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DEPARTMENT OF ENERGY
Environmental Management Los Alamos Field Office (EM-LA)
Los Alamos, New Mexico 87544

JUN 26 2019

Mr. John E. Kieling
Bureau Chief
Hazardous Waste Bureau
New Mexico Environment Department
2905 Rodeo Park Drive East, Building 1
Santa Fe, NM 87505-6303

Dear Mr. Kieling:

Subject: Submittal of the Revised Work Plan for Vadose Zone Moisture Monitoring at Material Disposal Area T at Technical Area 21, within the Nuclear Environmental Site

Enclosed please find two hard copies with electronic files of the "Revised Work Plan for Vadose Zone Moisture Monitoring at Material Disposal Area T at Technical Area 21, within the Nuclear Environmental Site." The work plan presents an approach for installation of a moisture monitoring network beneath Material Disposal Area T. The work plan also addresses vadose zone characterization that will be conducted in conjunction with drilling and coring that is necessary to install the moisture monitoring network. The plan satisfies Milestone 11 of the fiscal year 2019 version of Appendix B, Milestones and Targets, of the 2016 Compliance Order on Consent (Consent Order).

Pursuant to Section XXIII.C of the Consent Order, a pre-submission review meeting was held with the U.S. Department of Energy Environmental Management Los Alamos Field Office (EM-LA); Newport News Nuclear BWXT-Los Alamos, LLC (N3B); and the New Mexico Environment Department (NMED) on June 20, 2019, to discuss revisions to the original work plan pursuant to NMED's September 1, 2011, approval with direction. Key discussion topics included removal of sampling for volatile organic compounds (VOCs) in core material, addition of field screening for VOCs in core material, addition of target analyte list metals to the suite of samples collected from core and pore water, and removal of the modeling subsection in the plan. The revised work plan incorporates these changes as agreed to in the pre-submission review meeting. An electronic copy of the redline strikeout version of the plan that includes all changes made in response to NMED comments is included with this submittal.

If you have any questions, please contact Danny Katzman at (505) 309-1371 (danny.katzman@em-la.doe.gov) or Cheryl Rodriguez at (505) 665-5330 (cheryl.rodriguez@em.doe.gov).

Sincerely,

Arturo Q. Duran
Compliance and Permitting Manager
Environmental Management
Los Alamos Field Office

Enclosures:

1. Two hard copies with electronic files (including a redline strikeout version) – Revised Work Plan for Vadose Zone Moisture Monitoring at Material Disposal Area T at Technical Area 21, within the Nuclear Environmental Site (EM2019-0211)

cc (letter and enclosure[s] emailed):
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June 2019
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Revised Work Plan for Vadose Zone Moisture Monitoring at Material Disposal Area T at Technical Area 21, within the Nuclear Environmental Site

EM2019-0211

Revised Work Plan for Vadose Zone Moisture Monitoring at Material Disposal Area T at Technical Area 21, within the Nuclear Environmental Site

June 2019

Responsible program director:

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CONTENTS

Figures

Tables

Appendix

1.0 INTRODUCTION

This work plan is a revision to the vadose zone moisture monitoring work plan submitted to the New Mexico Environment Department (NMED) in August 2011 (LANL 2011, 204696). The revision incorporates modifications received from NMED in an approval with modifications letter dated September 1, 2011 (NMED 2011, 206276). The revised work plan describes a moisture-monitoring network to be installed in the vadose zone beneath Material Disposal Area (MDA) T at Technical Area 21 (TA-21) at Los Alamos National Laboratory (LANL or the Laboratory). The moisture-monitoring network was recommended in the “Technical Area 21 Groundwater and Vadose-Zone Monitoring Well Network Evaluation and Recommendations” (the network evaluation) (LANL 2010, 109947). The network evaluation addressed the adequacy of the existing groundwater and vadose zone monitoring networks for detecting known or potential hazardous constituent and radionuclide sources at TA-21. The evaluation recommended moisture and vapor monitoring near the waste disposal units at MDA T combined with groundwater monitoring of the regional aquifer (LANL 2010, 109947). Specifically, moisture-monitoring wells will be used to characterize and monitor vadose zone moisture content to evaluate potential corrective measures and long-term performance monitoring (LANL 2010, 109947). The moisture-monitoring network will focus on moisture migration because subsurface moisture can mobilize and transport soluble contaminants from the wastes buried at the site. The combination of moisture monitoring, as proposed in this work plan, vapor monitoring near the disposal units, and regional aquifer monitoring will provide a defense-in-depth program for monitoring MDA T.

Moisture monitoring is proposed at MDA T because of the radiological inventory stored in the shafts and elevated residual moisture in the vadose zone resulting from infiltration beneath the MDA T adsorption beds. Vadose zone moisture in contact with the waste in the shafts and with the radiological contaminants present in and beneath the adsorption beds is considered the carrier for mobilizing and transporting soluble contaminants in the subsurface from the wastes buried at the site. In particular, water-soluble radionuclides present in the disposed waste will not transport to groundwater unless moisture present near the waste migrates downward. Therefore, monitoring of moisture migration will provide direct and timely evidence for potential radiological contaminant migration. The moisture data also will be used to establish baseline moisture distributions that can be used to guide and evaluate remedial alternatives. In addition, chemical analyses of core samples collected during borehole installation will further characterize the distribution of radiological contaminants beneath waste disposal units at MDA T.

The nature and extent of hazardous constituents in soil has been defined at MDA T (LANL 2006, 094151; LANL 2007, 100484; LANL 2009, 108012; LANL 2010, 108864); however, some uncertainty related to the extent of volatile organic compounds (VOCs) in pore gas remains. A work plan for installing a proposed vapor-monitoring well to monitor for tritium and for VOCs is provided in the Phase III investigation work plan for MDA T (LANL 2009, 105645) and is therefore not included in this work plan. A work plan for two downgradient regional wells near MDA T has also been completed (LANL 2011, 111604), and one of the regional wells (R-64) has been installed.

The site addressed in this monitoring work plan is potentially contaminated with both hazardous and radioactive components. NMED, pursuant to the New Mexico Hazardous Waste Act, regulates cleanup of hazardous wastes and hazardous constituents. The U.S. Department of Energy (DOE) regulates cleanup of radioactive contamination, pursuant to DOE Order 5400.5, Radiation Protection of the Public and the Environment; DOE Order 435.1, Radioactive Waste Management; and DOE Order 458.1, Administrative Change 3, Radiation Protection of the Public and the Environment. Information on radioactive materials and radionuclides, including the results of sampling and analysis of radioactive constituents, is voluntarily provided to NMED in accordance with DOE policy.

Corrective actions at the Laboratory are subject to the 2016 Compliance Order on Consent (the Consent Order). This work plan describes activities that will be executed and completed in accordance with the Consent Order.

This moisture-monitoring work plan provides details of the well-specific work plan for vadose zone moisture-monitoring wells at MDA T. This work plan also provides a conceptual model of flow and transport based on characterization and modeling studies for MDA T, including a discussion of uncertainties in section 2; a description of the activities, including the installation of a vadose zone moisture-monitoring system for MDA T, in section 3; a sampling and analysis plan for drilling at MDA T in section 3; and a schedule in section 4. Appendix A includes reviews of moisture-monitoring technologies.

1.1 Objectives

This vadose zone moisture-monitoring work plan outlines the basis for, and general approach to, moisture monitoring at MDA T.

The objectives of this work plan are to

- collect moisture-monitoring data to establish a baseline dataset for moisture conditions at MDA T,
- monitor movement of subsurface water beneath the absorption beds and shafts,
- determine if radionuclides have migrated from shafts (by sampling and analysis),
- characterize the vadose zone beneath the trenches and shafts for non-radionuclide constituents,
- assess the source(s) of elevated moisture beneath MDA T (by sampling and analysis), and
- provide data on unsaturated flow and transport and use for calibration/validation of model simulations.

