dry day are RMD = 561.4, and AR = 242.8, and for a wet day the solar radiation parameter is RMW = 560.8. The mean wind speed is 9.3 mph and the standard deviation is 5.4 mph. The wind speed for the 9th of each month is given in Table G-1.1-2. The parameters used for wind were crude estimates because the generated wind values were not used in the analysis of MDA H.

Table G-1.1-1
Precipitation Parameters Used in WGEN to Generate Weather for All Scenarios for MDA H

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
P(W|W)	0.429	0.395	0.470	0.446	0.529	0.489	0.601	0.613	0.522	0.508	0.450	0.414
P(W|D)	0.121	0.164	0.162	0.131	0.151	0.159	0.344	0.369	0.192	0.120	0.114	0.128
Alpha (in.)	0.759	0.844	0.854	0.727	0.808	0.739	0.755	0.794	0.724	0.750	0.808	0.780
Beta (dimensionless)	0.212	0.148	0.185	0.227	0.214	0.259	0.290	0.318	0.292	0.345	0.245	0.223

Table G-1.1-2
Wind Speed Values for the 9th of Each Month
Used in WGEN to Generate Weather for All Scenarios for MDA H

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind speed (mph)	9	10	11	10	10	9	9	8	9	9	9	9

G-1.2 HELP Model

HELP is a quasi-two-dimensional model of the landfill water balance. HELP considers the following processes and storages: runoff, surface storage, snowmelt, infiltration, evapotranspiration, soil moisture storage, lateral subsurface drainage, unsaturated vertical drainage, and leakage through soil, geomembrane or composite liners (Schroeder et al. 1994, 70239). In the unsaturated zone, HELP assumes flow to be one-dimensional and the quasi-two-dimensional flow comes from diversions by barrier layers in lateral drainage layers. The input parameters to HELP are static I.e. they do not change with time during the simulation. This means that conditions such as changing vegetation or soil hydraulic properties are not considered in these simulations. Version 3 of HELP was used in this analysis.

For the analyses of MDA H all layers were assumed to be vertical percolation layers. The concrete shaft caps can be considered as barrier layers, but in the HELP code, barrier layers are saturated, which is not the case at MDA H.

There are three different surface configurations that have been assessed in this study. The background case used 0.08-m clay loam topsoil over a 1.75-m crushed tuff layer. The purpose of this simulation is to determine runoff and percolation characteristics for the site without any other influences. The current configuration of MDA H consists of concrete caps to prevent intrusion into the shafts. The concrete cap scenario uses a 0.9-m layer of crushed tuff over a 0.9-m concrete cap. Finally, an ET cover that uses loam topsoil with a thickness of 0.15 m over a crushed tuff layer of 1.0 m. This case is similar to the background case except for the topsoil thickness and soil type. The ET cover topsoil parameters are based on generalized design criteria for MDA H. The ET cover layer may be enhanced with a biobarrier to reduce intrusion by vegetation or animals, but that has not been included in this assessment.

Parameters required by HELP for these surface configurations were taken from existing values used in previous assessments or from HELP default values for the site. Table G-1.2-1 presents the properties for the soils and concrete used in the simulation.

Table G-1.2-1
Soil Properties used in HELP Model for MDA H

Property	Loam Soil	Clay Loam Soil	Crushed Tuff	Concrete
Porosity (cm^3/cm^3)	0.463	0.493	0.479	0.001
Field Capacity (cm^3/cm^3)	0.232	0.273	0.198	0.0002
Wilting Point (cm^3/cm^3)	0.116	0.099	0.012	0.0001
Saturated Hydraulic Conductivity (cm/s)	0.370E-03	0.250E-03	0.353E-03	0.100E-09

The properties for crushed tuff were taken from Springer (1996, 63131). Literature values for concrete are limited. Meyer and Serne (1999, 71346) provided a saturated hydraulic conductivity value of 1.33×10^{-9} cm/s for concrete, but the concrete parameters were obtained from a sample that was mixed in the 1940s. Granite represents another material that behaves like concrete with low permeability and storage. The values from Meyer and Serne were near those of granite providing a basis for using these values. There is relatively no information on field capacity and wilting point for concrete so low values are used to reduce any effect of water storage by the concrete on the calculations. The values for the loam and clay loam topsoil were taken from default values provided by HELP.

The internal routine for setting initial conditions was used for all scenarios. The amount of water in each profile will change between scenarios because of the different thickness of the layers and soil properties (Table G-1.1-1). Tables G-1.2-2 through G-1.2-4 list the initial conditions in terms of soil and snow water (equivalent depth) for the background case, concrete cap, and ET cover scenarios respectively.

Table G-1.2-2
Layer Thickness and Initial Conditions for
HELP Simulations of MDA H for the Background Simulation

Parameter	
Top Soil 2 Thickness (cm)	7.62
Crushed Tuff Thickness (cm)	175.26
Initial Water Content Top Soil 2 (cm^3/cm^3)	0.0643
Initial Water Content Crushed Tuff (cm^3/cm^3)	0.0639
Initial Water in the Evaporative Zone (cm)	1.81
Upper Limit of Evaporative Storage (cm)	43.89
Lower Limit of Evaporative Storage (cm)	1.78
Initial Snow Water (cm)	1.23
Initial Water in Layer Materials (cm)	11.69
Total Initial Water (cm)	12.92
Total Subsurface Flow (cm)	0

Table G-1.2-3
Layer Thickness and Initial Conditions for HELP Simulations of MDA H for the Concrete Shaft Configuration Simulation

Parameter	
Crushed Tuff Thickness (cm)	91.44
Concrete Shaft (cm)	91.44
Initial Water Content Crushed Tuff (cm^3/cm^3)	0.0133
Initial Water Content Concrete (cm^3/cm^3)	0.0009
Initial Water in the Evaporative Zone (cm)	1.21
Upper Limit of Evaporative Storage (cm)	43.8
Lower Limit of Evaporative Storage (cm)	1.12
Initial Snow Water (cm)	1.23
Initial Water in Layer Materials (cm)	1.3
Total Initial Water (cm)	2.52
Total Subsurface Flow (cm)	0

Table G-1.2-4
Layer Thickness and Initial Conditions for HELP Simulations of MDA H for the Evapotranspiration (ET) Cover Simulation

Parameter	
Top Soil 1 Thickness (cm)	15.24
Crushed Tuff (cm)	101.6
Initial Water Content Top Soil 1 (cm^3/cm^3)	0.1612
Initial Water Content Crushed Tuff (cm^3/cm^3)	0.0366
Initial Water in the Evaporative Zone (cm)	3.37
Upper Limit of Evaporative Storage (cm)	43.56
Lower Limit of Evaporative Storage (cm)	2.68
Initial Snow Water (cm)	0.33
Initial Water in Layer Materials (cm)	6.17
Total Initial Water (cm)	6.50
Total Subsurface Flow (cm)	0

Hydrologic parameters are needed to generate runoff and fix evaporative zone depth. Table G-1.2-5 lists the values used for curve number and evaporative zone depth for all three scenarios. The curve number value was the same as that used by Springer (Springer 1996, 63131) for the MDA G performance assessment (Hollis et al. 1997, 63131). The evaporative zone depth is a sensitive parameter as was shown by Springer (Springer 1996, 63131) for MDA G using a model similar to HELP. The area is a unit area for the case of this simulation.

The final set of parameters presented in Table G-1.2-6 is used to control evapotranspiration in the HELP model. The values in Table G-1.2-6 represent the best estimates for these parameters at this time. The maximum leaf area index value was taken from Lane (1984, 70238).

Table G-1.2-5
Hydrologic parameters for HELP simulations of MDA H

Parameter	
SCS Curve Number	85
Fraction of Area Allowing Runoff	1.0
Area projected on Horizontal Plane (ha)	0.40
Evaporative Zone Depth (cm)	91.44

Table G-1.2-6
Evapotranspiration and Weather Parameters for HELP Simulations of MDA H

Parameter	
Station Latitude (degrees)	36.0
Maximum Leaf Area Index (m^2/m^2)	1.0
Start of Growing Season (Julian Date)	120
End of Growing Season (Julian Date)	280
Average Annual Wind Speed (mph)	10.0
Average First Quarter Relative Humidity (percent)	15
Average Second Quarter Relative Humidity (percent)	25
Average Third Quarter Relative Humidity (percent)	15
Average Fourth Quarter Relative Humidity (percent)	25

For the prescriptive cover, the parameter values described in the NMED HELP guidance document (NMED, 1998, 71229) were used. The guidance document suggests using local weather data from the wettest five-consecutive-year period. The same Los Alamos weather station data were used as used in WGEN and it was found that the 1984–1988 period was the wettest five-consecutive-year period in the approximately 50-year data set. For the topsoil layer, the loam values shown in Table G-1.2-1 were used. For the 18-in. thick infiltration layer, a saturated hydraulic conductivity of 1×10^{-5} cm/s was used as prescribed in the guidance document. A version of the prescriptive cover was also run using an infiltration layer hydraulic conductivity of 3.53×10^{-4} cm/s that is consistent with the conductivity used in the MDA H Monte Carlo runs.

G-1.3 Results

The Monte Carlo approach allows statistics and distributions of selected response variables to be analyzed. The response variables selected were precipitation, which was generated by WGEN, runoff and leakage, which were generated by HELP. Runoff is indicative of the surface pathway and erosion of the surface cover with higher runoff generally meaning higher erosion, all other conditions held the same. Leakage out of the surface cover is related to the groundwater pathway. Leakage represents water that has passed through the cover and potentially could flow into the waste. The following analyses use annual values of these response variables for each scenario. The Monte Carlo simulations generated a total of 1,000,000 annual values for each of the three scenarios, background concrete shaft, and ET cover that were described in the previous section. The same random number seeds were used for WGEN for all cases so the weather inputs were the same for each scenario.

Infiltration was calculated by subtracting total annual precipitation from total annual runoff. Infiltration is defined as the amount of water that enters (infiltrates) the cover, as opposed to leakage which is water that leaves through the bottom of the cover.

The statistics for the key variables for the background case are presented in Table G-1.3-1. Figure G-1.3-1 shows the precipitation distribution, which appears to be symmetric and this is confirmed by the near zero value for the skew in Table G-1.3-1. For mean runoff, the standard deviation of 0.46 is greater than the mean value of 0.36. The distribution of runoff is presented in Figure G-1.3-2. This distribution is characteristic of semiarid environments where runoff is infrequent. The leakage distribution for the background case is presented in Figure G-1.3-3. The number of runoff and leakage estimates that are equal to zero are given on each figure for this and the succeeding scenarios. The magnitude of the mean leakage is greater than mean runoff, reflecting the winter and spring periods when evapotranspiration is low. From Figure G.1-3-3 and Table G-1.3-1, the distribution for annual leakage is skewed like runoff.

Table G-1.3-1
Statistics for Annual Precipitation, Runoff, Leakage and Infiltration for Background Case from HELP Using WGEN to Generate 1000 Simulations of 1000 Years in Length

Variable	Mean	Std Dev	Max	Min	Skew	Kurtosis
Precipitation (cm)	47.60	8.02	94.49	17.27	0.25	0.10
Runoff (cm)	0.36	0.46	7.73	0.0	2.69	11.24
Leakage (cm)	0.89	0.64	11.99	0.0	4.47	30.12
Infiltration (cm)	47.23	7.88	92.56	17.27	0.61	0.20

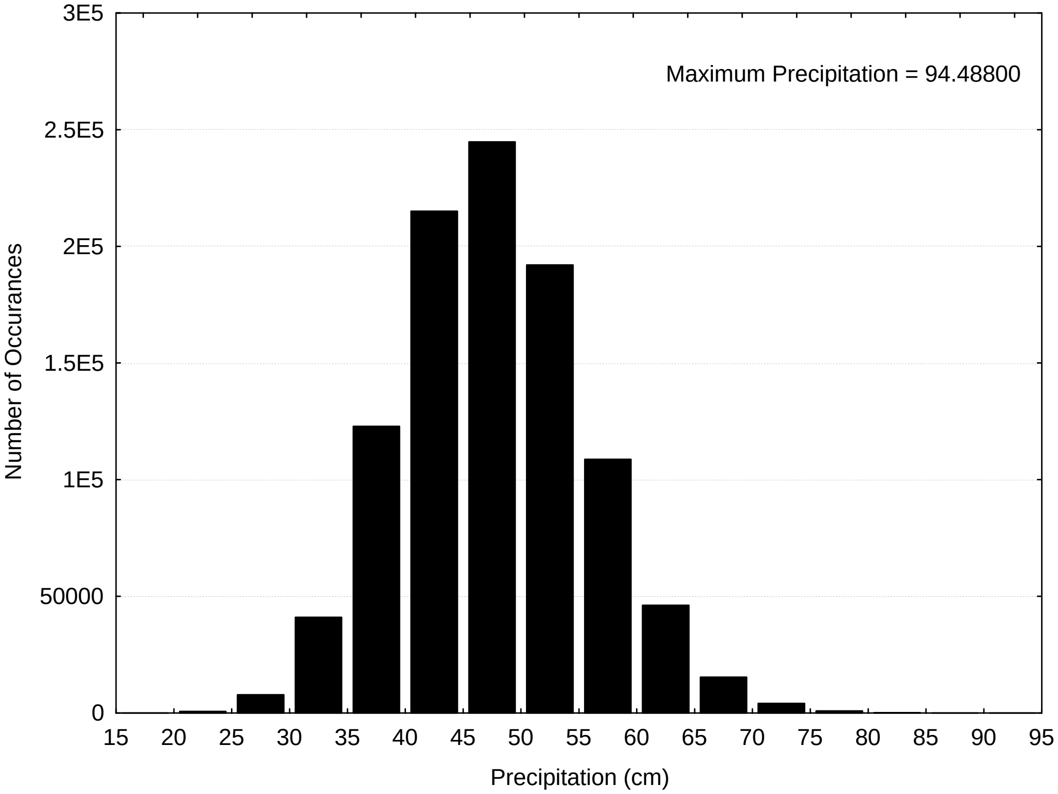
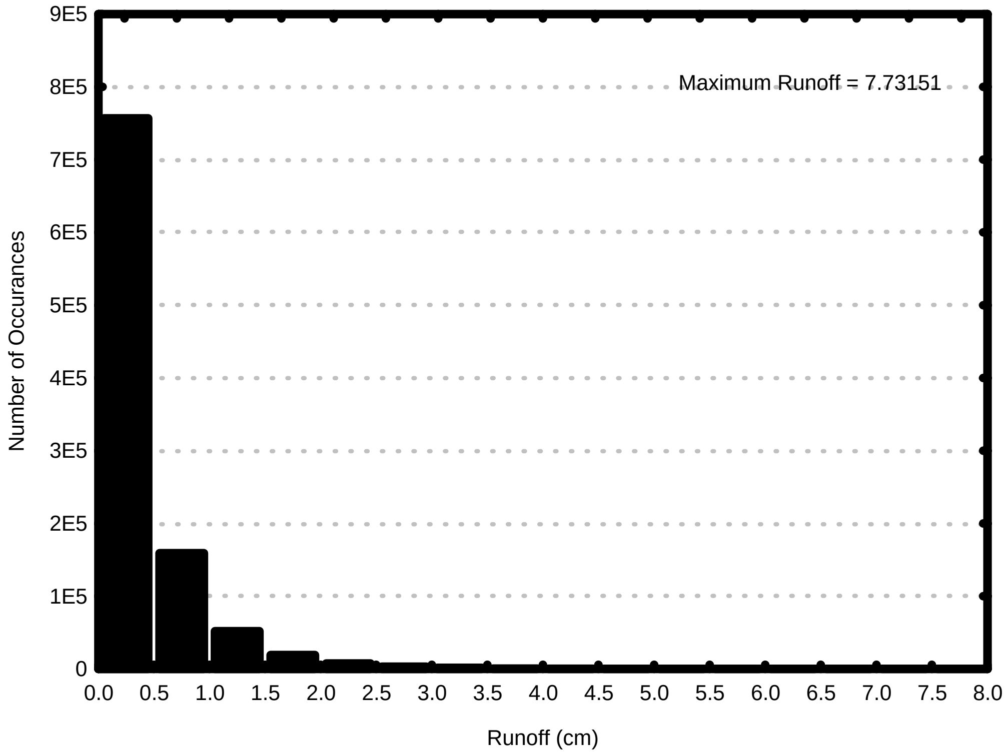
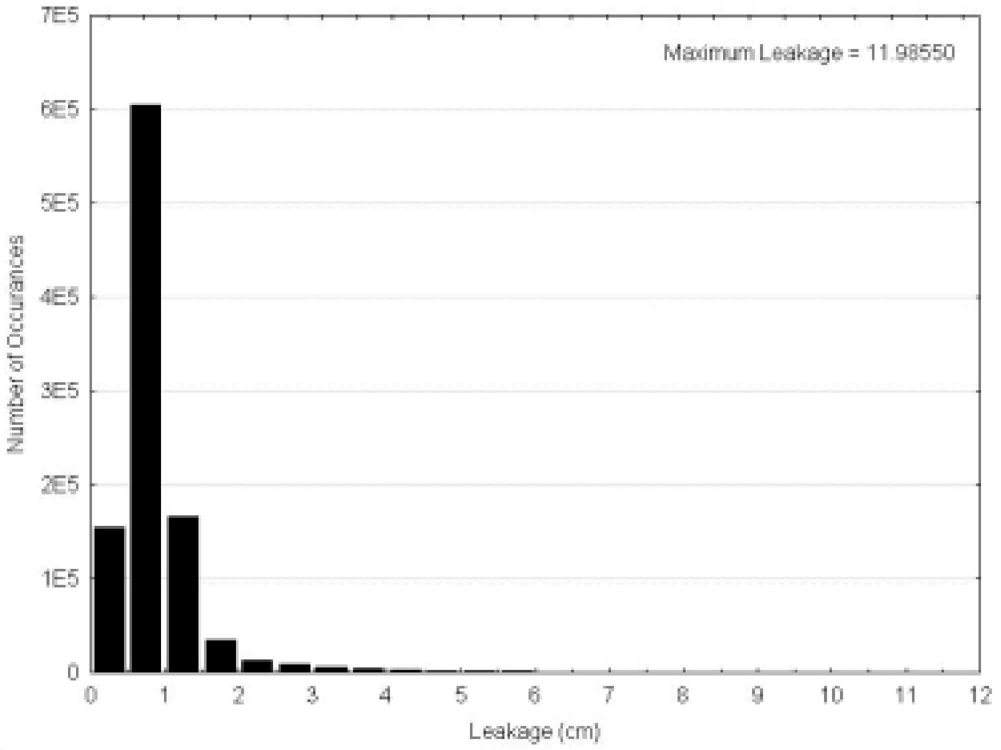


Figure G-1.3-1. Histogram for annual precipitation based on 1000 Monte Carlo simulations of 1000 years for MDA H from WGEN



Note: The number of observations equal to zero is 56908.

Figure G-1.3-2. **Histogram for annual runoff for MDA H from background case using 1000 Monte Carlo simulations of 1000 years each**



Note: The number of observations equal to zero is 6.

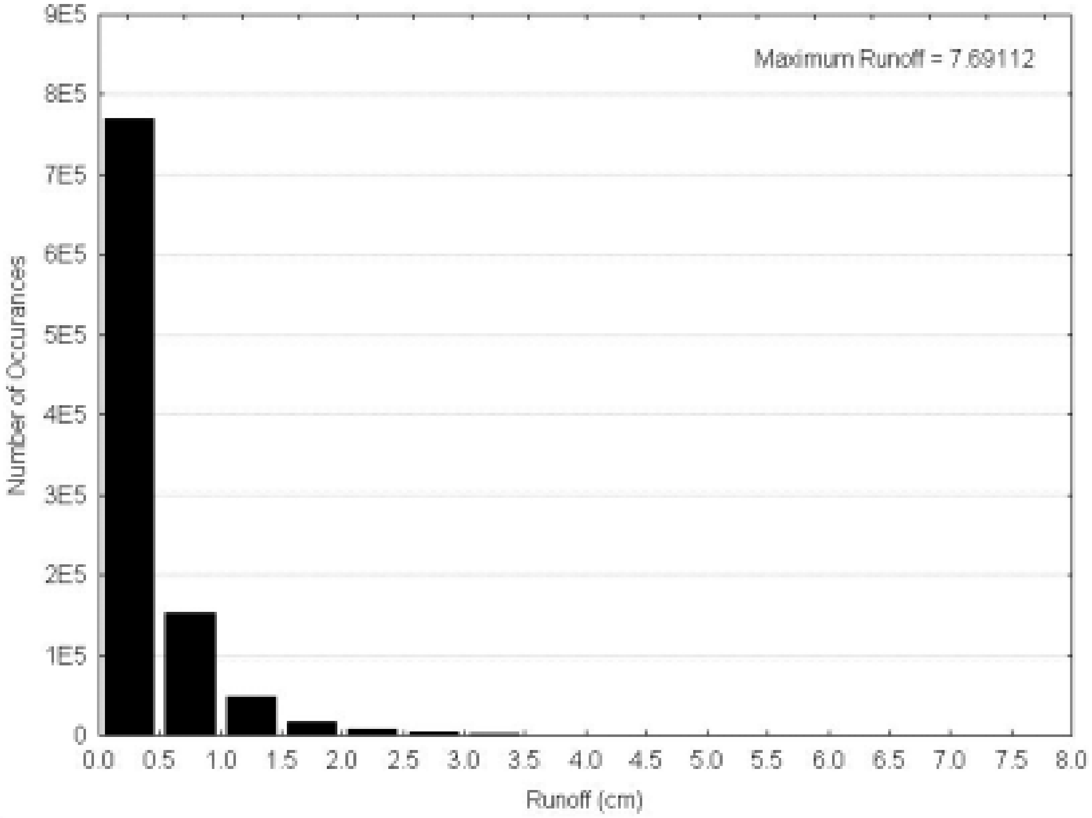
Figure G-1.3-3. **Histogram for annual leakage for MDA H from background case using 1000 Monte Carlo simulations of 1000 years each**

The combination of the statistics in Table G-1.3-1 and the histograms in Figures G-1.3-2 and G-1.3-3 provide numerical and illustrative information for assessing MDA H for the background scenario.

Results for the concrete cap scenario are presented in Table G-1.3-2 and histograms for runoff and leakage are given in Figures G-1.3-4 and G-1.3-5. In comparing to the background case (Tables G-1.3-1 and G-1.3-2), it can be seen that the runoff has essentially the same statistics. Annual leakage for the concrete cap scenario is approximately a factor of 3 less than the background case value. This is due to the lower hydraulic conductivity of the concrete (10^{-9} cm/sec), which reduces water movement from the tuff layer. The water in the tuff will have a greater opportunity to be removed by evapotranspiration.

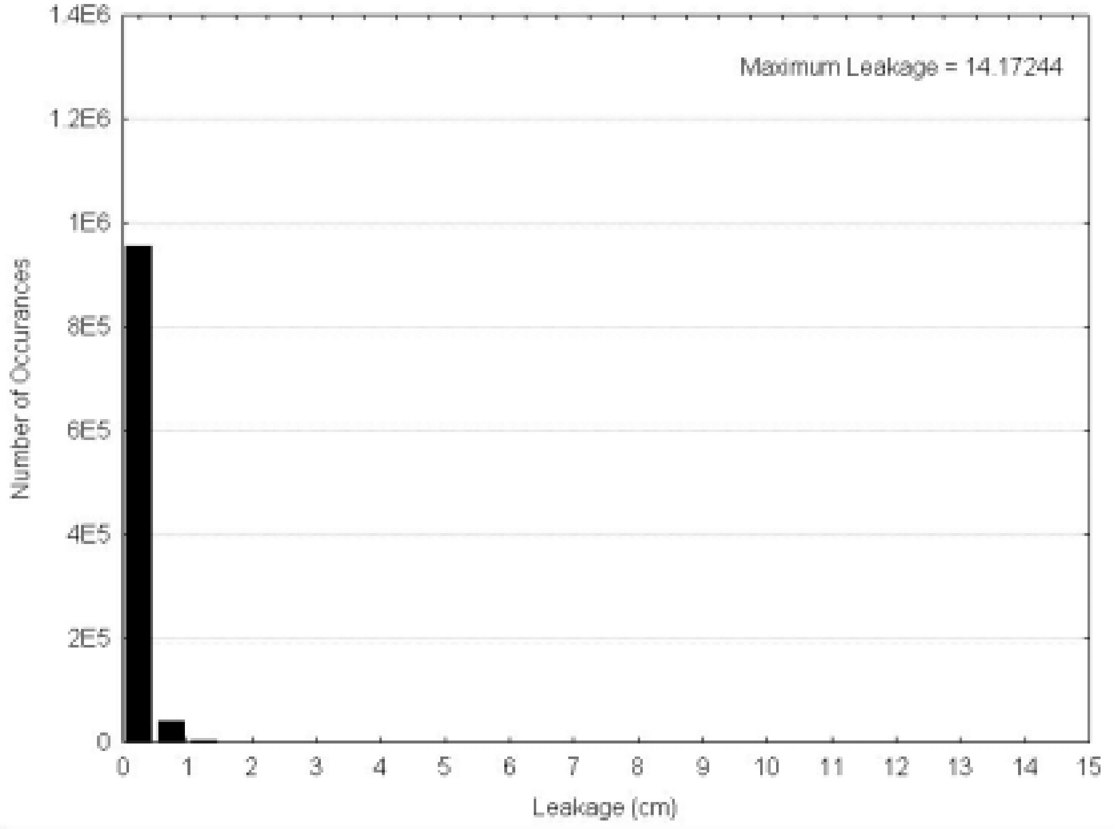
Table G-1.3-2
Statistics for Annual Precipitation, Runoff, and Leakage for Concrete Shaft Design from HELP Using WGEN to Generate 1000 Simulations of 1000 Years in Length

Variable	Mean	Std Dev	Max	Min	Skew	Kurtosis
Precipitation (cm)	47.60	8.02	94.49	17.27	0.25	0.10
Runoff (cm)	0.34	0.45	7.69	0.0	2.74	11.69
Leakage (cm)	0.27	0.17	14.17	0.0	10.22	307.66
Infiltration (cm)	47.25	7.89	92.77	17.27	0.61	0.21



Note: The number of observations equal to zero is 65985.

Figure G-1.3-4. **Histogram for annual runoff for MDA H from concrete cap using 1000 Monte Carlo simulations of 1000 years each**



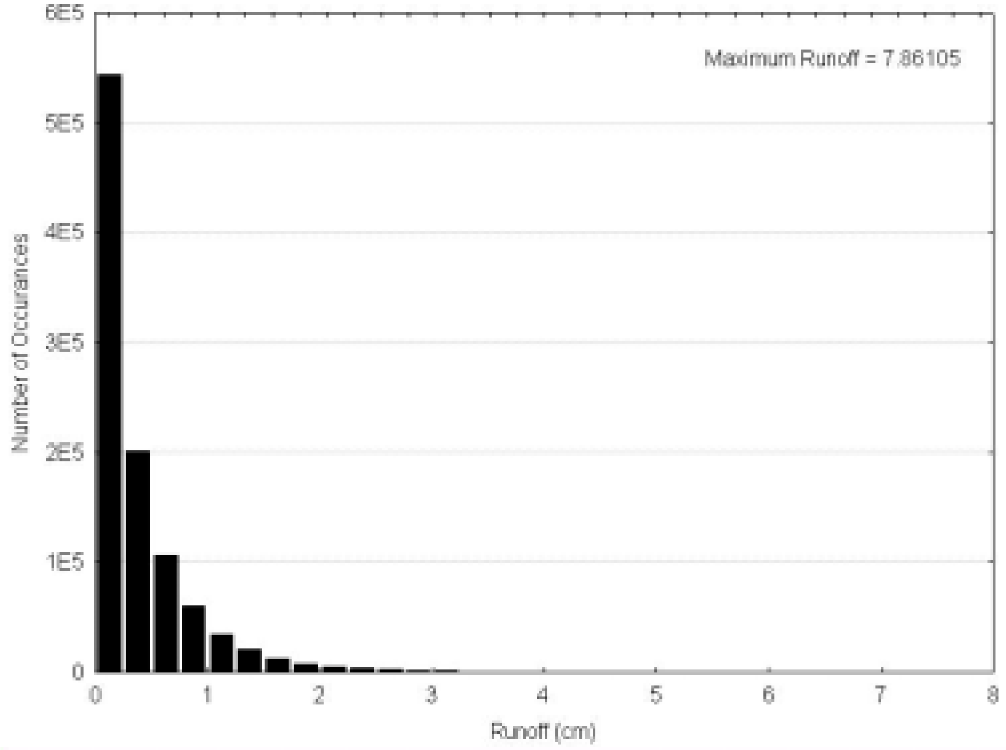
Note: The number of observations equal to zero is 4313.

Figure G-1.3-5. Histogram for annual leakage for MDA H from concrete cap using 1000 Monte Carlo simulations of 1000 years each

For the ET cover design, the statistics for runoff and leakage (Table G-1.3-3) are similar to those for the background case (Table G-1.3-1). This is not surprising because these are essentially the same design with differences in the type of topsoil (loam versus clay loam) and the thickness of the topsoil layers (Table G-1.2-1). Examining the soil properties in Table G-1.2-1, the loam soil has slightly less storage and higher saturated conductivity than the clay loam, and the primary difference can be seen in the maximum value of leakage between the background and ET cover scenarios. The runoff and leakage histograms are presented in Figures G-1.3-6 and G-1.3-7, respectively. The analysis is basically the same as that for the background case so no further discussion is needed.

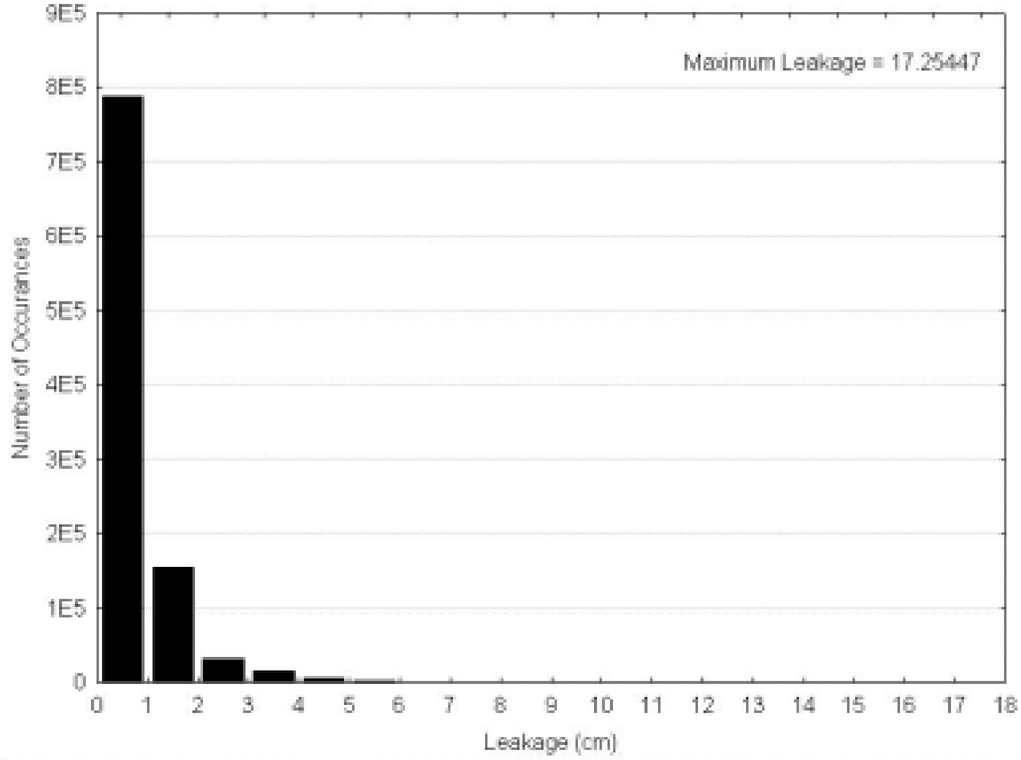
Table G-1.3-3
Statistics for Annual Precipitation, Runoff, and Leakage for ET Cover Design Background Case from HELP Using WGEN to Generate 1000 Simulations of 1000 Years in Length

Variable	Mean	Std Dev	Max	Min	Skew	Kurtosis
Precipitation (cm)	47.60	8.02	94.49	17.27	0.25	0.10
Runoff (cm)	0.38	0.47	7.86	0	2.65	10.93
Leakage (cm)	0.85	0.71	17.25	0	4.14	28.47
Infiltration (cm)	47.22	7.87	92.38	17.27	0.605	0.20



Note: The number of observations equal to zero is 65985.

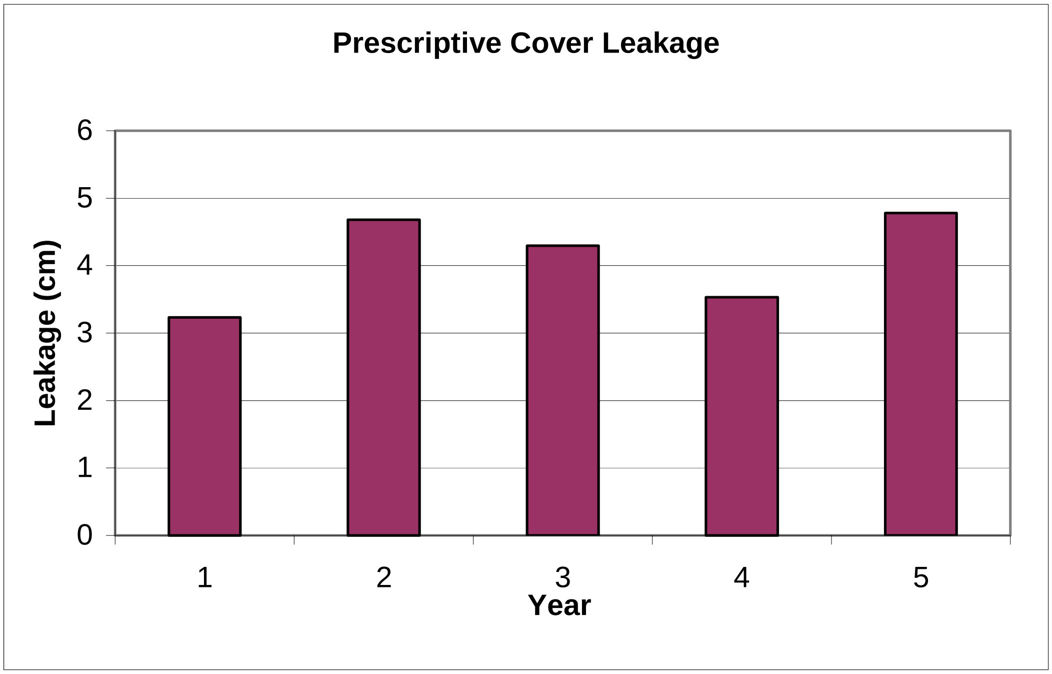
Figure G-1.3-6. Histogram for annual runoff for MDA H from ET cover scenario using 1000 Monte Carlo simulations of 1000 years each



Note: The number of observations equal to zero is 11.

Figure G-1.3-7. Histogram for annual leakage for MDA H from ET cover scenario using 1000 Monte Carlo simulations of 1000 years each

Leakage results for the prescriptive cover HELP run are shown in Figure G-1.3-8 and show relatively large amounts of leakage consistent with the wet precipitation regime that was imposed. Comparison of the prescriptive cover results (prescriptive case 2) to the MDA H scenarios (background, concrete cover, and ET cover) indicates that all of the MDA H scenarios should perform better than the prescriptive cover. A detailed comparison of the background and prescriptive results is shown in Table G-1.3-4 for similar precipitation inputs. The prescriptive 2 case shown in the table uses the NMED guidance of 1 x 10^{-5} cm/s, 18-in. thick infiltration layer while the prescriptive 3 case uses the same parameters, except has an infiltration layer with a hydraulic conductivity of 3.53 x 10^{-4} cm/s. The prescriptive 3 case was conducted to examine performance of the "prescriptive" cover using the same infiltration layer hydraulic conductivity as was used in the MDA H Monte Carlo simulations (i.e., background, concrete, and ET cases). For both the prescriptive-2 and prescriptive-3 cases, there is more leakage than in the background case. The concrete and ET cover results show even less leakage than the background cover in the Monte Carlo simulations, so even though they are not included in the detailed comparison, their performance should also be better than the prescriptive cover. Thus, any of the cover scenarios modeled for MDA H should be acceptable alternatives based on the NMED HELP guidance (NMED, 1998, 71299).



Note: Other HELP parameters were as specified in the NMED HELP Guidance Document (NMED 1990, 71299)

Figure G-1.3-8. Predicted leakage from the prescriptive cover using 1984–1988 precipitation inputs

Table G-1.3-4
Comparison of HELP Results from the Prescriptive Cover and the MDA H Background Scenario Using Similar Precipitation Inputs

	Precipitation Mean (cm)	Precipitation Min (cm)	Precipitation Max (cm)	Leakage Mean (cm)
Background Case	58.65	55.0	65.0	0.93
Prescriptive Case2[a,b]	59.38	49.3	64.8	4.1
Prescriptive Case3[c]	59.38	49.3	64.8	1.4

Note: P is mean, minimum, and maximum precipitation, and L is the mean leakage.

[a] The prescriptive case 2 simulation used a lower conductivity infiltration layer than prescriptive case 3.

[b] Prescriptive case 2 follows NMED guidance of a 1 x 10^{-5} cm/s saturated hydraulic conductivity infiltration layer.

[c] Prescriptive case 3 uses a saturated hydraulic conductivity of 3.54 x 10^{-4} cm/s consistent with the MDA H Monte Carlo simulations.

G-1.4 Conclusions

Simulation of the hydrologic response of the surface conditions used a Monte Carlo approach with two models, WGEN for the weather variables and HELP for the surface cover response. Runoff and leakage from three scenarios, background concrete shaft, and ET cover, were the two response variables that were described for the MDA H assessment. Runoff is related to the surface pathway and erosion of the surface cover, and leakage is an input term for the groundwater pathway. The parameters for the WGEN were obtained from the Los Alamos weather station, which has a higher annual precipitation than MDA H.

The surface cover for the background case consisted of 0.08 m of topsoil over a 1.75-m thick layer of crushed tuff. The concrete cap design was 0.9-m crushed tuff over a 0.9-m concrete barrier. The ET cover design had 15 cm of topsoil over a 1-m thick layer of crushed tuff. For each of these scenarios, 1000 simulation of 1000 years in duration were performed.

The statistics and histograms for runoff and leakage for each case were presented. Runoff was consistent in terms of the mean, standard deviation and distribution between the three scenarios. Leakage demonstrated more differences between the cases due to the lower saturated hydraulic conductivity and water storage properties assigned to the concrete in the shaft. There were minor differences between scenarios, but for the most part the response was similar. The results presented in this analysis bound behavior at MDA H for further analyses including groundwater flow and soil erosion.

Finally, a prescriptive cover comparison was done based on the NMED HELP modeling guidance document (NMED, 1998, 71299). Results show that all of the MDA H cover scenarios perform better than the prescriptive cover and therefore are acceptable for installation at MDA H.

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Appendix H

Environmental Transport and Health Effects Models

APPENDIX H ENVIRONMENTAL TRANSPORT AND HEALTH EFFECTS MODELS

H-1.0 INTRODUCTION

This appendix provides supporting information for the GoldSim computer model used to simulate biotic transport, gas-phase diffusion of radon, soil erosion, and aqueous-phase subsurface migration for chemicals and radionuclides present in the disposed waste. These processes result in surface soil contamination and radon flux; the potential health impacts associated with surface soil contamination are also calculated in GoldSim. The technical approach to, and results of, these modeling activities are discussed in Section 3 of the CMS Report.

