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Final Report for the Waste Area Group 7 Probing Project

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May 2005

Idaho Cleanup Project

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ABSTRACT

This document is the final report for the Waste Area Group 7 Probing Project at the Subsurface Disposal Area within the Idaho National Laboratory. The Waste Area Group 7 Probing Project developed sealed probes to safely investigate buried hazardous and radioactive waste. From December 1999 through August 2004, 398 probes were installed in the Subsurface Disposal Area to collect characterization and monitoring data directly from the buried waste. Probes were installed using a sonic drill rig that remotely pushed probes into the buried waste. The purpose of this project was to collect geophysical data, vapor samples, moisture data, and water samples, and to visually examine the buried waste.

This document summarizes the Waste Area Group 7 Probing Project, highlights the successes and limitations of the probes, and makes recommendations and observations to improve on the work completed.

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ACRONYMS

ECL	Environmental Chemistry Laboratory
FY	fiscal year
GEOPS	Geologic and Environmental Probe System
HPGe	high-purity germanium
INL	Idaho National Laboratory
OD	outside diameter
OU	operable unit
QA	quality assurance
RFP	Rocky Flats Plant
RI/FS	remedial investigation and feasibility study
RWMC	Radioactive Waste Management Complex
SDA	Subsurface Disposal Area
SMR	soil-moisture, resistivity, and temperature
SVR	soil vault row
TFR	technical and functional requirements
TRU	transuranic
VOC	volatile organic compound
WAG	waste area group

Final Report for the Waste Area Group 7 Probing Project

1. INTRODUCTION

This document is the final report for the Waste Area Group (WAG)[a] 7 Probing Project at the Subsurface Disposal Area (SDA). The SDA is a radioactive waste landfill located within the Radioactive Waste Management Complex (RWMC) at the Idaho National Laboratory (INL). Figure 1 provides a map of the INL showing the location of the RWMC and other major Site facilities.

The RWMC has been used for waste disposal operations since the 1950s, and is being investigated as part of a "Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)" (42 USC 9601 et seq., 1980) remedial investigation and feasibility study (RI/FS) pursuant to the *Federal Facility Agreement and Consent Order for the Idaho National Engineering Laboratory* (DOE-ID 1991). The WAG 7 Probing Project gathered data to support the Operable Unit (OU) 7-13/14 RI/FS (see Footnote a), as described in *Operable Unit 7-13/14 Plan for the Installation, Logging, and Monitoring of Probeholes in the Subsurface Disposal Area* (Becker et al. 2000). In addition, the project has gathered subsurface data describing the contents and states of various RWMC SDA pits, trenches, and soil vaults. Operations included placement of noninstrumented Type A probes and instrumented Type B probes throughout the SDA.

1.1 Scope

This report summarizes the use of driven probes to characterize buried radioactive, mixed, and transuranic (TRU) waste in the SDA. Data generated from these probes are being used to support the assessment of subsurface conditions within the buried waste, moisture infiltration through the waste, release rate and solubility of various contaminants, and the mass of the volatile organic compound (VOC) source remaining. The results will support development of the OU 7-13/14 comprehensive RI/FS for the RWMC.

This report also discusses the success and limitations of the WAG 7 Probing Project. The various probe types used are reviewed with respect to the following:

- Intended purpose
- Success in meeting the intended purpose
- Effectiveness and limitations
- Quality of data obtained from the probes
- Overall usefulness of the probes
- Lessons learned.

This report does not discuss probe data results or analysis of those data in terms of characterization of buried waste; that information is contained in annual year-end reports (Myers et al. 2002 and 2003).

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a. The *Federal Facility Agreement and Consent Order for the Idaho National Engineering Laboratory* (DOE-ID 1991) lists 10 WAGs for the INL. Each WAG is subdivided into OUs. The RWMC is identified as WAG 7 and originally contained 14 OUs. Operable Unit 7-13 (TRU pits and trenches RI/FS) and OU 7-14 (WAG 7 comprehensive RI/FS) were ultimately combined into the OU 7-13/14 comprehensive RI/FS for WAG 7.

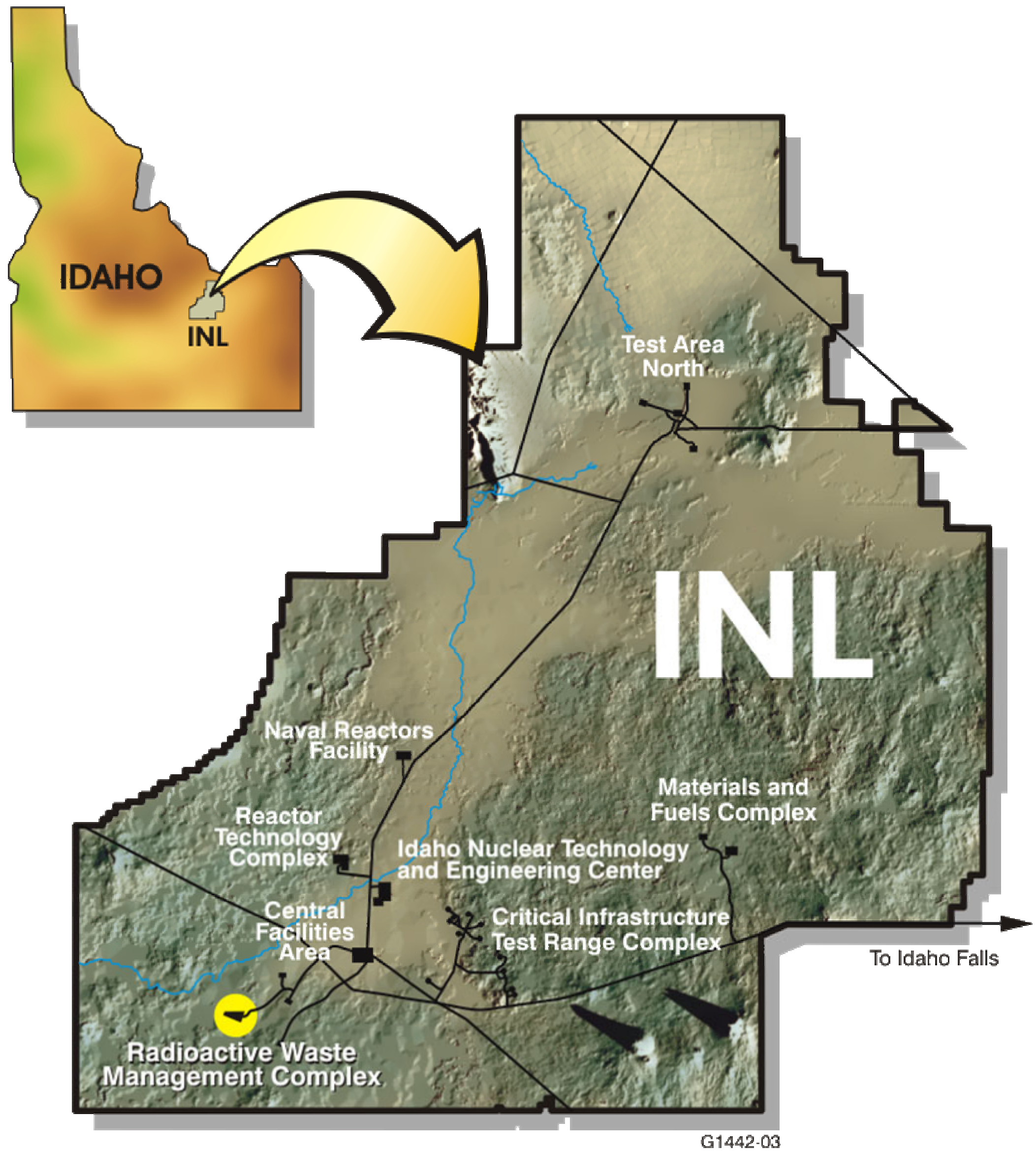

Figure 1. Map of the Idaho National Laboratory showing the location of the Radioactive Waste Management Complex and other major Site facilities.

1.2 Brief History and Description of the Subsurface Disposal Area

The RWMC covers 71.6 ha (177 acres) in the southwestern quadrant of the INL. This includes the administration area (8.9 ha [22 acres]), the SDA (39.3 ha [97.1 acres]), and the Transuranic Storage Area (23.3 ha [57.5 acres]). The map in Figure 2 shows the location of pits, trenches, and soil vaults in the SDA.

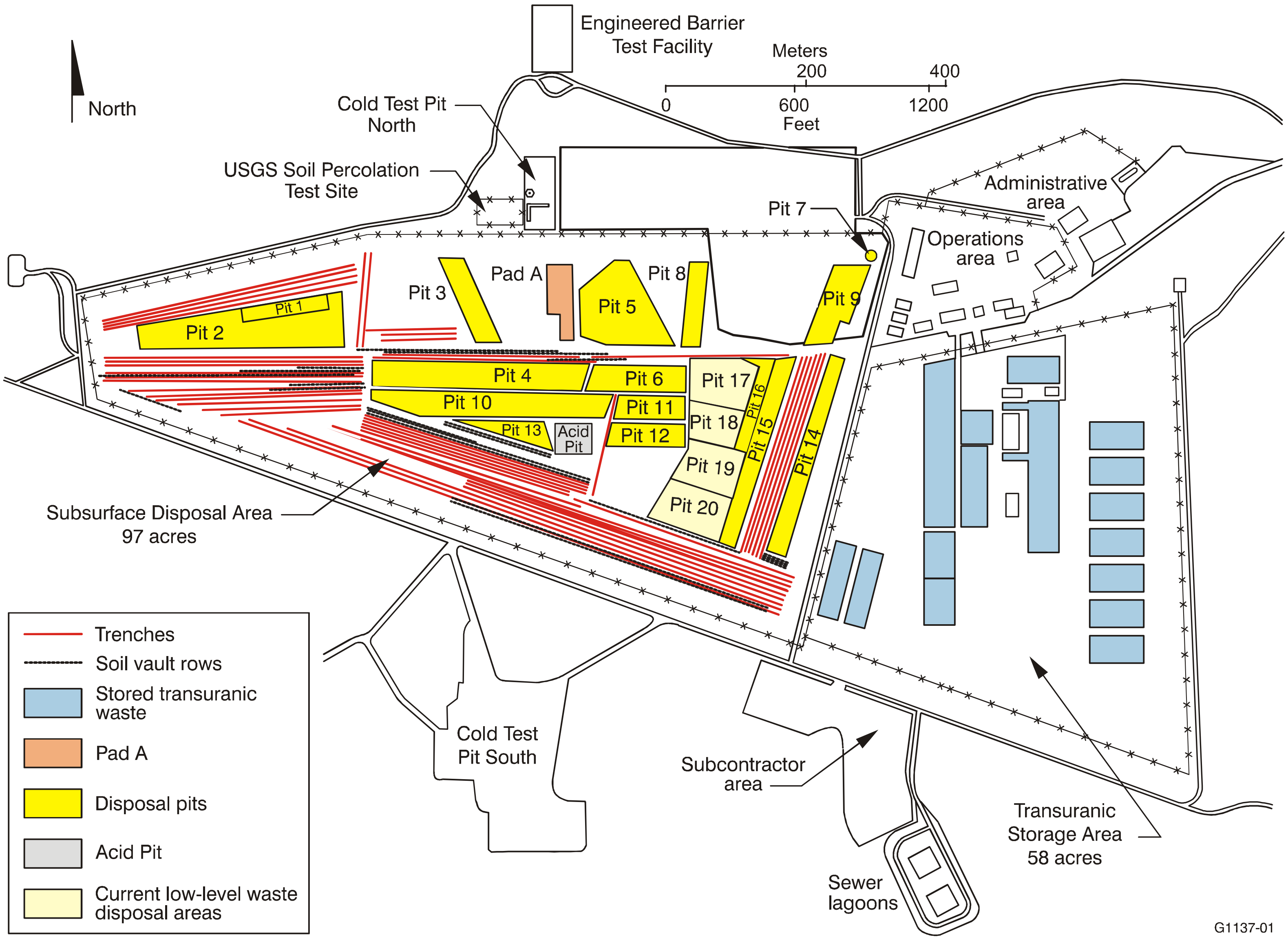

Figure 2. Map of the Radioactive Waste Management Complex showing the location of the Subsurface Disposal Area.

In 1952, the SDA was established at 5.26 ha (13 acres) for the disposal of solid radioactive waste. Burial of defense waste, with TRU elements, from the Rocky Flats Plant (RFP) began in 1954; by 1957, the original SDA was nearly full. In 1958, the SDA was expanded to 35.6 ha (88 acres), which remained the same until 1988 when the security fence was relocated outside the dike surrounding the SDA, and the current size of 39.3 ha (97.1 acres) was established. Roughly 14.6 ha (36 acres) are waste disposal areas, and 25 ha (61 acres) comprise space between the pits, trenches, and dikes surrounding the overall area.

From 1952 to 1970, radioactive waste was buried in pits, trenches, and soil vault rows (SVRs) excavated into a veneer of surficial sediment. This sediment is underlain by a series of basaltic lava and sedimentary deposits. In 1970, the shallow burial of TRU waste ended. Since 1970, burial of low-level and other radioactive waste has continued, and TRU waste has been stored on above ground asphalt pads in retrievable containers. Between 1952 and 1997, approximately 215,000 m^3 (7,592,653 ft^3) of radioactive waste containing about 12.6 million Ci of radioactivity was buried at the SDA (French and Taylor 1998).

Between 1960 and 1963, the RWMC accepted radioactive waste from private sources (e.g., universities, hospitals, and research institutes). This service stopped in September 1963 when commercial burial sites became available for contaminated waste from private industry. When the Transuranic Storage Area became operational in 1970, asphalt pads were constructed on which TRU waste was stacked and then covered with plywood, plastic sheeting, and 0.9 m (3 ft) of soil. From 1975 to 1996, air-support buildings were used to protect recently received waste containers during stacking operations. These support structures were emptied in 1996 and decommissioned in 1998.

1.3 Overview of the Waste Area Group 7 Probing Project

Waste Area Group 7 developed and deployed probes to investigate buried waste in the SDA. From December 1999 through August 2004, 398 probes were installed, using a sonic drill rig, to collect characterization and monitoring data directly from the waste zone. The purpose of the WAG 7 Probing Project was to gather data to support assessment of the parameters listed below:

- Locations of waste types, distributions of radionuclides in buried waste near the probeholes, and thicknesses of soil and waste layers
- Identification of radioisotopes present
- Infiltration rates through the cover, buried waste, and underburden soil at the SDA
- Release rate and solubility of uranium
- Release rate of C-14
- Release rate of the VOC sources remaining in the buried waste
- Physical characteristics of the buried waste.

Probes provided the capability to characterize and monitor the waste zone directly, and provided data for assessing the parameters listed above. Table 1 summarizes the types of probes and data collected by the probes. The two types of probes used were:

- **Type A**—hollow, bottom-sealed tubes that allow safe access into the waste zone with nuclear logging instruments.

- **Type B—**sealed tubes equipped with various instruments or access ports to provide additional monitoring capabilities in and immediately beneath the waste. Instruments in the Type B probes include tensiometers, lysimeters, vapor ports, and soil-moisture sensors (see Figure 3). A special set of transparent polycarbonate tubes for visual examination of buried waste also is classified as a Type B probe.

Table 1. Types of data collected for the Waste Area Group 7 Probing Project.

Type A Probes		
Data Source	Measurement Frequency	Type of Data Obtained
Passive spectral gamma detector	Single event	Used to measure and identify gamma-emitting radionuclides (e.g., Am-241, Cs-137, K-40, Np-237 [by way of Pa-233], Pu-239, Th-232 and its daughters, U-235, and U-238 and its daughters).
Neutron moisture logging tool	Single event	Used for assessing soil moisture content and also the interface between overburden and underburden and the waste zone.
Neutron-activated spectral gamma (n-γ) logging tool	Single event	Used to measure and identify prompt gamma rays from neutron activation of stable elements in the subsurface (e.g., Cl-35 in chlorine-containing VOCs like carbon tetrachloride).
Passive neutron logging tool	Single event	Used to identify neutron-rich zones, indicative of the presence of TRU radionuclides.
Azimuthal spectral gamma detector	Single event	Used to measure and identify gamma-emitting radionuclides (same as those listed for the passive spectral gamma) with the ability to determine from which azimuthal direction the gamma rays originated.
Type B Probes		
Data Source	Sampling Frequency	Type of Data Obtained
Tensiometer probe	Continuous monitoring	Soil water potential (centimeters of water).
Lysimeter probe	Quarterly sampling	Collect moisture samples from the waste zone. Samples were sent to an analytical laboratory for analysis.
SMR probe	Continuous monitoring	Moisture content (percent by volume), resistivity (ohm-meters), dielectric constant (MHz), and temperature (°C).
Vapor probe	Quarterly sampling	Collect soil-gas samples from the waste zone. Samples were analyzed with field instruments and also sent to an analytical laboratory for analysis of VOC concentrations and radioactive gas (i.e., C-14 and tritium).
Visual probe	Single event	Video recording, optical televiewer, and digital stills.

SMR = Soil-moisture, resistivity, and temperature (Note: An earlier probe design was called “SMRT”; therefore, this probe version is called the “SMR” to differentiate between the two. In addition, it should be noted that the SMR probe does measure temperature.)
TRU = transuranic
VOC = volatile organic compound

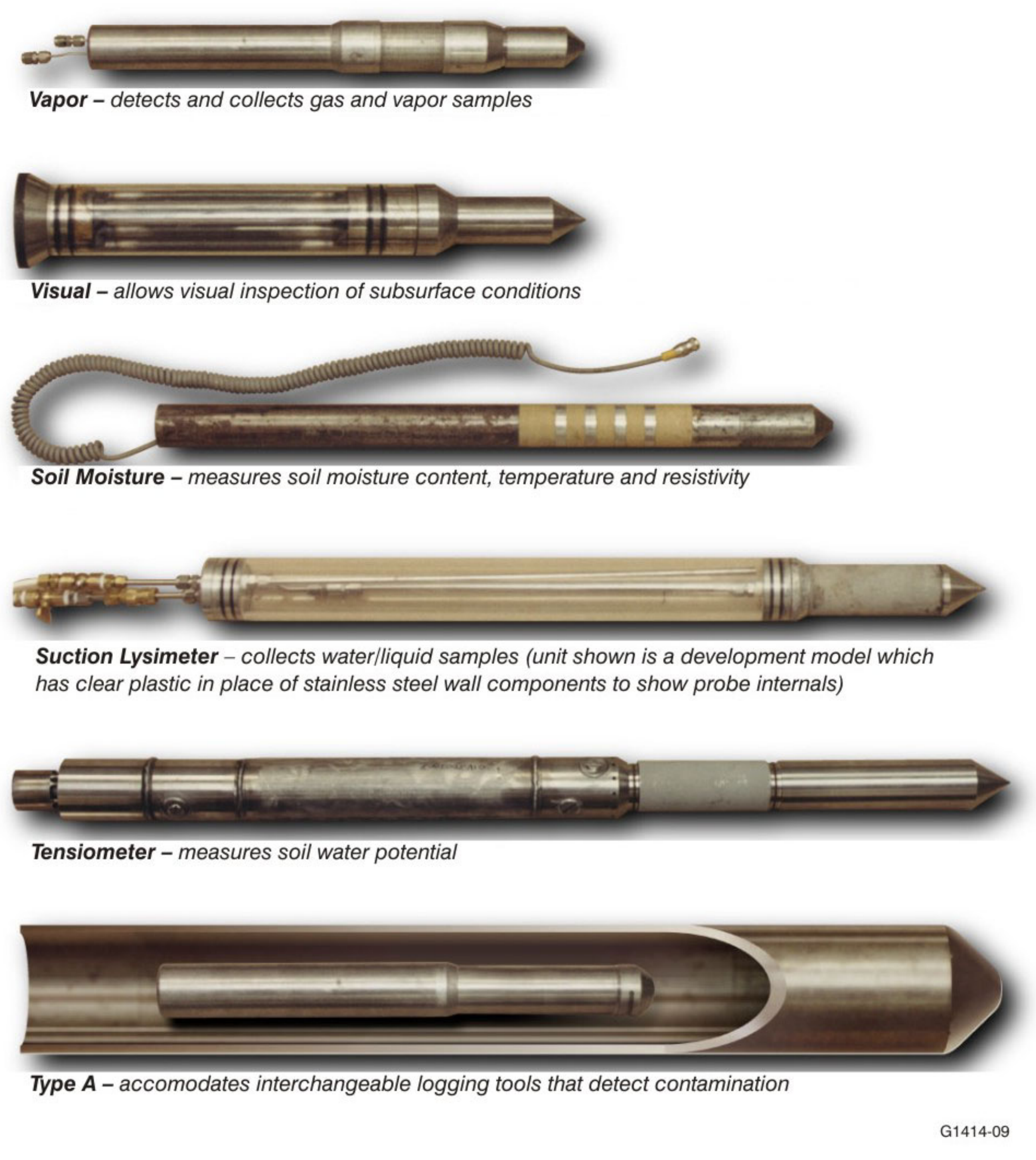

Figure 3. Probe types used in the Waste Area Group 7 Probing Project.

Originally, the OU 7-10 Project (Pit 9[b] Project Interim Action) planned to use enclosed drilling methods to satisfy the OU 7-10 Stage I subsurface exploration tasks (EG&G 1994, LMITCO 1997). However, development of the enclosed drilling equipment became impractical because of cost and schedule impacts. Waste Area Group 7 safely and successfully used three Type A probes during the Pit 9

b. Operable Unit 7-10 comprises Pit 9.

Preliminary Campaign (August 1999) to indirectly measure moisture content and to detect the presence of VOCs in Pit 9 (Okeson 1999, Flury and Harsh 2002). During the Pit 9 12.2 × 12.2-m (40 × 40-ft) campaign in December 1999, the OU 7-10 Project used 20 Type A probes to characterize buried waste in a 12.2 × 12.2-m (40 × 40-ft) section of Pit 9 planned for retrieval (Becker et al. 2000). The primary objective of analyzing logging data was to select a location in the study area for limited excavation and waste retrieval (Beitel et al. 2000, Josten 2002a).

Waste Area Group 7 then successfully negotiated with the Idaho Department of Environmental Quality and the U.S. Environmental Protection Agency to further employ probing to characterize Pit 9 and to meet Stage I objectives. Additional probing efforts were completed in Pit 9 to investigate potential plutonium-contaminated waste (Josten 2002a). Operable Unit 7-10 installed eight more Type A probes during the Pit 9 Campaign 1 (October 2000) along the northern boundary of the 12.2 × 12.2-m (40 × 40-ft) study area to define the extent of elevated gamma readings around Type A Probe P9-20 (Josten 2002a, p. 56). Operable Unit 7-10 then installed 15 more Type A probes, during November and December 2000 in two areas of Pit 9, that successfully encountered targeted RFP filter and graphite waste types (Josten 2002a, p. 63). In May 2001, six more Type A probes were installed around Type A Probe P9-20 to characterize the anomalously high gamma values at Probe P9-20 in advance of the Stage I retrieval (Josten 2002a, p. 58). Forty-nine Type A probes were installed in Pit 9.

The OU 7-13/14 Project used Type A and Type B probes to characterize other areas and waste types of interest within the SDA (Becker et al. 2000). Over 100 Type A probes and 200 Type B probes were installed in Pits 4, 5, 9, and 10, and in the SVRs, from August 2000 to November 2001. The general approach, including placement of original Type A probes, is outlined in the OU 7-13/14 Probehole Plan (Becker et al. 2000). This plan established focus areas for investigation (i.e., those areas suspected of containing depleted uranium, organic sludge, americium and neptunium, uranium, or plutonium [Holdren et al. 2002, Myers et al. 2003 and 2004, Salomon 2004]), based on shipping and inventory records. Type A probes were installed in transects or grids to identify the location of specific waste types. Results from the Type A geophysical logging then established areas for placement of both Type B clusters and individual probes (see Figure 4). Typically, a Type B cluster included multiple moisture probes, tensiometers, lysimeters, and vapor ports. These instruments were stacked vertically to measure the subject parameter changes through the cover material, waste zone, and underburden, and were placed throughout the area to measure horizontal variations of the parameters. The Type B probes also were used to collect information about contaminant release of C-14 and tritium from activated metals at the SDA. Additional Type A, Type B, and redesigned Type B lysimeter probes were installed in more target areas between June 2003 and August 2004, including Pits 2, 5, 6, and 10, and in numerous trenches (Salomon 2004, Josten 2005).

Specific numbers of the types of probes include the following:

- Type B tensiometers = 66
- Soil moisture resistivity probes = 51 locations (with 95 individual instruments)
- Vapor ports = 30
- Lysimeters = 18
- Visual probes = 10

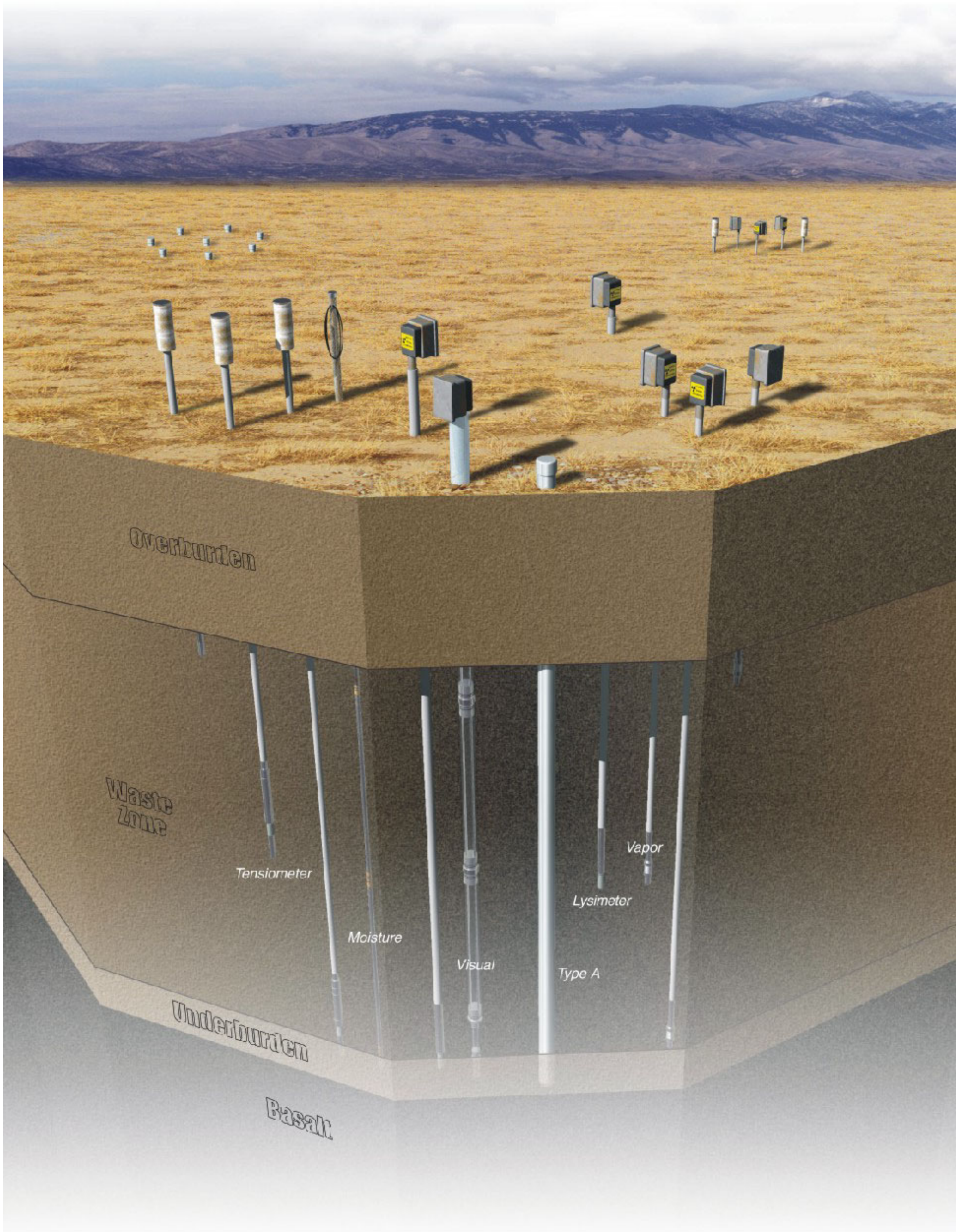

Figure 4. Typical probe suite installed in the Subsurface Disposal Area.

- Type A probes = 191[c]
- Geologic and Environmental Probe System (GEOPS) probes = 32 (31 lysimeters, 1 vapor port).

1.4 Document Organization

The remaining sections in this report are organized in the following manner:

- Section 2 contains a description of the probes used in the SDA, the type of data collected by each probe type, and the lessons learned.
- Section 3 contains a summary and recommendations.
- Section 4 lists the references cited throughout this report.
- Appendix A contains two tables summarizing probe data. Probes listed in Table A-1 are sorted by date installed, and probes listed in Table A-2 are sorted by probe type.
- Appendix B contains figures showing all the probe locations. Specific probes listed in Tables A-1 and A-2 can be located by cross-referencing between the probe type and probing project focus area columns to the probing project focus area figures in Appendix B.

c. This number includes three probes adjacent to Pit 9 used for soil moisture and excludes 10 probes not logged because of shallow completions (less than 1.9 m [6.25 ft]). Five of the shallow probes were replaced with deeper probes, which were logged.

2. SUMMARY OF WASTE AREA GROUP 7 PROBES

The following subsections discuss the successes and limitations of the WAG 7 Probing Project, the sonic drill rig, Type A probes, Type B probes, and the lessons learned.

2.1 Sonic Drill Rig

2.1.1 Drilling Objectives and Requirements

The main objective in using the sonic drill rig was to minimize personnel exposure and contaminant release to the environment. The sonic drill rig could be operated remotely and did not produce cuttings or bring waste material to the ground surface, thus minimizing dust and airborne hazards. In addition, the sonic drill rig had the capability to drive large-diameter probes (6.4–14 cm [2.5–5.5 in.] in diameter).

The sonic drill rig was selected to install the various probes to a zone of interest or to refusal (either basalt or to a point where the probe is incapable of proceeding any farther into the soil or waste). Performance requirements and intended purposes for the sonic drill rig, in accordance with Technical and Functional Requirements (TFR) -105, "Technical and Functional Requirements for the OU 7-13/14 Probing Project Type B Probes," were defined as follows:

- The probes will be installed using the sonic drill
- The sonic drill shall be the modified Hawker Siddley Super Drill 150, Series 2, resonant sonic drill (or equivalent), with the capability to install Type B probes
- The drill rig shall, where practical, remain fully functional for installing probes in an outdoor environment under the following conditions:
    - Temperatures from -20 to 40°C (-5 to 105°F)
    - Steady winds to 15 mph
    - Wind gusts to 25 mph.

2.1.2 History and Truck-conversion Data

The sonic drill rig was originally skid-mounted (see Figure 5) and was transferred to locations using a large crane. Accurate maneuverability was time consuming and inherently risky. Therefore, a government-owned tanker truck was located in the Site equipment excess pool (see Figure 6), the tank was removed, and the drill was rig-mounted on a new flatbed installed on the truck (see Figure 7). All appropriate safety devices and walkways were designed to make the drill rig accessible to the operators. The conversion increased the safety of the drilling operations and was a great cost savings to the company during subsequent probe installations.

Figure 5. Picture of the sonic drill before being mounted on the truck.

Figure 6. Picture of the truck before the conversion showing the tank that was subsequently removed.

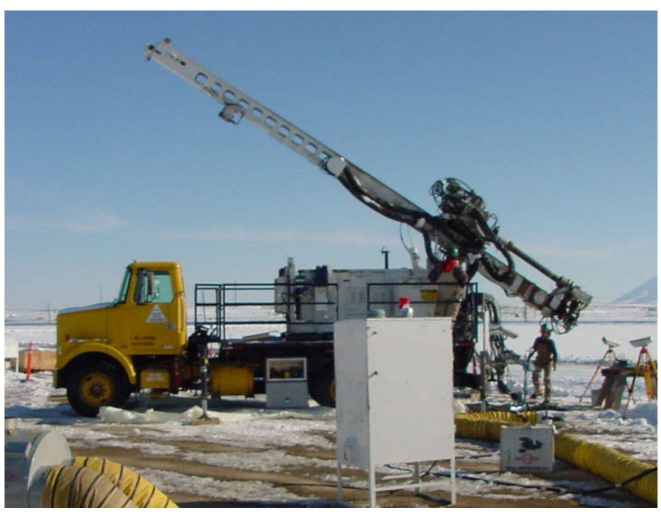
Figure 7. Picture of the truck-mounted sonic drill rig in service after the conversion was complete.

All U.S. Department of Transportation requirements were met during the conversion process; and as altered, the truck conforms to all applicable Federal Motor Vehicle Safety standards. Operability of the drill rig was not affected by mounting it on the truck.

2.1.3 Effectiveness and Limitations

The sonic drill rig provided extremely versatile probe-installation capabilities; some of the probes are within 0.6 m (2 ft) of one another. This is possible because of the drill setup off the back of the flatbed.

Operating the drill rig required one field team leader, one drill operator, two helpers, one Health and Safety officer, and often another safety observer when the rig was operated remotely. The probe installation procedure required all drilling to be done with all personnel at least 15 m (50 ft) away to minimize exposure risks to personnel. The control trailer provided this capability. Limitations of the sonic drill rig include:

- Maximum depth in soil estimated to be 15 m (50 ft)
- No cuttings were available to correlate with in situ data
- Probes were unable to be driven into bedrock
- Excessive stresses during drilling could damage probe design and instruments or sensors.

2.1.4 Overall Usefulness of the Method

The sonic drill rig was very effective in meeting all requirements for installing probes through soil and waste. The truck-mounted sonic drill rig was very portable, and it was very efficient at driving in very large-diameter (15.2-cm [6-in.]) probes. However, the sonic drilling technique may have been responsible for damaging probes and instruments during installation. The light hammer speeds and vibrations may have loosened fittings, disconnected wires, or forced soil into sample ports.

2.1.5 Lessons Learned on the Sonic Drill Rig

The sonic drill rig was very useful in driving the large-diameter Type A probes necessary to utilize nuclear logging tools. The conversion from the skid-mounted operation to a truck-mounted drill was well planned, and the entire unit is road-ready and can be relocated to virtually any location. However, too much focus was placed on the power of the sonic drill rig to drive the large-diameter Type A probes, and less attention was placed on the impact of the powerful tool on smaller and more sensitive probes.

2.2 Type A Probes

Type A probes have sealed steel casings with a 14-cm (5.5-in.) outside diameter and an 11.4-cm (4.5-in.) inside diameter. A total of 191 Type A probes were installed, using the sonic drill, within the waste disposal locations in the SDA. Type A probes were initially installed in transects or grids spaced approximately 1.8–2.1 m (6–7 ft) apart (see Appendix A). Fourteen separate logging campaigns were conducted. Each campaign targeted a specific group of waste shipments. Using five types of logging tools, over 31,000 individual logging measurements were obtained during these campaigns.

