INNOVATIVE VADOSE ZONE MONITORING SYSTEM FOR LONG-TERM PERFORMANCE ASSESSMENT OF A CORRECTIVE ACTION MANAGEMENT UNIT CONTAINMENT CELL SANDIA NATIONAL LABORATORIES, NEW MEXICO

M. J. Irwin, C. J. Wood
Sandia National Laboratories

L. Brouillard
Gram Inc.

J. G. Estrada
United States Department of Energy, Sandia Site Office

ABSTRACT

Sandia National Laboratories in Albuquerque, New Mexico (SNL/NM), operates a Corrective Action Management Unit (CAMU) for the United States Department of Energy (DOE). In 1997 SNL/NM was granted a permit modification that allowed construction and operation of a CAMU. The CAMU follows regulatory guidance that facilitates expedient and cost-effective cleanup and management of hazardous remediation wastes. Treatment operations were completed in January 2003 in conjunction with containment of 858,000 cubic feet (24,300 cubic meters) of treated soil. The containment cell cover was completed in July of 2003 and the cell is situated approximately 485 feet (148 meters) above groundwater in a semiarid region marked by low rainfall and high evapotransporation. These site conditions required a unique approach to monitoring the containment cell performance and ultimately protecting groundwater. Groundwater monitoring requirements in Resource Conservation and Recovery Act (RCRA) dictate that monitoring be sufficient to detect and characterize releases of hazardous constituents to groundwater that may originate from the containment cell after the closure of the CAMU.

In lieu of the typical RCRA required one up gradient and three down gradient groundwater monitoring wells, an innovative Vadose Zone Monitoring System (VZMS) was designed and installed during construction of the CAMU containment cell. The rational for incorporating this system into the containment cell design, is so that leaks can be detected near real-time versus the 500 plus year response time that was modeled for the typical well configuration in this region. One component of the VZMS, the Primary Subliner (PSL) monitoring system, utilizes the containment cell subliner to focus potential leakage into five longitudinal trenches. Each trench contains a wicking material and a vitrified clay pipe used to provide access for a neutron probe to measure soil moisture content directly under the containment cell. The other component of the VZMS, the Vertical Sensor Array (VSA), consists of 22 time-domain reflectometers that provide a backup to the PSL.

Environmental Protection Agency regulators accepted vadose zone monitoring of the CAMU containment cell as a substitution for groundwater monitoring wells because of its high probability for early detection of leakage if it were to occur. This innovative monitoring approach would enable timely implementation of a corrective action to mitigate the possibility of

any impacts to groundwater. The CAMU VZMS provides a superior methodology for the detection and subsequent characterization of any potential leaks emanating from waste contained in the cell versus the use of groundwater monitoring wells. One of the main advantages offered by the VZMS is its ability to provide new real-time data on containment cell performance. Because of the layout, aerial coverage, and the multiple monitoring parameters incorporated into the VZMS, the specific location of a leak from the cell can be defined as well as the nature of the contaminant liquid (volatile organic versus inorganic compounds).

This paper will take the reader through construction of the innovative VZMS and operation with a comparison of the benefits and costs of the system. The SNL/NM CAMU is the only facility within the DOE complex that implements this innovative approach to environmental restoration waste management and monitoring. A significant cost savings to taxpayers for on-site waste treatment and containment versus off-site disposal was achieved. A cost saving of approximately $200 million was realized by utilization of the CAMU versus off-site waste disposition. The VZMS monitoring system will be utilized during the 30-year post-closure care period for the containment cell.

INTRODUCTION

Sandia National Laboratories/New Mexico (SNL/NM) is operated for the U.S. Department of Energy (DOE) by Sandia Corporation, a subsidiary of Lockheed Martin Corporation. SNL/NM has been involved in nuclear weapons research, component development, testing, assembly, and other weapons-related activities since 1949. As a result of these and other activities, certain sites have been contaminated with hazardous wastes or hazardous constituents, and radioactive materials. These sites are being cleaned up under SNL/NM's Environmental Restoration (ER) Project. The clean up of ER solid waste management units at SNL/NM has been greatly facilitated through the use of the Resource Conservation and Recovery Act (RCRA) Subpart S, Corrective Action Program. In general, the term corrective action can be applied to investigation and remediation activities under a variety of statutes and regulatory programs, including RCRA, the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), and the Toxic Substances Control Act (TSCA).

In 1996 SNL/NM's ER Project was evaluating options for the management of its wastes associated with cleanup of legacy waste sites. The concept of an on-site Corrective Action Management Unit (CAMU) was reviewed and it was determined to have economic benefit based on the potential 1,000,000 cubic feet (28,300 cubic meters) of contaminated soils that could be generated in the next 3 to 5 years of cleanup activities. The expected transportation and manifesting requirements for off-site treatment and disposal of contaminated soils showed that using a CAMU would cost the ER Project about ½ as much as off-site waste disposition. The CAMU was permitted in 1997 as the first CAMU in New Mexico and the first in the DOE complex [1]. As hazardous soil was being generated from the excavation of a chemical waste landfill, the need for waste management of tritium-containing soils complicated off-site disposal options. A CAMU permit modification was approved by the Environmental Protection Agency (EPA) and New Mexico Environment Department for management of soil containing tritium up to 20 nanoCuries per liter in soil moisture content [2]. This permit modification increased the cost benefit ratio for use of the CAMU by more than three. EPA approval of a TSCA 761.61(c) permit for management of several thousand cubic feet of excavated soil containing polychlorinated biphenyls [3] resulted in the overall cost savings for use of the CAMU to over $200 million.