The GoldSim model developed to evaluate the various transport processes described above, and associated human exposure and health effects, may be described as a “system-level” model. In such a model, the various processes are represented in a generally simplified manner but all processes are integrated in a coherent manner. By contrast, the models described in Appendices G, I, and J may be described as “process-level” models where an individual transport process is represented by relatively sophisticated mathematical relationships to enhance confidence in the model results. The outputs of the process-level models are used for various purposes in the system-level GoldSim model: the output of the vapor-transport model is used to calibrate the simpler gaseous-diffusion radon model, the output of the surface cover model defines the infiltration rates, and the output of the vadose-zone, aqueous-phase transport model is used to verify the GoldSim solution. In this way, the size and complexity of the system-level GoldSim model are controlled.

This appendix is organized into two major parts. Section H-2.0 is devoted to information pertaining to environmental transport modeling. Subsection H-2.1 addresses the source term submodel. Subsection H-2.2 provides detailed information on the biotically-mediated transport pathways, including the plant transport and animal transport submodels. Subsection H-2.3 covers the submodels that pertain to abiotic transport pathways, including submodels for radon diffusion, water infiltration and vadose-zone transport, and soil erosion. The primary outputs of the coupled environmental transport models are contaminant concentrations in surface soil over time. Section H-3.0 contains information relating to human exposure to contaminated surface soils and associated health effects. Subsections of H-3.0 describe the equations for calculating health effects and the input parameter values to these equations.

H-2.0 ENVIRONMENTAL TRANSPORT MODELS

The environmental transport submodels described in this section of this appendix are integrated in a single system-level model within the GoldSim modeling environment (Kossik and Miller 2002, 71467). GoldSim is a dynamic simulation environment that represents a system with a group of mathematical relationships. In this case, the system is a simplified representation of the waste disposal shafts and surrounding environmental media at MDA H. The dynamic aspect of the simulation involves changes to this system over time due to naturally occurring physical processes described by the site conceptual model depicted in Figure 3.3-1. The simulation period used was 1000 yr. GoldSim Version 7.21 was used for the calculations.

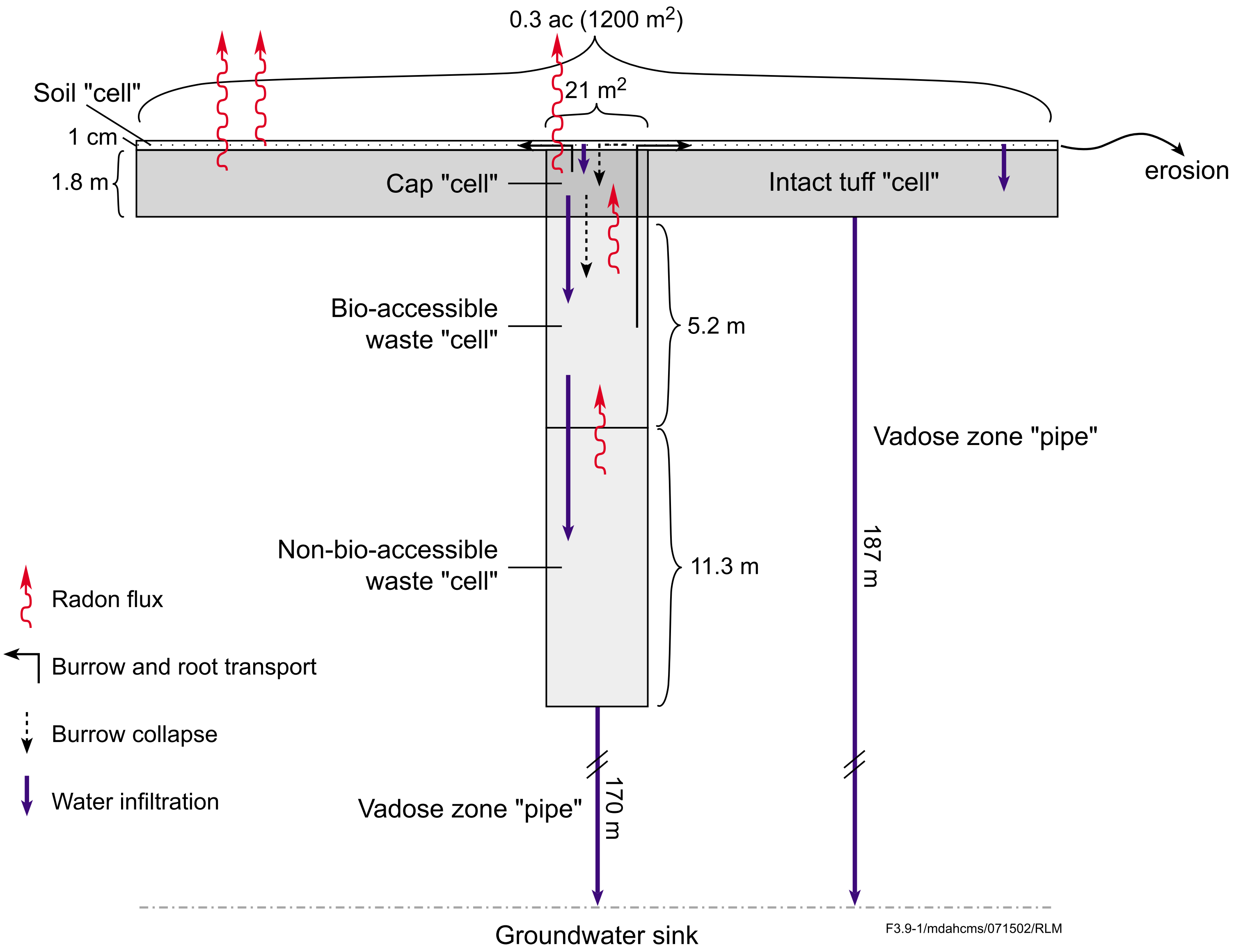
A visual portrayal of the components of the transport model and connections among these components is provided in Figure H-2.0-1. In a systematic process, contamination is brought from the upper waste cell to the surface soil cell by plant roots and burrowing animals. Contaminants may be returned to the waste cells by infiltration and burrow collapse. Radon gas may migrate upwards from waste by diffusion in air. Contamination in the soil, tuff, cap, and waste are all potentially susceptible to mobilization with infiltrating surface water. Contaminants that "break through" the tuff cell or lower waste cell are further evaluated for potential transport to the regional aquifer (represented in Figure H-2.0-1 as the groundwater sink). There are three "sinks" in the GoldSim model of MDA H where contaminants may leave the modeling environment. These are the groundwater sink, the erosion sink, and an atmospheric sink for radon gas.

The MDA H GoldSim model incorporates three solid media (waste, crushed tuff, and solid tuff) and two fluid media (water and air). In GoldSim parlance, these media are distributed among the "cell pathways": the two waste cells, the cap cell, the solid tuff cell, and the soil cell. The waste cells (i.e., disposal shafts) consist of waste, water and air. The cap cell and soil cell are modeled as consisting of crushed tuff, water, and air, and the solid tuff cell consists of solid tuff, water, and air. Chemicals are transported among the environmental media and cells over time as a function of the mathematical equations and parameters that constitute the "model". The majority of connections between these cells and media are advective connections, which means that contaminants are transported as a function of the movement of environmental media in which they are dissolved (liquids) or adsorbed (solids). The exceptions to this rule are contaminant transport via plants and gas-phase diffusion of radon. Details of the implementation of these transport pathways within the GoldSim system model are presented in the following sections of this Appendix.

H-2.1 Source Term Submodel

The waste inventory in the disposal shafts at MDA H was discussed in Section 2.1.2 of this document and described in detail in Appendix B. Contaminants associated with the buried waste items were generally assumed to be completely available for release from the disposal shafts at the beginning of the model simulation. The two exceptions to this rule include uranium in fuel elements and silver in photographic film. In these cases the chemicals were recognized to be effectively immobile and were therefore not included in the GoldSim waste inventory. The assumption of immediate availability of 100% of a chemical inventory is expected to result in an overestimate of the available inventory, especially at earlier times in the 1000-yr simulation. Many waste items, particularly solid materials such as shapes made of depleted uranium or other metals and alloys, would actually release contaminants in a transportable form only very slowly. Therefore, the effect of evaluating contaminant availability with time (i.e., corrosion) was investigated in GoldSim for the uranium (excepting fuel elements) in the inventory.

Several assumptions were necessary to evaluate the potential influence of corrosion on uranium soil concentrations over time. Uranium was assumed to exist in the waste predominantly as a layer upon another material, such as stainless steel. The material was assumed to have the configuration of a rectangular prism. To simplify the geometry, the area of uranium exposed on the sides of the layer was ignored. The ratio of area to volume for the uranium layer was then calculated as (height x width) / (height x width x thickness), which reduces to a "shape factor" of 1/thickness. A thickness of approximately 16 mm for the uranium layer was assumed based on best professional judgment. The uranium corrosion rate was assumed to vary from 1-10 µm/yr (see Appendix M); the mean value of 5.5 µm/yr was used in the GoldSim model. The uranium corrosion rate was then expressed in GoldSim as the fractional quantity of the uranium mass available per unit of time. This was calculated as the product of the shape factor (1/µm) and the corrosion rate (µm/yr), or 3.4×10^{-4}/yr.



F3.9-1/mdahcms/071502/RLM

Figure H-2.0-1. Schematic of the GoldSim system-level model

Three potential mechanisms for movement of contaminants away from the disposal shafts at MDA H were modeled, as described in Section 3.3.1.1. These include dissolution of contaminants into liquid water moving through the shafts, diffusion of gas-phase contaminants into pore air in the overlying cap and surrounding tuff, and biotic translocation of waste chemicals via uptake by plant roots or excavation of waste by burrowing animals. Complex release models relating to diffusion and dissolution are described in Appendices I and J, respectively. Biotic transport models are described in detail in Section H-2.2 of this appendix. Simplified representations of diffusion and dissolution processes employed in the GoldSim model are discussed in Section H-2.3.

The actual inventory of waste chemicals was overestimated to provide a protective bias for the estimation of potential human health effects. As described in Section H-2.2, plant roots and burrowing animals are only able to penetrate as deep as the upper 30% of the disposal shafts. For this reason, the available waste inventory for release via biotic processes is less than the total inventory. This region of the disposal shafts available to biota (the upper 17 ft of the waste in all 9 shafts) was modeled as a single “cell” in GoldSim and the remaining portion of the 9 shafts was modeled as a second “cell.” The inventory of chemicals was fully mixed within each separate cell with each model timestep. Modeling the upper 17 ft of the shafts as a single well-mixed cell resulted in plant roots and burrowing animals being able to contact higher concentrations of chemicals over time than they would otherwise be able to because the density of animal burrows and plant roots decreases with depth.

The inventory of specific chemicals and radionuclides evaluated in the GoldSim simulations is provided in Table H-2.0-1. As described in Section 3.3.1.3, calculations were performed using both upper-bound and best-estimate inventory values for uranium isotopes. Both values are provided in Table H-2.0-1. The waste inventory was represented as a single shaft with an area and volume equal to the sum of the disposal shafts. Because only a small fraction of waste materials were disposed within the biotically accessible portion of Shaft 9, the area and volume of shafts 1–8 was used for modeling biotic processes in GoldSim.

Table H-2.0-1
Inventory of Chemicals and Radionuclides (lb)

Species	Shaft 1	Shaft 2	Shaft 3	Shaft 4	Shaft 5	Shaft 6	Shaft 7	Shaft 8	Shaft 9	Total
Upper Waste Cell										
Ag	1.8	1.8	1.2	1.1	1.7	1.1	1.2	1.2	0.1	11
Al	2700	2800	1900	1700	2600	1700	1800	1800	170	17000
Ba	200	250	19	0	0	0	200	980	0	1600
Be	300	310	210	190	290	190	200	200	20	1900
Cd	0.89	0.92	0.62	0.56	0.86	0.57	0.61	0.61	0.056	5.7
Cr	89	92	62	56	86	57	61	61	5.6	570
Cu	110	110	74	67	100	68	73	73	6.7	680
Cyanuric Acid	0	640	0	0	0	0	640	0	0	1300
Fe	7100	7400	4900	4500	6900	4600	4900	4900	450	46000
H3[a]	4.8E-06	0	0	0	0	0	0	0	0	4.8E-06
Hg	59	62	41	37	57	38	41	40	3.7	380
Pb	3500	3700	2500	2200	3400	2300	2400	2400	220	23000
Pu-238	0	0	0	0	0	0	0	0	0	0

Table H-2.0-1 (continued)

Species	Shaft 1	Shaft 2	Shaft 3	Shaft 4	Shaft 5	Shaft 6	Shaft 7	Shaft 8	Shaft 9	Total
Upper Waste Cell (continued)										
Pu-239	0	0	0	0	0	0	0	0	0	0
Pu-240	0	0	0	0	0	0	0	0	0	0
Pu-241	0	0	0	0	0	0	0	0	0	0
Pu-242	0	0	0	0	0	0	0	0	0	0
RDX	0	0	10	0	50	40	40	0	0	140
U-234[b]	0.8/0.3	0.5/0.2	0.3/0.1	0.2/0.1	0.4/0.2	1.5/0.2	6.8/0.6	0.4/0.2	0.0	11/1.8
U-235[b]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	1100/180
U-236[b]	3.6/1.4	2.6/1.0	1.5/0.6	0.8/0.3	1.8/0.7	2.1/0.5	6.4/1.0	1.8/0.7	0.0	21/6.3
U-238[b]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	83000/31000
Lower Waste Cell										
Ag	5.7	2.9	2.7	2.4	3.7	2.5	2.7	2.6	2.4	28
Al	8600	4400	4000	3700	5600	3700	4000	4000	3700	42000
Ba	660	390	41	0	0	0.0	440	2100	0	3700
Be	950	490	450	410	620	410	440	440	410	4600
Cd	2.9	1.5	1.3	1.2	1.9	1.2	1.3	1.3	1.2	14
Cr	290	150	130	120	190	120	130	130	120	1400
Cu	340	180	160	150	220	150	160	160	150	1700
Cyanuric Acid	860	0	60	0	0	0	0	3100	0	4000
Fe	23000	12000	11000	9800	15000	9900	11000	11000	9800	110000
H3[a]	3.4E-05	0	0	0	0	0	0	0	0	3.4E-05
Hg	190	98	90	81	120	82	89	88	81	920
Pb	11000	5900	5400	4900	7500	5000	5300	5300	4900	55000
Pu-238	0	0	0	0	9.0E-10	0	9.9E-09	0	0	1.1E-08
Pu-239	0	0	0	0	8.4E-06	0	9.2E-05	0	0	1.0E-04
Pu-240	0	0	0	0	5.4E-07	0	5.9E-06	0	0	6.5E-06
Pu-241	0	0	0	0	1.8E-08	0	2.0E-07	0	0	2.2E-07
Pu-242	0	0	0	0	1.8E-09	0	2.0E-08	0	0	2.2E-08
RDX	2.0	0	1000	74	4.0	180	2.2	57	0	1300
U-234[b]	3.8/0.7	1.4/0.3	0.45/0.2	1.8/0.3	1.1/0.5	0.2/0.08	1.6/0.4	5.9/0.6	0.7/0.3	17/3.3
U-235[b]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	1700/330
U-236[b]	7.6/2.4	3.8/1.3	2.2/0.9	3.1/0.9	5.4/2.2	0.9/0.4	4.5/1.6	6.8/1.4	3.3/1.3	38/12
U-238[b]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	[c]	160000/62000

Note: Zero indicates no inventory of chemical in cell.

[a] Tritium values in upper and lower cells based on 168 Ci (from FEHM model of 1995 plume at MDA H, Appendix I) in tuff pore air with center-of-mass at 40 ft bgs. Values are arbitrarily assigned to Shaft 1 for convenience.

[b] Values listed are upper-bound/best-estimate values for this analyte.

[c] Total for all shafts.

The upper bound total mass of all contaminants across all shafts in Table H-2.0-1 is approximately 564,000 lb (412,000 using best-estimate values of uranium isotopes and cadmium) whereas the total mass recorded in the disposal records is about 391,000 lb. Therefore, the upper bound estimate of chemical mass exceeds the recorded mass of all waste materials (which includes paper, wood, graphite and other such items) by about 30%. This is practical evidence of the degree of conservatism employed in estimating chemical-specific inventories. Radioactive decay of the radioactive contaminants (tritium, and the uranium and plutonium isotopes) between the time of emplacement and the present day was not accounted for in the inventory estimate. Considering the use of intentional bias in the inventory estimates, and the large degree of uncertainty in the actual quantities emplaced, such refinement was considered unnecessary.

The density of the waste material used in the GoldSim model was calculated as the total mass of all contaminants (564,000 lb/412,000 lb) divided by the volume of the shafts occupied by waste (13,175 ft^3), which is approximately 43 lb/ft^3 for the upper bound estimate and 31 lb/ft^3 using the best-estimate value of uranium inventory. This waste material was represented as a homogenous medium as required by the definition of a solid material in GoldSim. Other attributes of the waste material required for the GoldSim transport model include porosity (0.479) and water content (7.5% by volume); these values were set equal to those of crushed tuff (described in Section H-3.0). In reality, the percentage of void space in the disposal shafts is likely to be on the order of 50% or more, which exceeds the porosity of tuff. However, given that the waste material is essentially a hypothetical construct in the model environment, no attempt was made to derive a waste-specific porosity or water content.

Radioactive decay of the uranium and plutonium isotopes listed in Table H-2.0-1 gives rise to decay products (i.e., progeny) during the modeling period. The decay chains for these nuclides are provided below. Bold type indicates the nuclides actually included in the GoldSim model. The radioactive emissions of the other nuclides shown in the decay chains are accounted for in the dose conversion factors used to calculate dose for the parent nuclides (progeny of Rn-222 are included in the dose conversion factor for Ra-226). The parenthetical value beside each nuclide indicates the half-life.

Pu-238(88 yr) ≡ **U-234**(244,500 yr)

Pu-239(24,130 yr) ≡ **U-235**(7.0E+08 yr) ≡ Th-231(25.5 hr)

Pu-240(6,540 yr) ≡ **U-236**(3.4E+06 yr)

Pu-241(14 yr) ≡ **Am-241**(432 yr) ≡ **Np-237**(2.1E+06 yr) ≡ Pa-233(27 d)

Pu-242(375,000 yr) ≡ **U-238**(4.47E+09 yr) ≡ Th-234(24 d) ≡ Pa-234m(1.2 min)

≡ **U-234**(246,000 yr) ≡ **Th-230**(77,000 yr) ≡ **Ra-226**(1,600 yr) ≡ **Rn-222**(3.8 d)

≡ Po-218(3 min) ≡ Pb-214(27 min) ≡ Bi-214(20 min) ≡ **Pb210**(22.3 yr)

≡ Bi-210(5 d) ≡ Po-210(138 d) ≡ **Pb**(stable)

The half-lives of the progeny of U-236, Th-231 and Pa-233 are sufficiently large that potential doses associated with these nuclides are negligible during the 1000-yr modeling period. In the GoldSim model, the decay of Ra-226 to Rn-222 was controlled to simulate an emanation coefficient for Rn, as discussed in Section H-2.3 of this appendix.

H-2.2 Biotic Transport Submodels

The biotic transport submodels (or biointrusion models) form the core of the MDA H GoldSim system model described in this appendix because only via these processes can contaminants other than radon gas migrate to surface soils, where they are available for human exposure. As discussed in Section 3.3.1, the GoldSim biotic transport submodels developed for MDA H are based on those used for the Performance Assessment and Composite Analysis (PA/CA) for MDA G (Hollis et al. 1997, 63131), with revisions to maintain consistency with recent refinements to these models under the performance assessment maintenance program. The basic architecture of the GoldSim system model, including the various media and "cells" as well as the general configuration of the physical system, is described in Section H-2.0. This section of the appendix will focus on the mechanistic details of the biotic transport submodels.

The animal burrow and plant root biointrusion models both incorporate a progressive change in the species composition with time. Present-day biotic communities at MDA H reflect ongoing maintenance activities to rid the site of deep-rooting plants and minimize the activities of burrowing animals. As described in Section 3.3.1, institutional controls are assumed to remain in place for 100 yr from the present day such that biotic activities will result in only moderate disturbance of the waste. After 100 yr, it is assumed that no steps are taken to affect the composition of the biotic community resulting in a gradual reversion to a natural species composition. This model of biotic succession is taken from *An Evaluation of the Potential Impacts of Plant and Animal Intrusion into Disposed Waste at TA-54, MDA G* (Shuman 1999, 66804), which reflects the current status of biointrusion models under the performance assessment maintenance program.

The various plant and animal species, and their relative abundance on-site under present-day and climax biotic conditions, are presented in Table H-2.2-1. These animal species and densities are supported by the information presented in Shuman (1999, 66804), although the specific values and their application are based on personal communication with Mr. Shuman. The transition period between present-day and climax conditions was assumed to be 200 yr; the 200-yr transition was modeled as a linear change beginning at model year 100, the end of the 100-yr institutional control period (Shuman 1999, 66804).

Table H-2.2-1
Plants and Animals Employed in the Biointrusion Models

Species	Present-Day Density	Climax Density
Animals		
Harvester ants	31.3 /ha	31.3 /ha
Chipmunks	0 /ha	34.9 /ha
Pocket gophers[a]	30.1 m^3/ha	0 m^3/ha
Deer mice	20.4 /ha	5.1 /ha
Plants		
Grasses	0.060 kg/m^2	0.011 kg/m^2
Forbs	0.019 kg/m^2	0.0096 kg/m^2
Shrubs	0.0088 kg/m^2	0.0076 kg/m^2
Trees	0 kg/m^2	6.56 kg/m^2

[a] Data provided in the form of burrowed volume of soil per area.

H-2.2.1 Animal Burrow Submodel

There are three basic components of the animal burrow submodel employed at MDA H. These components are listed below.

1. Excavation rate inputs: the product of animal densities $(m^2)^{-1}$, burrowed volumes (m^3), and burrow renewal rates $(yr)^{-1}$, and the area of the waste shafts (21 m^2) is the burrow excavation rate for each animal species (m^3/yr);
2. Burrow depth functions: mathematical functions are used to represent the fraction of animal burrow above a certain depth for each animal species;
3. Material transfer rates: The percentage of burrows at each depth, and the density, water content, and thickness of the soil, cap, and waste cells, are used in conjunction with the excavation rates to calculate the rate of material transfer to surface soil across all species (kg/yr of solid and m^3/yr of water). Mass is conserved by having an equivalent amount of material (after mixing in each cell) move from surface soil to cap to waste via burrow collapse.
4. The excavation rate inputs of burrowed volumes and burrow renewal rates are summarized in Table H-2.2-2. Animal densities relative to the endpoints of ecological succession were provided in Table H-2.2-1.

Table H-2.2-2
Burrow Excavation Rate Data

Animal	Burrowed Volume Present Day (m^3/ha)	Burrowed Volume at Climax (m^3/ha)	Burrow Renewal Rate $(yr)^{-1}$
Harvester ants	0.62	0.62	0.032[a]
Chipmunks	0	1.22	0.75
Pocket gophers	30.1	0	0.883
Deer mice	0.81	0.21	0.883

[a] Based on a colony lifespan of 31 yr.

The burrow depth data for the animal species were obtained by personal communication with Mr. Shuman because some revisions to the information presented in Shuman (1999, 66804) have occurred since publication. Mr. Shuman plans to document revisions to the biotic model in a revision of the MDA G PA/CA report anticipated to be published in 2004. The burrow depth data were obtained in the form of the percent of animal burrow above specific depths. A mathematical function was fit to these data in order to apply them in the GoldSim model. The form of this function is that of a modified gamma distribution according to:

$$fraction = 1 - \left(1 - \frac{z}{z_{\max}}\right)^{b-1}$$

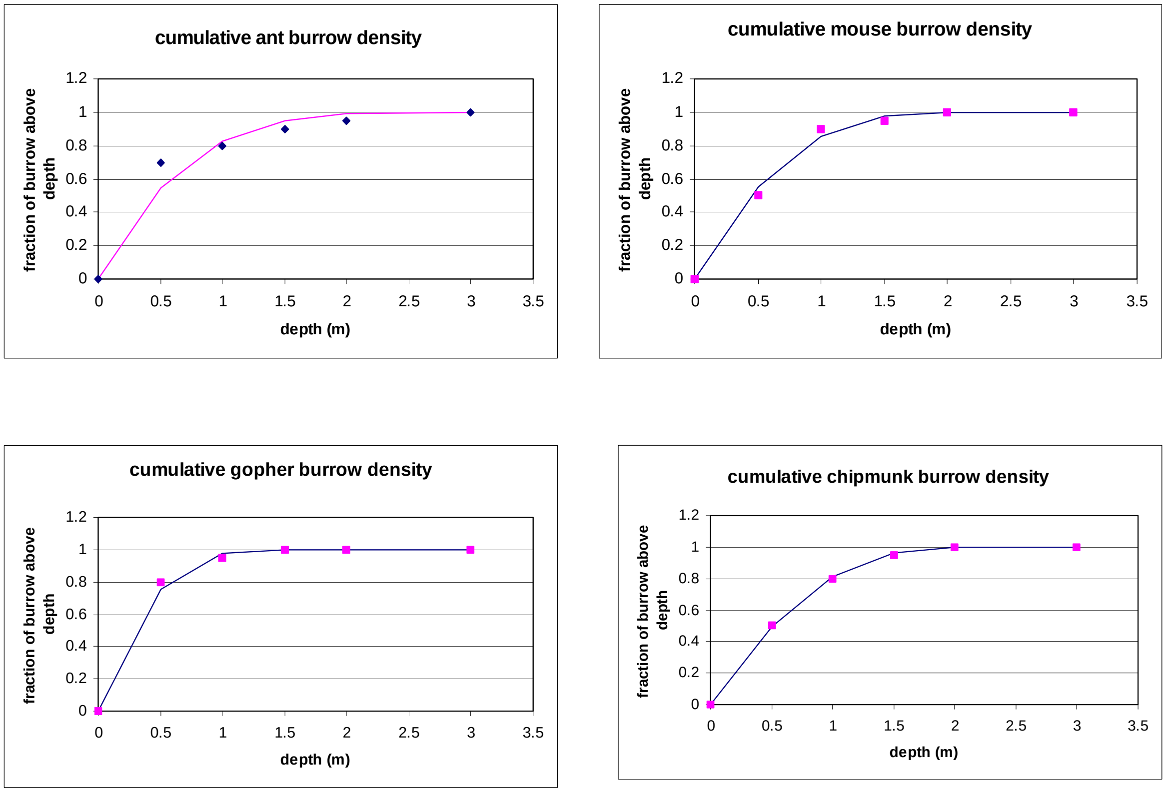
where, fraction = fraction of burrow above a specified depth

z = depths at which burrow fraction data were supplied

z_{max} = maximum value of function

b = fitting parameter

Curve fits for the four animal species are presented in Figure H-2.2-1. The points shown on each of the four graphs are the species-specific burrow depth data obtained from Mr. Shuman. The curve fit was obtained using the modified gamma distribution described above.


cumulative ant burrow density

cumulative mouse burrow density

cumulative gopher burrow density

cumulative chipmunk burrow density

Figure H-2.2-1. Animal burrow-depth functions

The transfer rate of waste material from the disposal shafts to surface soil over time is a function of the excavation rates of each species, the fraction of burrows within the waste, the depth of any cap or cover material, the cap or cover erosion rate, and the density of the waste material. The transfer rate over the 1000-yr simulation period is shown in Figure H-2.2-2. The change in the rate of waste excavation between 100 and 300 yr, relative to the steady rate in the following 700 yr, relates to changes in the biotic community and erosion rate during the transition periods following institutional control. The small but steady increase in the rate of excavation after 300 yr is a reflection of a relatively low erosion rate. The total mass of waste excavated by all animal species over the 1000-yr period is approximately two kg. Chipmunks, ants, and mice are responsible for excavating approximately 60%, 30%, and 10% of the total mass, respectively. Because gopher burrows are too shallow to intrude into the disposed wastes during the simulation period, these animals do not serve as a vector for waste excavation despite the fact that the volume of their burrows far exceeds that of the other animal species.

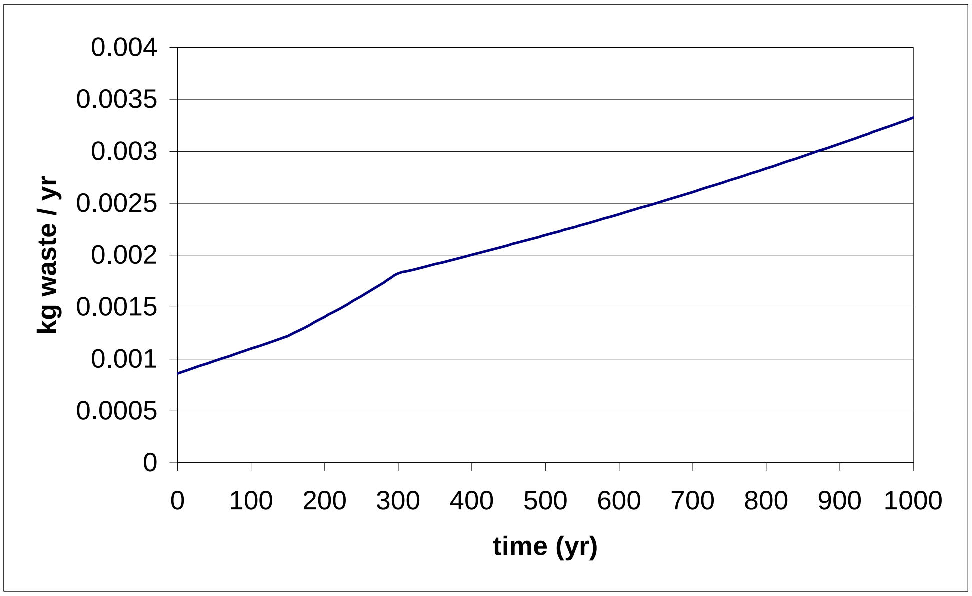


Figure H-2.2-2. Excavation rate of waste by burrowing animals

H-2.2.2 Plant Biointrusion Submodel

The plant biointrusion submodel is conceptually similar to that for animal burrowing activities. The primary distinction between these models is that animals transport contaminants in an incidental manner as they excavate bulk soil. By contrast, there is chemical specificity in the rate of root uptake of chemicals by plants. Also, the fact that contaminants alone are transported, rather than a solid or liquid medium such as soil or water, necessitates special modeling techniques in GoldSim.

There are four basic components of the plant biointrusion submodel employed at MDA H. These components are

1. Litter production rates: the product of the above-ground plant biomass (kg/m^2, dry weight), the area of the waste shafts (21 m^2), and a species-specific fraction of the biomass lost as litter (yr)$^{-1}$ is the theoretical litter production rate added to the soil cell (kg/yr);
2. Plant-soil ratios: the chemical-specific ratio of the chemical concentrations in plant tissue and a composite material consisting of the waste, cap, and surface soil cells;
3. Root depth functions: mathematical functions are used to represent the fraction of plant root mass above a certain depth for each plant species; and
4. Chemical transfer rates: the percentage of root mass at each depth, and the thickness of the soil, cap, and waste cells, is used in conjunction with the litter production rates and plant-soil ratios to calculate the rate at which individual chemicals are transported from the waste to surface soil.

The fraction of the biomass lost as litter each year (yr)$^{-1}$ by plant species is 1.0 for grasses and forbs, 0.183 for shrubs, and 0.065 for trees. Plant densities (*i.e.*, biomass) relative to the endpoints of ecological succession were provided in Table H-2.2-1. The annual litter production rate for each type of plant, weighted by the relative amount of the root mass present in the waste shafts, is shown in Figure H-2.2-3. Trees are responsible for the great majority of litter production and associated chemical transport.

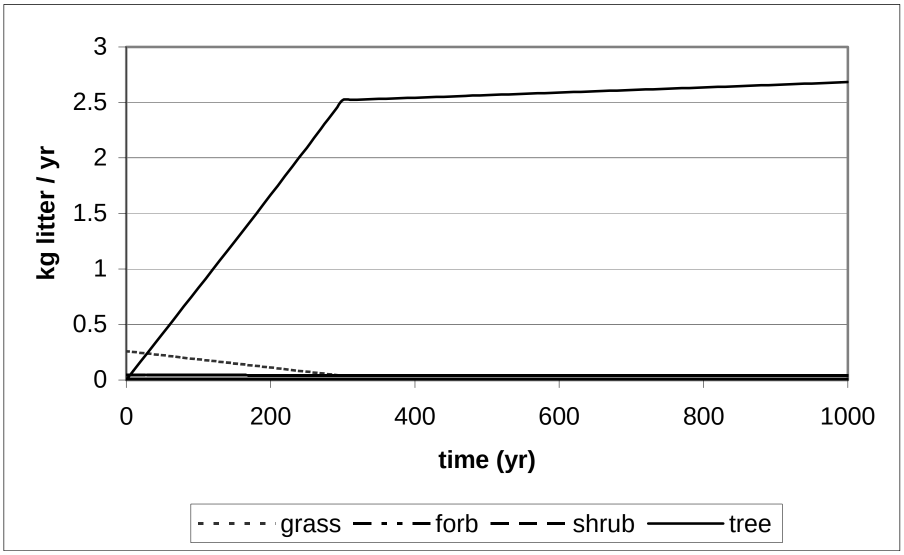


Figure H-2.2-3. Plant litter production rates weighted by root fraction in the waste

The plant-soil ratios were preferentially taken from the ECORISK Version 1.3 database (LANL 2001, 71211) because these values were developed in collaboration with the regulatory authorities. For chemicals not present in the database, the soil-to-plant transfer coefficient for vegetative portions of food crops and feed plants (B_v) from Figure 2.1 of Baes et al. (1984, 59788) were used. The B_v values were selected because the vegetative portions of plants (rather than the reproductive portions) likely constitute the bulk of plant litter. A value for tritium, which exists in the form of water, is not published in either reference. A value for tritium was calculated as the assumed fractional water content of a leafy vegetable (0.75) divided by the mean fractional water content of crushed tuff (0.0625) obtained from Table 3 of Appendix 2a of the PA/CA for MDA-G (Hollis et al. 1997, 63131). The plant-soil ratios used in the GoldSim plant biointrusion model are provided in Table H-2.2-3. The value for RDX was used as a surrogate for cyanuric acid.

Table H-2.2-3
Plant-Soil Ratios for the Plant Biointrusion Model

Contaminant	Plant-Soil Ratio	Contaminant	Plant-Soil Ratio
Ac (actinium)	0.0035	H3 (tritium)	12.0
Ag (silver)	0.4	Np (neptunium)	0.013
Al (aluminum)	0.004	Hg (mercury)	0.0375
Am (americium)	0.002	Pa (protactinium)	0.0025
Ba (barium)	0.15	Pb (lead)	0.045
Be (beryllium)	0.01	Pu (plutonium)	0.0004
Cd (cadmium)	0.364	Ra (radium)	0.075
cyanuric acid	9.442	RDX (high explosive)	9.442
Cr (chromium)	0.0075	Th (thorium)	0.0004
Cu (copper)	0.4	U (uranium)	0.0085
Fe (iron)	0.004		

The root-depth data for the plant species were obtained by personal communication with Mr. Shuman because some revisions to the information presented in Shuman (Shuman 1999, 66804) have occurred since publication. Mr. Shuman plans to document revisions to the biotic model in a revision of the MDA G PA/CA report anticipated to be published in 2004. The root depth data were obtained in the form of the percent of root mass above specific depths. Mathematical functions were fit to these data in order to apply them in the GoldSim model. Curve fits for the four plant species are provided in Figure H-2.2-4. Modified gamma functions identical to those described for the animal burrow model were fit to the data for grasses and forbs. The modified gamma function could not be fit to the data for shrubs and trees. Instead, a sigmoidal function (the Boltzman equation) was used, according to

$$\textbf{function} = \frac{\mathbf{A_1 - A_2}}{1 + e^{(x - x_0)/dx}} + \mathbf{A_2}$$

where, function = fraction of roots above a specified depth

x = a depth at which root data were supplied

x_0 = the root depth at approximate center of the sigmoidal function

dx = the fraction of root mass above depth x

A_1 = the initial value of the cumulative root fraction shown on the y-axis of the graphs

A_2 = the final value of the cumulative root fraction shown on the y-axis of the graphs

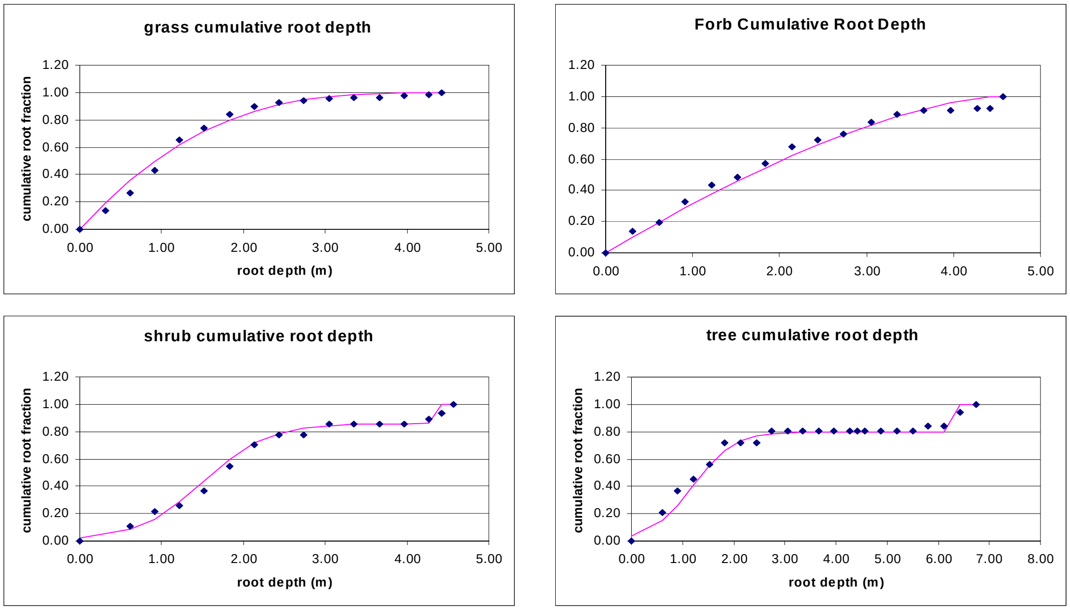


Figure H-2.2-4. Plant root depth functions

The transfer rate of individual contaminants from the disposal shafts to surface soil over time is a function of the litter production rate and fraction of roots within the waste for each plant species, the depth of any cap or cover material, the cap or cover erosion rate, and the chemical-specific plant-soil ratios. The mass of a chemical transported from the waste cell to the surface soil cell is calculated as the product of the concentration of a chemical in the upper waste cell, the chemical-specific plant-soil ratio, the litter production fraction associated with the mass of roots in the waste cell, and the timestep length. Therefore, the output of the calculation has units of mass and changes in the modeling timestep do not affect the contaminant transfer rate. Inputs to the calculations described here are provided in Table H-2.0-1, Figures H-2.2-3 and H-2.2-4, and Table H-2.2-3.

The rates of chemical transport by plants from the upper waste cell to surface soil for the contaminants with the highest rates of plant transport are shown in Figure H-2.2-5.