2.0 CONCEPTUAL MODEL

2.1 Hydrology and Contaminant Transport at DP Mesa

Under natural conditions, DP Mesa fits the "dry and disturbed mesa conceptual model" for the Pajarito Plateau as defined by Birdsell et al. (2005, 092048). It is a dry finger mesa; the hydrologic conditions on the surface and within such dry mesas generally lead to slow unsaturated flow and transport. Dry mesas shed precipitation as surface runoff to the surrounding canyons such that most deep infiltration occurs episodically following snowmelt, and even then much of the water is lost through evapotranspiration. As a result, annual net infiltration rates for dry mesas are less than 10 mm/yr and are more often estimated to be on the order of 1 mm/yr or less (Kwicklis et al. 2005, 090069). Because dry mesas are generally composed of nonwelded to moderately welded unsaturated tuffs with low water content, water flow is matrix-dominated rather than fracture-dominated. Under natural or undisturbed conditions, travel times for contaminants migrating through dry mesas to the regional aquifer are expected to be several hundred to thousands of years (Nylander et al. 2003, 076059.49; Birdsell et al. 2005, 092048). However, beneath disturbed sites or those where liquid wastes were disposed of, travel times to groundwater may be shorter.

MDA T was used for disposal of liquid waste. Enhanced moisture migration and decreased contaminant travel times to groundwater are expected beneath liquid waste disposal sites where infiltration beneath absorption beds increased the moisture content, decreased matric potential, and increased downward driving forces in the underlying tuffs. Field observations indicate moisture migration may have included components of both fracture and matrix flow during periods of liquid discharge (Nyhan et al. 1984, 058906; LANL 2004, 085641). With discharges discontinued, the adsorption beds and underlying tuff are no longer saturated, and moisture migration is expected to occur as matrix flow under present-day and future conditions (Soll and Birdsell 1998, 070011; Birdsell et al. 2005, 092048). Also, infiltration rates at the ground surface are expected to have returned to near-background levels. However, an extended period of greater than normal, downward water flow likely continues at depth under MDA T based upon elevated vadose zone moisture contents.

A reported total of approximately 18 million gallons of wastewater containing plutonium was disposed of in the MDA T absorption beds between 1945 and 1967, 14 million gallons of which was disposed of between 1945 and 1950 (Rogers 1977, 005707). During disposal operation, water movement from the beds was probably primarily vertical. Water from the absorption beds may have moved rapidly through vertical fractures (primarily in units Qbt 3 and Qbt 2) and paleochannel soils during near-saturated conditions. Water may also have moved laterally at hydrologic contacts (e.g., at the vapor phase notch between Qbt 1v/1g, in Cerro Toledo interval and Tsankawi Pumice Bed).

The disposal shafts were installed between 1968 and 1974, 18 to 24 yr after 14 million gallons of the 18 million gallons of wastewater had been disposed of (LANL 2006, 094151). Over 99% of the radiologic inventory disposed of at MDA T was disposed of in the shafts, while less than 1% was disposed of in the beds with wastewater. Wastes disposed of in the shafts were primarily radiological waste mixed with cement for stabilization. This process is thought to immobilize the radiological constituents through a mineralization reaction with the cement. Therefore, the vast majority of the radiologic inventory of MDA T should not be affected by water movement because it is bound in a cement-based waste. Figure 2.1-1 shows the percentages of radiologic inventory between the absorption beds and the shafts at MDA T.

There is no direct evidence of high residual moisture from wastewater disposed of in absorption beds being present in the shaft field during shaft installation, which began in 1968. In contrast, Purtymun et al. reported volumetric water contents (VWCs) of 7% to 10% in a borehole (TH-7) located 2 ft (to the north) from a shaft drilled in 1968, which correspond to gravimetric water contents (GWCs) of approximately 5% to 7%, consistent with the data shown in Figure 2.1-2 (Purtymun et al. 1978, 005730). Purtymun et al. also reported that water contents in a separate borehole (TH-7A) drilled in 1969 and located 2 ft (to the east) from the same shaft had VWCs of 4% to 8% (GWCs of 3% to 5%), indicating apparent drying because of cement hydration. They concluded that disposing of wet cement wastes in the shafts at MDA T may not have increased the subsurface moisture content because the cement removed water from the surrounding formation as it cured. Also, these reported water contents are low and indicate that the area of boreholes TH-7 and TH-7A located 60 cm from an unidentified shaft were either unaffected by disposed wastewater in the absorption beds or else elevated water contents had decreased in the time since most of the approximately 18 million gallons had been disposed of in the absorption beds (Purtymun et al. 1978, 005730).

2.2 Vadose Zone Moisture Field Observations

Vadose zone moisture data from the vicinity of MDA T have been compiled in the form of gravimetric water content versus depth. Core samples from seven boreholes at or near MDA T are included. Water content data from deep boreholes at MDAs A and V are included, along with data from boreholes LADP-3 and LADP-4 for comparison. These data are used to define the extent of moisture beneath MDA T so the vadose zone monitoring network will target the appropriate strata to detect moisture migration. Information on these 11 boreholes is summarized in Table 2.2-1.

The MDA A borehole is included because it was drilled in a dry site that was unaffected by liquid disposal activities and should represent near-ambient conditions. Unfortunately, this borehole is only 360 ft deep and does not penetrate into the Otowi Member. The MDA V borehole is included because it was drilled in the center of MDA V, which consists of three absorption beds where approximately 40 million gallons of wastewater was disposed of between 1945 and 1961 (LANL 2006, 094361), so these data should represent wet conditions, perhaps throughout the Otowi Member. The water contents in borehole LADP-3 represent wet conditions in Los Alamos Canyon where the canyon floor is subjected to large runoff and infiltration events, and the canyon has a shallow alluvial aquifer. The water contents in borehole LADP-4 represent drier conditions beneath DP Canyon compared with Los Alamos Canyon. Although borehole LADP-4 is located at the bottom of a canyon, DP Canyon is a small canyon that experiences smaller runoff events than occur in Los Alamos Canyon. Figure 2.2-1 shows the locations of the seven boreholes at MDA T plus borehole LADP-4 in DP Canyon.

Figure 2.1-2 shows water content profiles from all 11 boreholes, with the profiles from boreholes LADP-3 and LADP-4 repositioned to align stratigraphic contacts to the approximate equivalent depths of the MDA T borehole data (since they are located within canyons below the ground surface [bgs] elevation of MDA T). The water content data are fairly consistent in the top 350 ft of the profile. The profile from MDA A appears to have lower water contents, but the data density from this borehole is lower than for the other boreholes for a direct comparison. The water contents in the Otowi Member (between about 350 and 625 ft deep) from boreholes 21-25262 and 21-607955 (both drilled near MDA T) are similar to the water contents from the MDA V borehole where 40 million gallons of wastewater was disposed of. In addition, these two MDA T boreholes have similar water contents to those measured in the Otowi Member in borehole LADP-3 located in wet Los Alamos Canyon. The water contents from borehole LADP-4 in dry DP Canyon are considerably lower than for all other borehole data from the Otowi Member. These data suggest that throughout the Otowi Member under MDA T, conditions are wetter than ambient dry mesa conditions. Since the water contents do not decline in borehole 21-607955 until a depth of between 800 and 875 ft, it is possible that the gravimetric water contents are elevated to this depth as a result of previous wastewater disposal in the MDA T absorption beds. Comparison to the gravimetric water contents in the Otowi Member from TA-49 (Stimac et al. 2002, 073391) and TA-54 (Krier et al. 1997, 056834) also suggests the water contents observed in the Otowi Member beneath MDA T are elevated relative to these other two TAs.

2.3 Nature and Extent of Contamination

The nature and extent of contamination at MDA T are described in detail in the MDA T investigation report (LANL 2006, 094151); the Phase II MDA T investigation report (LANL 2007, 100484); the Phase III MDA T investigation report (LANL 2009, 108012); and the replacement pages for the Phase III MDA T investigation report (LANL 2010, 108864).

To summarize the findings in those reports, the radionuclides plutonium and americium were detected to depths of 342 and 109.5 ft bgs, respectively, and tritium was detected to 340 ft bgs. Strontium-90 was detected at a concentration of 0.348 pCi/g at a depth interval of 800 to 802 ft bgs in borehole 21-607955. These data are anomalous because strontium-90 was not detected between depths of 179 ft and 799 ft bgs. No samples were collected beneath the shafts during the investigations at MDA T, so it is not known if radionuclides have migrated from the shafts.

The nature and extent of hazardous constituents have been defined: perchlorate and nitrate appear to have migrated to depths of 335 and 373 ft bgs, respectively, while VOCs appear to have reached depths of 575 ft bgs as vapors (LANL 2009, 108012; LANL 2010, 108864). Metals have not migrated as deep as other hazardous constituents (LANL 2006, 094151).