Type A probes were installed specifically for deploying downhole nuclear logging tools to obtain information about the subsurface conditions and waste buried in the SDA. The SDA logging program focused exclusively on qualitative objectives. Original objectives for the Type A probes included the following:

- Substantiate the presence of waste types that have been tentatively located using waste inventory records and surface geophysics

- Identify areas with high relative-contamination levels suitable for detailed in situ studies using Type B probes

- Identify areas with waste characteristics suitable for pilot remediation studies.

Many Type A probes were successfully driven to the underlying basalt, while some Type A probes met refusal before reaching basalt. Additional probes were placed in clusters around select probe locations to enhance evaluation of source characteristics. The subsurface adjacent to the Type A probes was characterized with the logging instruments identified in Table 1. Detailed descriptions of these tools and results of the logging are presented in three primary reports:

- *Type A Nuclear Logging Data Acquisition and Processing for OU 7-13, 7-14 and 7-10* (Josten 2002b)

- *Compilation of Analytical Notes and Data Analyses for the Integrated Probing Project 1999–2002* (Josten 2002a)

- *Surface Geophysics and Downhole Geophysical Logging Results for the Radioactive Waste Management Complex, 2003–2004* (Josten 2005).

2.2.1 Passive Gamma Ray Logging Tool

The passive gamma ray logging tool contains a 35% relative efficiency high-purity germanium (HPGe) gamma detector. The detector, cooling system, and electronics are contained in a stainless steel housing with a maximum diameter of approximately 9 cm (3 in.). The center of the detector was positioned approximately 76 cm (30 in.) from the logging tool end plug during early deployment at Pit 9, but was later changed to 10 cm (4 in.) to support measurements closer to the bottom of the Type A probes. At each measurement point, the passive gamma ray logging tool produces a summary of the gamma ray-emitting radionuclides (both man-made and naturally occurring) present in the material surrounding the Type A probe.

2.2.1.1 Intended Purpose of the Passive Gamma Ray Logging Tool. The passive gamma ray logging tool was deployed in Type A probes in the SDA to support the OU 7-10 and OU 7-13/14 probing projects. The purpose of deploying the passive gamma ray logging tool was to identify radionuclide contaminants in the waste zone and underburden, and to identify areas of relatively high radionuclide concentrations, to aid in the placement of Type B probes. Radionuclide contaminants targeted with the passive gamma ray logging tool included TRU radionuclides Am-241, Np-237 (by way of Pa-233), and Pu-239. Uranium-235 and U-238 (by way of Pa-234m) were targeted to identify areas containing enriched uranium; Cs-137 and Co-60 were targeted to identify fission and activation products.

2.2.1.2 Success in Meeting the Purpose. The passive gamma ray logging tool was successful in meeting its intended purpose of identifying radionuclide contaminants in the waste zone and underburden. (It was assumed that the overburden did not contain any anthropogenic radionuclides.) The passive gamma ray data obtained during the Type A logging clearly identified locations within the waste zone containing measurable activities of targeted radionuclides. Radionuclides identified with this detector include Am-241, Cs-137, Co-60, K-40 (natural), Np-237 (by way of Pa-233), Pu-239, U-235, U-238 and its daughters, and Th-232 daughters.

2.2.1.3 Effectiveness and Limitations of the Gamma Ray Logging Tool. The passive gamma ray logging tool was effective in supporting the WAG 7 Probing Project. Specific information obtained from the data collected with the passive gamma ray logging tool include:

- Thicknesses of overburden, underburden, and waste-bearing zones.

- Specific waste types (e.g., Pu-239-bearing graphite mold waste, Series 741 sludge, depleted uranium, and enriched uranium) were identified based on characteristics of the radionuclide mixtures and composition of the waste media. Results were consistent with waste profile information available from inventory records.

It was readily apparent from the onset of logging activities with the passive gamma ray logging tool that the data were limited to qualitative interpretation. This limitation was a result of the calibration method and assumptions. The passive gamma ray tool was calibrated for an infinite, homogeneous source. The high degree of heterogeneity in the buried waste led to unreasonable or ambiguous results when quantitative interpretations were attempted. Furthermore, the *Evaluation of Nuclear Logging Tool Calibrations for use in Type A Probes at the INEEL Subsurface Disposal Area, OU 7-13/14* (Giles, Josten, and Broomfield 2003) documents an in-depth evaluation of passive gamma ray tool calibration options. This evaluation document concluded that valid quantitative results for the heterogeneous conditions in the SDA could not be achieved with any type of standard calibration.

2.2.1.4 Quality of Data from the Passive Gamma Ray Logging Tool. Because of the high degree of heterogeneity in buried waste in the SDA, quantitative results contained significant errors of varying magnitude and high uncertainty. During the analysis of the Type A probe data, it was discovered that data analysis methods were available that could be used to mitigate, to a certain extent, the magnitude of the errors. These methods included:

- **Differential attenuation analysis—**Differential attenuation analysis could be used to estimate the amount of material between the detector and the source.

- **Isotopic ratio analysis—**Using a more robust gamma ray analysis code, information from the passive gamma ray spectra could be used to calculate ratios of TRU radionuclides and uranium isotopes. The ratios of Am-241 to Pu-239, Np-237 to Am-241, and Np-237 to Pu-239 could be calculated for the waste surrounding the probe; subsequently, the information could be used to estimate the age of the waste surrounding the probe. Additionally, areas of elevated Am-241 and Np-237 activities (elevated relative to the activities associated with aged weapons-grade plutonium) could be identified to fingerprint specific waste types. Uranium isotopic ratios were calculated to differentiate between depleted, natural, and enriched uranium waste.

- **Monte Carlo modeling**—Modeling would make use of all Type A logging data and all analyses performed in an attempt to provide a three-dimensional depiction of the radionuclide distribution around each probe.

Although the data quality obtained from the passive gamma ray logs lends itself for more detailed analysis, the uncertainty caused by waste heterogeneity propagates through any analysis that would be performed, providing an unacceptable degree of uncertainty in the end result.

2.2.1.5 Overall Usefulness of the Gamma Ray Logging Tool. In general, passive gamma ray data from the Type A probes provided the probing project with a detailed qualitative picture of the waste zone, when viewed with the other Type A logging data. Specific information about waste genesis could, in some cases, be determined from the calculation of isotopic ratios. From these data, general inferences could be made as to the waste types encountered and whether the targeted waste was actually found.

2.2.2 Neutron Moisture Logging Tool

The neutron moisture logging tool used for SDA operations incorporates a 50-mCi americium-beryllium neutron source and a 3 × 13.2-cm (1 × 5.2-in.) He-3 detector to measure thermal neutron flux at a fixed distance from the source. High-energy neutrons emitted by the source are moderated through collisions with hydrogen nuclei in the surrounding soil. Neutron moisture tools operate on the assumption that hydrogen atoms constitute the principal neutron moderator in the soil formation, and that hydrogen is present mainly in the form of water. The moisture logging tool used in the SDA logging programs was a close-spaced type, which means that the measured count rate increases with increasing hydrogen content.

2.2.2.1 Intended Purpose of the Neutron Moisture Logging Tool. The neutron moisture logging tool was developed to provide accurate measurements of the percent volumetric moisture content in the overburden, underburden, and waste zones in the SDA. The percent moisture then could be used in evaluating placement of the Type B probes.

2.2.2.2 Success in Meeting the Purpose. The neutron moisture logging tool was used successfully in meeting its intended purpose of measuring the soil-moisture content of the overburden and underburden; however, heterogeneity, physical characteristics, and composition of the waste zone precluded accurate soil-moisture measurements in the waste zone and at the interfaces between the waste zone and the overburden and underburden.

2.2.2.3 Effectiveness and Limitations Neutron Moisture Logging Tool. As stated previously, the neutron moisture logging tool was used to effectively and accurately quantify the volumetric soil-moisture content of the overburden and underburden. However, it was readily apparent that the moisture data collected in the waste zone, and at the waste zone interfaces with the overburden and underburden, were inaccurate. These inaccuracies were realized after careful examination of the moisture logs with the other nuclear borehole logs discussed in this report. As with the passive gamma ray logging tool, the conditions under which the neutron moisture logging tool was calibrated (Becker et al. 2000) were significantly different than those present in the waste zone.

Limitations in providing quantitative moisture-content estimates in the SDA waste zone were due to a number of factors including the presence of high thermal neutron removal cross-section materials (e.g., chlorine, plutonium, and boron) that would cause low indicated-water content at some locations. The high cross-section materials remove thermal neutrons before the neutrons can be detected by the He-3 detector. Additionally, the presence of large amounts of material containing light elements other than hydrogen (e.g., carbon, lithium, and beryllium) may have caused erroneously high indicated-water concentrations at some locations. The water concentration also can be overestimated if the medium contains hydrocarbons, because the instrument cannot differentiate between hydrogen in the form of water and hydrogen in the form of hydrocarbons. The presence of large voids also may have led to inaccurate results, with the magnitude of the inaccuracy dependent on the size and shape of the voids. Finally, the actual distribution of water in the waste zone was likely not uniform, and led to inaccurate indicated-water concentrations.

2.2.2.4 Overall Usefulness of the Neutron Moisture Logging Tool. In addition to providing accurate soil-moisture-content readings in the overburden and underburden, data obtained from the neutron moisture tool provided an indication of the location of the waste zone. In nearly all Type A probes, the moisture data reliably depicted depth profiles of the overburden, waste zone, and underburden.

After the initial logging campaign in Pit 9, the neutron moisture logging tool was used to rapidly scan the Type A probes to identify the waste zone and underburden. These areas then were targeted for additional nuclear logging using the passive gamma, neutron-activated spectral gamma, and passive neutron logging tools. Using data from the neutron moisture tool in this fashion effectively reduced the time required to complete the logging activities for a given Type A probe.

Data collected from the neutron moisture logging tool were analyzed, in conjunction with the other logging data, to provide an interpretation of the potential types of waste surrounding the Type A probes. Additionally, the neutron moisture logging tool data were used to aid placement of Type B tensiometer probes (see Section 2.3) and the soil-moisture, resistivity, and temperature (SMR)[d] probes (see Section 2.5).

2.2.3 Neutron-activated Spectral Gamma (n,γ) Logging Tool

The active gamma ray logging tool used at the SDA employs a Cf-252 source mounted immediately above the tool end-plug with a 35% relative efficiency HPGe detector located 41 cm (16 in.) above the source. Neutron-activated gamma (n,γ) logging employs a gamma ray spectrometer combined with a neutron source on the same tool string. The neutron source produces a neutron cloud in the vicinity of the probehole, and the gamma spectrometer detects gammas emitted during neutron-capture reactions. Certain nonradioactive elements (e.g., chlorine) that have a high affinity for neutron capture may be detected based on their characteristic capture gammas.

2.2.3.1 Intended Purpose of the Neutron-activated Spectral Gamma (n,γ) Logging Tool. The intended purpose of the active gamma ray logging tool was to collect data that could be used to assist in the qualitative identification of buried waste-bearing zones in the SDA by identifying stable elements comprising specific targeted waste. Elements of interest detected during n-gamma logging at the SDA include chlorine, iron, calcium, silicon, and hydrogen. Chlorine measurements were sought as an indicator for chlorinated VOCs. Iron, calcium, silicon, and hydrogen provide information on the soil and waste matrix properties.

2.2.3.2 Success in Meeting the Purpose. The active gamma ray logging tool was used successfully to identify waste zones containing chlorine; however, this was not without several limitations and caveats on interpretation of the data. These limitations are summarized in the next section.

2.2.3.3 Effectiveness and Limitations of the Neutron-activated Spectral Gamma (n,γ) Logging Tool. The active gamma ray logging tool can easily measure relatively low chlorine concentrations. As with the moisture gauge, the presence of materials with high thermal neutron-removal cross sections can perturb the results of this logging tool. For example, the presence of chlorine, plutonium, or boron can lead to an erroneously low indicated content of all the elements detected by this logging tool. This is because the high cross-section material removes the thermal neutrons (i.e., depressing the thermal neutron flux) before the neutrons can be captured by the other elements of interest. However, because chlorine has a very high thermal neutron capture cross section, self-shielding causes the uncertainties in the measurement results to increase for chlorine concentrations above a few weight percent, and the technique tends to saturate at a chlorine concentration somewhere between 15 and 25%, effectively limiting the ability of the instrument to provide any estimate of chlorine content at concentrations greater than 25%. Chlorine from other sources (e.g., halide salts and PVC) cannot be distinguished from VOCs. These characteristics, coupled with the method of calibration for the tool (Becker et al. 2000), limited the effectiveness of the active gamma ray logging tool in providing definitive

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d. An earlier probe design was called "SMRT"; therefore, this probe version is called the "SMR" to differentiate between the two. In addition, it should be noted that the SMR probe does measure temperature as well.

identification of VOC-containing waste, and relative quantities of chlorine-containing waste were limited to a maximum of 25% (weight percent chlorine).

2.2.3.4 Quality of Data from the Neutron-activated Spectral Gamma (n,γ) Logging Tool. The gamma ray spectra obtained are very complex and exhibit gamma ray energies ranging from about 100 keV to about 8 MeV. Many of the elements detected exhibit multiple gamma rays. For these elements, this will allow results to be based on the intensities of multiple gamma rays rather than a single gamma ray. As with the passive gamma ray logging data, differential attenuation can be used to provide information about distribution of the various elements in the bulk medium (e.g., how close to a uniform distribution is observed) and the effective amount of material through which the gamma rays have traveled. Additionally, modeling can be used in conjunction with information obtained from the active gamma ray logging data, differential attenuation information, and gamma ray ratio data to obtain more information about the distribution of elements in the nonhomogeneous medium around the probehole.

2.2.3.5 Overall Usefulness of the Neutron-activated Spectral Gamma (n,γ) Logging Tool. The principal benefit of the active gamma ray logging tool was as an indicator of the distribution of chlorine within SDA buried waste. The n-gamma tool showed chlorine to be far more widespread and continuous between probeholes than was the case for radionuclide contamination. Although valid quantitative chlorine concentrations could not be obtained, the relative increase and decrease of the chlorine signal was found to correlate well with waste type VOC content as described in inventory records. The active gamma ray logging tool contributed significantly to the understanding of waste characteristics within the campaign areas.

2.2.4 Passive Neutron Logging Tool

The passive neutron logging tool used at the SDA employs a 5 × 30-cm (2 × 12-in.) He-3 detector. Passive neutron logging employs a thermal neutron detector (e.g., He-3) to detect neutrons emitted by spontaneous fission and alpha-neutron reactions initiated by the decay of TRU radionuclides within buried waste. At each measurement point, the passive neutron logging tool measures the gross neutron count rate. High neutron flux is interpreted to indicate the presence of elevated levels of TRU radionuclides, particularly Am-241 and plutonium isotopes.

2.2.4.1 Intended Purpose of the Passive Neutron Logging Tool. The purpose of the passive neutron logging tool was to qualitatively identify waste zones containing TRU radionuclides, particularly Am-241 and plutonium isotopes.

2.2.4.2 Success in Meeting the Purpose. The passive neutron logging tool was deployed in the SDA and successfully identified zones in the subsurface with neutron count rates above the identified background (as measured in the overburden). The presence of TRU radionuclides in the high neutron count-rate zones was correlated with the identification of specific TRU radionuclides by the passive gamma ray logging tool.

2.2.4.3 Effectiveness and Limitations Passive Neutron Logging Tool. The passive neutron probe was used strictly as a qualitative indicator of the presence of TRU-containing waste. As with the active spectral gamma ray logging tool, the passive neutron logging tool response is affected by the amount of neutron absorbers (e.g., chlorine) surrounding the probe at a given measurement depth. Depending on the activity of Am-241 or plutonium isotopes present, a modest amount of chlorine could absorb the neutrons being produced in the waste, thereby effectively shielding the passive neutron detector from the incident neutrons. The passive neutron detector also lacks the ability to discriminate between neutrons produced from interactions of the alpha particles from Am-241 or light nuclei from those produced by the spontaneous fission of Pu-240.

2.2.4.4 Quality of Data from the Passive Neutron Logging Tool. Data from the passive neutron logging tool were used to supplement data collected with other Type A logging tools.

2.2.4.5 Overall Usefulness of the Passive Neutron Logging Tool. Data from the passive neutron logging tool was used, in conjunction with data from the other Type A probe nuclear logging tools, to identify types of buried waste in target areas within the SDA.

2.2.5 Azimuthal Spectral Gamma Tool

The azimuthal spectral gamma tool consists of a 10% relative efficiency HPGe detector, fitted with a windowed, mild steel shield. After initial surveys at Pit 9, the azimuthal tool was refitted with an 18% relative efficiency HPGe detector and an alloyed tungsten shield to improve the directional sensitivity of the tool. Most gamma rays from buried waste are effectively blocked from reaching the detector by the shield; however, some gamma rays emitted from buried waste pass through the shield window and interact with the HPGe detector. Azimuthal gamma logging is performed by rotating the detector and shield assembly incrementally around the probehole at fixed depths and measuring a gamma spectrum at each azimuthal position. The tool permits differentiation between uniformly distributed radionuclides and radionuclides distributed as concentrated localized sources. In a typical azimuthal survey, measurements are initially obtained at 45-degree angular increments to identify the general source direction. Additional spectra are then obtained at intermediate angles to refine the source location. The azimuth of the highest gamma response indicates the direction of the localized gamma source.

2.2.5.1 Intended Purpose of the Azimuthal Spectral Gamma Tool. The purpose of the azimuthal spectral gamma tool was to qualitatively evaluate the angular distribution of radionuclides in the subsurface surrounding the Type A probes. The ability to determine the direction from which the radiation originates was identified as necessary information with regard to making decisions on the placement of Type B probes and other Type A probes.

2.2.5.2 Success in Meeting the Purpose. The azimuthal spectral gamma tool was used effectively during the logging campaigns at the SDA to identify the approximate location or distribution of radioactive material (at a given measurement depth) that had previously been identified by the passive gamma ray logging tool. The selection and placement of Type B probes was determined based on results of the azimuthal gamma ray measurements and in conjunction with data from the other Type A-probe nuclear logging tools.

2.2.5.3 Probe Effectiveness and Limitations. The azimuthal spectral gamma tool was invaluable in identifying the distribution of radionuclides surrounding the probes. In principle, the gamma rays incident upon the shield are blocked from reaching the detector, and the only gamma rays that reach the detector are those that come through the open gap or window. In reality, some of the gamma rays incident upon the shield actually do reach the detector; the amount of gamma rays doing this is dependent on the energy of the gamma rays, the material and density of the shield, and the thickness of the shield. The shield is more effective for lower energy gamma rays (e.g., those from U-235 and Pu-239) than it is for the higher energy gamma rays (e.g., those from Th-232 daughters, U-238 daughters, and Cs-137). Therefore, the ability of the tool to detect changes in distribution of the various radionuclides is dependent on the energy of the gamma rays emitted by the radionuclide.

2.2.5.4 Quality of Data from the Azimuthal Gamma Ray Logging Tool. The quality of the azimuthal gamma ray logging tool was significantly improved through implementation of the tungsten alloy shield. The improved directional sensitivity that resulted from the new shield provided project personnel with higher quality data upon which decisions were made for placement of additional Type A and Type B probes.

2.2.5.5 Overall Usefulness of the Azimuthal Gamma Ray Logging Tool. Data obtained from the azimuthal gamma ray logging tool was extremely useful in detailing the spatial distribution of radionuclides around the probeholes. Additionally, the significant utility of the azimuthal gamma ray logging tool was demonstrated during the decision-making process for the placement of Type B probes and additional Type A probes.

2.2.6 Lessons Learned from the Type A Probes

As stated previously, over 31,000 data points were collected by using the Type A probes during the WAG 7 Probing Project. This large amount of data, combined with the high degree of unknown heterogeneity of the buried waste, provided an opportunity to gain a significant amount of information about the buried waste and the underburden. Additionally, important lessons were learned during Type A probe data collection and analysis; the most significant are listed below:

- It is very important that high quality spectral analysis methods be used and that the data be qualified before the concentration values are used. Because of the complex nature of the gamma ray spectra obtained from logging of probeholes in pits at the SDA, multiple gamma rays should be used, where possible, to obtain detailed, qualitative information for a radionuclide. The data should be inspected for possible interferences to ensure that gamma ray count rates are used only after being properly corrected for interferences. For example, in regions with high Np-237 concentrations, a gamma ray from Pa-233 (the decay product of Np-237) will interfere with the prime gamma ray used for measuring plutonium. The resulting plutonium concentration—if based on only the one primary gamma ray, and if left uncorrected—will be erroneously high.

- It is very important that the n-gamma tool be calibrated for chlorine using a medium as close as possible to the one that will be encountered in probehole logging efforts. For example, using a brine solution (as was used to calibrate the current system) can lead to large errors, because the active volume seen by the gamma ray detector is different in brine solutions vs. soil and rock formations.

2.2.7 Overall Usefulness of the Type A Probes

Collectively, the nuclear logging tools were deployed in the SDA to obtain information about subsurface conditions at the SDA including obtaining qualitative data depicting waste types identified from waste inventory records, identifying areas with relatively high contamination levels (both radionuclides and VOCs) to locate Type B probes, and identifying target waste suitable for pilot remediation studies. To this end, specific information obtained from the subsurface data collected during the logging campaigns includes the following:

- Determining clearly delineated thicknesses of overburden, underburden, and waste-bearing zones.

- Identifying specific waste types (e.g., Pu-239-bearing graphite mold waste, Series 741 and 743 sludge, depleted uranium, and enriched uranium), based on measured characteristics of the radionuclide and elemental (i.e., chlorine) mixtures of the waste media. Results were consistent with waste profile information available from inventory records.

- Allowing, through Type A-probe nuclear logging, Type B probes to be placed into specific waste types of interest.

Although the Type A probes, and the tools employed therein, provided a large, high-quality data set, the data were primarily qualitative. Uncertainty associated with the heterogeneity of the waste zone overwhelmed attempts at quantitative estimates from the data sets (particularly the passive gamma ray and the n-gamma logging data), and required significant computational efforts (Jewell, Reber, and Hertzog 2002). As such, further attempts at obtaining definitive quantitative estimates of contaminant concentrations from the existing data sets are not recommended.

2.3 Type B Tensiometer Probes

2.3.1 Intended Purpose of the Tensiometer Probes

Tensiometers measure either the water potential of soil water in a porous medium under unsaturated conditions or the pressure head if saturated. Tensiometers were placed in locations to provide data on the moisture conditions within the waste zones, to quantify the amount and timing of moisture infiltration, and to define the presence and extent of any saturated conditions (Salomon 2004).

Sixty-six direct-push tensiometers were installed throughout the SDA in nested groups of three (see Appendix A). The upper group was placed near the overburden and upper waste contact; the middle group was placed in the upper third of the waste zone; and the lower group was placed at the underburden and waste contact, or immediately above the underlying basalt, as conditions allowed. In most instances, the tensiometers were paired with soil-moisture probes. Data generated by these instruments were collected on data loggers, typically taking measurements at 2-hour intervals.

The originally proposed tensiometer design (i.e., called the drive cone tensiometer and used successfully in nonwaste areas) was quite simple. It consisted of a drive tube with a porous tip on the base that was pushed into the ground; then, a pressure sensor was inserted to complete and activate it as a tensiometer. This tensiometer was designed for installation using a cone penetrometer rig using hydraulic push, without vibration or rotation. This instrument design was simple to construct, had no moving parts, and allowed versatility to permit different instrument "inserts" to be placed within the device, and thereby, to be used as either a tensiometer or a lysimeter.

As requirements for the probing project were developed, safety and radiation concerns developed about the materials that would be encountered during installation and subsequent operation of the tensiometers. A requirement stipulated that at least two isolation barriers be placed between the waste and the instrument at land surface, with the porous steel not being considered as an isolation barrier. This requirement necessitated substantial design modifications to the original drive cone tensiometer. The inner workings of the tensiometer were modified to include permanent valves, tubing, and sensors, producing a single-purpose, dedicated instrument for exclusively measuring water potential. Sonic drilling was chosen for installing the probes, requiring a more robust probe design to withstand the forces associated with being driven through waste materials. The tensiometer design was structurally tested and hardened to deal with the increased stresses of installation. This increased the design complexity, fabrication costs, and maintenance requirements of the tensiometer. The more complex design increased the time and cost required for construction. The instruments were delivered and placed in the SDA following field structural integrity tests. It was noted, during probe installation, that the greatest penetration resistance was observed within 0.6–0.6 m (2–3 ft) of land surface. At that point, the sonic vibration was discontinued, and the probes were then pushed to the total sampling depth.

2.3.2 Success in Meeting the Purpose

Overall, the tensiometers had limited success providing data on the moisture conditions within the waste zone, quantifying the timing of moisture infiltration, and defining the presence and extent of any saturated conditions. The small number of tensiometers that provided useable data limits the data; however, the operational instruments provide valuable data on the soil-water status within and beneath the waste. Several tensiometers provided data indicating the timing of moisture infiltration. None of the tensiometers indicated the formation of saturated conditions over the period of record.

Only 14 of 66 (i.e., 22%) of the instruments provided useable data over portions of the monitoring period. About 28 instruments (i.e., 42%) did not work at all, and the remaining instruments (i.e., 36%) may be functional but need additional testing. It is believed this is due, in part, to the consequences of using the sonic drilling technique, or because of dry conditions in the material being monitored that are outside the operating range of the instrument. This is discussed in greater detail in the following section.

2.3.3 Effectiveness and Limitations of the Tensiometer Probes

The working tensiometer probes were effective in obtaining the desired information. A combination of hydrologic, sonic drilling technique, maintenance, and operational factors has limited the effectiveness of these instruments. It is not possible to predict how many of the Type B tensiometers should be capable of providing water-potential data due to the site-specific field conditions that can effect their operation. These field conditions and other instrument limitations will be discussed in greater detail in this section.

Hydrologically, tensiometers operate over the "wet" range of water potentials that can be observed in the field. This tensiometric range is of greatest interest when investigating contaminant movement, because sediments have the highest vertical water flow rates over this range. From previous observations and measurements obtained between the pits, trenches, and SVRs in the SDA (Hubbell et al. 1985 and 1987, Laney et al. 1987), it was believed that the waste and surrounding sediment in many locations within the SDA are moist much of the year, and may become saturated during short time intervals because of infiltration events. The presence of moist conditions in and near the waste would promote episodic high flow events. The instruments were placed at locations immediately above, within, and below buried waste where no previous information was available on anticipated moisture content or water potential. If waste material and sediment do not have sufficiently high water potential or water content, the tensiometers will not provide quantitative data, but will provide only qualitative data that the sediments are too dry for the tensiometers to provide data.

Changing climatic conditions of the Site played a part in the availability of moisture for monitoring and sampling at the SDA. The INL is located in a high, cold desert that experiences significant variations in the timing and volume of precipitation. These tensiometers were installed and operated during a period of sustained drought, thus limiting the temporal availability of water throughout the subsurface.

Tensiometers also must have a hydraulic connection to a porous medium to produce representative data in a reasonable period. Voids in the waste material, the presence of nonaqueous-phase fluids or other substances at the monitoring location, the impact by the insertion method, or desiccation of the sediments from the ongoing drought (5 years) may limit the hydraulic connection to the material being monitored.

Sediments at the SDA are primarily fine-grained (e.g., loam); as such, sediments promote evapotranspiration (i.e., drying) to greater depths than coarse-grained material (e.g., sand and gravel). Sediments are typically driest near land surface and are progressively moister with increasing depth, so that tensiometers at the greatest depth have the highest probability of being located at sites with moisture conditions measurable with tensiometers. Tensiometers placed at depths or locations with water potentials lower than their range (e.g., too dry to operate) will provide data immediately following servicing that indicate (1) that the hydrologic conditions are beyond the operational range of tensiometers and (2) that this does not favor high vertical-flux rates over the period of observation.

The effectiveness of probes in obtaining data is also influenced by physical (e.g., mechanical) factors, instrument design, maintenance requirements, and ease of operation. Internal complexity of the tensiometers (i.e., required to meet the "double barrier" requirement) makes the instrument more likely to experience mechanical problems while increasing maintenance requirements. Complex operation of probes in the field, and limited immediate feedback while working on them, makes it difficult to determine the precise problem and to implement a solution to correct the problem.

High stresses during installation by the sonic drilling technique are suspected of having caused mechanical problems with sensors, tubing connections, and spool valves. Several sensors appear to have been damaged during installation by the sonic vibration, and other instruments had valves stuck in the open or closed positions. Some instruments also had electrical problems with wiring connections, possibly caused by the sonic vibrations, and initial data-logger problems and period-data dropouts.

2.3.4 Quality of Data from the Tensiometer Probes

Tensiometers measure water potential and gas pressure using high-precision, high-accuracy, absolute-pressure sensors. Field calibration checks were conducted on selected pressure sensors to validate that the pressure data from the sensors are accurate after installation. The range of water potential measurements from the 14 operational tensiometers is similar to that obtained from tensiometers in nonwaste areas. These data also had diagnostic pressure-response curves that indicate they were responding to the ambient water potentials in the surrounding sediments.

2.3.5 Overall Usefulness of the Tensiometer Probes

Data from the functioning tensiometers were useful in determining hydrologic characteristics of the sediment and waste material that previously were unattainable. These data provided a range of water-potential measurements from within and below the waste, indicating that the sediments were unsaturated during the period of tensiometer operation. Several tensiometers provided data on the timing of infiltration events at the measurement location.

Understanding why only a small number of instruments provided data has been a concern, and Section 2.3.4 discussed some potential reasons why many of the tensiometers have not provided useable data. Potential reasons for the low data-collection rate include both hydrologic and mechanical limitations that include (1) sediments too dry for tensiometer operation; (2) poor hydraulic contact between the membrane and material being monitored, so the instruments respond slowly or do not respond at all due to being in contact with low permeability waste materials; (3) damage to tensiometers during installation with the sonic drill technique; (4) improper installation; (5) difficulties in maintaining and servicing tensiometers; and (6) data collection and storage problems. The complex operation of the tensiometer, combined with challenging RWMC operational requirements, made it difficult to test and interpret data from the tensiometers.

These difficulties in keeping the tensiometers serviced and operational prompted development of the GEOPS as the next-generation probe. The GEOPS is a multifunctional sensor platform that can be installed by sonic drilling or the direct-push technique; it allows emplacement of several different sensors (inserts) to measure soil water potential (as a tensiometer) or to sample fluids (water or soil gas) (see Section 2.9), from the unsaturated sediments.

2.3.6 Lessons Learned from the Tensiometer Probes

Type B tensiometer probes provided valuable quantitative water-potential data from above, within, and below the waste. These data indicate that many of the monitored waste locations are within the tensiometeric range (i.e., the range where there is a higher potential for water and contaminant transport). Several probes provided data indicating increases in water potential over time, suggesting water infiltration at these locations. The tensiometers did not conclusively show that saturated conditions formed at any of the monitoring locations. The difficult geologic environment being measured, dry sediments due to low precipitation rates over the past 5 years, field maintenance requirements, and failure of instruments combined so that only 14 of 66 (i.e., 22%) of the instruments provided water potential measurements. Evaluation of the field calibration data, combined with field-testing, should indicate which instruments are functional, which are in dry sediments, and which should be abandoned. The success of the GEOPS lysimeters (see Section 2.9) indicates that the tensiometer insert for the GEOPS should be used when additional tensiometers are desired. If data were tracked more carefully, and servicing were limited to when it was absolutely required, some continuity could be restored. More communication is needed between data interpreters and field personnel. A more integrated approach will likely bring more of the Type B probes on line and generate more consistent and useable data.

2.4 Type B Lysimeter Probes

The Type B lysimeters are suction probes that have many physical and operational similarities to the Type B tensiometers installed at the SDA. Lysimeter probes collect soil-moisture samples through application of a partial vacuum to a porous stainless steel membrane that is in contact with soil. Lysimeter probes typically were installed in pairs using the following vertical horizon location guidance:

- In or just below the targeted waste for that area
- At the waste and underburden contact or at the contact with underlying basalt.

Eighteen Type B lysimeter probes were installed in 2001: 16 in Pits 4, 5, and 10, and two near SVR 12 (see Appendix A). The analytical suites for lysimeter samples are described in the *Field Sampling Plan for Monitoring Type B probes for the Operable Unit 7-13/14 Integrated Probing Project* (Salomon 2004). Samples collected from the pits were to be analyzed for a broad range of radionuclides, VOCs, nonradioactive metals, and other inorganic constituents, depending on available sample volume. Lysimeter samples collected near the SVRs were analyzed for a smaller suite of radionuclides to focus on those typically associated with activated metallic waste.

2.4.1 Intended Purpose of the Type B Lysimeter Probes

Type B lysimeter probes are intended to collect soil-moisture samples from two intervals; the first is within or below the targeted waste for a given area, and the second is at the waste and underburden contact or at the contact with underlying basalt. Pressure data obtained during lysimeter sampling also can provide data on the hydrologic characteristics of the media at the sampling interval.

Discussion on the Type B tensiometer design and subsequent modifications to allow their installation in waste at the SDA parallels development of the single-function lysimeter including the “double barrier” requirement. During the lysimeter development stage, one-way check valves were incorporated into the design to allow sampling to depths of about 7 m (23 ft).

2.4.2 Success in Meeting the Purpose

The Type B lysimeter probes did not yield many or large-quantity samples. Four of the 18 lysimeters (i.e., 22%) yielded small sample volumes (1–20 mL) immediately after installation; only two lysimeters (i.e., 11%) produced periodic small moisture-volume (5–20 mL) samples during subsequent sampling activities. Analysis for selected chemical constituents was possible, but the sample size limits the detection limits and the number of constituents that can be sampled.

2.4.3 Effectiveness and Limitations of the Type B Lysimeter Probes

The volume of fluid and the percentage of Type B lysimeters that yielded consistent fluid samples were low compared to those obtained from commercial ceramic or stainless steel samplers installed in drilled and backfilled wells. It is not possible to accurately predict how many Type B lysimeters should yield samples because of the site-specific field conditions. The Type B lysimeters function in a manner similar to the Type B tensiometers, so they have the same physical limitations: (1) requiring a good hydraulic connection to the sampled media and (2) sufficient moisture in the media to allow moisture to be drawn into the lysimeter through application of a partial vacuum in the lysimeter. These two factors probably limited the number of lysimeters that yielded fluid samples.