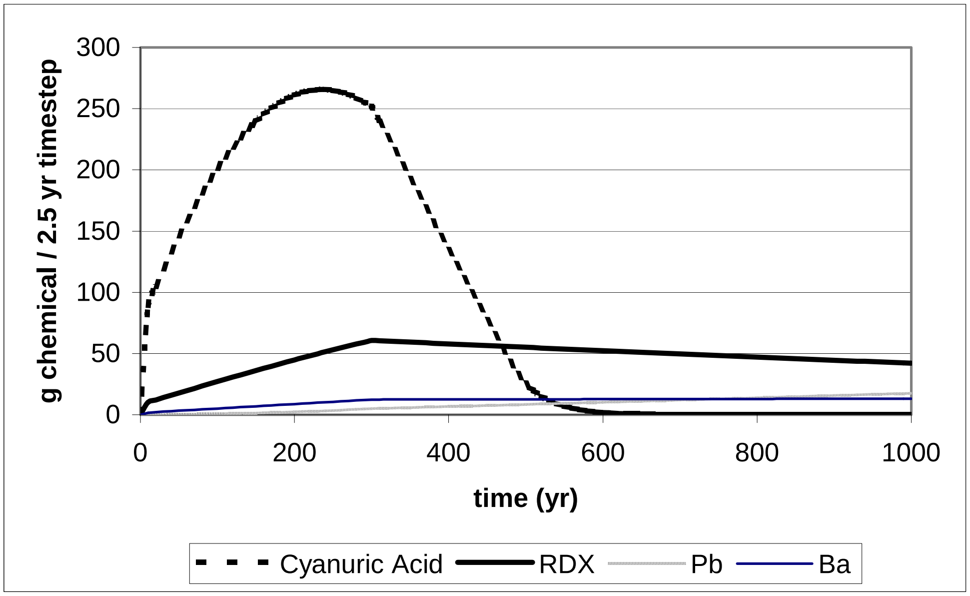


Figure H-2.2-5. Rate of plant transport of chemicals from waste to soil

The y-axis of this graph shows the mass of contaminant transported with each 2.5-yr time step during the simulation. Similar to bulk material transport by burrowing animals, this graph shows an inflection at 300 yr when the shift in the biotic community to climax conditions is complete. The fact that the mass of cyanuric acid and RDX transported with each timestep decreases beyond 300 yr is an indication that, unlike barium and lead, the inventory of these chemicals in the upper waste zone is being effectively depleted over time. This depletion is due to dissolution with infiltrating water, as discussed in Section H-2.3 of this appendix.

The total mass of the four chemicals shown in Figure H-2.2-5 transferred from the waste cell to the surface soil cell via plant uptake over the 1000-yr modeling period was

- RDX—19 kg,
- barium—4.4 kg,
- lead—3.4 kg, and
- cyanuric acid—37 kg.

The rates of radionuclide transport by plants from the upper waste cell to surface soil for the contaminants with the highest rates of plant transport are shown in Figure H-2.2-6. The y-axis of this figure is shown on logarithmic scale because the rate of tritium transport via roots in the early years of the simulation is much greater than the rate of other radionuclides. This graph, like Figure H-2.2-5, shows an inflection at 300 yr when the shift in the biotic community to climax conditions is complete. The uranium transport rates shown in Figure H-2.2-6 are based on GoldSim calculations using the best-estimate inventory of uranium and assumptions regarding the corrosion rate of uranium metal in the shafts.

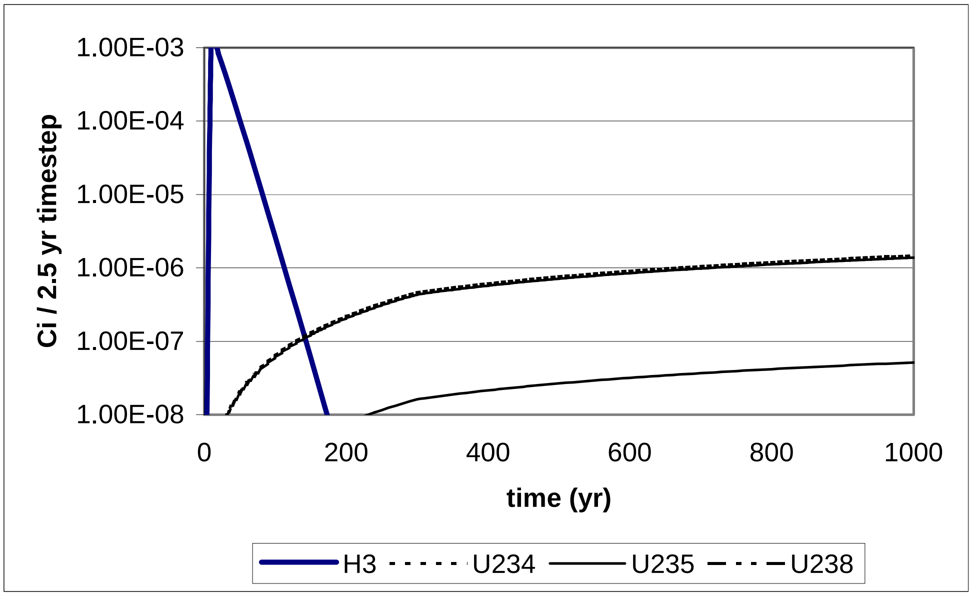


Figure H-2.2-6. Rate of plant transport of radionuclides from waste to soil (best-estimate inventory and corrosion-limited availability of uranium)

The total activity of the four radionuclides shown in Figure H-2.2-6 transferred from the waste cell to the surface soil cell via plant uptake over the 1000-yr modeling period was

- H3—0.013 Ci,
- U234—0.0003 Ci,
- U235—0.00001 Ci, and
- U238—0.0003 Ci.

The total mass of *waste* transported by animal activities in the 1000-yr modeling period was only about two kg. Comparing that value to the mass of individual chemicals transported via plants (see summary above), it is clear that plants are the more important mechanism in the MDA H biotic transport model for mobilizing contaminants in the disposal shafts over time. The main reason for this can be observed in the depth functions for animal burrows (Figure H-2.2-1) and plant roots (Figure H-2.2-4). Virtually no animal burrows penetrate below the 2-m cover and cap above the waste shafts. As described in the following section, the calculated rate of erosion is sufficiently low that this condition does not appreciably change over the modeling period. As shown in Figure H-2.2-3, trees are responsible for most plant-related chemical transport due to their high litter production rate.

H-2.3 Diffusion, Infiltration and Vadose Transport, and Erosion Submodels

Each of these submodels within the GoldSim system-level model are concerned with migration within or among the solid, water, and/or air phases of environmental media and/or disposed wastes. Although they are not directly related to the biotic transport models described in Section H-2.2, they are nevertheless directly coupled with the biota models in the sense that all GoldSim submodels use as their basis the contaminant concentrations over time in the various cells (waste, soil, cap, and tuff) depicted in Figure 3.3-2. Movement of chemicals and radionuclides in the vapor-phase diffusion, infiltration, and aqueous-phase vadose transport models are differentiated by contaminant-specific parameters. Identification of appropriate parameters values is described in the context of the infiltration, diffusion, and vadose/groundwater transport process-level models in Appendices G, I, and J. As discussed in Section H-1.0 of this appendix, the output of the vapor-phase diffusion and aqueous-phase vadose transport process-level models were also employed to either calibrate or verify the results of these submodels within GoldSim.

As with the plant transport results described in Section H-2-2, the diffusion, infiltration, vadose-zone transport, and erosion results discussed in this subsection are based on GoldSim calculations using the best-estimate inventory of uranium and assumptions regarding the corrosion rate of uranium metal in the shafts.

H-2.3.1 Vapor-Phase Diffusion Submodel

Vapor-phase diffusion between cells in GoldSim is handled by a special diffusive link. In the GoldSim system-level model, Rn-222 diffusion in air from the buried waste was modeled by using a series of such links from the lower to the upper waste cell, the upper waste cell to the cap, and the cap to the atmosphere. Additionally, diffusion links from the 1-cm thick soil layer and the underlying solid tuff cell to the atmosphere were established to account for Rn-222 that may be generated via the uranium decay chain in these cells. Uranium series radionuclides, like all other contaminants in the GoldSim model, may be transported to surface soil from the buried waste via biotic processes and subsequently infiltrate into underlying tuff with water. Figure H-2.0-1 shows the diffusion and infiltration pathways among cells schematically. Tritium diffusion is not modeled in GoldSim because the present-day tritium inventory is largely located in tuff pore gas outside the waste disposal system. Tritium diffusion modeling is discussed in Appendix I.

A shortcoming of the diffusive links between cells in GoldSim is that radioactive decay is not accounted for during the diffusion process. GoldSim solves the systems equations that define the transport of chemicals and radionuclides among the cells simultaneously. Once a new equilibrium among cells is established at each timestep, radioactive decay calculations are performed. If the overall diffusion path length is relatively small and the radioactive half-life relatively large, the GoldSim solution of diffusion is reasonably accurate. However, with Rn-222 (half-life of 3.8 days) diffusing through a cap with a thickness of 6 ft, the diffusive flux at the surface was overestimated by approximately 40% relative to the output of the process-level diffusion model described in Appendix I.

Two modifications to the GoldSim system model were required to fit the Rn-222 surface flux GoldSim results to the output of the process-level model. The process-level model uses a radon emanation coefficient of 0.01. This coefficient implies that only one percent of the radon atoms generated by the decay of Ra-226 successfully enter pore air and become available for diffusive transport. The remaining radon atoms decay within the matrix of the solid phase that harbors the Ra-226. This radon emanation coefficient was introduced into GoldSim by defining the stoichiometry of Ra-226 progeny to be 99% Pb-210 and 1% Rn-222. Thus, 99% of Ra-226 decay generates Pb-210 instead of Rn-222 gas. Decay of Rn-222 rapidly generates Pb-210 in approximately 3.83 days, as shown in Figure F-2.0-4. The second modification in GoldSim was to define the air-phase diffusion coefficient for Rn-222 to be 60% of the value (4E-06 m^2/s) employed in the process-level model. The surface radon flux over time above the disposal shafts calculated using GoldSim is shown in Figure 3.3-7 (Radon surface flux above the disposal shafts). The Rn-222 surface flux from the soil and solid tuff cells is negligible compared to flux above the shafts (less than 0.01%).

H-2.3.2 Infiltration and Aqueous-Phase Vadose Transport Submodel

The near-surface water infiltration submodel for MDA H is described in detail in Appendix G. There are three rates of infiltration that pertain to the GoldSim model under discussion: the shallow infiltration rate, the leakage rate through the cap, and the deep net infiltration rate. The shallow infiltration rate was used in the GoldSim model for the 1-cm thick surface soil layer. The leakage rate was used in the GoldSim model for the infiltration rate through the cap (the 6-ft thick layer above the shafts with the properties of crushed tuff), the tuff layer beneath the soil, and the waste cells. The deep net infiltration rate applies to the two vadose-zone ”pipe pathways” (described below) that transport aqueous-phase constituents from the base of the waste cell and tuff layer toward the water table.

The shallow infiltration rate and leakage rate used in the GoldSim model are best-estimate values from within the ranges estimated from the modeling work discussed in Appendix G. The shallow infiltration rate was calculated in Appendix G as the average precipitation rate (47.6 cm/yr) minus the average surface runoff (0.36 cm/yr). The leakage rate is based on the average value of 0.89 cm for the “background cover” described in Appendix G. Finally, the deep net infiltration rate agrees with the base-case rate discussed in Appendix J. The three infiltration values are

- infiltration rate through the soil = 472 mm/yr;
- leakage rate through the cap, upper tuff layer, and waste = 8.9 mm/yr; and
- deep net infiltration rate through the vadose-zone pipes = 1.0 mm/yr.

In order to understand the application of these infiltration rates in the GoldSim system-level model it is advisable to refer to the graphical depiction of the system in Figure H-2.0-1. Biotic processes transport waste contaminants to surface soil, from which some contaminants may return to the cap and waste via animal burrow collapse. Infiltration is another mechanism, in addition to burrow collapse, by which contaminants may leave the surface soil cell. Infiltration may also remove contaminants from the cap, the two waste cells, and the tuff layer beneath the soil. Because the rate of infiltration is much larger for the surface soil cell than for the cap, tuff, or waste cells, infiltration is more effective in transporting contaminants from soil than from the other media.

The infiltration rate of water through the tuff layer and waste cells serves as the inflow into two GoldSim “pipe pathways” that model transport of contaminants in the vadose zone to groundwater. The pipe pathways are used to model one-dimensional advective transport of contaminants in a fluid (water) medium. Inputs to the vadose zone transport submodel, such as longitudinal dispersivity, thickness of the vadose zone tuff, and fluid saturation, were set in GoldSim to match those employed in the process-level model described in Appendix J.

Dissolution of contaminants in water, and partitioning of contaminants between water and solid media, is governed in GoldSim via solubility and solid-water partition coefficients (K_d), respectively. Water solubility of an element or compound is dependent upon chemical form, which is in turn a function of physical system attributes such as pH and reduction-oxidation potential. K_d values are likewise dependent on attributes of both the water and solid phases in the system. The chemical-specific values employed for solubility and K_d in the GoldSim system model are identical to those used in the process-level vadose transport model presented in Appendix J. The K_d values are also used in GoldSim for the waste cell because, as described in Section H-2.1 of this appendix, the waste material is a hypothetical homogenous substance without definitive physical characteristics. However, it is likely that over time as the waste materials degrade and void space within the shafts is filled with soils and tuff from the surrounding environment the assumption that waste has similar physical properties as tuff will likely be realized.

The results of the GoldSim vadose transport model, using a deep net infiltration rate of 1 mm/yr, are similar to those observed in the process-level model with an infiltration rate of 1 mm/yr. In both cases, no breakthrough of any chemical or radionuclide to groundwater occurred within the 1000-yr modeling period. Additional analysis of vadose-zone transport at other infiltration rates is provided in Appendix J. Contaminants present in the intact tuff cell below surface soil (excepting Rn-222), or in the pipe pathways, as shown in Figure H-2.0-1, are effectively removed from the modeling environment where they could potentially contribute to exposure and health effects. The quantities of contaminants with the highest masses or activities in the two pipe pathways and the tuff layer after 1000 yr are shown in Table H-2.3-1.

Table H-2.3-1
Location and Quantity of Contaminants Lost Via Infiltration After 1000 Yr

Contaminant	Pipe from Waste (kg)	Tuff Layer (kg)	Pipe from Tuff (kg)
Aluminum	negligible	0.46	0.0037
Barium	1.3	3.3	0.0054
Copper	negligible	1.3	0.03
Cyanuric acid	1050	1.6[a]	36[b]
Mercury	0.78	0.24	0.0048
Lead	negligible	3.1	0.15
RDX	8.9	0.35[c]	18
Uranium (total)[d]	5.4	0.59	0.29
Contaminant	Pipe from Waste (Ci)	Tuff Layer (Ci)	Pipe from Tuff (Ci)
Uranium-234[d]	0.0018	2.1E-04	1.0E-04
Uranium-235[d]	6.1E-05	7.4E-06	3.6E-06
Uranium-238[d]	0.0018	2.0E-04	9.6E-05

[a] Maximum value, at model year 250.

[b] All cyanuric acid is flushed from soil by model year 770.

[c] Maximum value, at model year 330.

[d] Best-estimate inventory and corrosion-limited availability of uranium.

Table H-2.3-1 indicates that about 20% of the initial inventory of cyanuric acid (see Table H-2.0-1) in the waste cells is lost via infiltration of water through the shafts during the 1000-yr simulation period. A much smaller amount was lost from surface soil following biotic transport from the upper waste cell. The mobility of cyanuric acid evidenced in Table H-2.3-1 is a function of its high solubility (5,000 mg/L) and high plant-soil concentration ratio (9.4). The information for RDX in Table H-2.3-1 also indicates that it has a relatively high plant-soil concentration ratio (9.4), but a comparatively low solubility (42 mg/L). Hence, considerably less RDX is mobilized from the waste shafts via dissolution. The relative solubilities and plant-soil concentration ratios for the other constituents in Table H-2.3-1 may also be inferred from examination.

There is a bias in the GoldSim model that causes infiltration at the base of the shafts to be about 10% high. The bias is related to the period of time required for surface moisture to penetrate the waste shafts at an infiltration rate of 8.9 mm/yr and a volumetric moisture content of 7.5 percent (about 100 yr). In GoldSim, however, breakthrough from the base of the shafts occurs immediately because the cells have no intrinsic spatial dimensions and their contents are completely mixed at each time step. Because the thicknesses of the soil and tuff layer cells are comparatively small, this bias is not as pronounced for infiltration out of these cells.

Tritium is not shown in Table H-2.3-1 because, due to it's short half-life of 12.3 yr, it will be largely lost through radioactive decay before it can realistically break through with water at the base of the shafts. It will also tend to escape the disposal system via evaporation of water to the atmosphere, a process not evaluated in the GoldSim system model. Surface flux of tritium above the subsurface waste is discussed in Chapter 3.

H-2.3.3 Erosion

The erosion rate is modeled to vary through time. During the institutional control period (100 yr), it is assumed that a gravel mulch cap will be maintained over the disposal shafts and the erosion rate was based on the value used in the PA/CA for MDA G (Hollis et al. 1997, 63131). This value is 0.45 g/m^2-yr, which corresponds to 3.5 x 10^{-7} m/yr given an average crushed tuff density of 1,400 kg/m^3 (Appendix 2a, §3.2.3.1.2 in Hollis et al. 1997, 63131). The standard deviation surrounding this value is reported as 1.1 g/m^2-yr, corresponding to a value of 8.6 x 10^{-7} m/yr (Table 3-4 in Hollis et al. 1997, 63131).

The rate of erosion is likely to be a critical parameter in determining the long-term performance of subsurface disposal systems like MDA H. For this reason, erosion was the subject of specific attention during environmental work at MDA G subsequent to the PA/CA. A team of local hydrologists was assembled in 1998 in order to perform an expert elicitation concerning the modeling of future erosion potential at MDA G. The results of this elicitation are applied to MDA H in this CMS report since they are likely to apply across Mesita del Buey and perhaps other mesas on the Pajarito Plateau as well. As a starting point, these experts agreed that the value of 3.5 x 10^{-7} m/yr used in the PA/CA was reasonable as long as a gravel mulch cap was intact, but that the integrity of this cap could not be assured for more than 200 yr, after which the site would be subject to natural erosion rates. It was agreed by the panel that the gravel mulch cap would perform perfectly for between 10 and 200 yr, after which time natural erosion rates would prevail. Their collective opinion was that the lifespan of the gravel mulch layer could be represented as a triangular distribution with endpoints of 10 and 200 yr and a most-likely value of 50 yr. The gravel mulch layer was assumed to be maintained in original condition throughout the 100-yr institutional control period. The best-estimate value of 50 yr employed in the GoldSim modeling corresponds to 150 yr from the beginning of the simulation.

After failure of the gravel mulch surface, two types of erosion were envisioned to ensue: erosion under normal climatic conditions and erosion following severe drought conditions. The former was believed to occur at twice the rate of the gravel mulch erosion, corresponding to a best estimate of 7 x 10^{-7} m/yr. Drought-induced erosion rates were expected to be much higher, and the panel assigned a triangular distribution with endpoints of 2 x 10^{-4} and 4 x 10^{-3} m/yr, and a most-likely value of 1 x 10^{-3} m/yr. Severe drought conditions were assumed to occur on a 500-yr return period, with about 50 yr needed for the herbaceous vegetation to recover. The fraction of time spent in severe drought conditions was therefore assigned a distribution centered on 10% (50 yr out of every 500 spent in recovery). The panel agreed upon a triangular distribution with endpoints of 0.05 and 0.15, and a most-likely value of 0.1 for the amount of time erosion rates corresponded to drought conditions. The erosion of the cap after failure of the gravel mulch was defined as 90% of the non-drought rate plus 10% of the drought rate. The best-estimate values from the triangular distributions were employed in the MDA H GoldSim model.

Erosion applies solely to the surface soil cell. Throughout the simulation period, GoldSim automatically replaces bulk material lost via erosion from the soil cell with "new" clean soil such that the volume and mass of the surface soil cell remain constant with time. Contaminants that leave the surface soil cell via erosion are effectively lost to the system and are tracked in an erosion "sink". Table H-2.3-2 shows the quantity of the various contaminants in the erosion sink after 1000 yr. The values for uranium isotopes and progeny shown in Table H-2.3-2 are based on GoldSim calculations using the best-estimate inventory of uranium and assumptions regarding the corrosion rate of uranium metal in the shafts.

Table H-2.3-2
Quantity of Contaminants Lost Via Erosion After 1000 Yr

Contaminant	Quantity in Erosion Sink (kg)
Al (aluminum)	0.02
Ba (barium)	0.92
Cu (copper)	0.021
Pb (lead)	0.025
Contaminant	**Quantity in Erosion Sink (Ci)**
U-234[a]	2.5E-07
U-238[a]	2.3E-07
Th-230[a]	1.3E-07
Ra-226[a]	1.3E-07
Pb-210[a]	1.2E-07

[a] Best-estimate inventory and corrosion-limited availability of uranium.

Among the various chemicals, only barium is lost to the erosion sink in quantities approaching 1 kg over 1000 yr. Chemicals not shown in Table H-2.3-2 were lost to the erosion sink in quantities of a few grams or less over 1000 yr. The radionuclides with the greatest activity lost via erosion are all members of the uranium decay series. By comparison with Table H-2.3-1, it is apparent that radionuclide loss via infiltration greatly exceeds that of erosion. The soil lost via surface erosion would, in the natural environment, enter the canyons adjoining Mesita del Buey. Potential impacts from a variety of contaminant sources to the canyons systems, including regional material disposal areas, will be addressed in a future surface aggregates report.

H-3.0 EXPOSURE AND HEALTH EFFECTS MODELS

The output of the coupled environmental transport models discussed in Section H-2.0 of this appendix consist of time-series of surface soil contaminants concentrations, radon surface flux, and mass of contaminants entering groundwater. The soil concentrations over time serve as the inputs to the exposure and health effects models described in this section. The exposure pathways and receptors associated with the long-term land use scenarios (residential and recreational) are discussed in Section 3.3.1 of the CMS Report. As indicated in that section, the recreational scenario was used to characterize potential exposures to workers during the 100-yr institutional control period.

Equations used to calculate potential health effects in the GoldSim model are provided in Section H-3.1. Input parameter values for these equations are provided in Section H-3.2. Both the equations and parameter values generally reflect EPA guidance for conducting human health risk assessment. Specific references for the parameter values used in the risk equations are provided in Section H-3.2.

Surface soil concentrations of chemicals and radionuclides over time are presented in Tables H-3.0-1 and H-3.0-2, respectively. The values for total uranium in Table H-3.0-1 are based on the best-estimate uranium inventory. In Table H-3.0-2, concentrations of isotopic uranium are presented for best-estimate conditions of uranium inventory and corrosion rate, as described in Section 3.3.1.3 of the CMS Report. Table H-3.0-3 provides radionuclide soil concentrations based on upper-bound estimates of the uranium inventory and an assumption that 100% of the uranium is immediately available for transport. These soil concentrations may be used in conjunction with the exposure and toxicity parameter values to verify risk and dose assessment results presented in Section 3.3.1. The material properties of surface soil affect the concentrations tabulated in H-3.0-1, H-3.0-2, and H-3.0-3. The surface soil, solid tuff, and cap cells have effectively identical bulk density, porosity, and moisture content values, and these are consistent with inputs to the PA/CA for MDA G (Hollis et al. 1997, 63131, Appendix 2a) for crushed tuff. The bulk density of the soil, solid tuff, and cap cells was set at 1,400 kg/m^3. The fractional porosity and fractional water content were set at approximately 0.48 (0.479 for crushed tuff and 0.481 for intact tuff) and 0.075, respectively. The thickness of the soil cell is constant over the simulation period and was defined as 1 cm, as described in Section H-2.0.

The zero values over time for plutonium isotopes and their progeny Am-241 and Np-237 in Tables H-3.0-2 and H-3.0-3, reflect the fact that (as shown in Table H-2.0-1) the entire inventories of these contaminants are present in the lower waste cell. Because the top of the lower waste cell is at a depth below the root and burrow depths shown in Figures H-2.2-1 and H-2.2-4, there is no natural physical mechanism by which these deeply buried contaminants can be transported to surface soil.

Analyte-specific background soil concentrations for the Pajarito Plateau (LANL 1998, 59730) are provided at the base of Tables H-3.0-1, H-3.0-2, and H-3.0-3 for reference. Background values pertain to mesa top soils across all sampled soil horizons.

H-3.1 Health Effects Equations

The equations used to calculate hazard quotient (HQ), incremental cancer risk (ICR), and radiation dose for the various exposure pathways associated with the residential, recreational, and site-worker scenarios are presented in this section. Equations used for the residential scenario are presented in Section H-3.1.1. Equations used for the recreational and worker scenarios are presented in Sections H-3.1.2 and H-3.1.3, respectively.

H-3.1.1 Residential Scenario Equations

CHEMICAL HAZARD—Chemical hazard for an individual chemical is defined by the HQ, which is calculated as the ratio of the exposure level to a single chemical (i) to the toxicity reference dose for that chemical. Separate calculations are performed for adult and child receptors for incidental soil ingestion, dust inhalation, and dermal absorption exposure pathways, using the input parameters provided in Table H-3.1-1, and the larger of the result of the adult or child calculations is used in the risk assessment. In almost all cases the calculated health effects are larger for the child receptor due to their smaller body size. Calculations for the produce ingestion pathway pertain to a general population of both adults and children because the ingestion rate information is based on survey data across all ages (see Table H-3.1-1).

Table H-3.0-1
Concentrations of Chemicals in Surface Soil With Time (mg/kg)

Year	Ag	Al	Ba	Be	Cd	Cr	Cu	Cyanuric acid	Fe	Hg	Pb	RDX	Total Uranium
0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	1.9E-05	2.8E-03	1.3	1.9E-04	1.4E-05	5.3E-06	0.0028	0.0051	0.0004	0.0099	0.0035	6.2E-04	1.1E-04
100	6.1E-05	8.8E-03	2.5	6.3E-04	4.6E-05	1.7E-05	0.0090	0.0071	0.0014	0.015	0.011	9.5E-04	3.4E-04
150	1.2E-04	1.7E-02	3.5	1.3E-03	9.4E-05	3.3E-05	0.018	0.0084	0.0028	0.021	0.022	0.0013	0.0007
200	2.1E-04	2.9E-02	3.9	2.1E-03	1.6E-04	5.5E-05	0.031	0.0092	0.0046	0.026	0.038	0.0016	0.0011
250	3.2E-04	4.4E-02	4.8	3.3E-03	2.4E-04	8.4E-05	0.048	0.0094	0.0070	0.032	0.058	0.0019	0.0017
300	4.6E-04	0.062	5.7	0.0047	3.5E-04	1.2E-04	0.068	0.0090	0.010	0.037	0.082	0.0021	0.0024
350	5.4E-04	0.074	6.1	0.0056	4.1E-04	1.4E-04	0.080	0.0069	0.012	0.038	0.097	0.0021	0.0029
400	6.3E-04	0.086	6.2	0.0065	4.7E-04	1.6E-04	0.092	0.0049	0.014	0.038	0.11	0.0021	0.0033
450	7.1E-04	0.098	6.2	0.0074	5.4E-04	1.9E-04	0.10	0.0028	0.016	0.039	0.13	0.0020	0.0037
500	7.9E-04	0.11	6.3	0.0083	6.0E-04	2.1E-04	0.12	0.0010	0.018	0.039	0.14	0.0020	0.0041
550	8.8E-04	0.12	6.3	0.0092	6.6E-04	2.3E-04	0.13	2.6E-04	0.020	0.039	0.16	0.0019	0.0045
600	9.6E-04	0.14	6.3	0.010	7.3E-04	2.6E-04	0.14	7.2E-05	0.022	0.040	0.17	0.0019	0.0049
650	0.0010	0.15	6.4	0.011	7.9E-04	2.8E-04	0.15	1.9E-05	0.024	0.040	0.19	0.0018	0.0053
700	0.0011	0.16	6.4	0.012	8.6E-04	3.0E-04	0.17	5.3E-06	0.026	0.040	0.20	0.0018	0.0058
750	0.0012	0.18	6.5	0.013	9.3E-04	3.3E-04	0.18	1.4E-06	0.029	0.040	0.22	0.0017	0.0062
800	0.0013	0.19	6.5	0.014	9.9E-04	3.5E-04	0.19	3.9E-07	0.031	0.041	0.24	0.0017	0.0066
850	0.0014	0.20	6.6	0.015	0.0011	3.8E-04	0.21	1.0E-07	0.033	0.041	0.25	0.0016	0.0070
900	0.0015	0.22	6.6	0.016	0.0011	4.1E-04	0.22	2.8E-08	0.036	0.041	0.27	0.0016	0.0074
950	0.0016	0.24	6.6	0.017	0.0012	4.3E-04	0.23	7.7E-09	0.038	0.042	0.29	0.0015	0.0079
1000	0.0017	0.25	6.7	0.018	0.0013	4.6E-04	0.25	2.1E-09	0.041	0.042	0.30	0.0015	0.0083
Bckgrnd	NA[a]	29200	295	1.83	0.4	19.3	14.7	NA	21500	0.1	22.3	NA	5.45

[a] NA = not available.

Table H-3.0-2
Best-Estimate Concentrations of Radionuclides in Surface Soil With Time (pCi/g)

Year	Ac-227	Am-241	H3	Np-237	Pa-231	Pb-210	Pu Isotopes	Ra-226	Rn-222	Th-230	U-234	U-235	U-236	U-238
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	1.3E-08	0.0E+00	4.5E-03	0	9.6E-09	1.3E-08	0	7.5E-08	3.1E-14	9.5E-07	3.8E-05	1.3E-06	1.4E-06	3.6E-05
100	1.2E-07	0.0E+00	1.2E-04	0	5.8E-08	2.1E-07	0	1.2E-06	4.7E-13	7.5E-06	1.2E-04	4.2E-06	4.3E-06	1.1E-04
150	4.1E-07	0.0E+00	2.6E-06	0	1.7E-07	1.0E-06	0	5.6E-06	2.3E-12	2.4E-05	2.4E-04	8.5E-06	8.7E-06	2.3E-04
200	9.6E-07	0.0E+00	5.3E-08	0	3.8E-07	2.9E-06	0	1.7E-05	6.8E-12	5.3E-05	4.1E-04	1.4E-05	1.5E-05	3.8E-04
250	1.9E-06	0.0E+00	1.0E-09	0	7.1E-07	6.7E-06	0	4.0E-05	1.6E-11	1.0E-04	6.2E-04	2.2E-05	2.2E-05	5.8E-04
300	3.3E-06	0.0E+00	2.0E-11	0	1.2E-06	1.3E-05	0	8.1E-05	3.3E-11	1.8E-04	8.6E-04	3.0E-05	3.1E-05	8.1E-04
350	4.6E-06	0.0E+00	3.3E-13	0	1.6E-06	2.0E-05	0	1.3E-04	5.4E-11	2.5E-04	1.0E-03	3.6E-05	3.7E-05	9.5E-04
400	6.1E-06	0.0E+00	5.3E-15	0	2.2E-06	2.9E-05	0	2.0E-04	8.0E-11	3.3E-04	1.2E-03	4.1E-05	4.2E-05	1.1E-03
450	7.9E-06	0.0E+00	8.6E-17	0	2.8E-06	4.0E-05	0	2.8E-04	1.1E-10	4.3E-04	1.3E-03	4.6E-05	4.7E-05	1.2E-03
500	9.8E-06	0.0E+00	1.4E-18	0	3.4E-06	5.4E-05	0	3.8E-04	1.5E-10	5.3E-04	1.5E-03	5.1E-05	5.3E-05	1.4E-03
550	1.2E-05	0.0E+00	2.3E-20	0	4.2E-06	7.0E-05	0	5.0E-04	2.1E-10	6.5E-04	1.6E-03	5.6E-05	5.8E-05	1.5E-03
600	1.4E-05	0.0E+00	3.7E-22	0	5.0E-06	8.9E-05	0	6.5E-04	2.6E-10	7.8E-04	1.8E-03	6.2E-05	6.3E-05	1.6E-03
650	1.7E-05	0.0E+00	6.0E-24	0	5.9E-06	1.1E-04	0	8.2E-04	3.3E-10	9.2E-04	1.9E-03	6.7E-05	6.9E-05	1.8E-03
700	2.0E-05	0.0E+00	9.7E-26	0	6.9E-06	1.4E-04	0	1.0E-03	4.1E-10	1.1E-03	2.1E-03	7.2E-05	7.4E-05	1.9E-03
750	2.3E-05	0.0E+00	1.6E-27	0	8.0E-06	1.6E-04	0	1.2E-03	5.0E-10	1.2E-03	2.2E-03	7.7E-05	7.9E-05	2.1E-03
800	2.7E-05	0.0E+00	2.6E-29	0	9.1E-06	1.9E-04	0	1.5E-03	6.1E-10	1.4E-03	2.4E-03	8.2E-05	8.5E-05	2.2E-03
850	3.0E-05	0.0E+00	4.1E-31	0	1.0E-05	2.3E-04	0	1.8E-03	7.2E-10	1.6E-03	2.5E-03	8.8E-05	9.0E-05	2.3E-03
900	3.4E-05	0.0E+00	6.7E-33	0	1.2E-05	2.7E-04	0	2.1E-03	8.5E-10	1.8E-03	2.7E-03	9.3E-05	9.6E-05	2.5E-03
950	3.8E-05	0.0E+00	1.1E-34	0	1.3E-05	3.1E-04	0	2.4E-03	9.9E-10	2.1E-03	2.8E-03	9.8E-05	1.0E-04	2.6E-03
1000	4.3E-05	0.0E+00	1.8E-36	0	1.5E-05	3.5E-04	0	2.8E-03	1.1E-09	2.3E-03	3.0E-03	1.0E-04	1.1E-04	2.8E-03
bckgrnd	NA[a]	0.013	0.08[b]	NA	NA	[c]	—	[c]	NA	[c]	1.94	0.084	NA	1.82

[a] NA = not available.

[b] The background soil value for tritium is 0.76 pCi/ml. The value of 0.08 pCi/g assumes an approximate soil moisture content of 10% in the background samples.

[c] The background soil activity levels of Pb-210, Ra-226, and Th-230 should be approximately equivalent to those tabulated for U-234 and U-238.

Table H-3.0-3
Upper-Bound Concentrations of Radionuclides in Surface Soil With Time (pCi/g)

Year	Ac-227	Am-241	H3	Np-237	Pa-231	Pb-210	Pu Isotopes	Ra-226	Rn-222	Th-230	U-234	U-235	U-236	U-238
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	4.4E-06	0.0E+00	3.3E-03	0	3.2E-06	4.8E-06	0	2.4E-05	9.7E-12	3.6E-04	3.7E-03	1.3E-04	7.3E-05	1.5E-03
100	1.9E-05	0.0E+00	8.4E-05	0	9.0E-06	3.6E-05	0	1.7E-04	6.9E-11	1.2E-03	1.1E-02	4.0E-04	2.2E-04	4.7E-03
150	4.1E-05	0.0E+00	1.9E-06	0	1.7E-05	1.1E-04	0	5.2E-04	2.1E-10	2.6E-03	2.3E-02	8.0E-04	4.5E-04	9.4E-03
200	7.2E-05	0.0E+00	3.9E-08	0	2.9E-05	2.3E-04	0	1.2E-03	4.8E-10	4.0E-03	2.9E-02	1.0E-03	5.7E-04	1.2E-02
250	1.1E-04	0.0E+00	7.8E-10	0	4.3E-05	4.1E-04	0	2.2E-03	9.1E-10	6.2E-03	3.5E-02	1.2E-03	6.9E-04	1.4E-02
300	1.6E-04	0.0E+00	1.5E-11	0	6.0E-05	6.6E-04	0	3.8E-03	1.5E-09	8.8E-03	4.1E-02	1.4E-03	8.1E-04	1.7E-02
350	2.0E-04	0.0E+00	2.5E-13	0	7.2E-05	8.7E-04	0	5.3E-03	2.2E-09	1.1E-02	4.2E-02	1.5E-03	8.2E-04	1.7E-02
400	2.3E-04	0.0E+00	4.0E-15	0	8.4E-05	1.1E-03	0	6.9E-03	2.8E-09	1.3E-02	4.2E-02	1.5E-03	8.3E-04	1.7E-02
450	2.7E-04	0.0E+00	6.6E-17	0	9.6E-05	1.3E-03	0	8.8E-03	3.6E-09	1.5E-02	4.2E-02	1.5E-03	8.4E-04	1.8E-02
500	3.0E-04	0.0E+00	1.1E-18	0	1.1E-04	1.6E-03	0	1.1E-02	4.4E-09	1.6E-02	4.3E-02	1.5E-03	8.5E-04	1.8E-02
550	3.4E-04	0.0E+00	1.7E-20	0	1.2E-04	1.9E-03	0	1.3E-02	5.4E-09	1.8E-02	4.3E-02	1.5E-03	8.6E-04	1.8E-02
600	3.8E-04	0.0E+00	2.9E-22	0	1.4E-04	2.2E-03	0	1.6E-02	6.4E-09	2.0E-02	4.4E-02	1.5E-03	8.6E-04	1.8E-02
650	4.2E-04	0.0E+00	4.7E-24	0	1.5E-04	2.6E-03	0	1.8E-02	7.5E-09	2.3E-02	4.4E-02	1.6E-03	8.7E-04	1.8E-02
700	4.6E-04	0.0E+00	7.6E-26	0	1.6E-04	3.0E-03	0	2.1E-02	8.7E-09	2.5E-02	4.5E-02	1.6E-03	8.8E-04	1.9E-02
750	5.0E-04	0.0E+00	1.2E-27	0	1.8E-04	3.3E-03	0	2.4E-02	1.0E-08	2.7E-02	4.5E-02	1.6E-03	8.9E-04	1.9E-02
800	5.5E-04	0.0E+00	2.0E-29	0	1.9E-04	3.8E-03	0	2.8E-02	1.1E-08	2.9E-02	4.6E-02	1.6E-03	9.0E-04	1.9E-02
850	5.9E-04	0.0E+00	3.3E-31	0	2.1E-04	4.2E-03	0	3.1E-02	1.3E-08	3.2E-02	4.6E-02	1.6E-03	9.1E-04	1.9E-02
900	6.4E-04	0.0E+00	5.4E-33	0	2.3E-04	4.7E-03	0	3.5E-02	1.4E-08	3.4E-02	4.6E-02	1.6E-03	9.2E-04	1.9E-02
950	6.9E-04	0.0E+00	8.9E-35	0	2.4E-04	5.1E-03	0	3.9E-02	1.6E-08	3.6E-02	4.7E-02	1.7E-03	9.3E-04	2.0E-02
1000	7.3E-04	0.0E+00	1.4E-36	0	2.6E-04	5.6E-03	0	4.3E-02	1.8E-08	3.9E-02	4.7E-02	1.7E-03	9.4E-04	2.0E-02
bckgrnd	NA[a]	0.013	0.08[b]	NA	NA	[c]	—	[c]	NA	[c]	1.94	0.084	NA	1.82

[a] NA = not available.

[b] The background soil value for tritium is 0.76 pCi/ml. The value of 0.08 pCi/g assumes an approximate soil moisture content of 10% in the background samples.

[c] The background soil activity levels of Pb-210, Ra-226, and Th-230 should be approximately equivalent to those tabulated for U-234 and U-238.