2.4 Uncertainties in Vadose Zone Conceptual Model

During the process of evaluating information for this work plan, two key uncertainties related to the conceptual model of the vadose zone were identified.

1. The first uncertainty is related to the depth to which the water contents are elevated beneath MDA T. Water contents appear to be elevated in deep boreholes beneath MDA T to depths between 800 and 875 ft bgs compared with water content data from borehole LADP-4 in DP Canyon. However, contaminants have not migrated as deep as the apparent elevated moisture front. In terms of monitoring moisture to indicate contaminant transport, uncertainty related to the extent of the moisture front is important where contaminants are also present.
2. The second uncertainty is related to migration of radionuclides from the shafts. Since no samples have been taken directly beneath the shafts, it is uncertain whether radionuclides have migrated out of the cement in the shafts.

The deepest penetration of wastewater is presumed to be beneath absorption bed 1 (which reportedly received the most wastewater) or beneath the center of the shaft field, as a result of converging wetting fronts from all four beds. No deep boreholes are located in the center of MDA T.

These uncertainties can be reduced by (1) drilling a borehole in the center of the MDA T shaft field to a depth of approximately 400 ft to determine the extent of a moisture front caused by wastewater disposal in the absorption beds and by measuring radioactive constituents in core collected in this borehole; (2) drilling a 400-ft borehole in an undisturbed area of TA-21 (probably near the eastern end of DP Mesa) to determine ambient water content and to collect data to compare with data from the borehole located in MDA T; and (3) drilling angled boreholes beneath the shafts and measuring radioactive constituents in core collected in these boreholes.

To determine whether the water content values in the Otowi Member beneath MDA T are elevated because of wastewater disposal, or if they represent ambient conditions unaffected by disposal activities, this work plan proposes drilling a new deep borehole in a relatively undisturbed area of TA-21 to provide data on ambient conditions unaffected by liquid disposal activities. Data from this borehole will also support calibration and/or validation of numerical flow and transport models that are used for the performance assessment of MDA T.

The monitoring approach described below collects data specifically to address these uncertainties.

3.0 APPROACH

The vadose zone monitoring system described in this work plan consists of three primary activities.

- Install a deep borehole in an undisturbed area of TA-21.
- Install a vadose zone moisture monitoring system at MDA T.
- Conduct chemical and radionuclide analyses of core samples.

The first two activities will provide data to address the uncertainty related to the extent of elevated moisture where contaminants are also present. The analyses conducted on core samples are designed to characterize the vadose zone beneath the shafts to address uncertainty related to potential contaminant migration from the site. These data will also support modeling that will be conducted for future corrective measures evaluations.

Table 3.0-1 summarizes the activities proposed in the six vadose zone boreholes (VZM-01 through VZM-06) and the borehole proposed for characterizing moisture in an undisturbed area.

3.1 Install a Deep Borehole in an Undisturbed Area of TA-21

The purpose of installing a deep borehole in an undisturbed area is to collect water content and water potential data for comparison with water content data collected near MDA T. This borehole will be used to establish ambient water content conditions in the vadose zone, including at the interface between the Cerro Toledo interval and the Otowi Member and into the Otowi Member. Analyses of water potential and water content will provide information on whether or not the water content data shown in Figure 2.1-2 indicate moisture conditions that are above background conditions. This borehole will be drilled to 400 ft bgs, samples will be collected, neutron logging will be conducted once, and then the borehole will be backfilled. These data will reduce uncertainty related to the depth of elevated moisture beneath MDA T to a depth that is consistent with observations of contaminant nature and extent beneath MDA T. These data will also enable calibration and validation of numerical models of flow and transport that are used for the radiological dose assessment of MDA T.

3.2 Install a Vadose Zone Moisture Monitoring System at MDA T

Installation of the MDA T moisture-monitoring system consists of the following activities:

- Two 400-ft-deep vertical boreholes will be drilled in the middle of the shaft field and instrumented with heat dissipation probes (HDPs). If the hollow-stem auger drilling is advancing with no issues at 400 ft, attempts will be made to advance to the base of the Guaje Pumice Bed.
- Prior to installation of the HDPs, the boreholes will be video logged to obtain information that can be used to optimize placement of the HDPs.
- Open-hole straddle-packer sampling and testing will be conducted at 40-ft intervals and at representative fractures and other geologic features (e.g., surge beds, depositional contacts) that may be associated with enhanced vapor and/or fluid transport. Discrete vapor samples will be collected for VOC and tritium analysis. In-situ permeability data will also be collected. For each test interval, vapor sampling for VOCs and tritium analyses will precede the in-situ permeability test.
- Four 140-ft-long (100-ft-deep), 45-degree angled boreholes will be drilled under the absorption beds and shaft field and instrumented with HDPs.

Figure 3.2-1 shows the proposed locations of the two vertical and four angled boreholes at MDA T.

Two 400-ft-deep vertical borehole drilled in the middle of the shaft field (VZM-01 and VZM-02) are proposed. These boreholes will be instrumented with HDPs and backfilled. The HDPs installed in VZM-01 and VZM-02 will provide moisture-monitoring data at depths into the Otowi Member. Figure 3.2-2 shows a cross-section schematic diagram of a vertical borehole in the shaft field.

Four 140-ft-long (100-ft-deep), 45-degree angled boreholes drilled under absorption beds and shafts (VZM-03, -04, -05, -06) will also be used to collect more data to determine the nature and distribution of radionuclides and non-radionuclide constituents beneath the disposal units. These four boreholes will be instrumented with HDPs and backfilled to provide high-density moisture data beneath the shafts. Figure 3.2-3 shows a cross-section schematic diagram of an angled borehole under the shaft field.

The exact numbers of sensors and citing of sensors in the boreholes will depend on the water content values observed during drilling. Sensor citing will also consider the locations of hydrogeologic units and minimum numbers of sensors per unit. Water contents and water potentials will be measured in the field during drilling as well as at an analytical laboratory using core samples collected during drilling.
A maximum of 64 HDPs can be wired into one datalogger using one multiplexer. If one datalogger is sited with each borehole, then 64 HDPs can be installed in each borehole. If HDPs are installed with two sensors at each location (for redundancy in case of failure), then a total of 32 depths can be instrumented in each borehole. It is more likely that about 20 HDPs will be installed in each of the four angled boreholes, and about 32 installed in each of the two vertical boreholes for a total of 144 HDPs.

3.3 Conduct Chemical Analyses of Core Samples

Chemical analyses of core collected from the six MDA T boreholes will be used to characterize the vadose zone beneath the shafts. For the two vertical boreholes, samples will be collected at an interval of one sample per 20 ft of core. For the four angled boreholes, core samples will be collected at an interval of one sample per 20 ft of core for the first 80 ft of borehole and at 10-ft intervals for the remaining 60 ft of borehole. Core samples will be analyzed for metals, inorganic compounds, organic compounds, moisture, and radionuclides (Table 3.3-1). Additional samples will be collected at representative fractures and other geologic features (e.g., surge beds, depositional contacts) that may be associated with enhanced vapor and/or fluid transport.

Samples will be collected with an emphasis on maintaining the representativeness of moisture in the sampled medium. Sample retrieval will be conducted in accordance with American Society for Testing and Materials (ASTM) method D6640–01 (2015) or an equivalent method. As soon as the coring apparatus (e.g., split-spoon) is brought to the surface, each end of the core barrel will be field screened for VOCs using a photoionization detector (or equivalent). The field VOC screening data will be collected to complement the straddle-packer samples collected for VOC analysis. Discrete core samples will then be collected for water-content analysis prior to sealing the core barrels to maintain sample integrity. Pore water will be separated from the core and the resultant water, and the core material phases will be containerized for analysis.

VOC analysis will not be conducted on core material or pore water because the VOC data would not be expected to be representative of conditions in the subsurface. The process of crushing core material comprised of Bandelier Tuff prior to placing the material in a sample bottle would likely compromise the amount of VOCs that may be present in a sample. Additionally, with the expectations that pore water contents will be relatively low, it would be the case that the majority of any VOCs that may be present in the vadose zone would be predominantly in the vapor phase and not associated pore water.