Long-term containment of soil is being conducted at the SNL/NM CAMU, which followed the on-site treatment operations that were completed in January 2003. CAMUs and other RCRA-regulated disposal facilities in the United States of America are required to be protective of groundwater and to verify continued containment of managed waste. RCRA regulations typically require installation of one up-gradient and three down-gradient monitoring wells to detect and characterize any releases of hazardous constituents to groundwater. With the depth to groundwater under the CAMU approximately 485 feet (148 meters), the expected travel time for migration of a liquid contaminant release to groundwater is several hundred years at best case. Because of the substantial delay in identifying a release that reached groundwater using traditional groundwater monitoring wells, an alternative monitoring method that provided early detection was proposed. To better detect any contaminant movement that could potentially adversely affect water quality, a vadose zone monitoring system (VZMS) was integrated into the CAMU containment cell design and was accepted by the EPA. The CAMU VZMS, although not unique, is innovative and a superior method for earlier detection of leaks and long-term verification of containment cell performance.

HYDROGEOLOGIC SETTING

SNL/NM is located in central New Mexico along the east-central edge of the Albuquerque Basin, one of a north-south-trending line of basins that make up the Rio Grande rift. The sediments underlying the CAMU are a heterogeneous sequence of unconsolidated to semi-consolidated valley fill deposits [4,5]. The sediments are composed primarily of cobbles, gravels, sands, silts, and clays of alluvial and fluvial origin. These sediments are locally cemented by caliche. The very-fine to fine sand and silt matrix in these sediments is characterized by interbedded lenses and sheets of gravel, sand, silt, silty clay, and clay. Data from monitoring wells in the area indicate that the depth to groundwater under the CAMU is approximately 485 feet (148 meters).

The average annual precipitation in the area is approximately 9 inches (22.9 centimeters), the average annual evapotranspiration is 95 percent, and the calculated infiltration rate is 0.3 inches (0.76 centimeters) per year. The regional area recharge rate outside of the arroyos is estimated to be less than 5 percent of the total annual precipitation [6], and the recharge estimate across the SNL/NM ranges from 0.05 (0.13 cm) to 0.66 inches (1.68 centimeters) per year [7].

CAMU CONTAINMENT CELL DESCRIPTION

The CAMU was designed as turnkey waste management facility with support areas for waste storage, waste treatment and waste containment. The CAMU has operated mainly to safely store, treat and contain contaminated soils derived from excavation of a nearby chemical waste landfill. The typical contaminants found in the excavated soil included metals such as lead, chrome, and mercury, and organic compounds such as acetone, bis(2-ethylhexyl)phthalate, aniline, and 1,1,1-trichloroethane, and o-toluidine. The CAMU was constructed with waste staging areas that provided sufficient space for the accumulation of large waste volumes prior to initiating treatment, and the area needed for staging soil while awaiting for analytical results for treatment verification.

The CAMU containment cell was designed with a maximum storage capacity of approximately 1 million cubic feet (28,300 cubic meters) of waste. With 2:1 (horizontal to vertical) sidewall slopes and a surface footprint of 200 by 300 feet (61 by 91 meters), a below-grade capacity of approximately 720,000 cubic feet (20,400 cubic meters) is available. Above grade mounding of the waste allows for additional capacity. Approximately 858,000 cubic feet (24,300 cubic meters) of waste has been placed in the cell. The depth of the bottom of the waste below grade ranges from 15 feet (4.6 meters) at the south end to 20 feet (6.1 meters) at the north end of the containment cell. This bottom gradient directs any leachate to the sump located at the northern end of the cell. The containment cell has an engineered liner system designed to prevent migration of hazardous constituents from leachate, contaminated runoff, and hazardous waste decomposition products to adjacent geologic materials or to groundwater. The engineered containment cell liner system includes a bottom liner system and sidewall liner system components. The bottom liner system components include the following in descending order:

- Protective layer - A minimum 18-inch-thick (45.7 centimeter) protective layer consisting of native, compacted on-site soil.
- Geocomposite drainage layer consisting of a geonet with a nonwoven geotextile bonded to the upper surface with drainage to a collection sump.
- Geomembrane - 60-mil (1.5 millimeter) smooth high-density polyethylene (HDPE).
- Geosynthetic clay liner (GCL) - nonwoven geotextile outer layers needle-punched through an inner layer of low-permeability sodium bentonite.