Table H-3.1-1
Parameter Values for Health Effects Equations

Parameter	Unit	Resident Farmer		Recreational/Worker	
		Value	**Reference**	**Value**	**Reference**
$IR_{s,a}$	mg/d	50	EPA 1997a[a]	50	EPA 1997a[a]
$IR_{s,c}$	mg/d	200	EPA 1997a[b]	400	EPA 1997a[c]
EF_a	d/y	350	EPA 1991a	50	BPJ[d]
EF_c	d/y	350	EPA 1991a	50	BPJ
ED_{a_carc}	y	24	EPA 1991a	24	EPA 1991a
ED_{a_nc}	y	30	EPA 1991a	30	EPA 1991a
ED_c	y	6	EPA 1991a	6	EPA 1991a
BW_a	kg	71.8	EPA 1997a[e]	71.8	EPA 1997a[e]
BW_c	kg	17.4	EPA 1997a[f]	17.4	EPA 1997a[f]
AT_{carc}	d	75 y X 365 d/y	EPA 1997	75 y X 365 d/y	EPA 1997
AT_{nc}	d	= ED × 365	EPA 1989	= ED × 365	EPA 1989
$InhR_a$	m^3/h	0.63	EPA 1997a[g]	1.6	EPA 1997a[h]
$InhR_c$	m^3/h	0.42	EPA 1997a[i]	1.2	EPA 1997a[j]
ET_a	h/d	20	BPJ	2	BPJ
ET_c	h/d	24	BPJ	2	BPJ
PEF	m^3/kg	5×10^7	[k]	5×10^7	[k]
SA_a	cm^2	5700	EPA 2001a[l]	5700	EPA 2001a[l]
SA_c	cm^2	2800	EPA 2001a[l]	2800	EPA 2001a[l]
AF_a	mg/cm^2-d	0.07	EPA 2001a[m]	0.07	EPA 2001a[m]
AF_c	mg/cm^2-d	0.2	EPA 2001a[m]	0.2	EPA 2001a[m]
IR_v	g/kg-d	1.2	EPA 1997b[n]	n/a[o]	incomplete pathway
CvF_v	unitless	0.2	Baes et al. 1984[p]	n/a	incomplete pathway
CF_v	unitless	1	BPJ	n/a	incomplete pathway
IR_f	g/kg-d	1.4	EPA 1997b[q]	n/a	incomplete pathway
CvF_f	unitless	0.2	Baes et al. 1984[p]	n/a	incomplete pathway
CF_f	unitless	1	BPJ	n/a	incomplete pathway
EF_p	d/y	365	[r]	n/a	incomplete pathway
BW_p	kg	60	EPA 1997b[s]	n/a	incomplete pathway
ET_{in}	h/d	18	EPA 1997c[t]	n/a	incomplete pathway

Table H-3.1-1 (continued)

Parameter	Unit	Resident Farmer		Recreational/Worker	
		Value	Reference	Value	Reference
DRF	unitless	0.7	EPA 1991b	n/a	incomplete pathway
ρ_b	g/cm^3	1.4	see F-3.0	1.4	see F-3.0

[a] Central tendency estimate, no upper-bound provided; assumes 100% of daily soil ingestion is of soil from the affected area.

[b] Conservative estimate of the mean; assumes 100% of daily soil ingestion is of soil from the affected area.

[c] Upper percentile estimate; assumes 100% of daily soil ingestion is of soil from the affected area.

[d] BPJ = best professional judgment. Values are intended to be consistent with reasonable maximum exposure conditions. Values of CF_v and CF_f result in 100% of garden plant roots within the 1-cm contaminated surface soil layer.

[e] Recommended mean body weight of adult; Chapter 7.3.

[f] Mean body weight of male and female children, age 4; Table 7-3.

[g] Recommended mean value for adult men.

[h] Recommended mean value for children ages 6–8 yr.

[i] Recommended short-term adult exposure value for moderate activities.

[j] Recommended short-term child exposure value for moderate activities.

[k] Based on an average of 15 PM_{10} measurements (2×10^{-8} kg/m^3) at the Laboratory between 1990 and 1998 recorded in Environmental Surveillance Reports.

[l] Recommended values, Section 3.2.2.1.

[m] Recommended values, Section 3.2.2.3.

[n] 75th percentile of seasonally adjusted consumer intake of homegrown vegetables for Western U.S., corrected by 18% average preparation loss for corn, pumpkin, peppers, and tomatoes; Tables 13-33 and 13-7.

[o] n/a = not applicable.

[p] Weighted average of protected produce; Table 2.3.

[q] 75th percentile of seasonally adjusted consumer intake of homegrown fruit for Western U.S., corrected by 23% average preparation loss for apples, pears, and peaches; Tables 13-33 and 13-6.

[r] Exposure frequency is set at 100% because IR_v and IR_f are based on survey data adjusted for exposure across a full calendar year.

[s] Recommended value for survey population that includes adults and children; Section 9.2.2.

[t] Based on a 90th percentile value for time spent outdoors; Table 15-132.

Soil Ingestion

$$HQ = (C_{s,i} \times IR_s \times EF \times ED \times 10^{-6}\ \text{kg/mg}) / (BW \times AT_{nc} \times RfD_{ing,i})$$

where $C_{s,i}$ = concentration of contaminant i in soil (mg/kg soil),

IR_s = soil ingestion rate (mg of soil/d),

EF = exposure frequency (d/y),

ED = exposure duration (y),

BW = body weight (kg),

AT_{nc} = averaging time for noncarcinogenic effects (d), and

$RfD_{ing,i}$ = ingestion reference dose, contaminant i (mg/kg-d).

Dust Inhalation

$$HQ = (C_{s,i} \times InhR \times ET \times EF \times ED) / (PEF \times BW \times AT_{nc} \times RfD_{inh,i})$$

where $C_{s,i}$ = concentration of contaminant i in soil (mg/kg soil),

InhR = inhalation rate (m^3/h),

ET = exposure time (h/d),

EF = exposure frequency (d/y),

ED = exposure duration (y),

PEF = particulate emission factor (m^3/kg),

BW = body weight (kg),

AT_{nc} = averaging time for noncarcinogenic effects (d), and

$RfD_{inh,i}$ = inhalation reference dose, contaminant i (mg/kg-d).

Ingestion of Garden Produce

$$HQ = (C_{s,i} \times K_{p\text{-}s,\, i} \times [(IR_v \times CvF_v \times CF_v) + (IR_f \times CvF_f \times CF_f)] \times EF_p \times ED \times 10^{-3} \text{ kg/g}) / (AT_{nc} \times RfD_{ing,i})$$

where $C_{s,i}$ = concentration of contaminant i in soil (mg/kg soil);

$K_{p\text{-}s,\, i}$ = plant to soil concentration ratio for produce, contaminant i (mg/kg dry plant per mg/kg soil);

IR_v = ingestion rate of vegetables; wet weight (g/kg-d);

CvF_v = dry-to-wet weight conversion factor for vegetables;

CF_v= correction factor for rooting depth of vegetables, calculated as the mixing (cultivation) depth divided by the root depth (not to exceed 1.0);

IR_f = ingestion rate of fruits; wet weight (g/kg-d);

CvF_f = dry-to-wet weight conversion factor for fruits;

CF_f = correction factor for rooting depth of fruits, calculated as the mixing (cultivation) depth divided by the root depth (not to exceed 1.0);

EF_p = exposure frequency for produce ingestion pathway (d/y);

ED = exposure duration (y);

AT_{nc} = averaging time for noncarcinogenic effects (d); and

$RfD_{ing,i}$ = ingestion reference dose, contaminant i (mg/kg-d).

Dermal Absorption from Soil

$$HQ = (C_{s,i} \times ABS_i \times AF \times SA \times EF \times ED \times 10^{-6} \text{ kg/mg}) / (BW \times AT_{nc} \times (RfD_{ing\ i} \times GI_{abs,i})$$

where $C_{s,i}$ = concentration of contaminant i in soil (mg/kg soil),

ABS_i = skin absorption factor, contaminant i (unitless),

AF = adherence factor (mg/cm^2-d),

SA = exposed surface area (cm^2),

EF = exposure frequency (d/y),

ED = exposure duration (y),

BW = body weight (kg),

AT_{nc} = averaging time for noncarcinogenic effects (d),

$RfD_{ing,i}$ = ingestion reference dose, contaminant i (mg/kg-d), and

$GI_{abs,i}$ = gastrointestinal absorption fraction, contaminant i (unitless).

INCREMENTAL CANCER RISK—Cancer risk for an individual chemical is defined by the ICR, which is calculated as the product of exposure to a single chemical (i) and the cancer slope factor for that chemical. Lifetime cancer risk is considered to be additive over time, therefore exposures during childhood and adulthood are summed to calcuate the ICR. As with the HQ calculations, calculations for the produce ingestion pathway pertain to a general population of both adults and children because the ingestion rate information is based on survey data across all ages (see Table H-3.1-1).

Soil Ingestion

$$ICR = (C_{s,i} \times [(IR_{s,a} \times EF_a \times ED_a / BW_a) + (IR_{s,c} \times EF_c \times ED_c / BW_c)] \times SF_{ing,i} \times 10^{-6}\ kg/mg) / (AT_{carc})$$

where $C_{s,i}$ = concentration of contaminant i in soil (mg/kg soil),

$IR_{s,c}$ = child soil ingestion rate (mg of soil/d),

EF_c = child exposure frequency (d/y),

ED_c = child exposure duration (y);

BW_c = child body weight (kg),

$IR_{s,a}$ = adult soil ingestion rate (mg of soil/d),

EF_a = adult exposure frequency (d/y),

ED_a = adult exposure duration (y),

BW_a = adult body weight (kg),

$SF_{ing,i}$ = ingestion slope factor, contaminant i $(mg/kg\text{-}d)^{-1}$, and

AT_{carc} = averaging time for carcinogenic effects (d).

Dust Inhalation

$$ICR = (C_{s,i} \times EF \times [(InhR_a \times ET_a \times ED_a / BW_a) + (InhR_c \times ET_c \times ED_c / BW_c)] \times SF_{inh,i}) / (PEF \times AT_{carc})$$

where $C_{s,i}$ = concentration of contaminant i in soil (mg/kg soil),

EF = exposure frequency (d/y),

$InhR_c$ = child inhalation rate (m^3/h),

ET_c = child exposure time (h/d),

ED_c = child exposure duration (y),

BW_c = child body weight (kg),

$InhR_a$ = adult inhalation rate (m^3/h),

ET_a = adult exposure time (h/d),

ED_a = adult exposure duration (y),

BW_a = adult body weight (kg),

PEF = particulate emission factor (m^3/kg),

$SF_{inh,i}$ = slope factor for inhalation, contaminant i $(mg/kg\text{-}d)^{-1}$, and

AT_{carc} = averaging time for carcinogenic effects (d).

Ingestion of Garden Produce

$$ICR = (C_{s,i} \times K_{p\text{-}s,\,i} \times [(IR_v \times CvF_v \times CF_v) + (IR_f \times CvF_f \times CF_f)] \times EF_p \times ED \times SF_{ing,i} \times 10^{-3}\ kg/g) / (AT_{carc})$$

where $C_{s,i}$ = concentration of contaminant i in soil (mg/kg soil);

$K_{p\text{-}s,\,i}$ = plant to soil concentration ratio for produce, contaminant i (mg/kg dry plant per mg/kg soil);

IR_v = ingestion rate of vegetables; wet weight (g/kg-d);

CvF_v = dry-to-wet weight conversion factor for vegetables;

CF_v= correction factor for rooting depth of vegetables, calculated as the mixing (cultivation) depth divided by the root depth (not to exceed 1.0);

IR_f = ingestion rate of fruits; wet weight (g/kg-d);

CvF_f = dry-to-wet weight conversion factor for fruits;

CF_f = correction factor for rooting depth of fruits, calculated as the mixing (cultivation) depth divided by the root depth (not to exceed 1.0);

EF_p = exposure frequency for produce ingestion pathway (d/y);

ED = exposure duration (y);

AT_{carc} = averaging time for carcinogenic effects (d); and

$SF_{ing,i}$ = ingestion slope factor, contaminant i $(mg/kg\text{-}d)^{-1}$.

Dermal Absorption from Soil

$$ICR = (C_{s,i} \times ABS_i \times [(SA_c \times EF_c \times AF_c \times ED_c / BW_c) + (SA_a \times EF_a \times AF_a \times ED_a / BW_a)] \times (SF_{ing,i} / GI_{abs,i}) \times 10^{-6}\ kg/mg) / (AT_{carc})$$

where $C_{s,i}$ = concentration of contaminant i in soil (mg/kg soil),

ABS_i = skin absorption factor, contaminant i (unitless),

SA_c = child exposed surface area (cm^2),

EF_c = child exposure frequency (d/y),

AF_c = child adherence factor (mg/cm^2-d),

ED_c = child exposure duration (y),

BW_c = child body weight (kg),

SA_a = adult exposed surface area (cm^2),

EF_a = adult exposure frequency (d/y),

AF_a = adult adherence factor (mg/cm^2-d),

ED_a = adult exposure duration (y),

BW_a = adult body weight (kg),

$SF_{ing,i}$ = ingestion slope factor, contaminant i $(mg/kg\text{-}d)^{-1}$,

$GI_{abs,i}$ = gastrointestinal absorption fraction, contaminant i (unitless), and

AT_{carc} = averaging time for carcinogenic effects (d).

RADIATION DOSE—The radiation dose associated with the EPA dose conversion factors used here is the annual committed effective dose equivalent (internal) or annual effective dose equivalent (external), expressed in units of millirem per year. Dose is calculated as the product of the exposure level to a single radionuclide (i) and the dose conversion factor for that radionuclide. Although the dose conversion factors apply to adults, not children, exposure parameters for children were used in the calculations if a higher rate of exposure resulted. This is analogous to the use of the larger of the results for child or adult for the calculation of the hazard quotient, discussed above. As with the HQ and ICR calculations, calculations for the produce ingestion pathway pertain to a general population of both adults and children because the ingestion rate information is based on survey data across all ages (see Table H-3.1-1). Consistent with EPA guidance (EPA 1989, 8021), dose via dermal absorption is not quantified as it is likely to be negligible compared with the other exposure pathways.

Soil Ingestion

$$\text{Dose} = C_{s,i} \times IR_s \times EF \times DCF_{ing,i} \times 10^{-3}\ \text{g/mg}$$

where $C_{s,i}$ = concentration of contaminant i in soil (pCi/g soil),

IR_s = soil ingestion rate (mg of soil/d),

EF = exposure frequency (d/y), and

$DCF_{ing,i}$ = dose conversion factor for ingestion, contaminant i (mrem/pCi).

Dust Inhalation

$$\text{Dose} = (C_{s,i} \times InhR \times ET \times EF \times DCF_{inh,i} \times 1000\ \text{g/kg}) / (PEF)$$

where $C_{s,i}$ = concentration of contaminant i in soil (pCi/g soil),

InhR = inhalation rate (m^3/h),

ET = exposure time (h/d),

EF = exposure frequency (d/y),

$DCF_{inh,i}$ = dose conversion factor for inhalation, contaminant i (mrem/pCi), and

PEF = particulate emission factor (m^3/kg).

Ingestion of Garden Produce

$$\text{Dose} = C_{s,i} \times K_{p\text{-}s,\,i} \times [(IR_v \times CvF_v \times CF_v) + (IR_f \times CvF_f \times CF_f)] \times EF_p \times BW_p \times DCF_{ing,i}$$

where $C_{s,i}$ = concentration of contaminant i in soil (pCi/g soil);

$K_{p\text{-}s,\,i}$ = plant to soil concentration ratio for produce, contaminant i (pCi/g dry plant per pCi/g soil);

IR_v = ingestion rate of vegetables; wet weight (g/kg-d);

CvF_v = dry-to-wet weight conversion factor for vegetables;

CF_v= correction factor for rooting depth of vegetables, calculated as the mixing (cultivation) depth divided by the root depth (not to exceed 1.0);

IR_f = ingestion rate of fruits; wet weight (g/kg-d);

CvF_f = dry-to-wet weight conversion factor for fruits;

CF_f = correction factor for rooting depth of fruits, calculated as the mixing (cultivation) depth divided by the root depth (not to exceed 1.0);

EF_p = exposure frequency for produce ingestion pathway (d/y);

BW_p = body weight for produce ingestion pathway (kg); and

$DCF_{ing,i}$ = dose conversion factor for ingestion, contaminant i (mrem/pCi).

External Irradiation from Soil

$$\text{Dose} = C_{s,i} \times EF \times [(ET_{in} \times DRF) + (ET - ET_{in})] \times DCF_{ext,i} \times \rho_b \times 1.14 \text{ x } 10^{-4} \text{ y/h}$$

where $C_{s,i}$ = concentration of contaminant i in soil (pCi/g soil),

EF = exposure frequency (d/y),

ET = exposure time at site (h/d),

ET_{in} = indoor exposure time (h/d),

DRF = dose reduction factor for shielding offered by structure (unitless),

$DCF_{ext,i}$ = external radiation dose conversion factor, contaminant i (mrem-cm^3 / pCi-y), and

ρ_b = bulk soil density (g/cm^3).

H-3.1.2 Recreational Scenario Equations

CHEMICAL HAZARD—The chemical hazard for the recreational scenario is based on incidental soil ingestion, dust inhalation, and dermal absorption exposure pathways, using the input parameters provided in Table H-3.1-1. The equations used to calculate HQs for the incidental soil ingestion, dust inhalation and dermal absorption exposure pathways are identical to those presented in Section H-3.1.1. As in the residential scenario calculations, the larger of the result of the adult or child calculations is used in the risk assessment. Exposure caused by the ingestion of garden produce is not included as a pathway for the recreational scenario.

INCREMENTAL CANCER RISK—Cancer risk for the recreational scenario is calculated for the sum of child and adult exposure via incidental soil ingestion, dust inhalation, and dermal absorption from soil. The equations used to calculate ICR for the recreational user are identical to those presented in Section

H-3.1.1 for these three exposure pathways. Parameter values are listed in Table H-3.1-1. Ingestion of garden produce is not included as an exposure pathway for the recreational scenario.

RADIATION DOSE—The radiation dose for the recreational scenario is based on exposure to radionuclides via incidental soil ingestion, dust inhalation and external irradiation from soil. The equations used to calculate radiation dose for these three pathways are identical to those presented in Section H-3.1.1 for the residential scenario. Parameter values are listed in Table H-3.1-1. As for the residential calculations, parameter values associated with exposure for a child were employed if these resulted in a larger calculated dose.

H-3.1.3 Site Worker Scenario Equations

CHEMICAL HAZARD— The chemical hazard for the site worker scenario is based on incidental soil ingestion, dust inhalation, and dermal absorption exposure pathways, using the input parameters provided in Table H-3.1-1. The equations used to calculate HQs for the incidental soil ingestion, dust inhalation and dermal absorption exposure pathways are identical to those presented in Section H-3.1.1. However, unlike the residential scenario calculations, hazard is only calculated and presented for an adult receptor. Exposure caused by the ingestion of garden produce is not included as a pathway for the site worker scenario.

INCREMENTAL CANCER RISK—Cancer risk for the site worker scenario is calculated for adult exposure via incidental soil ingestion, dust inhalation, and dermal absorption from soil. The equations used to calculate ICR for the site worker user are identical to those presented in Section H-3.1.1 for these three exposure pathways. Parameter values are listed in Table H-3.1-1. Ingestion of garden produce is not included as an exposure pathway for the site worker scenario.

RADIATION DOSE— The radiation dose for the site worker scenario is based on exposure to radionuclides via incidental soil ingestion, dust inhalation and external irradiation from soil. The equations used to calculate radiation dose for these three pathways are identical to those presented in Section H-3.1.1 for the residential scenario. However, unlike the residential scenario calculations, hazard is only calculated and presented for an adult receptor. Parameter values are listed in Table H-3.1-1. Ingestion of garden produce is not included as an exposure pathway for the site worker scenario.

H-3.2 Input Parameter Values

Exposure-related input parameter values for the equations defined in Section H-3.1 are provided in Table H-3.1-1. References for some of the values have accompanying notes referred to by number. These notes explain the specific nature of the parameter value obtained in the reference text. Values for recreational and worker scenarios with the subscript “c” refer to a child receptor and are pertinent only for the recreational scenario.

Chemical-specific parameter values for dose conversion factors, reference doses, and slope factors are provided in Table H-3.2-1. Other chemical-specific parameter values are provided in Table H-3.2-2.

Internal DCFs for soil ingestion and inhalation, incorporating the radioactivity of short-lived daughters, were borrowed from tables obtained within RESRAD Version 5.95. The DCFs originate with Federal Guidance Report (FGR) 11 (EPA 1988, 50123). For external DCFs at 1 cm soil thickness, effective dose coefficients were obtained from FGR 12 (EPA 1993, 62798). The conversion factor from Sv-m^3/Bq-s to mrem-cm^3/pCi-yr used was 1.167E+17. Short-lived daughters were included in the external DCF values (when necessary) by summing individual dose coefficients to the next primary nuclide. For example, the external DCF for U-235 is the sum of those for U-235 and Th-231.

Table H-3.2-1
Toxicity Parameter Values for Health Effects Equations

Analyte	**DCF_{ing} (mrem/pCi)**	**DCF_{inh} (mrem/pCi)**	**DCF_{ext} (mrem-cm^3/ pCi-yr)**	**RfD_{ing} (mg/kg-d)**	**RfD_{inh} (mg/kg-d)**	**SF_{ing} (kg-d/mg)**	**SF_{inh} (kg-d/mg)**
Ac-227	0.0148	6.72	0.846	—[a]	—	—	—
Ag	—	—	—	0.005	NA[b]	NC[c]	NC
Al	—	—	—	1.0	0.001	NC	NC
Am-241	0.00364	0.444	0.0134	—	—	—	—
Ba	—	—	—	0.07	1E-04	NC	NC
Be	—	—	—	0.002	5.7E-06	NC	8.4
Cd	—	—	—	0.001	2E-04	NC	6.3
Cyanuric Acid	—	—	—	0.033	0.033	NC	NC
Cr	—	—	—	0.018	1.9E-04	NC	42
Cu	—	—	—	0.04	NA	NC	NC
Fe	—	—	—	0.3	NA	NC	NC
H-3	6.4E-08	6.4E-08	0	—	—	—	—
Np-237	0.00444	0.54	0.16	—	—	—-	—
Hg	—	—	—	3E-04	8.6E-05	NC	NC
Pa-231	0.0106	1.28	0.0268	—	—	—	—
Pb	—	—	—	[d]	[d]	NC	NC
Pb-210	0.00727	0.0232	0.00162	—	—	—	—
Pu-238	0.0032	0.392	7.4E-05	—	—	—	—
Pu-239	0.00354	0.429	6.55E-05	—	—	—	—
Pu-240	0.00354	0.429	7.24E-05	—	—	—	—
Pu-241	6.85E-05	0.00825	1.1E-06	—	—	—	—
Pu-242	0.00336	0.411	6.1E-05	—	—	—	—
Ra-226	0.00133	0.0086	1.26	—	—	—	—
RDX	—	—	—	0.003	0.003	0.11	0.11
Th-230	5.48E-04	0.326	2.72E-04	—	—	—	—
U-234	2.83E-04	0.132	1.18E-04	0.003	NA	NC	NC
U-235	2.67E-04	0.123	0.119	0.003	NA	NC	NC
U-236	2.69E-04	0.125	7.26E-05	0.003	NA	NC	NC
U-238	2.69E-04	0.118	0.0161	0.003	NA	NC	NC

[a] — = not applicable to this class of contaminant.

[b] NA = not available.

[c] NC = not carcinogenic, or no chemical slope factor published.

[d] Lead soil concentrations may be compared to the EPA residential screening benchmark of 400 mg/kg.

Table H-3.2-2
Chemical-Specific Parameter Values for Health Effects Equations

Analyte	**$K_{p\text{-}s,\,i}$**	**ABS_i**	**$GI_{abs,i}$**
Ac (actinium)	0.00035	0	1
Ag (silver)	0.1	0	0.04
Al (aluminum)	0.00065	0	1
Am (americium)	0.00025	0	1
Ba (barium)	0.015	0	0.07
Be (beryllium)	0.0015	0	0.007
Cd (cadmium)	0.15	0.001	0.025
Cyanuric Acid	9.442	0.1	1
Cr (chromium)	0.0045	0	0.013
Cu (copper)	0.25	0	1
Fe (iron)	0.001	0	1
H3 (tritium)	3.2	1	1
Np (neptunium)	0.01	0	1
Hg (mercury)	0.2	0	1
Pa (protactinium)	0.00025	0	1
Pb (lead)	0.009	0	1
Pu (plutonium)	0.000045	0	1
Ra (radium)	0.0015	0	1
RDX	9.442	0.1	1
Th (thorium)	0.000085	0	1
U (uranium)	0.004	0	1

SF and RfD values were obtained according to the following prioritization of sources: (1) EPA's Integrated Risk Information System (IRIS) (EPA 2001b), (2) EPA's Health Effects Assessment Summary Tables (HEAST) (EPA 1997, 66597), and (3) provisional values published as internal documents by EPA's National Center for Environmental Assessment (NCEA). Unit risk values and reference concentrations published by EPA were converted to SF and RfD values, respectively, assuming a breathing rate 20 m^3/d and a 70 kg body weight. Route-to-route extrapolation to obtain SF or RfD values was performed only for organic chemicals.

Slope factor and reference dose values for specific chemical contaminants were obtained from the following sources:

Aluminum—The oral RfD is from the NCEA publication "Risk assessment issue paper for: toxicity and carcinogenicity of aluminum". The inhalation RfD is from the NCEA publication "Risk assessment issue paper for: derivation of provisional RfC for aluminum".

Barium—The oral RfD was obtained from IRIS. The inhalation RfD was obtained from the 1997 revision of HEAST.

Beryllium—All values were obtained from IRIS.

Cadmium—All values were obtained from IRIS. The cadmium RfD pertains to food ingestion.

Chromium—All values were calculated based on values obtained from IRIS. Chromium toxicity values reflect an assumed 6:1 ratio of chromiumIII and chromiumVI.

Copper—The copper oral RfD is from the NCEA publication “Interim oral RfD for copper”.

Cyanuric Acid—IRIS values for hexazinone used as a surrogate, see text below. Route-to-route extrapolation used for inhalation pathway.

Iron—The oral RfD is from the NCEA publication “Risk assessment issue paper for: derivation of provisional RfD for iron”.

Lead—EPA does not publish toxicity values for lead. Calculated soil concentrations of lead were compared to the EPA residential soil screening value of 400 mg/kg, derived by EPA using a pharmacokinetic uptake model.

Mercury—The oral RfD pertains to mercuric chloride. The inhalation RfD pertains to elemental mercury. Both values were obtained from IRIS.

RDX—All values were obtained from IRIS. Route-to-route extrapolation used for inhalation pathway.

Uranium—The oral RfD is from IRIS.

Cyanuric acid (2,4,6-trihydroxy-1,3,5-triazine) is an herbicide based on atrazine. It’s use in mock HE was probably due to a gross structural similarity to RDX, for which the parent molecule is cyclohexane with nitrogen substituted for carbon at the 1, 3, and 5 positions of the ring. Atrazine is a benzene ring (i.e., containing double bonds) where nitrogen is substituted for carbon at the 1, 3, and 5 positions of the ring. Cyanuric acid differs from atrazine by the substitution of a hydroxyl (-OH) group for a hydrogen atom at the 2, 4, and 6 positions of the ring. EPA does not publish toxicity values for cyanuric acid, although it does publish such values for various other herbicides based on atrazine. However, most of these herbicides differ from cyanuric acid in that they contain amino (-NH_2) or substituted amino groups and/or chlorine atoms. These chemical substitutions are likely to cause the metabolism and toxicity of these herbicides to differ relative to cyanuric acid. An exception in this regard among the atrazine-based herbicides is hexazinone, which has no amino or chlorine substitutions. However, it differs from the other atrazine-based herbicides in that it has only has a single double bond instead of three such bonds.

The chemical oral reference dose values published by EPA for the atrazine-based herbicides range from 0.001 to 0.035 mg/kg-d. Information on the potential carcinogenicity of cyanuric acid was not discovered in EPA publications nor in the monographs of the International Agency for Research on Cancer.

ametryn	0.009 mg/kg-d
atrazine	0.035 mg/kg-d
cyanazine	0.002 mg/kg-d
cyromazine	0.0075 mg/kg-d
hexazinone	0.033 mg/kg-d
prometon	0.015 mg/kg-d
prometryn	0.004 mg/kg-d
propazine	0.02 mg/kg-d

simazine	0.005 mg/kg-d
terbutryn	0.001 mg/kg-d

In 1981, EPA published an LD_{50} value of 5 g/kg, from oral administration in rats, in a draft Chemical Hazard Information Profile: Cyanuric Acid and Chlorinated Derivatives (reported in TOXNET, Hazardous Substances DataBank, National Library of Medicine, http://toxnet.nlm.nih.gov). No-Observable-Effects-Levels (NOEL) in a single-dose rat and rabbit study of 10 g/kg, and a 0.68% dose in 6-month (rat) and 6- and 12-month (dog) studies are provided in Patty's Industrial Hygiene and Toxicology, 3rd Edition, 1981–1982 (reported in TOXNET, Hazardous Substances DataBank, National Library of Medicine (http://toxnet.nlm.nih.gov).

The NOEL used by EPA to calculate the oral RfD for hexazinone was 200 ppm (0.2 g/kg) in food. This value is considerably lower (i.e., shows higher toxicity) than those reported in TOXNET for cyanuric acid, and hexazinone is unique among the atrazine-based herbicides for which EPA publishes toxicity values in that it does not contain amino ($-NH_2$) or substituted amino groups and/or chlorine atoms. Among the atrazine-based herbicides the oral RfD for hexazinone is proposed as a surrogate for cyanuric acid based on chemical/structural similarity and the available animal toxicity data.

An inventory chemical that was not incorporated in the GoldSim system model is lithium hydride. Lithium hydride is hygroscopic and rapidly decomposes in water to form lithium hydroxide and hydrogen (Merck Index, 1996). In the environment, therefore, it is the various salts of lithium that might form following the release of the lithium ion that are of concern. In Casarett and Doull's Toxicology (Amdur et al., eds, 1991), daily lithium intake is said to be about 2 mg. Related to a child soil ingestion rate of 200 mg/d (see Table H-3.0-3), two mg/day would equate to 1% lithium by weight in soil, or 10,000 mg/kg. 10,000 mg/kg is a soil concentration that is orders-of-magnitude beyond those for other metals shown in Table H-3.0-1. Another reference value for lithium toxicity via exposure to contaminated soils is the soil screening value published by EPA Region 6 (http://www.epa.gov/earth1r6/6pd/rcra_c/pd-n/screen.htm). The residential screening value of 1,600 mg/kg is subject to considerable uncertainty because it was calculated using a lithium reference dose that has been withdrawn by EPA pending further study. However, the value of 1,600 mg/kg is also much higher than the soil concentration of any metal in the MDA H inventory.

The plant-soil ratios ($K_{p\text{-}s,i}$) were taken from Figure 2.2 of Baes et al. (1984, 59788). These values represent the soil to plant transfer coefficient (B_r) for reproductive portions of food crops and feed plants, which form the bulk of garden produce. A value for RDX, which is not published in Baes et al., was obtained from the October 2001 version of the ECORISK database (LANL 2001, 71211), which was developed in collaboration with the regulatory authorities. A value for tritium, which exists in the form of water, is not published in either reference. A value for tritium was calculated as the assumed water content of produce (0.8) divided by an assumed water content of garden soil (0.25). No value was discovered for cyanuric acid; the value for RDX, a structurally similar molecule, was used as a surrogate.

The dermal absorption fraction (ABS_i) is used in the dermal pathway equations to account for the amount of a chemical that may be absorbed through the skin from soil adhering to the skin surface. The values were obtained from Exhibit 3.4 of Risk Assessment Guidance for Superfund, Part E (EPA 2000, 71431). In accordance with this guidance, a default of zero (no skin uptake) was applied for metals and radionuclides with no published values. A default value of 0.1 was applied for semivolatile organic chemicals (in this case, RDX and cyanuric acid).

The gastrointestinal absorption fraction ($GI_{abs,i}$) is used in the dermal pathway equations to modify oral toxicity values for application to dermal absorption. The values were obtained from Exhibit 4.1 of Risk

Assessment Guidance for Superfund, Part E (EPA 2000, 71431). In accordance with this guidance, a default value of 100% was applied to chemicals for which specific values are not published.

H-4.0 INTERPRETATION OF RESULTS FOR THE LONG-TERM IMPACTS ASSESSMENT FOR ALTERNATIVES 1, 2, AND 3

There are several aspects of the long-term human health impacts assessment under Alternative 1 that require consideration to understand the applicability of the recreational and residential scenario results. These include the following components of the GoldSim system-level model, all described in greater detail in Sections H-2.0 and H-3.0: inventory and release models; biotic transport models; erosion, infiltration and vadose transport, and diffusion models; exposure models; and health effects models.

Inventory and Release Models: As discussed in Section 2, uncertainty in the quantities of chemicals and radionuclides disposed at MDA H was addressed by applying protective assumptions to the mass estimates used in the human health impacts assessments. Because protective assumptions were applied across many contaminants, the total mass of contaminants contained in the MDA H GoldSim model exceeds the recorded mass of total waste disposed in the shafts. The total mass of all waste in MDA H disposal shafts is recorded to be approximately 390,000 lb in the waste disposal records. By contrast, the total mass of chemicals and radionuclides used in the GoldSim model (which excludes such material as recording media and graphite) was approximately 412,000 lb. The mass estimate of certain constituents (for example, uranium and cadmium) have a lower degree of protective bias that most other constituents because better information was available to support the inventory estimate. An evaluation of the effect of uncertainty in the mass of uranium on residential dose is provided below.

The conservative nature of the release model is described in Appendix F-3.0. All chemicals and radionuclides with the exception of uranium were assumed to be immediately available to burrowing animals and plant roots and infiltrating water. In reality, the time required for the various waste forms to degrade such that all chemicals and radionuclides would be available to be solubilized in water and/or sufficiently friable to be excavated by burrowing animals would be considerable. Animal excavation would also be inhibited until the concrete caps above the shafts had degraded, although plant roots could likely penetrate any gap between the cap and the tuff. In order to evaluate the potential significance of assuming immediate availability of contaminants in the waste, the corrosion rate and form of uranium present under conditions likely to exist in the MDA H shafts was investigated (Appendix M). As described in Section 3.3, the GoldSim model was implemented using best-estimate assumptions for the rate at which uranium would become available for transport.

A range of values for residential dose was calculated based on uncertainty in the uranium inventory and the availability of the uranium for release to environmental media. The thick and thin solid lines in Figure H-4.0-1 reflect a residential dose estimate using upper-bound and best-estimate values, respectively, for both the inventory and availability of uranium-containing wastes. The best-estimate value uses the best-estimate value for the uranium inventory and employs the assumption that DU is available only in its oxide form and, therefore, has a low corrosion rate. The upper-bound estimate uses a higher value for the uranium inventory and assumes that DU exists only in the hydride form and, therefore, 100% of the uranium inventory is immediately available for transport. The dotted line shows the residential dose using the upper bound uranium inventory and the assumption that DU is available only in its oxide form and has a low corrosion rate. Because the dotted line is closer to the best estimate dose curve, it may be inferred that uncertainty in the availability of DU over time has a greater impact on dose than uncertainty in the uranium inventory.

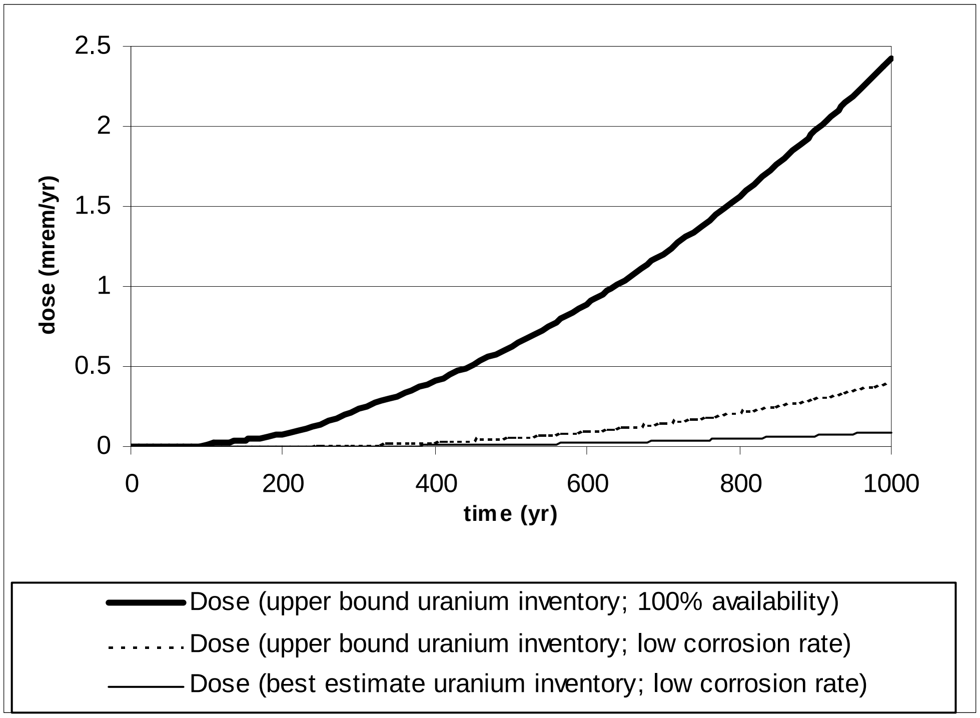


Figure H-4.0-1. Effect of uncertainty in uranium inventory and corrosion rate on residential dose

Information pertaining to the corrosion rate of uranium is provided in Appendix M. Uranium corrosion was evaluated relative to the likely shapes associated with DU, but has been applied to all uranium in the inventory. Details on the assumptions related to the physical configuration of uranium are provided in Section H-2.1. Information supporting development of best-estimate and upper-bound uranium inventory is contained in Section 2 of the CMS Report and Appendix B.

Approximately 99% of the upper-bound dose at 1000 yr is due to exposure via external irradiation. At earlier model times, soil and plant ingestion contribute approximately 15% to dose. At all times, however, radium-226 (a decay product of uranium-234) is responsible for almost all of the residential radiation dose. The difference between upper-bound and best-estimate values for estimated peak dose at 1000 yr is a factor of approximately 25, most of which is attributable to the incorporation of information on uranium corrosion over time. The upper-bound inventory with immediate availability, upper-bound inventory with low corrosion rate, and best-estimate inventory with low corrosion rate residential dose values at 1000 yr are approximately 2.4, 0.4, and 0.09 mrem/yr, respectively.

Because a decay product of uranium-234 is responsible for the great majority of residential dose, it may be inferred that uncertainty related to uranium inventory and release is of particular importance among the various inventory constituents. This analysis suggests that these uncertainties are not of a magnitude that could result in potential residential doses exceeding the target dose limit of 15 mrem/yr.

Biotic Transport Models. Among the transport model components of the GoldSim model, the biotic transport models have perhaps the greatest degree of uncertainty. The most obvious source of uncertainty is applying field data for burrow and plant root depths to biota that may intrude into the waste disposal shafts. The waste in the shafts was modeled as a homogenous material when in fact it is highly heterogenous and much of the volume of a shaft may be empty space. The implications are that plant roots encountering empty space may extend well beyond their normal limits in soil, while burrowing animals encountering empty space would have no reason to excavate material in order to form a cavity.

Another aspect of uncertainty in the biotic transport models is the applicability of general data on plant and animal density per unit area to conditions at MDA H. For example, deep-rooted plants and burrowing animals may preferentially locate themselves on the shafts because of the relative ease of penetrating the subsurface material compared to the tuff that underlies surface soils in adjacent areas. It is possible that over time the ground surface above one or more shafts may subside as the waste within the shafts compacts into the void space between waste packages. Such subsidence could create small microclimates in the resulting depressions that, due to collection of water, favor the occurrence of certain plant and animal species. In such an event, the biotic density used in the model could significantly under-represent the actual density of these species above the disposal shafts.

Erosion, Infiltration and Vadose Transport, and Diffusion Models. The erosion model is also a source of considerable uncertainty in the GoldSim health effects model. The results of the expert elicitation described in Appendix F.2 of this report were actually distributions of values, from which “best estimates” were applied here. The standard deviations (for a normal distribution) of the estimates of erosion rates with and without gravel mulch were more than twice the average. Uncertainty in erosion rates under drought conditions was represented by the expert panel as a triangular distribution with a minimum of 2×10^{-4} m/yr, a maximum of 4×10^{-3} m/yr, and best estimate of 1×10^{-3} m/yr.

Another issue in the erosion model is the form of erosion considered. Sheet erosion is the type assumed in the GoldSim model, rather than erosion that occurs via rills and gullies. However, because the shafts are drilled into solid tuff, gully formation originating at the shafts is unlikely. A more likely scenario, because of the large amount of void space, would be subsidence of the shafts due to compaction of the wastes. Subsidence of the waste would probably be followed by deposition of soil into the depression formed, such that the thickness of the cap above the wastes would be effectively increased over time. However, there is a three foot concrete cap/plug over each of the shafts that would have to deteriorate sufficiently before subsidence would occur.