The analyses may also enable “fingerprinting” of vadose zone pore water to help determine if the moisture source at a given depth is from the absorption beds or the shafts. Fingerprinting of the water is a secondary priority that may provide information about shaft waste mobility, inform the site conceptual model, and be useful for modeling related to long-term site performance.

Laboratory analyses that will be conducted include

- water content,
- water potential, and
- pH.

3.4 Conduct Radionuclide Analysis on Core Samples

Since no samples have been collected directly beneath the shafts, it is uncertain whether the radionuclides in cement wastes disposed of in the shafts are immobile or if they have migrated. The priority of this activity is to address this uncertainty. Characterization of the nonradionuclide constituents will support existing information on nature and extent of contamination as presented in previous reports on investigations at MDA T (LANL 2006, 094151; LANL 2007, 100484; LANL 2009, 108012; LANL 2010, 108864).

The set of radionuclide analyses of core samples proposed in this work plan includes the following:

- Americium-241
- Cesium-137
- Europium-152
- Plutonium-238
- Plutonium-239
- Strontium-90
- Tritium
- Uranium-234
- Uranium-235
- Uranium-238
- Neptunium-237

3.5 Pore-Water and Isotopic Analyses

Activities for the radionuclides listed above will also be analyzed from extracted pore-water samples and compared with core sample data to evaluate mobile versus bound radiological constituents. In addition, isotopic analyses of pore water will be conducted and include the following:

- Chloride (to evaluate pore water age and the degree to which pore water has been subjected to infiltration and evaporation). Although chloride is usually most useful for estimating natural infiltration, comparison of chloride profiles between disturbed and undisturbed locations will help identify the source of MDA T pore water.
- Sulfur stable isotopes ($\delta^{34}S$) (to differentiate water from beds or shafts). Sulfur is found in minerals used in cement, and the isotopic analysis should help to identify whether any water has migrated from the MDA T shafts.
- Oxygen and hydrogen stable isotopes ($\delta^{18}O$, δD) (to differentiate water sources, the degree to which water has been subjected to evaporation, and combined with chloride to evaluate relative age).
- Nitrogen stable isotopes ($\delta^{15}N$) of nitrate (to differentiate water source from beds or shafts). Nitric acid may have been disposed of with the wastewater into the absorption beds, so isotopic analysis of nitrate will help to identify whether the pore waters are from absorption beds.

4.0 SCHEDULE

Reports that follow from implementation of the work proposed in this work plan will be subject to the annual Appendix B planning process under the Consent Order.

5.0 REFERENCES

The following reference list includes documents cited in this work plan. Parenthetical information following each reference provides the author(s), publication date, and ERID, ESHID, or EMID. This information is also included in text citations. ERIDs were assigned by the Laboratory's Associate Directorate for Environmental Management (IDs through 599999); ESHIDs were assigned by the Laboratory's Associate Directorate for Environment, Safety, and Health (IDs 600000 through 699999); and EMIDs are assigned by Newport News Nuclear BWXT-Los Alamos, LLC (N3B) (IDs 700000 and above). IDs are used to locate documents in N3B's Records Management System and in the Master Reference Set. The NMED Hazardous Waste Bureau and N3B maintain copies of the Master Reference Set. The set ensures that NMED has the references to review documents. The set is updated when new references are cited in documents.

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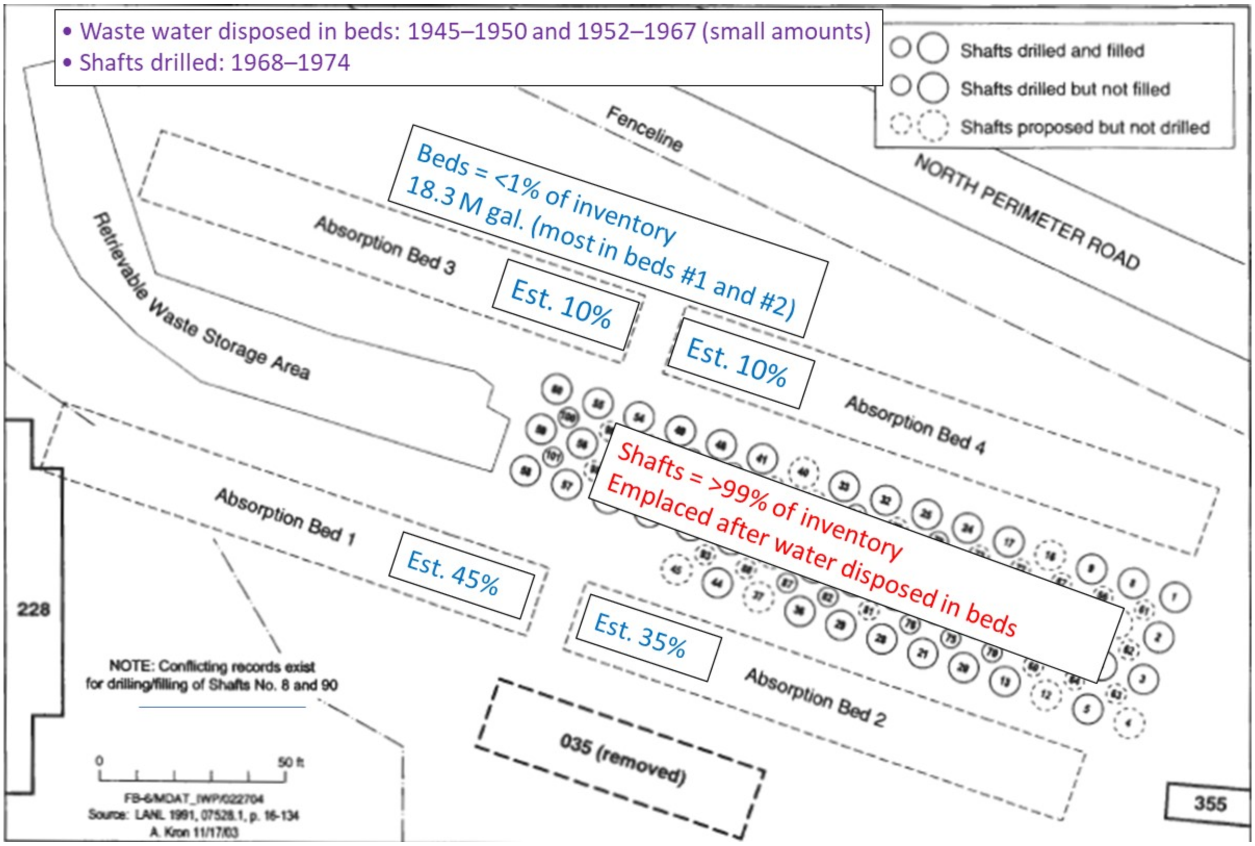

Figure 2.1-1 Locations of absorption beds and shafts at MDA T illustrating relative radionuclide inventory estimates