The containment cell cover system incorporates a capillary barrier and vegetation cover for primary hydraulic control. A HDPE liner positioned at the base of the cover system provides reinforced hydraulic control. In addition to the vegetative cover, engineering controls are applied to prevent or minimize erosion losses. These include slope control, surface runoff control, and perimeter flow control. The crown of the cover slopes to the north, south, east, and west at a 3-percent grade. Transition slopes range from 8:1 to 4:1. This design facilitates low profile mounding and gentle slopes that enhance resistance to erosion caused by wind and precipitation.

VADOSE ZONE MONITORING SYSTEM

The VZMS is being used to provide real-time information on the containment cell performance, which allows for early detection of leaks from the containment cell if they were to occur. The VZMS consists of three monitoring subsystems, as follows:

- The Primary Subliner (PSL) Monitoring Subsystem
- The Vertical Sensor Array (VSA) Monitoring Subsystem
- The Chemical Waste Landfill and Sanitary Sewer Line (CSS) Monitoring Subsystem.

The three subsystems are designed to be used in an integrated fashion to achieve a high probability of detecting "real" leakage from the containment cell and to avoid false detections caused by environmental factors beyond the control of the CAMU operation. The design allows for detection monitoring, and if a leak is suspected, for additional activities to effectively determine whether a leak has actually occurred, and if so, to determine the general character and magnitude of the leak. The design includes features that allow identification of in-situ condensation buildup, moisture increases from a nearby sanitary sewer, and if organic vapors from a nearby inactive landfill have resulted in false indication of containment cell leakage.

PSL Monitoring Subsystem

The PSL monitoring subsystem is designed to detect increased moisture content below the containment cell liner and is used as the primary indicator of cell leakage attributed to waste emplacement. The PSL monitoring subsystem consists of five sub-horizontal access tubes oriented parallel to the long axis of the containment cell (Fig. 1). The access tubes are located approximately 4 feet (1.2 meters) below the containment cell primary liner within trenches horizontally spaced 17 to 27 feet (5.2 to 8.2 meters) apart (Fig. 2). The trenches are backfilled with an engineered wicking material that consists of native sand and gravel obtained from an on-site borrow area and sieve-screened to a specified particle size distribution (i.e., silty sand). The primary role of the wicking material is to provide a layer of soil that will direct leachate toward the PSL access tubes in the event that the primary liner system fails. The ends of the panels that comprise the cell subliner drape into each trench to facilitate transport of moisture to the access tubes (Fig. 2).