Instrument design, construction, and installation techniques of the lysimeter also will impact the sampling success. The overall design of the lysimeter was fully capable of collecting soil-water samples, once installed. A limitation on the design is the inclusion of a check valve, which prevents pressure from being applied to the porous membrane and diminishes sample backflow into the formation during sample collection. Without the check valve, the pressure used to push the sample to land surface will force fluid back into the formation and may displace water from the membrane, desaturating the membrane. However, inclusion of the check valve into the design does not permit the porous membranes to be rewetted following installation. Thus, if the membranes became desaturated following installation, then air flow through the membrane will prevent water-sample collection. Membranes will be rewetted only by the collection of perched water around the membrane or by water added from inside the sampler. The check valve prevents water flow into the membrane; therefore, it is not possible to restore the sampling capability of the device, once desaturated.

Some lysimeters may have been installed with the porous membranes not fully wetted at the time of installation; those lysimeters provided either very small or no samples. It is hypothesized that the sonic vibration during installation may have dislodged the water in the membrane pores (i.e., dewatering the membrane and allowing air flow), thus reducing sample sizes or preventing sample collection. Other instrument factors that affected the water-sample collection are fittings or connections within the lysimeter that were loosened or damaged by the sonic vibration, and leaks at connectors or crimped flexible tubing from the surface cap installation.

Subsurface conditions are also suspected of impacting the lysimeters. Lysimeters completed in waste zones may have been limited success because of poor hydraulic connection. The poor hydraulic connection could be related to voids, hydro-phobic waste or sludges that plugged the sampling ports.

This probe limitation for rewetting the porous membrane can be corrected in future installations by not using the lower check valve between the porous membrane and the upper water chamber. If this valve were removed, then water could be placed in the device from land surface to rewet the porous membrane. Alternately, the GEOPS can be used to collect samples by using the lysimeter insert. The GEOPS lysimeter insert allows rewetting of the membrane, does not subject the lysimeter's interior working to installation stresses, and permits replacement of any interior parts of the lysimeter that could impede sampling. Several GEOPS probes have been successfully deployed and sampled at the SDA (see Section 2.9). Subsurface conditions were minimized by using Type A data to locate subsurface zones with abundant soil, and quality could not be judged because lysimeters did not produce sufficient samples.

2.4.4 Quality of Data from the Type B Lysimeter Probes

The purpose of the Type B lysimeter probes is to yield representative water samples, of sufficient quantity over time, for chemical analysis. The samples collected (i.e., following initial sampling of the lysimeters to remove water introduced to the membrane during installation) should represent the quality of the soil moisture at the point of measurement. Chemical interactions may occur between devices and the samples; however, the literature provides no information, nor were tests performed to determine such interactions. The sample size and quantity of lysimeters yielding samples were less than anticipated.

2.4.5 Overall Usefulness of the Type B Lysimeter Probes and Recommendations

This generation of lysimeters has not been very effective in collecting samples due to the inability to rewet the instrument following installation and leaks or damage to the instrument from the stress of installation. The lysimeter pressure response during sampling can be used to indicate areas that are in the tensiometeric range, supplementing the tensiometer data. It is recommended that the GEOPS be used in subsequent deployments, because this design allows rewetting of the membrane, and the lysimeter insert is not subject to installation stresses.

Pressure response data from the Type B lysimeters should be compared to those from the GEOPS to determine why the Type B lysimeters did not obtain samples. If a noncontaminated lysimeter is decommissioned, it should be examined and tested to determine why it did not collect samples. If additional waste zone lysimeters are considered in the future, the proposed locations and depths should be evaluated by a vadose zone hydrologist so that the hydrologic factors can be optimized to increase the probability of obtaining samples. Then, once installed, the frequency and technique for sampling should be optimized using the pressure response data to ensure that the lysimeters are not over sampled. In addition, testing should be conducted to determine which installation method produces the best hydraulic connection to the sampled material.

2.4.6 Lessons Learned about the Type B Lysimeter Probes

Type B lysimeters provided small samples (less than 20 mL) from a limited number of monitoring locations (i.e., two lysimeters periodically and two sites, only, immediately following installation). This indicates that sediments are in the tensiometric range at these locations. Type B lysimeters have limitations similar to those discussed in the tensiometer section including the difficult geologic environment being measured, dry sediments due to low precipitation rates over the past 5 years, poor hydraulic connection, and instrument failures. As a result, these factors combined so that only 18 lysimeters (i.e., 22%) provided water samples. The success of the GEOPS lysimeters (see Section 2.9) indicates these samplers should be used in subsequent investigations.

2.5 Type B Soil-Moisture, Resistivity, and Temperature Probes

The SMR probes (see Footnote d) indirectly measure volumetric moisture content of the porous media surrounding the probe by using the relationship between the soil dielectric constant and the moisture content. The SMR probes also measure resistivity of the electrical contrasts between different geologic media and temperature of surrounding material.

The SMR probes are an off-the-shelf instrument manufactured by Applied Research Associates. The body of the instrument is made of 4340 carbon steel that has been heat-treated. A series of electrode rings, made of 304 stainless steel and located near the lower end of the instrument, is used to take the measurements. In Figure 3, the SMR probe is the third probe shown (entitled “Soil Moisture”).

2.5.1 Intended Purpose of the Soil-Moisture, Resistivity, and Temperature Probes

The SMR probes were intended for use in describing the following characteristics (Salomon 2004):

- Relative changes in moisture over time to corroborate and supplement water potential measurements from tensiometers

- Extent of infiltration to corroborate and supplement water potential measurements.

Ninety-five SMR sensors in 51 probes were pushed into the soil and waste at the RWMC (see Appendix A). The original 2001 network included 76 sensors, but was increased in 2004 to 95 sensors. Sixteen of the 95 sensors were subsequently abandoned either because of location or malfunction.

Installation targeted depths at the top of the waste, in the waste, and in sediment below the waste. To monitor each of the targeted locations, probes were generally stacked as shown in Figure 8. The objective for stacking the probes was to monitor infiltrating water that might move through the waste and potentially transport contaminants into the vadose zone.

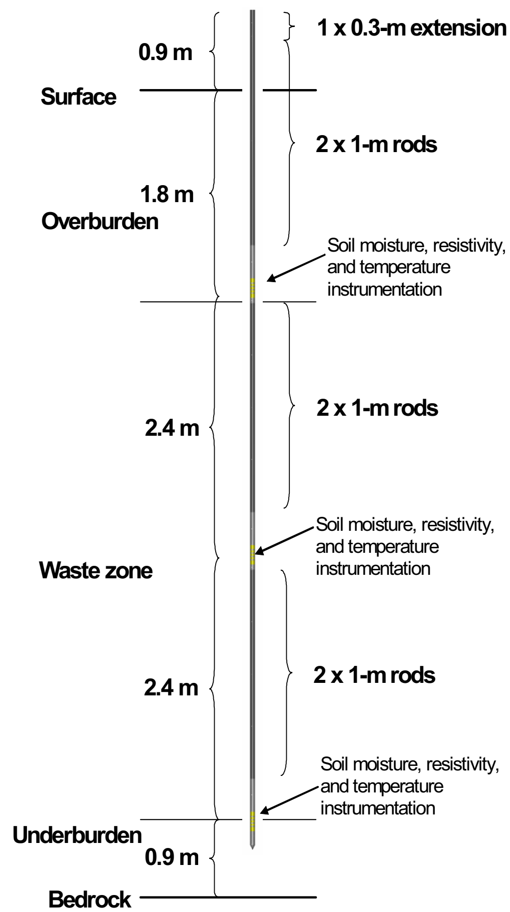

Figure 8. Stacked probe configuration.

Generally, the SMR probe installations were paired with Type B tensiometer probe installations. The purpose for pairing the instrument types was to verify moisture measurements. Moisture content (SMR data) and water potential (tensiometer data) are related (e.g., when the moisture content approaches

100%, water potential moves toward zero). Additionally, with field measurements of moisture and water potential in the same location, provided there is sufficient fluctuation in moisture range, a field moisture characteristic curve can be developed and used in transport modeling to decrease modeling uncertainty. Because of instrument malfunctions (generally the Type B tensiometer), paired measurements were available at only one location, and monitoring at this location was discontinued in 2004 to accommodate the Accelerated Retrieval Project in Pit 4. However, Type B tensiometer and SMR data from 2003 indicated that a wetting front had moved through the soil and waste in that area.

2.5.2 Success in Meeting the Purpose

Over two-thirds of the SMR probes are providing data, with some clearly indicating infiltration. Most infiltration at the SDA results from snowmelt in the early spring when little or no evapotranspiration occurs. Infiltration in the subsurface is usually observed from March through June.

The amount of precipitation and frozen ground under snowmelt influence the amount of infiltration that reaches the subsurface.

In the years since the SMR probes were installed (i.e., 2001), precipitation has been slight—in most years, less than half the long-term average of 21.6 cm (8.5 in.) per year. Even so, if the snowmelt occurs over frozen ground, causing the melt water to redistribute to low areas in the SDA (e.g., along roadway ditches), deep infiltration can occur in those areas even though precipitation is slight. In that case, only those probes located near water-accumulation areas are likely to show infiltration, even though all of the probes might be working.

2.5.3 Effectiveness and Limitations of the Soil-Moisture, Resistivity, and Temperature Probes

Most of the SMR probes are effective in providing moisture data. When a wetting front moves past the SMR probe, the probe tracks the gradual increase in moisture followed by the decline in moisture, indicating the passing of the wetting front. In addition to moisture measurements, soil temperature and resistivity also are measured.

The SMR probes are collecting reliable and continuous moisture data in the surficial soil at the SDA. This alone makes them very important. In addition, the Fiscal Year (FY) 2004 data indicate that several SMR probes may be tracking nonconductive fluid movement in the waste. Of the few limitations inherent with the SMR probes, none are insurmountable.

One of the biggest limitations of moisture data results from the probes not being calibrated to SDA waste. However, no way is currently available by which probes may be calibrated to the waste, because of waste heterogeneity. This results in qualitative measurements in the waste zones. When placed near conductive material, the measurement typically is exaggerated, yielding moisture measurements as high as 100% in these zones. The probes were calibrated to the moisture extremes of air and water; this calibration is sufficient to provide quantitative data from soil.

A limitation found in some probes (roughly half) on moisture and potentially resistivity data is the impact of temperature on the measurements. Whether the temperature is surface air temperature or soil temperature is uncertain. Data suggest that soil temperature may be responsible, because probes at different depths show a highly damped amplitude attenuation and phase lag as a function of depth, and the direct current component approaches the ambient ground temperature as a function of depth. Another hypothesized alternative is that the probe casing conducts surface air temperatures down to the probe electronics. The casing typically extends above the land surface 0.3–1.2 m (1–4 ft) (see Figure 4), where it is heated or cooled by surface temperatures. However, temperature impacts on the casing have ample opportunity for equilibrating conduction with the soil column above the electronics.

Removing temperature impacts is usually done by applying a correction equation to the data. In this case, developing an equation is more difficult because of the quadric (nonlinear) nature of the data and the existing temperature-moisture correlation. Applied Research Associates conducted laboratory tests using the SMR probe to determine the relationship between moisture and temperature. From that information, a general equation was developed that removes the influence of surface air temperature. Because the equation requires unique slopes and intercepts for each probe, Applied Research Associates is continuing to develop the information. Currently, the equation, along with slope and intercept information, has been developed for 11 of the probes. Applied Research Associates is expected to supply slope and intercept data for the remainder of the probes that are sensitive to temperature.

Once data are processed through the temperature-correction equation, some of the seasonal curve will be removed; however, the trend line may not be flat, because statistically, there appears to be some correlation between moisture and temperature.

One of the probes may be experiencing another type of limitation. The probe shaft may be providing a conduit for preferential flow into the subsurface. This may have been caused by the lateral component of sonic vibration as the probe was pushed into the ground.

An Excel macro program was built to aid in processing the moisture data, decreasing the time needed to process the data. Using this program, data are processed in minutes rather than hours. The program is so effective that it is being adapted to process tensiometer data.

2.5.4 Quality of Data from the Soil-Moisture, Resistivity, and Temperature Probes

Data loggers are programmed to read processed SMR probe data on a 2-hour basis. The SMR data include both raw and processed measurements. Calibration equations are applied directly to the processed data. One purpose for collecting the raw data is to improve data quality. During the reprogramming of data loggers to collect raw data, some of the original programming appeared to be in error; this may have impacted some of the data collected earlier.

Data quality was improved by collecting raw data (e.g., data before processing equations are applied). Applied Research Associates representatives recommended that the dataloggers be programmed to collect reference data, because the reference data can be used as an indicator of the functionality of the probe. This is being done and is expected to improve data quality.

Eleven SMR datasets were processed to remove the temperature impacts. Equations for the rest of the temperature-sensitive probes will be applied when they become available. When equations are applied to the data, most SMR probes will yield excellent field-quality data, and this can be made retroactive to much of the old data.

Moisture data collected by the SMR probes provide quantitative data (soil zones) and qualitative data (waste zones) that is most valuable for detecting trends in the moisture content and developing preremediation baseline conditions. Current data analyses also suggest that the probes are capable of providing data on the movement of fluids within the waste.

2.5.5 Overall Usefulness of the Soil-Moisture, Resistivity, and Temperature Probes

The SMR probes are very useful and should be maintained. Even with the limitations and dry SDA conditions, these probes are identifying areas where infiltration is and is not occurring. The data clearly show the timing of and relative size of each event. At present, the SMR probes provide the only reliably continuous moisture data currently being collected in the surficial soils. The SMR network is large enough to monitor much of the SDA.

The SMR probe data are used to model infiltration through the waste and can be used to complete the RWMC infiltration model.

Usefulness of the SMR data is limited not only to detecting moisture changes in the sediment and waste, but also in providing valuable information on RWMC hydrology and documenting changes over time.

2.5.6 Lessons Learned from the Soil-Moisture, Resistivity, and Temperature Probes

Lessons learned from using the SMR probes include those listed below:

- Collecting raw data is extremely important for verification and quality assurance (QA) and quality control purposes

- Collecting reference data (i.e., diagnostic) is important in some data interpretation

- Instruments should be tested for temperature sensitivity before being installed in soil or waste.

2.5.7 Recommendations

Recommendations include the following:

- Whether the temperature effect on some of the SMR probes occurs because the casing serves as a conductor of surface temperature or from simple soil-temperature variations is unknown. The only way to be confident that the probe is short-circuiting surface temperature conduction to depth is to either model or experimentally evaluate the dynamic heat transfer. Such an experiment might include selecting probes in proximity to each other whose temperature behaviors with depth are comparable. One probe would be isolated, while maintaining control of the surface temperature of the above ground portion. The other probe would be allowed to respond to the natural environment. The results would be compared over a given time period.

- Apply a granular bentonite seal around surface expressions of the casing to keep holes from becoming conduits.

2.6 Type B Vapor Probes

Commercially available vapor ports were combined with Type B probes and installed to collect soil gas from waste zones and the area surrounding SVRs in the SDA. Vapor ports in the VOC source areas usually were bundled in threes and installed, generally, at the following three vertical horizons:

- Just below the overburden and waste contact

- Middle of the waste zone or in close proximity to a desired source in the waste

- Slightly above the waste and underburden contact.

Thirty vapor port probes were installed in the SDA (see Appendix A). Ten vapor port probes were installed in the Organic Sludge Focus Area, and seven vapor port probes were installed in the Depleted Uranium Focus Area (see Appendix A). Thirteen vapor port probes were installed near activated metal sources located in SVRs 12 and 20. Samples were analyzed in accordance with the Type B Probe Field Sampling Plan (FSP) (Salomon 2004). All samples from the VOC source areas were analyzed for VOCs, and some were analyzed to evaluate subsurface oxidation-reduction (redox) conditions by assessing oxygen, hydrogen, methane, and carbon dioxide. Samples collected from vapor probes near the SVRs were analyzed for C-14. Samples collected at SVR 20 were also analyzed for tritium.

2.6.1 Intended Purpose of the Type B Vapor Probes

Primary purposes of the Type B vapor probes included:

- Substantiating the nature and location of the VOC source and assisting in estimating the remaining VOC mass

- Determining trends in the rate of VOC release from the source

- Assessing redox conditions in the pits for transport and transformation potential

- Estimating form and release rate of C-14 from SVR waste.

Type B vapor probes were not intended to provide a quantitative estimate of remaining VOC mass. Chlorine data from the Type A neutron-gamma probe were believed to have the best potential for estimating the VOC mass. Nevertheless, Type B vapor probes were meant to provide additional information about waste-form and release-rate trends that could assist estimation of the VOC mass. Vapor probes near SVR waste were intended to provide C-14 concentration data at several depths and distances from the buried beryllium. These data were to be used to calibrate a model of the release and subsurface migration of C-14 from activated steel (SVR 12) and activated beryllium (SVR 20). Based on descriptions of disposals at SVR 12 (Salomon 2004) and SVR 20 (Ritter and McElroy 1999), the source environments near these disposals contain very little organic material; therefore, C-14 is likely to be released from these sources as carbon dioxide.

2.6.2 Success in Meeting the Purpose

Type B vapor probes were moderately successful at meeting the objectives. Data from the probes helped confirm VOC source-area locations and helped confirm the veracity of disposal records and other assumptions used to estimate the source mass. For example, Miller and Varvel (2001) used disposal records and other information to split Series 743 drums into two populations, the difference being the percentage of carbon tetrachloride vs. the other VOCs (i.e., TCE, PCE, and 1,1,1-TCA). Data support the theory that the drums with the higher percentage of carbon tetrachloride were buried almost exclusively in the Series 743 Focus Area, and the other drums were buried in the Depleted Uranium Focus Area.

The VOC probe data also were helpful in characterizing the nature of the waste and some of the containment. Vapor concentrations at some locations were high enough to suggest that at least some of the sludge was relatively “fresh” or recently exposed. The concentrations were near the saturated vapor concentration predicted for the sludge mixture (Myers et al. 2004). Because the VOCs diffuse through and escape the sludge matrix relatively rapidly (months to a few years) (Lowe et al. 2003), it is believed that the high concentrations of VOCs, are the result of sludge that was only recently exposed. The waste exposure easily could have been the result of probe insertion through a drum or intact bag. This information is consistent with an observation of sludge in a bag unearthed during excavation for the OU 7-10 Glovebox Excavator Method Project. During that excavation, an intact bag believed to contain Series 743 sludge was opened, and the sludge surface had a sheen reminiscent of oil. After several minutes, the sheen was no longer visible, and the surface appeared to be drying.

Type B vapor probes did not establish a temporal trend in the VOC release rate. During FY 2002 and part of FY 2003, the concentrations remained essentially the same (flat trend) or decreased slightly. However, the data then became suspect due to a lack of agreement between the results of field samples (analyzed with the portable INNOVA photoacoustic analyzer) and the results of confirmatory laboratory samples (analyzed using gas chromatography and mass spectroscopy). In general, the field sample results remained largely the same (flat to slight decrease), while the laboratory results showed a significant decrease in concentration. Although there was confidence in the early results, the time period was not long enough to establish a baseline or any meaningful long-term temporal trends. In addition, discrepancy in the data has not been fully resolved.

Type B vapor probe data were successful in assessing redox conditions in the pits by measuring redox gas concentrations (i.e., oxygen, hydrogen, methane, and carbon dioxide). Destruction of carbon tetrachloride is facilitated by the presence of hydrogen gas as an electron donor. Hydrogen gas has been detected in probes in the Series 743 Focus Area. This provides a mechanism for the transformation of carbon tetrachloride and chloroform to less toxic compounds.

Methane and hydrogen gas in the Series 743 Focus Area indicates areas of reducing conditions in the pit. Actinide elements are significantly less soluble under reduced conditions (i.e., in the +IV valence state) than in the presence of oxygen (i.e., more likely to be present in the +V or +VI valence state). Measurement of the redox gases provides a relatively simple and inexpensive means of indirectly determining the oxidation state of the buried waste. Although the redox gas data were useful for assessing geochemical conditions, additional and better quality data are necessary for quantifying the impacts.

The original plan for the SVR 20 Type B vapor ports called for installation of five sets of three probes (one port per probe), spaced at 0.9-m (3-ft) intervals beginning 2.1 m (7 ft) from the perimeter of the soil vault containing activated beryllium. Four probes were installed—a set of three located 0.9 m (10 ft) from the soil vault (i.e., SVR 20-3-VP1, 2, and 3) and a single probe installed 4.9 m (16 ft) from the soil vault at a depth of 5.1 m (17 ft) (i.e., SVR 20-5-VP3). Only SVR 20-5-VP3 yielded a sample of sufficient volume for C-14 analysis; none of the Type B probes at SVR 20 were sufficiently permeable to be used for H-3 sampling.

The results of C-14 measurements from SVR 20-5-VP3 were of limited use for modeling (Nalla 2004) when combined with data from gas sampling ports installed in an augured hole (GSP-1) (Ritter and McElroy 1999) near the beryllium. Measurements at a range of distances would have provided a better basis for model development. Tritium concentration data also would have been helpful.

Three sets of three Type B probes were installed near activated steel buried in SVR 12. Eight of the nine probes yielded useful samples for C-14 analysis. Carbon-14 was measured at very low concentration in soil near the activated steel. These results were not used for model development. Based on model studies (Nalla 2004) and column studies, C-14 is expected to be very mobile in soil, especially if vapor-phase transport occurs. It is possible that the C-14 measured at SVR 12 originated from relatively nearby disposals of activated beryllium. The beryllium was grouted in 2004, and it is expected that the release rate of C-14 from the beryllium will be sharply reduced. Further measurements will be performed using the three remaining Type B probes (six were removed for grading operations) to determine whether C-14 concentration measurements at SVR 12 were substantially affected by releases from nearby beryllium. Data from SVR 12 probably could be used for model development if the true source of the C-14 is identified.

2.6.3 Effectiveness and Limitations of the Type B Vapor Probes

Eight of the 16 VOC probes and 10 of the 13 SVR probes yielded a sample more than 50% of the time. Some yielded a sample nearly all of the time while others would occasionally yield a sample, which indicates obtaining a sample was dependent upon a transient phenomenon (e.g., moisture content). Probes that did not yield a sample probably were damaged during installation or placed directly into sludge.

The Type B probe FSP (Salomon 2004) called for continuous collection of tritium samples from the probes at SVR 20. None of the SVR 20 probes were free-flowing (three of four yielded no sample, even when pumped at 1–2 psia), and the SVR 12 probes generally were not as free-flowing as desired. Neither the original H-3 sampling equipment for SVR 20 or the more powerful grab-sampling equipment used for other vapor port sampling at SVR 20 was usable, because the pumps could not maintain the required flow against the resistance. In general, the resistance to flow through the vapor ports should be as small as possible (e.g., greater than 1/10 psi at 1-L/minute flow) to reduce the possibility of significant leakage across connections in the sampling system.

2.6.4 Quality of Data from the Type B Vapor Probes

The quality of VOC data from Type B vapor probes was suspect until the third quarter of FY 2002 when the laboratory that performed analysis on the confirmation samples was switched from an off-Site laboratory to the Environmental Chemistry Laboratory (ECL) at the INL. During that quarter, several samples were taken in both Tedlar bags and SUMMA canisters and were analyzed using both the portable INNOVA photoacoustic analyzer and the gas chromatography and mass spectroscopy at ECL. Agreement between the two analysis methods was very good, prompting continued use of ECL for future analysis. However, after four quarters of relatively good agreement between INNOVA results and ECL results, a discrepancy occurred again. The INNOVA has sent back to the vendor twice for recalibration, but the difference in results continued and is presently not resolved.

Many of the data gathered to assess redox conditions were deemed unusable or questionable because of faulty dilution procedures or implausible results. Most of the problem data came from oxygen and carbon dioxide analyses performed by an off-Site contract laboratory. For example, several samples analyzed for oxygen were rejected because numerous results were well above 210,000 ppmv (21%). The quality of the hydrogen and methane data from ECL is good, but the usefulness was limited without information on the other gases.

The quality of C-14 data from soil-gas samples has been evaluated using replicate measurements and from the counting statistics of individual samples. Replicate samples (n = 6) taken in 2002 from SVR 20, which has relatively high C-14 concentrations, indicate that the overall precision (natural variability plus analytical uncertainty) is near 2% (relative error) for measurements of C-14 specific activity (i.e., activity of C-14 per unit mass of carbon in the sample). The relative error of C-14 volume-concentration (i.e., activity of C-14 per unit gas-sample volume) measurements for the same samples was 18%. Removing the results for the first sample from the set (n = 5) reduced the relative error to 8%, suggesting that the precision of the C-14 volume concentration measurement is improved by longer purge times. The C-14 volume concentration measured in three sets of field replicate samples taken from SVR 20 in 2004 had relative percent differences of 20, 7, and 9% (counting uncertainties all less than or equal to 1.5%). Standard C-14 material from the INL quality control laboratory (i.e., Idaho Nuclear Technology Engineering Center) was used in a spiked matrix sample to determine counting efficiency. Overall, the quality of the C-14 data is acceptable for the purpose of detecting trends in concentration and to assess contaminant release.

2.6.5 Overall Usefulness of the Type B Vapor Probes

The Type B vapor probes were very successful in meeting several project objectives. Objectives not met are the result of data quality and data quantity issues not related to the probes; rather, objectives not met relate to analysis methods. Usefulness of the probes could be improved with better quality data for VOCs and some redox gases and data collected over a longer time period. Better and longer-term data would allow for a more quantitative assessment with increased certainty.

Type B vapor probes installed at SVR 12 were successful for C-14 sampling. The Type B probe FSP called for installation of 15 probes at SVR 20 in a range of depths and distances from the buried beryllium, to develop a data set with better spatial coverage for model benchmarking and validation. Four probes were installed, but three of the four failed. The reason for the large percentage of failures at SVR 20 is not clear, but could be the result of mechanical failure of the sample-transport lines within the probes (e.g., pinched off) or plugging of the inlets by impermeable clay. Restriction of flow through the probes is a particularly serious problem for H-3 sampling, which requires a relatively large sample volume. Carbon-14 sampling requires a smaller sample volume; however, if a large pressure differential is required to collect a sample in a reasonable length of time, the potential for leaks into the sampling train is increased. The Type B vapor probes are promising, but there is room for improvement in the rate of successful (i.e., free-flowing) installations.

2.6.6 Lessons Learned from the Type B Vapor Probes

Information from the Type B vapor probes was helpful in characterizing VOC waste and in verifying certain assumptions and details used to estimate the mass and location of the VOC source. It is likely that this information could not have been obtained by any means other than direct investigation of the waste; in which case, the costs and risks would be significantly higher. The probes were also instrumental in helping establish redox conditions in the waste.

Unfortunately, the probing was not as successful as had been anticipated. First, several of the probes were nonfunctional (i.e., did not yield a sample), and the cause was never determined. Even some of the SVR probes that did yield samples were not sufficiently free-flowing for tritium sampling, which requires large sample volumes. It is recommended that testing of probes be performed in a controlled environment to determine whether a design flaw, the installation method, subsurface conditions, or some combination of the three, caused so many of the probes to not function. Another reason the probing was not as successful as originally planned was that the primary analysis method for VOCs was unreliable. Frequent discrepancies in the results between the INNOVA and the gas chromatography and mass spectroscopy method, and poor quantification of standard gases by the INNOVA, made it impossible to determine trends in release rate. However, even with higher quality data from the INNOVA, it appears that a longer period of time (5–10 years) may be required to establish trends, because of the seasonal fluctuations indicated by the data.

2.7 Type B Visual Probes

Ten Type B visual probes were installed to allow physical observation of the soil overburden and waste zone. Visual probes are transparent polycarbonate tubes reinforced with an internal steel cage. A miniature video camera can be lowered through this type of probe to visually observe the waste and subsurface conditions. The videos are interpreted by personnel familiar with historical waste-generating processes (e.g., the RFP and historical waste-disposal operations at RWMC). Visual probe video logs were used in conjunction with other probing data to evaluate conditions in the waste zone.

Video logs improved with each deployment of the video camera. The format and output from the last downhole camera run was extremely useful. The previous software output was captured on video home system tapes, and camera results can only be witnessed on a video cassette recorder. The latest software actually used the captured video to produce the view folded out into a 360-degree, printable, flat spread. The new format expanded the viewing capabilities for analysis and expedited interpretation of the videos.

2.7.1 Intended Purpose of the Type B Visual Probes

The requirements and intended purpose for the Type B visual probes were defined as follows (INL 2003):

- Ensure the outer shell is transparent, with the objective of having visual inspection capability downhole.

- Obtain photographic views of the soil and waste.

- Ensure sufficient space to enable a 3.8-cm (1.5-in.) outside-diameter (OD) camera to move within the casing.

- Ensure the capability to provide visual confirmation of waste zone interfaces, of conditions within the waste zone, of coloration clues to waste-form status, and of moisture conditions. Visual inspection would help in interpreting results of the data and sample analysis and in assessing validity of measurements and samples collected.

- Ensure the design has a 50% survival rate (i.e., the outer shell shall be transparent) for the first month.

2.7.2 Success in Meeting the Purpose

All requirements defined in the *Technical and Functional Requirements for the OU 7-13/14 Probing Project Type B Probes* (INL 2003), except maintaining a leak-tight barrier, were met with the installed visual-probe system. The survival rate was actually 100%, considering that none of the probes were scarred enough to prevent the camera from capturing downhole images.

2.7.3 Effectiveness and Limitations of the Type B Visual Probes

The Type B visual probe was extremely effective in meeting all requirements. According to the *Ancillary Basis for Risk Analysis of the Subsurface Disposal Area* (Holdren et al. 2002), use of the visual probe enabled identification of the following parameters in the buried waste:

- Location of the top and bottom of the overburden and underlying sediment
- Thickness of sediment beneath the waste
- Relative grain size of the geologic media (e.g., cobbles, pebbles, sand, silt, and clay) next to the probe
- Stratification in the sediment beneath the waste or disturbance in the sediment

- Color of sediment beneath the waste for redox indication
- Amount of sediment vs. waste adjacent to the tube in the waste zone
- Visual indication of moisture movement
- Evidence of how tightly the tube is sealing
- Condition of the drums
- Void spaces caused by drum placement or lack of material
- Presence of cellulose material (e.g., boxes, wood, or paper)
- Identification of waste forms (e.g., sludge, graphite, combustibles, nitrate salts, or noncombustibles).

Limitations of the visual probes were that some of the seals were hard to maintain, the polycarbonate material scratched easily, the polycarbonate material became opaque in the presence of VOCs, and the internal carbon steel cage corroded heavily.

2.7.4 Quality of Data and Overall Usefulness of the Type B Visual Probes

As defined in Section 1.1.2, the quality of the data exceeded all requirements. Images of the cover material and buried waste were invaluable in understanding logging data, anticipating waste forms for retrieval and treatment, and in planning retrieval activities. The OU 7-10 Project reported that smaller, more efficient gloveboxes were planned and used for that retrieval project as a direct result of examining video images of the waste zone produced by the visual probes.

2.7.5 Lessons Learned from the Type B Visual Probes

During installation of Type B visual probes into the subsurface, each 1.2 m (4-ft) section was required to hold 5 psi of pressure for 5 minutes before the next section was installed. This precaution would identify any possible breach of the transparent polycarbonate sections before opening the system for additional sections. Some of the sections would not hold pressure after being installed. A second procedure was approved, which allowed a camera run in probes that did not hold pressure—only if, after an internal contamination smear, no contamination was present. In no case was internal contamination discovered on any of the sections not holding pressure, and camera runs were made in all probes.

Sealing problems stemmed from inconsistent cleaning and fabrication methods. An outside subcontractor built all the tensiometers and lysimeters, and visual probes built by the Idaho Cleanup Project. Idaho Cleanup Project work was split between three on-Site machine and welding shops. Valuable lessons were learned about flaws and inconsistencies between manufacturers of the visual probes. The following recommendations for inspections and design changes should be considered before more visual probes are manufactured:

- Perform QA inspection on cleaning of components and assemblies to ensure that solvents identified on drawings are used, and approved methods are followed.
- Perform QA inspection on polycarbonate tube and internal frame interface dimensions.
- Perform QA pressure test on final assembled probe casing segments before probes leave the shop.
- Reduce size of plug welds on bottom hub to relieve potential heat warping on the internal rods.

- Specify (by subassembly or general note) that interiors of frame rods be welded first, followed by the exteriors, so that excessive warping of rods (or fit-up over the internal frame) is controlled more uniformly. Existing probes showed inconsistency between welders and welding techniques; some welders used a random pattern of welds that caused excessive warping of rods.

- Perform all work using only one shop. Also, select a shop that is customer-oriented and has an ownership element. Working with three shops provided an atmosphere of finger pointing when flaws were discovered, and that was unfortunate.

The Type B visual probe is a great design; based on the mock-up results, it should have performed brilliantly. However, some sections did not maintain the pressure seal, because the Idaho Nuclear Technology Engineering Center shop used an ammonia-based window cleaner to clean out the polycarbonate sections instead of water, as directed in the cleaning notes. The Viton O-rings were chemically affected by the ammonia, which caused them to quickly lose their sealing characteristics. Once the seal was broken, water seeped into the installed probes and corroded the internal framework. The internal framework was not built with stainless steel, because the frame was not supposed to be exposed to moisture. If water had been used to clean the sections, the O-rings would not have failed.

The polycarbonate sections of one of the visual probes got so hot from the sonic drill operation that it melted slightly (based on the camera results) while going through the hard pan. The solution to this problem would be to build the visual probe with a smaller OD. In retrospect, one requirement was that the probe be designed for a 3.8-cm (1.5-in.) OD camera. Current technology provides for much smaller camera equipment. And if the probe OD were reduced, the probe could enter the ground much more easily.

2.8 Type B Geochemical Probes

2.8.1 Intended Purpose of the Type B Geochemical Probes

The Type B geochemical probes, also referred to as the redox potential/pH probes, were intended to measure soil characteristics including the redox potential, pH, and temperature. Redox and pH data indicate the likelihood of dissolved contaminants remaining dissolved or undergoing a chemical reaction that would cause binding or bonding with the soil or rock matrix. The soil temperature was required for moisture calculation in support of tritium analysis and vapor-transport studies.

2.8.2 Success in Meeting the Purpose

Two prototype geochemical probes were ordered. These probes were not off-the-shelf components and had to be developed. Existing probes were modified by the manufacturer to house the necessary electronics (see Figure 9). The prototypes were produced at a cost of $15,000 each.

To operate, these probes require complete saturation of the soil. However, in the vadose zone, complete saturation occurs only briefly, following snow melt or moisture from an occasional very heavy rainfall passing through on the way to the aquifer. Also, to bring the water into the probe sample chamber, personnel must be present to apply a vacuum. Therefore, constant data logging would not have been possible, and the only way to obtain readings would have been for an operator to respond at just the right time, applying the vacuum and taking readings while the waterfront was collocated with the probe port. Furthermore, applying a vacuum can change the pH conditions, depending on how it is applied.