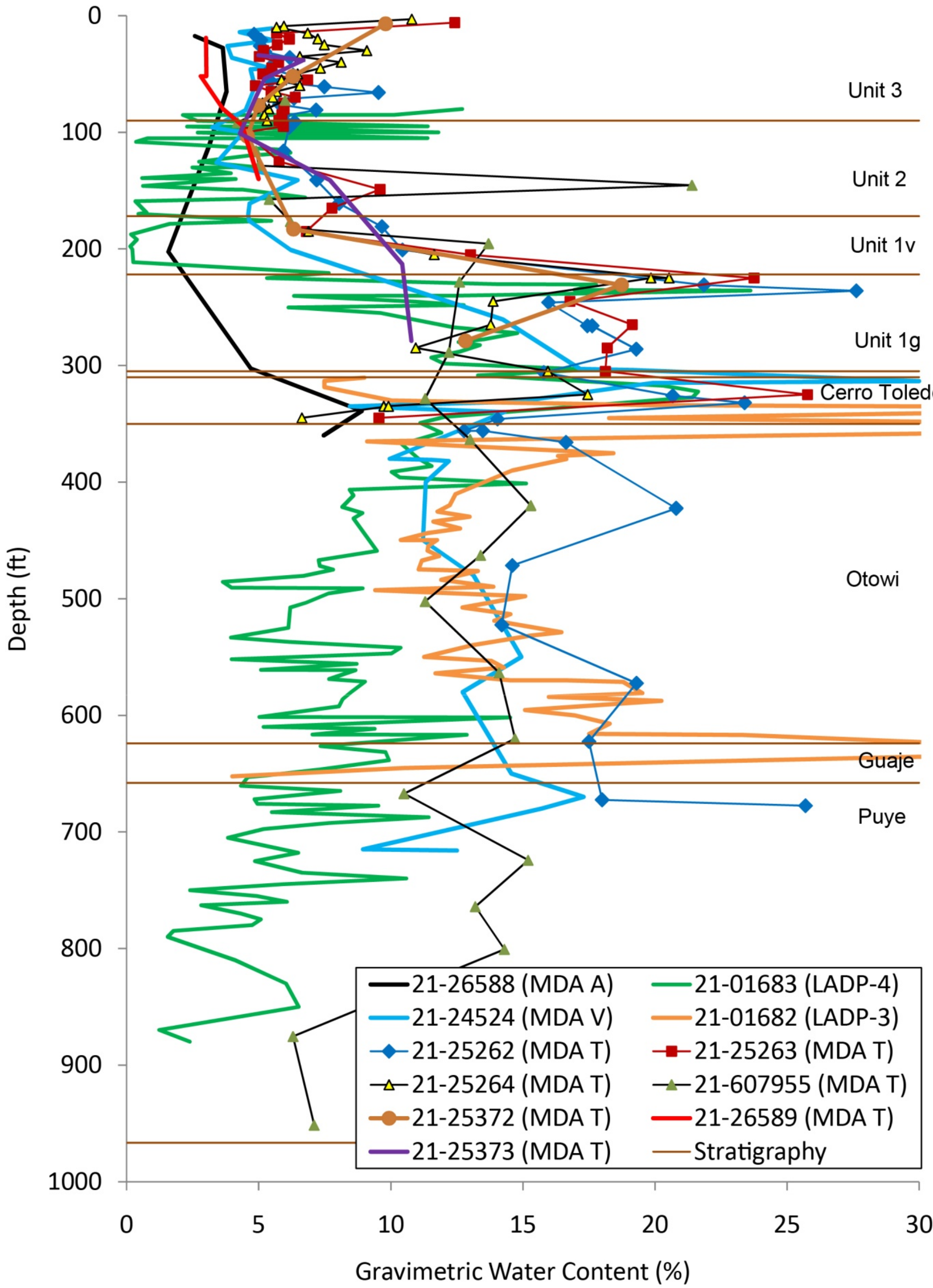

Figure 2.1-2 Water-content data from boreholes at and near MDA T

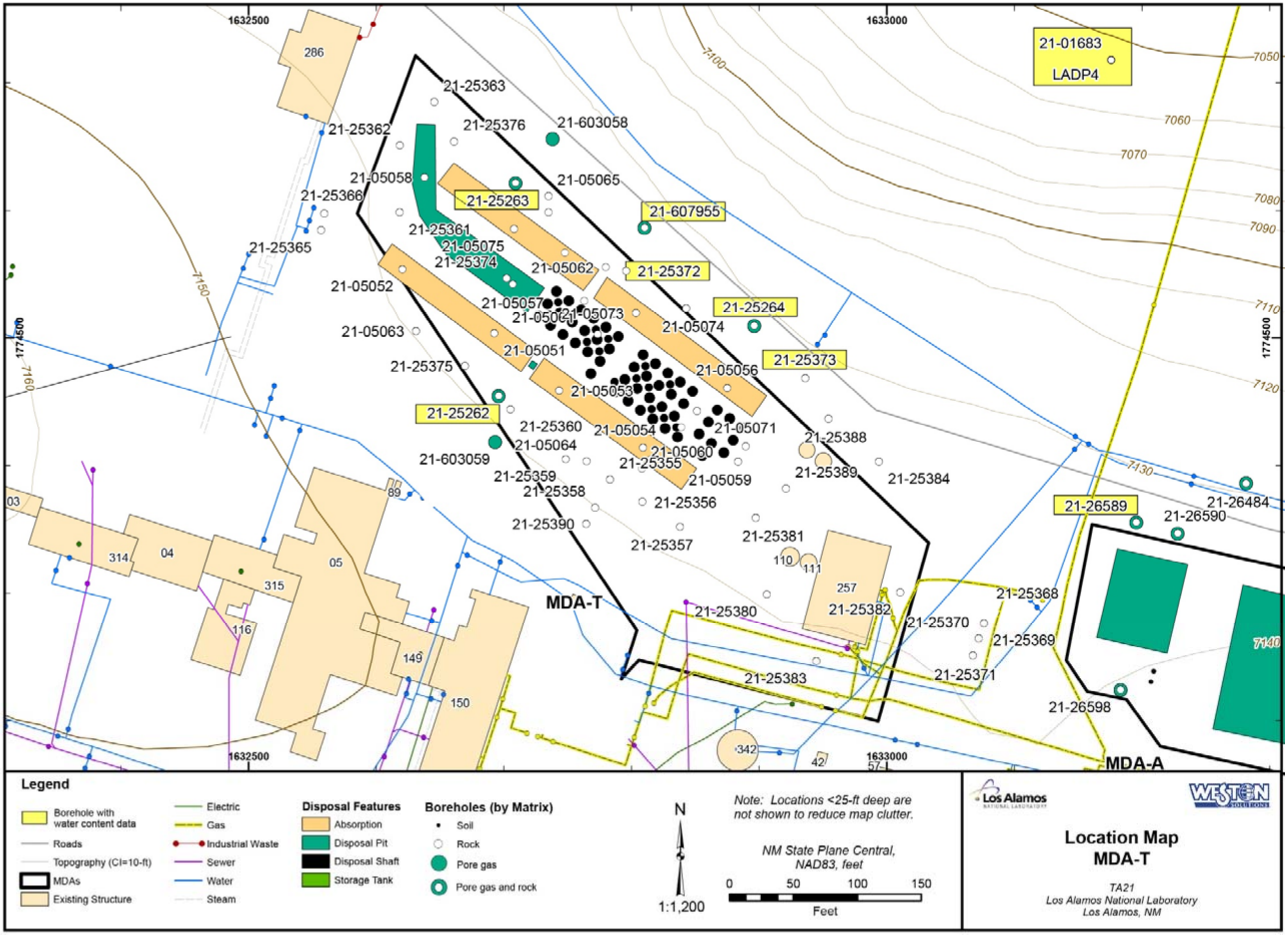

Figure 2.2-1 Locations of boreholes with water-content data at MDA T and in DP Canyon

