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STUDY OF VADOSE ZONE MONITORING AT THE HANFORD SITE, TASK 1, USE IN NEW CELLS AT THE ENVIRONMENTAL RESTORATION DISPOSAL FACILITY

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

United States
Department of Energy
P.O. Box 550
Richland, Washington 99352

Project Hanford Management Contractor for the
U.S. Department of Energy under Contract DE-AC06-96RL13200

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Submitted to

U.S. Department of Energy, Richland Operations Office

By
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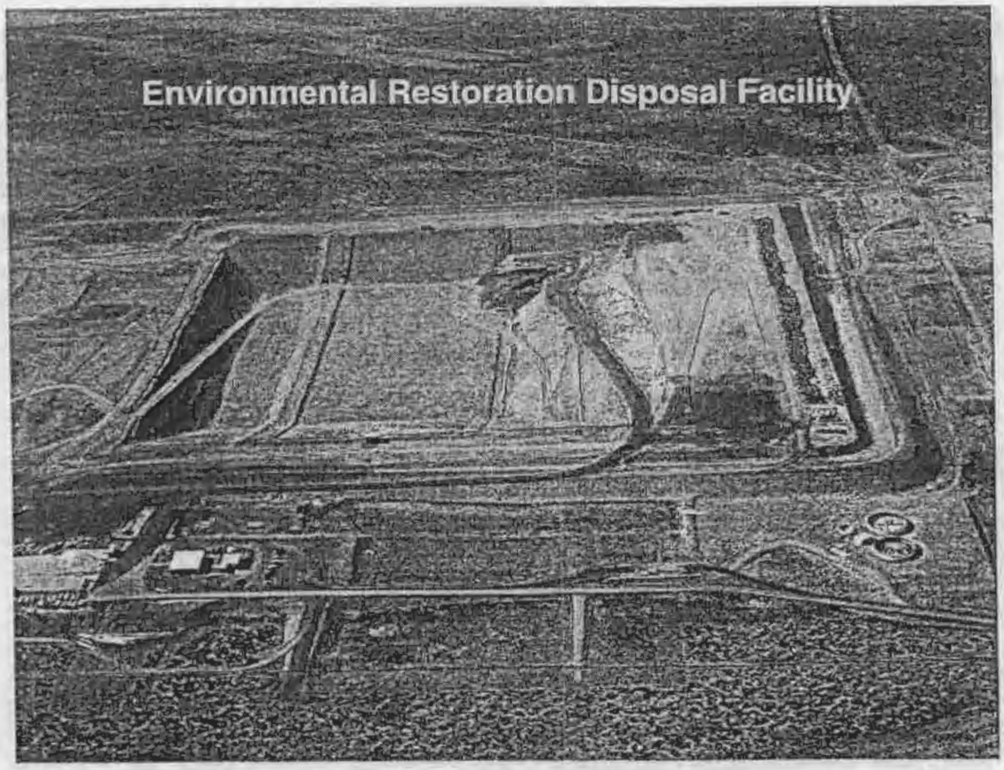

Executive Summary

This is the first part of the study that was promised by the U.S. Department of Energy according to letter, M. S. Schlender, DOE, to M. L. Goldstein, EPA, and M. A. Wilson, Ecology, "Vadose Zone Monitoring Study," 02-ERD-0055, dated March 11, 2002. This part is a study of the potential for vadose zone monitoring at the Environmental Restoration Disposal Facility (ERDF). The second part of this study will be the potential for vadose zone monitoring at other places in the Central Plateau.

The main features of the construction of the ERDF are presented. A discussion of the regulatory context for vadose zone monitoring is given. A survey of the current technologies available for vadose zone monitoring is discussed, along with examples of how they are currently deployed. A survey is made of the use of vadose zone monitoring at selected representative commercial facilities in the Western States of the U.S. Auxiliary issues of vadose zone monitoring deployment are presented. Based on these examples and the current available technologies, conclusions are drawn as to what would be feasible for the ERDF.

Two distinct phases in the life cycle of a landfill (the operational and final closure) are identified, with corresponding recommendations for each phase. It is recommended that a monitoring system be developed for the incorporation into the design of the caps when the ERDF cells are closed. Several possibilities are suggested. Since the access to the caps is much easier than access below the landfill, there is an opportunity to design the latest technologies into each newly constructed cap. Current technologies point toward the use of strategically place lysimeters and the consideration of tomographic methods for evaluation of the integrity of landfill covers.