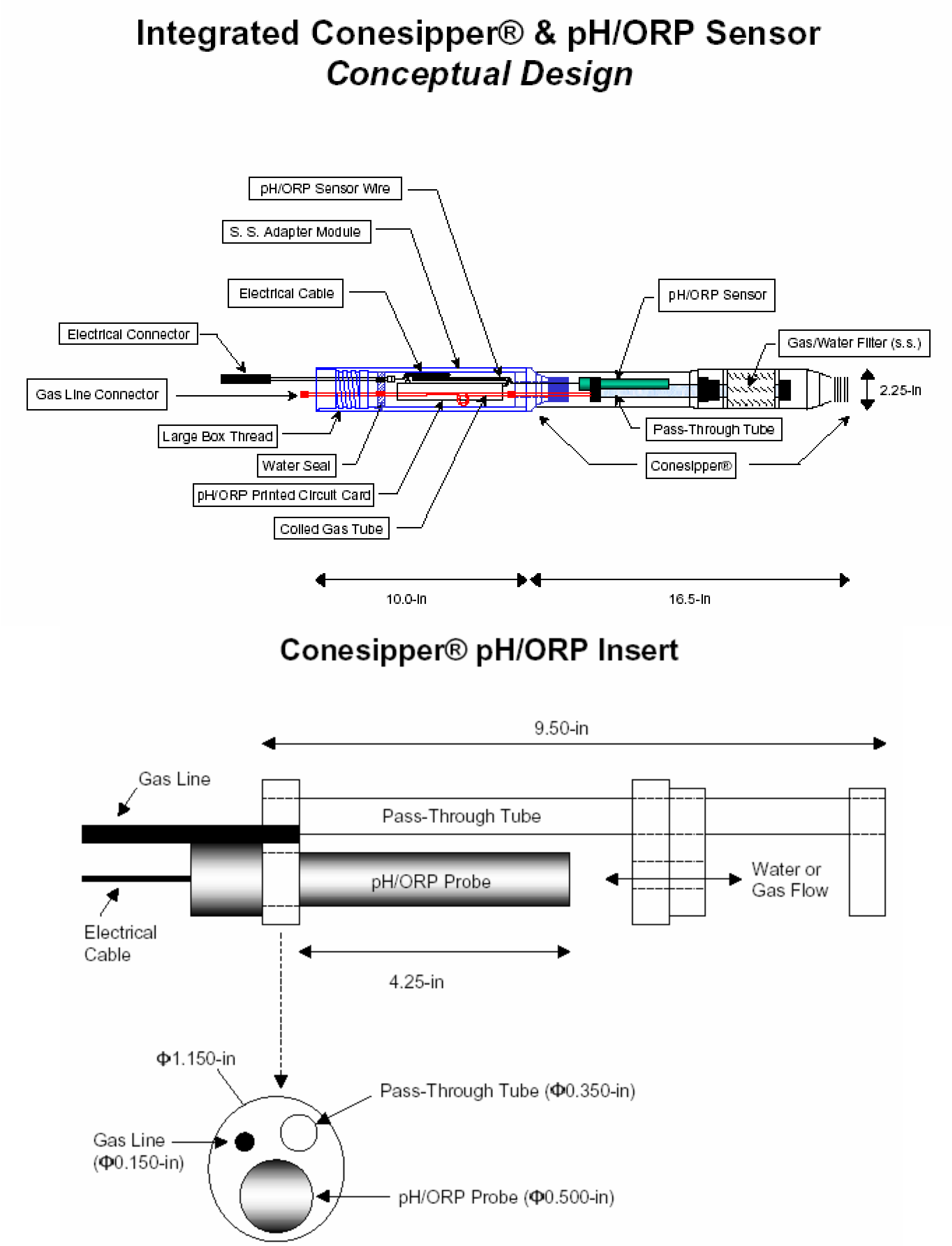

Figure 9. Modified Type B vapor port geochemical probes.

One of the prototypes was installed in Cold Test Pit-South in May 2001, and hundreds of gallons of water were poured down an adjacent hole in an attempt to saturate the soil. However, the vacuum was not applied when the conditions were ideal. This served to highlight the difficulties that such a probe and associated sampling requirements would present. It was determined that the small likelihood of regularly collecting useable data did not justify the continued research of these probes, and further work was cancelled.

2.8.3 Effectiveness and Limitations of the Type B Geochemical Probes

See Section 2.8.2.

2.8.4 Quality of Data from the Type B Geochemical Probes

See Section 2.8.2.

2.8.5 Overall Usefulness of the Type B Geochemical Probes

See Section 2.8.2.

2.8.6 Lessons Learned from the Type B Geochemical Probes

The geochemical probe was not readily available and required extensive testing. The geochemical probe also required unique, fully saturated vadose zone conditions that were not possible in the arid desert of Idaho. Finally, data collection would require operators in the field to monitor for optimal conditions, which was not feasible at the project level.

2.9 Geological and Environmental Probe System Probe

The GEOPS probe was designed to address deficiencies in the Type B probes. The main advantage is that the probe casing for the GEOPS is designed to be driven into place with a sonic drill, and then monitoring tools are installed by hand into the casing. Like the Type B probes, it is not necessary to predrill a borehole to install borehole casings or pull samples. The installation technique for GEOPS can place the probes within or directly below a buried waste zone, bringing no cuttings to the surface, and thereby eliminating any risk of personnel exposure from downhole contamination. The potential for damaging sensors or sampling equipment using the direct-push or direct-driven in situ installation techniques is avoided. The GEOPS probe casing also allows different tools to be inserted into the same casing, reducing casing and installation costs and increasing data comparability, because all data can be collected from the same location.

Lysimeters, tensiometers, and vapor ports are designed to fit into the GEOPS probes. This allows for monitoring soil-moisture conditions and for the collection of liquid and gas samples from the waste zone.

2.9.1 Intended Purpose of the Geological and Environmental Probe System Probe

The GEOPS probe was designed to address several problems with existing methods for installing in situ sampling instruments. Standard boring techniques have the potential to bring contaminants to the surface with drill cuttings. Commercial monitoring instruments often require an initial bored hole, where the delicate instruments are placed, and then the hole is backfilled with cuttings or clean material. This technique alters the subsurface conditions adjacent to the instruments and often damages the instruments before any data can be collected. Once such instruments are installed, if the instrument fails, another bore hole must be completed for another instrument, substantially increasing monitoring costs. Other commercial direct-push or driven techniques also pose a high risk of damaging the single-purpose instruments during installation.

The GEOPS addresses the problems by (1) eliminating contaminants brought to the surface during installation, (2) minimizing the disturbance of the zone of interest, and (3) preventing damage to the instruments. If one of the GEOPS instruments fails, the instruments can be safely retrieved, recalibrated, repaired, or replaced. If other data are required from the same location, an instrument can be removed and another type placed into the same GEOPS casing. Other unique capabilities include the ability to remove the instruments and to conduct vertical geophysical logging surveys at the same location where monitoring data are being obtained. This flexibility increases the understanding of subsurface conditions for characterization purposes and provides a much better opportunity for subsurface data integration at a much lower cost than commercially available probes.

2.9.2 Success in Meeting the Purpose

Thirty-two GEOPS probes were installed within the SDA during the last quarter of FY 2004 (Josten 2005). Lysimeter instruments were deployed in 31 probes. The 32nd location hit a solid object, and the probe was observed to flex and twist. It was impossible to install a lysimeter because of the severe bend in the casing, so the GEOPS casing will be used as a vapor port without any instruments. The flexibility of the GEOPS probe casing system allowed this location to be utilized and not abandoned. To date, GEOPS has met all intended purposes of the system.

2.9.3 Effectiveness and Limitations of the Geological and Environmental Probe System Probe

The initial GEOPS lysimeter probe sampling event started in November 2004. Nine GEOPS instruments were sampled. Three of the GEOPS probes were sampled as vapor ports, which involved the installation of a higher vacuum on the instrument than was required for pulling liquid samples. All three produced several drops of liquid along with vapor samples. Four of the remaining six instruments produced liquid samples (i.e., one at 50 mL, two between 100 and 250 mL, and one at 260 mL). On December 1, 2004, a 260-mL sample was found to contain an unexpectedly high concentration of VOCs; therefore, sampling was temporarily suspended until the sampling trailer was redesigned. When sampling resumed in March 2004, 11 more GEOPS lysimeters produced liquid samples above 8 mL (including five producing over 100 mL, with 645 mL being the maximum). In summary, of the 31 GEOPS probes, 15 produced above 8 mL, and only 10 produced no liquid samples at all during the initial sampling event.

Because over 65% of the sampled GEOPS probes produced liquid, and four of the six GEOPS lysimeter probes collocated with Type B lysimeters (which historically yielded little or no water) obtained substantial liquid samples, the effectiveness of the new probe system has been confirmed. No limitations have been reported or observed on the sampled probes to date. The three GEOPS pulled as vapor ports provided vapor as well as drops of moisture. A larger database, over a longer term, will provide a more thorough and complete evaluation of the GEOPS.

The GEOPS probes have been in position for less than 1 year. No limitations have been reported or observed on the sampled probes to date. The three GEOPS probes pulled as vapor ports provided vapor as well as drops of moisture.

2.9.4 Quality of Data from the Geological and Environmental Probe System Probe

The GEOPS lysimeter samples appear to be of high quality and adequate volume to perform priority analyses. Like all lysimeters, results from organics and C-14 are potentially biased low because of the application of a vacuum for 1 week and associated volatilization and degradation that might occur by pulling the vacuum and not collecting the sample immediately. However, the sampling data obtained, to date, from GEOPS are very encouraging.

2.9.5 Overall Usefulness of the Geological and Environmental Probe System Probe

The ease of use, flexibility, and potential to monitor, maintain, and replace instruments when using the GEOPS probe casing has been demonstrated to be very useful. Continued monitoring of the GEOPS probes at the SDA will verify their capabilities and potential.

2.9.6 Lessons Learned from the Geological and Environmental Probe System Probe

Lessons learned during the fabrication, installation, and operation of the GEOPS probes include the following:

- As much as possible, personnel involved in previous generations of any new design should be engaged in the new design. A great deal of design time was lost in fabricating the GEOPS. The initial path forward on GEOPS was to weld the porous stainless steel instead of using the previously proven simple O-ring system; this essentially became a costly exercise. The O-ring system eventually used in GEOPS is the same system as that used previously. Only after personnel were changed back to the original team was this complication resolved.

- Field personnel should be enlisted in the early design stage, and their input should be valued highly. It should be noted that after the original team was back on board, field personnel were again included in design discussions.[e]

- Subcontracted, critical material should be lab-tested at the earliest opportunity. The original Mott Corporation porous stainless steel used on the Type B probes was 0.2 μ, and lab results with that material proved the material was acceptable for use at the INL. The 0.2-μ stainless steel order from Mott for the GEOPS probes was received, and the new order passed the receipt inspection and physical criteria specified for Quality Level 3 material. The new order was not tested in the lab until 1 month after arrival. It was presumed that the material from this order would work the same as the first batch; however, it did not perform as expected in the lab. A new order of 0.1 μ was necessary, which seriously delayed the fabrication and installation schedule.

- Mock-up testing can be very cost-effective; therefore, mock ups and testing should be used at locations such as at the Cold Test Pits at RWMC. Testing fit, form, and function in the field before final fabrication can be extremely beneficial in providing timely input into, or confirmation of, design features.

- The prejob and other training prior to sampling ensures the probes are sampled properly and safely. The GEOPS lysimeter recently produced an unanticipated amount of VOCs in one sample. During actual field operations, personnel did exactly as they had been trained by stopping activities at the first sign of an unusual odor in the sampling trailer that was generated by VOCs. Consequently, the sampling trailer was redesigned, the procedure was modified, and then operations continued. The training and feedback system worked as it was supposed to work.

2.10 Data Integration

The WAG 7 Probing Project spanned 5 years, from 1999 through 2004. The WAG 7 Probing Project generated enormous amounts of data that have been used to interpret disposal locations, subsurface conditions, contaminant distribution, and waste types. Results from the WAG 7 Probing

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e. Field personnel became a critical part of the team, and were recognized in the 2004 Research and Development 100 Award.

Project were described in earlier reports (e.g., Holdren et al. 2002, Josten 2002a and 2002b, and Myers et al. 2003 and 2004). The benefit and data uses of the probing project are summarized in the following sections.

2.10.1 Uses of Type A Probe Data

One hundred and ninety-one Type A probes were installed and logged in the SDA from December 1999 through August 2004. Type A probe locations were selected by first choosing a target waste stream, evaluating inventory records for likely source areas, and reviewing surface geophysical data to refine the probe location (Salomon 2004). After installation, probe locations were surveyed in, and then a suite of logging tools (see Section 2.2) were lowered into these probes to collect data on the physical and contaminant characteristics surrounding each probe. Type A logging data then were analyzed with respect to subsurface conditions, buried waste, and contaminant distribution.

Type A probes were very useful in quantitatively measuring thickness of the overburden, waste zone, and underburden. In general, the depths were as expected based on historical information (i.e., previous investigations, geophysical data, and RWMC maintenance records), but Type A probe data were more definitive. The neutron-neutron moisture logging tool mapped vertical changes in the moisture content that correlated closely with each of these layers (Holdren et al. 2002, p. 3-99). The cover thickness data corroborated known cover data for pits where probes were installed (Holdren et al. 2002, pp. 3-69 and 3-99; Josten 2002a, pp. 91–99). The depth to bedrock was directly obtained from probe refusal and correlated very well with known bedrock topography information (Josten 2002b, Holdren et al. 2002). In addition, the 191 new data locations improved the ability to interpolate bedrock topography.

Type A probe data also were capable of revealing the heterogeneous nature of the waste zone (Josten 2002a and 2002b, Josten 2005). For Pits 4, 5, 9, and 10, the Type A probe data corroborated inventory records and photographic information that waste was randomly buried and covered; indicated that containers were intact and others were in various stages of deterioration; and indicated that voids, soil, and waste were randomly distributed. Probes placed several feet from each other in areas of known random burials routinely encountered different waste types and subsurface conditions. Type A probe records from Pit 2, where waste was known to comprise stacked drums, indicated that probes encountered moments of initially high resistance followed by a loud screeching noise and several feet of easy probe advancement during installation. It was inferred that the probe had penetrated stacked drums with minimal soil backfill (Josten 2005).

Type A probe data also correlated very well with surface geophysical data and inventory records. Surface geophysical data were used to evaluate pit boundaries, locate metallic objects, and map suspected waste streams and waste types in pits and trenches. Many of these interpreted subsurface conditions were confirmed when compared with the Type A probe logging data (Josten 2002a and 2002b).

Using Type A nuclear logging data, it was possible to define unique combinations of various radioisotopes, spatial distribution of the radioisotopes, or unique characteristics used to target Type B probes. Unique combinations of various radioisotopes (termed “fingerprints”) were used to readily identify waste streams. Each targeted waste stream (i.e., depleted uranium, enriched uranium, organic sludge waste, plutonium-contaminated waste, or americium/neptunium waste) had different radioisotopes or different ratios of the radioisotopes, which then could be used to crudely identify, or fingerprint, the waste. For example, WAG 7 personnel were able to discriminate graphite molds from filter waste using the fingerprint radioisotope data and surface geophysics during Pit 9 Campaign 2 (Josten 2002b, pp. 63–67). This capability was refined no further.

Spatial distributions (i.e., changes in instrument intensity of the same radioisotope with a single probe or among a group of probes) also were used to define location, relative concentration, and waste type. For instance, if the trend of a radioisotope stayed relatively constant over a lateral area, it was inferred that a similar waste type was present. If the trend of a radioisotope changed quickly, the boundary for that waste type was assumed.

In some instances, the azimuthal logging tool (see Section 2.2.5) was used to define what direction a target waste was in relation to the Type A probe. Unique characteristics of the waste learned during the probing project include the following:

- Anomalously large logging responses were attributed to voids in the subsurface
- Moisture log data showed low apparent values throughout areas exhibiting elevated chlorine values
- Silicon, calcium, and potassium were reliable indicators of soil.

Using these interpretations, Type B probes then were installed either in a vertical stack or lateral array to optimize sensors and sampling ports to specific waste types or within the soil overburden, underburden, or layers of soil within the waste.

2.10.2 Uses of Type B Probe Data

Type B probe data were used to characterize the physical nature of the subsurface, moisture trends, and contaminant movement (see Appendix B, Figures B-1 and B-2). Visual probes were very useful in gaining an understanding of the waste form and the layer moisture trends (Myers et al. 2003 and 2004, Josten 2002a). Video logs showed the appearance of different waste types. When combined with the logging data of adjacent Type A probes, video probes provided a better understanding of the Type A probe data. For example, physical features (e.g., a void, soil layers, unique waste, or the presence of moisture) could be seen in the visual probe, and its correlating response could be seen in the nuclear logging data.

Vapor probe data were useful in characterizing the organic sludge and in understanding the behavior of VOCs within the waste. These data also were coupled with Type A probe data to better understand VOC distribution and behavior (Miller and Varvel 2001, Myers et al. 2003 and 2004).

Very little opportunity was available to integrate Type B moisture probe data, because the soil moisture lysimeter and tensiometer probes did not provide much useable data for 2002–2004 (Myers et al. 2003 and 2004). Reasons for the poor data from these instruments include lack of precipitation, heterogeneous waste, installation technique, and instrument design.

The Type B lysimeter probe was redesigned as the GEOPS in 2004, and had much better success than its predecessor in collecting water samples in November 2004. A full assessment of the new Type B lysimeter probe cannot be offered, because these instruments have been in use for only a short time.

2.10.3 Data Summary for Organic Sludge Focus Area Characterization

Data from Type A and B probes, in combination with other investigations, were very useful in characterizing the Organic Sludge Focus Area located in the eastern end of Pit 4. Surface geophysical data defined areas of low metallic waste, high metallic waste, and no metallic waste, which correlated with the SDA inventory records for organic sludge drum waste, other types of drummed waste, and debris, respectively (Josten 2002b). Subsequent Type A probes confirmed boundaries of the organic waste (Josten 2002b, pp. 5–14) with respect to adjacent debris and other drummed waste. The Type A probe n-gamma chlorine logging data also correlated extremely well with the plume boundaries of historical soil vapor data. Several mapped areas of elevated VOCs were shown to directly correlate to either large concentrations of buried organic sludge, areas of thinner overburden, or shallow waste suspected in the cover material (Josten 2002b) (see Figure 10). Type B vapor probes also were installed within the Organic Sludge Focus Area, and the data validated assumptions about historical disposal information from the 1960s (Myers et al. 2003, Miller and Varvel 2001).

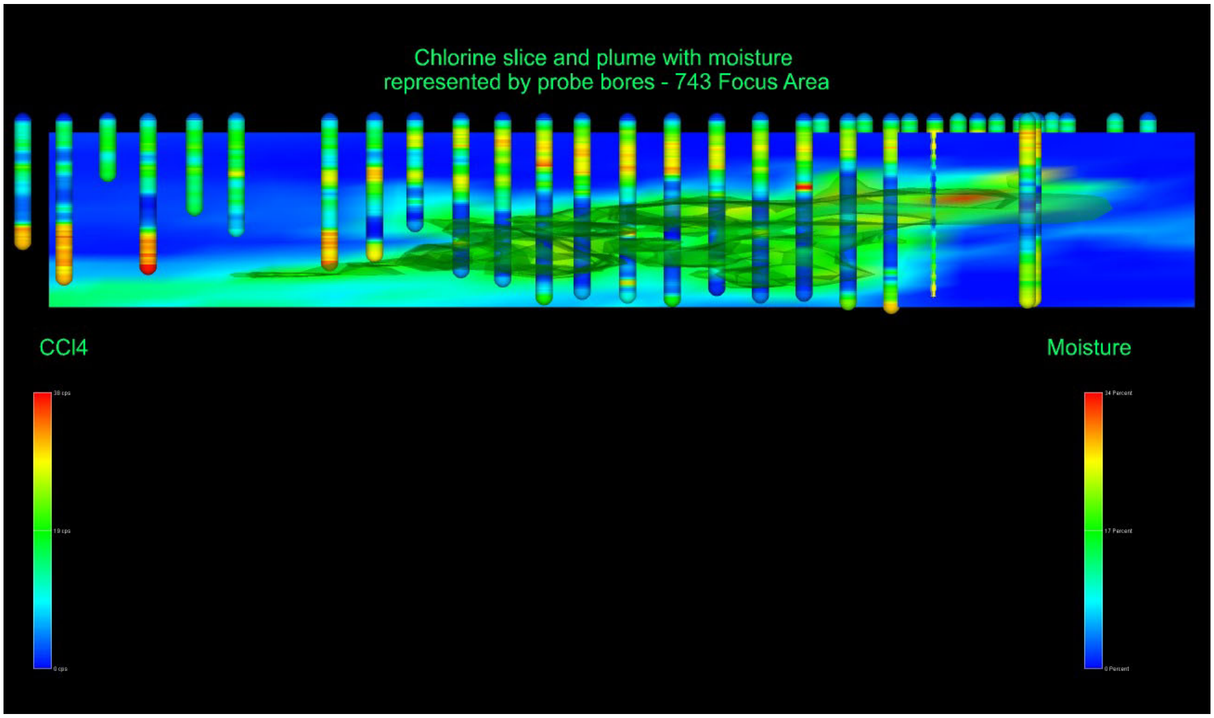

Figure 10. Two-dimensional graphic showing chlorine and moisture data from probes in the Series 743 Focus Area. Note the inverse relationship where there is little moisture when chlorine values are higher.

2.10.4 Data Summary for P9-20 Investigation

Type A and B probe data were used to characterize elevated levels of plutonium reported at Probe P9-20 in Pit 9 (see Appendix B, Figures B-1 and B-3). During the Pit 9 12.2 × 12.2-m (40 × 40-ft) campaign, 20 Type A probes were installed in a grid pattern over an area suspected of containing plutonium waste from RFP. One of the Type A probes, P9-20, encountered elevated levels of Pu-239, with values orders of magnitude greater than any other probe. Eight more Type A probes were installed just north of Probe P9-20 during Pit 9 Campaign 1 in an effort to bound the area of elevated plutonium. The logging data from the additional eight probes revealed that the elevated levels of Pu-239 were restricted to the P9-20 probe only.

Six additional Type A probes were installed in a circular, 0.9-m (3-ft) -radius pattern around Probe P9-20 and logged. A Type B visual probe was also installed within 0.3 m (1 ft) of Probe P9-20, and showed that Probe P9-20 had penetrated a drum at 1.8 m (6 ft) and waste material at 2.7 m (9 ft), large voids were present and adjacent to the elevated Pu-239 areas, and that soil was abundant around Probe P-9-20. Azimuthal logging data confirmed that the Pu-239 sources were within the circular pattern of six Type A probes and close to Probe P9-20. Interpretation of the logging data determined that the waste type was likely plutonium-contaminated graphite waste at 1.8 m (6 ft) and Series 741 waste at

2.7–3 m (9–10 ft). Figure 11 is a three-dimensional graphical model of the P9-20 area, and shows that Pu-239 is not uniform throughout the study area, but rather is present as discrete sources. In Figure 11, the graphite source is shown in red above the Series 741 source, which is shown as a large, diffuse, yellowish cloud. These data were further modeled to define the volume and concentration of the Pu-239 source(s) present (Jewell, Reber, and Hertzog 2002). The modeling effort estimated that several small, discrete sources of Pu-239 were likely present and contained 50–500 g of Pu-239.

Plutonium-239 Azimuthal Logging Data - P9-20 Focus Area

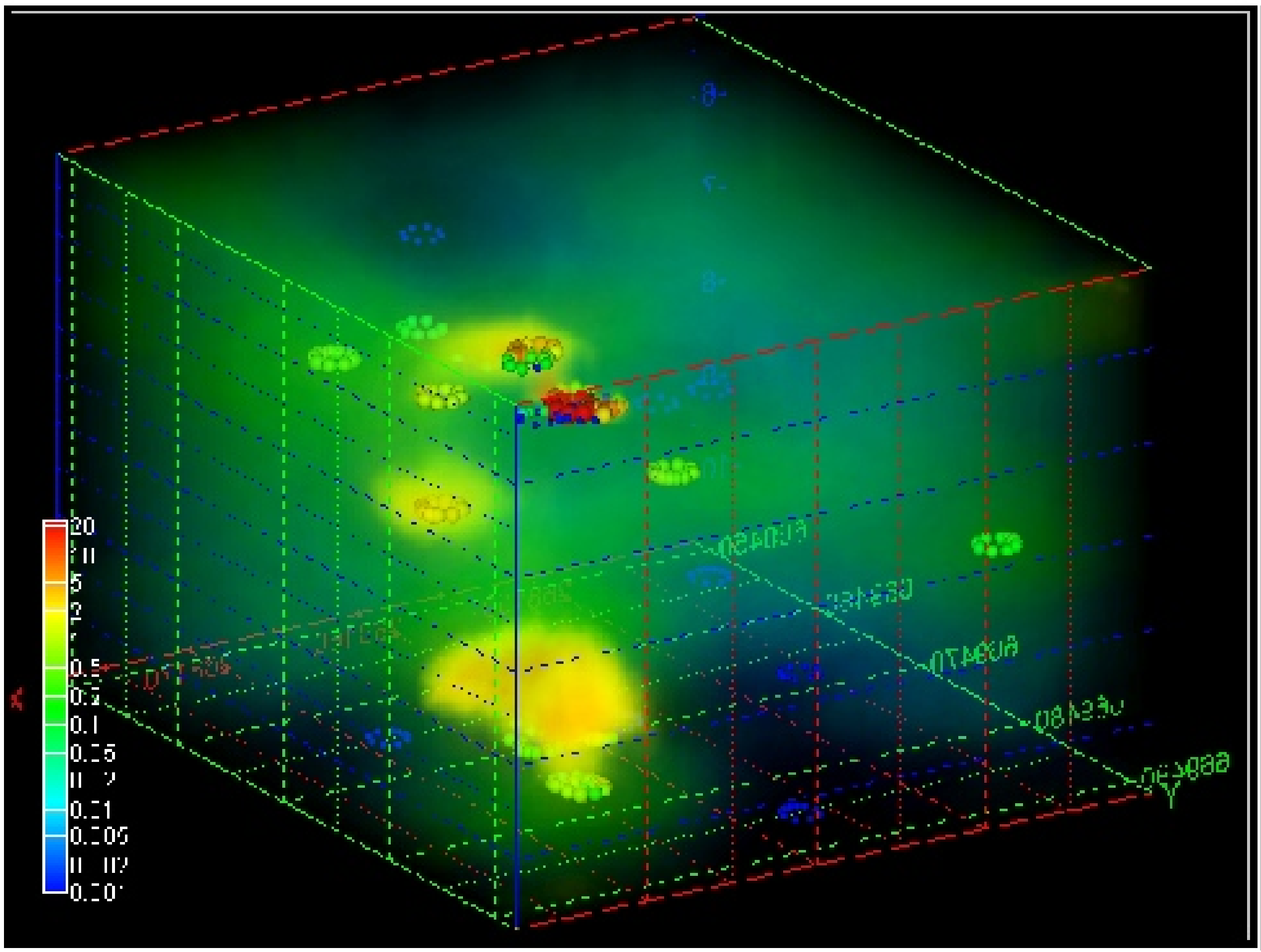

Figure 11. Three-dimensional illustration of plutonium-239 azimuthal logging data for the P9-20 focus area.

Further analysis to support the Pit 9 excavation showed that distribution of waste types identified in the Pit 9 Type A probes correlated very well with historical inventory records (Jamison and Preussner 2002) (see Figure 12). The chlorine data in Figure 12 (purple) correlates very closely to the historical location of the Series 743 organic waste shipments; inversely, the moisture data (gray) occur where there are no historical-record locations for Series 743 waste. The actual excavation encountered these waste types and subsurface conditions, as predicted by the Type A probe data, and did, in fact, reveal that Probe P9-20 pierced a drum containing graphite waste at 1.8 m (6 ft) and a Series 741 drum at 2.7 m (9 ft) (see Figure 13). Information about the drum containing graphite waste also is recorded in field representative logbooks and project photographs of the excavation. The Probe P9-20 investigation demonstrated that quantitative analysis of radionuclide concentrations and distribution is possible, but requires extensive data collection and analysis to reduce uncertainty to acceptable levels. It was not feasible to do this level of analysis for every probe, as was learned during the VOC analysis (Miller and Varvel 2002).

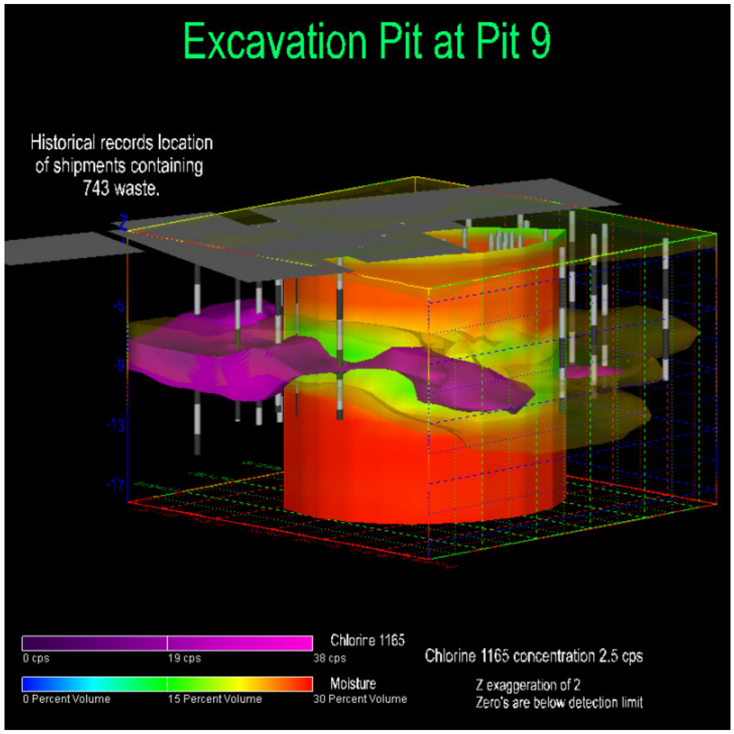

Figure 12. Three-dimensional illustration showing Series 743 shipment locations (gray) based on historical records overlying chlorine and moisture probe data.

Figure 13. Actual excavation photograph showing a drum containing graphite at a depth of 6 ft within the P-9-20 probe cluster (DSC02091-P9-20).

3. SUMMARY

Waste Area Group 7 successfully developed and deployed a unique set of sealed probes to safely investigate buried hazardous and radioactive waste in the SDA. Three hundred and ninety-eight probes were installed between December 1999 and August 2004 to collect characterization and monitoring data directly from the buried waste. The purpose of the WAG 7 Probing Project was to collect characterization data to support the OU 7-13/14 RI/FS.

Waste Area Group 7 originally planned to use conventional drilling and sampling techniques; however, sonic drilling was selected to minimize exposure risks from dangerous waste (e.g., high gamma fields, alpha contamination, and VOCs). Probing provided a safe alternative to obtain in situ contaminant and moisture data directly from the waste zone while minimizing personnel exposure and the potential for contaminant release to the environment.

Probes were installed using a remotely operated sonic drill rig that pushed or rotated the probes through the cover soil and into the buried waste. The sonic drill rig was modified from a skid-mounted setup to a truck bed to improve maneuverability. The sonic drill rig met all project objectives to safely and reliably install 6.4–14-cm (2.5–5.5-in.) -diameter probes through soil and waste to refusal depths greater than 7.6 m (25 ft). The main advantages of the sonic drilling technique were that it created no waste, produced no drill cuttings that would bring hazardous and radioactive constituents to the surface, and used no water. One limitation of the sonic drilling technique was that large-diameter probes sometimes were unable to penetrate hard-packed soil; even with combined rotation and hammering, probes could be located no closer than 0.6 (2 ft) from one another. Additional limitations were that no drill cuttings were produced to assist in data analysis, and the sonic drilling technique was capable of damaging sensitive instruments and sampling probes.

Various probe designs were used to collect geophysical data, moisture and vapor samples, and moisture data, and to visually examine the buried waste. The geophysical logging data were very successful in identifying waste types and subsurface conditions, and in defining locations for further data collection. Subsurface conditions that were successfully evaluated included thickness of the overburden, thickness of the waste, depth to bedrock, the presence of voids and moisture, and the degree of waste heterogeneity. Limitations of the geophysical data were that (1) the data could not be calibrated to specific subsurface conditions; (2) the data were qualitative, because no definitive contaminant concentrations could be determined; and (3) large numbers of closely spaced probes were necessary to characterize the heterogeneous waste zone within the SDA.

Visual probes provided unique in situ data about the waste condition and visual confirmation for collocated geophysical probe data. Videos and photographs directly from the waste zone were very useful in planning retrieval operations, understanding geophysical and moisture data, and observing in situ waste conditions. Limitations of the visual probes were related to problems in maintaining air seals due to inconsistent machining and welding between the three shops that manufactured the probes.

Vapor probe data helped (1) confirm source locations of VOCs, (2) characterize the nature of the waste, and (3) assess redox conditions of the waste. The vapor probe data could not establish temporal trends in the volatile release rate because of problems with analysis. Vapor probes also were used to evaluate C-14 and tritium release from activated metal disposals; however, only one of the four probes functioned. One limitation of the vapor probes was that a high percentage of probes did not yield a sample. It is not known whether this is a result of low-permeability waste or damage to the probe during installation.

Moisture monitoring within the buried waste using SMR probes was successful even though precipitation was lower than normal during the study period, and difficulties were encountered with waste zone calibration due to waste heterogeneity. Tensiometer probes provided valuable quantitative water-potential data from above, within, and below the waste. These data indicate that some of the waste locations are within the tensiometric range where there is a higher potential for water and contaminant transport. Several probes indicated water infiltration while saturated conditions were not detected. The challenging media being measured dry sediments, field maintenance requirements and instrument failure combined so that 22% provided useable data. Enhanced field testing with directed servicing will likely bring more of the Type B probes on-line and will generate more consistent and useable data.

The lack of sample collection was a major limitation of lysimeter probes with only two of 18 lysimeters consistently yielding samples greater than 5–20 mL. Experience with the Type B probes and lysimeters consequently led to the design and building of a more durable, versatile, and reliable moisture-probe system. The redesigned moisture probe (i.e., GEOPS) combined a vapor port, lysimeter, and tensiometer, and was tested and installed in the SDA in late 2004. The GEOPS probe demonstrated a sample-collection success rate greater than 80%. Thirty-two GEOPS probes (i.e., 31 lysimeters and one vapor port probe) were driven into the SDA using the sonic drilling technique, and greater than 50% of the GEOPS lysimeters sampled in November 2004 and March 2005 produce moisture.

One factor that indirectly impacted the WAG 7 Probing Project and the performance of Type B probes was the aggressive schedule to design, test, and install these unique tools within 1 year. Mock-up testing was done at Cold Test Pit-South to demonstrate that the probes could be safely driven following RWMC safety procedures. However, the Type B probes were not fully tested to ensure that sensors and sampling ports would survive installation into these heterogeneous materials and still provide a sample or data.