The uncertainty in the infiltration component of the GoldSim model (Appendix G), as it affects the dose, risk and hazard calculations, pertains mostly to the definition of the thickness of the soil layer that acts as the exposure medium. A relatively thin (1 cm) depth was used in the GoldSim model to maximize soil concentrations, but as a consequence of this the more soluble contaminants in surface soil are susceptible to loss into subsurface tuff via infiltration. The sensitivity of the health effects estimates to this variable was investigated by increasing the surface soil depth to 15 cm in GoldSim, while simultaneously decreasing the infiltration rate. The decrease in the infiltration rate reflects the fact that proportionally more water may be lost to evapotranspiration from 15 cm of soil than from just 1 cm of soil. It was determined that the infiltration rate of water through surface soil would have to be decreased from 470 mm/yr to 50 mm/yr before the effect of the greater soil thickness was mitigated (i.e., when health effects were approximately the same as those calculated using a 1-cm soil thickness). In other words, an evapotranspiration rate greater than about 75% within the top 15 cm of soil would be required to generate calculated health effects greater than those shown in Figures 3.3-3 through 3.3-8.

Exposure Models. Uncertainty in future land use were accounted for by using two scenarios that are intended to bound likely land uses. The less likely residential land use scenario was used to represent high-intensity land use. As such, residential use forms the basis of soil screening values employed by the New Mexico Environment Department as well as EPA regional offices that publish such values. However, unlike such residential scenarios generally employed by state and EPA offices, the residential scenario developed for future land use at MDA H incorporates a garden produce exposure pathway.

The possibility of an individual growing a significant portion of their yearly produce within the 0.3-acre confines of MDA H is likely to be quite remote when better conditions for such an enterprise exist in the canyons below. Thus, the residential ICR and HI values (which are driven by the plant ingestion pathway) are considered to be biased in a protective manner relative to a traditional residential scenario used by NMED and EPA regional offices that lack this exposure pathway. Additionally, it was assumed that the soil concentrations throughout the root zone of garden produce and fruit trees were equal to concentrations in the 1-cm thick surface soil layer. This protective and simplifying assumption was made because it is difficult to accurately model soil contaminant concentrations over time as a function of infiltration, evaporation, and transpiration in a 6-in. or 1-ft zone of soil cultivation. Because residential HI values are less than 1, refinement of the model and parameter values used in the garden produce exposure pathway was not deemed necessary. If the plant ingestion pathway is removed from the residential scenario, ICR values, shown in Figure 3.3-5 would decrease to approximately 5×10^{-10} at 300 yr. Adult and child residential HI values, shown in Figure 3.3-7, would decrease to approximately 0.004 and 0.0004, respectively.

The evaluation of the recreational land-use scenario resulted in significantly lower health effects estimates than the less likely residential land use scenario. A recreational receptor was assumed to spend 2 hr/day, 50 day/yr, on site. These constraints are likely to be protective of casual uses such as hiking. The range between residential and recreational values for dose, ICR, and HI in Figures 3.3-3 through 3.3-8 may thus be considered to contain the range of potential health effects using protective exposure assumptions for both residential and recreational land use.

Health Effects Models. Three health effects endpoints were calculated to project impacts to humans: carcinogenic risk, noncarcinogenic hazard, and radiation dose. Health effects related to radionuclides were evaluated in terms of radiation dose, specifically the 50-yr whole-body effective dose equivalent. Radionuclide dose conversion factors (DCFs) were taken from Federal Guidance Report 11 (EPA 1988, 50123) and Federal Guidance Report 12 (EPA 1993, 62798).

The DCFs published by EPA were derived for an adult in an occupational setting and so are not directly applicable to a general population that includes infants and children. It is likely that infants and children are more susceptible to certain malignancies associated with radiation exposure than adults (ICRP 1997, 68750). This may be due to a greater proportional dose equivalent for children and/or a greater biological effectiveness per unit dose in children. It is important to note, however, that empirical dose-response models for the biological effects of ionizing radiation do not exist at the very low dose levels associated with projected future exposures at MDA H. The DCFs are based on dose-response data for populations exposed to very high doses over a short time period (for example, Japanese A-bomb survivors) and opinion regarding their applicability for low dose / long duration exposure differs.

Chemical slope factors are derived by EPA to be protective of both children and adults. Slope factors are usually calculated by EPA as an upper bound on the dose-response curve observed in human or animal data. There is a question whether the assumption of no threshold dose for carcinogenic effects upon which the cancer slope factors are based is in fact valid, or whether there may be little or no carcinogenicity at low exposure rates. In the case of RDX, which is responsible for most of the cancer risk in the residential scenario, there is only marginal evidence of carcinogenicity. Hence, EPA classifies RDX as only a Class C (possible) human carcinogen. The basis of the oral cancer slope factor for RDX is liver carcinomas and adenomas in a strain of mouse used for such testing. RDX has tested negative for carcinogenicity in other mutagenicity and genotoxicity studies.

The majority of chemical hazard in the residential exposure scenario was related to ingestion of mercury via the plant ingestion exposure pathway. The oral reference dose for mercury (as mercuric chloride) published by EPA in IRIS is based on subchronic feeding and subcutaneous administration studies in rats where autoimmune effects were identified as the critical endpoint. An uncertainty factor of 1000 was applied by EPA in calculating the mercuric chloride oral reference dose, which is based on the rat studies used by EPA to establish a drinking water advisory level for inorganic mercury. This uncertainty factor is relatively large and indicative of a high degree of uncertainty in potential chronic human health effects related to long-term exposure to inorganic mercury. Chemical hazard in the recreational exposure scenario was related to ingestion of both mercury and barium. Unlike inorganic mercury, however, the oral reference dose for bioavailable compounds of barium is based on human studies and has comparatively little associated uncertainty. There is a question, though, of whether barium present in disposed wastes at MDA H exists primarily in a bioavailable form such as barium chloride or as relatively inert compounds such as barium sulfate.

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Appendix I

Vapor-Phase Contaminant Transport Modeling

APPENDIX I VAPOR-PHASE CONTAMINANT TRANSPORT MODELING

I-1.0 INTRODUCTION

This appendix describes the modeling of the transport of vapor-phase contaminants (tritiated water vapor and radon gas) through the region beneath the land surface and above the regional aquifer, i.e., the vadose zone beneath the mesa at MDA H. This modeling was completed to support the assessment of Alternative 1 for the MDA H CMS.

In unsaturated porous, fractured rock in semi-arid climates (like MDA H), certain contaminants are transported as gases or vapors, constantly exchanging with contaminants in the pore water, resulting in complex situations where transport in the vapor phase can affect concentrations in the liquid phase.

Mesita del Buey is one of the drier mesas found at the Laboratory. Infiltration beneath the mesa is very low, approximately 0.04 in./yr (1 mm/yr) and occurs during snowmelts or intense summer thunderstorms, which leads to slightly higher moisture contents within the uppermost few meters of the mesa surface. During dry periods, evapotranspiration removes moisture from the surface of the mesa; permeable zones such as fractures and surge beds act as conduits for air and aid in the drying of the mesa (Turin and Rosenberg 1996, 63559). Net infiltration during these alternating infiltration episodes and normal drying conditions is difficult to measure. However, models of the site (Birdsell et al. 1999, 69792; Newman 1996, 59372) that are calibrated to moisture content data and in situ chloride profiles estimate that approximately 1 mm a year or less percolates below the root zone.

Volatile organic compounds have been measured at concentrations in the parts-per-billion range in subsurface tuff, but these concentrations do not affect the risk assessment. The only remaining measured contaminant that can travel readily in the vapor phase is tritium (Hydrogen-3). Because of the high measured tritium concentrations found in the soil moisture from the tuff samples at MDA H, tritium was retained as a vapor-phase contaminant for the risk analysis.

Radon gas (radon-222) was also included in the vapor-phase transport analysis because radon-222 is generated from the decay of uranium-238 and uranium-234, both of which are present in solid form in the estimated inventory.

I-1.1 Tritium Transport Modeling

Tritium was disposed of at MDA H in presumably empty, residually contaminated steel canisters that originally contained high-pressure tritium gas. The transport modeling was conducted to estimate first the amount of tritium already released in the subsurface. Then, the amount of tritium expected to be released to air and water over time was estimated in order to assess the dose from tritium for Alternative 1.

I-1.1.1 Conceptual Model of Tritium Transport

Tritium, radioactive hydrogen with a half-life of 12.4 years, exists in the environment as one of the hydrogen atoms attached to a water molecule. Being intimately bound to the water, tritium travels in the vapor phase as water vapor, not as a separate component (Knight 1996, 70152). Water vapor in equilibrium with tritiated water will have the same concentration of tritium as the source water. However, at 100% humidity and 10°C, water vapor contributes only about 1% to the partial pressure of the soil atmosphere. Additionally, the density of air is approximately 1000 times lower than the density of liquid water leading to an effective Henry’s constant for tritium of about 1×10^{-5} [(moles/L)air/(moles/L)water]. Within the porous media, equilibrium between water and water vapor is assumed (a well-mixed model) because diffusional transport is slow relative to the rate of tritium exchange between pore water and pore gas (Smiles et al. 1995, 70153). The combination of Henry's Law fractionation with equilibrium mixing results in very different plume behavior than would be generated by a volatile organic compound or a noble gas. First, the soil contains water that provides a very large sink for tritium. Second, the equilibrium condition requires that rapid transport in the vapor phase must first fill the available storage in the liquid phase before the vapor-phase plume can advance. Additionally, during the time of institutional control, the short half-life of tritium causes a large reduction in the inventory. For example, if the entire inventory of tritium were contained for 100 years, then released, the total amount available would be 0.36% of the initial amount.

I-1.1.2 Numerical Model of Tritium Transport

The porous-flow simulator FEHM (Zyvoloski et al. 1997, 70147) was used to model the behavior of tritium in the subsurface of MDA H. FEHM is a finite-volume code that models multi-phase fluid flow and reactive contaminant transport through porous and fractured media, including fully coupled thermodynamics. FEHM has been tested for both Henry's Law fractionation and unsaturated transport test problems. Peer reviewed publications show conclusively that FEHM can correctly model many complex phenomenon, including thermal air convection (Stauffer et al. 1997, 70219) and multi-component reactive transport (Viswanathan et al. 1998, 70220).

A site model of MDA H was constructed using the Sitewide Geologic Model (Carey et al. 1999, 66782) and the LANL DEM (Digital Elevation Model) data set. Combined, these two data sets allow creation of a numerical grid that maintains the canyon/ mesa topography and the general thicknesses and dips of the underlying geologic units (Gable et al. 1995, 70148; Figures I-1.1-1 and I-1.1-2). The topography of the mesa has been shown to be especially important for simulating diffusional transport of vapor-phase contaminants at TA-54 (Stauffer et al. 2000, 69794).

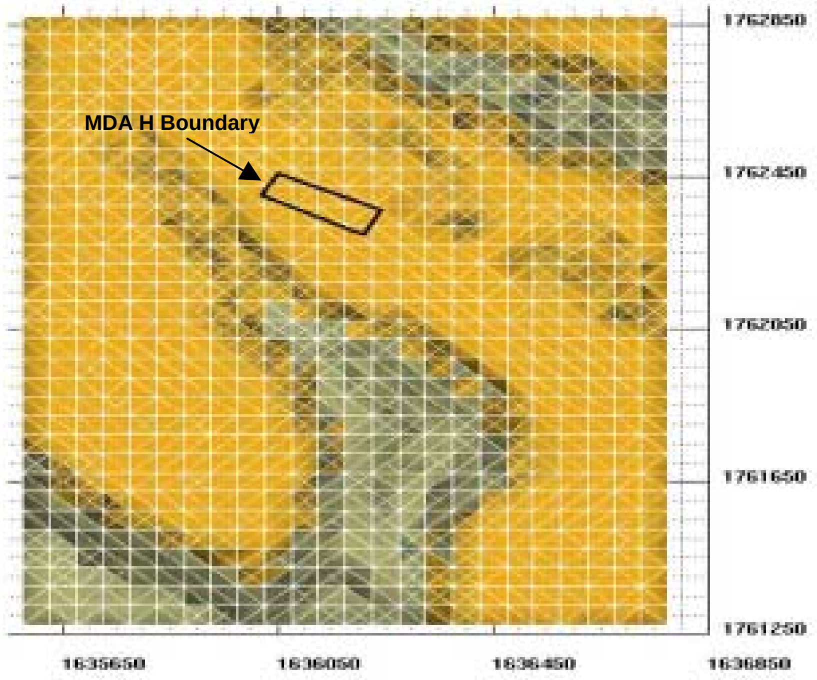
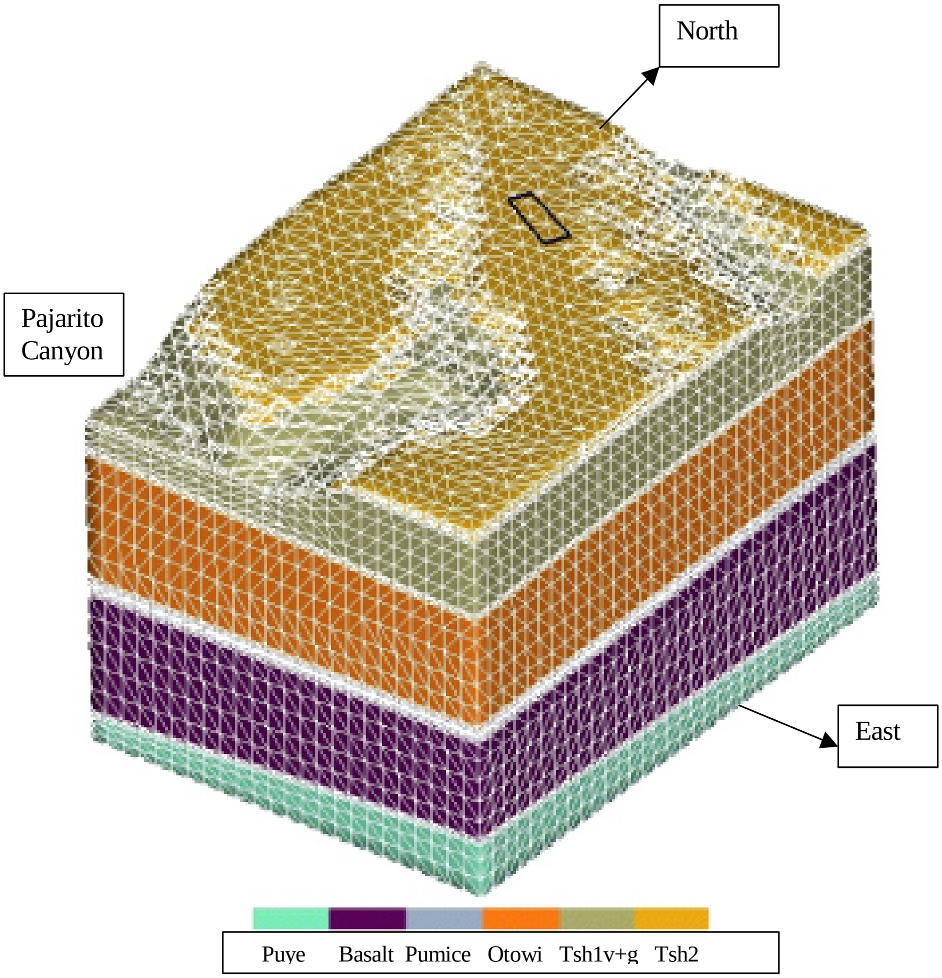


Figure I-1.1-1. The simulation mesh in relationship to the MDA H site boundary



Notes:
1. The surface of MDA H directly above the simulated source is located at an elevation of 6882.5 ft while the water table is located at approximately 5830 ft above sea level.
2. The MDA H site boundary (fence line) is shown on the surface with a black rectangle.

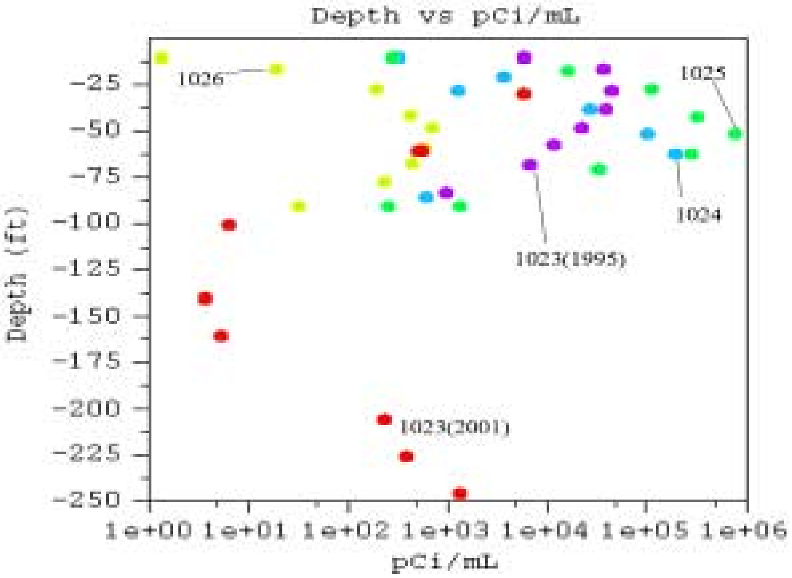
Figure I-1.1-2. View from the southeast corner of the simulation domain

The grid spacing in the horizontal direction is 50 ft, with variable spacing in the vertical direction. North is up in Figure I-1.1-1, and the axes are labeled in NM State Plane easting and northing in feet. The color scheme is the same for Figure I-1.1-2, showing that the surface of MDA H is located in the Tshirege Unit 2 (Qbt or Tsh in the figure) of the Bandelier Tuff.

The physical properties of the geologic units beneath MDA H have been well studied and the values used are those reported by Bird sell et al. (1999, 69792). Infiltration below the root zone is extremely slow on Mesita del Buey, allowing the modeling of only the processes of radioactive decay and diffusion of tritium in both liquid and vapor phases. Because only diffusion of tritium was modeled, the site modeling is fixed to background pressure and temperature fields (10°C, 0.08 Mpa) based on local measurements (Bowen, 1992, 12016). Saturations were fixed to values representing measurements made across Mesita del Buey. The initial condition for the transport simulations has no advection of liquid or vapor. The simulations use 2.5×10^{-3} m^2/s for the vapor-phase diffusion coefficient and 1×10^{-11} m^2/s for the liquid-phase diffusion coefficient in the top 60 ft of the mesa, while the rest of the domain uses a lower vapor diffusion coefficient of 4.0×10^{-6} m^2/s. The high vapor-phase diffusion coefficient is adapted from Vold (1996, 70155) and Vold and Eklund (1996, 70156) and is based on analysis of a large tritium plume at MDA G, located to the east on Mesita del Buey. Vold determined an effective diffusion coefficient, which incorporates near surface processes such as barometric pumping and evaporation of water vapor, and determined that this increased diffusion reached to approximately 60 ft below the surface. The lower vapor-phase diffusion coefficient is taken from Stauffer (2000, 69794) and is based on analysis of a large VOC plume at MDA L, located 1 km to the east of MDA H on Mesita Del Buey.

I-1.1.3 Results of Tritium Transport Modeling

Estimates of the current plume size were generated using FEHM and the measured subsurface tritium concentrations. The size of the plume was established by fixing the measured tritium at points within the numerical grid that correspond to the measurement points (Figure I-1.1-3). The model is then run until the tritium distribution reaches steady state. This technique provides an estimate of the plume size for a given set of measurement points and helps to constrain the total mass of the tritium plume. The estimate is expected to be high because the grid spacing requires fixing the measured points over a fairly large volume. For example, the closest node to the 8×10^5 pCi/mL measurement has a volume of 66,000 ft^3 (50 ft x 50 ft x 26 ft deep). The source region is meant to represent a combined release, not release from individual shafts or containers.



Notes: 1. The samples were collected as liquid water extracted from vapor sampling ports using specially designed cartridges.

2. One pCi/ml is equal to 1000 pCi/L. Colors represent individual boreholes and/or year of sampling as marked on the figure.

Figure I-1.1-3. MDA H tritium data from sampling in 1995 and 2001

The first plume estimate was made using the measured concentrations from the 1995 sampling. Borehole 1025 at MDA H has the highest tritium concentrations of the 1995 sampling (800 million pCi/L). The measurements were interpolated onto the closest two nodes within the model domain. The results of this simulation show that the plume size in 1995, based on the steady state approximation, could be as large as 167 Ci. As seen in Figure I-1.1-4, the simulated source region is located at the center of the MDA H site boundary, and the steady state plume at 39 feet below the surface is limited by the topography. Figure I-1.1-5 shows that the fixed source has reached steady state with the atmospheric sink within approximately 100 years.

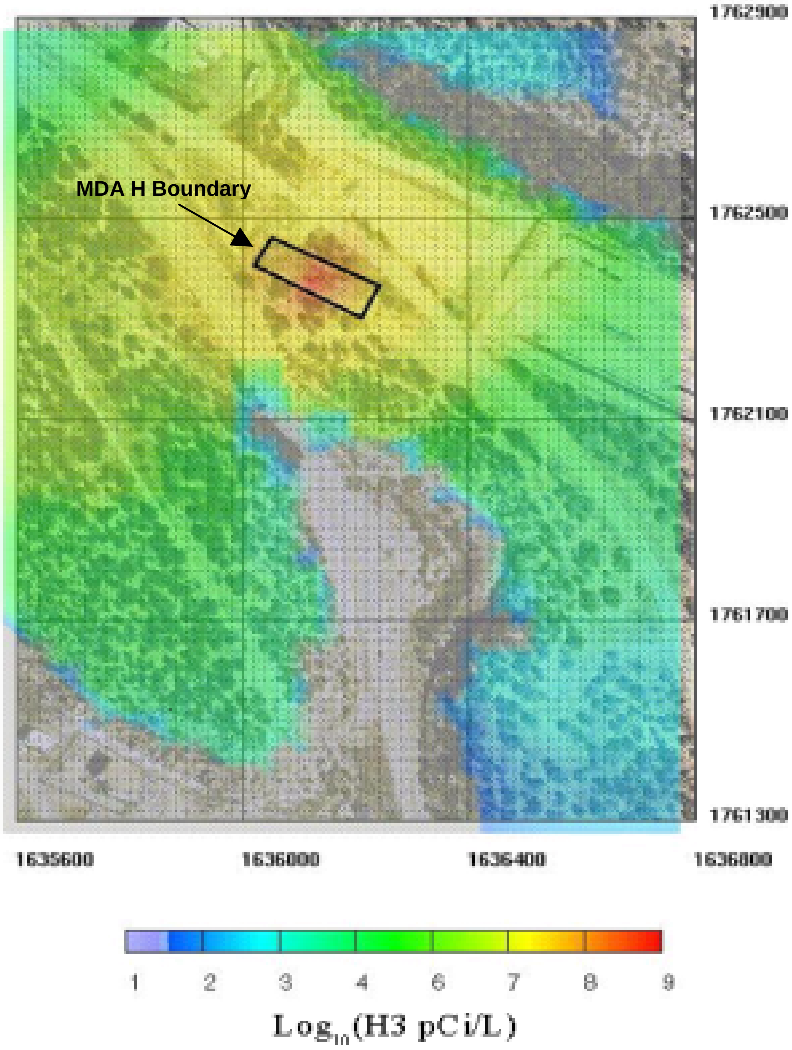


Figure I-1.1-4. Slice of the 1995 plume estimate at the depth of 39 ft below the surface (concentration in pore water)

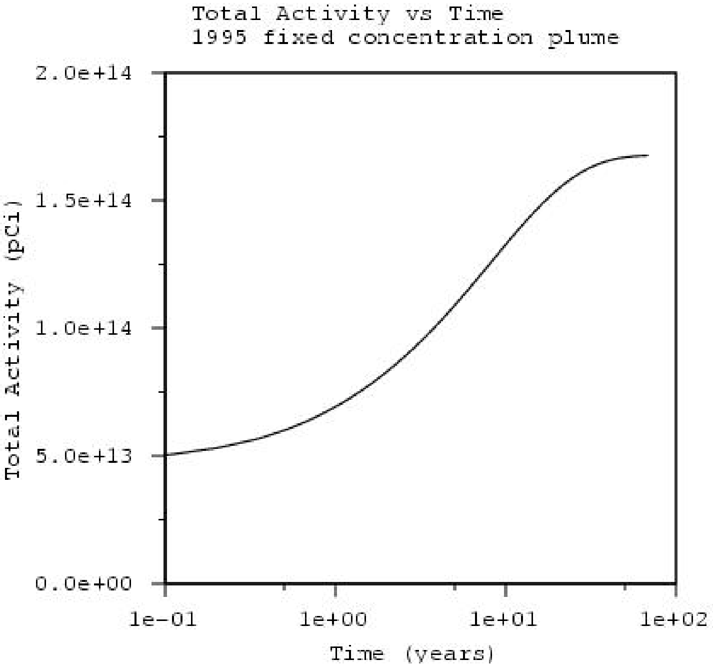


Figure I-1.1-5. The 1995 plume estimate achieves steady state in less than 100 years and results in a plume with a total activity of 167 Ci

The second plume estimate is based on the measured values of tritium from Borehole 1023 made in 2001. Interpolating these values onto the simulation grid and allowing the model to reach steady state results in a tritium plume with a mass on the order of 3.5 Ci.

The rapid decrease in measured tritium during the 6 years between samplings is unexpectedly large given that in simulations of the 1995 plume, radioactive decay and diffusion remove only 79 Ci of activity by the year 2001. The inconsistency between simulations and data is explained by the coarse resolution of the grid and the likely overestimation of the 1995 plume activity caused by fixing a very high measurement within a large volume computational cell.

The second type of simulation used the estimate of 167 Ci of tritium in 1995 to examine the behavior of the tritium plume through time. Modeling shows that tritium concentrations in the near surface pore water drop rapidly, and fall below background (<6 pCi/l) concentrations within 75 years after the period of institutional control has ended (Figure I-1.1-6). The high effective diffusion coefficient and the radioactive decay of tritium cause the plume to dissipate within 100 years and result in liquid-phase concentrations that are well below drinking water guidelines (20,000 pCi/L). Vapor concentrations in the near surface have much lower peak values (5 orders of magnitude) that become undetectable (less than 1 pCi/L) by the end of institutional control. The expected liquid values at the end of institutional control are similar to atmospheric concentrations found throughout North America during the early 1960's, which were caused by atmospheric testing of nuclear devices.

Because this simulation is conservative, using the highest available source estimate, the tritium contained within MDA H presents no potential impacts to human health.

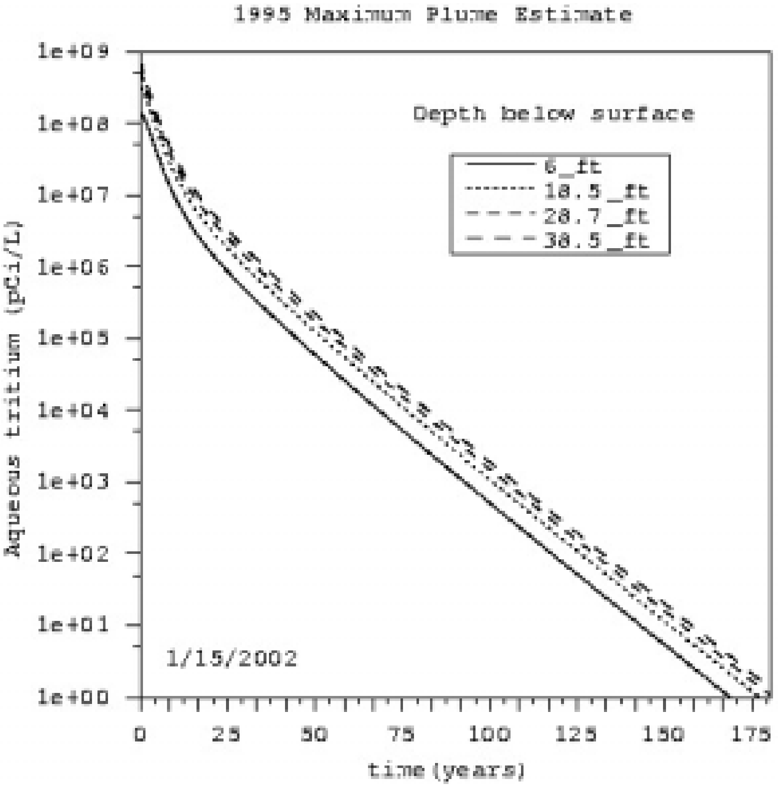


Figure I-1.1-6. Concentration of tritium in pore water as a function of time for 5 depths in the simulation of decay of the 1995 plume estimate

I-1.2 Radon Gas Transport Modeling

Radon-222 is a naturally occurring radioactive gas with a short half-life of 3.8 days. Radon was not disposed of at MDA H, but will “grow into” the inventory over a long period of time as uranium present in the inventory undergoes radioactive decay, as illustrated in Figures F-2.0-1 and F-2.0-4. Modeling was conducted to estimate if the time-dependent atmospheric release of radon from MDA H would exceed the corrective-action radon flux objective of 20 pCi/m^2/s for the Alternative 1 configuration.

I-1.2.1 Conceptual Model of Radon Gas Transport

The conceptual model of radon-222 exposure via the vapor pathway was based on many publications in the fields of health physics and groundwater hydrogeology (Robinson and Sextro 1997, 70151; Sun and Semkow 1998, 70154; and Bonotto and Andrews 1999, 70150). Radon is produced from the decay of naturally occurring uranium-238 and its daughter products. Once formed, the radon atom is ejected from its parent, radium-226, with significant force. Within a porous medium, the radon-222 must come to rest, either within a solid or within a fluid filled pore. Only the radon-222 that stops within a pore is available for transport. The fraction of radon-222 that arrives in pore spaces is known as the radon escape efficiency. Escape efficiency is related to both grain size and recoil energy. Studies of soil-sized (200 micron) porous media show that typical escape efficiencies are near 0.1 or less (Bonotto and Andrews 1999, 70150). As grain size increases, escape efficiency decreases. Thus for pieces of uranium-238 larger than a grain of sand, the escape efficiency approaches zero rapidly with increasing size. For the following analysis, we assume a radon escape efficiency of 0.01, a conservative estimate given the expected size of the shapes buried at MDA H.

Radon transport is modeled as diffusion from waste in an aggregate homogenized shaft to the surface. Calculations are presented for a one-dimensional representation of the system. As developed for the Goldsim System model presented in Appendix H, our conceptual model locates the near-surface inventory (homogenously distributed) in the subsurface between depths of 1.72 m and 7 m, with a surface area of 23.64 m^2. This geometry corresponds to the upper waste cell in Appendix H. The lower waste cell, lying below 7m, was ignored in these calculations because radon from this depth decays to very low values before reaching the surface because to its short half-life.

I-1.2.2 Numerical Model of Radon Gas Transport

First, a simple simulation of radioactive decay was performed with FEHM and compared to an identical Goldsim run to verify that FEHM correctly simulates the long decay chain with an end product in the vapor phase. Next, FEHM was used to model one-dimensional diffusive transport from buried waste to the surface over a time period of 1000 years. The FEHM process model is more appropriate for a simulation of this nature, and due to constraints inherent in GoldSim, a true process model is not feasible. The FEHM results were used to adjust parameters within GoldSim so that the GoldSim system model was able to approximate the behavior of the process model (FEHM). Finally, for verification purposes, the FEHM simulation was compared to an identical problem set up with RAECOM, a one-dimensional code developed by UMTRA and used extensively for radon analyses (USNRC 1989).

One-Dimensional Simulations

Verification of Simple Decay

Goldsim and FEHM were configured to model a closed system containing exactly the same source density, air volume, and decay sequence. Concentrations and total masses were compared at various times with the result that FEHM and Goldsim are in complete agreement for production of radon from decay of U-234 and U-238. For example, the mass of radon at 1000 years is 6.6e-7 g in both the FEHM and Goldsim simulations.

One-Dimensional Transport from the Upper Waste Cell to the Surface

The FEHM radon model consists of a porous medium, the waste inventory, and air. The model uses inventory estimates of total source from MDA H to simulate decay of uranium-238 and uranium-234 through their daughter products, which lead to radon-222. Radon decays from radium-226 and escapes into the soil air with an escape efficiency of 0.01. The radon in the soil air is then transported by diffusion from the source region toward the ground surface. Following the logic developed in the GoldSim system model, the source is assumed to be homogeneously distributed in a volume of 125 m^3. The source region is assumed to span a 5.28-m depth (shown schematically on Figure I-1.2-1) and the air in this region is assumed to have the same diffusion coefficient as the native tuff (4.e-6 m^2/s; Stauffer et al. 2000, 69794). The waste inventories used for U-238 and U-234 values are those reported in Appendix H (Table H-2.0-1) for the Upper Waste Cell. The FEHM simulation was done on a 0.5 m^2 cross section of the hypothetical waste shaft aggregate with a bottom depth of 24 m. The volumes and inventories in the simulation were corrected to achieve the same waste density found in the Goldsim System model. Both the upper-bound inventory estimate and the best-estimate inventory were simulated in FEHM and compare well to the output from the GoldSim model. This simulation did not include the corrosion modeling described in Appendix H. Using FEHM for the upper bound inventory estimate, the calculated radon flux at the surface at 1000 yrs is 1.82 pCi/(m^2 s). With a predicted flux of 3.7 pCi/(m^2 s), the GoldSim model slightly over predicts the process model results because it is less suited to the complex diffusion/decay physics. For the best-estimate inventory, FEHM predicts a surface flux of 0.3 pCi/(m^2 s). For the best-estimate inventory, the GoldSim system model also includes a corrosion-limited source that results in a slightly lower flux of 0.17 pCi/(m^2 s). Given the difficulties in adapting results from a highly precise process model to a simplified systems model, we believe the surface flux of radon generated within the GoldSim model is quite good with respect to the more accurate FEHM results.

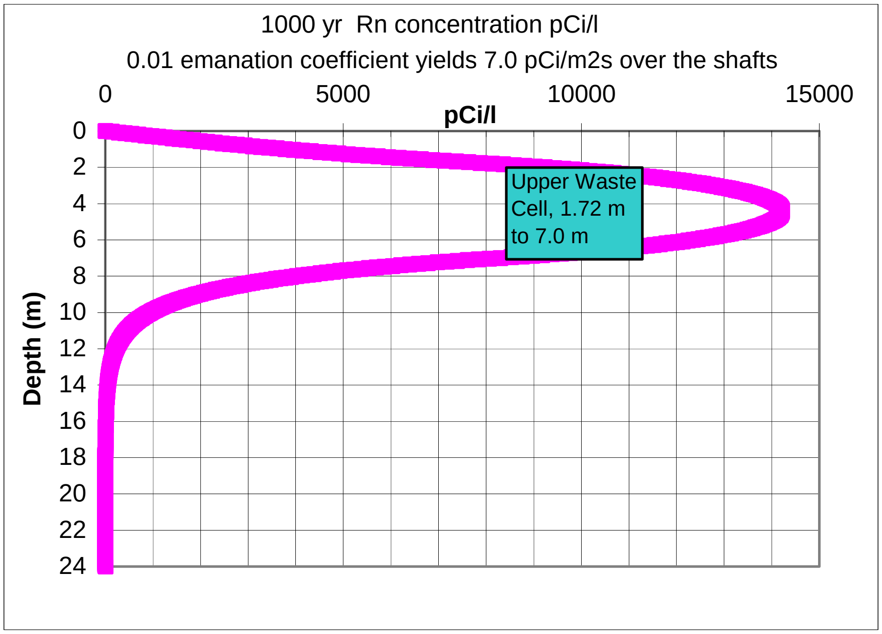


Figure I-1.2-1. Profile of Subsurface Radon Concentration calculated with FEHM at 1000 yr

Figure I-1.2-1 shows that between the source and the surface the radon develops a nearly linear concentration profile that begins to bend near the surface (0 meters depth) due to decay of radon-222 along the diffusive pathway. The character of the concentration profile below the source region (i.e., below 7 m) (Figure I-1.2-1) shows that for radon-222, the effective infinite distance (the distance beyond which virtually no radon may diffuse because of the short half-life) is slightly greater than 7 m. Concentrations drop to 1/1000 of the peak concentration in the source region at 16.6 m, a distance of 9.6 m below the simulated Upper Waste Cell.

One-Dimensional Comparison of FEHM and RAECOM

Finally, we present the results of a comparison between FEHM and RAECOM, a one-dimensional radon flux calculator available from UMTRA. The US Government has validated RAECOM for use (USNRC 1989). This comparison was run with a higher inventory estimate than presented in Table I-1.2-1, but the comparison still shows the favorable comparison between the two codes. The only correction needed to the FEHM Ra-226 soil concentration (841 pCi/g) before input to RAECOM is the ratio of assumed grain densities, which is 2.0/2.7 (FEHM/RAECOM). With this correction, the input concentration for RAECOM in 5.28 m of waste is 623 pCi/g. When the emanation coefficient is set to 1.00, the output flux at the surface is 700 pCi/m^2s in both FEHM and RAECOM. Furthermore, when the emanation coefficient is set to 0.01

both codes give the identical result of 7.0 pCi/m^{2}s. This test provides independent evidence that FEHM is correctly modeling radon surface flux given the assumptions associated with the one-dimensional model. The results of the one-dimensional analysis will tend to over predict surface flux of radon because in a three-dimensional system, radon can escape to the lateral boundaries, reducing the amount of radon available for transport to the surface.

Table I-1.2-1
Values Used in FEHM Radon Model

GoldSim Object/Variable/Parameter	Value
Soil Porosity	0.5
Soil Saturation	0.05
Uranium-238 Inventory (Upper Waste Cell)	37730/14060 kg
Uranium-234 Inventory (Upper Waste Cell)	5/0.816 kg
Uranium-238 half-life	4.49 Ga
Uranium-234 half-life	0.248 Ma
Thorium-230 half-life	75.2 Ka
Radium-226 half-life	1622 a
Radon-222 half-life	3.83 days
Upper Waste Cell Volume	124.82 m^3

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Appendix J

Groundwater Transport Modeling

APPENDIX J GROUNDWATER TRANSPORT MODELING

J-1.0 INTRODUCTION

This study predicts the migration of contaminants, due to aqueous-phase transport through the unsaturated subsurface, to the regional aquifer for waste disposed of at Material Disposal Area (MDA) H located on Mesita del Buey, at Technical Area (TA) 54, Los Alamos National Laboratory (the Laboratory). These simulations provide good estimates for unsaturated-zone transport times for water-soluble solid wastes. Site characterization data were synthesized into a conceptual model that summarizes the current understanding of the processes that control subsurface contaminant migration at the site. This study then incorporates detailed processes and site-characterization data into a process-level numerical model of flow and transport through the unsaturated zone below MDA H to evaluate aqueous-phase transport through the unsaturated zone.

The models were used to calculate the migration of a generic waste from the disposal shafts at MDA H through the unsaturated zone. The three-dimensional unsaturated-zone flow and transport model captures the complex hydrogeology and topography of the site and yields estimates of contaminant concentrations that may enter the regional aquifer over a 1000-year period. The study considers a base-case flow field and a conservative (high) flow field. A range of distribution coefficients (Kd) is also considered so that the sensitivity of migration to this key parameter is understood. An advantage of using process models throughout the analyses is that a strong link is maintained between the numerical model and the conceptual model. All calculations were run with the finite-element code FEHM (Zyvoloski et al. 1997, 70147).