For the double lined ERDF cells, as currently designed and operated, the addition of vadose zone monitoring during the operational phase is not required or necessary. However, it is recommended that vadose zone monitoring systems be installed for the purpose of developing Hanford Site specific data on the performance of these systems at a well-designed and well-controlled facility. This will provide information on the expected performance of vadose zone monitoring systems and their potential use in future multi-use disposal facilities at the Hanford Site. For this purpose, it is recommended that basin lysimeters be installed below the sumps and that perforated access tubes be installed below the secondary liner and admix layer of newly constructed cells. Data collected from these systems will be used to evaluate the vadose zone systems and will not be part of the performance monitoring for the ERDF cells.

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List of Acrynoms

ASTM	American Society for Testing and Materials International
CP	Central Plateau Remediation Project
CERCLA	Comprehensive Environmental Response, Compensation and Liabilty Act
CWM	Chemical Waste Management
DQO	Data Quality Objectives
EMI	Electromagnetic Induction
ERDF	Environmental Restoration Disposal Facility
EPA	Environmental Protection Agency
HDPE	High-Density Polyethylene
NRC	Nuclear Regulatory Commission
RCRA	Resource Conservation and Recovery Act
RL	U.S. Department of Energy, Richland Operations Office
SDRI	Sealed Double Ring Infiltrometer
SWL	Solid Waste Landfill
TDR	Time Domain Reflectometry
VZM	Vadose Zone Monitoring
WMI	Waste Management Incorporation

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STUDY OF VADOSE ZONE MONITORING AT THE HANFORD SITE

Task 1

USE IN NEW CELLS AT THE ENVIRONMENTAL RESTORATION DISPOSAL FACILITY

1.0 BACKGROUND AND OBJECTIVES

The objective of this study is to evaluate the use of vadose zone monitoring (VZM) in the Central Plateau Remediation Project (CP) at the Hanford Site. This is the study indicated in the letter (Reference 02-ERD-0055) from Michael H. Schlender of the U.S. Department of Energy, Richland Operations Office (RL) to Michael L. Goldstein of the U.S. Environmental Protection Agency (EPA) and Michael A. Wilson of the State of Washington Department of Ecology, which says in part, "... the U.S. Department of Energy, Richland Operations Office (RL) will perform a vadose zone monitoring study in the Central Plateau." Data quality objectives (DQO) were evaluated at the beginning of the study in order to provide insight into the technical objectives and evaluation methods.

Task 1 of the study evaluates the use of vadose monitoring for new cells of the Environmental Restoration Disposal Facility (ERDF). The remaining task will be to evaluate current VZM activities on the rest of the CP and the potential use of VZM in the future.

2.0 INTRODUCTION

Understanding when and where contaminants may be released, how they become distributed, and how they may be transported in the unsaturated zone is important in giving early warnings of possible contamination of the groundwater. Monitoring of possible release sites could provide information that could be used in minimizing the impact of a release from these sources. The applicability of such monitoring depends, however, on the likelihood of a release, design specifications for facilities, the actual geology, geochemistry, and transport properties of the area surrounding the release, and the nature of the material released. Another very important aspect of VZM is how data can or might be used in the interpretation of events. Unlike groundwater monitoring, which has an extensive technical and regulatory history related to its application, VZM has a limited history with respect to the technical and regulatory bases for its application (i.e., issues dealing with the probability of detection vs. probability of false alarm and response actions are still under considerable debate and development).

Task 1 of the study evaluates the option of adding VZM for Cells 5 and 6 and subsequent cells at the ERDF Site. This initial task is designed to provide recommendations on VZM in a timely manner so that it can be considered for the design of Cells 5 and 6, which is in last months of completion, and subsequent cells as they are designed in the future. There are two primary aspects to the recommendations. The first aspect deals with monitoring recommendations under the liner and sump systems for Cells 5 and 6 and subsequent cells. If the recommendations related to the liner and sump systems cannot be incorporated in the current design for Cells 5 and 6, then they should be considered for future ERDF cells. The second aspect deals with general considerations for VZM in the cap when the cells of ERDF are closed. Cap design and closure are a number of years away so detailed recommendations at this time would be premature. Addressed in Task 1 are the needs for monitoring, the reliability of current monitoring technology, and the evaluation of appropriate monitoring strategies. The study includes a general identification of the potentially applicable instrumentation or methods for VZM, a discussion of how some of the sensor technology is used, and recommendations specifically for Cells 5 and 6 and subsequent cells.