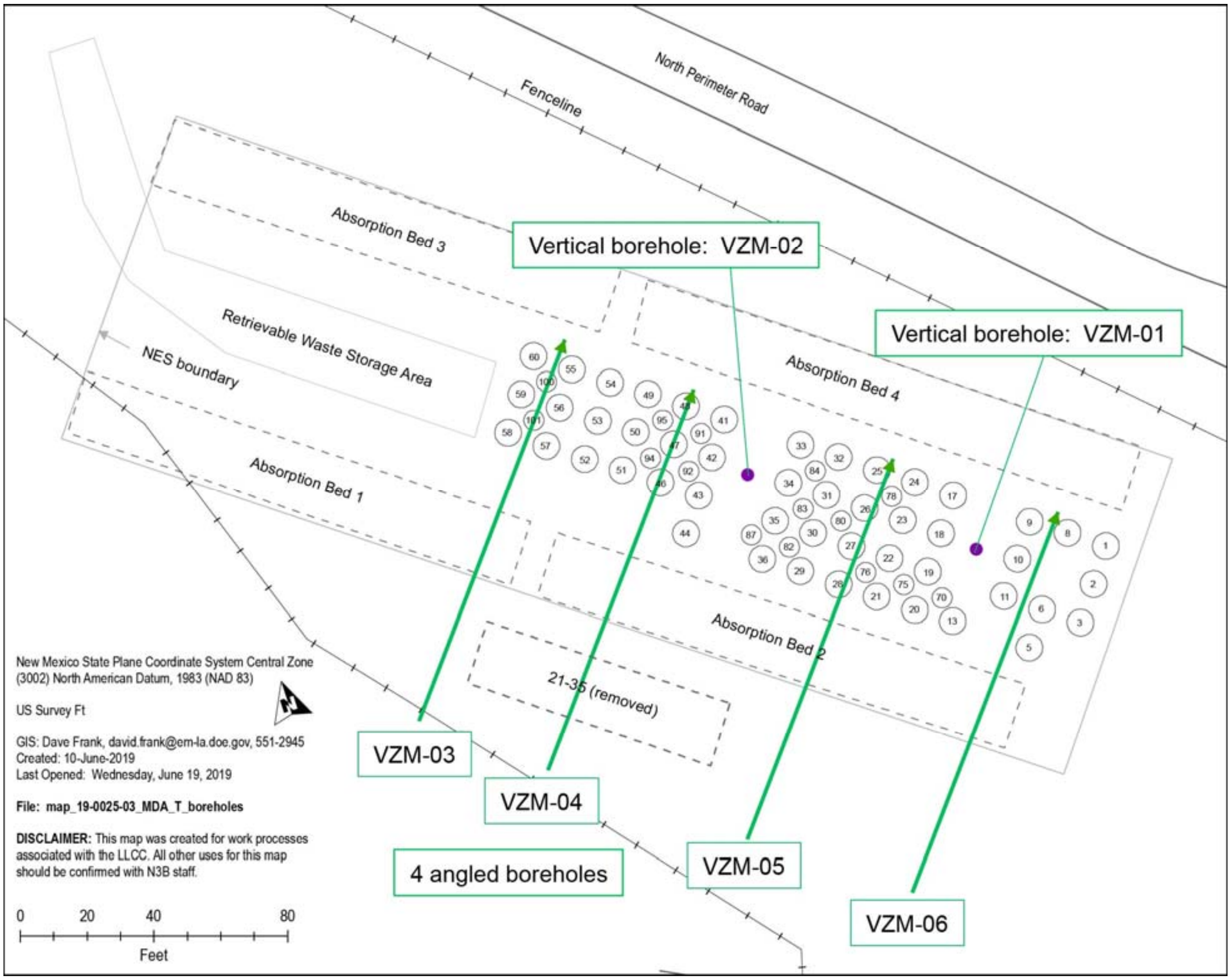

Figure 3.2-1 Locations of proposed vertical and angled boreholes at MDA T

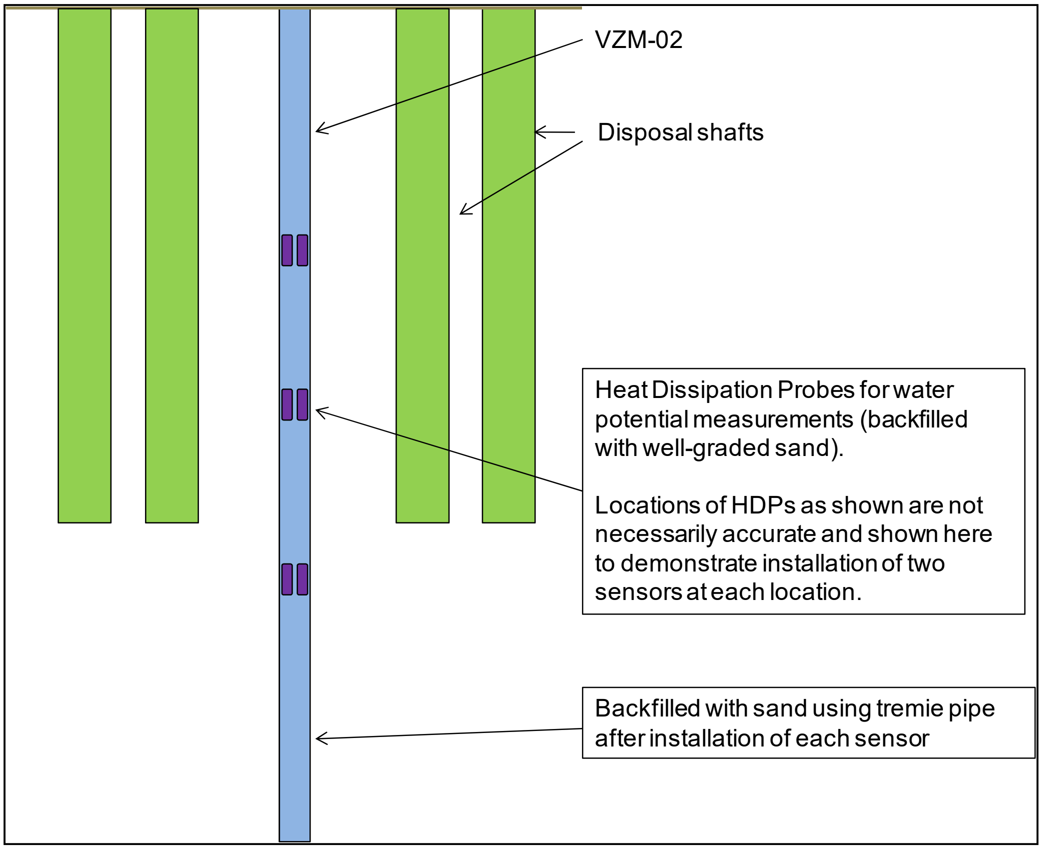

Figure 3.2-2 Cross-section schematic diagram of vertical boreholes in shaft field

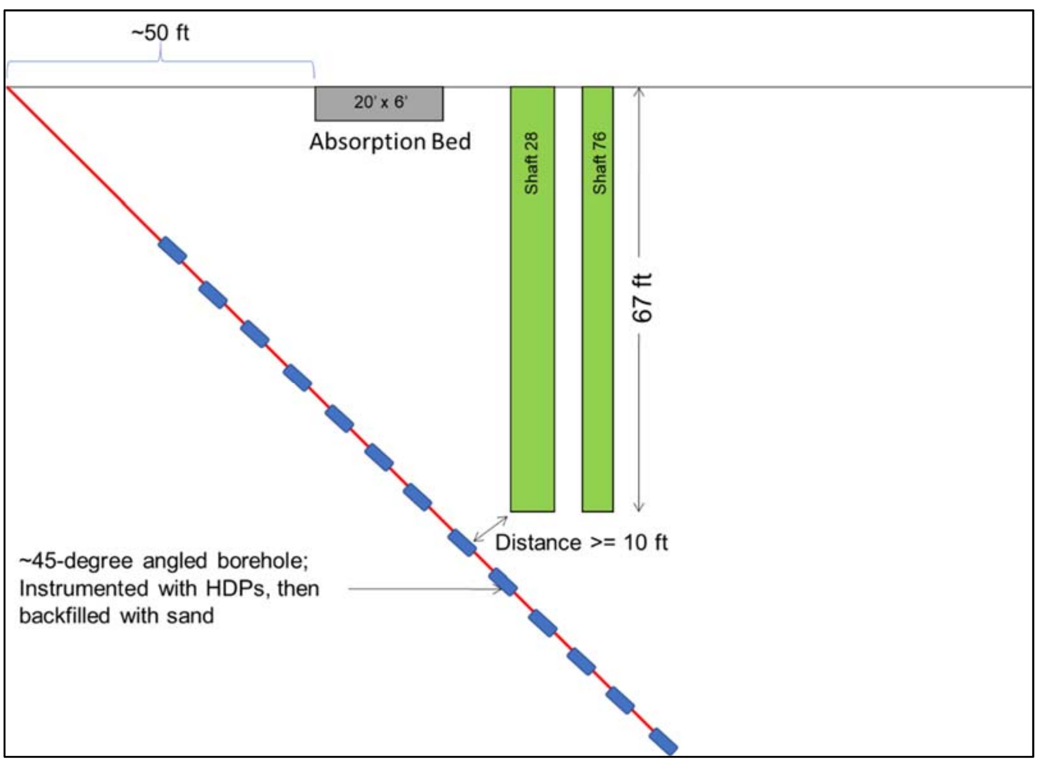

Figure 3.2-3 Cross-section schematic diagram of angled boreholes under shaft field

Table 2.2-1
Summary of MDA T and Nearby Boreholes with Moisture Data

Borehole ID	Depth (ft)	Location	Conditions
21-25262	680	South of bed #1	Potentially affected by MDA T wastewater
21-25263	345	North of bed #3	Potentially affected by MDA T wastewater
21-25264	345	Northeast of bed #4	Potentially affected by MDA T wastewater
21-60755	953	North of bed #4	Potentially affected by MDA T wastewater
21-25372	279	North of bed #4	Potentially affected by MDA T wastewater
21-25373	279	Northeast of bed #4	Potentially affected by MDA T wastewater
21-26589	140	East side of MDA T	Unlikely to be affected by MDA T wastewater
21-26588	360	MDA A	Dry (no known liquid disposal)
21-24524	716	MDA V	Wet (40 million gallons disposed of)
21-01682 (LADP-3)	342	Los Alamos Canyon	Wet
21-01683 (LADP-4)	800	DP Canyon	Dry; especially in Otowi Member