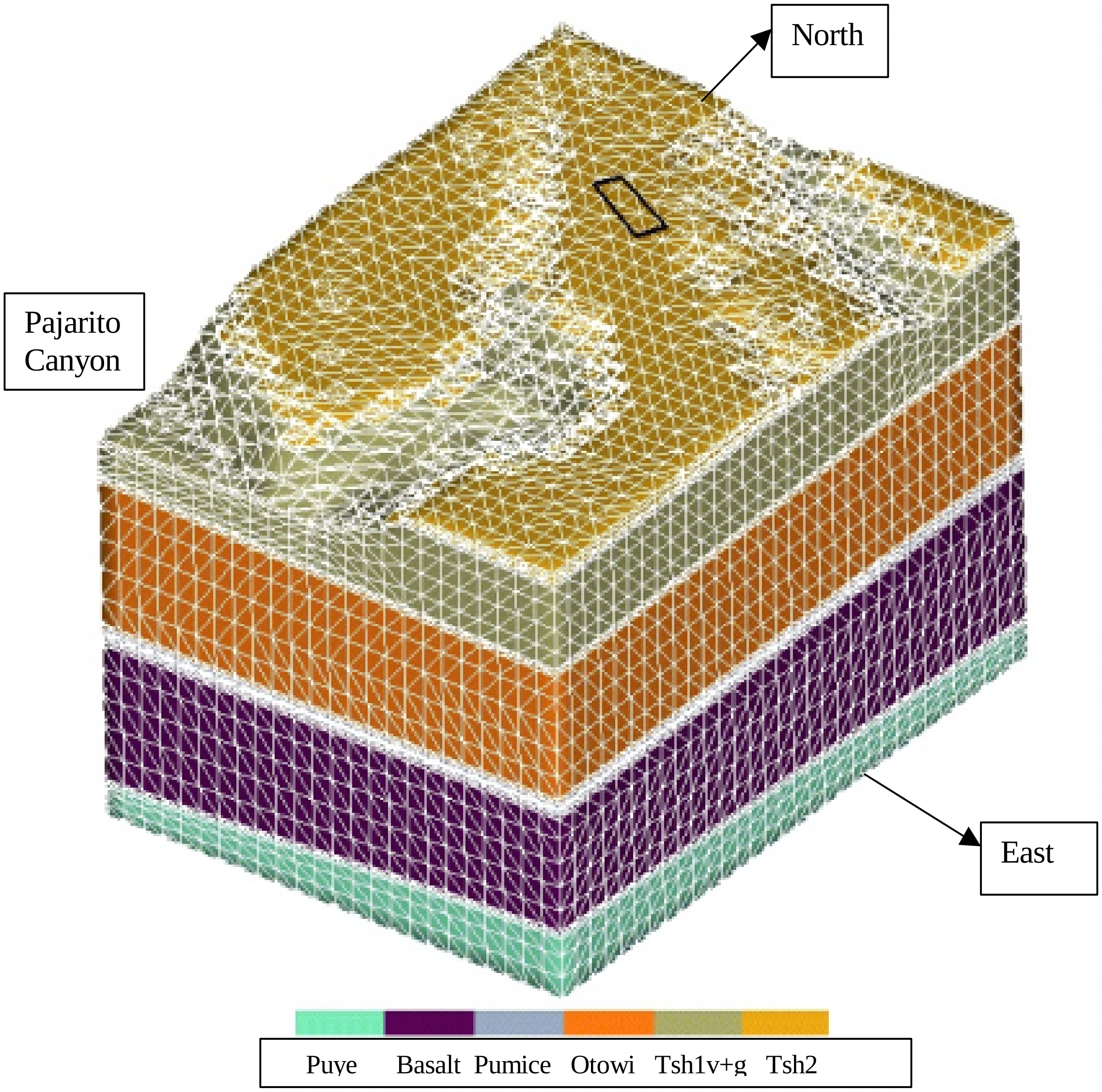
J-2.0 SITE DESCRIPTION

Stratigraphy and Topography

The strata that lie beneath Mesita del Buey are composed of a series of nonwelded to moderately welded rhyolitic ash-flow and ash-fall tuffs underlain by a thin pumice bed, a thick basalt, and a conglomerate formation (Carey et al. 1999, 66782), as shown in Figure J-2.0-1. The site stratigraphy and topography used in this study are from the Laboratory site-wide geologic model (Carey et al.1999, 66782). The geologic model describes the topography and the base elevation of each geologic unit as surfaces (northing, easting and elevation) defined on 50-ft (15.2-m) spacings.

The tuff layers were deposited during violent eruptions of volcanic ash from the Valles Caldera some 1.2 to 1.6 million years ago (Smith and Bailey 1966, 21584; Gardner et al. 1986, 59104). Since then, the tuff has eroded to leave a system of alternating finger-shaped mesas and canyons. MDA H is located atop one such mesa, Mesita del Buey, with the waste buried in 60-ft (18.2-m) deep disposal shafts. The surrounding canyons lie approximately 80 ft (24 m) below the steep-sided mesa, and the water table is located approximately 980 ft (300 m) below the disposal shafts.

The upper stratigraphic units, through the Otowi Member, make up the Bandelier Tuff. These units dip gently and thin toward the eastern end of the mesa. The top tuff layer, Tshirege Unit 2, and the upper few meters of the second layer, Tshirege Unit 1, are extensively fractured and are separated by a thin surge bed (Krier et al. 1997, 56834). The surge bed is made up of fine, sand-sized material and is genetically related to the overlying deposits of poorly sorted, relatively massive ashflow tuff. The deeper tuff units have few observed fractures in outcrop (Krier et al. 1997, 56834).



Note: The MDA H site boundary (fence line) is shown on the surface with a black rectangle.

Figure J-2.0-1. Three-dimensional, geologic model of the unsaturated zone at MDA H, including the numerical grid

The Cerros del Rio Basalts, which comprise approximately 35% of the unsaturated zone, display wide variability (Turin 1995, 70225). The basalts range from extremely dense with no apparent porosity, to highly fractured, to so vesicular as to appear foamy. In the current site-wide geologic model, the Puye Conglomerate lies at the base of the unsaturated zone and extends into the saturated zone. The conglomerate consists of cobbles and boulders of volcanic debris in a matrix of silts, clays, and sands (Purtymun 1995, 45344). Clay, silt and pumice lenses, and interbedded basalts are also common. However, the Puye Conglomerate lies within the saturated zone in the recently completed regional well R-22, which is located at the eastern end of Mesita del Buey (Ball et al. 2002, 71471). Therefore, the Basalts may be thicker and the Puye Conglomerate thinner than shown in Figure J-2.0-1.

Contaminant Source

Waste at MDA H is buried in 60-foot (18-m) deep shafts. The inventory is described in detail in Appendix B. Constituents of the inventory include by decreasing mass: metals (including depleted uranium), some reactive materials (such as lithium compounds and high explosives), graphite, fuel elements and plastics. Both RCRA and radioactive constituents are present.

Hydrologic Data

The van Genuchten model (van Genuchten 1980, 49927) is used to represent the moisture retention characteristic curves for all units in the unsaturated-zone model. Table J-2.0-1 summarizes the hydrologic parameters used for all of the units in the unsaturated-zone flow and transport model. The parameters for the van Genuchten model (saturated hydraulic conductivity, porosity, inverse air entry pressure, etc.) are fairly well characterized for the Bandelier Tuff units but not for the deeper units. The properties for the tuff units (Krier et al. 1997, 56834) and the Guaje Pumice were measured on core samples of matrix material.

Table J-2.0-1
Hydrologic Properties

Unit	Ksat[a] (cm/s)	Porosity	van Genuchten θ_r, α (cm^{-1}), n[b]
Unit 2[c]	4.27×10^{-4}	0.481	0.013, 0.0060, 1.890
Unit 1v+g[c]	1.48×10^{-4}	0.517	0.002, 0.0030, 1.932
Otowi Member[c]	2.49×10^{-4}	0.435	0.0188, 0.0059, 1.713
Guaje Pumice[d]	1.5×10^{-4}	0.667	0.0, 0.00081, 4.0264
Cerros del Rio basalts[e] and Puye Formation*(equivalent continuum)*			
matrix properties	9.7×10^{-5}	1×10^{-4}	6.6×10^{-6}, 0.0384, 1.474
fracture properties	9.7×10^{2}	1×10^{-4}	3.0×10^{-6}, 0.0384, 1.474

[a] Ksat = Hydraulic Conductivity.

[b] θ_r = Residual Moisture Content (volume percent). α, n = van Genuchten fitting parameters (van Genuchten 1980, 49927).

[c] Mean values from Krier et al. (1997, 56834).

[d] Springer et al. 2000, 71097.

[e] Bishop (1991, 70221).

Hydrologic property data were not yet available for the local basalts at the time these simulations were performed. The basalt is modeled as a composite-continuum medium made up of both fractures and matrix material (Peters and Klavetter 1988, 70223) with the matrix properties based on a basalt flow in Idaho (Bishop 1991, 70221). To insure conservatism, the continuum porosity of the basalt is set to that of the fractures, thus forcing very low residence times of solutes in this unit for which characterization data were poor. Since the stratigraphy at well R-22 indicates that the Puye Conglomerate may not be present in the unsaturated zone beneath Mesita del Buey (Ball et al. 2002, 71471), the Puye Conglomerate is also conservatively treated in the model as having the same properties as the Cerros del Rio Basalts.

The upper-two tuff units are fractured and extremely dry, as demonstrated by the site data in Figure J-2.0-2. Site data indicate that evaporation is an important process within the mesa top. These data include low mesa-top moisture contents (Krier et al. 1997, 56834; Bergfeld and Newman 2001, 71246) and high matrix potential measured along the surge bed (Rogers et al. 1997, 63131). Also, chloride and

δ^{18}O profile analyses indicate strong evaporative effects yielding low, net water fluxes (Newman 1996, 59372). For example, high porewater chloride concentrations observed across Mesita del Buey lead to flux estimates ranging from 0.03 to 1.5 mm/yr, while chloride concentrations below the canyon level yield fluxes near 5 mm/yr (Newman 1996, 59372). More recent chloride data from Borehole 1023 at MDA H yield a water flux of 0.2 mm/yr to a depth of 140 ft (the depth of the Unit 1v/Unit 1g contact) and a flux of 2.8 mm/yr below that (Bergfeld and Newman 2001, 71246). Previous numerical simulations indicate that evaporative effects can reasonably account for the low moisture contents observed in undisturbed regions of the mesa at the site and can justify a low net percolation rate (Birdsell et al. 1999, 69792).

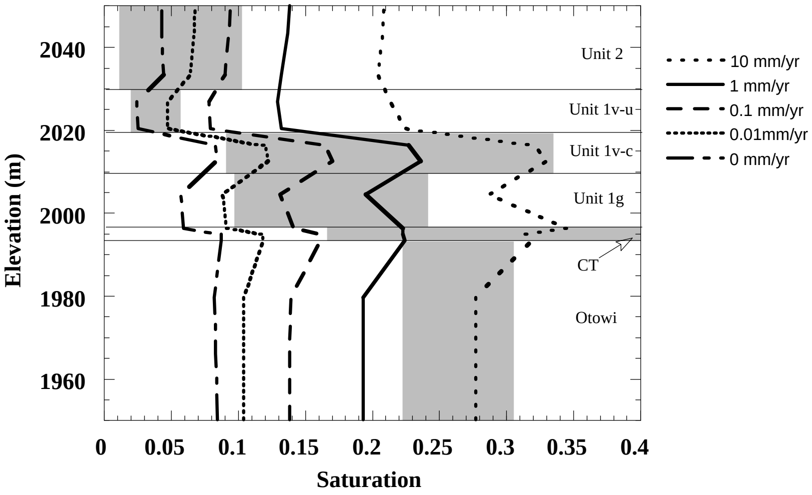


Figure J-2.0-2. Comparison of site data from across TA-54 (gray boxes) to calculated steady-state saturation profiles for several infiltration rates (Birdsell et al. 1999, 69792)

Transport Properties

Distribution coefficients (Kd values) for americium, neptunium, plutonium, technetium and uranium were measured under saturated conditions with local rock samples using synthetic solutions representing local porewaters from the unsaturated zone and the aquifer (Longmire et al. 1996, 56030). However, Kd values for the remaining nuclides are based on experiments performed for the Yucca Mountain project (as summarized by Krier et al. 1997, 56834) and are not differentiated by tuff integrity or location. Kd values and solubility limits for wastes buried at MDA H and their byproducts are shown in Table J-2.0-2.

Solubility limits for americium, plutonium and neptunium are based on experiments with Yucca Mountain tuffs and synthetic water samples with chemistry similar to either natural groundwaters at Yucca Mountain or at the Laboratory(Longmire et al. 1996, 56030). Other solubility limits are derived from the literature (Krier et al. 1997, 56834). Solute speciation simulations based on porewater composition and pH and on tuff mineralogy were performed to ensure the applicability of the distribution coefficients and solubility limits used in the study (Longmire et al. 1996, 56030).

Table J-2.0-2
Solubility Limits and Median Distribution Coefficients for Chemicals in the MDA H Inventory

Species	Solubility Limit (mole/L)	Reference for Solubility Data	Kd (mL/g)	Reference for Kd Value
Ac (actinium)	1.2e-9	Krier et al. 1997, 56834, Table 13	130	Krier et al. 1997, 56834, Table 7
Ag (silver)	5.6e-10	Krier et al. 1997, 56834, Table 13	90	Krier et al. 1997, 56834, Table 7
Al (aluminum)	1.72e-5	Longmire 1999, 70226	141	Longmire 1999, 70226
Am (americium)	1.2e-9	Krier et al. 1997, 56834, Table 13	141	Longmire 1999, 70226
Ba (barium)	4.5e-5	Krier et al. 1997, 56834, Table 13	946	Krier et al. 1997, 56834, Table 7
Be (beryllium)	1e-6	Longmire 1999, 70226	250	Longmire 1999, 70226
Cd (cadmium)	5e-8	Krier et al. 1997, 56834, Table 13	80	Krier et al. 1997, 56834, Table 7
Cyanuric Acid	3.9e-2	Windholz 1983 34771	0	Winholz 1983, 34771
Cr (chromium)	9.88e-9	Longmire 1999, 70226	70	Longmire 1999, 70226
Cu (copper)	2.49e-7	Longmire 2001, 70227	10 to 90	Longmire 2001, 70227
Fe (iron)	8.88e-7	Longmire 1999, 70226	220	Longmire 1999, 70226
H3 (tritium)	Very large	Krier et al. 1997, 56834, Table 13	0	Longmire 2001, 70241
Hg (mercury)	1.84e-5	Longmire 1999, 70226	80	Longmire 1999, 70226
Np (neptunium)	1.3e-4	Krier et al. 1997, 56834, Table 13	2.25 to 7.5	Longmire 1996, 56030
Pa (protactinium)	1.3e-4	Krier et al. 1997, 56834, Table 13	50	Krier et al. 1997, 56834, Table 7
Pb (lead)	1.6e-6	Krier et al. 1997, 56834, Table 13	25	Krier et al. 1997, 56834, Table 7
Pu (plutonium)	2.3e-7	Krier et al. 1997, 56834, Table 13	4.13 to 711	Longmire 1996, 56030
Ra (radium)	9.36e-7	Longmire 1999, 70226	200	Longmire 1999, 70226
RDX (high explosive)	2.34e-4	Longmire 2001, 70241	0	Longmire 2001, 70241
Th (thorium)	1.9e-10	Krier et al. 1997, 56834, Table 13	500	Krier et al. 1997, 56834, Table 7
TNT (high explosive)	6.6e-4	Broxton et al. 2002, 72640	0.0524	Broxton et al. 2002, 72640
U (uranium)	1.1e-4	Krier et al. 1997, 56834, Table 13	2.61 to 4.85	Longmire 1996, 56030

Site-specific measurements for diffusion coefficients and dispersivity are not available. These parameters are therefore estimated. Studies by Conca and Wright (Conca and Wright 1990, 70228) show that the molecular diffusion coefficient decreases as moisture content decreases. For the unsaturated zone, the diffusion coefficient is modeled in this fashion and decreases parabolically from 10^{-10} m^2/s at saturation to 10^{-15} m^2/s at a moisture content of 0.001. The dispersivity used is 1 m in the vertical direction and 0.1 m in the horizontal plane.

J-3.0 CONCEPTUAL MODEL

Infiltration and Unsaturated-Zone Flow

The average precipitation rate for the area is 35.6 cm/yr (Bowen 1990, 6899). Most of this precipitation is lost to runoff and evapotranspiration, resulting in a heterogeneous infiltration pattern that is controlled by the mesa/canyon setting of the site. Infiltration is thought to be seasonal with most occurring during spring snowmelt and, to a lesser extent, during the summer thunderstorm season (Rogers et al. 1997, 63131). Figure J-2.0-1 shows the topography near MDA H. As stated previously, measured rock saturations and chloride data indicate that low net percolation rates (0 to 5 mm/yr) are thought to exist within the mesa (Newman 1996, 59372; Bergfeld and Newman 2001, 71246). Pajarito Canyon is wetter with an estimated percolation rate of 10 to 300 mm/yr, while Cañada del Buey is dry with a percolation rate similar to the mesa top. The small drainages surrounding the site are also expected to have percolation similar to the mesa top because they have small catchment areas and also are quite steep in some areas. The coupling of the fractured units separated by the high-permeability surge bed with the mesa's topographic relief is thought to enhance air circulation and consequently evaporative drying within the mesa interior.

Matrix flow is expected to dominate in the unsaturated tuff units at the site. The only observations of fracture transport at the Laboratory occurred beneath MDA T at TA-21. MDA T received liquid radioactive wastes in trenches that were heavily used between 1945 and 1952 (Rogers 1977, 5707). The tuff beneath the site was nearly fully saturated by disposal operations. Although radioactivity has been measured in fractures beneath this former liquid waste site, it appears that transport in the fractures stopped soon after waste disposal ceased, based on observations made in the 1960s and 1970s (Nyhan et al. 1984, 6529). Also, numerical studies of fracture flow for TA-54 indicate that flow through fractured tuffs is difficult to maintain in low-saturation, high-capillarity systems (Soll and Birdsell 1998, 70011). Because solid wastes were disposed of at MDA H, significant fracture flow through the unsaturated tuff units is unlikely.

Since whether flow occurs in the matrix or the fractures in the basalt cannot be predicted, the basalts were conservatively treated as a system dominated by vertical fracture flow. The basalt is modeled as an equivalent continuum medium made up of both fractures and matrix material (Peters and Klavetter 1988, 70223) (see Table J-2.0-1). Matrix properties are derived from analogue basalts in Idaho (Bishop 1991, 70221). Fracture properties are chosen, through numerical sensitivity studies, so that no lateral diversion occurs at the top of the basalts in the simulations, even when the flow rate exceeds the matrix saturated hydraulic conductivity. Then, the continuum porosity is set equal to the fracture volume fraction, 10^{-4}, to ensure rapid transport of about one to ten years through this unit, hence forgoing any retardation due to matrix flow or sorption. This treatment of transport through the basalt yields a conservative result (e.g., faster groundwater travel times and higher peak concentrations than actually expected). The Puye Conglomerate is treated similarly because of uncertainty related to its presence within the unsaturated zone, as observed in well R-22.

In designing the boundary conditions for the predictive models, preliminary simulations investigate how well modeled and observed saturation values correspond for various infiltration rates, how appropriate a steady-state infiltration rate is, and the representation of fracture matrix interactions. These are described in the numerical modeling section of this appendix.

Source Term and Unsaturated-Zone Transport Processes

The release of waste from the disposal units is represented as a constant, solubility-limited release. In this study, the transport of aqueous-phase chemicals is calculated through a series of generic simulations that are used to establish breakthrough curves (concentration vs. time plots) at the base of the unsaturated zone for a range of sorption coefficients. In each simulation, the waste is conservatively assumed to have a constant source concentration of 1.0 moles/liter throughout the entire shaft volume and for the 1000-year simulation. This behavior represents a solubility-limited release, and breakthrough concentrations can be scaled by a constituent's actual solubility limit to determine the maximum possible concentration for that particular waste constituent as it exits the unsaturated zone.

The fundamental processes affecting migration rates of solutes in this unsaturated environment are advection, adsorption, diffusion, dispersion, and radioactive decay. A linear-adsorption isotherm (Kd model) is expected to adequately describe adsorption in the unsaturated zone because of slow percolation rates and the indication that transport in the units above the basalt occurs predominantly in the matrix. Once released from the disposal unit, the mesa-top infiltration rate and the constituent's Kd control the waste's mobility in the unsaturated zone.

In these generic simulations, radioactive decay of the parent species is neglected. However, the maximum concentration of any daughter product can be calculated as the minimum of either the daughter product's solubility limit or the concentration resulting from the decay of the parent species at its solubility limit. Short-lived nuclides with half-lives less than 20 years, such as ^{3}H (tritium), are expected to decay to insignificant levels before reaching the aquifer. The remaining constituents can be classified as nonsorbing (Kd = 0 mL/g), weakly sorbing ($0 < Kd \leq 10$ mL/g), and strongly sorbing (Kd > 10 mL/g), as shown in Table J-2.0-2. Nonsorbing species are expected to travel most rapidly, while strongly sorbing species are expected to have very long travel times. The basalts and Puye Conglomerate are assumed to be nonsorbing, consistent with the assumption of rapid transport through the basalts.

J-4.0 NUMERICAL MODEL

Overview

The migration of aqueous-phase contaminants from the subsurface shafts at MDA H through the unsaturated zone was modeled through a series of simulations. The unsaturated-zone flow and transport model is a three-dimensional representation of the complex mesa/canyon hydrogeologic system. Infiltration is assumed to be steady in time but variable in space over the mesa top, two bordering drainages and Pajarito Canyon.

The model incorporates a source region as a series of vertical nodes that represent the disposal shafts at MDA H. As mentioned above, the generic source with a constant concentration over the simulation time is used to study the effect of flow fields and distribution coefficients on breakthrough to the regional aquifer. The simulations are run for 1000 years.

The simulations are run with FEHM, a two- or three-dimensional finite-element/finite-volume code suitable for simulating systems with complex geometries that arise when modeling subsurface flow and transport (Zyvoloski et al. 1997, 70147). In the unsaturated zone, the governing equations for flow are based on the principles of conservation of water and air. Darcy's law is assumed to be valid for the momentum of the air and water phases. The advection-dispersion equation governs solute transport (Zyvoloski et al. 1997, 70147) in these analyses.

Computational Grid

The three-dimensional unsaturated-zone grid is generated with the Geomesh/X3D software (Gable et al. 1995, 70148) from the geologic framework model, as shown in Figure J-2.0-1. It is constructed with the 50-ft (15.2-m) spacing of the geologic framework model. The final grid contains 30,342 nodes and

175,172 tetrahedral elements. This grid is identical to that used for the FEHM calculations of tritium transport at MDA H that are presented in Appendix I of this report. For these calculations, the source area is defined by a set of three vertical nodes that are approximately located near the shafts at MDA H. These nodes act as the source region for waste during the transport calculations.

Boundary Conditions

Preliminary Calculations

As described in the conceptual model, a series of preliminary calculations was performed to evaluate infiltration rates and modeling assumptions, such as the use of steady flow rates and the dominance of matrix flow through the tuff units.

To determine appropriate infiltration rates for the site, simulated saturation profiles for a number of different steady, mesa-top infiltration rates are compared to site field data. Infiltration rates of 10 mm/yr, 1 mm/yr, 0.1 mm/yr, 0.01 mm/yr and 0.0 mm/yr were run using a two-dimensional cross section of Mesita del Buey (Birdsell et al. 1999, 69792). Figure J-2.0-2 shows calculated steady-state saturation profiles at the center of the mesa for the five infiltration rates along with the ranges of *in situ* saturation data measured in the six Bandelier Tuff units. The shape of the calculated saturation profiles shows the same trend as the data (e.g. saturations decrease from Unit 2 to Unit 1v-u and then increase again in Unit 1v-c, etc.), but no single infiltration rate yields predicted saturation values that fit the entire data set. Results for the lowest infiltration rates (0.01 and 0.0 mm/yr) most closely match the site saturation data in Units 2 and 1v-u, the two mesa-top units. Higher infiltration rates (0.1 and 1 mm/yr) are needed to match the saturation data from Units 1v-c and 1g, and an even higher rate (10 mm/yr) is needed to match the data in the Cerro Toledo and the Otowi Member. Newman (1996, 59372) and Bergfeld and Newman (2001, 71246) also found that no single percolation rate fits *in situ* chloride data from the site. For example, fluxes were estimated within the mesa ranging from 0.03 to 1.5 mm/yr and deeper fluxes of 2.8 to 5 mm/yr based on chloride mass-balance based flux estimates.

Upper-bound percolation rates are obtained from mean leakage rates calculated with HELP for the Surface Cover (Appendix G). The leakage rates are 8.9 mm/yr for a background cover, 2.7 mm/yr for the concrete-covered shafts, and 8.5 mm/yr for an ET cover design. Leakage represents the water leaving the near-surface cover and does not include any deep evaporation. Based on all of these studies, the calculations consider two mesa-top percolation rates of 1 mm/yr as a base-case value and 10 mm/yr as a high upper bound.

Since deep percolation is thought to be seasonal with most occurring during spring snow melt and to a lesser extent during the summer thunderstorm season (Rogers et al. 1997, 63131), separate, small-scale modeling studies were performed to test the assumption of steady-state flow used for the assessment. Birdsell et al. (1999, 69792) studied the effects of annual transients in percolation rate on unsaturated-zone transport at the site. They found that simulated transient pulses are damped with depth so that the calculated cumulative contaminant flux at the base of the Bandelier Tuff is similar under transient and steady flow fields. By using a steady infiltration rate at the high end of the expected range, and forcing short travel times through the basalt, the subsequent transport calculations are expected to yield conservative results, assuming that fracture flow has little effect on transport in the upper two fractured tuff units.

Numerical studies of fracture flow for the site indicate that transport through fractured tuffs has a minimal effect on contaminant flux at depth (Soll and Birdsell 1998, 70011). Also, direct evidence of fracture flow at the Laboratory has only been observed at one historic liquid waste disposal site, beneath the liquid disposal trenches at MDA T (Nyhan et al. 1984, 6529). Therefore, fractures are considered only for the deep basalt in this unsaturated-zone model.

Transport Calculations

The mesa/canyon setting leads to a set of spatially-dependent, surface boundary conditions categorized by position depending whether infiltration is applied to the mesa top, to the relatively wet Pajarito Canyon, or to the surrounding drainages, as shown in Figure J-2.0-1. Two different unsaturated-zone flow fields are considered in order to predict both a realistic, yet conservative, set of breakthrough curves, and a set of breakthrough curves that represent higher than expected infiltration rates. Two mesa-top flows are used (1 and 10 mm/yr), two flow rates for the drainages surrounding the site are considered (1 and 10 mm/yr), and two flow rates for Pajarito Canyon are used (100 and 300 mm/yr). Table J-4.0-1 summarizes the two cases. Both the base case, 1_100, and the high flow case, 10_300, are thought to be conservative for the site based on chloride flux estimates (Newman 1996, 59372; Bergfeld and Newman 2001, 71246) and on the saturation profiles shown in Figure J-2.0-2, which show that the range 1 to 10 mm/yr fits the higher range of site moisture data. Percolation equal to the mesa-top rate is assumed at the nodes within the drainages that surround the mesa top. The bottom boundary represents the water table, where both water and contaminants can exit.

Table J-4.0-1
Percolation Rates (mm/yr) Used as Upper Boundary Conditions

	Mesa Top	Drainages	Pajarito Canyon
1_100 (Base Case)	1	1	100
10_300 (High Flow Case)	10	10	300

For each flow case, liquid-phase contaminant concentrations in the source region were held constant at 1.0 mole/L for 1,000-year simulations. The adsorption coefficient of the tuff units and the Puye Conglomerate was modified over a range of values from 0.0 to 1.0 mL/g to predict contaminant concentrations from the unsaturated zone to the aquifer. To assure that the same mass of contaminant enters a given set of simulations, it was assumed that no adsorption occurred on the crushed tuff that fills the waste shafts. The basalt unit and Puye Conglomerate were assumed to be nonsorbing.

J-5.0 RESULTS

J-5.1 Unsaturated-Zone Transport Simulations

Figures J-5.1-1 and J-5.1-2 show contaminant breakthrough curves at the base of the unsaturated zone for the two sets of generic predictions discussed above and a range of Kd values. The curves show the maximum concentration at the base of the unsaturated zone for the generic source. Contaminant transport is predominantly downward in the simulations, and therefore, maximum concentrations occur directly beneath the disposal shafts.

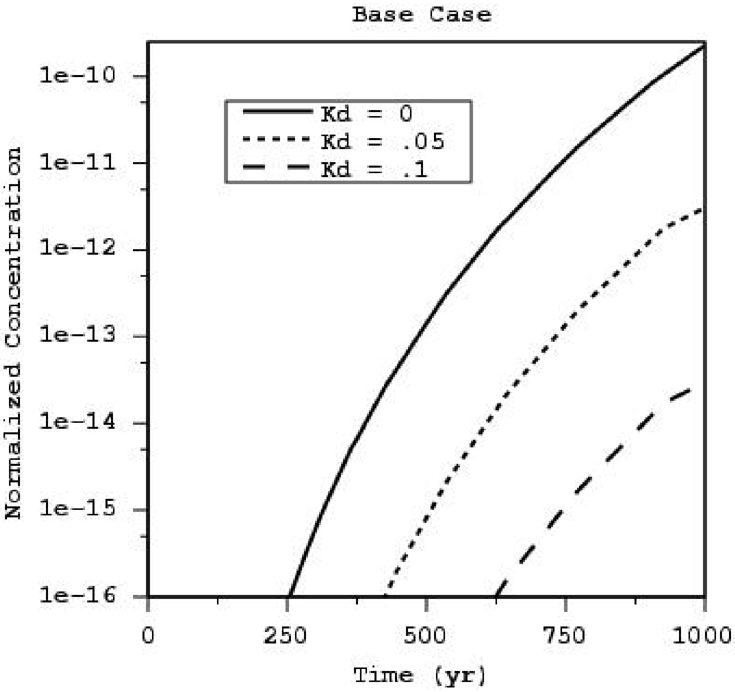


Figure J-5.1-1. Maximum breakthrough concentration exiting the unsaturated zone as a function of Kd (mL/g) - generic source concentration of 1 mole/L, base-case flow field (1_100)

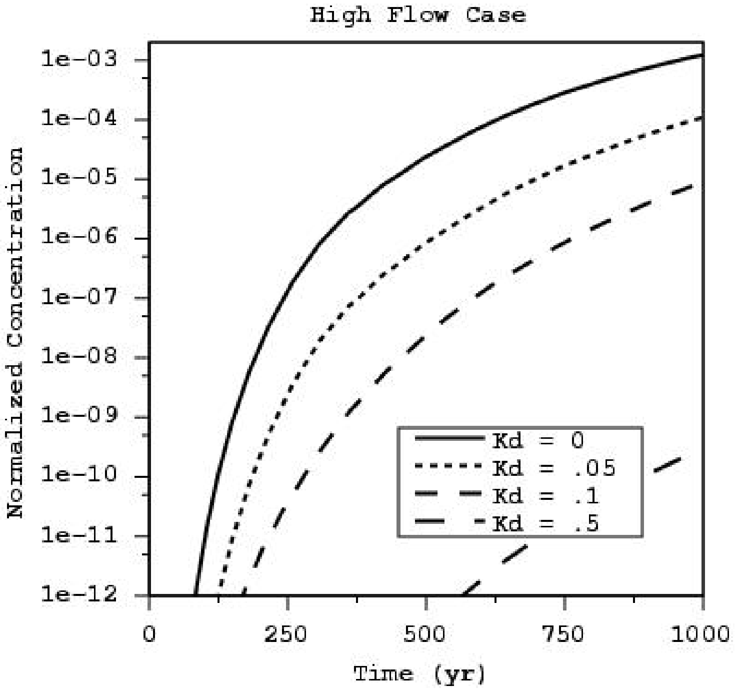


Figure J-5.1-2. Maximum breakthrough concentration exiting the unsaturated zone as a function of Kd (mL/g) - generic source concentration of 1 mole/L, high flow field (10_300)

At 1000 years, releases for constituents with Kd > 0 migrating under the base-case flow field and for constituents with Kd > 0.5 mL/g for the high flow case are less than 10^{-10} times their source concentration. It is conservatively assumed that a concentration of 10^{-10} times a species' solubility limit is a sufficient decrease to not pose a health risk. This assumption should be verified for specific species in question to determine the appropriate reduction required.

Using the MDA H inventory analysis (Appendix B) as an example, the reduction factor required for uranium and plutonium to each achieve a 15 mrem/yr drinking water dose was calculated and compared to the breakthrough curves in Figures J-5.1-1 and J-5.1-2. These calculations require the following input for uranium and plutonium and their isotopes: the elemental solubility limit, the mass fraction of each isotope in the inventory, the dose conversion factor for each isotope, and the half-life of each isotope. Table J-5.1-1 shows the results of these calculations. To interpret this table with respect to uranium, a reduction of 2.0×10^{-3} times its solubility limit is required to achieve a dose of 15 mrem/yr. Figures J-5.1-1 and J-5.1-2 show that this reduction is achieved for all distribution coefficients for both flow fields (e.g., all breakthrough concentrations are less than 2.0×10^{-3} at 1000 years). Given that uranium's Kd is greater than 2, its breakthrough curve falls below the plotted curves in each case. This means that the value of uranium's reduction factor is expected to be much less than 10^{-12} (the lower bounds of the plot in Figure J-5.1-2) or more than 9 orders of magnitude better than the minimum required. By the same arguments, plutonium requires a minimum Kd of less than 0.2 mL/g to meet its required reduction factor with the higher flow case, and its measured value is greater than 4 mL/g.

Table J-5.1-1
Reduction Factor and Minimum Kds Required to
Meet 15 mrem/yr Dose for Uranium and Plutonium Based on the MDA H Inventory Estimates

Species	Minimum Required Reduction Factor	Base-Case Kd (mL/g) to Achieve Minimum Reduction Factor, From Figure J-5.1-1	High Flow Kd (mL/g) to Achieve Minimum Reduction Factor, From Figure J-5.1-2	Measured Kd (mL/g) (From Table J-2.0-2)
Uranium	2.0e-3	0	0	2.43 to 4.85
Plutonium	1.4e-6	0	<0.2	4.13 to 711

The cancer risk for RDX can likewise be estimated using the predicted Kd = 0 concentrations at 1000 years shown in Figures J-5.1-1 and J-5.1-2, the solubility of RDX from Table J-2.0-2, an assumed drinking water ingestion rate of 2 L/day, and exposure inputs and the RDX slope factor discussed in Appendix H. This estimate results in predicted cancer risks on the order of 10^{-12} for the base-case simulation and 10^{-5} for the high-flow case simulation. These predicted cancer risks are well below (for the base case) or within the acceptable range (for the high-flow case) of 10^{-6} to 10^{-4} cancer risk specified as the corrective action objectives for this CMS.

Recall that the simulations assume no adsorption onto crushed tuff within the source region. This assumption was required so that the same mass was input into each simulation making the results of the different generic simulations comparable. Adsorption onto the backfill material would further delay breakthrough of any sorbing species and decrease the breakthrough concentrations presented in Figures J-5.1-1 and J-5.1-2. Also, transport and dilution within the aquifer would reduce contaminant concentrations as well.

Because the breakthrough results are based on a constant source concentration throughout the entire volume of the shafts, they can be directly scaled for solubility-limited species (as demonstrated with the uranium and plutonium examples above) to calculate the absolute maximum breakthrough concentration, assuming the release of the species is solubility limited over the entire 1000-year simulation period. If insufficient inventory exists to maintain the source at its solubility limit throughout the 1000-year time frame and/or if the constituent does not occupy a large portion of the shaft volumes, then breakthrough is overestimated with these simulations.

Few species are expected to have sufficient inventory to create a solubility-limited release. In these cases, source concentration would be less than the elemental solubility limit of the species. For species controlled by a rapid-release source mechanism, as described in the MDA G PA work (Birdsell et al. 1999, 69792), upper bound breakthrough concentrations can be obtained by estimating a maximum source concentration and scaling the breakthrough curves by that concentration. This approach should be used with caution for rapid-release components, as the calculated upper bound may be several orders of magnitude higher than the value calculated with a true time-varying rapid-release source model.

To determine which contaminants may be of concern over 1000 years. The adsorption coefficients presented in Table J-2.0-2 are compared to the results in Figures J-5.1-1 and J-5.1-2. For this general discussion, it is conservatively assumed that a concentration of 10^{-10} times a species' solubility limit is a sufficient decrease to not pose a health risk. However, this assumption needs to be verified for individual constituents of concern.

- Under the base-case flow field, cyanuric acid and RDX could potentially reach the aquifer in 1000 years. Under the upper-bound flow field, cyanuric acid, RDX and TNT could potentially reach the aquifer in 1000 years. As noted above, the cancer risk for RDX was estimated and found to be acceptable according to the corrective action objectives for this CMS.
- Since tritium is a radioactive constituent with a short half-life of 12.4 years, radioactive decay precludes it from reaching the aquifer. This is because the source is constantly decaying, rather than the constant source assumed in the calculations, and its minimum travel times is in the range of 125 years (10 tritium half-lives) through the mesa, based on Figure J-5.1-2.
- Based on isotopic ratios for plutonium and uranium in the MDA H inventory, these nuclides were shown to have sufficiently low solubility and large Kd to not exceed a 15 mrem/yr dose over 1000 years.
- None of the other wastes at MDA H have Kd values less than 2.0 mL/g, and therefore these constituents will not break through to the water table over the 1000-year compliance period.

J-5.2 Implications for Monitoring in the Unsaturated Zone

The simulation results indicate that the unsaturated zone at MDA H acts as a protective barrier with respect to groundwater. That is, under conditions for both the base-case flow field and the upper-bound flow field, both risk and dose to a groundwater receptor will fall within or well below the desired range over the next 1000 years. With this in mind, the simulation results for the upper-bound flow case can be used to specify monitoring requirements that will act to maintain protection of groundwater.

Figure 2.1-5 in the main text of this CMS report shows measured moisture profiles in boreholes 54-15462 and 54-15461. Volumetric water content in unit Qbt1vu from depths of 60 to 100 ft are in the range of 3 to 5%. Since the shafts terminate at a depth of 60 ft at MDA H, neutron monitoring in some or all of these holes at this interval (60 to 100 ft) within Qbt1vu would indicate whether enhanced percolation through the shafts occurs in the future. The simulations show that the saturation level in Unit Qbt1vu would rise to approximately 20 to 22% (see Figure J-2.0-2) if the infiltration rate rises to the steady upper-bound mesa top rate of 10 mm/yr. Saturation of 20 to 22% in Qbt1vu corresponds to volumetric water content ranging from 10 to 11%. Therefore, monitoring of these holes at depths from 60 to 100 ft within Unit Qbt1vu is recommended. Increases in volumetric water content above 10 to 11% in this interval warrant concern. Although this higher water content would need to be maintained over a minimum of several decades to affect a long-term increase in transport velocities, an increase of this magnitude at this depth would indicate that the system behavior has changed significantly and is proposed as the monitoring criterion.

J-6.0 UNCERTAINTY

As in any predictions of the long-term migration of solutes through the subsurface, the results of these transport simulations contain intrinsic uncertainty. The greatest uncertainties associated with predicting unsaturated-zone transport from the site are related to the understanding of the mechanisms that control flow and transport within the unsaturated zone and the ability to model these mechanisms. At this point, the uncertainty related to the hydrologic processes themselves (conceptual model uncertainty) dominates the ability to make accurate predictions of transport at the site more so than uncertainty related to the hydrologic and geochemical properties (data uncertainty). However, predicted concentrations using parameters from the most conservative ends of the uncertain ranges are still well below those that would cause concern.

Unsaturated Zone Flow

In situ saturation data are difficult to match with any single infiltration rate using our current unsaturated-zone model. It is possible that the mesa and the submesa units are not strongly connected hydrologic systems. Higher saturations beneath the mesa may result from a recharge source other than percolation through the mesa or could represent moisture from a past, wetter climate. Evaporation is clearly an important mechanism controlling fluxes within the mesa, yet it is only indirectly incorporated into the flow modeling through the application of low infiltration rates of one and ten mm/yr. By directly simulating evaporation in fractures and surge beds within the mesa interior, calculated solute migration through the mesa may behave similarly to that seen with environmental tracers such as chloride. These tracers accumulate within the mesa and have estimated travel times on the order of 1,000 to 17,000 years through the Bandelier Tuff (Newman 1996, 59372). Accumulation of contaminants within the mesa top would lead to a reduction in predicted aquifer-related doses.