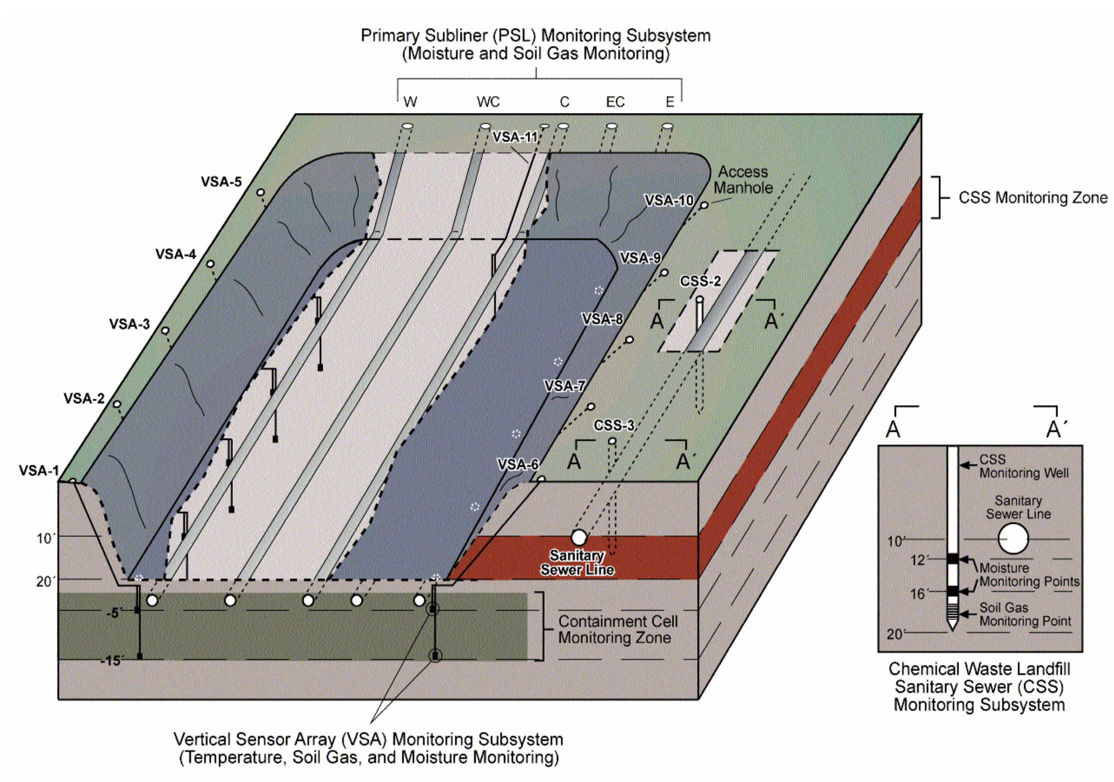

Fig. 1 Block Diagram of CAMU Containment Cell and Vadose Zone Monitoring System

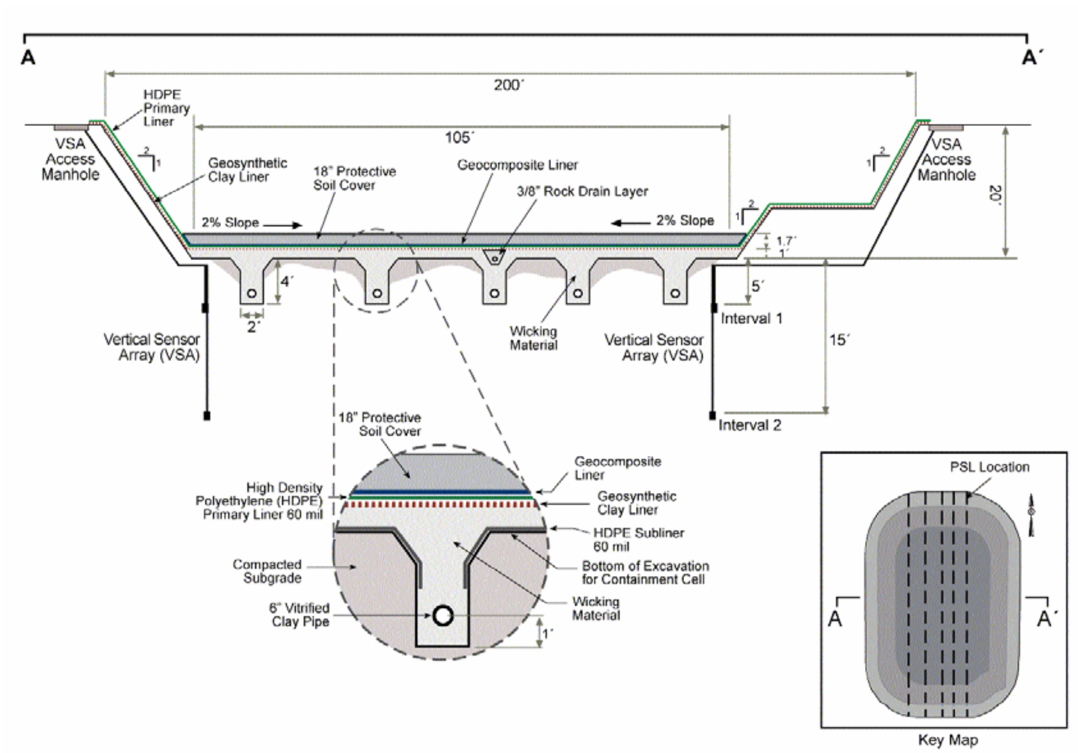

Fig. 2. Cross-Sectional View of Containment Cell and Primary Subliner Monitoring System

The PSL access tubes, which consist of extra high-strength vitrified clay pipe (VCP), allow for soil moisture detection and provide sufficient porosity for soil-gas sampling. Clay pipe was selected for the access tubes because of its service life, resistance to crushing, and material compatibility with soil moisture sensor operation and soil-gas volatile organic compound (VOC) monitoring. The VCP access tubes have a nominal 6-inch (15.2 centimeter) inside diameter and a 10-inch (25.4 centimeter) outside diameter. Each of the five VCP sequences underlying the bottom of the cell is approximately 220 feet (67 meters) long. Inclined polyvinyl chloride (PVC) riser pipe sections, approximately 65 feet (19.8 meters) in length, are located at both ends of each access tube and enable access for monitoring equipment.

A CPN 503 DR Hydroprobe® neutron probe is used to measure counts at selected points along each pipe run. Neutron counts can be translated into soil moisture data by using a correlation formula relating count values to soil moisture content. Neutron count data from the probe is displayed in the field on the probe control box and downloaded into a personal computer.

Modeling data indicate that at a worst-case leak location (i.e., at a point farthest from a PSL access tube), a point leak as small as 600 gallons (2,271 liters) will cause a moisture-content increase of approximately 4 percent over antecedent conditions at one or both of the adjacent PSL access tubes. The PSL monitoring subsystem provides a probability of greater than 95 percent for reliable detection of this magnitude increase in moisture.

VSA Monitoring Subsystem

The VSA monitoring subsystem is used to gather information on moisture content, temperature, and soil-gas concentrations below the containment cell. This monitoring subsystem is designed to provide confirmatory or supplemental data on moisture content when operated in conjunction with the PSL monitoring subsystem. It is also used to determine if vertical moisture gradients occur below the containment cell. The VSA monitoring subsystem provides data to aid in determining whether an increase in soil moisture content is the result of leakage from the containment cell or related to a source adjacent to the cell.