Table 3.0-1
Summary of MDA T Vadose Zone Boreholes

Borehole ID	Borehole Description	Purpose	Methods
VZM-01 Vertical	8-in.-diameter vertical, 400-ft deep, uncased, backfilled with sand around HDPs. Located in eastern portion of the shaft field.	Characterize pore-water content. Monitor water potential at multiple depths using sensors with data logger. Collect in situ subsurface data and samples from core for vadose zone characterization.	Drill using hollow-stem auger (HSA). Collect core material inside of core barrels inside of hollow-stem augers. Solid phase samples will be analyzed after pore water is removed. Liquid phase samples will be analyzed from pore water separated from core material.
VZM-02 Vertical	8-in.-diameter vertical, 400-ft deep, uncased, backfilled with sand around HDPs. Located in the western portion of the shaft field.	Characterize pore-water content. Monitor water potential at multiple depths using sensors with data logger. Collect in situ subsurface data and samples from core for vadose zone characterization.	Drill using HSA. Collect core material inside of core barrels inside of hollow-stem augers. Solid phase samples will be analyzed after pore water is removed. Liquid phase samples will be analyzed from pore water separated from core material.
VZM-03 45-degree angle	8-in.-diameter angled, 100-ft deep, uncased, backfilled with sand around HDPs. Located 50 ft south of absorption bed 2.	Characterize pore-water content. Monitor water potential at multiple depths using sensors with data logger. Collect in situ subsurface data and samples from core for vadose zone characterization.	Drill using HSA. Collect core material inside of core barrels inside of hollow-stem augers. Solid phase samples will be analyzed after pore water is removed. Liquid phase samples will be analyzed from pore water separated from core material.
VZM-04 45-degree angle	8-in.-diameter angled, 100-ft deep, uncased, backfilled with sand around HDPs. Located 50 ft south of absorption bed 2.	Characterize pore-water content. Monitor water potential at multiple depths using sensors with data logger. Collect in situ subsurface data and samples from core for vadose zone characterization.	Drill using HSA. Collect core material inside of core barrels inside of hollow-stem augers. Solid phase samples will be analyzed after pore water is removed. Liquid phase samples will be analyzed from pore water separated from core material.
VZM-05 45-degree angle	8-in.-diameter angled, 100-ft deep, uncased, backfilled with sand around HDPs. Located 50 ft south of absorption bed 2.	Characterize pore-water content. Monitor water potential at multiple depths using sensors with data logger. Collect in situ subsurface data and samples from core for characterization.	Drill using HSA. Collect core material inside of lined core barrels and seal samples for analysis to preserve sample integrity.
VZM-06 45-degree angle	8-in.-diameter angled, 100-ft deep, uncased, backfilled with sand around HDPs. Located 50 ft south of absorption bed 2.	Characterize pore-water content. Monitor water potential at multiple depths using sensors with data logger. Collect in situ subsurface data and samples from core for characterization.	Drill using HSA. Collect core material inside of lined core barrels and seal samples for analysis to preserve sample integrity.
Borehole in undisturbed area outside of NES	8-in. diameter vertical, 400-ft deep, uncased, backfilled after neutron logging. Drilled in undisturbed area on DP Mesa. Backfill after logging.	Provides baseline vadose-zone moisture content. Also provides information for model calibration.	Log with neutron logging tool. Collect core material inside of line core barrels and seal samples for analysis to preserve sample integrity.

Table 3.3-1
Borehole and Nominal Core Sampling Suite and Intervals

Borehole ID	Straddle-Packer VOCs and Tritium (ft)	In Situ Permeability (ft)	Pore Moisture (ft)	Target Analyte List Metals (ft)	General Inorganics (ft)[a]	Radionuclides (ft)[b]	Chloride (ft)[c]	Sulfur Stable Isotopes (ft)[c]	Stable Isotopes of Oxygen and Hydrogen (ft)[c]	Nitrogen Stable Isotopes (ft)[c]
VZM-01	40	40	20	20	20	20	20	20	20	20
VZM-02	40	40	20	20	20	20	20	20	20	20
VZM-03 VZM-04 VZM-05 VZM-06	n/a[d]	20	20 over first 80, then 10 to 140	20 over first 80, then 10 to 140	20 over first 80, then 10 to 140	20 over first 80, then 10 to 140	20	20	20	20

[a] General inorganics includes perchlorate, nitrate, sulfate, and total phosphorous. Analysis will be run for pore water samples only.

[b] Radionuclides include Am-241, Np-237, Cs-137, Eu-152, Pu-238, Pu-239, Pu-240, Sr-90, H-3, U-234, U-235, and U-238. Analysis will be run for solid-phase material and for pore-water samples.

[c] Analysis will be run for pore-water samples only.

[d] n/a = Not applicable.

Appendix A

Review of Moisture-Monitoring Technologies

A-1.0 WATER CONTENT

This appendix presents reviews of vadose zone moisture-monitoring technologies and concludes with a recommendation of technologies that should be employed at Material Disposal Area (MDA) T at Los Alamos National Laboratory (the Laboratory).

A-1.1 Neutron Moisture Meter (Neutron Probe)

For many decades, neutron moisture meters, also called neutron probes, have been used to measure and monitor moisture in soil and rock. Neutron moisture meters have a neutron source that is typically lowered down a cased borehole where measurements are taken at the depth of interest. Measurements typically take less than one minute, but cannot be easily automated and are therefore labor intensive. Boreholes can be vertical, angled, or horizontal. McLin et al. (2005, 204544) describe applications using horizontal access boreholes under waste facilities to monitor changes in moisture.

Advantages: well-accepted, simple, reliable, has been used for more than 50 yr.

Disadvantages: requires calibration (to media, to meter, and to borehole geometry and casing material), labor intensive, infrequent observations. Neutron probe contains a radioactive source: there is a risk of losing a radioactive source in unstable boreholes.

A-1.2 Time Domain Reflectometry

Topp et al. (1980, 204680) first described the application of time-domain reflectometry (TDR) for measuring soil water content. Since then, Topp et al. (1980, 204680) has been cited thousands of times. TDR probes are generally about 30 cm long and rigid and not applicable for downhole installation. However, flexible TDR (FTDR) sensors have been also been used in boreholes (e.g., Dahan et al. 2009, 204542), although this type of application requires very good contact between the TDR probes and the surrounding media. If the borehole is backfilled, then the backfill material must be very similar to the surrounding media for TDR (or any other water content sensor) to be accurate.

Advantages: accurate, well-accepted.

Disadvantages: difficult to ensure good contact against tuff in open borehole; can be used in crushed tuff, but only if good contact is ensured (e.g., no air gaps from bridging).

A-2.0 WATER POTENTIAL

A-2.1 Heat Dissipation Probes

Heat dissipation probes (HDPs) (e.g., Flint et al. 2002, 204543) are water potential sensors whose premise is that water potential is proportional to thermal conductivity. When a constant power is dissipated from a line heat source, the temperature increase is proportional to the thermal conductivity of the media, and dry and wet media have different thermal conductivities. HDPs can measure a very wide range of water potentials (and inferred moisture content). Figure A-2.1-1 shows the measurement range of HDPs, and other water potential sensors, as well as the range of water potentials that might be expected in boreholes beneath MDA T (see predicted water potentials in Figure 2.4-3 of the work plan).

Advantages: accurate, well-accepted, very high resolution and large range of measurement, small sensor that can be installed in any type of backfill material (e.g., crushed tuff or sand), no cable length limitation.

Disadvantages: sensors are ceramic and subject to damage during installation. Sensor measures water potential, not water content.

A-2.2 Thermocouple Psychrometers

Thermocouple psychrometers (TCPs) are used to infer water potential of the surrounding media by measuring the relative humidity of the media. These sensors have been in use for decades (Rawlins and Campbell 1986, 204547) and have a much smaller measurement range than HDPs (see Figure A-2.1-1).