The mesa-top infiltration rate has the greatest impact on the simulated migration of waste through the unsaturated zone. This uncertainty was bounded by considering a base-case flow field and a high-flow case. As shown in Figures J-5.1-1 and J-5.1-2, an increase in mesa-top infiltration rate from one to ten mm/yr results in approximately a seven order of magnitude increase in concentration after 1000 years for a nonsorbing species. Because simulated breakthrough shows that the site performs adequately, conservative yet realistic infiltration rates seem adequate for this site.

Other uncertainties are related to flow within the deeper unsaturated-zone units for which few hydrologic data are available. The simulations take virtually no credit for transport times through the Cerros del Rio Basalts or the Puye Conglomerate, which make up more than 50% of the unsaturated zone. Understanding the mechanisms that govern flow and transport in the deeper unsaturated-zone and incorporating them into the model could add hundreds or thousands of years to predicted transport times and result in lower peak aquifer concentrations.

The transport results are based on the steady-flow assumption and on the use of matrix, hydrologic properties for all tuff units at the site. The understanding of the response of this fractured system to transient flow events remains uncertain. Transient calculations (Birdsell et al. 1999, 69792) indicate that the steady-flow assumption is adequate because fluctuations in both saturation and contaminant fluxes damp with depth even when including fractures in the upper two units. Fracture infiltration studies (Soll and Birdsell 1998, 70011) lead to the conclusion that fracture flow is difficult to initiate and is short lived in the upper two tuff units at the observed low field saturations. This conclusion helps justify the use of the matrix hydrologic properties for the calculations. Only Unit 2 and the uppermost portion of Unit 1v-u show evidence of significant fracturing at TA-54 (Krier et al. 1997, 56834), and these units were excavated during shaft emplacement. Therefore, the waste is already placed at depths within or below these units. Below the shafts, waste should not migrate through any highly fractured units until reaching the basalts. The matrix units that underlie the shafts should attenuate transient pulses and fracture flow should be minimal, except possibly in the basalts.

Transport Properties and Source Term

The transport simulations are highly sensitive to the value of the distribution coefficient, Kd, in the unsaturated zone. Uncertainty in this parameter for weakly sorbing nuclides plays an important role in the results of this analysis over 1000 years. According to the simulations, a nuclide with a Kd greater than 0.5 mL/g will not reach the aquifer within 1000 years at concentrations higher than 10^{-10} times its solubility limit, under the high-flow case. Site-specific Kd values for several nuclides at MDA H and expected low distribution coefficients were measured to decrease the uncertainty in the model predictions that results from data uncertainty related to retardation (Longmire et al. 1996, 56030). The combination of a low-Kd nuclide traveling along a fast flow path could lead to breakthrough of slightly sorbing species. However, for this mechanism to create a risk, fast flow paths would need to contact a significant portion of the inventory. The effect of inventory uncertainty can be estimated by linearly scaling the simulation results.

The source term used in these simulations is extremely conservative in that it assumes that all constituents are immediately and always available at their solubility limit, and that the volumes of the releases are equivalent to the total volume of the nine shafts at MDA H.

7.0 DISCUSSIONS AND CONCLUSIONS

Numerical simulations are used to predict the long-term migration of wastes through the unsaturated zone from MDA H at TA-54. The study uses information on the site geology, hydrology, and geochemistry to define the conceptual model of flow and transport processes that occur at the site. This conceptual understanding is then incorporated into a processed-based numerical model that simulates groundwater flow and contaminant transport through the unsaturated zone that lies beneath TA-54. Screening and scaling techniques, as well as simplifying assumptions, are used to make an assessment of unsaturated-zone, aqueous-phase contaminant transport for a variety of chemical constituents tractable. The predictions simulate the release of a constant, generic source (Co=1 mole/L) followed by subsequent transport toward the regional aquifer. A base case and higher-flow case are simulated in order to address the effect of uncertainty in infiltration rate on breakthrough concentrations exiting the unsaturated zone. A variety of distribution coefficients (Kd) are also considered. Results of breakthrough concentrations using this model can be scaled by a contaminant’s solubility limit to estimate the maximum concentration of a contaminant as it exits the unsaturated zone. Aquifer dilution would further decrease concentrations before a receptor could be exposed through the groundwater pathway.

The simulation results indicate the following:

1. Only the constituents RDX, TNT and cyanuric acid have the potential for reaching the aquifer over 1000 years. As noted above, the cancer risk for RDX was estimated to be on the order of 10^{-12} for the base-case simulation and 10^{-5} for the high-flow case simulation.
2. The calculations show that none of the nuclides present in the MDA H inventory reach the aquifer in sufficient concentrations to produce a dose of 15 mrem/yr over the 1000-year time frame.

Process-based predictions provide a science-based site assessment that readily demonstrates the incorporation of the conceptual model into the numerical predictions. Such predictions can also highlight data needs or identify data that are not crucial to a site assessment. For this example, the mesa-top infiltration rate is the strongest control over the predicted dose. Chloride profiles (Newman 1996, 59372) and predicted saturation profiles indicate that the range of infiltration rates chosen is conservative for the site. For this reason, a continued effort that couples chloride and isotope analyses with modeling studies is planned to better understand local and site-wide net infiltration across the Laboratory.

In contrast, although there is little information on the hydrologic properties of the basalt unit at the site, such data are not currently required. The site appears to perform significantly better than is required despite the assumption of nearly instantaneous transport through the basalt unit. Any data gathered to increase the understanding of transport through the basalt would presumably increase travel times and decrease predicted aquifer concentrations.

These results are incorporated into a system-level model of MDA H that includes all of the transport processes expected to occur at the site in a coupled manner, as discussed in Appendix H. The entire estimated inventory and list of constituents documented in Appendix B are included in the system-level model. With this approach, the assessment considers the cumulative effects of the entire inventory with respect to all of the corrective measures objectives.

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Appendix K

Supporting Information for Cost Estimates

APPENDIX K SUPPORTING INFORMATION FOR COST ESTIMATES

K-1: Alternative 1, Upgrade Existing Cover

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #:	**1.0**
Level:	**Summary**
Name:	**Alternative 1, Upgrade Existing Cover**
Date:	**10/26/01**
Revision #:	**1.1**
Description:	The "As Is" cost estimate is based on maintaining the current condition of MDA H, with minor improvements known as Best Management Practices (BMPs). In addition to leaving the solid waste inventory in the shafts, this alternative includes the following: • Retaining the concrete/crushed tuff covers • Maintaining institutional controls for site surveillance and maintenance for 100 years • Regrade and place 6 in of topsoil, thin gravel mulch cover, revegetate with native grasses and plants • Install pressure drop sensors and automatic shutoff valves in two adjacent water lines north (up gradient) of MDA H
Cost Estimate Assumptions:	Preliminary Estimate only, no detail design available. Assumes that all standard Federal, State, and Laboratory policies, procedures, training and certification requirements in place as of 8/2002 will be the regulatory framework for this work and that more stringent requirements may require re-estimation of costs. Assumes that all subordinate cost estimate assumptions shown in the preliminary estimate backup sheets are also included in this set of assumptions. Assumes maintenance to consist of annual BMP renewal and repair of erosional geomorphology (gullies, arroyos) and reseeding and/or regravelling as needed. All estimated dollars in constant FY 2002 dollars (no escalation). Assumes three-month design/permitting period, 6 weeks site work. Estimate does not include annual maintenance and surveillance costs – use average $4,500/year (FY2002 dollars), or $450,000 for a 100-year period (semi-annual site visit, erosion control, replace fencing once). Assumes no archeology mitigation.
Estimate:	**Summary of WBS 1.0**
Preliminary Estimate	**WBS Element**
$3,000	WBS 1.1 – MOBILIZATION, DEMOBILIZATION
$13,800	WBS 1.2 – Fence Removal and Site Preparation
$9,000	WBS 1.3 - Regrading/Topsoil/Gravel/Revegetation
$31,500	WBS 1.4 – Install new Fencing/gate
$50,000	WBS 1.5 – Utility work – pressure valves
$29,000	WBS 1.6 - Health & Safety
$24,000	WBS 1.7 – Design & Permitting
$18,000	WBS 1.8 - Manage the Project
$35,700	Contingency @ 20%
$214,000	Total Preliminary Estimate for MDA H Alternative 1, Upgrade Existing Cover

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #:	**1.0**
Level:	**Summary**
Name:	**Contingency**
Date:	**10/26/01**
Revision #:	**1.1**
Description:	Includes Contingency amounts for unknown conditions that are known to exist at MDA H. Contingency driven by lack of preliminary design, but conditions at site are well known and no subsurface disruption is anticipated.
Cost Estimate Assumptions:	Contingency also assumes that site conditions including normal rainfall and temperature will exist during construction activities. Contingency amounts are assumed to be within normal preliminary estimate range when design data is not available at the time of the estimate.
Estimate:	Use 20% contingency overall for the project. Contingency estimates will be refined at a later date when additional design information is available.

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.1 – Mobilization, Demobilization**
Level	**SUMMARY**
Name	**Mobilization, Demobilization**
Date	**10/26/01**
Revision #	**1.1**
Description	Includes mobilization and demobilization of equipment to MDA H. Includes mobilization of workforce and initial site placement of equipment.
Cost Estimate Assumptions	Assumes no additional traffic control is needed, no on-site construction trailer is needed, no on-site decontamination needed. Assumes mob/demob of backhoe, dump trucks, grader, and service truck. Assumes site storage of equipment, no special facilities or equipment protection needed.
Estimate	Summary of WBS 1.1
Preliminary Estimate	**Cost Item**
$1,500	Mobilization
$1,500	Demobilization
$3,000	Total, WBS 1.1

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.2 – Fence Removal and Site Preparation**
Level	**Summary**
Name	**Fence Removal and Site Preparation**
Date	**10/26/01**
Revision #	**1.1**
Description	Includes removal of existing security fencing and site clearing and grubbing. Assumes removal and disposal of ~ 700 LF fencing and existing gate.
Cost Estimate Assumptions	No additional security workforce is required during fence teardown. Site preparation includes leveling of existing dirt mound within the fence boundary at MDA H, clearing of vegetation and slope grading to the southeast at existing contours. Material to be reused on site – no off-site removal or need for fill material is anticipated.
Estimate	
Preliminary Estimate	**Cost Item**
$ 9,800	Remove existing fencing, haul to landfill use $ 12/LF to remove, $2/LF Dispose
$ 4,000	Site Clearing and grubbing, 0.4 acres includes debris hauling @ $ 12,000/Acre
$13,800	Total, WBS 1.2

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.3 - Regrading/Topsoil/Gravel/Revegetation**
Level	**Summary**
Name	**Regrading/Topsoil/Gravel/Revegetation**
Date	**10/26/01**
Revision #	**1.1**
Description	Add 6” of topsoil over the area of .4 acres (320 CY). Add a thin layer of gravel (50 CY) for erosion control after reseeding with native plants and grasses. Task involves spreading and fine grading of topsoil, watering (dust abatement) and watering of planted areas for vegetation germination at approved levels.
Cost Estimate Assumptions	Assumes planting at appropriate time of year. Assumes topsoil and gravel available within 50 miles in the quantities required for this task. Assumes coordination with fencing task to achieve minimal planting disturbance.
Estimate	
$4,500	Topsoil addition 320 CY @ $14/CY delivered and placed
$2,000	Replanting, 0.4 ac., LS
$900	Gravel addition 50 CY spread at $18/CY delivered and placed
$1,600	Misc. grading, blue stake
$9,000	Total, WBS 1.3

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.4 – Install New Fencing/Gate**
Level	**Summary**
Name	**Install new Fencing/gate**
Date	**10/26/01**
Revision #	**1.1**
Description	Install 700 LF of security fencing to replace aged fencing on site. Install one gate, padlocked sufficient in size to allow for site entry by vehicle. Sign and post perimeter.
Cost Estimate Assumptions	Assume fencing to be comparable to existing.
Estimate	
$31,500	Install 700 LF fencing, $45/LF

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.5 – Utility Work – Pressure Valves**
Level	**Summary**
Name	**Utility work – pressure valves**
Date	**10/26/01**
Revision #	**1.1**
Description:	Install pressure drop valves to reduce risk of major water infiltration to MDA H. Includes two valves per line.
Cost Estimate Assumptions	Assume lines are available per as-builds. Assume water protection during construction. Assume weekend work to avoid TA-54 site operations disruption.
Estimate	
$50,000	2 line valves @ $25,000 LS/valve, installed, tested and flushed

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.6 - Health & Safety**
Level	**Summary**
Name	**Health & Safety**
Date	**10/26/01**
Revision #	**1.1**
Description	Develop site health and safety plan. Coordinate surface sampling confirmation of non-hazardous site conditions (haz or rad waste). Monitor site activities and conform to standard construction health and safety policies, laws, and procedures.
Cost Estimate Assumptions	Assume no hazardous or radioactive waste disturbance on surface grading operations. Assume and confirm no health and safety issues at depth or locations of fencing removal or installation.
Estimate	
$24,000	6 weeks site health and safety @ $4,000/week
$5,000	Site specific health and safety plan (minimal)

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.7 – Design & Permitting**
Level	**Summary**
Name	**Design & Permitting**
Date	**10/26/01**
Revision #	**1.1**
Description	Minimal design for small site activity. Includes security planning, preliminary and final design, and permitting.
Cost Estimate Assumptions	Assumes no additional site security required. Assumes design includes no hazardous, toxic, or radioactive waste permitting required.
Estimate	
$10,000	Preliminary Design, LS
$14,000	Final Design, including comment incorporation, as-built drawings, LS.

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.8 - Manage the Project**
Level	**Summary**
Name	**Manage the Project**
Date	**10/26/01**
Revision #	**1.1**
Description	Includes working foreman project manager, site progress and daily reporting, office support at ¼ time basis for size/complexity of project.
Cost Estimate Assumptions	Assumes no special PM requirements. Assumes standard job PM reporting and project documentation
Estimate	
$18,000	PM for duration of project, LS

K-2: Alternative 2, Engineered ET Cover with Maintenance and Monitoring

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.0**
Level	**Summary**
Name	**Alternative 2, Engineered ET Cover w/ Maintenance & Monitoring, MDA H**
Date	**10/28/01**
Revision #	**1.2**
Description	Design and install an engineered ET cover over the MDA H site based on research previously conducted on suitable ET covers for the geology and climate of the Pajarito Plateau. The goal is to limit downward percolation, reduce surface erosion, and limit the amount of water that percolates into the shaft waste. Utilize a biobarrier layer to inhibit the impact of deep-rooting plants and burrowing animals. Cobble barrier design will include a surface of dense, shallow-rooting vegetation to facilitate moisture removal by ET.
Cost Estimate Assumptions	Preliminary Estimate only, no detail design available. Assumes that all standard Federal, State, and Laboratory policies, procedures, training and certification requirements in place as of 8/2002 will be the regulatory framework for this work and that more stringent requirements may require re-estimation of costs. Assumes that all subordinate cost estimate assumptions shown in the preliminary estimate backup sheets are also included in this set of assumptions. Assumes maintenance to consist of annual ET cover renewal and repair of erosional geomorphology (gullies, arroyos) and reseeding and/or regravelling as needed. All estimated dollars in constant FY 2002 dollars (no escalation). Assumes four-month design/permitting period, two months site work. Estimate does not include annual maintenance and surveillance costs – use average $5,000/year (FY2002 dollars), or $500,000 for a 100-year period (semi-annual site visit, erosion control, replace fencing once). Assumes no archeology mitigation.
Estimate	**Summary of WBS 1.0**
Preliminary Estimate	**WBS Element**
$5,000	WBS 1.1 – Mobilization, Demobilization
$13,800	WBS 1.2 – Fence Removal and Site Preparation
$30,200	WBS 1.3 - Regrading/ET Cover installation/revegetation
$31,500	WBS 1.4 – Install new Fencing/gate
$50,000	WBS 1.5 – Utility work – pressure valves
$72,000	WBS 1.6 - Health & Safety
$36,000	WBS 1.7 – Design & Permitting
$40,000	WBS 1.8 - Manage the Project
$69,600	Contingency @ 25%
$348,100	Total Preliminary Estimate for MDA H Alternative 2, Engineered ET Cover

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.0**
Level	**Summary**
Name	**Contingency – ET Cover**
Date	**10/26/01**
Revision #	**1.1**
Description	Includes Contingency amounts for unknown conditions that are known to exist at MDA H. Contingency driven by lack of preliminary design, but conditions at site are well known and no major subsurface disruption is anticipated.
Cost Estimate Assumptions	Contingency also assumes that site conditions including normal rainfall and temperature will exist during construction activities. Contingency amounts are assumed to be within normal preliminary estimate range when design data is not available at the time of the estimate. Contingency slightly higher than Alt 1 due to site soil scarification and additional possibility of unknown soil conditions in the top 18” of the soil column.
Estimate	Use 25% contingency overall for the project. Contingency estimates will be refined at a later date when additional design information is available.

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.1 – Mobilization, Demobilization**
Level	**SUMMARY**
Name	**Mobilization, Demobilization**
Date	**10/26/01**
Revision #	**1.1**
Description	Includes mobilization and demobilization of equipment to MDA H. Includes mobilization of workforce and initial site placement of equipment.
Cost Estimate Assumptions	Assumes no additional traffic control is needed, no on-site construction trailer is needed, no on-site decontamination needed. Assumes mob/demob of backhoe, dump trucks, grader, and service truck. Assumes site storage of equipment, no special facilities or equipment protection needed.
Estimate	**Summary of WBS 1.1**
Preliminary Estimate	**Cost Item**
$2,500	Mobilization
$2,500	Demobilization

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.2 – Fence Removal and Site Preparation**
Level	**Summary**
Name	**Fence Removal and Site Preparation**
Date	**10/26/01**
Revision #	**1.1**
Description	Includes removal of existing security fencing and site clearing and grubbing. Assumes removal and disposal of ~ 700 LF fencing and existing gate.
Cost Estimate Assumptions	No additional security workforce is required during fence teardown. Site preparation includes leveling of existing dirt mound within the fence boundary at MDA H, clearing of vegetation and slope grading to the southeast at existing contours. Material to be reused on site—no off-site removal or need for fill material is anticipated.
Estimate	
Preliminary Estimate	**Cost Item**
$9,800	Remove existing fencing, haul to landfill use $ 12/LF to remove, $2/LF Dispose
$4,000	Site Clearing and grubbing, 0.4 acres includes debris hauling @ $ 12,000/Acre
$13,800	Total, WBS 1.2

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.3 - Regrading/Topsoil/Gravel/Revegetation**
Level	**Summary**
Name	**Regrading/Topsoil/Gravel/Revegetation**
Date	**10/26/01**
Revision #	**1.1**
Description	Add 2 feet of cobble (1,250 CY) over site-scarified area. Add 6” of topsoil over the area of 0.4 acres (320 CY). Add a thin layer of gravel (50 CY) for erosion control after reseeding with native plants and grasses. Task involves mechanical cobble placement, spreading and fine grading of topsoil, watering (dust abatement) and watering of planted areas for vegetation germination at approved levels.
Cost Estimate Assumptions	Assumes planting at appropriate time of year. Assumes topsoil, cobble, and gravel available within 50 miles in the quantities required for this task. Assumes coordination with fencing task to achieve minimal planting disturbance. Assumes average cobble placement at 24” depth with mechanical placement.
Estimate	
$4,500	Topsoil addition 320 CY @ $14/CY delivered and placed
$21,200	Cobble, 1250 CY @ $17/CY
$2,000	Replanting, 0.4 ac., LS
$900	Gravel addition 50 CY spread at $18/CY delivered and placed
$1,600	Misc. grading, blue stake
$30,200	Total, WBS 1.3

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.4 – Install New Fencing/Gate**
Level	**Summary**
Name	**Install new Fencing/gate**
Date	**10/26/01**
Revision #	**1.1**
Description	Install 700 LF of security fencing to replace aged fencing on site. Install one gate, padlocked sufficient in size to allow for site entry by vehicle. Sign and post perimeter.
Cost Estimate Assumptions	Assume fencing to be comparable to existing.
Estimate	
$31,500	Install 700 LF fencing, $45/LF

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.5 – UTILITY WORK – PRESSURE VALVES**
Level	**Summary**
Name	**Utility work – pressure valves**
Date	**10/26/01**
Revision #	**1.1**
Description	Install pressure drop valves to reduce risk of major water infiltration to MDA H. Includes two valves per line.
Cost Estimate Assumptions	Assume lines are available per as-builds. Assume water protection during construction. Assume weekend work to avoid TA-54 site operations disruption.
Estimate	
$50,000	2 line valves @ $25,000 LS/valve, installed, tested and flushed

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.6 - Health & Safety**
Level	**Summary**
Name	**Health & Safety**
Date	**10/26/01**
Revision #	**1.1**
Description	Develop site health and safety plan. Coordinate surface sampling confirmation of non-hazardous site conditions (haz or rad waste). Monitor site activities and conform to standard construction health and safety policies, laws, and procedures. Includes HPT monitoring, testing of soils.
Cost Estimate Assumptions	Assume no hazardous or radioactive waste disturbance on surface grading operations. Assume and confirm no health and safety issues at depth or locations of fencing removal or installation. Assumes that testing of soils results in tritium levels within acceptable non-hazardous classification range.
Estimate	
$64,000	Eight weeks site health and safety @ $8,000/week, testing, HPT
$8,000	Site-specific health and safety plan (minimal)

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.7 – Design & Permitting**
Level	**Summary**
Name	**Design & Permitting**
Date	**10/26/01**
Revision #	**1.1**
Description	Minimal design for small site activity. Includes ET engineering, security planning, preliminary and final design, and permitting.
Cost Estimate Assumptions	Assumes no additional site security required. Assumes design includes no hazardous, toxic, or radioactive waste permitting required.
Estimate	
$18,000	Preliminary Design, LS
$18,000	Final Design, including comment incorporation, as-built drawings, LS.

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.8 - Manage the Project**
Level	**Summary**
Name	**Manage the Project**
Date	**10/26/01**
Revision #	**1.1**
Description	Includes working foreman project manager, site progress and daily reporting, office support at ¼ time basis for size/complexity of project. Includes ET specialist for placement/configuration monitoring during construction.
Cost Estimate Assumptions	Assumes no special PM requirements. Assumes standard job PM reporting and project documentation
Estimate	
$40,000	PM for duration of project, LS

K-3: Alternative 3, Stabilization (Complete Encapsulation)

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.0**
Level	**Summary**
Name	**Alternative 3, Stabilization, (Complete Encapsulation), MDA H**
Date	**10/30/01**
Revision #	**1.3**
Description	Alternative 3, complete encapsulation, involves designing and drilling of containment shafts and the use of grouting to surround the existing nine shafts containing solid buried waste at MDA H. Once grouted, an interlocked concrete lid to prevent shaft intrusion will also cap the shafts. Design and install an engineered ET cover over the MDA H site based on research previously conducted on suitable ET covers for the geology and climate of the Pajarito Plateau. The goal is to limit downward percolation, reduce surface erosion, and limit the amount of water that percolates into the shaft waste. Utilize a biobarrier layer to inhibit the impact of deep-rooting plants and burrowing animals. Cobble barrier design will include a surface of dense, shallow-rooting vegetation to facilitate moisture removal by ET.
Cost Estimate Assumptions	Preliminary Estimate only, no detail design available. Assumes that all standard Federal, State, and Laboratory policies, procedures, training and certification requirements in place as of 8/2002 will be the regulatory framework for this work and that more stringent requirements may require re-estimation of costs. Assumes that all subordinate cost estimate assumptions shown in the preliminary estimate backup sheets are also included in this set of assumptions. Assumes maintenance to consist of annual ET cover renewal and repair of erosional geomorphology (gullies, arroyos) and reseeding and/or regravelling as needed. All estimated dollars in constant FY 2002 dollars (no escalation). Assumes four-month design/permitting period, two months site work. Assumes seismic construction of shafts with I-Beam center posts interlocked to lids (8/shaft). Assumes no archeology mitigation.
Estimate	**Summary of WBS 1.0**
Preliminary Estimate	WBS Element
$40,000	WBS 1.1 – Mobilization, Demobilization
$668,000	WBS 1.2 – Drilling
$295,000	WBS 1.3 - Grouting
$45,000	WBS 1.4 – Surface Caps, 9 shafts
$230,000	WBS 1.5 - Health & Safety
$145,000	WBS 1.6 – Design & Permitting
$177,000	WBS 1.7 - Manage the Project
$640,000	**Contingency @ 40%**
$310,000	**Engineered ET Cover (backup in Alt 2, less redundant PM, mob/demob costs**
$2,550,000	**Total Preliminary Estimate for MDA H Alternative 3, Stabilization**

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.0**
Level	**Summary**
Name	**Contingency – Stabilization with complete encapsulation**
Date	**10/26/01**
Revision #	**1.1**
Description	Includes Contingency amounts for unknown conditions that are known to exist at MDA H. Contingency driven by lack of preliminary design and need to bench test and find the most suitable grouting mixture (Ceramicrete, Tuff/grout mix, etc.) coupled with unknown contaminant migration at depth. Geologic properties of the tuff are well known, but rock fractures that potentially could impact shaft construction or placement are generally but not specifically known.
Cost Estimate Assumptions	Assumes no shaft content disturbances will occur (heat, vibration and/or penetration) that will adversely impact or delay construction of the encapsulation curtains. Contingency also assumes that site conditions including normal rainfall and temperature will exist during construction activities. Contingency amounts are assumed to be within normal preliminary estimate range when design data is not available at the time of the estimate.
Estimate	Use 40% contingency overall for the project (encapsulation portion) and 20% for the ET cover cost estimate (estimated ET contingency described in Alt 2, ET cover). Contingency estimates will be refined at a later date when additional design information is available.

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.1 – Mobilization, Demobilization**
Level	**SUMMARY**
Name	**Mobilization, Demobilization**
Date	**10/28/01**
Revision #	**1.2**
Description	Includes mobilization and demobilization of equipment to MDA H. Includes mobilization of workforce and initial site placement of equipment. Includes mobilization of drill rig and stabilization soil mixing plant. Includes demobilization decontamination costs of drilling equipment.
Cost Estimate Assumptions	Assumes site storage of equipment, no special facilities or equipment protection needed. Assumes on-site construction trailer for the duration of the project.
Estimate	Summary of WBS 1.1
Preliminary Estimate	Cost Item
$8,000	Mobilization
$32,000	Demobilization & Decontamination
$40,000	**Total, WBS 1.1**

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.2 – Drilling**
Level	**Summary**
Name	**Shaft Drilling**
Date	**10/30/01**
Revision #	**1.1**
Description	Drill interlocking shafts of 2 to 3 feet in diameter in proximity to each MDA H shaft to a depth of 60 feet. It is estimated that 12–16 shafts will be required to isolate each of the 9 waste-containing shafts at MDA H.
Cost Estimate Assumptions	Assume 16 shafts per MDA-H shaft for a total of 144 boreholes. Assume additional costs for downtime on equipment and for drill rig movement
Estimate	
Preliminary Estimate	**Cost Item**
$648,000	144 Shafts @ $4,500/shaft
$20,000	LS, equipment movement
$668,000	Total, WBS 1.2

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.3 - Grouting**
Level	**Summary**
Name	**Grouting**
Date	**10/30/01**
Revision #	**1.1**
Description	Grouting mixture of crushed tuff (extracted from drill holes) and grout mix processed in on-site batch soil mixer facility. Bench test add mixtures for correct ph, heat, and chemical composition to arrive at grout mix design.
Cost Estimate Assumptions	Assume 16 CY mix/curtain shaft, 2,400 CY total mixture. Assume bench test for safe, reliable mix design.
Estimate	
$ 50,000	Bench Test for mix design
$ 20,000	Batch plant grout operation downtime cost
$ 96,000	Grout Cost, placed @ $ 40/CY
$ 129,000	I-Beam placement w/ crane, 144 each @ $900/Beam (Seismic protection)
$ 295,000	Total, WBS 1.3

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.4 – Surface Caps, 9 Shafts**
Level	**Summary**
Name	**Install new Concrete Plug Caps**
Date	**10/26/01**
Revision #	**1.1**
Description	Place new, uniform concrete caps on isolated shaft columns to seal top of shafts prior to installation of ET cover. Used for intrusion security, moisture protection.
Cost Estimate Assumptions	Assume reinforced concrete, 1-foot thick slabs to be tied in to I-Beams, 9 each.
Estimate	
$ 45,000	Install 9 slab covers, tied to I-beams (see WBS 1.3) @ $5k/slab

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.5 - Health & Safety**
Level	**Summary**
Name	**Health & Safety**
Date	**10/30/01**
Revision #	**1.1**
Description	Develop site health and safety plan. Coordinate surface sampling confirmation of non-hazardous site conditions (haz or rad waste). Monitor site activities and conform to standard construction health and safety policies, laws, and procedures. Includes HPT monitoring, testing of soils, testing of shaft cuttings.
Cost Estimate Assumptions	Assume no hazardous or radioactive waste disturbance on surface grading operations and in shafts. Assume and confirm no health and safety issues at depth or locations of shaft material removal or grout installation. Assumes that testing of soils results in tritium levels within acceptable non-hazardous classification range, and no waste is generated.
Estimate	
$200,000	Site health and safety @ $10,000/week, testing, HPT
$30,000	Site specific health and safety plan

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.6 – Design & Permitting**
Level	**Summary**
Name	**Design & Permitting**
Date	**10/30/01**
Revision #	**1.1**
Description	Includes shaft grouting and ET engineering, security planning, preliminary and final design, and permitting. Includes seismic design.
Cost Estimate Assumptions	Assumes no additional site security required. Assumes design includes no hazardous, toxic, or radioactive waste permitting required. Assumes batch design is acceptable to the state of NM.
Estimate	
$ 85,000	Preliminary Design, LS
$ 60,000	Final Design, including comment incorporation, as-built drawings, LS.

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**WBS 1.7 - Manage the Project**
Level	**Summary**
Name	**Manage the Project**
Date	**10/30/01**
Revision #	**1.1**
Description	Includes working on-site project manager, site progress and daily reporting, office support at 1/2 time basis for size/complexity of project. Includes drilling specialist and ET specialist for placement/configuration monitoring during construction.
Cost Estimate Assumptions	Assumes no special PM requirements. Assumes standard job PM reporting and project documentation. Assumes one full-time, on-site PM plus engineering specialists and on-site geologist.
Estimate	
$57,000	PM for duration of project, LS
$100,000	PM Technical Support personnel (2 @ $50k / staff)
$20,000	PM Reporting/change management
$177,000	Total, WBS 1.7

K-4: Alternative 4, Excavation Alternative

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.0**
Level	**Summary**
Name	**Alternative 4, Excavation Alternative - MDA H**
Date	**03/04/03**
Revision #	**3.4**
Description	Excavation and complete removal of previously disposed classified, solid-form waste in nine, 60-ft deep, 6-ft diameter shafts at Material Disposal Area H, TA-54, Los Alamos National Laboratory. Disposal of hazardous and radioactive material will be off-site in licensed and approved waste disposal facilities. HE will be burned on site. Classified shapes will be deformed and rendered unclassified prior to packing and shipping.
Cost Estimate Assumptions	Preliminary Estimate only, no detail design available. Assumes placement of suggested Excavation Alternative Significant Controls per Table 10, *Transportation and Worker Risk Assessment for MDA-H, TA-54, LANL* (01-OMICRON-014, 9/30/01). Costs estimated in constant 2002 dollars; no escalation applied. Estimated duration of design/construction is 46 months (6 month design, 40 month construct). Assume full PPE in sorting and contact fieldwork, remote equipment excavation used in shaft areas. Assumes a need for a full Safety Analysis Report (SAR) due to the possible presence of Uranium Hydride and **a complete re-estimation of costs if the SAR indicates high hazards due to the presence of Uranium Hydride.** Assume off-site disposal for all shaft materials that meet hazardous/radioactive waste disposal requirements. Assumes that all standard Federal, State, and Laboratory policies, procedures, training and certification requirements in place as of 3/2003 will be the regulatory framework for this excavation and that more stringent requirements may require re-estimation of costs. Assumes that all subordinate cost estimate assumptions shown in the preliminary estimate backup sheets are also included in this set of assumptions.
Estimate	**Summary of WBS 1.0**
Preliminary Estimate	**WBS Element**
1,162,080	WBS 1.1 - Excavation/Refill
5,724,400	WBS 1.2 - Shaft Material Remove & Sort
8,790,000	WBS 1.3 - Declassify, Treat, Package & Dispose (Off Site)
3,757,400	WBS 1.4 - Construct Support Facilities
3,879,600	WBS 1.5 - Provide Security
6,426,800	WBS 1.6 - Health & Safety, including SAR
1,730,000	WBS 1.7 - Provide Design
3,815,400	WBS 1.8 - Manage the Project
16,620,000	Contingency @ 47%
51,906,000	**Total Preliminary Estimate for Alternative 4, MDA H Excavation & Removal**

<table>
<tr><th colspan="2">WBS Dictionary/MDA H Preliminary Cost Estimate Backup</th></tr>
<tr><td>WBS #</td><td>1.0</td></tr>
<tr><td>Level</td><td>Summary</td></tr>
<tr><td>Name</td><td>Contingency</td></tr>
<tr><td>Date</td><td>3/04/03</td></tr>
<tr><td>Revision #</td><td>3.4</td></tr>
<tr><td>Description</td><td>Includes Contingency amounts for unknown conditions that are known to exist at MDA H. Due to the nature and placement of material in all nine shafts and the lack of exhaustive records for these materials and placements, a large contingency is warranted. Experience on the ER Project at MDA P indicates that solid material removal can expose unknown quantities, shapes, types, materials, and configuration of placed materials during removal. It is anticipated that quantities and types of materials are fairly well know at MDA H, but that inter-shaft placement, state of deterioration, and material condition are not well known.</td></tr>
<tr><td>Cost Estimate Assumptions</td><td>Contingency is not provided for removal of different materials not stated in LANL placement logbooks or other records. Contingency is provided for Tritium contamination that may exist in quantities larger than stated in the shaft excavation portion of the estimate and for mixed waste classification of overburden, so long as this quantity does not exceed 10% of the total overburden quantity. Contingency also assumes that site conditions including normal rainfall and temperature will exist during excavation activities. Contingency is also provided for normal security measures and does not include extraordinary measures caused by increased security measures lab wide. Contingency amounts are assumed to be within normal preliminary estimate range when design data is not available at the time of the estimate.</td></tr>
<tr><td>Estimate</td><td>Use 47% contingency overall for the project. Contingency estimates will be refined at a later date when additional design information is available. See table for current contingency considerations</td></tr>
<tr><td>Contingency Table</td><td>
<table>
<tr><th>Contingency Event</th><th>Probability Of Occurrence</th><th>Estimated Cost of Occurrence</th><th>Added Cost to Base Estimate</th></tr>
<tr><td>Preliminary to final design changes incl. Regulatory changes</td><td>100%</td><td>13,000,000</td><td>13,000,000</td></tr>
<tr><td>Uranium Hydride work around</td><td>10%</td><td>4,000,000</td><td>400,000</td></tr>
<tr><td>HE/U Fire or detonation, (lightning or other source) including rerouting, overall LANL impacts</td><td>1%</td><td>150,000,000</td><td>1,500,000</td></tr>
<tr><td>Undocumented shaft contents adding waste handling/disposal costs</td><td>50%</td><td>1,000,000</td><td>500,000</td></tr>
<tr><td>Impacts to local operations requiring road closures</td><td>10%</td><td>2,000,000</td><td>200,000</td></tr>
<tr><td>Impacts due to moisture control</td><td>20%</td><td>1,000,000</td><td>200,000</td></tr>
<tr><td>Impacts due to removal technology changes/slow removal</td><td>50%</td><td>1,000,000</td><td>500,000</td></tr>
<tr><td>Impacts due to staff shortages of cleared/sorting personnel</td><td>80%</td><td>400,000</td><td>320,000</td></tr>
<tr><td>Total</td><td></td><td></td><td>16,620,000</td></tr>
</table>
</td></tr>
</table>

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.1**
Level	**Summary, 1**
Name	**Excavation/Refill**
Date	**10/4/01**
Revision #	**3.1**
Description	Excavation/Refill involves removal of material at MDA H in Los Alamos National Laboratory Technical Area (TA-54). This removal includes mobilization, site preparation (archeological mitigation, utility relocation, clearing & grubbing), soil and rock excavation, truck & stockpile, pit refill, site resloping, addition of 6” of topsoil/gravel mix, revegetation, and decontamination and demobilization.
Cost Estimate Assumptions	Assume excavation footprint at ground level of 120 X 240 ft with a depth of 62' and bottom width of 70' for a total of ~50,000 CY. Excavated material is composed of consolidated volcanic tuff on the Pajarito Plateau with an overburden soil depth of < 2 feet throughout the site. Specific Excavation/Refill assumptions included in detail sheets.
Estimate	Summary of WBS 1.1
Preliminary Estimate	WBS Element
$50,000	WBS 1.1.1
$142,000	WBS 1.1.2
$324,880	WBS 1.1.3
$135,200	WBS 1.1.4
$90,000	WBS 1.1.5
$80,000	WBS 1.1.6
$340,000	WBS 1.1.7
$1,162,080	**Total, WBS 1.1**

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.1.1**
Level	**Detail**
Name	**Mobilization**
Date	**9/18/01**
Revision #	**2.2**
Description	Mobilization consists of movement of all required equipment to TA-54 at Los Alamos National Laboratory and placement of equipment on site at MDA H. Movement includes trucking of equipment on Pajarito Road with preliminary staging adjacent to the site. Included in mobilization is the placement of the on-site construction trailer in an area cleared and leveled.
Cost Estimate Assumptions	Assume standard mobilization with no special load restrictions. Assume equipment moved from within the State.
Estimate	
$50,000	Use LS $50,000 (10 moves @ $5,000 move/setup)

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.1.2**
Level	**Detail**
Name	**Site Preparation**
Date	**9/18/01**
Revision #	**2.2**
Description	Includes utility hardening for access over existing lines, archeological mitigation, site clearing and grubbing.
Cost Estimate Assumptions	Assume utility hardening over access areas, mitigation monies for potential review along haul route and overburden areas. Assume preliminary assessment of design is correct and that no archeological sites will be impacted by construction based on mapping and preliminary field surveys. Assume standard clearing and grubbing including dust control. Assume waterline pressure sensor shutoff valves are installed for mitigation of potential line breaks causing water release into construction area.
Estimate	
$20,000	Use LS for utility hardening
$50,000	Use LS for utility valve placement (2 each @ $25k/valve)
$22,000	Use LS clearing and grubbing (5 days)
$50,000	Use LS for archeological survey along haul route/overburden area
$ 142,000	Total

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.1.3**
Level	**Detail**
Name	**Excavation**
Date	**9/18/01**
Revision #	**2.2**
Description	Excavate area around shafts in a footprint of 120 feet by 240 feet (surface) with a final trench bottom width of 65–70 feet. Use normal construction practices including use of dozers/scrapers. Does not include excavation within 4 feet of each shaft. Includes dust control, entrance/exit ramping, removal of material and placement in 10 CY capacity bobtail dump trucks. Overburden removal to take place in cooler months to reduce Tritium release to the environment.
Cost Estimate Assumptions	Assume excavation in area is similar to waste trenches in TA-54; consolidated volcanic tuff with bench construction practices of 4 foot benches every 10 feet in excavation depth. Assume 50% productivity reduction due to need to leave shaft area overburden in place for remote removal, and "stop and go" lift removal of material.
Estimate	
$324,880	Use $6.20/CY based on productivity reduction on historical $4.00/CY costs.
	52,400 CY estimated volume

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.1.4**
Level	**Detail**
Name	**Truck & Stockpile**
Date	**10/4/01**
Revision #	**3.1**
Description	Involves trucking of overburden material to storage area site and stockpiling using 10 CY bobtail trucks.
Cost Estimate Assumptions	Assume flagger, truck drivers. Assume 5,250 roundtrips, "stop and go" hauling based on removal pace. Assume closed route with no public access, and daily dust control on haul road. Assume 200 round trips/day, 26-day removal total. Assume removal by lifts and that schedule gaps between lifts for remote operations will cause 5 mob/demob cycles for trucks.
Estimate	
$20,800	Use LS for Dust Control, Flagger
$114,400	Use LS for ~ 10 trucks, 26 days, include stand down mob/demob
$135,200	Total