In conclusion, the WAG 7 Probing Project was successful in collectively designing, deploying, and sampling a unique set of probes to collect a diverse range of data directly from a zone of hazardous and radioactive buried waste. The project spanned more than 5 years, and continually revised and improved the probe designs, data collection, and use. The probing data increased confidence in waste inventory and location, provided in situ waste and moisture data for characterization and risk assessment, and assisted in the location selection and planning for retrieval demonstration in Pit 9.

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Appendix A

Probe Attribute Data

Appendix A

Probe Attribute Data

Four hundred and forty-two Type A and B probe and instrument packages were installed by Waste Area Group (WAG) 7 throughout the Subsurface Disposal Area as part of the WAG 7 Probing Project between December 1999 and August 2004.

This appendix contains two tables that provide probe-attribute data (e.g., probe names, survey information, sample port depths, and various support information) compiled during installation. Table A-1 provides information by probe date, and Table A-2 provides information by probe type.

Table A-1. Probes by date.

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Pit 9	TP-01	08/01/99	9.5	NA
Type A	Pit 9	TP-02B	08/01/99	17.0	NA
Type A	Pit 9	TP-03	08/01/99	14.5	NA
Type A	Pit 9	P9-08	12/01/99	13.5	NA
Type A	Pit 9	P9-03	12/14/99	11.5	NA
Type A	Pit 9	P9-09	12/15/99	11.5	NA
Type A	Pit 9	P9-17	12/15/99	14.8	NA
Type A	Pit 9	P9-18	12/15/99	18.0	NA
Type A	Pit 9	P9-10	12/16/99	9.5	NA
Type A	Pit 9	P9-15	12/16/99	13.5	NA
Type A	Pit 9	P9-16	12/16/99	13.8	NA
Type A	Pit 9	P9-02	12/20/99	15.5	NA
Type A	Pit 9	P9-04	12/20/99	16.5	NA
Type A	Pit 9	P9-14	12/20/99	14.5	NA
Type A	Pit 9	P9-05	12/21/99	16.9	NA
Type A	Pit 9	P9-07	12/21/99	15.8	NA
Type A	Pit 9	P9-11	12/21/99	15.0	NA
Type A	Pit 9	P9-12	12/21/99	16.5	NA
Type A	Pit 9	P9-13	12/21/99	15.8	NA
Type A	Pit 9	P9-01	12/22/99	13.9	NA
Type A	Pit 9	P9-06	12/22/99	14.5	NA
Type A	Pit 9	P9-19	12/22/99	15.0	NA
Type A	Pit 9	P9-20	12/22/99	12.3	NA
Type A	Depleted uranium	DU-04	08/14/00	14.0	NA
Type A	Depleted uranium	DU-05	08/14/00	18.3	NA

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Depleted uranium	DU-01	08/15/00	14.3	NA
Type A	Depleted uranium	DU-02	08/15/00	14.8	NA
Type A	Depleted uranium	DU-03	08/15/00	14.5	NA
Type A	Depleted uranium	DU-06	08/16/00	18.5	NA
Type A	Depleted uranium	DU-07	08/16/00	14.5	NA
Type A	Depleted uranium	DU-08	08/16/00	18.7	NA
Type A	Americium/Neptunium	741-07	08/21/00	6.3	NA
Type A	Americium/Neptunium	741-08	08/22/00	22.3	NA
Type A	Americium/Neptunium	741-09	08/22/00	14.3	NA
Type A	Americium/Neptunium	741-05	08/23/00	6.4	NA
Type A	Americium/Neptunium	741-06	08/23/00	18.0	NA
Type A	Americium/Neptunium	741-03	08/24/00	20.3	NA
Type A	Americium/Neptunium	741-04	08/24/00	24.3	NA
Type A	Americium/Neptunium	741-01	08/28/00	5.9	NA
Type A	Americium/Neptunium	741-02	08/28/00	18.1	NA
Type A	Organic sludge	743-23	08/31/00	8.4	NA
Type A	Organic sludge	743-24	08/31/00	23.5	NA
Type A	Organic sludge	743-25	08/31/00	17.8	NA
Type A	Organic sludge	743-22	09/05/00	21.4	NA
Type A	Organic sludge	743-21	09/06/00	14.8	NA
Type A	Organic sludge	743-20	09/07/00	16.3	NA
Type A	Organic sludge	743-19	09/11/00	4.2	NA
Type A	Organic sludge	743-18	09/25/00	21.0	NA
Type A	Organic sludge	743-17	09/27/00	20.7	NA
Type A	Organic sludge	743-15	09/28/00	21.9	NA
Type A	Organic sludge	743-16	09/28/00	16.2	NA
Type A	Organic sludge	743-13	10/02/00	25.6	NA
Type A	Organic sludge	743-14	10/02/00	23.0	NA
Type A	Organic sludge	743-12	10/10/00	25.0	NA
Type A	Organic sludge	743-09	10/11/00	24.3	NA
Type A	Organic sludge	743-10	10/11/00	25.8	NA
Type A	Organic sludge	743-11	10/11/00	25.5	NA
Type A	Organic sludge	743-05	10/12/00	27.0	NA
Type A	Organic sludge	743-06	10/12/00	26.2	NA
Type A	Organic sludge	743-07	10/12/00	25.3	NA
Type A	Organic sludge	743-08	10/12/00	25.3	NA
Type A	Organic sludge	743-03	10/16/00	19.5	NA

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Organic sludge	743-04	10/16/00	25.5	NA
Type A	Organic sludge	743-01	10/17/00	17.2	NA
Type A	Organic sludge	743-02	10/17/00	20.7	NA
Type A	Pit 9	P9-21A	10/26/00	13.3	NA
Type A	Pit 9	P9-24A	10/26/00	12.7	NA
Type A	Pit 9	P9-22	10/30/00	12.3	NA
Type A	Pit 9	P9-26A	10/30/00	11.3	NA
Type A	Pit 9	P9-27	10/30/00	11.3	NA
Type A	Pit 9	P9-23	10/31/00	11.4	NA
Type A	Pit 9	P9-25A	10/31/00	11.4	NA
Type A	Pit 9	P9-28A	10/31/00	10.1	NA
Type A	Pit 9	P9-GR-07	11/28/00	12.8	NA
Type A	Pit 9	P9-GR-03	11/29/00	13.8	NA
Type A	Pit 9	P9-GR-04	11/29/00	11.5	NA
Type A	Pit 9	P9-GR-05	11/29/00	11.5	NA
Type A	Pit 9	P9-GR-06	11/29/00	11.2	NA
Type A	Pit 9	P9-GR-01	11/30/00	13.7	NA
Type A	Pit 9	P9-GR-02	11/30/00	13.8	NA
Type A	Pit 9	P9-FI-02	12/05/00	12.1	NA
Type A	Pit 9	P9-FI-03	12/05/00	16.3	NA
Type A	Pit 9	P9-FI-07	12/05/00	16.0	NA
Type A	Pit 9	P9-FI-08	12/05/00	16.2	NA
Type A	Pit 9	P9-FI-04	12/06/00	13.2	NA
Type A	Pit 9	P9-FI-05	12/06/00	13.2	NA
Type A	Pit 9	P9-FI-06	12/06/00	17.9	NA
Type A	Pit 9	P9-FI-01	12/07/00	10.1	NA
Type A	Organic sludge	743-32	12/11/00	12.1	NA
Type A	Organic sludge	743-33	12/11/00	12.1	NA
Type A	Organic sludge	743-34	12/11/00	11.9	NA
Type A	Organic sludge	743-35	12/11/00	16.4	NA
Type A	Organic sludge	743-38	12/12/00	15.5	NA
Type A	Organic sludge	743-39	12/12/00	19.8	NA
Type A	Organic sludge	743-40	12/12/00	18.4	NA
Type A	Organic sludge	743-41	12/12/00	21.5	NA
Type A	Organic sludge	743-42	12/12/00	22.2	NA
Type A	Organic sludge	743-36	12/13/00	25.8	NA
Type A	Organic sludge	743-37	12/13/00	25.8	NA

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Depleted uranium	DU-09	12/14/00	18.5	NA
Type A	Depleted uranium	DU-10	12/14/00	17.3	NA
Type A	Depleted uranium	DU-11	12/14/00	18.1	NA
Type A	Depleted uranium	DU-12	12/14/00	18.3	NA
Type A	Depleted uranium	DU-13	12/14/00	18.1	NA
Type A	Depleted uranium	DU-14	12/14/00	17.3	NA
Type A	Depleted uranium	DU-15	12/18/00	17.1	NA
Type A	Depleted uranium	DU-16	12/18/00	16.3	NA
Type A	Depleted uranium	DU-17	12/18/00	20.2	NA
Soil-moisture probe	Moisture monitoring	MM4-3	03/01/01	10.0	9.11
Soil-moisture probe	Moisture monitoring	MM4-2	03/07/01	18.3	17.39
Soil-moisture probe	Moisture monitoring	MM4-4	03/07/01	11.2	10.28
Soil-moisture probe	Moisture monitoring	MM4-5	03/08/01	14.8	13.88
Soil-moisture probe	Moisture monitoring	MM4-1	03/12/01	20.3	19.44
Soil-moisture probe	Moisture monitoring	MM3-1	03/22/01	10.6	9.69
Soil-moisture probe	Moisture monitoring	MM3-2	03/26/01	9.4	8.53
Soil-moisture probe	Moisture monitoring	MM3-3	03/26/01	17.9	17.00
Soil-moisture probe	Moisture monitoring	MM2-1	03/28/01	16.9	16.00
Soil-moisture probe	Moisture monitoring	MM2-2	03/28/01	11.7	10.78
Soil-moisture probe	Moisture monitoring	MM2-3	03/28/01	3.9	3.05
Soil-moisture probe	Moisture monitoring	MM1-1	04/12/01	18.7	17.79
Soil-moisture probe	Moisture monitoring	MM1-2	04/12/01	14.8	13.89
Soil-moisture probe	Moisture monitoring	MM1-3	04/16/01	12.4	11.47
Soil-moisture probe	Moisture monitoring	MM1-3B	04/17/01	10.6	4.90
Soil-moisture probe	Moisture monitoring	MM1-3B	04/17/01	10.6	9.75
Soil-moisture probe	Moisture monitoring	MM1-1B	04/18/01	12.5	11.58
Soil-moisture probe	Moisture monitoring	MM1-1B	04/18/01	12.5	5.50
Soil-moisture probe	Moisture monitoring	MM1-2B	04/18/01	11.6	10.75
Soil-moisture probe	Moisture monitoring	MM1-2B	04/18/01	11.6	6.00
Soil-moisture probe	Moisture monitoring	MM2-1B	04/18/01	13.4	7.25
Soil-moisture probe	Moisture monitoring	MM2-1B	04/18/01	13.4	12.51
Soil-moisture probe	Moisture monitoring	MM2-2B	04/18/01	10.0	4.00
Soil-moisture probe	Moisture monitoring	MM2-2B	04/18/01	10.0	9.14
Soil-moisture probe	Moisture monitoring	MM2-3B	04/23/01	7.9	6.98
Soil-moisture probe	Moisture monitoring	MM2-3B	04/23/01	7.9	1.67
Soil-moisture probe	Organic sludge	743-03-M1	04/24/01	20.0	12.31
Soil-moisture probe	Organic sludge	743-03-M1	04/24/01	20.0	3.36

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Soil-moisture probe	Organic sludge	743-03-M1	04/24/01	20.0	19.09
Type A	Organic sludge	743-08-01	04/24/01	25.6	NA
Type A	Organic sludge	743-08-02	04/24/01	25.0	NA
Type A	Organic sludge	743-08-03	04/24/01	26.3	NA
Type A	Organic sludge	743-08-04	04/25/01	25.1	NA
Type A	Organic sludge	743-08-05	04/25/01	25.0	NA
Type A	Organic sludge	743-08-06	04/25/01	25.1	NA
Vapor port	Organic sludge	743-08-VP1	04/25/01	20.8	20.19
Vapor port	Organic sludge	743-08-VP2	04/25/01	14.0	13.38
Vapor port	Organic sludge	743-03-VP2	04/26/01	13.9	13.25
Vapor port	Organic sludge	743-03-VP3	04/26/01	5.4	4.78
Vapor port	Organic sludge	743-03-VP1	04/26/01	18.6	17.96
Vapor port	Organic sludge	743-08-VP3	04/26/01	5.5	4.88
Soil-moisture probe	Organic sludge	743-08-M1	04/30/01	23.1	6.60
Soil-moisture probe	Organic sludge	743-08-M1	04/30/01	23.1	13.90
Soil-moisture probe	Organic sludge	743-08-M1	04/30/01	23.1	22.28
Soil-moisture probe	Organic sludge	743-18-M1	04/30/01	20.0	6.47
Soil-moisture probe	Organic sludge	743-18-M1	04/30/01	20.0	19.20
Soil-moisture probe	Organic sludge	743-18-M1	04/30/01	20.0	12.83
Vapor port	Organic sludge	743-18-Abandoned	05/01/01	14.9	14.28
Vapor port	Organic sludge	743-18-VP1	05/01/01	20.6	20.00
Vapor port	Organic sludge	743-18-VP3	05/02/01	8.2	7.61
Vapor port	Organic sludge	743-18-VP4	05/02/01	15.2	14.57
Type A	Uranium/enriched uranium	Pit5-4-1	05/03/01	16.5	NA
Type A	Uranium/enriched uranium	Pit5-4-2	05/03/01	16.4	NA
Type A	Uranium/enriched uranium	Pit5-4-3	05/03/01	16.3	NA
Type A	Uranium/enriched uranium	Pit5-4-4	05/03/01	12.7	NA
Type A	Uranium/enriched uranium	Pit5-4-5	05/03/01	10.5	NA
Type A	Uranium/enriched uranium	Pit5-4-6	05/03/01	16.5	NA
Type A	Uranium/enriched uranium	Pit5-4-7	05/03/01	14.1	NA

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Uranium/enriched uranium	Pit5-1-1	05/07/01	7.8	NA
Type A	Uranium/enriched uranium	Pit5-1-2	05/07/01	7.8	NA
Type A	Uranium/enriched uranium	Pit5-1-3	05/07/01	9.1	NA
Type A	Uranium/enriched uranium	Pit5-1-4	05/07/01	8.5	NA
Type A	Uranium/enriched uranium	Pit5-1-5	05/07/01	3.8	NA
Type A	Uranium/enriched uranium	Pit5-1-6	05/08/01	11.7	NA
Type A	Uranium/enriched uranium	Pit5-1-7	05/08/01	16.0	NA
Type A	Uranium/enriched uranium	Pit5-1-8	05/08/01	13.6	NA
Type A	Pit 9	P9-20-01	05/10/01	13.9	NA
Type A	Pit 9	P9-20-02	05/10/01	11.6	NA
Type A	Pit 9	P9-20-03	05/10/01	12.2	NA
Type A	Pit 9	P9-20-04	05/10/01	12.6	NA
Type A	Pit 9	P9-20-05	05/10/01	12.0	NA
Type A	Pit 9	P9-20-06	05/10/01	12.3	NA
Soil-moisture probe	Moisture monitoring	MM3-1B	05/14/01	8.4	7.62
Soil-moisture probe	Moisture monitoring	MM3-1C	05/14/01	5.3	4.47
Soil-moisture probe	Moisture monitoring	MM3-2B	05/14/01	7.8	6.96
Soil-moisture probe	Moisture monitoring	MM3-2C	05/14/01	4.8	3.97
Soil-moisture probe	Moisture monitoring	MM3-3B	05/14/01	13.8	13.82
Soil-moisture probe	Moisture monitoring	MM3-3B	05/14/01	13.8	7.46
Soil-moisture probe	Moisture monitoring	MM4-3B	05/21/01	6.2	6.18
Lysimeter	Organic sludge	743-03-L1	06/05/01	12.9	12.80
Lysimeter	Organic sludge	743-03-L2	06/06/01	9.9	9.80
Lysimeter	Organic sludge	743-18-L1	06/07/01	12.2	12.10
Lysimeter	Organic sludge	743-18-L2	06/07/01	12.9	12.85
Soil-moisture probe	Moisture monitoring	MM4-3C	06/12/01	5.6	4.80
Soil-moisture probe	Moisture monitoring	MM4-4B	06/12/01	9.5	8.72
Soil-moisture probe	Moisture monitoring	MM4-4B	06/12/01	9.5	4.17
Visual probe	Depleted uranium	DU-10-V	06/14/01	7	NA
Lysimeter	Depleted uranium	DU-10-L1	06/19/01	9.9	9.76

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Lysimeter	Depleted uranium	DU-10-L2	06/19/01	7.1	7.03
Vapor port	Depleted uranium	DU-10-VP2	06/19/01	10.6	10.00
Lysimeter	Depleted uranium	DU-08-L1	06/20/01	16.2	16.10
Vapor port	Depleted uranium	DU-08-VP2	06/20/01	16.4	15.84
Vapor port	Depleted uranium	DU-10-VP1	06/20/01	12.1	11.55
Vapor port	Depleted uranium	DU-10-VP3	06/20/01	6.8	6.19
Type A	Depleted uranium	DU-08-A	06/28/01	18.1	NA
Type A	Depleted uranium	DU-08-B	06/28/01	17.6	NA
Type A	Depleted uranium	DU-10-A	06/28/01	17.0	NA
Type A	Depleted uranium	DU-14-A	06/28/01	17.5	NA
Type A	Depleted uranium	DU-14-B	06/28/01	17.6	NA
Type A	Americium/Nepunium	741-08-A	07/02/01	20.8	NA
Type A	Depleted uranium	DU-10-B	07/02/01	17.2	NA
Type A	Americium/Nepunium	741-08-B	07/03/01	21.8	NA
Lysimeter	Americium/Nepunium	741-08-L1	07/03/01	15.3	15.24
Lysimeter	Americium/Nepunium	741-08-L2	07/03/01	7.9	7.78
Soil-moisture probe	Americium/Nepunium	741-08-M1	07/09/01	20.7	19.86
Soil-moisture probe	Americium/Nepunium	741-08-M1	07/09/01	20.7	4.14
Soil-moisture probe	Americium/Nepunium	741-08-M1	07/09/01	20.7	11.50
Lysimeter	Depleted uranium	DU-08-L2	07/10/01	14.2	14.08
Soil-moisture probe	Depleted uranium	DU-08-M1	07/10/01	18.7	6.14
Soil-moisture probe	Depleted uranium	DU-08-M1	07/10/01	18.7	11.50
Soil-moisture probe	Depleted uranium	DU-08-M1	07/10/01	18.7	17.86
Soil-moisture probe	Moisture monitoring	MM4-2B	07/10/01	12.9	12.08
Soil-moisture probe	Moisture monitoring	MM4-2B	07/10/01	12.9	4.72
Soil-moisture probe	Depleted uranium	DU-10-M1	07/11/01	10.1	9.25
Soil-moisture probe	Depleted uranium	DU-10-M2	07/11/01	7.4	6.64
Soil-moisture probe	Depleted uranium	DU-10-M3	07/11/01	4.8	3.97
Vapor port	Depleted uranium	DU-14-VP1	07/12/01	16.6	16.05
Vapor port	Depleted uranium	DU-14-VP2	07/12/01	12.3	11.73
Vapor port	Depleted uranium	DU-14-VP3	07/12/01	5.5	4.88
Soil-moisture probe	Depleted uranium	DU-14-M1	07/16/01	16.0	15.20
Soil-moisture probe	Depleted uranium	DU-14-M1	07/16/01	16.0	9.83
Soil-moisture probe	Depleted uranium	DU-14-M1	07/16/01	16.0	4.47
Soil-moisture probe	Moisture monitoring	MM4-1B	07/16/01	15.5	14.67
Soil-moisture probe	Moisture monitoring	MM4-1B	07/16/01	15.5	6.30
Soil-moisture probe	Moisture monitoring	MM4-5B	07/16/01	10.6	9.75

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Soil-moisture probe	Moisture monitoring	MM4-5B	07/16/01	10.6	4.39
Visual probe	Organic sludge	743-18-V	07/19/01	12	NA
Soil-moisture probe	Activated metal	SVR 12-M	07/25/01	12.3	11.45
Soil-moisture probe	Activated metal	SVR 12-MB	07/25/01	9.2	4.30
Soil-moisture probe	Activated metal	SVR 12-MB	07/25/01	9.2	8.39
Vapor port	Activated metal	SVR12-3-VP1	07/25/01	12.4	11.82
Vapor port	Activated metal	SVR12-2-VP1	07/26/01	12.5	11.90
Vapor port	Activated metal	SVR12-2-VP2	07/26/01	8.3	7.67
Vapor port	Activated metal	SVR12-3-VP2	07/26/01	8.2	7.59
Vapor port	Activated metal	SVR12-3-VP3	07/26/01	3.1	2.50
Vapor port	Activated metal	SVR12-1-VP2	07/31/01	8.2	7.59
Vapor port	Activated metal	SVR12-1-VP3	07/31/01	3.3	2.67
Vapor port	Activated metal	SVR12-2-VP3	07/31/01	3.2	2.59
Vapor port	Activated metal	SVR12-1-VP1	08/01/01	12.3	11.73
Lysimeter	Activated metal	SVR12-1-L1	08/13/01	11.2	11.14
Lysimeter	Activated metal	SVR12-1-L2	08/13/01	5.9	5.76
Lysimeter	Uranium/enriched uranium	Pit5-4-L1	08/14/01	10.7	10.55
Soil-moisture probe	Uranium/enriched uranium	Pit5-4-M	08/14/01	11.0	10.16
Soil-moisture probe	Uranium/enriched uranium	Pit5-4-MB	08/14/01	9.0	8.18
Soil-moisture probe	Uranium/enriched uranium	Pit5-4-MB	08/14/01	9.0	2.81
Lysimeter	Uranium/enriched uranium	Pit5-TW1-L1	08/14/01	12.3	12.16
Soil-moisture probe	Uranium/enriched uranium	Pit5-TW1-M	08/14/01	11.1	10.24
Lysimeter	Organic sludge	743-08-L1	08/15/01	23.4	23.28
Lysimeter	Organic sludge	743-08-L2	08/15/01	9.1	8.99
Soil-moisture probe	Uranium/enriched uranium	Pit5-TW1-MB	08/15/01	9.0	2.85
Soil-moisture probe	Uranium/enriched uranium	Pit5-TW1-MB	08/15/01	9.0	8.22
Soil-moisture probe	Depleted uranium	DU-10-MD	08/20/01	7.5	6.72
Lysimeter	Depleted uranium	DU-14-L2	08/20/01	8.0	7.91
Soil-moisture probe	Moisture monitoring	MM4-4D	08/20/01	11.8	10.86
Lysimeter	Depleted uranium	DU-14-L1	08/21/01	16.1	15.95

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Soil-moisture probe	Moisture monitoring	MM4-1D	08/21/01	17.6	16.72
Visual probe	Organic sludge	743-03-V	08/27/01	13.6	NA
Visual probe	Organic sludge	743-08-V	08/29/01	13.6	NA
Visual probe	Americium/Nepunium	741-08-V	08/30/01	13.5	NA
Vapor port	Activated metal	SVR20-3-VP1	09/05/01	6.9	6.34
Vapor port	Activated metal	SVR20-3-VP2	09/05/01	13.5	12.94
Vapor port	Activated metal	SVR20-3-VP3	09/05/01	15.6	14.96
Soil-moisture probe	Activated metal	SVR 20-M	09/06/01	18.2	17.44
Soil-moisture probe	Activated metal	SVR 20-MB	09/06/01	14.6	13.79
Soil-moisture probe	Activated metal	SVR 20-MB	09/06/01	14.6	4.43
Vapor port	Activated metal	SVR20-5-VP3	09/10/01	17.8	17.17
Tensiometer	Activated metal	SVR20-1-T1	09/12/01	9.1	8.26
Tensiometer	Activated metal	SVR20-1-T2	09/12/01	13.5	12.68
Tensiometer	Activated metal	SVR20-1-T3	09/12/01	17.2	16.39
Tensiometer	Moisture monitoring	MM4-1-T2	09/17/01	15.7	14.87
Tensiometer	Moisture monitoring	MM4-1-T3	09/17/01	19.3	18.51
Tensiometer	Moisture monitoring	MM4-5-T1	09/17/01	4.9	4.14
Tensiometer	Moisture monitoring	MM4-5-T2	09/17/01	10.5	9.72
Tensiometer	Moisture monitoring	MM4-5-T3	09/17/01	14.3	13.51
Tensiometer	Depleted uranium	DU-14-T2	09/18/01	9.8	8.95
Tensiometer	Depleted uranium	DU-14-T3	09/18/01	16.1	15.30
Visual probe	Depleted uranium	DU-14-V	09/18/01	10.5	NA
Tensiometer	Moisture monitoring	MM4-1-T1	09/18/01	6.5	5.72
Tensiometer	Depleted uranium	DU-08-T1	09/19/01	6.1	5.30
Tensiometer	Depleted uranium	DU-08-T2	09/19/01	11.0	10.22
Tensiometer	Depleted uranium	DU-08-T3	09/19/01	17.2	16.39
Tensiometer	Depleted uranium	DU-14-T1	09/19/01	4.5	3.72
Tensiometer	Depleted uranium	DU-10-T3	09/20/01	9.9	9.10
Tensiometer	Moisture monitoring	MM4-2-T1	09/20/01	5.7	4.89
Tensiometer	Moisture monitoring	MM4-2-T2	09/20/01	12.2	11.39
Tensiometer	Moisture monitoring	MM4-2-T3	09/20/01	16.6	15.80
Tensiometer	Depleted uranium	DU-10-T1	09/24/01	4.8	4.03
Tensiometer	Depleted uranium	DU-10-T2	09/24/01	7.5	6.74
Tensiometer	Moisture monitoring	MM4-4-T1	09/24/01	4.4	3.60

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Tensiometer	Moisture monitoring	MM4-4-T2	09/24/01	9.0	8.22
Tensiometer	Moisture monitoring	MM4-4-T3	09/24/01	10.3	9.45
Visual probe	Depleted uranium	DU-08-V	09/25/01	17.6	NA
Tensiometer	Moisture monitoring	MM3-1-T1	09/26/01	5.7	4.89
Tensiometer	Moisture monitoring	MM3-1-T2	09/26/01	7.9	7.08
Tensiometer	Moisture monitoring	MM3-1-T3	09/26/01	10.5	9.74
Tensiometer	Moisture monitoring	MM3-2-T1	09/27/01	5.8	4.97
Tensiometer	Moisture monitoring	MM3-2-T2	09/27/01	7.4	6.55
Tensiometer	Moisture monitoring	MM3-2-T3	09/27/01	9.2	8.43
Tensiometer	Moisture monitoring	MM3-3-T2	09/27/01	5.4	4.55
Tensiometer	Moisture monitoring	MM3-3-T3	09/27/01	17.8	17.01
Tensiometer	Moisture monitoring	MM3-3-T1	10/01/01	14.8	13.99
Tensiometer	Moisture monitoring	MM2-1-T1	10/02/01	7.5	6.66
Tensiometer	Moisture monitoring	MM2-1-T2	10/02/01	12.7	11.91
Tensiometer	Moisture monitoring	MM2-1-T3	10/02/01	16.8	15.97
Tensiometer	Moisture monitoring	MM2-2-T1	10/02/01	5.7	4.93
Tensiometer	Moisture monitoring	MM2-2-T2	10/02/01	9.4	8.58
Tensiometer	Moisture monitoring	MM2-2-T3	10/02/01	10.0	9.22
Tensiometer	Moisture monitoring	MM2-3-T2	10/02/01	5.9	5.14
Tensiometer	Moisture monitoring	MM2-3-T3	10/02/01	7.4	6.55
Tensiometer	Organic sludge	743-18-T1	10/03/01	6.3	5.47
Tensiometer	Organic sludge	743-18-T2	10/03/01	15.7	14.91
Tensiometer	Organic sludge	743-18-T3	10/03/01	10.0	9.16
Tensiometer	Moisture monitoring	MM2-3-T1	10/03/01	4.6	3.78
Tensiometer	Organic sludge	743-08-T1	10/04/01	6.4	5.55
Tensiometer	Organic sludge	743-08-T2	10/04/01	13.8	12.99
Tensiometer	Organic sludge	743-08-T3	10/04/01	23.2	22.39
Tensiometer	Organic sludge	743-03-T1	10/08/01	6.1	5.30
Tensiometer	Organic sludge	743-03-T2	10/08/01	12.0	11.22
Tensiometer	Organic sludge	743-03-T3	10/08/01	19.3	18.49
Tensiometer	Moisture monitoring	MM1-1-T1	10/09/01	6.4	5.60
Tensiometer	Moisture monitoring	MM1-1-T2	10/09/01	11.3	10.49
Tensiometer	Moisture monitoring	MM1-1-T3	10/09/01	18.5	17.72
Tensiometer	Moisture monitoring	MM1-2-T1	10/09/01	6.4	5.55
Tensiometer	Moisture monitoring	MM1-2-T2	10/09/01	10.1	9.26
Tensiometer	Moisture monitoring	MM1-2-T3	10/09/01	14.8	13.97
Tensiometer	Moisture monitoring	MM1-3-T2	10/09/01	9.2	8.43

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Tensiometer	Moisture monitoring	MM1-3-T3	10/09/01	12.5	11.72
Tensiometer	Moisture monitoring	MM1-3-T1	10/10/01	5.9	5.14
Tensiometer	Americium/Nepunium	741-08-T2	10/11/01	11.4	10.55
Tensiometer	Americium/Nepunium	741-08-T3	10/11/01	20.7	19.91
Tensiometer	Activated metal	SVR12-1-T1	10/11/01	4.4	3.60
Tensiometer	Activated metal	SVR12-1-T2	10/11/01	9.2	8.43
Tensiometer	Activated metal	SVR12-1-T3	10/11/01	11.6	10.83
Tensiometer	Americium/Nepunium	741-08-T1	10/16/01	4.4	3.60
Visual probe	Pit 9	P9-09-V	10/23/01	6.7	NA
Visual probe	Pit 9	P9-20-V	10/25/01	12.6	NA
Visual probe	Pit 9	P9-09-VB	11/01/01	10.9	NA
Type A	Uranium/enriched uranium	P5-UEU-7	06/05/03	13.1	NA
Type A	Uranium/enriched uranium	P5-UEU-8	06/05/03	16.1	NA
Type A	Uranium/enriched uranium	P5-UEU-1	06/09/03	18.9	NA
Type A	Uranium/enriched uranium	P5-UEU-2	06/09/03	19.1	NA
Type A	Uranium/enriched uranium	P5-UEU-3	06/09/03	16.3	NA
Type A	Uranium/enriched uranium	P5-UEU-4	06/09/03	17.8	NA
Type A	Uranium/enriched uranium	P5-UEU-5	06/09/03	16.3	NA
Type A	Uranium/enriched uranium	P5-UEU-6	06/09/03	16.1	NA
Type A	Irradiated fuel material	T47-IF-1	06/10/03	11.6	NA
Type A	Irradiated fuel material	T47-IF-2	06/10/03	10.8	NA
Type A	Irradiated fuel material	T47-IF-3	06/10/03	11.6	NA
Type A	Irradiated fuel material	T47-IF-4	06/10/03	9.8	NA
Type A	Enriched uranium source	T3-EU-01	06/11/03	18.4	NA
Type A	Enriched uranium source	T3-EU-02	06/11/03	21.8	NA

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Enriched uranium source	T3-EU-03	06/11/03	11.9	NA
Type A	Enriched uranium source	T3-EU-04	06/12/03	13.5	NA
Type A	Liquid waste disposal	HAL1	06/16/03	20	NA
Type A	Liquid waste disposal	HAL2	06/16/03	22.4	NA
Type A	Liquid waste disposal	HAL3	06/16/03	8.7	NA
Type A	Liquid waste disposal	HAL4	06/16/03	12.9	NA
Type A	Pit 6 high plutonium density	P6-PU-3	06/19/03	8.3	NA
Type A	Pit 6 high plutonium density	P6-PU-1	06/23/03	20.3	NA
Type A	Pit 6 high plutonium density	P6-PU-2	06/23/03	20.3	NA
Type A	Pit 10 high plutonium density	P10-PU-1	06/25/03	5.9	NA
Type A	Pit 10 high plutonium density	P10-PU-2	06/25/03	10.4	NA
Type A	Pit 10 high plutonium density	P10-PU-3	06/25/03	20.7	NA
Type A	Americium/Nepunium	741-10	06/30/03	20.2	NA
Type A	Americium/Nepunium	741-11	06/30/03	20.1	NA
Type A	Unrecorded disposal	UD-04	07/01/03	14.4	NA
Type A	Unrecorded disposal	UD-05	07/01/03	4.7	NA
Type A	Unrecorded disposal	UD-05B	07/02/03	5.2	NA
Type A	Unrecorded disposal	UD-05C	07/02/03	5.5	NA
Type A	Unrecorded disposal	UD-05D	07/02/03	5.6	NA
Type A	Unrecorded disposal	UD-05E	07/07/03	10.8	NA
Type A	Unrecorded disposal	UD-03	07/09/03	4.6	NA
Type A	Unrecorded disposal	UD-03B	07/09/03	14.9	NA
Type A	Unrecorded disposal	UD-01	07/10/03	10.7	NA
Type A	Americium/Nepunium	741-08-C	11/12/03	22.2	NA
Type A	Americium/Nepunium	741-08-D	11/12/03	19.3	NA
Soil-moisture probe	Depleted uranium	DU-10-ME	11/20/03	6.3	5.5
Soil-moisture probe	Depleted uranium	DU-14-M2	11/20/03	12	12

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Soil-moisture probe	Depleted uranium	DU-08-M2	11/24/03	19	12.08
Soil-moisture probe	Depleted uranium	DU-08-M2	11/24/03	19	6
Soil-moisture probe	Depleted uranium	DU-08-M2	11/24/03	19	18.6
Soil-moisture probe	Organic sludge	743-03-M2	11/25/03	19.38	18.54
Soil-moisture probe	Organic sludge	743-03-M2	11/25/03	19.38	12.46
Soil-moisture probe	Organic sludge	743-18-M2	11/26/03	9	8.16
Soil-moisture probe	Organic sludge	743-18-M3	12/02/03	20	19.16
Type A	Pit 2 high plutonium density	P2-PU-1	12/03/03	19	NA
Type A	Pit 2 high plutonium density	P2-PU-2	12/04/03	14.3	NA
Type A	Pit 2 high plutonium density	P2-PU-4	12/08/03	13.2	NA
Type A	Pit 2 high plutonium density	P2-PU-5	12/08/03	15.5	NA
Type A	Pit 2 high plutonium density	P2-PU-3	12/09/03		NA
Type A	Pit 2 high plutonium density	P2-PU-6	12/09/03	21	NA
Type A	Uranium/enriched uranium	P5-UEU-9	12/10/03	17.8	NA
Lysimeter	Uranium/enriched uranium	P5-UEU-L1	08/03/04	16.6	NA
Lysimeter	Uranium/enriched uranium	P5-UEU-L2	08/03/04	13.4	NA
Soil-moisture probe	Uranium/enriched uranium	P5-UEU-M	08/04/04	14.8	4.3
Vapor port	Uranium/enriched uranium	P5-4-L2	08/04/04	13.5	NA
Soil-moisture probe	Uranium/enriched uranium	P5-UEU-M	08/04/04	14.8	3.0
Lysimeter	Uranium/enriched uranium	P5-TW1-L2	08/05/04	12.3	NA
Soil-moisture probe	Pit 6 high plutonium density	P6-PU-M	08/05/04	3.6	3.9
Soil-moisture probe	Pit 6 high plutonium density	P6-PU-M	08/05/04	3.6	14.5
Lysimeter	Pit 6 high plutonium density	P6-PU-L1	08/09/04	15.2	NA

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Lysimeter	Pit 6 high plutonium density	P6-PU-L2	08/09/04	20.5	NA
Lysimeter	Liquid waste disposal	HAL2-L1	08/11/04	22.0	NA
Lysimeter	Liquid waste disposal	HAL2-L2	08/11/04	22.0	NA
Soil-moisture probe	Liquid waste disposal	HAL2-M1	08/11/04	22.3	20.4
Soil-moisture probe	Liquid waste disposal	HAL2-M2	08/11/04	22.6	20.8
Lysimeter	Pit 2 high plutonium density	P2-PU-L3	08/16/04	13.6	NA
Lysimeter	Pit 2 high plutonium density	P2-PU-L4	08/16/04	13.6	NA
Soil-moisture probe	Pit 2 high plutonium density	P2-PU-M1	08/16/04	20.7	19.0
Lysimeter	Pit 2 high plutonium density	P2-PU-L1	08/17/04	10.9	NA
Lysimeter	Pit 2 high plutonium density	P2-PU-L2	08/17/04	15.0	NA
Soil-moisture probe	Pit 2 high plutonium density	P2-PU-M2	08/18/04	20.5	19.0
Lysimeter	Depleted uranium	DU-11-L1	08/19/04	17.1	NA
Lysimeter	Depleted uranium	DU-14-L3	08/19/04	13.3	NA
Lysimeter	Depleted uranium	DU-14-L4	08/19/04	13.2	NA
Lysimeter	Depleted uranium	DU-11-L2	08/23/04	11.3	NA
Lysimeter	Depleted uranium	DU-15-L1	08/23/04	16.1	NA
Lysimeter	Depleted uranium	DU-15-L2	08/23/04	16.1	NA
Lysimeter	Well focus area	T48N-IF-L1	08/24/04	10.1	NA
Lysimeter	Well focus area	T48S-IF-L1	08/24/04	14.1	NA
Lysimeter	Well focus area	T50-IF-L1	08/24/04	12.7	NA
Lysimeter	Irradiated fuel material	T47-IF-L1	08/25/04	11.1	NA
Lysimeter	Irradiated fuel material	T47-IF-L2	08/25/04	11.2	NA
Lysimeter	Americium/Neptunium	741-08-L3	08/26/04	15.1	NA
Lysimeter	Americium/Neptunium	741-08-L5	08/26/04	15.3	NA
Lysimeter	Americium/Neptunium	741-08-L6	08/26/04	8.8	NA
Lysimeter	Americium/Neptunium	741-08-L4	08/30/04	7.9	NA

Table A-1. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Lysimeter	Enriched uranium source	T3-EU-L1	08/30/04	13.4	NA
Lysimeter	Enriched uranium source	T3-EU-L2	08/30/04	9.7	NA
Lysimeter	Depleted uranium	DU-10-L3	09/02/04	7.9	NA
Lysimeter	Enriched uranium source	T3-EU-L3	09/02/04	21.7	NA
Lysimeter	Uranium/enriched uranium	P5-4-L3	09/07/04	13.1	NA
Type A	Irradiated fuel material	T47-IF-5	08/24/04	11.10	NA
Type A	Irradiated fuel material	T47-IF-6	08/24/04	11.70	NA

Table A-2. Probe by type.