Advantages: accurate, well-accepted, high resolution, small sensor that can be installed in any type of backfill material (e.g., crushed tuff or sand).

Disadvantages: thermocouple wires are known to break after many measurements (due to heating). No known commercial manufacturer. Sensor measures water potential, not water content.

A-2.3 Tensiometers

Tensiometers are very simple water potential sensors that consist of a vacuum gauge that measures the suction caused by a tube filled with water coming into equilibrium with unsaturated media via a porous membrane (that allows water but not air to pass). Tensiometers have been in use since around 1922 (Cassel and Klute 1986, 204546). Sisson et al. (2002, 204545) describe an advanced tensiometer for use in shallow or deep vadose zones. Installation of these sensors at the Laboratory has been suggested by the Northern New Mexico Citizens' Advisory Board (NNMCAB) at its September 19, 2007 meeting (https://plus44.safe-order.net/nnmcab//minutes/2007_Attachments/9-19-07_CAB_MINUTES_FINAL_Part1.pdf). These sensors are not well suited for most sites at the Laboratory because conditions are too dry for any type of tensiometers. Ambient water potential conditions beneath the dry mesas at the Laboratory commonly exceed (are drier than) −10 bars while tensiometers have a range of suction of zero to about −700 cm (−0.7 bars) (see Figure A-2.1-1). Although conditions beneath MDA T are expected to be wetter than ambient conditions under dry mesas, they may not be wetter.

Advantages: simple design.

Disadvantages: measurement range is too limited, requires water in sensor (can dry out). No known commercial manufacturer. Sensor measures water potential, not water content.

A-3.0 WATER FLUX

Although water fluxmeters have been described in the literature for decades in various designs, they have recently become well-known in the soil science and vadose zone hydrology community since Dr. Glendon Gee wrote his first paper on them (Gee et al. 2002, 204679). Fluxmeters are unique in that they are the only method for measuring vertical water flux directly (i.e., deep infiltration or recharge). Fluxmeters are generally installed just below the root zone rather than in deep settings such as beneath MDA T.

Advantages: accurate, well-accepted, the only method for direct measurement of water flux.

Disadvantages: device is large (8 in. × 5 ft) and difficult to install in boreholes (must be greater than 12 in. diameter), some depth limitations (~100 ft maximum). Only a limited number of meters can be deployed because of their size and wire-length limitations.

A-4.0 POTENTIAL ISSUES WITH SENSORS

Sensor Damage during Installation

Sensors can be damaged while on the ground surface before installation, during installation into a borehole, or during backfilling of media around the sensors. The impacts of sensor damage can be mitigated by installing duplicate sensors at each location of interest and by testing sensors before/during/after installation.

Sensor Longevity

Little data on sensor longevity are available. Some sensors are known to last longer than others. For example, the fine-wire thermocouple in thermocouple psychrometers can break after many readings. Sensor longevity can be increased by taking limited measurements (daily versus hourly).

Time to Reach Equilibrium

Sensors can take anywhere from days to years to come into equilibrium with the surrounding media after drilling and sensor installation. In the case of HDPs, the manufacturer recommends installing sensors with their ceramic porous casing wetter than the surrounding media. Numerical modeling results suggest that sensor equilibrium will be reached faster using a well-graded sand that using a well-sorted (poorly graded) silica sand.

A-5.0 RECOMMENDED MOISTURE-MONITORING TECHNOLOGY FOR MDA T

Based on the information summarized in this appendix and given the constraints of sensor size, sensor contact requirements, and sensor measurement ranges, HDPs are the recommended moisture-monitoring technology for installing downhole sensors at MDA T.

A-6.0 REFERENCES

The following reference list includes documents cited in this work plan. Parenthetical information following each reference provides the author(s), publication date, and ERID, ESHID, or EMID. This information is also included in text citations. ERIDs were assigned by the Laboratory's Associate Directorate for Environmental Management (IDs through 599999); ESHIDs were assigned by the Laboratory's Associate Directorate for Environment, Safety, and Health (IDs 600000 through 699999); and EMIDs are assigned by Newport News Nuclear BWXT-Los Alamos, LLC (N3B) (IDs 700000 and above). IDs are used to locate documents in N3B's Records Management System and in the Master Reference Set. The NMED Hazardous Waste Bureau and N3B maintain copies of the Master Reference Set. The set ensures that NMED has the references to review documents. The set is updated when new references are cited in documents.

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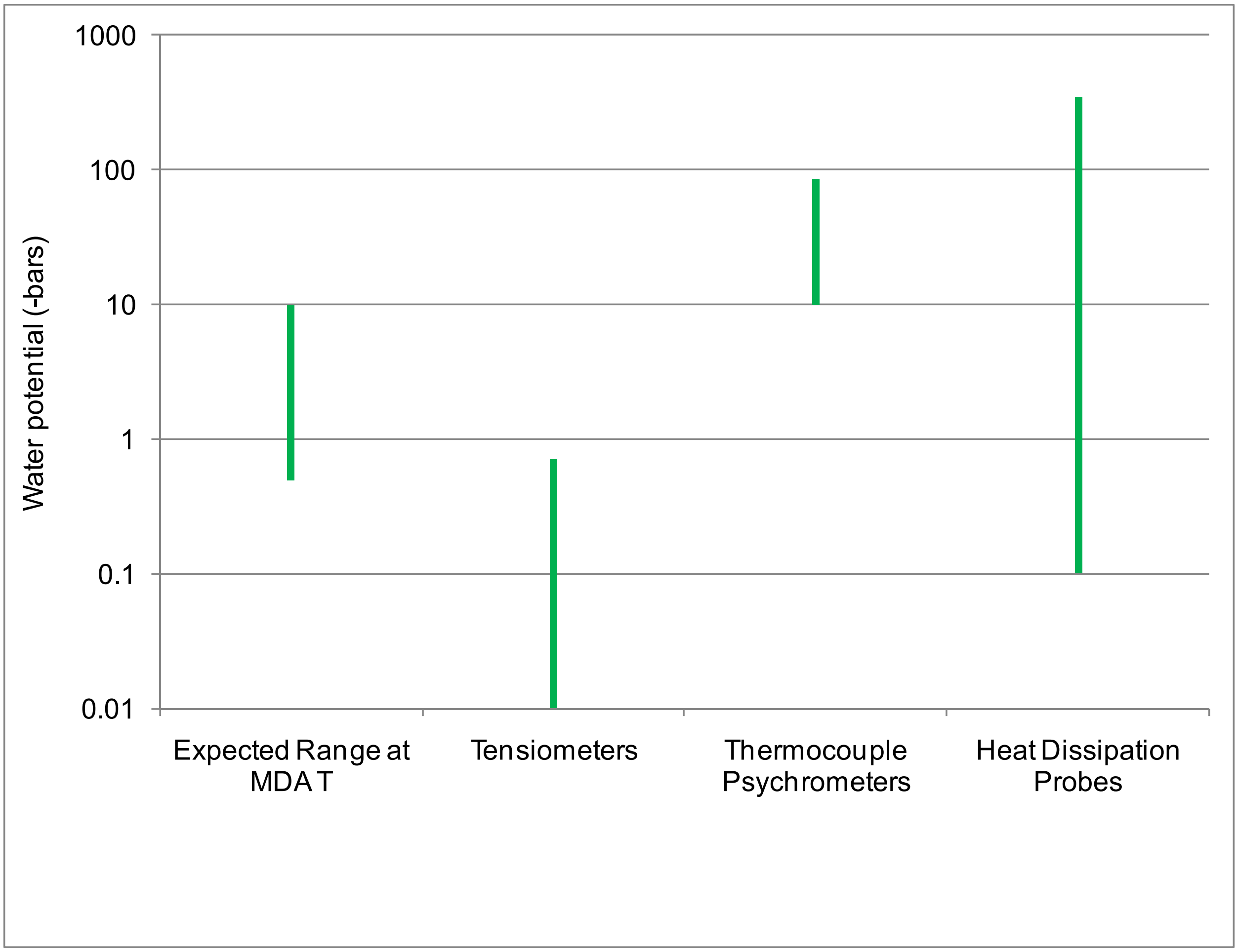

Figure A-2.1-1 Comparison of water potential sensor measurement ranges with the range expected beneath MDA T