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.1.5**
Level	**Detail**
Name	**Refill**
Date	**10/4/01**
Revision #	**3.1**
Description	Refill trench area. Includes haul and placement of overburden into trench.
Cost Estimate Assumptions	Assume quick fill with 20% swell. Assume compaction at 10' lifts and watering to avoid future site settling. Assume overburden material is non-hazardous and that no external fill is required.
Estimate	
$90,000	Use 10 day refill cycle, 6 lifts @ $ 9,000/day

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.1.6**
Level	**Detail**
Name	**Reslope & Vegetation Cover**
Date	**10/4/01**
Revision #	**3.1**
Description	Regrade site, removal gravel haul road, place 6 inches of topsoil on impacted footprint and reseed with native vegetation.
Cost Estimate Assumptions	Assume standard to return to native vegetation, no capping or engineered controls.
Estimate	
$80,000	Use LS $80,000

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.1.7**
Level	**Detail**
Name	**Decontaminate & Demobilize**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes D&D of surface facilities, removal of structures/sheet piling, final equipment decontamination.
Cost Estimate Assumptions	Assumes surface contamination only and removal of facilities for landfill level dumping allowed.
Estimate	
$140,000	Use LS for dump truck station, final equipment clean/demob
$200,000	Use LS for sort and declass facility removal/vault clean
$340,000	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.2**
Level	**Summary, 1**
Name	**Shaft Material Remove & Sort**
Date	**10/4/01**
Revision #	**3.1**
Description	Primary removal activity of MDA H waste. Includes remote handling of material from nine shafts and conveyance to the sorting facility. Involves careful removal and handling due to HE solids and heavy lift items including DU. Sort into three waste streams: classified, hazardous non-classified, and non-hazardous non-classified.
Cost Estimate Assumptions	Assumes remote handling and total waste mass disposed of ~ 400,000 pounds (ref. Page A-1, *Transportation and Worker Risk Assessment for MDA H, TA-54, LANL*, 01-OMICRON-014, 9/30/2001). Assumes additional overburden around shafts to be removed remotely and sorted in the non-hazardous, non-classified waste stream at ~ 200,000 pounds.
Estimate	Summary of WBS 1.2
Preliminary Estimate	**WBS Element**
$50,000	WBS 1.2.1
$3,646,400	WBS 1.2.2
$2,028,000	WBS 1.2.3
$5,724,400	Subtotal, WBS 1.2

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.2.1**
Level	**Detail**
Name	**Assessment & Removal Planning**
Date	**10/4/01**
Revision #	**3.1**
Description	Due to the nature of this removal, site planning and shaft/lift sequence planning is required. Includes planning for waste removal and analysis of removal technologies (electromagnetic, crane, remote backhoe, etc.) and remote sensing and video monitoring. Includes planning for trench covering placement and equipment movement charting and process development
Cost Estimate Assumptions	Assumes remote handling for all was+B150te and overburden within the vicinity (5 feet) of the shafts.
Estimate	
$50,000	Use LS for planning/site mapping

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.2.2**
Level	**Detail**
Name	**Remote Handling Removal (In Trench)**
Date	**10/4/01**
Revision #	**3.1**
Description	Remove shaft waste material and place in the sorting facility. Removal is assumed to be lateral in 5' lifts using remote removal technology (Komatsu 220 or 250 with robotics).
Cost Estimate Assumptions	Assumes careful removal with unknown productivity factor due to vertical shaft waste emplacement. Assume 100% additional hours due to history at MDA P over conventional removal methods. Assume remote backhoe as primary excavating equipment, and above trench crane for heavy item removal. Assumes stop and go removal based on flow rates of waste through sorting and declassification, and lift removal of surrounding overburden.
Estimate	
$2,246,400	Use 12 site personnel, one year removal sequence, $90/hr rate
$1,400,000	Use LS for equipment
$3,646,400	Total

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.2.3**
Level	**Detail**
Name	**Split Sort for Rad/Non-Rad/Hazardous for 3 streams**
Date	**9/18/01**
Revision #	**2.2**
Description	Sort waste material into three streams. Provide remote handling based on log records for all wastes. Prepare material for packaging or declassification base on assessment.
Cost Estimate Assumptions	Assumes trained/certified personnel including EOD experts, declassification experts. Assume slow rate flow due to PPE and lost productivity. Assumes solids with little/no gas/liquid waste. Assume an 18-month sort period, small crew (5 sort personnel + HPT support). Sort time/crew size based on removal activities of buried classified material at Sandia Laboratories (on-going) for analogous estimating purposes.
Estimate	
$2,028,000	Use LS, 5 staff for 18 months, $130/hr average rate

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.3**
Level	**Summary, 1**
Name	**Declassify, Treat, Package & Dispose**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes declassification, treatment, packaging, and shipment to off-site disposal facilities.
Cost Estimate Assumptions	Assumes permitted facilities exist in the United States at time of need. Assumes declassification is complete and all shapes can be reshaped. Assumes standard cost escalation (3%/year) for disposal charges.
Estimate	Summary of WBS 1.3
Preliminary Estimate	WBS Element
$3,050,000	WBS 1.3.1
$2,200,000	WBS 1.3.2
$340,000	WBS 1.3.3
$3,200,000	WBS 1.3.4
$8,790,000	Subtotal, WBS 1.3

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.3.1**
Level	**Detail**
Name	**Declassify three streams**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes declassification of waste removed from nine vertical shafts. Involves shredding, milling, compacting and deshaping materials for off-site disposal.
Cost Estimate Assumptions	Assumes no recycling opportunities. Assumes full declassification is possible for all materials removed that undergo shape change (assumes that any shapes that cannot be declassified will be received by LANL and are not included within the scope of this effort)
Estimate	
$1,700,000	Use LS Operations Costs
$1,300,000	Use LS Equipment Costs
$50,000	Use LS Material Costs
$3,050,000	Total

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.3.2**
Level	**Detail**
Name	**Treat - Shred, Machine, Compact**
Date	**10/4/01**
Revision #	**3.1**
Description	Shred, machine, compact, and mill shapes per declassification specifications and classified material handling requirements.
Cost Estimate Assumptions	Assumes all on-site declassified material reshaping under controlled conditions. Assumes sufficient on-site vault storage for containing holding sets of shapes.
Estimate	
$2,200,000	Use LS Operations Costs

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.3.3**
Level	**Detail**
Name	**Package for Shipping**
Date	**10/4/01**
Revision #	**3.1**
Description	Standard waste packaging and overpacks for shipment preparation. Includes drum storage area and materials for packaging.
Cost Estimate Assumptions	Assumes materials that are logbook listed are the only types of materials to be processed. Assumes quantities of materials are within 20% of listed logbook values.
Estimate	
$340,000	Use LS costs based on $500/drum for packing + oversight
$120,000	Use LS costs based on $250/drum for materials (avg.)
$340,000	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.3.4**
Level	**Detail**
Name	**Dispose - Off-Site**
Date	**10/4/01**
Revision #	**3.1**
Description	Off-site disposal of materials contained in shafts.
Cost Estimate Assumptions	Assumes remote handling and total waste mass disposed of ~ 400,000 pounds (ref. Page A-1, Transportation and Worker Risk Assessment for MDA H, TA-54, LANL, 01-OMICRON-014, 9/30/2001). 86% of waste by mass is contained in metals of concern with steel as the primary constituent. Assumes EnviroCare waste quantities will be charged $40,000 per disposal waste stream as a minimum fee (will apply to Silver, Cadmium, non-hazardous radioactive waste, and Beryllium. Costs will vary significantly based on rad versus non-rad findings. For purposes of this estimate, assume all costs as rad-waste except non-hazardous, non-rad waste (overburden). Assumes permitted and operating facilities will be found at the time of need.
Estimate	
$3,200,000	Use LS based on quantities listed, 400,000 lb disposal, average $8/lb

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.4**
Level	**Summary, 1**
Name	**Construct Support Facilities**
Date	**10/22/01**
Revision #	**3.2**
Description	Includes installation of two pre-engineered dome structures (sort, shape change facilities) and one pre-cast storage vault, haul road and placement area, over-trench security cover, and sheet pile blast shielding.
Cost Estimate Assumptions	Assumes pre-engineered structures, fire retardant coverings for domes and trench cover. Assumes partial trench cover with move and erection costs. Assumes lined overburden placement area to reduce cross-contamination.
Estimate	Summary of WBS 1.4
Preliminary Estimate	WBS Element
$660,000	WBS 1.4.1
$1,680,000	WBS 1.4.2
$725,000	WBS 1.4.3
$600,000	WBS 1.4.4
$92,400	WBS 1.4.5
$3,757,400	Subtotal, WBS 1.4

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.4.1**
Level	**Detail**
Name	**Sort Facility**
Date	**10/4/01**
Revision #	**3.1**
Description	Pre-engineered dome structure with sort equipment. Fifty by eighty ft (4,000 sq. ft) structure for sorting shaft material.
Cost Estimate Assumptions	Assumes minimal maintenance cost and building life in excess of the project duration (3.2 years). Assumes fire retardant cover. Assumes sort conveyors and vestibule change out area.
Estimate	
$480,000	Use $120/SF for structure, erected
$180,000	Use LS for equipment
$660,000	Total

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.4.2**
Level	**Detail**
Name	**Shape Change Facility**
Date	**10/4/01**
Revision #	**3.1**
Description	Pre-engineered dome structure with sort equipment. Fifty by eighty ft (4,000 sq. ft) structure for declassifying shaft material.
Cost Estimate Assumptions	Assumes minimal maintenance cost and building life in excess of the project duration (3.2 years). Assumes fire retardant cover. Assumes declassification equipment (shears, shredders, compactors) and vestibule change out area. Assumes all shapes to be declassified on-site with the exception of lathe or milling work to be performed in existing machine shops at LANL. Assumes vault for material-in-process storage.
Estimate	
$480,000	Use $120/SF for structure, erected
$1,200,000	Use LS for equipment
$1,680,000	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.4.3**
Level	**Detail**
Name	**Haul Road and Placement Area**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes grading and gravel placement of 35-foot-wide haul road and placement area. Includes initial dust abatement and liner purchase and laydown for overburden storage area.
Cost Estimate Assumptions	Assumes footprint of barrier to extend 40 feet beyond placement edge for overburden isolation. Assumes minimal archeological impact.
Estimate	
$125,000	Use LS Haul Road, Placement Area
$600,000	Use LS Liner costs, incl. Laydown
$725,000	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.4.4**
Level	**Detail**
Name	**Over-top Trench Cover**
Date	**10/4/01**
Revision #	**3.1**
Description	Fire retardant over-top trench cover for visual protection and moisture protection of shaft removal area.
Cost Estimate Assumptions	Assume coverage of open shafts. Assume lightning protection (grounded cover). Assume movement of cover based on
Estimate	
$600,000	Use LS $600,000

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.4.5**
Level	**Detail**
Name	**Blast Shielding**
Date	**10/22/01**
Revision #	**3.2**
Description	Install blast shielding along Pajarito Road and the TA-54 access road for both blast protection and visual abatement.
Cost Estimate Assumptions	Assume 15 foot above grade protection with steel sheet pilings interlocked and placed on both long sides of the trench excavation. Assume 25-ft total piling dimension (10 ft burial).
Estimate	
$92,400	Use 440 LF installed @ $210/LF

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.5**
Level	**Summary, 1**
Name	**Provide Security**
Date	**10/4/01**
Revision #	**3.1**
Cost Estimate Assumptions	Assumes detailed site-specific security plan will be developed. Assumes remote camera surveillance in addition to security personnel on-site. Assumes "buddy system" requirement for two guards, all shifts.
Estimate	Summary of WBS 1.5
Preliminary Estimate	WBS Element
$300,000	WBS 1.5.1
$170,000	WBS 1.5.2
$3,409,600	WBS 1.5.3
$3,879,600	Subtotal, WBS 1.5

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.5.1**
Level	**Detail**
Name	**Provide Security Fencing**
Date	**10/4/01**
Revision #	**3.1**
Description	Provide secure perimeter fencing around all operations during excavation.
Cost Estimate Assumptions	Assume 3-year site security requirement due to classified material. Assume last two months of the project will not require security personnel on-site.
Estimate	
$300,000	Use 4,000 LF at $75/LF for fencing

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.5.2**
Level	**Detail**
Name	**Security Monitoring**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes site security monitoring equipment, site security plan
Cost Estimate Assumptions	Assumes remote cameras and recording devices. May also include motion detection equipment. Assumes monitoring by on-site guard force.
Estimate	
$120,000	Use LS equipment of $40,000/year
$50,000	Use LS site security Plan
$170,000	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.5.3**
Level	**Detail**
Name	**Security Staffing**
Date	**10/4/01**
Revision #	**3.1**
Description	24/7 security staffing of MDA H using 4 shifts, two trained security personnel per shift.
Cost Estimate Assumptions	Assume 3-year site security requirement due to classified material. Assume last two months of the project will not require security personnel on-site. Assumes full time staff and includes security refresher training. Assumes one substitute in addition to paired guards for fill-in.
Estimate	
$3,369,600	Use 3 years X 9 staff/year X 2,080/year X $60/hr.
$40,000	Use equipment (two pickups) for three years
$3,409,600	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.6**
Level	**Summary, 1**
Name	**Health & Safety**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes all MDA H Health and Safety including the development of the SSHASP, Radiation and Chemical Hazards monitoring, worker training (Rad Worker II, Hazwoper, Explosives Safety), and site safety monitoring. Assumes a need for SAR development and **a complete re-estimation of costs if the SAR indicates high hazards due to the presence of Uranium Hydride.**
Cost Estimate Assumptions	Assumes medium hazard conditions for worker safety, low hazards for public safety.
Estimate	Summary of WBS 1.6
Preliminary Estimate	WBS Element
$1,100,000	WBS 1.6.1
$4,046,800	WBS 1.6.2
$1,280,000	WBS 1.6.3
$6,426,800	Subtotal, WBS 1.6

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.6.1**
Level	**Detail**
Name	**Site Health & Safety Plan, SAR**
Date	**10/4/01**
Revision #	**3.1**
Description	Develop the site specific health and safety plan and SAR
Cost Estimate Assumptions	Assumes greater than average planning due to HE and radioactive constituents. Assumes one draft, incorporate comments, and one final plan. Assumes need for a full SAR based on the possible presence of Uranium Hydride.
Estimate	
$750,000	SAR costs based on medium to high difficulty SAR – range of $500k - $750k
$350,000	Use LS $350,000

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.6.2**
Level	**Detail**
Name	**Rad & Chem Monitoring**
Date	**10/4/01**
Revision #	**3.1**
Description	On-site radiation and chemical hazards monitoring for the duration of the project. Includes trained and certified Health Physics Technicians (HPTs) for all work on the project. Includes monitoring equipment, sampling, and analysis.
Cost Estimate Assumptions	Assumes full HPT coverage per LANL policies. Assumes remote monitoring of shafts during removal of material. Assume Non-destructive analysis (NDA) in adjacent TA-54 RANT facility when required.
Estimate	
$1,996,800	Use 3.2 years X 3 HPTs X 2,080 hrs/yr X $100/hr
$800,000	Use LS Equipment costs for remote monitoring
$150,000	Use LS Material costs for sampling
$1,100,000	Use LS Laboratory costs for analysis
$4,046,800	Total

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.6.3**
Level	**Detail**
Name	**Worker Training**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes training required for safety, including Rad Worker II, Hazwoper 40 hour and refreshers, explosive safety training, and other LANL training as required.
Cost Estimate Assumptions	Assumes full training and certification requirements. Assumes need for all personnel to maintain requirements for the duration of the project. Assumes local travel only for training. Assumes average site worker burden of training at 100 hours/year.
Estimate	
$1,280,000	Use 100 hours X $100/Hr average rate X 40 staff for 3.2 years
$200,000	Use LS for instructors/prep time
$1,480,000	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.7**
Level	**Summary, 1**
Name	**Provide Design**
Date	**10/4/01**
Revision #	**3.1**
Description	Provide Design for the MDA H project including development of a preliminary design, final design, and as-builds. Provide for design review and incorporation of comments. Include design features of all support facilities, traffic plan, excavation, haul road and overburden storage area, remote handling, and full design from concept to final.
Cost Estimate Assumptions	Assumes preliminary design one and two, final design one and two, and one final as-built engineering documentation. Assumes review of designs and incorporation of comments.
Estimate	Summary of WBS 1.7
Preliminary Estimate	WBS Element
$550,000	WBS 1.7.1
$1,100,000	WBS 1.7.2
$80,000	WBS 1.7.3
$1,730,000	Subtotal, WBS 1.7

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.7.1**
Level	**Detail**
Name	**Preliminary Design**
Date	**10/4/01**
Revision #	**3.1**
Description	Prepare a draft preliminary design and a final preliminary design based on functional requirements of the MDA H excavation.
Cost Estimate Assumptions	Assumes Conceptual Design Report (CDR) level design for review and approval based on functional requirements. Assumes design on pre-engineered structures such as the excavation cover, sort facility, and declassification facility. Assumes design for sheet piling (blast shield), haul roads, and overburden containment.
Estimate	
$400,000	Use LS Preliminary Design one
$150,000	Use LS Preliminary Design two
$550,000	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.7.2**
Level	**Detail**
Name	**Final Design**
Date	**10/4/01**
Revision #	**3.1**
Description	Prepare a draft final design and a final design based on functional requirements of the MDA H excavation. Includes additional engineering required to move design from preliminary to final stage.
Cost Estimate Assumptions	Assumes additional fieldwork to verify design. Does not include additional sample wells, boreholes, but may include subsurface geophysical work to finalize design
Estimate	
$800,000	Use LS Final Design one
$300,000	Use LS Final Design two
$1,100,000	

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.7.3**
Level	**Detail**
Name	**As-builds**
Date	**10/4/01**
Revision #	**3.1**
Description	Provide as-builds for final project configuration.
Cost Estimate Assumptions	Assumes as-builds per LANL policy.
Estimate	
$80,000	Use LS for as-builds

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.8**
Level	**Summary, 1**
Name	**Manage the Project**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes on-site Project Management and off-site overall Project Management of the MDA H full excavation alternative. Includes Project Management, Permitting, Records Management, and Quality Assurance (QA) for the duration of the project.
Cost Estimate Assumptions	Assumes trained and qualified project management personnel familiar with Laboratory policies, procedures, and MDA H site conditions. Assumes standard record keeping and project reporting (earned value, change management). Assumes standard permitting and QA activities consistent with past ER Project material removals.
Estimate	Summary of WBS 1.8
Preliminary Estimate	WBS Element
$1,910,400	WBS 1.8.1
$150,000	WBS 1.8.2
$468,000	WBS 1.8.3
$1,287,000	WBS 1.8.4
$3,815,400	Subtotal, WBS 1.8

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.8.1**
Level	**Detail**
Name	**On-site PM**
Date	**10/4/01**
Revision #	**3.1**
Description	Project Management
Cost Estimate Assumptions	Assumes LANL personnel and contractor personnel will manage the site. Assumes one full-time LANL PM and one full time contractor PM for the duration of the project. Use 2080 hrs/yr/person and $110/hr for burdened costs. Assumes one staff support PM off site for the duration of excavation and removal.
Estimate	
$1,830,400	Use 3.2 years X 2.5 PM staff X $110/hr
$80,000	Use LS for equipment incl. Trailer lease, 2 pickup trucks
$1,910,400	Total

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.8.2**
Level	**Detail**
Name	**Permitting**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes permitting for excavation to meet state/local requirements
Cost Estimate Assumptions	Assumes standard permitting costs and State oversight charges
Estimate	
$150,000	Use LS for permitting/review

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.8.3**
Level	**Detail**
Name	**Records Management**
Date	**10/4/01**
Revision #	**3.1**
Description	Includes costs for maintaining records of the project including waste removal, handling, shipping, PM, safety, QA, and monitoring.
Cost Estimate Assumptions	Assume one full-time records manager assigned for the duration of the project.
Estimate	
$468,000	Use 44 months X 1 record keeper X $60/hr

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.8.4**
Level	**Detail**
Name	**Quality Assurance**
Date	**10/4/01**
Revision #	**3.1**
Description	Standard project QA including development and review of a site QA plan, QA monitoring.
Cost Estimate Assumptions	Assumes QA plan development and on-site QA monitoring.
Estimate	
$1,287,000	Use 1.5 staff at $110 hour for 44 months

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.0**
Level	**Summary**
Name	**Alternative 5A, Excavation Alternative - MDA H, with On-Site RCRA Storage**
Date	**05/05/03**
Revision #	**3.0**
Description	Excavation and complete removal of previously disposed classified, solid-form waste in nine, 60 foot deep, 6-foot diameter shafts at Material Disposal Area H, TA-54, Los Alamos National Laboratory. Disposal of hazardous and radioactive material will be on-site in a licensed and approved waste disposal facility (RCRA Landfill. Classified shapes will be deformed and rendered unclassified prior to packing and shipping. Includes on-site storage in a 40 cy capacity RCRA-permitted landfill versus Alternative 4 that disposes of waste material off-site.
Cost Estimate Assumptions	Preliminary Estimate only, no detail design available. Assumes placement of suggested Excavation Alternative Significant Controls per Table 10, *Transportation and Worker Risk Assessment for MDA-H, TA-54, LANL* (01-OMICRON-014, 9/30/01). Costs estimated in constant 2002 dollars; no escalation applied. Estimated duration of design/construction is 44 months (6 month design, 38 month construct), with estimated duration of RCRA Landfill construction of 72 months (60 months permitting, 6 months construction). Assume full PPE in sorting and contact fieldwork, remote equipment excavation used in shaft areas. Assume on-site disposal for all shaft materials that meet hazardous/radioactive waste disposal requirements. Assumes that all standard Federal, State, and Laboratory policies, procedures, training and certification requirements in place as of 3/2003 will be the regulatory framework for this excavation and that more stringent requirements may require re-estimation of costs. Assumes that all subordinate cost estimate assumptions shown in the preliminary estimate backup sheets are also included in this set of assumptions.
Estimate	**Summary of WBS 1.0**
Preliminary Estimate	**WBS Element**
$1,162,080	WBS 1.1 - Excavation/Refill
$5,724,400	WBS 1.2 - Shaft Material Remove & Sort
$8,790,000	WBS 1.3 - Declassify, Treat, Package & Dispose (Off Site)
$3,757,400	WBS 1.4 - Construct Support Facilities
$3,879,600	WBS 1.5 - Provide Security
$6,426,800	WBS 1.6 - Health & Safety, including SAR
$1,730,000	WBS 1.7 - Provide Design
$3,815,400	WBS 1.8 - Manage the Project
$16,620,000	Contingency @ 47%
51,905,680	**Total Preliminary Estimate for Alternative 4, MDA H Excavation & Removal**
	Alternative 5 Adjustments
($5104,000)	WBS 1.3 – Remove off-site disposal costs, transportation, and contingency for this portion of WBS 1.3
$19,332,000	WBS 1.9 – Add RCRA Landfill permit, design, construct, fill, cap & cover with contingency for this section (35%)
$66,133,680	**Total Preliminary Estimate for Alternative 5A, MDA H Excavation & Removal with On-Site RCRA Landfill Storage**

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.9 Alternative 5A**
Level	**Summary, 1**
Name	**RCRA Landfill Permit, Design, Construction, Fill, Cap & Cover**
Date	**03/07/03**
Revision #	**2.4**
Description	In lieu of off-site disposal, develop a RCRA permitted landfill facility to dispose of MDA H solid wastes. Facility would be constructed on LANL property and will contain 40 CY of waste extracted from MDA H. The landfill would have a double composite liner system and an impenetrable cap system on final closure. The facility would have leachate collection, leak detection, and fluid monitoring sensors.
Cost Estimate Assumptions	1. Preliminary estimate, 0% design complete as of estimate date, 35% contingency used. 2. Assume permitting issues with NMED will continue to take many years to resolve. 3. Design to be based on standard RCRA landfills constructed in DOE (Hanford, etc.) 4. No other wastes from other sites will be disposed of in this facility 5. Only the off-site transport and disposal costs will be displaced by this estimate; all de-shaping, sorting, and removal activities already estimated will remain part of turn-key MDA H cleanup. 6. Assume 5 years Permitting, 18 months design (in parallel with permitting), 6 month construction, total duration 5.5 years. 7. Assume a forty-year post-closure monitoring period. 8. All costs estimated in FY 2003 constant dollars, NMGRT included and not broken out. 9. Costs consistent with on-site waste disposal estimate of $839/cy in RF/ER-95-0105 UN, Rev. 0, Draft Interim Measure/Interim Remedial Action Decision Document for the Waste Management Facility at the Rocky Flats Environmental Technology Site and $650/cy at the Hanford RCRA Disposal Facility (Bechtel, 1998).
Estimate	
Preliminary Estimate	WBS Element
$2,900,000	WBS 1.0 -Design & Siting Study
$6,000,000	WBS 2.0 - Permitting
$2,320,000	WBS 3.0 - PM & Site Safety
$3,100,000	WBS 4.0 - Construction/Placement
$19,332,000	Total, includes 35% contingency

WBS Dictionary/MDA H Preliminary Cost Estimate Backup	
WBS #	**1.0**
Level	**Summary**
Name	**Alternative 5B, Excavation Alternative - MDA H, with On-Site CAMU Storage**
Date	**05/07/03**
Revision #	**3.1**
Description	Excavation and complete removal of previously disposed classified, solid-form waste in nine, 60 foot deep, 6-foot diameter shafts at Material Disposal Area H, TA-54, Los Alamos National Laboratory. Disposal of hazardous and radioactive material will be on-site in a licensed and approved waste disposal facility CAMU Landfill. Classified shapes will be deformed and rendered unclassified prior to packing and shipping. Includes on-site storage in a 40 cy capacity CAMU-permitted landfill versus Alternative 4 that disposes of waste material off-site.
Cost Estimate Assumptions	Preliminary Estimate only, no detail design available. Assumes placement of suggested Excavation Alternative Significant Controls per Table 10, *Transportation and Worker Risk Assessment for MDA-H, TA-54, LANL* (01-OMICRON-014, 9/30/01). Costs estimated in constant 2002 dollars; no escalation applied. Estimated duration of design/construction is 44 months (6 month design, 38 month construct), with estimated duration of RCRA Landfill construction of 72 months (60 months permitting, 6 months construction). Assume full PPE in sorting and contact fieldwork, remote equipment excavation used in shaft areas. Assume on-site disposal for all shaft materials that meet hazardous/radioactive waste disposal requirements. Assumes that all standard Federal, State, and Laboratory policies, procedures, training and certification requirements in place as of 3/2003 will be the regulatory framework for this excavation and that more stringent requirements may require re-estimation of costs. Assumes that all subordinate cost estimate assumptions shown in the preliminary estimate backup sheets are also included in this set of assumptions.
Estimate	**Summary of WBS 1.0**
<u>Preliminary Estimate</u>	**<u>WBS Element</u>**
$1,162,080	WBS 1.1 - Excavation/Refill
$5,724,400	WBS 1.2 - Shaft Material Remove & Sort
$8,790,000	WBS 1.3 - Declassify, Treat, Package & Dispose (Off Site)
$3,757,400	WBS 1.4 - Construct Support Facilities
$3,879,600	WBS 1.5 - Provide Security
$6,426,800	WBS 1.6 - Health & Safety, including SAR
$1,730,000	WBS 1.7 - Provide Design
$3,815,400	WBS 1.8 - Manage the Project
$16,620,000	Contingency @ 47%
51,905,680	**Total Preliminary Estimate for Alternative 4, MDA H Excavation & Removal**
	Alternative 5B Adjustments
($5104,000)	WBS 1.3 – Remove off-site disposal costs, transportation, and contingency for this portion of WBS 1.3
$17,982,000	WBS 1.9 – Add CAMU permit, design, construct, fill, cap & cover with contingency for this section (35%)
$64,783,680	**Total Preliminary Estimate for Alternative 5B, MDA H Excavation & Removal with On-Site CAMU Storage**

WBS Dictionary/MDA H Preliminary Cost Estimate Backup

WBS #	**1.9 Alternative 5B**
Level	**Summary, 1**
Name	**CAMU Permit, Design, Construction, Fill, Cap & Cover**
Date	**03/11/03**
Revision #	**3.0**
Description	In lieu of off-site disposal, develop a CAMU permitted landfill facility to dispose of MDA H solid wastes. Facility would be constructed on LANL property and will contain 40 CY of waste extracted from MDA H. The landfill would have a double composite liner system and an impenetrable cap system on final closure. The facility would have leachate collection, leak detection, and fluid monitoring sensors.
Cost Estimate Assumptions	1. Preliminary estimate, 0% design complete as of estimate date, 35% contingency used. 2. Assume permitting issues with NMED will continue to take many years to resolve. 3. Design to be based on standard CAMU landfills constructed in DOE (Sandia, etc.) 4. No other wastes from other sites will be disposed of in this facility 5. Only the off-site transport and disposal costs will be displaced by this estimate; all de-shaping, sorting, and removal activities already estimated will remain part of turn-key MDA H cleanup. 6. Assume 5 years Permitting, 18 months design (in parallel with permitting), 6 month construction, total duration 5.5 years. 7. Assume a forty-year post-closure monitoring period. 8. All costs estimated in FY 2003 constant dollars, NMGRT included and not broken out. 9. Costs consistent with on-site waste disposal estimate of $839/cy in RF/ER-95-0105 UN, Rev. 0, Draft Interim Measure/Interim Remedial Action Decision Document for the Waste Management Facility at the Rocky Flats Environmental Technology Site and $650/cy at the Hanford RCRA Disposal Facility (Bechtel, 1998).
Estimate	
<u>Preliminary Estimate</u>	<u>WBS Element</u>
$2,900,000	WBS 1.0 -Design & Siting Study
$5,000,000	WBS 2.0 - Permitting
$2,320,000	WBS 3.0 - PM & Site Safety
$3,100,000	WBS 4.0 - Construction/Placement
$17,982,000	Total, includes 35% contingency

Appendix L

Evaluation of Partial Excavation and Reburial at MDA H

APPENDIX L PROJECT-SPECIFIC OUTREACH PLAN

L-1.0 PARTIAL EXCAVATION AND REBURIAL AT MDA H

Excavation and reburial to a deeper on-site location was evaluated to determine if the risk/dose from materials in the MDA H inventory could be reduced to lower levels by removing specific wastes from within the top 17 ft of the shafts. This option would also require drilling an additional shaft on site for some relocated waste. DOE and NMED would have to approve this disposal option.

In Section 3, the major risk drivers for MDA H are identified as uranium-234, RDX and cadmium. Table H-2.0-1 in Appendix H was used to determine the mass and location of each of these risk/dose drivers to determine if a partial excavation alternative would remove a significant volume of the materials that drive risk/dose at MDA H. Table H-2.1 lists the mass of each contaminant by shaft, for both the upper and lower waste cells. The upper waste cell of the shaft is the waste that is accessible to plant roots and burrowing animals - this cell is 17 ft thick (23 ft below ground surface including the 6-ft thick cap). The lower waste cell is 37 ft thick (60 ft below ground surface).

L-1.1 U-234

Approximately 99% of the total MDA H residential dose at 1000 years is due to external irradiation from radium-226, a decay product of uranium-234. The peak dose is 2.4 mrem/yr at 1000 years. Approximately 49% of the uranium-234 inventory in MDA H is in the upper waste cells of the shafts. Approximately 66% of the total uranium-234 in the upper waste cells was disposed in one shaft (or 31% of the total). Removal of the material in the upper portion of the one shaft would reduce the surface dose from 2.4 mrem/yr to 1.6 mrem/yr. Removal of the uranium-234 in the entire shaft would remove approximately 37% of the total uranium-234 inventory, although the reduction in surface dose would be equivalent to removing just the upper portion (1.6 mrem/yr).

L-1.2 RDX

Approximately 90% of the residential incremental cancer risk (ICR) of 4×10^{-7} is due to ingestion of RDX via the garden produce pathway from RDX in the upper waste cells. Virtually all of the remainder of the ICR for the resident is associated with cadmium exposure via inhalation of suspended soil (dust). Shafts 5, 6, and 7 have roughly equivalent amounts of RDX in their upper waste cell, and each contribute about 30% to the total amount of RDX in all of the upper waste cells. Excavation of the upper waste cells in shafts 5, 6 and 7 would reduce the ICR from 4×10^{-7} to approximately 4×10^{-8}. The largest amount of RDX (68% of total RDX) is in the bottom waste cell of Shaft 7. Although excavation of Shaft 7 would minimize any possibility of transport of RDX to groundwater, fate and transport modeling documented in Section 3 indicates that effectively no contamination reaches groundwater in the 1000-year evaluation period.

L-1.3 Cadmium

Approximately 50% of the residential chemical hazard quotient (HQ) of 0.6 is associated with cadmium. Ingestion of garden produce is responsible for approximately 90% of chemical hazard, the remainder being due to soil ingestion. The amount of cadmium is about twice as large in the lower waste cells as in the upper. Removal of cadmium in the upper waste cells would reduce the HQ from 0.6 to about 0.3. The amount of cadmium varies by only a factor of 2 between shafts in both the upper and lower cells, so the cadmium is spread fairly equally throughout the shafts. Therefore, excavation of any one shaft would not materially affect the HQ of 0.6.

L-1.4 Partial Excavation

The MDA H shafts are located approximately 20 ft apart on center. OSHA regulations for excavation require a minimum slope of 1 1/2:1 for excavations of more than 3 ft in depth for worker protection. Removal of any shaft to a 62-ft depth would require partial to full removal of material in 5 to 6 shafts in order to achieve the required construction slope. Removal of the upper 17 ft of material in any one shaft would require partial removal of material in 3 shafts in order to achieve the required construction slope. Partial excavation and reburial at MDA H would not have a significant effect on risk/dose to human and ecological receptors (as discussed in L-1.1 through L-1.3) and is therefore eliminated. There would also be worker risk associated with partial excavation as discussed in Appendix M.

Appendix M

Uranium Corrosion

APPENDIX M URANIUM CORROSION

As described in Section 2.1.2.1, a significant portion of the inventory of waste present in disposal shafts at MDA H consists of uranium metal. Uranium metal can corrode by reacting with atmospheric water and oxygen to form uranium oxide and hydrogen. Corrosion of the uranium metal in MDA H is of potential concern for several reasons:

- corrosion results in formation of friable uranium oxide scale that is more available than uranium metal for transport to the surface by burrowing animals;
- uranium oxide scale is readily dispersible and could easily be released during excavation of buried wastes, creating an inhalation hazard; and
- corrosion in the presence of water can form uranium hydride, which is pyrophoric.

The corrosion behavior of uranium in oxygen, water and water plus oxygen mixtures was evaluated to determine the significance of corrosion and its potential impacts on corrective measures alternatives for MDA H.

Uranium is readily oxidized by water following the reaction in Equation 1 (Baker et al. 1966, 73812).

Equation 1: $U + 2H_2O = UO_2 + 2H_2$

Oxygen serves to retard the reaction, but as it is consumed the reaction returns to the oxidation reaction (Equation 1). Baker, et al. (1966, 73812) also found that hydrogen production during the uranium oxidation reaction was less than predicted, and it was determined that some uranium hydride (UH_3) was being formed. The amount of hydride production is correlated to the relative humidity (the higher the humidity, the higher the hydride production). The uranium hydride product will also further react with water to form some uranium oxide (Equation 2).

Equation 2: $2UH_3 + 4H_2O = 2UO_2 + 7H_2$

Uranium will also react directly with oxygen to form uranium oxide (Equation 3).

Equation 3: $U + (2 + x)/2\ O_2 = UO_{2+x}$

The value of x in Equation 3 is in the range 0.2 to 0.4 at temperatures below 200°C (Hightower and Trabalka 2000, 75929).

The rate at which uranium corrodes depends on the amount of water and oxygen present. Hightower and Trabalka (2000, 75929) presented a review of uranium corrosion rates and identified four general categories of water and oxygen content with respect to reaction rates:

- dry air (normal oxygen content, but no moisture);
- “normal” air (normal oxygen content, relative humidity in the range of 2% to 90%);
- saturated air (normal oxygen content, 100% relative humidity); and
- saturated air with no oxygen (no oxygen, 100% relative humidity).

The corrosion rates for dry air and normal air were reported to be approximately the same. The corrosion rate for saturated air with oxygen was reported to be approximately 20 times greater than for dry air and normal air, and the corrosion rate for saturated air with no oxygen was reported to be approximately 1000 times greater than for dry air and normal air (Hightower and Trabalka 2000, 75929). As previously noted, the presence of water (i.e., normal to saturated air) can result in formation of uranium hydride. Uranium hydride is of concern because it is highly pyrophoric and will spontaneously ignite in the presence of oxygen (e.g., atmospheric air). The resulting hydride fire can then cause the associated uranium metal to ignite and burn.

The depleted uranium (DU) used for weapons mockups (in the form of shapes) and disposed as classified material at MDA H, would have been "machined", "plated", or "finished" (e.g., annealed). Under the known environmental conditions at MDA H, i.e., low soil moisture in the surrounding subsurface tuff (5–10%) and concrete covers over the disposal shafts, the DU is present in a liquid water limited environment (i.e., the uranium should not be in contact with free liquid water). Gas present in the disposal shafts at MDA H is expected to be representative of normal air or saturated air. Normal oxygen content is expected because most of the waste is not biodegradable and the low subsurface moisture content does not readily support biodegradation. The behavior of vapor-phase plumes at other locations at TA-54 (e.g., MDA L) indicates significant interaction of subsurface pore gas with the atmosphere (LANL 2000, 64360). Thus, oxygen depleted by subsurface reactions would be expected to be replenished. Some humidity will be present in the air due to the presence of water within the pores in the tuff. Saturated air would result if the moisture content of the air was in equilibrium with this water. The corrosion rate constants reported by Hightower and Trabalka (2000, 75929) for these expected oxygen/water conditions at 25°C result in initial corrosion rates of smooth surfaces in the range of 0.10 to 1.9 microns/yr. As corrosion progresses, the metal surface will become rougher with a greater surface area and correspondingly higher corrosion rates. In 200 to 1000 yr, all of the DU should be converted from metal to a stable oxide form where there would be no risk from hydride formation.

Based on the above information, hydride formation is expected to occur as the uranium objects present in the MDA H shafts corrode. The hydride present in the shafts will react with oxygen present in the shafts. The amount of oxygen present in the shafts and the flux of oxygen into the shafts are not sufficient, however, to allow or sustain a hydride fire. Thus, the formation and presence of hydride in the shafts at MDA H will not pose a hazard as long as these objects remain in the shafts and are not directly exposed to the atmosphere. These conclusions are consistent with a recent evaluation of options for disposal of excess DU (Croff et al. 2000, 75928). This evaluation indicated that hydriding or hydrogen generation should not be significant at disposal sites in arid conditions. Although this evaluation specifically addressed the Nevada Test Site and the Hanford Site, the conclusions should also be applicable to LANL.

The following conclusions regarding uranium corrosion are relevant to evaluating corrective measure alternatives at MDA H:

- The uranium objects present in the shafts at MDA H will corrode to form uranium oxide and uranium hydride, with the uranium hydride subsequently being oxidized to uranium oxide. The time required for the uranium present in the shafts to be completely converted to stable uranium oxide is estimated to be 200 to 1000 years.
- Corrosion may slightly increase the amount of uranium immediately available for transport to the surface by burrowing animals, but the mass of uranium corroded would not be a significant fraction of the total uranium inventory. Assuming that the total inventory of uranium in MDA H is immediately available for transport is unrealistic and overly conservative.
- Excavation of MDA H prior to conversion of the uranium inventory to uranium oxide, in the absence of suitable engineering controls, would be expected to result in a uranium fire that could potentially involve the entire contents of the shafts. Corrective measures alternatives that include excavation would require engineering controls to prevent hydride fires during excavation (e.g.,

excavation in an inert atmosphere) followed by controlled ignition of the hydride on uranium objects removed from the shafts.

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