The VSA monitoring subsystem consists of 11 pairs of vertically oriented monitoring points strategically located along the perimeter of the base of the containment cell. Ten VSA monitoring locations are positioned along the eastern and western margins of the base of the containment cell (Fig. 1). The eleventh monitoring location is situated at the northern end of the cell with monitoring points below the leachate containment and removal system sump. All VSA locations contain monitoring points at 5 and 15 feet (1.5 and 4.6 meters) below the containment cell subliner. Each monitoring point contains the following three components: a time-domain reflectometry (TDR) soil-moisture content probe; a temperature sensor; and a soil-gas sampling port (Fig. 3).

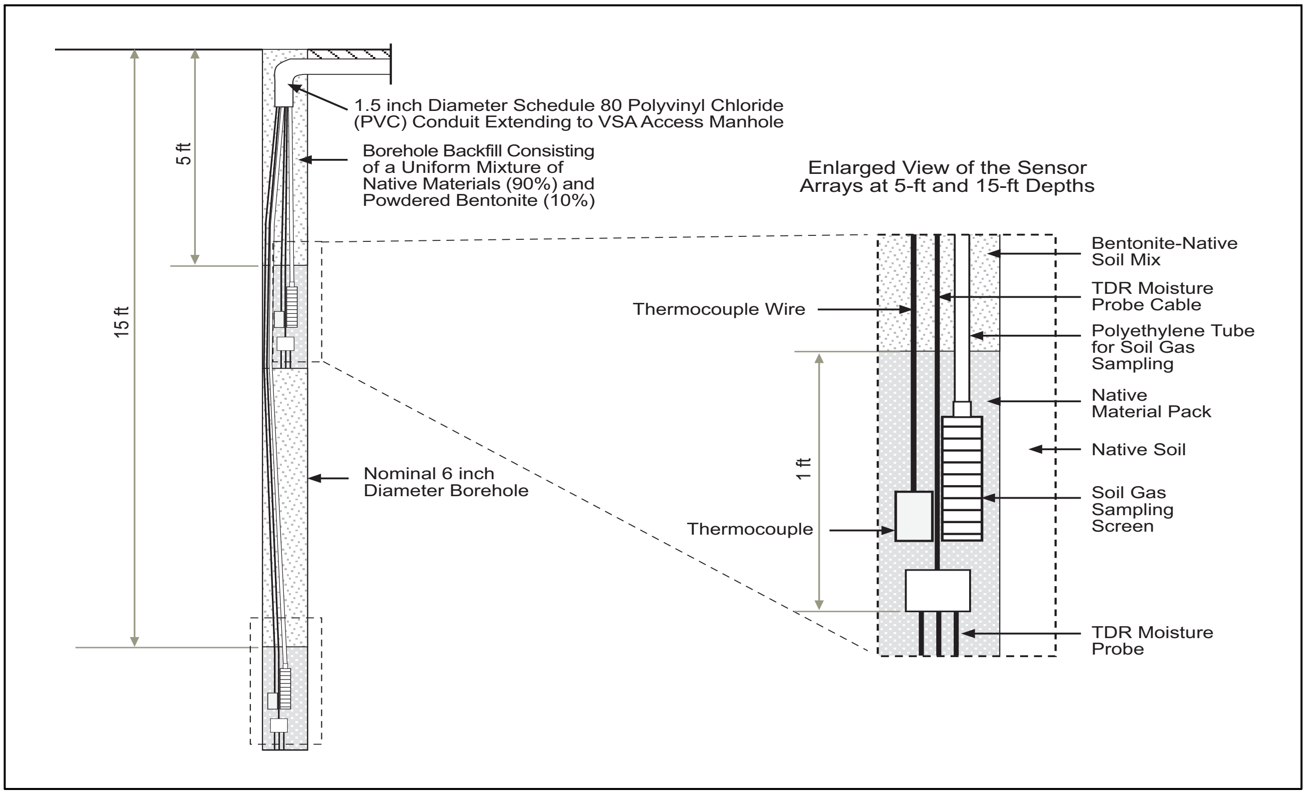

Fig. 3 Configuration of Vertical Sensor Array Monitoring Subsystem

CSS Monitoring Subsystem

The CSS monitoring subsystem, located approximately 40 feet (12.2 meters) east of the containment cell, is designed to provide early detection of leaks emanating from an adjacent sanitary sewer line, thereby delineating a moisture source that could also impact the PSL or VSA moisture monitoring subsystems (Fig. 1). Six vertical monitoring well points are positioned between the containment cell and the sanitary sewer line. The sanitary sewer line is oriented north-to-south and runs parallel to the containment cell. Each CSS monitoring well is designed to be accessed by a neutron probe to monitor moisture content and is also equipped for soil-gas sampling. The soil-gas monitoring component of the CSS is used to monitor VOCs within the vadose zone that may be generated by a source outside the containment cell area. Transport diffusion modeling results [8] indicate that there is a potential for soil-gas containing VOCs to migrate toward the containment cell from former source materials that were buried in the adjacent chemical waste landfill, located approximately 400 feet (120 meters) to the southeast.