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Lysimeter	Organic sludge	743-03-L1	06/05/01	12.9	12.80
Lysimeter	Organic sludge	743-03-L2	06/06/01	9.9	9.80
Lysimeter	Organic sludge	743-18-L1	06/07/01	12.2	12.10
Lysimeter	Organic sludge	743-18-L2	06/07/01	12.9	12.85
Lysimeter	Depleted uranium	DU-10-L1	06/19/01	9.9	9.76
Lysimeter	Depleted uranium	DU-10-L2	06/19/01	7.1	7.03
Lysimeter	Depleted uranium	DU-08-L1	06/20/01	16.2	16.10
Lysimeter	Americium/Neptunium	741-08-L1	07/03/01	15.3	15.24
Lysimeter	Americium/Neptunium	741-08-L2	07/03/01	7.9	7.78
Lysimeter	Depleted uranium	DU-08-L2	07/10/01	14.2	14.08
Lysimeter	Activated metal	SVR12-1-L1	08/13/01	11.2	11.14
Lysimeter	Activated metal	SVR12-1-L2	08/13/01	5.9	5.76
Lysimeter	Uranium/enriched uranium	Pit5-4-L1	08/14/01	10.7	10.55
Lysimeter	Uranium/enriched uranium	Pit5-TW1-L1	08/14/01	12.3	12.16
Lysimeter	Organic sludge	743-08-L1	08/15/01	23.4	23.28
Lysimeter	Organic sludge	743-08-L2	08/15/01	9.1	8.99
Lysimeter	Depleted uranium	DU-14-L2	08/20/01	8.0	7.91
Lysimeter	Depleted uranium	DU-14-L1	08/21/01	16.1	15.95
Lysimeter	Uranium/enriched uranium	P5-UEU-L1	08/03/04	16.6	NA
Lysimeter	Uranium/enriched uranium	P5-UEU-L2	08/03/04	13.4	NA
Lysimeter	Uranium/enriched uranium	P5-TW1-L2	08/05/04	12.3	NA
Lysimeter	Pit 6 high plutonium density	P6-PU-L1	08/09/04	15.2	NA
Lysimeter	Pit 6 high plutonium density	P6-PU-L2	08/09/04	20.5	NA
Lysimeter	Liquid waste disposal	HAL2-L1	08/11/04	22.0	NA
Lysimeter	Liquid waste disposal	HAL2-L2	08/11/04	22.0	NA
Lysimeter	Pit 2 high plutonium density	P2-PU-L3	08/16/04	13.6	NA
Lysimeter	Pit 2 high plutonium density	P2-PU-L4	08/16/04	13.6	NA

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Lysimeter	Pit 2 high plutonium density	P2-PU-L1	08/17/04	10.9	NA
Lysimeter	Pit 2 high plutonium density	P2-PU-L2	08/17/04	15.0	NA
Lysimeter	Depleted uranium	DU-11-L1	08/19/04	17.1	NA
Lysimeter	Depleted uranium	DU-14-L3	08/19/04	13.3	NA
Lysimeter	Depleted uranium	DU-14-L4	08/19/04	13.2	NA
Lysimeter	Depleted uranium	DU-11-L2	08/23/04	11.3	NA
Lysimeter	Depleted uranium	DU-15-L1	08/23/04	16.1	NA
Lysimeter	Depleted uranium	DU-15-L2	08/23/04	16.1	NA
Lysimeter	Well focus area	T48N-IF-L1	08/24/04	10.1	NA
Lysimeter	Well focus area	T48S-IF-L1	08/24/04	14.1	NA
Lysimeter	Well focus area	T50-IF-L1	08/24/04	12.7	NA
Lysimeter	Irradiated fuel material	T47-IF-L1	08/25/04	11.1	NA
Lysimeter	Irradiated fuel material	T47-IF-L2	08/25/04	11.2	NA
Lysimeter	Americium/Neptunium	741-08-L3	08/26/04	15.1	NA
Lysimeter	Americium/Neptunium	741-08-L5	08/26/04	15.3	NA
Lysimeter	Americium/Neptunium	741-08-L6	08/26/04	8.8	NA
Lysimeter	Americium/Neptunium	741-08-L4	08/30/04	7.9	NA
Lysimeter	Enriched uranium source	T3-EU-L1	08/30/04	13.4	NA
Lysimeter	Enriched uranium source	T3-EU-L2	08/30/04	9.7	NA
Lysimeter	Depleted uranium	DU-10-L3	09/02/04	7.9	NA
Lysimeter	Enriched uranium source	T3-EU-L3	09/02/04	21.7	NA
Lysimeter	Uranium/enriched uranium	P5-4-L3	09/07/04	13.1	NA
Soil-moisture probe	Moisture monitoring	MM4-3	03/01/01	10.0	9.11
Soil-moisture probe	Moisture monitoring	MM4-2	03/07/01	18.3	17.39
Soil-moisture probe	Moisture monitoring	MM4-4	03/07/01	11.2	10.28
Soil-moisture probe	Moisture monitoring	MM4-5	03/08/01	14.8	13.88
Soil-moisture probe	Moisture monitoring	MM4-1	03/12/01	20.3	19.44
Soil-moisture probe	Moisture monitoring	MM3-1	03/22/01	10.6	9.69
Soil-moisture probe	Moisture monitoring	MM3-2	03/26/01	9.4	8.53
Soil-moisture probe	Moisture monitoring	MM3-3	03/26/01	17.9	17.00
Soil-moisture probe	Moisture monitoring	MM2-1	03/28/01	16.9	16.00

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Soil-moisture probe	Moisture monitoring	MM2-2	03/28/01	11.7	10.78
Soil-moisture probe	Moisture monitoring	MM2-3	03/28/01	3.9	3.05
Soil-moisture probe	Moisture monitoring	MM1-1	04/12/01	18.7	17.79
Soil-moisture probe	Moisture monitoring	MM1-2	04/12/01	14.8	13.89
Soil-moisture probe	Moisture monitoring	MM1-3	04/16/01	12.4	11.47
Soil-moisture probe	Moisture monitoring	MM1-3B	04/17/01	10.6	4.90
Soil-moisture probe	Moisture monitoring	MM1-3B	04/17/01	10.6	9.75
Soil-moisture probe	Moisture monitoring	MM1-1B	04/18/01	12.5	11.58
Soil-moisture probe	Moisture monitoring	MM1-1B	04/18/01	12.5	5.50
Soil-moisture probe	Moisture monitoring	MM1-2B	04/18/01	11.6	10.75
Soil-moisture probe	Moisture monitoring	MM1-2B	04/18/01	11.6	6.00
Soil-moisture probe	Moisture monitoring	MM2-1B	04/18/01	13.4	7.25
Soil-moisture probe	Moisture monitoring	MM2-1B	04/18/01	13.4	12.51
Soil-moisture probe	Moisture monitoring	MM2-2B	04/18/01	10.0	4.00
Soil-moisture probe	Moisture monitoring	MM2-2B	04/18/01	10.0	9.14
Soil-moisture probe	Moisture monitoring	MM2-3B	04/23/01	7.9	6.98
Soil-moisture probe	Moisture monitoring	MM2-3B	04/23/01	7.9	1.67
Soil-moisture probe	Organic sludge	743-03-M1	04/24/01	20.0	12.31
Soil-moisture probe	Organic sludge	743-03-M1	04/24/01	20.0	3.36
Soil-moisture probe	Organic sludge	743-03-M1	04/24/01	20.0	19.09
Soil-moisture probe	Organic sludge	743-08-M1	04/30/01	23.1	6.60
Soil-moisture probe	Organic sludge	743-08-M1	04/30/01	23.1	13.90
Soil-moisture probe	Organic sludge	743-08-M1	04/30/01	23.1	22.28
Soil-moisture probe	Organic sludge	743-18-M1	04/30/01	20.0	6.47
Soil-moisture probe	Organic sludge	743-18-M1	04/30/01	20.0	19.20
Soil-moisture probe	Organic sludge	743-18-M1	04/30/01	20.0	12.83
Soil-moisture probe	Moisture monitoring	MM3-1B	05/14/01	8.4	7.62
Soil-moisture probe	Moisture monitoring	MM3-1C	05/14/01	5.3	4.47
Soil-moisture probe	Moisture monitoring	MM3-2B	05/14/01	7.8	6.96
Soil-moisture probe	Moisture monitoring	MM3-2C	05/14/01	4.8	3.97
Soil-moisture probe	Moisture monitoring	MM3-3B	05/14/01	13.8	13.82
Soil-moisture probe	Moisture monitoring	MM3-3B	05/14/01	13.8	7.46
Soil-moisture probe	Moisture monitoring	MM4-3B	05/21/01	6.2	6.18
Soil-moisture probe	Moisture monitoring	MM4-3C	06/12/01	5.6	4.80
Soil-moisture probe	Moisture monitoring	MM4-4B	06/12/01	9.5	8.72
Soil-moisture probe	Moisture monitoring	MM4-4B	06/12/01	9.5	4.17
Soil-moisture probe	Americium/Neptunium	741-08-M1	07/09/01	20.7	19.86
Soil-moisture probe	Americium/Neptunium	741-08-M1	07/09/01	20.7	4.14

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Soil-moisture probe	Americium/Neptunium	741-08-M1	07/09/01	20.7	11.50
Soil-moisture probe	Depleted uranium	DU-08-M1	07/10/01	18.7	6.14
Soil-moisture probe	Depleted uranium	DU-08-M1	07/10/01	18.7	11.50
Soil-moisture probe	Depleted uranium	DU-08-M1	07/10/01	18.7	17.86
Soil-moisture probe	Moisture monitoring	MM4-2B	07/10/01	12.9	12.08
Soil-moisture probe	Moisture monitoring	MM4-2B	07/10/01	12.9	4.72
Soil-moisture probe	Depleted uranium	DU-10-M1	07/11/01	10.1	9.25
Soil-moisture probe	Depleted uranium	DU-10-M2	07/11/01	7.4	6.64
Soil-moisture probe	Depleted uranium	DU-10-M3	07/11/01	4.8	3.97
Soil-moisture probe	Depleted uranium	DU-14-M1	07/16/01	16.0	15.20
Soil-moisture probe	Depleted uranium	DU-14-M1	07/16/01	16.0	9.83
Soil-moisture probe	Depleted uranium	DU-14-M1	07/16/01	16.0	4.47
Soil-moisture probe	Moisture monitoring	MM4-1B	07/16/01	15.5	14.67
Soil-moisture probe	Moisture monitoring	MM4-1B	07/16/01	15.5	6.30
Soil-moisture probe	Moisture monitoring	MM4-5B	07/16/01	10.6	9.75
Soil-moisture probe	Moisture monitoring	MM4-5B	07/16/01	10.6	4.39
Soil-moisture probe	Activated metal	SVR 12-M	07/25/01	12.3	11.45
Soil-moisture probe	Activated metal	SVR 12-MB	07/25/01	9.2	4.30
Soil-moisture probe	Activated metal	SVR 12-MB	07/25/01	9.2	8.39
Soil-moisture probe	Uranium/enriched uranium	Pit5-4-M	08/14/01	11.0	10.16
Soil-moisture probe	Uranium/enriched uranium	Pit5-4-MB	08/14/01	9.0	8.18
Soil-moisture probe	Uranium/enriched uranium	Pit5-4-MB	08/14/01	9.0	2.81
Soil-moisture probe	Uranium/enriched uranium	Pit5-TW1-M	08/14/01	11.1	10.24
Soil-moisture probe	Uranium/enriched uranium	Pit5-TW1-MB	08/15/01	9.0	2.85
Soil-moisture probe	Uranium/enriched uranium	Pit5-TW1-MB	08/15/01	9.0	8.22
Soil-moisture probe	Depleted uranium	DU-10-MD	08/20/01	7.5	6.72
Soil-moisture probe	Moisture monitoring	MM4-4D	08/20/01	11.8	10.86
Soil-moisture probe	Moisture monitoring	MM4-1D	08/21/01	17.6	16.72
Soil-moisture probe	Activated metal	SVR 20-M	09/06/01	18.2	17.44
Soil-moisture probe	Activated metal	SVR 20-MB	09/06/01	14.6	13.79
Soil-moisture probe	Activated metal	SVR 20-MB	09/06/01	14.6	4.43
Soil-moisture probe	Depleted uranium	DU-10-ME	11/20/03	6.3	5.5
Soil-moisture probe	Depleted uranium	DU-14-M2	11/20/03	12	12

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Soil-moisture probe	Depleted uranium	DU-08-M2	11/24/03	19	12.08
Soil-moisture probe	Depleted uranium	DU-08-M2	11/24/03	19	6
Soil-moisture probe	Depleted uranium	DU-08-M2	11/24/03	19	18.6
Soil-moisture probe	Organic sludge	743-03-M2	11/25/03	19.38	18.54
Soil-moisture probe	Organic sludge	743-03-M2	11/25/03	19.38	12.46
Soil-moisture probe	Organic sludge	743-18-M2	11/26/03	9	8.16
Soil-moisture probe	Organic sludge	743-18-M3	12/02/03	20	19.16
Soil-moisture probe	Uranium/enriched uranium	P5-UEU-M	08/04/04	14.8	4.3
Soil-moisture probe	Uranium/enriched uranium	P5-UEU-M	08/04/04	14.8	3.0
Soil-moisture probe	Pit 6 high plutonium density	P6-PU-M	08/05/04	3.6	3.9
Soil-moisture probe	Pit 6 high plutonium density	P6-PU-M	08/05/04	3.6	14.5
Soil-moisture probe	Liquid waste disposal	HAL2-M1	08/11/04	22.3	20.4
Soil-moisture probe	Liquid waste disposal	HAL2-M2	08/11/04	22.6	20.8
Soil-moisture probe	Pit 2 high plutonium density	P2-PU-M1	08/16/04	20.7	19.0
Soil-moisture probe	Pit 2 high plutonium density	P2-PU-M2	08/18/04	20.5	19.0
Tensiometer	Activated metal	SVR20-1-T1	09/12/01	9.1	8.26
Tensiometer	Activated metal	SVR20-1-T2	09/12/01	13.5	12.68
Tensiometer	Activated metal	SVR20-1-T3	09/12/01	17.2	16.39
Tensiometer	Moisture monitoring	MM4-1-T2	09/17/01	15.7	14.87
Tensiometer	Moisture monitoring	MM4-1-T3	09/17/01	19.3	18.51
Tensiometer	Moisture monitoring	MM4-5-T1	09/17/01	4.9	4.14
Tensiometer	Moisture monitoring	MM4-5-T2	09/17/01	10.5	9.72
Tensiometer	Moisture monitoring	MM4-5-T3	09/17/01	14.3	13.51
Tensiometer	Depleted uranium	DU-14-T2	09/18/01	9.8	8.95
Tensiometer	Depleted uranium	DU-14-T3	09/18/01	16.1	15.30
Tensiometer	Moisture monitoring	MM4-1-T1	09/18/01	6.5	5.72
Tensiometer	Depleted uranium	DU-08-T1	09/19/01	6.1	5.30
Tensiometer	Depleted uranium	DU-08-T2	09/19/01	11.0	10.22
Tensiometer	Depleted uranium	DU-08-T3	09/19/01	17.2	16.39
Tensiometer	Depleted uranium	DU-14-T1	09/19/01	4.5	3.72
Tensiometer	Depleted uranium	DU-10-T3	09/20/01	9.9	9.10

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Tensiometer	Moisture monitoring	MM4-2-T1	09/20/01	5.7	4.89
Tensiometer	Moisture monitoring	MM4-2-T2	09/20/01	12.2	11.39
Tensiometer	Moisture monitoring	MM4-2-T3	09/20/01	16.6	15.80
Tensiometer	Depleted uranium	DU-10-T1	09/24/01	4.8	4.03
Tensiometer	Depleted uranium	DU-10-T2	09/24/01	7.5	6.74
Tensiometer	Moisture monitoring	MM4-4-T1	09/24/01	4.4	3.60
Tensiometer	Moisture monitoring	MM4-4-T2	09/24/01	9.0	8.22
Tensiometer	Moisture monitoring	MM4-4-T3	09/24/01	10.3	9.45
Tensiometer	Moisture monitoring	MM3-1-T1	09/26/01	5.7	4.89
Tensiometer	Moisture monitoring	MM3-1-T2	09/26/01	7.9	7.08
Tensiometer	Moisture monitoring	MM3-1-T3	09/26/01	10.5	9.74
Tensiometer	Moisture monitoring	MM3-2-T1	09/27/01	5.8	4.97
Tensiometer	Moisture monitoring	MM3-2-T2	09/27/01	7.4	6.55
Tensiometer	Moisture monitoring	MM3-2-T3	09/27/01	9.2	8.43
Tensiometer	Moisture monitoring	MM3-3-T2	09/27/01	5.4	4.55
Tensiometer	Moisture monitoring	MM3-3-T3	09/27/01	17.8	17.01
Tensiometer	Moisture monitoring	MM3-3-T1	10/01/01	14.8	13.99
Tensiometer	Moisture monitoring	MM2-1-T1	10/02/01	7.5	6.66
Tensiometer	Moisture monitoring	MM2-1-T2	10/02/01	12.7	11.91
Tensiometer	Moisture monitoring	MM2-1-T3	10/02/01	16.8	15.97
Tensiometer	Moisture monitoring	MM2-2-T1	10/02/01	5.7	4.93
Tensiometer	Moisture monitoring	MM2-2-T2	10/02/01	9.4	8.58
Tensiometer	Moisture monitoring	MM2-2-T3	10/02/01	10.0	9.22
Tensiometer	Moisture monitoring	MM2-3-T2	10/02/01	5.9	5.14
Tensiometer	Moisture monitoring	MM2-3-T3	10/02/01	7.4	6.55
Tensiometer	Organic sludge	743-18-T1	10/03/01	6.3	5.47
Tensiometer	Organic sludge	743-18-T2	10/03/01	15.7	14.91
Tensiometer	Organic sludge	743-18-T3	10/03/01	10.0	9.16
Tensiometer	Moisture monitoring	MM2-3-T1	10/03/01	4.6	3.78
Tensiometer	Organic sludge	743-08-T1	10/04/01	6.4	5.55
Tensiometer	Organic sludge	743-08-T2	10/04/01	13.8	12.99
Tensiometer	Organic sludge	743-08-T3	10/04/01	23.2	22.39
Tensiometer	Organic sludge	743-03-T1	10/08/01	6.1	5.30
Tensiometer	Organic sludge	743-03-T2	10/08/01	12.0	11.22
Tensiometer	Organic sludge	743-03-T3	10/08/01	19.3	18.49
Tensiometer	Moisture monitoring	MM1-1-T1	10/09/01	6.4	5.60
Tensiometer	Moisture monitoring	MM1-1-T2	10/09/01	11.3	10.49
Tensiometer	Moisture monitoring	MM1-1-T3	10/09/01	18.5	17.72

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Tensiometer	Moisture monitoring	MM1-2-T1	10/09/01	6.4	5.55
Tensiometer	Moisture monitoring	MM1-2-T2	10/09/01	10.1	9.26
Tensiometer	Moisture monitoring	MM1-2-T3	10/09/01	14.8	13.97
Tensiometer	Moisture monitoring	MM1-3-T2	10/09/01	9.2	8.43
Tensiometer	Moisture monitoring	MM1-3-T3	10/09/01	12.5	11.72
Tensiometer	Moisture monitoring	MM1-3-T1	10/10/01	5.9	5.14
Tensiometer	Americium/Neptunium	741-08-T2	10/11/01	11.4	10.55
Tensiometer	Americium/Neptunium	741-08-T3	10/11/01	20.7	19.91
Tensiometer	Activated metal	SVR12-1-T1	10/11/01	4.4	3.60
Tensiometer	Activated metal	SVR12-1-T2	10/11/01	9.2	8.43
Tensiometer	Activated metal	SVR12-1-T3	10/11/01	11.6	10.83
Tensiometer	Americium/Neptunium	741-08-T1	10/16/01	4.4	3.60
Type A	Pit 9	TP-01	08/01/99	9.5	NA
Type A	Pit 9	TP-02B	08/01/99	17.0	NA
Type A	Pit 9	TP-03	08/01/99	14.5	NA
Type A	Pit 9	P9-08	12/01/99	13.5	NA
Type A	Pit 9	P9-03	12/14/99	11.5	NA
Type A	Pit 9	P9-09	12/15/99	11.5	NA
Type A	Pit 9	P9-17	12/15/99	14.8	NA
Type A	Pit 9	P9-18	12/15/99	18.0	NA
Type A	Pit 9	P9-10	12/16/99	9.5	NA
Type A	Pit 9	P9-15	12/16/99	13.5	NA
Type A	Pit 9	P9-16	12/16/99	13.8	NA
Type A	Pit 9	P9-02	12/20/99	15.5	NA
Type A	Pit 9	P9-04	12/20/99	16.5	NA
Type A	Pit 9	P9-14	12/20/99	14.5	NA
Type A	Pit 9	P9-05	12/21/99	16.9	NA
Type A	Pit 9	P9-07	12/21/99	15.8	NA
Type A	Pit 9	P9-11	12/21/99	15.0	NA
Type A	Pit 9	P9-12	12/21/99	16.5	NA
Type A	Pit 9	P9-13	12/21/99	15.8	NA
Type A	Pit 9	P9-01	12/22/99	13.9	NA
Type A	Pit 9	P9-06	12/22/99	14.5	NA
Type A	Pit 9	P9-19	12/22/99	15.0	NA
Type A	Pit 9	P9-20	12/22/99	12.3	NA
Type A	Depleted uranium	DU-04	08/14/00	14.0	NA
Type A	Depleted uranium	DU-05	08/14/00	18.3	NA
Type A	Depleted uranium	DU-01	08/15/00	14.3	NA

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Depleted uranium	DU-02	08/15/00	14.8	NA
Type A	Depleted uranium	DU-03	08/15/00	14.5	NA
Type A	Depleted uranium	DU-06	08/16/00	18.5	NA
Type A	Depleted uranium	DU-07	08/16/00	14.5	NA
Type A	Depleted uranium	DU-08	08/16/00	18.7	NA
Type A	Americium/Neptunium	741-07	08/21/00	6.3	NA
Type A	Americium/Neptunium	741-08	08/22/00	22.3	NA
Type A	Americium/Neptunium	741-09	08/22/00	14.3	NA
Type A	Americium/Neptunium	741-05	08/23/00	6.4	NA
Type A	Americium/Neptunium	741-06	08/23/00	18.0	NA
Type A	Americium/Neptunium	741-03	08/24/00	20.3	NA
Type A	Americium/Neptunium	741-04	08/24/00	24.3	NA
Type A	Americium/Neptunium	741-01	08/28/00	5.9	NA
Type A	Americium/Neptunium	741-02	08/28/00	18.1	NA
Type A	Organic sludge	743-23	08/31/00	8.4	NA
Type A	Organic sludge	743-24	08/31/00	23.5	NA
Type A	Organic sludge	743-25	08/31/00	17.8	NA
Type A	Organic sludge	743-22	09/05/00	21.4	NA
Type A	Organic sludge	743-21	09/06/00	14.8	NA
Type A	Organic sludge	743-20	09/07/00	16.3	NA
Type A	Organic sludge	743-19	09/11/00	4.2	NA
Type A	Organic sludge	743-18	09/25/00	21.0	NA
Type A	Organic sludge	743-17	09/27/00	20.7	NA
Type A	Organic sludge	743-15	09/28/00	21.9	NA
Type A	Organic sludge	743-16	09/28/00	16.2	NA
Type A	Organic sludge	743-13	10/02/00	25.6	NA
Type A	Organic sludge	743-14	10/02/00	23.0	NA
Type A	Organic sludge	743-12	10/10/00	25.0	NA
Type A	Organic sludge	743-09	10/11/00	24.3	NA
Type A	Organic sludge	743-10	10/11/00	25.8	NA
Type A	Organic sludge	743-11	10/11/00	25.5	NA
Type A	Organic sludge	743-05	10/12/00	27.0	NA
Type A	Organic sludge	743-06	10/12/00	26.2	NA
Type A	Organic sludge	743-07	10/12/00	25.3	NA
Type A	Organic sludge	743-08	10/12/00	25.3	NA
Type A	Organic sludge	743-03	10/16/00	19.5	NA
Type A	Organic sludge	743-04	10/16/00	25.5	NA
Type A	Organic sludge	743-01	10/17/00	17.2	NA

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Organic sludge	743-02	10/17/00	20.7	NA
Type A	Pit 9	P9-21A	10/26/00	13.3	NA
Type A	Pit 9	P9-24A	10/26/00	12.7	NA
Type A	Pit 9	P9-22	10/30/00	12.3	NA
Type A	Pit 9	P9-26A	10/30/00	11.3	NA
Type A	Pit 9	P9-27	10/30/00	11.3	NA
Type A	Pit 9	P9-23	10/31/00	11.4	NA
Type A	Pit 9	P9-25A	10/31/00	11.4	NA
Type A	Pit 9	P9-28A	10/31/00	10.1	NA
Type A	Pit 9	P9-GR-07	11/28/00	12.8	NA
Type A	Pit 9	P9-GR-03	11/29/00	13.8	NA
Type A	Pit 9	P9-GR-04	11/29/00	11.5	NA
Type A	Pit 9	P9-GR-05	11/29/00	11.5	NA
Type A	Pit 9	P9-GR-06	11/29/00	11.2	NA
Type A	Pit 9	P9-GR-01	11/30/00	13.7	NA
Type A	Pit 9	P9-GR-02	11/30/00	13.8	NA
Type A	Pit 9	P9-FI-02	12/05/00	12.1	NA
Type A	Pit 9	P9-FI-03	12/05/00	16.3	NA
Type A	Pit 9	P9-FI-07	12/05/00	16.0	NA
Type A	Pit 9	P9-FI-08	12/05/00	16.2	NA
Type A	Pit 9	P9-FI-04	12/06/00	13.2	NA
Type A	Pit 9	P9-FI-05	12/06/00	13.2	NA
Type A	Pit 9	P9-FI-06	12/06/00	17.9	NA
Type A	Pit 9	P9-FI-01	12/07/00	10.1	NA
Type A	Organic sludge	743-32	12/11/00	12.1	NA
Type A	Organic sludge	743-33	12/11/00	12.1	NA
Type A	Organic sludge	743-34	12/11/00	11.9	NA
Type A	Organic sludge	743-35	12/11/00	16.4	NA
Type A	Organic sludge	743-38	12/12/00	15.5	NA
Type A	Organic sludge	743-39	12/12/00	19.8	NA
Type A	Organic sludge	743-40	12/12/00	18.4	NA
Type A	Organic sludge	743-41	12/12/00	21.5	NA
Type A	Organic sludge	743-42	12/12/00	22.2	NA
Type A	Organic sludge	743-36	12/13/00	25.8	NA
Type A	Organic sludge	743-37	12/13/00	25.8	NA
Type A	Depleted uranium	DU-09	12/14/00	18.5	NA
Type A	Depleted uranium	DU-10	12/14/00	17.3	NA
Type A	Depleted uranium	DU-11	12/14/00	18.1	NA

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Depleted uranium	DU-12	12/14/00	18.3	NA
Type A	Depleted uranium	DU-13	12/14/00	18.1	NA
Type A	Depleted uranium	DU-14	12/14/00	17.3	NA
Type A	Depleted uranium	DU-15	12/18/00	17.1	NA
Type A	Depleted uranium	DU-16	12/18/00	16.3	NA
Type A	Depleted uranium	DU-17	12/18/00	20.2	NA
Type A	Organic sludge	743-08-01	04/24/01	25.6	NA
Type A	Organic sludge	743-08-02	04/24/01	25.0	NA
Type A	Organic sludge	743-08-03	04/24/01	26.3	NA
Type A	Organic sludge	743-08-04	04/25/01	25.1	NA
Type A	Organic sludge	743-08-05	04/25/01	25.0	NA
Type A	Organic sludge	743-08-06	04/25/01	25.1	NA
Type A	Uranium/enriched uranium	Pit5-4-1	05/03/01	16.5	NA
Type A	Uranium/enriched uranium	Pit5-4-2	05/03/01	16.4	NA
Type A	Uranium/enriched uranium	Pit5-4-3	05/03/01	16.3	NA
Type A	Uranium/enriched uranium	Pit5-4-4	05/03/01	12.7	NA
Type A	Uranium/enriched uranium	Pit5-4-5	05/03/01	10.5	NA
Type A	Uranium/enriched uranium	Pit5-4-6	05/03/01	16.5	NA
Type A	Uranium/enriched uranium	Pit5-4-7	05/03/01	14.1	NA
Type A	Uranium/enriched uranium	Pit5-1-1	05/07/01	7.8	NA
Type A	Uranium/enriched uranium	Pit5-1-2	05/07/01	7.8	NA
Type A	Uranium/enriched uranium	Pit5-1-3	05/07/01	9.1	NA
Type A	Uranium/enriched uranium	Pit5-1-4	05/07/01	8.5	NA
Type A	Uranium/enriched uranium	Pit5-1-5	05/07/01	3.8	NA
Type A	Uranium/enriched uranium	Pit5-1-6	05/08/01	11.7	NA
Type A	Uranium/enriched uranium	Pit5-1-7	05/08/01	16.0	NA

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Uranium/enriched uranium	Pit5-1-8	05/08/01	13.6	NA
Type A	Pit 9	P9-20-01	05/10/01	13.9	NA
Type A	Pit 9	P9-20-02	05/10/01	11.6	NA
Type A	Pit 9	P9-20-03	05/10/01	12.2	NA
Type A	Pit 9	P9-20-04	05/10/01	12.6	NA
Type A	Pit 9	P9-20-05	05/10/01	12.0	NA
Type A	Pit 9	P9-20-06	05/10/01	12.3	NA
Type A	Depleted uranium	DU-08-A	06/28/01	18.1	NA
Type A	Depleted uranium	DU-08-B	06/28/01	17.6	NA
Type A	Depleted uranium	DU-10-A	06/28/01	17.0	NA
Type A	Depleted uranium	DU-14-A	06/28/01	17.5	NA
Type A	Depleted uranium	DU-14-B	06/28/01	17.6	NA
Type A	Americium/Neptunium	741-08-A	07/02/01	20.8	NA
Type A	Depleted uranium	DU-10-B	07/02/01	17.2	NA
Type A	Americium/Neptunium	741-08-B	07/03/01	21.8	NA
Type A	Uranium/enriched uranium	P5-UEU-7	06/05/03	13.1	NA
Type A	Uranium/enriched uranium	P5-UEU-8	06/05/03	16.1	NA
Type A	Uranium/enriched uranium	P5-UEU-1	06/09/03	18.9	NA
Type A	Uranium/enriched uranium	P5-UEU-2	06/09/03	19.1	NA
Type A	Uranium/enriched uranium	P5-UEU-3	06/09/03	16.3	NA
Type A	Uranium/enriched uranium	P5-UEU-4	06/09/03	17.8	NA
Type A	Uranium/enriched uranium	P5-UEU-5	06/09/03	16.3	NA
Type A	Uranium/enriched uranium	P5-UEU-6	06/09/03	16.1	NA
Type A	Irradiated fuel material	T47-IF-1	06/10/03	11.6	NA
Type A	Irradiated fuel material	T47-IF-2	06/10/03	10.8	NA
Type A	Irradiated fuel material	T47-IF-3	06/10/03	11.6	NA
Type A	Irradiated fuel material	T47-IF-4	06/10/03	9.8	NA

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Enriched uranium source	T3-EU-01	06/11/03	18.4	NA
Type A	Enriched uranium source	T3-EU-02	06/11/03	21.8	NA
Type A	Enriched uranium source	T3-EU-03	06/11/03	11.9	NA
Type A	Enriched uranium source	T3-EU-04	06/12/03	13.5	NA
Type A	Liquid waste disposal	HAL1	06/16/03	20	NA
Type A	Liquid waste disposal	HAL2	06/16/03	22.4	NA
Type A	Liquid waste disposal	HAL3	06/16/03	8.7	NA
Type A	Liquid waste disposal	HAL4	06/16/03	12.9	NA
Type A	Pit 6 high plutonium density	P6-PU-3	06/19/03	8.3	NA
Type A	Pit 6 high plutonium density	P6-PU-1	06/23/03	20.3	NA
Type A	Pit 6 high plutonium density	P6-PU-2	06/23/03	20.3	NA
Type A	Pit 10 high plutonium density	P10-PU-1	06/25/03	5.9	NA
Type A	Pit 10 high plutonium density	P10-PU-2	06/25/03	10.4	NA
Type A	Pit 10 high plutonium density	P10-PU-3	06/25/03	20.7	NA
Type A	Americium/Neptunium	741-10	06/30/03	20.2	NA
Type A	Americium/Neptunium	741-11	06/30/03	20.1	NA
Type A	Unrecorded disposal	UD-04	07/01/03	14.4	NA
Type A	Unrecorded disposal	UD-05	07/01/03	4.7	NA
Type A	Unrecorded disposal	UD-05B	07/02/03	5.2	NA
Type A	Unrecorded disposal	UD-05C	07/02/03	5.5	NA
Type A	Unrecorded disposal	UD-05D	07/02/03	5.6	NA
Type A	Unrecorded disposal	UD-05E	07/07/03	10.8	NA
Type A	Unrecorded disposal	UD-03	07/09/03	4.6	NA
Type A	Unrecorded disposal	UD-03B	07/09/03	14.9	NA
Type A	Unrecorded disposal	UD-01	07/10/03	10.7	NA
Type A	Americium/Neptunium	741-08-C	11/12/03	22.2	NA

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Type A	Americium/Neptunium	741-08-D	11/12/03	19.3	NA
Type A	Pit 2 high plutonium density	P2-PU-1	12/03/03	19	NA
Type A	Pit 2 high plutonium density	P2-PU-2	12/04/03	14.3	NA
Type A	Pit 2 high plutonium density	P2-PU-4	12/08/03	13.2	NA
Type A	Pit 2 high plutonium density	P2-PU-5	12/08/03	15.5	NA
Type A	Pit 2 high plutonium density	P2-PU-3	12/09/03		NA
Type A	Pit 2 high plutonium density	P2-PU-6	12/09/03	21	NA
Type A	Uranium/enriched uranium	P5-UEU-9	12/10/03	17.8	NA
Type A	Irradiated fuel material	T47-IF-5	08/24/04	11.10	NA
Type A	Irradiated fuel material	T47-IF-6	08/24/04	11.70	NA
Vapor port	Organic sludge	743-08-VP1	04/25/01	20.8	20.19
Vapor port	Organic sludge	743-08-VP2	04/25/01	14.0	13.38
Vapor port	Organic sludge	743-03-VP2	04/26/01	13.9	13.25
Vapor port	Organic sludge	743-03-VP3	04/26/01	5.4	4.78
Vapor port	Organic sludge	743-03-VP1	04/26/01	18.6	17.96
Vapor port	Organic sludge	743-08-VP3	04/26/01	5.5	4.88
Vapor port	Organic sludge	743-18-Abandoned	05/01/01	14.9	14.28
Vapor port	Organic sludge	743-18-VP1	05/01/01	20.6	20.00
Vapor port	Organic sludge	743-18-VP3	05/02/01	8.2	7.61
Vapor port	Organic sludge	743-18-VP4	05/02/01	15.2	14.57
Vapor port	Depleted uranium	DU-10-VP2	06/19/01	10.6	10.00
Vapor port	Depleted uranium	DU-08-VP2	06/20/01	16.4	15.84
Vapor port	Depleted uranium	DU-10-VP1	06/20/01	12.1	11.55
Vapor port	Depleted uranium	DU-10-VP3	06/20/01	6.8	6.19
Vapor port	Depleted uranium	DU-14-VP1	07/12/01	16.6	16.05
Vapor port	Depleted uranium	DU-14-VP2	07/12/01	12.3	11.73
Vapor port	Depleted uranium	DU-14-VP3	07/12/01	5.5	4.88
Vapor port	Activated metal	SVR12-3-VP1	07/25/01	12.4	11.82
Vapor port	Activated metal	SVR12-2-VP1	07/26/01	12.5	11.90

Table A-2. (continued).