All six locations contain monitoring well points completed to a depth of approximately 20 feet (6 meters) and spaced approximately 100 feet (31 meters) apart. The bottom of each well contains a 6-inch (15 centimeters) steel drive point and a 2-foot (0.61 meter) section of 0.010-inch (0.03 centimeter) 10-slot galvanized steel screen. The remaining length of each well is constructed of nominal 2-inch-diameter (5.1 centimeter) galvanized steel pipe.

DETERMINATION OF SOIL MOISTURE CONTENT

Two different moisture-monitoring methods are employed with the VZMS. Primary leak detection is accomplished using a neutron probe within the PSL monitoring subsystem. Moisture monitoring adjacent to the containment cell, within the CSS monitoring subsystem, is also conducted using a neutron probe. Auxiliary or supplemental moisture monitoring under the containment cell is accomplished using TDR probes within the VSA monitoring subsystem. Additional information on how the raw data measurements (neutron counts and TDR waveform lengths) are converted to determine soil moisture content values is provided below.

Soil Moisture Content Determined With The Neutron Probe

To determine in-situ soil moisture content within the vadose zone using the neutron probe, count response is correlated to known soil moisture values. To provide the correlation, test fixtures were built using native soil with known moisture content. Four soil moisture drums were constructed for use in developing the neutron count to soil moisture correlation for the PSL and CSS monitoring environments. Two correlation drums were built for each monitoring subsystem. Moisture content for the soil in the drums was selected to encompass the potential range of values that would be encountered under normal conditions. One drum represents soil in a dry environment (approximately 2% moisture by mass). The soil in the other has soil with a moisture content of approximately 9.7 % moisture by mass. To construct each correlation drum, soil was added and compacted in layers, with the moisture content of each layer controlled to achieve the desired final moisture level. The correlation drums simulate the configuration of the PSL and CSS monitoring tubes (i.e., VCP and galvanized steel) and the surrounding soil. The neutron count measurements taken within these fixtures are used to develop the mathematical formula that expresses the correlation between neutron counts and soil moisture content. Once the relationship between instrument count data and soil moisture content is established, the correlation provides the basis with which to determine the soil moisture values associated with the PSL and CSS monitoring subsystems. Since they were originally built, the drums have been stored and kept sealed when not in use. Neutron count measurements are taken each year from the correlation drums and a new correlation formula is calculated and compared to what was originally established. The original correlation and newly determined equations are compared to identify any changes in the count statistics.

Soil Moisture Content Determined With TDR

Each TDR moisture measurement instrument package includes a Campbell Scientific, Inc. Model CS610-L, three-pronged TDR probe positioned at 5 and 15 feet (1.5 and 4.6 meters) below the containment cell liner. The TDR probes at each VSA monitoring point are surrounded with repacked native material to duplicate the adjacent native material's effective pore size. Moisture content is determined by the characteristics of the electrical signal response from the TDR probes. The equipment and software utilized to collect this moisture data has changed over the course of the monitoring program. When moisture monitoring using the TDR probes was started over three years ago, a cable tester was used to initiate the electrical pulse and view the signal response from the probe. The voltage signal was sent from a Tektronix® 1502B cable tester to the TDR probe. The 1502B cable tester displayed the voltage signal transmitted through the probe and the surrounding soil as a waveform. Two waveform distance measurements were taken from the cable tester display for each TDR measurement: one at the start of the displayed waveform and the other at the perigee near the end of the waveform. The two waveform distance measurements were recorded for later determination of equivalent moisture values. Application of a correlation formula was used to translate the waveform length to an equivalent soil moisture value expressed as percent mass. Approximately a year ago, the cable tester was replaced with Campbell Scientific Inc. TDR100 monitoring equipment. The TDR100, when used with a portable personnel computer, enables signal generation, response measurement, display of the waveform, and immediate determination of moisture content using software algorithms. Soil moisture content is calculated on a volumetric basis.

ROLE OF BASELINE VADOSE ZONE CHARACTERIZATION IN CONTAINMENT CELL PERFORMANCE ASSESSMENT

Monitoring of the vadose zone underlying the containment cell was initiated following completion of installation of the liner system. Initial monitoring was conducted to establish a background or baseline data set that would be used for comparison when reviewing soil moisture content values collected after treated soil had been placed in the containment cell. The baseline monitoring results provided information on the characteristics of the vadose zone within a 15 feet (4.6 meters) deep region directly below the containment cell.

PSL Monitoring Environment

The effect on soil moisture content, as it was influenced by cell construction activities is evident in the baseline PSL monitoring data. Compaction specifications for the wicking soil surrounding the vitrified clay pipe access tubes used for the PSL monitoring system required the introduction of water. To achieve a soil compaction objective of 95%, the addition of substantive amounts of water was required. This added water resulted in baseline monitoring data showing elevated moisture levels compared to in-situ native soil (approximately 2 –5% moisture by mass). With monitoring points in each PSL access tube spaced approximately 6 feet (1.8 meters) apart, detailed information on the lateral variability in soil moisture content adjacent to the access tubes is evident. An example of the lateral variability in moisture content that can be measured using the PSL access tubes is displayed in one of the plan view moisture maps that are prepared for each monitoring event (Fig. 4). The baseline monitoring data for the PSL monitoring system have been used for comparison with the monitoring results collected since treated soil started to be placed in the containment cell. To assess the containment cell's performance in leak prevention during each monitoring event, the moisture value measured at each PSL monitoring location is compared to the value obtained from the previous monitoring event. Measuring net changes in moisture content values observed between monitoring events, in association with documenting long-term moisture trends, provides the basis for determining the response of the vadose zone to cell construction and treated soil emplacement. Monitoring short and long-term moisture changes supports the primary function of verifying performance of the containment cell.

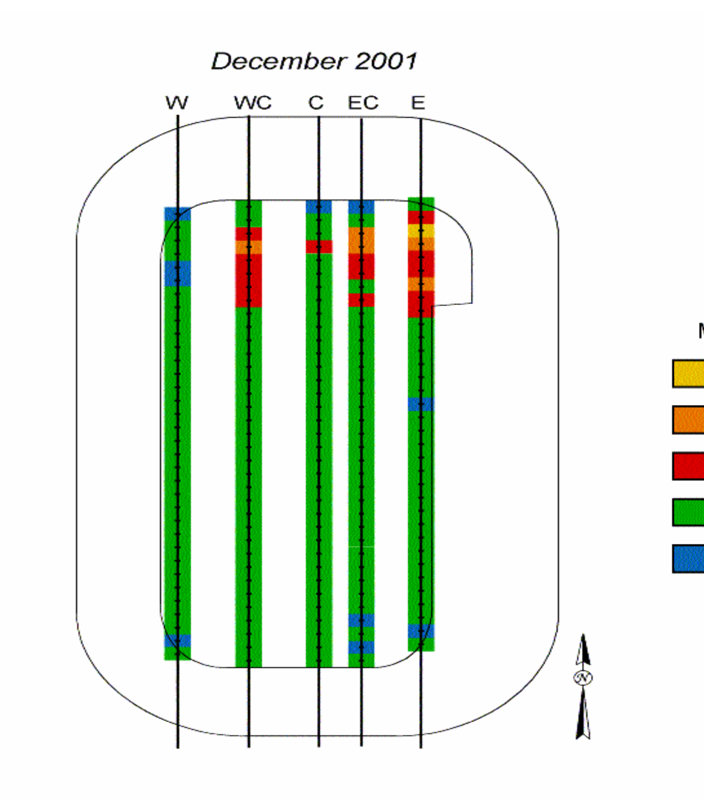

Fig. 4 Plan View of Containment Cell Showing Variations in Moisture Levels Measured in the PSL Access Tubes

VSA Monitoring Environment

Baseline soil moisture content data gathered from the VSA, as well as the more recent monitoring results gathered since initiating soil placement into the containment cell, provide auxiliary information for use in evaluating PSL monitoring subsystem results. Information on the vadose zone provided by the VSA monitoring system is of particular importance when determining if an increase in soil moisture content observed in the outermost PSL access tubes is associated with a moisture source outside the containment cell. The VSA monitoring subsystem also includes two monitoring locations positioned below the leachate collection sump. These monitoring points can be used to indicate the vertical extent of leak migration if it were to occur in this area. The temperature data collected from below the containment cell with the VSA subsystem is used in calculations to adjust TDR moisture values and to monitor temperature variations below the liner. Prior to placement of soil in the containment cell, seasonal temperature fluctuations and the associated changes in radiant heat levels transmitted through the liner and monitored in the underlying soil were very evident. Following placement of soil in the containment cell, the insulating affect of an additional 20 feet (6.1 meters) of soil placed above the temperature sensors has resulted in a more consist temperature environment. Before treated soil was placed into the containment cell, temperatures recorded at the 5 and 15 foot (1.5 and 4.6 meter) monitoring depths (depths expressed as below bottom liner) had generally shown approximately 15 ^{o}C and 5 ^{o}C temperature seasonal temperature variations respectively. Six months after the containment cell was filled, soil temperature variability observed at the 5 foot (1.5 meter) was generally less than 5 ^{o}C, and approximately 2 ^{o}C at the 15 foot (4.6 meter) monitoring interval.

Soil Gas Characterization

The VZMS also permits the analysis of VOC concentrations in the soil gas directly underlying the containment cell. As part of baseline data collection, the PSL, VSA and CSS monitoring systems were sampled to determine local VOC soil gas characteristics. The baseline soil gas data set can be used for comparison to VOC data that might be obtained during a leak verification assessment. Soil gas data collected during a leak verification/confirmation analysis would be used to determine if new VOCs and/or elevated concentrations of VOCs detected during baseline monitoring are present. The data could be used to further characterize the nature of a release identified by moisture monitoring, and assess whether VOCs are potential constituents.

Of particular interest during the baseline evaluation, was determining what influence an adjacent source area had on the soil gas characteristics underlying and next to the containment cell. The extensive number of soil gas monitoring points that are available in the entire VZMS (33 total), along with their aerial distribution, provides the ability to map VOC concentration gradients under the containment cell. The baseline soil gas data set identified those compounds that occurred ubiquitously throughout the monitored environment, as well as the specific compounds and concentrations that could be attributed to a source outside the CAMU.