Probe Type	Probing Project Focus Area	Probe Name	Installation Date	Probe Depth (from surface) (ft)	Sensor/Port Depth (from surface) (ft)
Vapor port	Activated metal	SVR12-2-VP2	07/26/01	8.3	7.67
Vapor port	Activated metal	SVR12-3-VP2	07/26/01	8.2	7.59
Vapor port	Activated metal	SVR12-3-VP3	07/26/01	3.1	2.50
Vapor port	Activated metal	SVR12-1-VP2	07/31/01	8.2	7.59
Vapor port	Activated metal	SVR12-1-VP3	07/31/01	3.3	2.67
Vapor port	Activated metal	SVR12-2-VP3	07/31/01	3.2	2.59
Vapor port	Activated metal	SVR12-1-VP1	08/01/01	12.3	11.73
Vapor port	Activated metal	SVR20-3-VP1	09/05/01	6.9	6.34
Vapor port	Activated metal	SVR20-3-VP2	09/05/01	13.5	12.94
Vapor port	Activated metal	SVR20-3-VP3	09/05/01	15.6	14.96
Vapor port	Activated metal	SVR20-5-VP3	09/10/01	17.8	17.17
Vapor port	Uranium/enriched uranium	P5-4-L2	08/04/04	13.5	NA
Visual probe	Depleted uranium	DU-10-V	06/14/01	7	NA
Visual probe	Organic sludge	743-18-V	07/19/01	12	NA
Visual probe	Organic sludge	743-03-V	08/27/01	13.6	NA
Visual probe	Organic sludge	743-08-V	08/29/01	13.6	NA
Visual probe	Americium/Neptunium	741-08-V	08/30/01	13.5	NA
Visual probe	Depleted uranium	DU-14-V	09/18/01	10.5	NA
Visual probe	Depleted uranium	DU-08-V	09/25/01	17.6	NA
Visual probe	Pit 9	P9-09-V	10/23/01	6.7	NA
Visual probe	Pit 9	P9-20-V	10/25/01	12.6	NA
Visual probe	Pit 9	P9-09-VB	11/01/01	10.9	NA

Appendix B

Probe Location Figures

Appendix B

Probe Location Figures

Appendix B provides figures showing probe locations discussed in the main body of this report and listed in Appendix A.

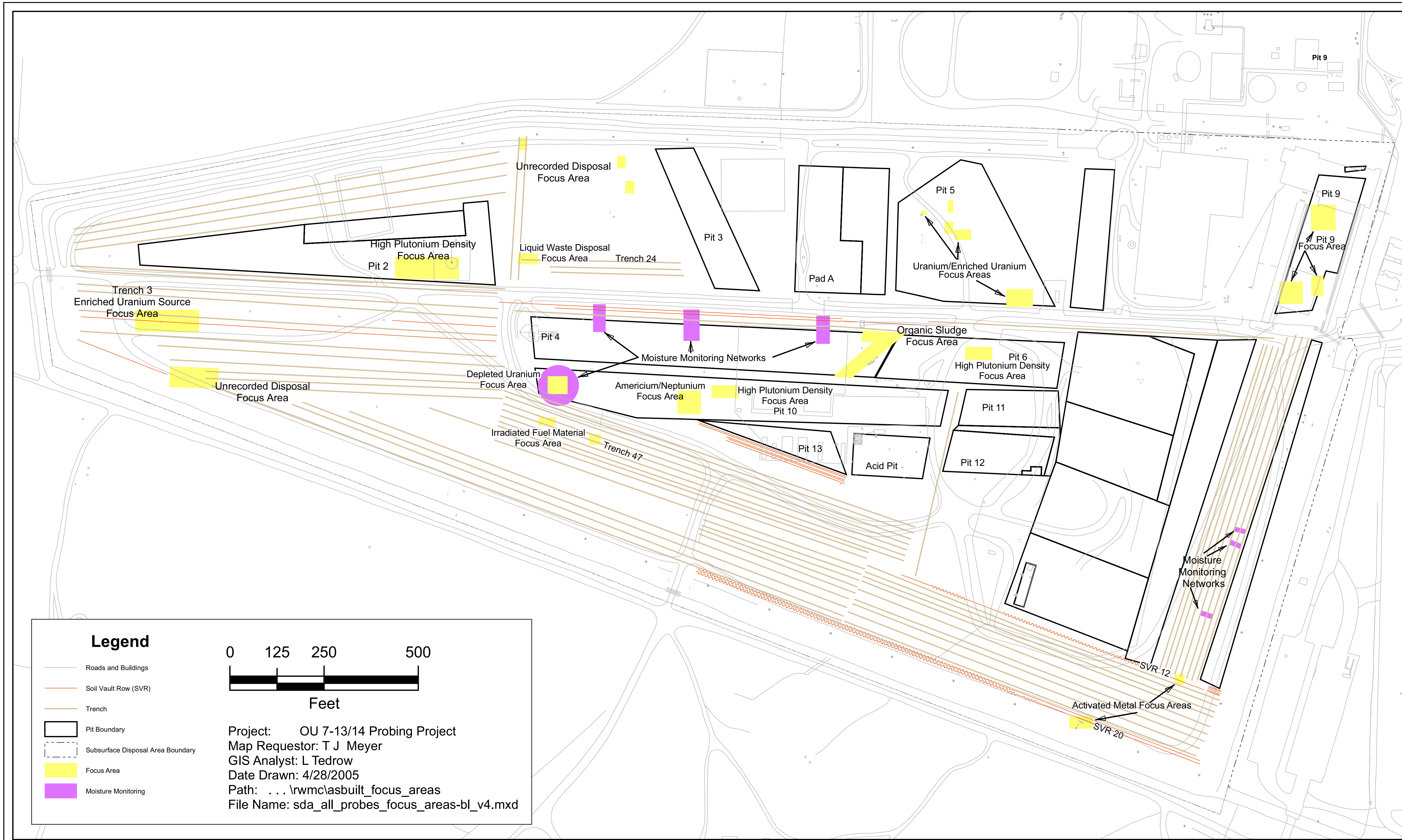

Figure B-1. Subsurface Disposal Area probe focus areas and moisture monitoring networks.

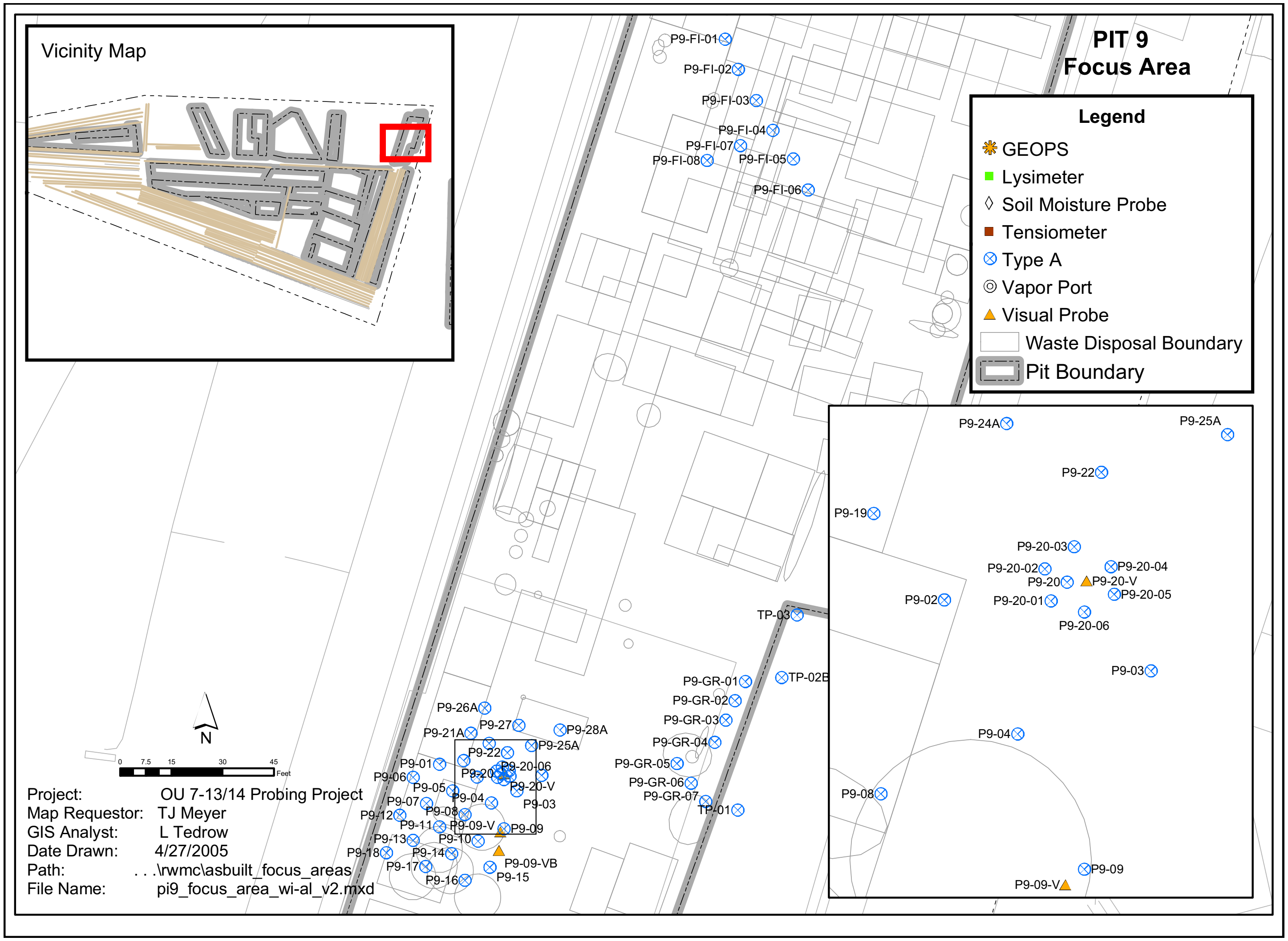

Figure B-2. Probes installed in the Pit 9 focus area.

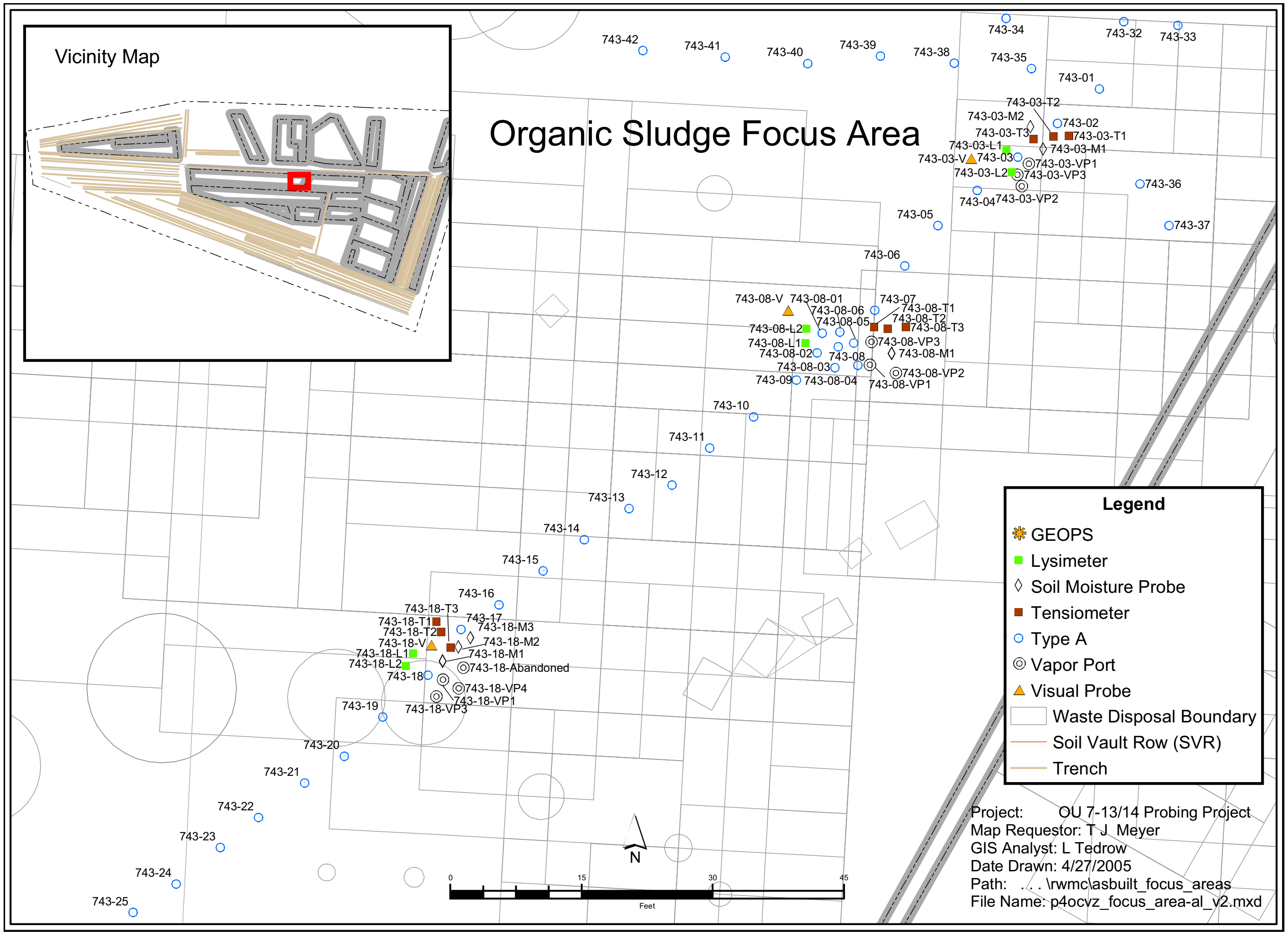

Figure B-3. Probes installed in the Organic Sludge Focus Area in the east end of Pit 4.

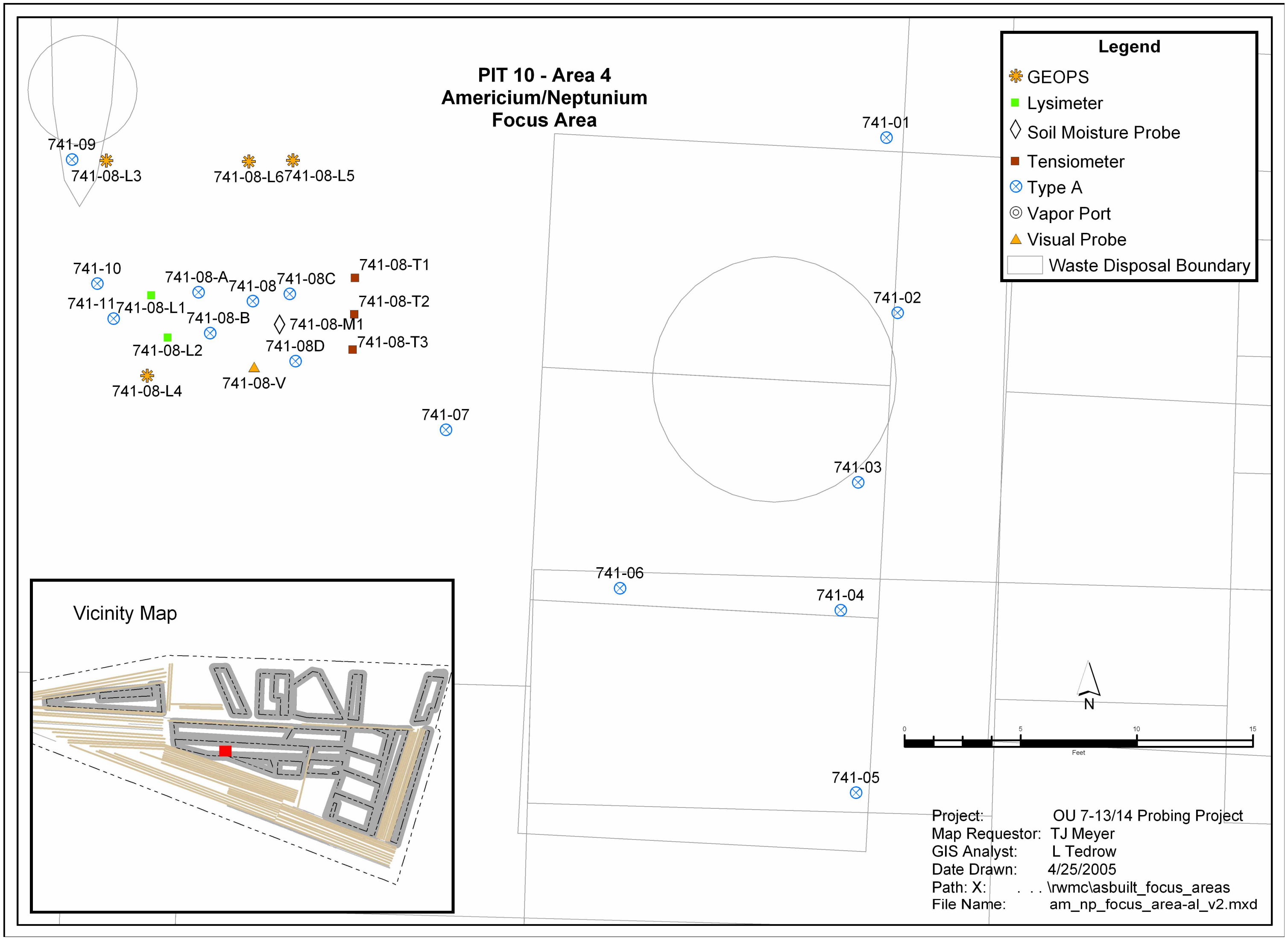

Figure B-4. Probes installed in the Americium and Neptunium Focus Area in the central portion of Area 4, Pit 10.

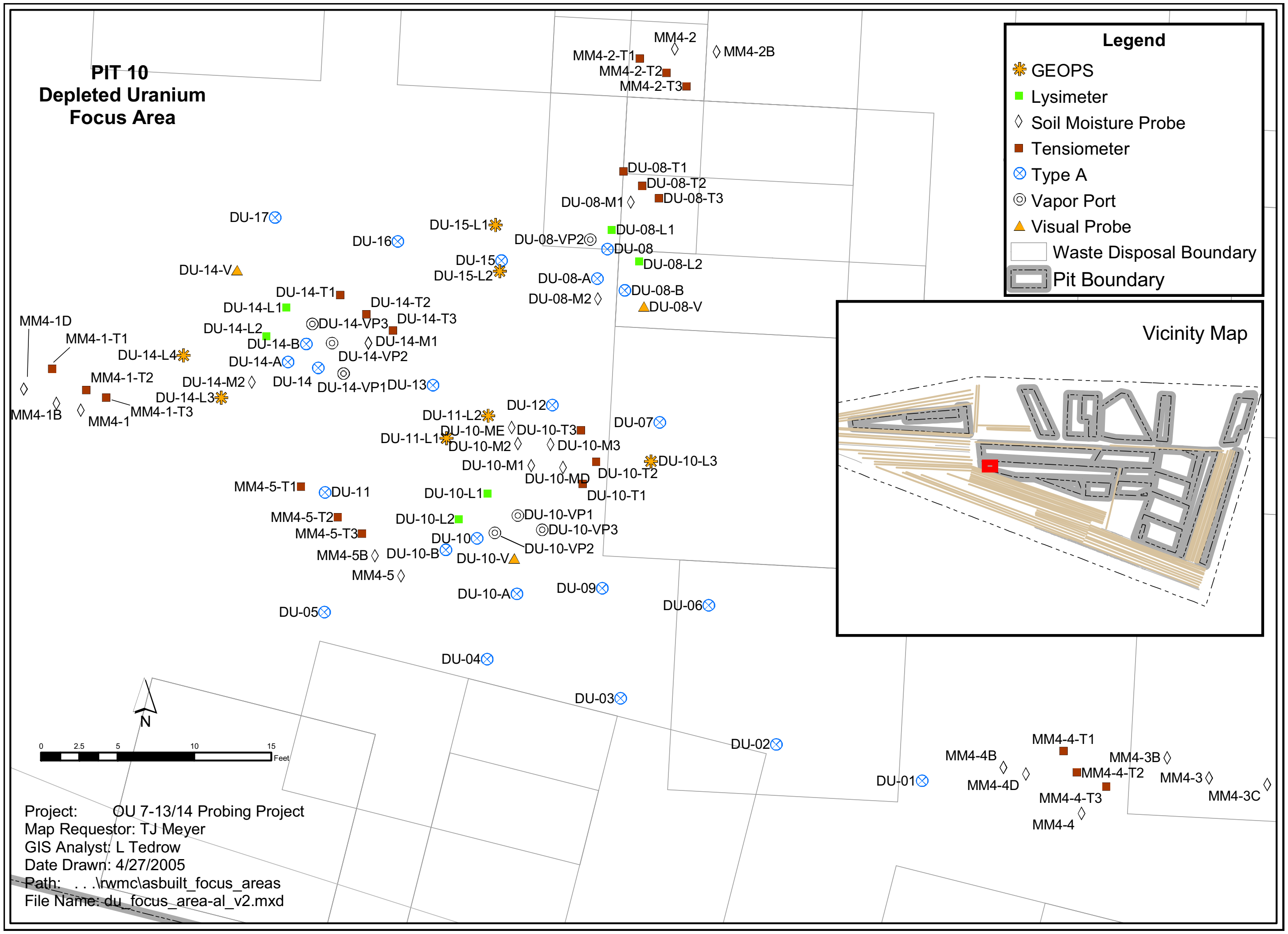

Figure B-5. Probes installed in the Depleted Uranium Focus Area in the west end of Pit 10.

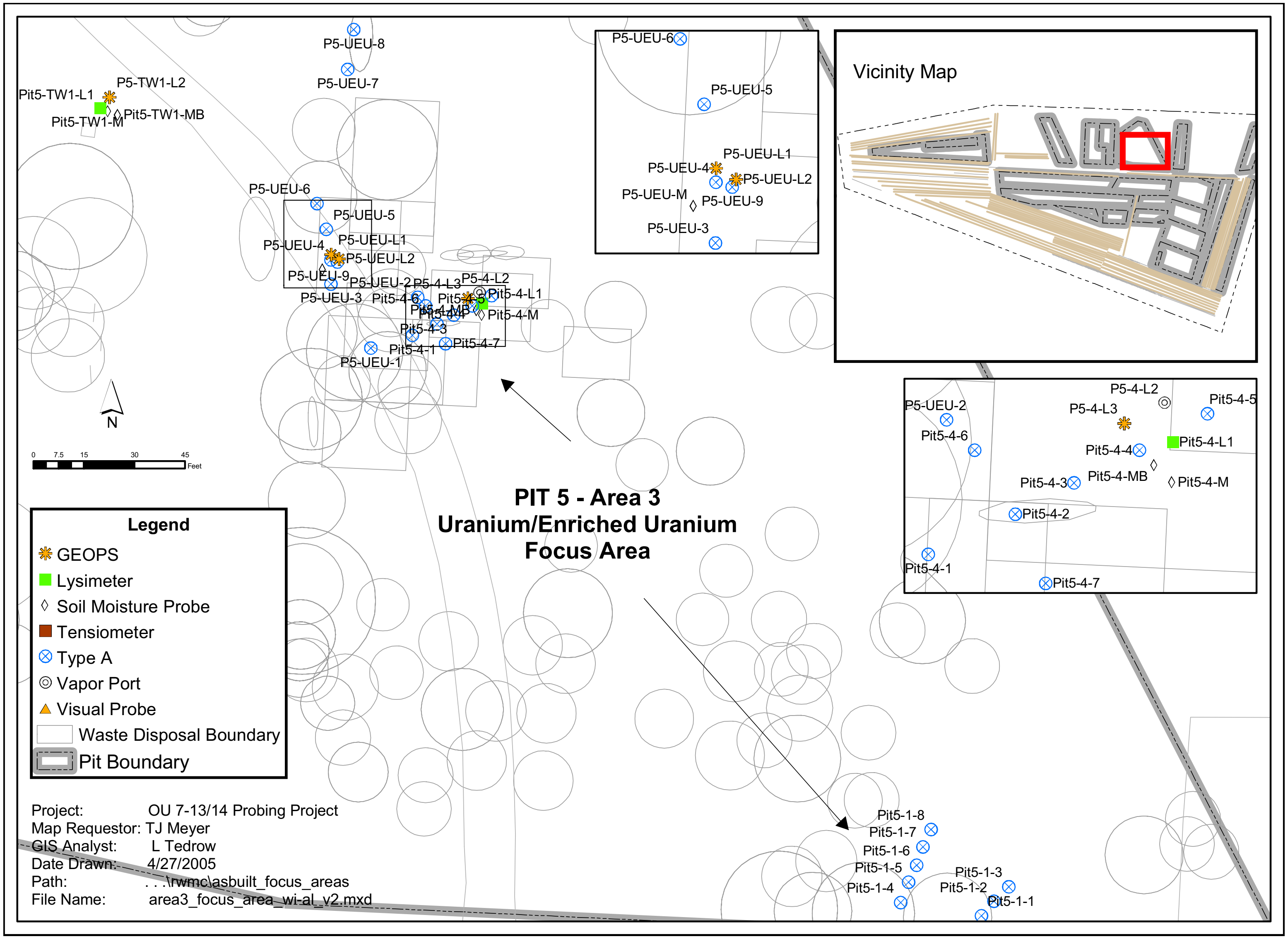

Figure B-6. Probes installed in the Uranium and Enriched Uranium Focus area in Area 3, Pit 5.

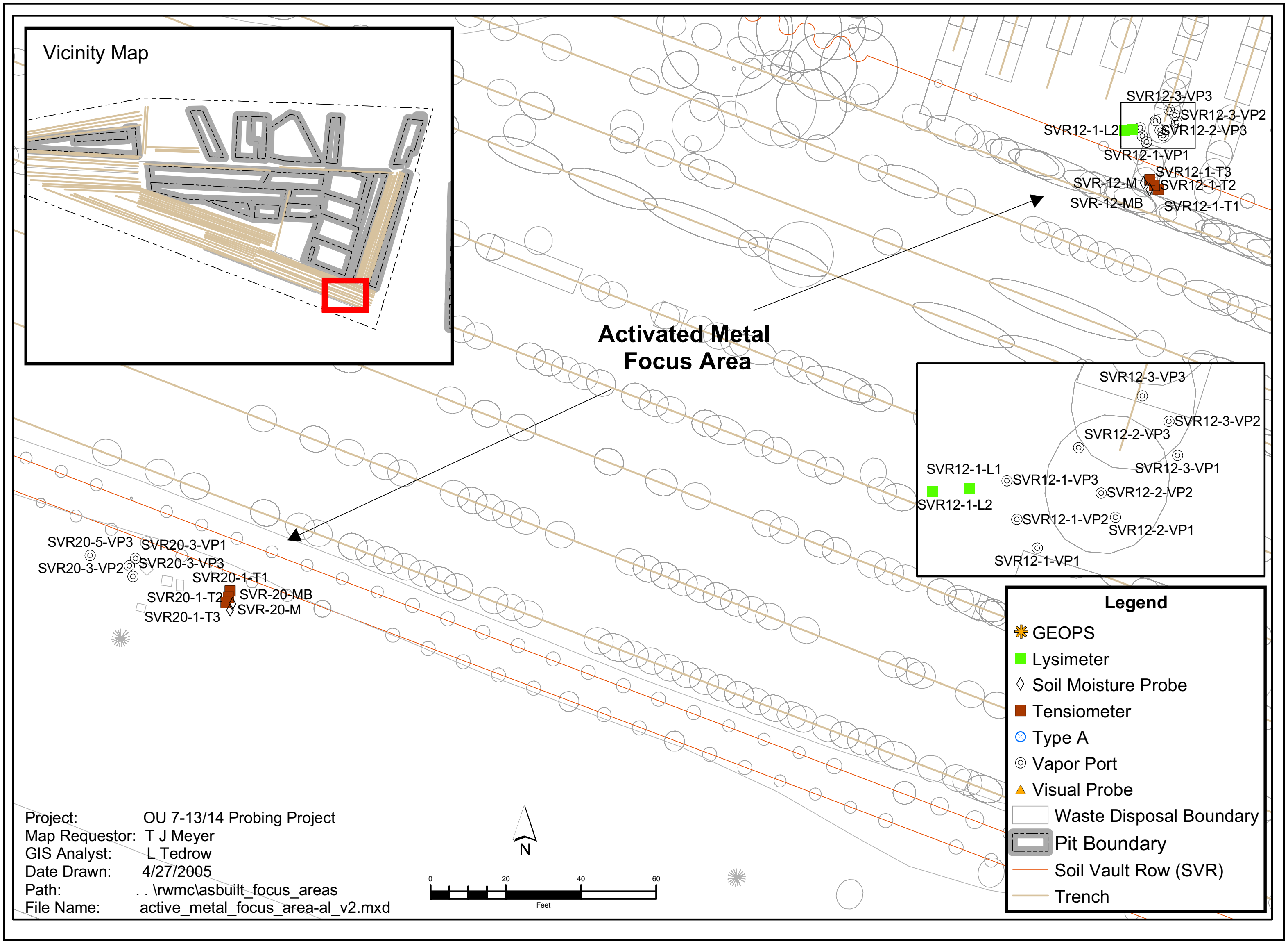

Figure B-7. Probes installed in the Activated Metals Focus Area in Soil Vault Rows 12 and 20.

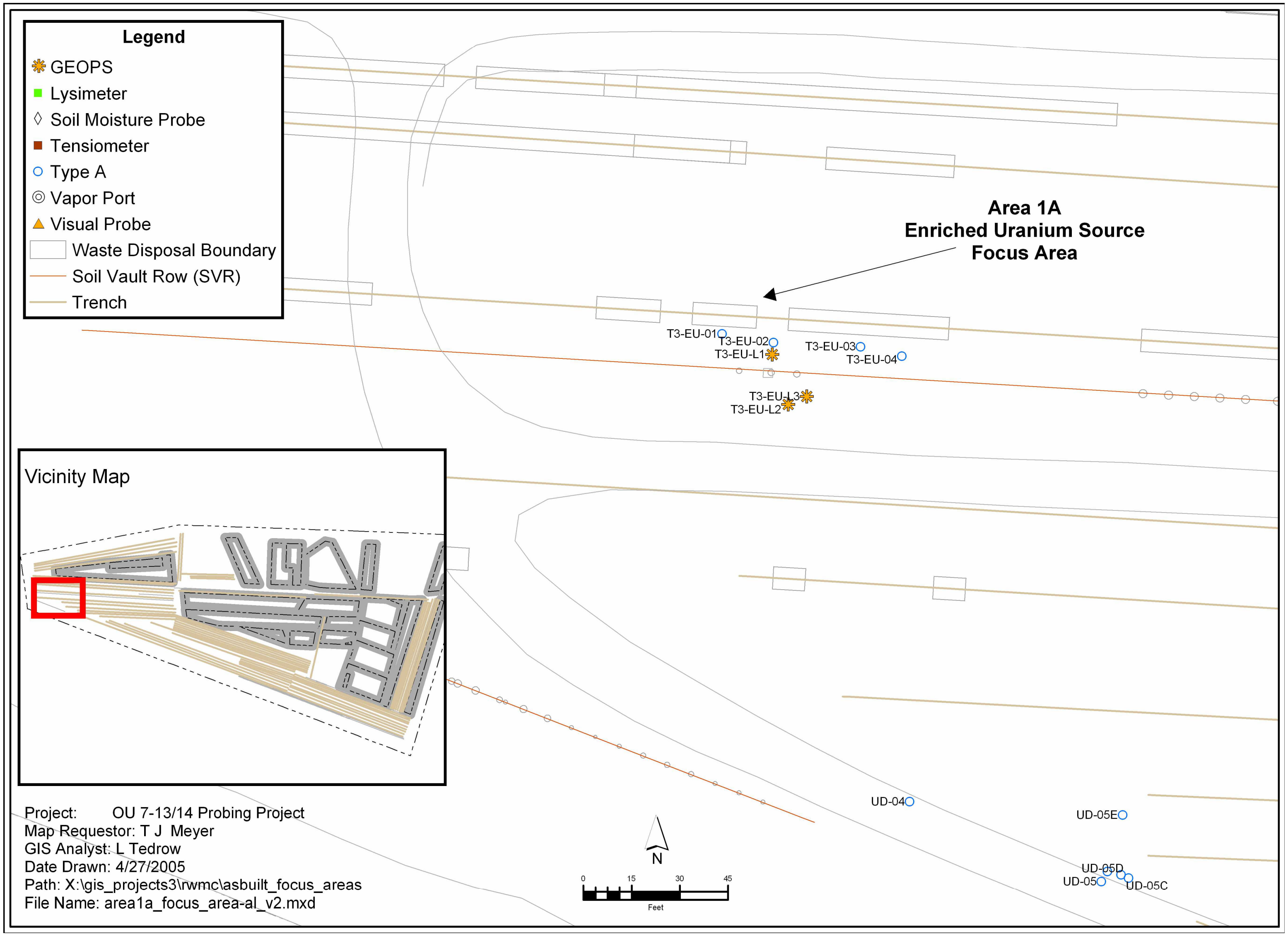

Figure B-8. Probes installed in the Enriched Uranium-Source Focus Area in the west end of Area 1A, Trench 3.

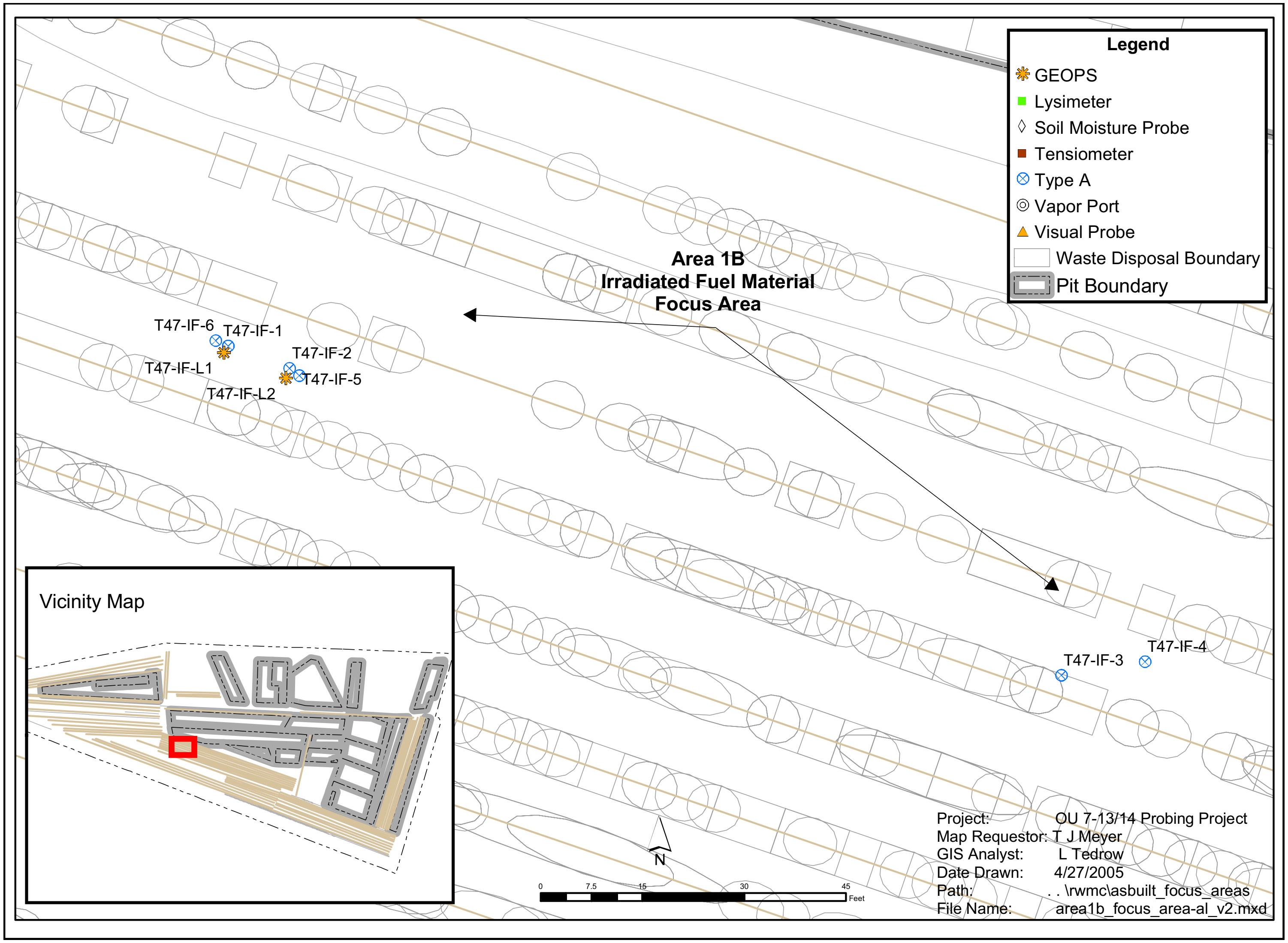

Figure B-9. Probes installed in the Irradiated Fuel Material Focus Area in the west end of Area 1B, Trench 47.

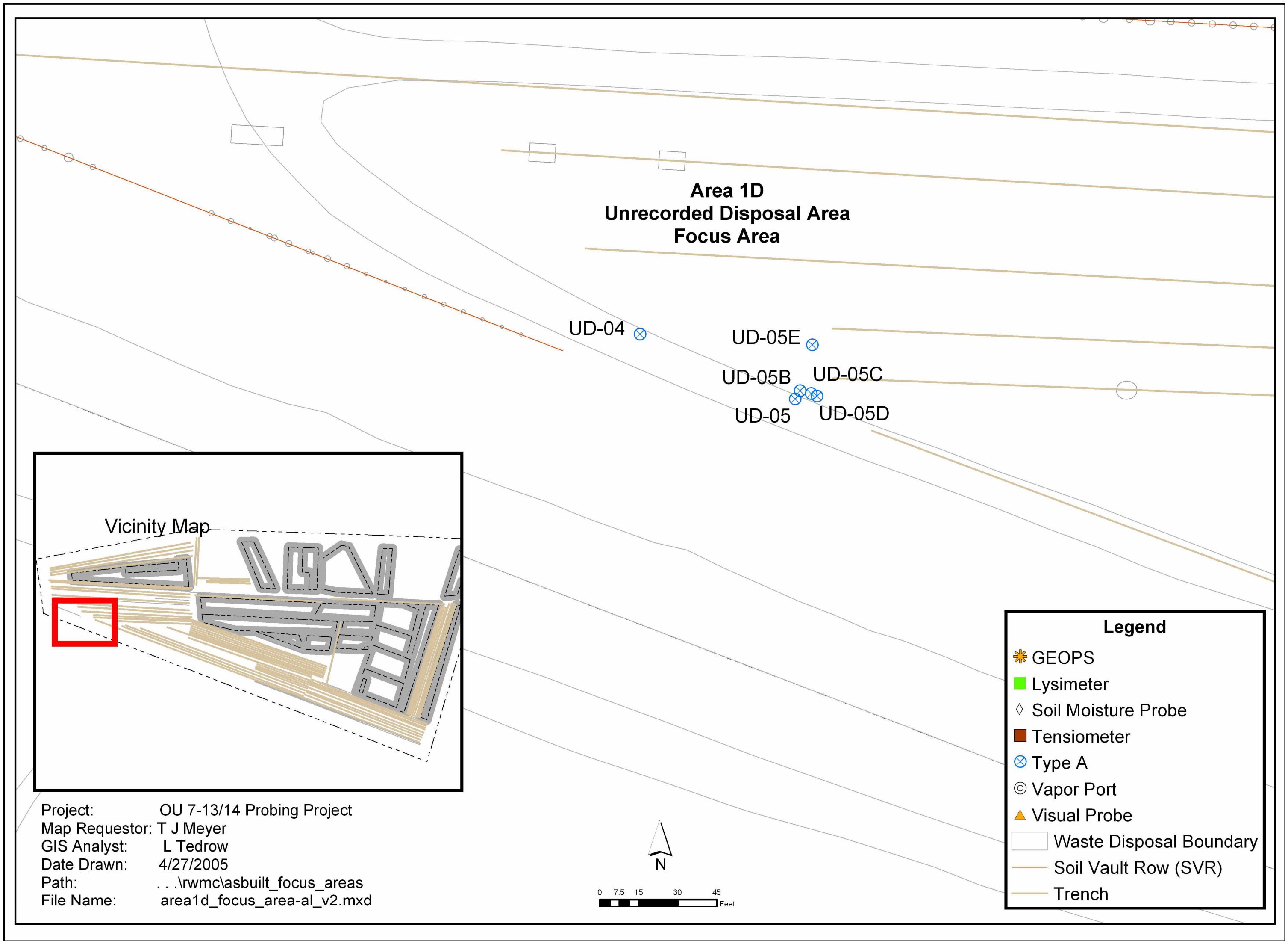

Figure B-10. Probes installed in the Unrecorded Disposal Focus Area in the west end of the Subsurface Disposal Area, Area 1D.

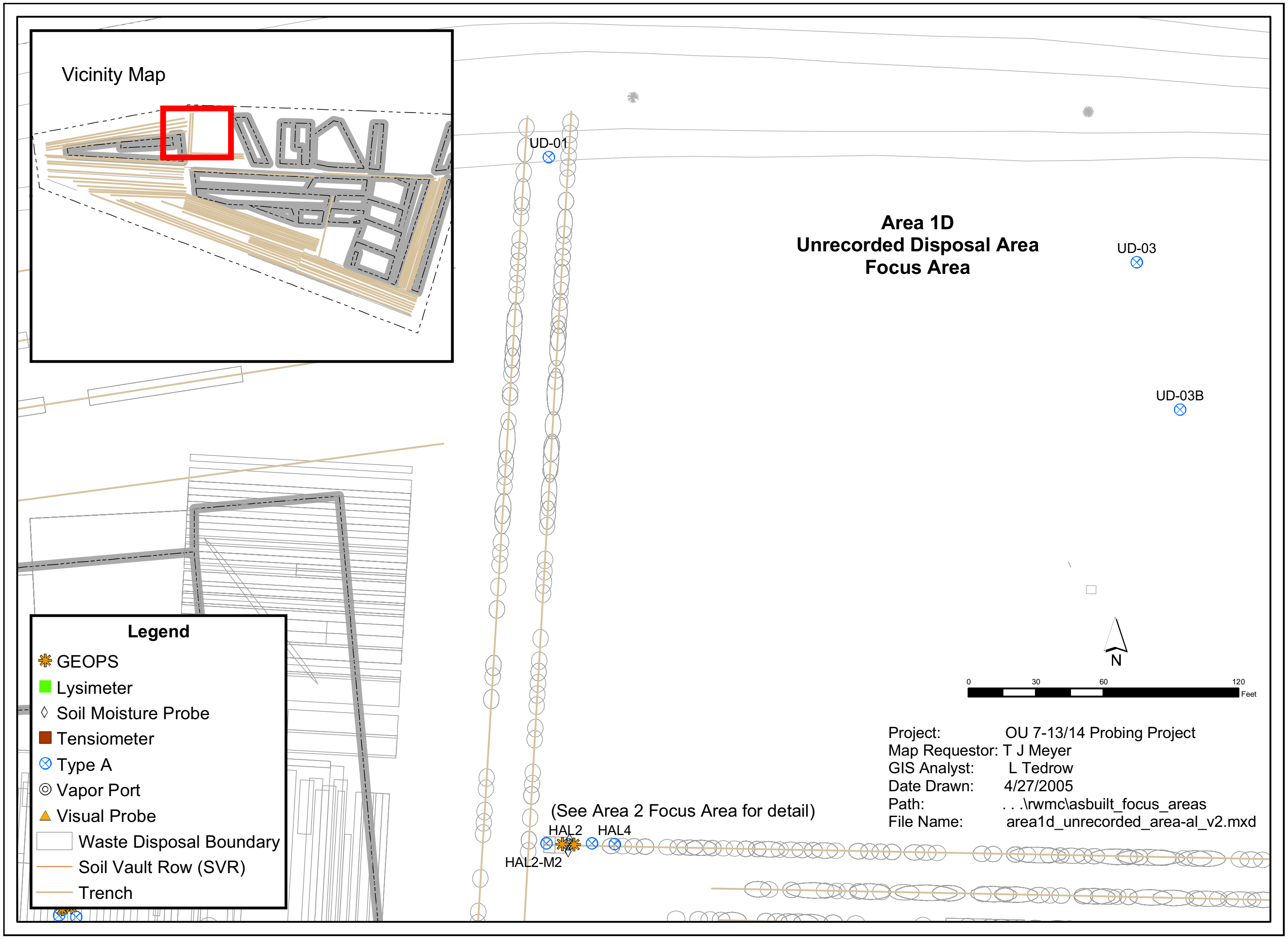

Figure B-11. Probes installed in the Unrecorded Disposal Focus Area west of Area 1D, Pit 3.

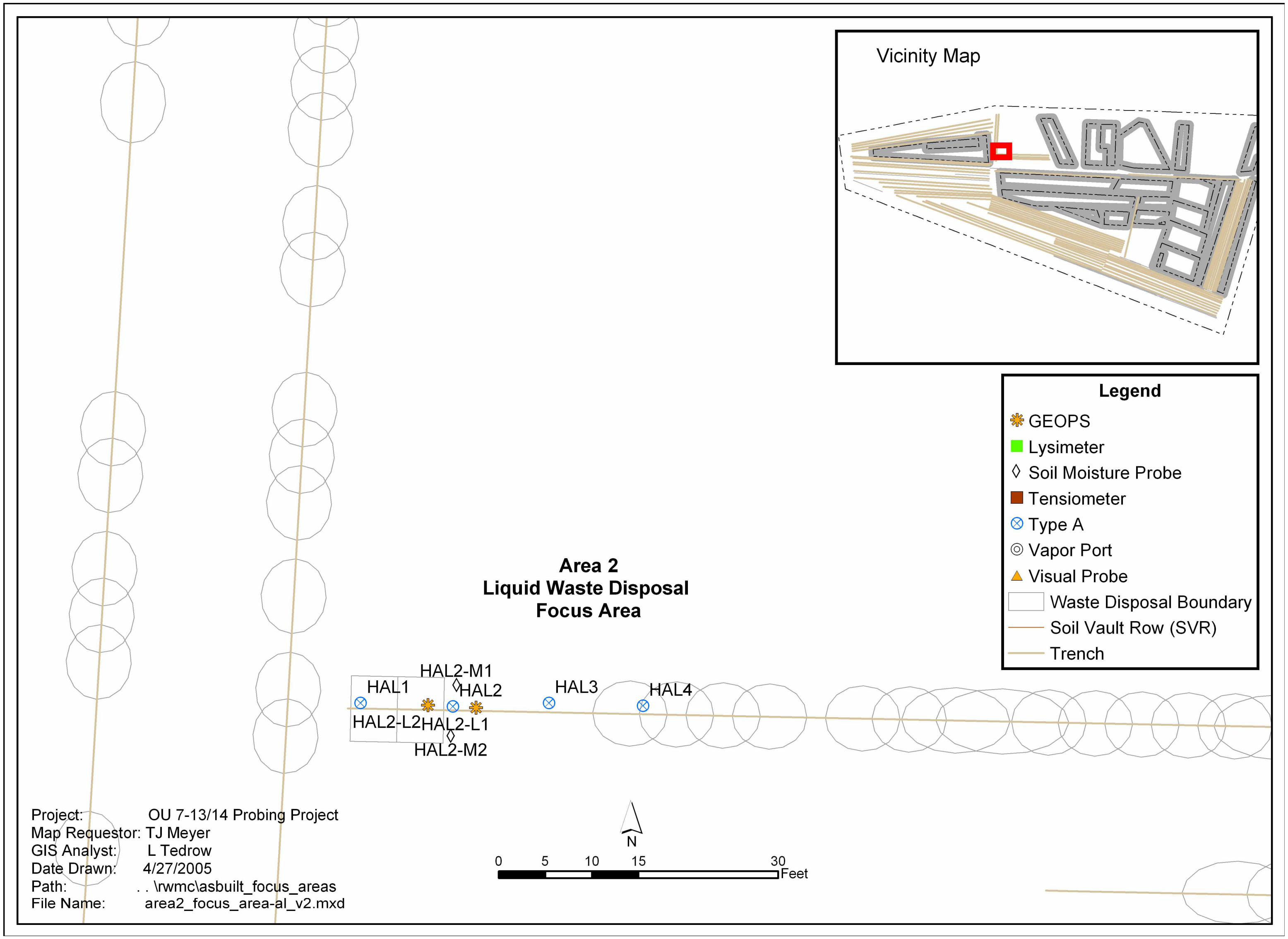

Figure B-12. Probes installed in the Liquid Waste Disposal Focus Area in the west end of Area 2, Trench 24.

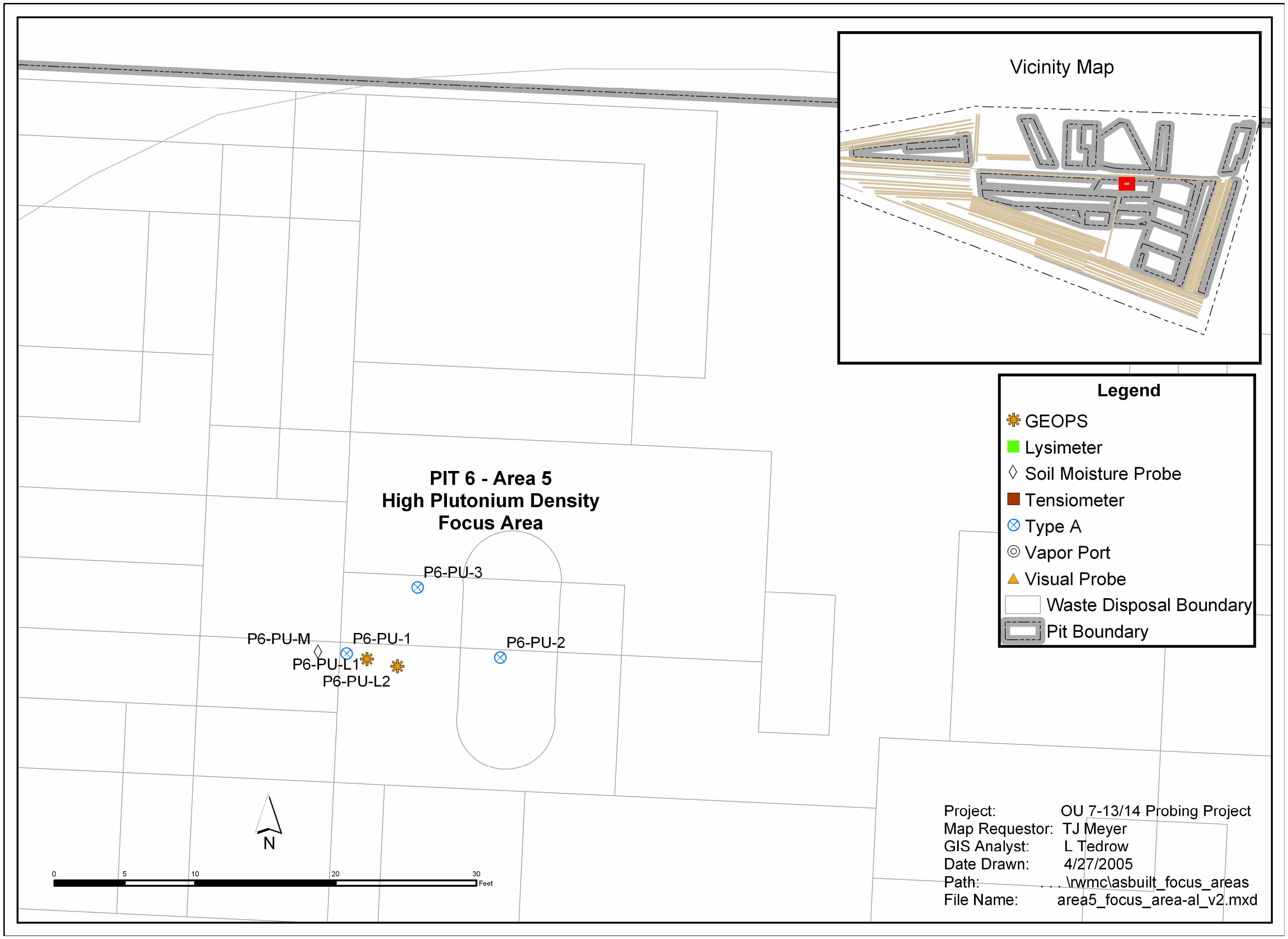

Figure B-13. Probes installed in the High Plutonium Density Focus Area in the central portion of Pit 6.

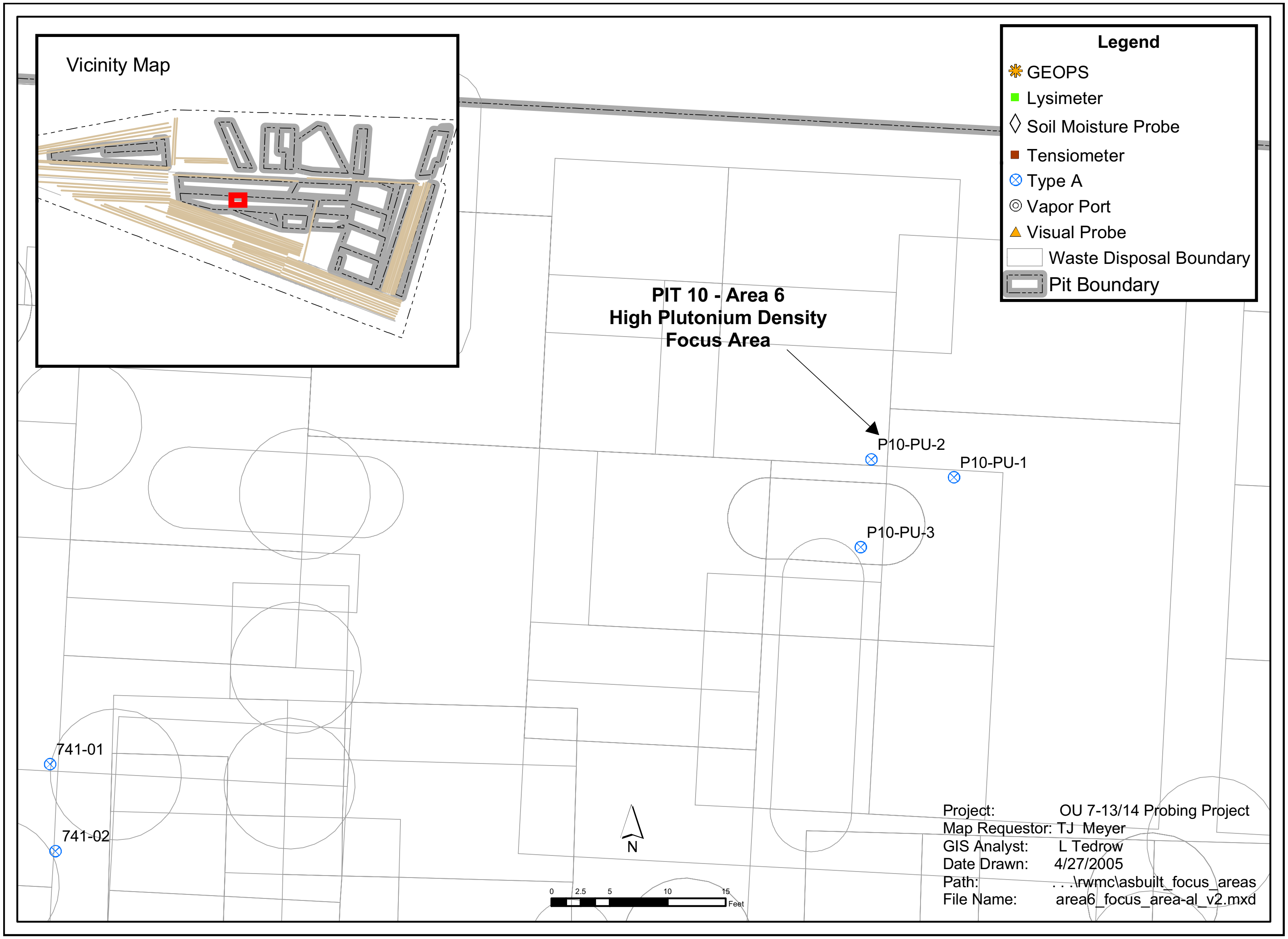

Figure B-14. Probes installed in the High Plutonium Density Focus Area in the central portion of Pit 10.

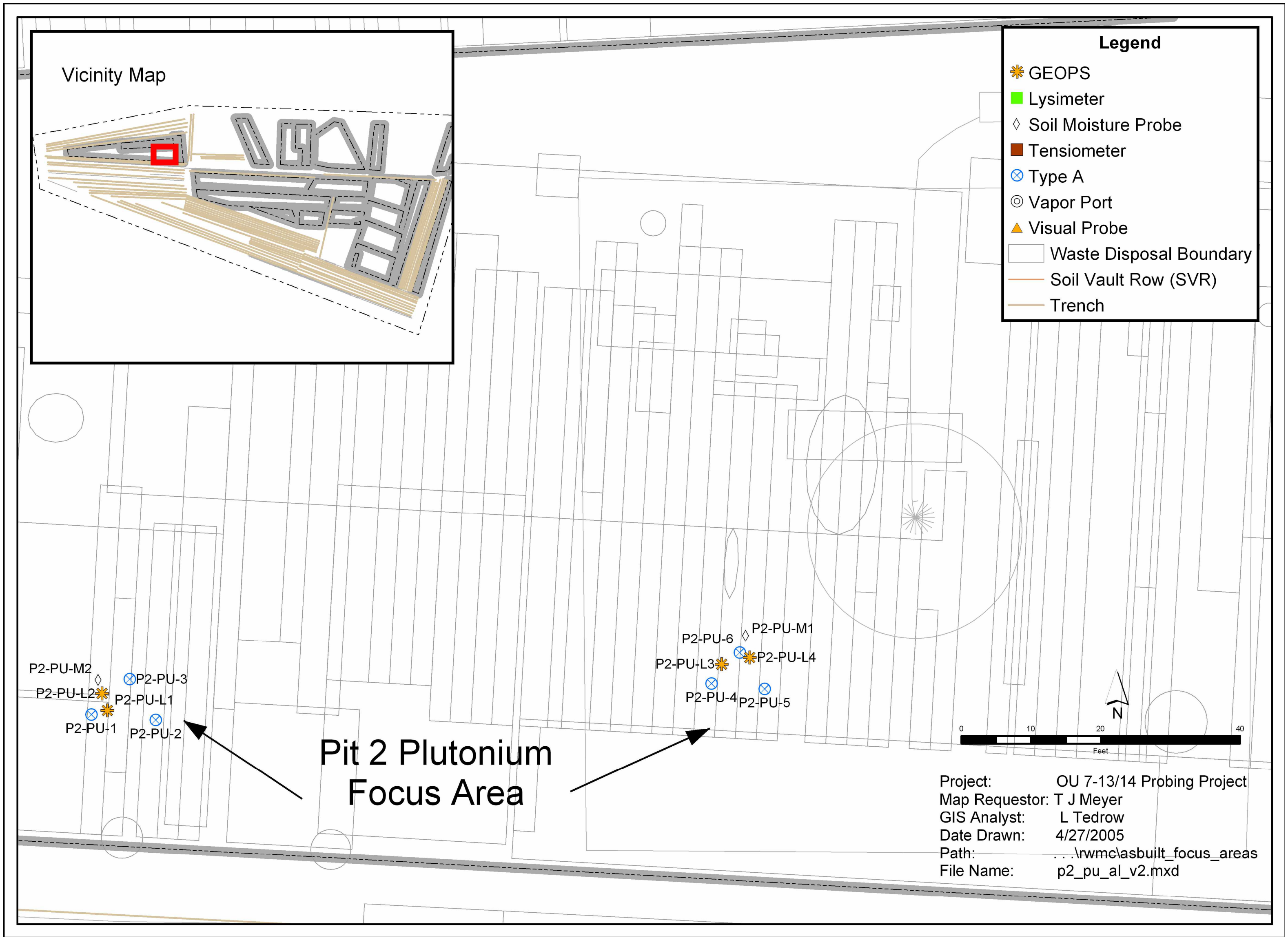

Figure B-15. Probes installed in the High Plutonium Density Focus Area in the eastern portion of Pit 2.

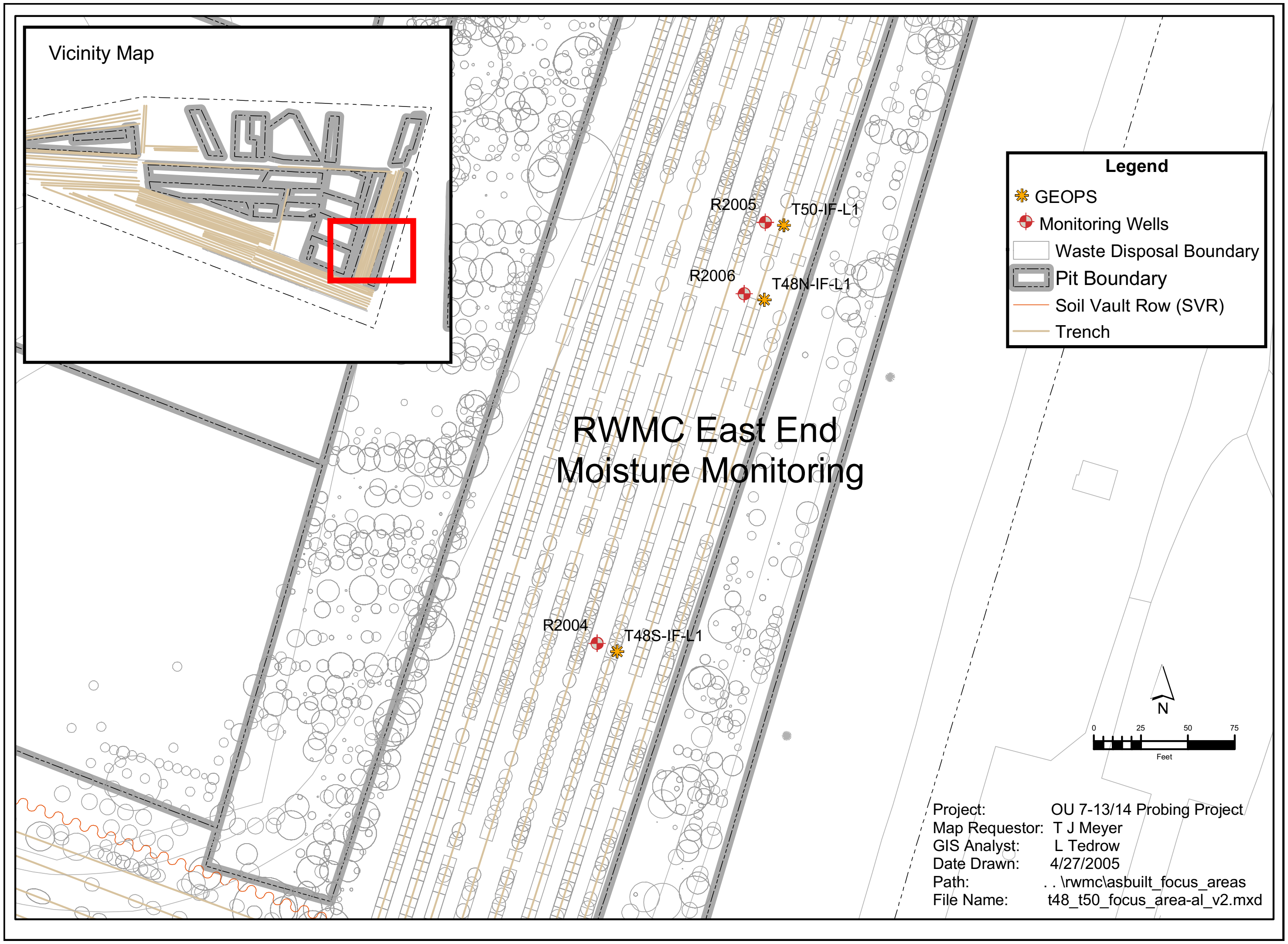

Figure B-16. Probes installed in the east end of the Radioactive Waste Management Complex adjacent to monitoring wells for moisture monitoring.