LONG TERM PERFORMANCE ASSESSMENT OF THE CONTAINMENT CELL

The VZMS is designed to meet the long term monitoring requirements for waste containment at the CAMU. With a diverse set of capabilities, the system, if needed, can easily be adapted to new and changing monitoring initiatives. Existing plans call for the operation of the VZMS and inspections of the containment cell cover system and supporting CAMU infrastructure for the next 30 years. The VZMS provides a fast and efficient mechanism for the assessment of the current and long-term containment cell performance. The monitoring system can be utilized at any sampling frequency needed to verify that contaminants are remaining in-place and groundwater is not threatened by the continued operation of the CAMU. Currently, soil moisture content in the vadose zone is determined at 173 locations within the PSL subsystem, 22 locations with the VSA subsystem, and 12 locations within the CSS subsystem. Soil gas samples can be collected from up to 33 locations. During the 30 year post-closure care period, the VZMS is designed to provide real-time data verifying the stability and effectiveness of the containment cell.

Notwithstanding the costs of the soil gas analyses, the total cost per annum for monitoring using the VZMS during post closure is expected to be less than $100K. This cost includes, personnel, equipment, and regulatory reporting requirements. If soil gas measurements continue to be required during the post-closure period, an additional $20K would be needed for laboratory analytical and data management costs each year. It is anticipated that soil gas sampling will be eliminated during the 30-year post closure period, saving the taxpayers approximately $0.6 million.

If conditions change at the facility and/or within the regulatory environment, the requirements for monitoring and maintaining the CAMU's VZMS will be able to change accordingly. The VZMS has the capability to verify containment cell performance and the sensitivity to identify the location of leakage within the cell if it were to occur. These attributes of the VZMS will be of considerable benefit over the post-closure period and provide confidence that the containment cell is meeting its design criteria and regulatory monitoring requirements.

CONCLUSIONS

Vadose zone monitoring has provided a much-improved "early warning system" for demonstrating that the SNL/NM can construct, operate and safely close a disposal cell for contaminated soils. The configuration of the VZMS allows for changes in the requirements for selected monitoring components, monitoring frequency and level of sensitivity. A vadose zone monitoring approach assures the regulators that the wastes placed in the CAMU containment cell are safe and secure and pose no threat to the environment. Comparatively, the costs of operating the CAMU's VZMS are higher than a traditional RCRA groundwater monitoring system. But the benefit in the VZMS's preventative capacity for advanced warning of leakage from a few feet under the containment cell, versus the indication gathered from a monitoring well when contamination has traveled over of 485 feet (148 meters), is substantial.

REFERENCES

1 Sandia National Laboratories/New Mexico (SNL/NM), 1997. "Class III Permit Modification Request for the Management of Hazardous Remediation Waste in the Corrective Action Management Unit, Technical Area III," Environmental Restoration Project, Sandia National Laboratories, Albuquerque, New Mexico (as modified).

2 Sandia National Laboratories/New Mexico (SNL/NM), 1999. "Class III Permit Modification Request for the Management of Tritium-Containing Soil in the Corrective Action Management Unit, Technical Area III," Environmental Restoration Project, Sandia National Laboratories, Albuquerque, New Mexico.

3 Sandia National Laboratories/New Mexico, (SNL/NM), 2001. "Risk-Based Approval Request 40 CFR 761.61(c) Risk-Based Method for Management of PCB Materials, Chemical Waste Landfill Remediation and Corrective Action Management Unit Operation," Sandia National Laboratories, Albuquerque, New Mexico.

4 Hawley, J.W., and C.S. Haase (editors), 1992. "Hydrogeologic Framework of the Northern Albuquerque Basin," New Mexico Bureau of Mines and Mineral Resources, Open-File Report 387, Socorro, NM.

5 Lozinsky, R.P., 1988. "Stratigraphy, Sedimentology, and Sand Petrology of the Santa Fe Group and Pre-Santa Fe Tertiary Deposits in the Albuquerque Basin, Central New Mexico," unpublished Ph.D. dissertation, New Mexico Institute of Mining and Technology, Socorro, NM.

6 Sandia National Laboratories/New Mexico (SNL/NM), 1994. *Sitewide Hydrogeologic Characterization Program, Calendar Year 1993 Annual Report*, Albuquerque, NM: Sandia National Laboratories, Environmental Restoration Project.

7 Sandia National Laboratories/New Mexico (SNL/NM), 1996. *Site-Wide Hydrogeologic Characterization Project, Calendar Year 1995 Annual Report*, Albuquerque, NM: Sandia National Laboratories, Environmental Restoration Project.

8 Sandia National Laboratories/New Mexico (SNL/NM), 2000. "Chemical Waste Landfill Stage I Extraction Voluntary Corrective Measure Design Report," Sandia National Laboratories, Albuquerque, New Mexico.