This study evaluated the conditions at the ERDF for the possible utilization of monitoring. Generic elements of a 1997 evaluation of monitoring for the ERDF have been included in this report. Extensive use was made of information derived from other landfill sites, with emphasis on commercial sites in places having deep vadose zones, consultation with internationally recognized experts in vadose zone flow and monitoring, and reference to the most current literature on monitoring of landfill performance.

3.0 ENVIRONMENTAL RESTORATION DISPOSAL FACILITY CONSTRUCTION AND PERFORMANCE

3.1 Liner Construction

The facility is a landfill authorized by a Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) Record of Decision that is designed to meet Resource Conservation and Recovery Act (RCRA) Subtitle C requirements of Subpart N, 40 CFR 264. An existing groundwater monitoring program, consisting of one up gradient and three down gradient wells, has been installed.

The ERDF is a double lined waste disposal facility that complies with EPA's Minimum Technology Requirements for hazardous waste landfills. The design of the disposal cells (including new Cells 5 and 6) call for the following: a primary (upper) liner with a 60-mil textured high-density polyethylene (HDPE) sheet and a secondary (lower) liner with of a 60-mil textured HDPE sheet-in direct contact with a three-foot-thick layer of soil / bentonite admixture in the bottom of each cell. Although there is a 100-mil HDPE sheet attached to the sump carrier pipe, it has no containment function. (Design Analysis, Vol. 1, Vol. 2, Bechtel, 1995).

The side slopes of the landfill have grades of 3H:1V, while the floors slope toward the sump at grades of 1.5% to 3%. Thus, any leachate should drain toward the sumps. Under normal conditions, the liner systems outside of the sumps should not experience any standing leachate (pressure head). Within the sumps, submersible pumps remove leachate so that the head pressure on the floor of the sump, except for transient storm conditions, should be less than one-foot.

The low permeability soil used as the lower component of the secondary liner consists of silty fine sand mixed with approximately 12% bentonite by weight. This material was carefully moisture conditioned, placed in lifts, and compacted in the field. To establish compaction requirements, a sealed double ring infiltrometer (SDRI) test was performed prior to construction of the liner in the landfill itself. The SDRI test is a large-scale simulation of the actual liner and is intended to identify any flaws in construction techniques. SDRI results indicated a soil layer permeability of about 1 x 10-8 cm/sec.

The top and bottom leachate collection system are sampled, and the volumes from each are recorded. In general, the volume ratio is 100:1, between the upper and lower leachate collection system and well within the allowable leakage through the primary liner of 175 gallons per day per acre. In the past, leachate samples were combined and analyzed together. It was assumed that the chemistry of leachate from the upper and lower collection system was the same. To confirm this, samples from the upper and lower leachate collection systems are being analyzed separately during the next several rounds of sampling. Volume measurements and sampling results are provided in the Annual ERDF monitoring report. The facility appears to be operating according to design.

3.2 Environmental Restoration Disposal Facility Closure

The landfill cells have been open and therefore exposed to precipitation. Dust suppression using water was used both at the collection site and at ERDF, resulting in large initial amounts of water in the facility. A low-permeability interim cover has been placed over each cell after that cell has been filled, approximately three years after initial waste placement. A final closure cover is in the design stage. These covers will reduce or eliminate infiltration into the waste. The leachate collection and detection sumps will continue to remove infiltrating rainfall and dust suppression water in the waste. Once a permanent cup is in place, the leachate volume should be considerably reduced. General recommendations for vadose monitoring in the final closure cap are discussed in this report. The long term use of the facility consist of two parts; (1) the operational stage, during which the facility receives waste and comes to equilibrium with an interim cover; and (2) a final closure stage, during which the final cover has been put in place and long term monitoring continues.

4.0 REGULATORY CONTEXT FOR VADOSE ZONE MONITORING

4.1 U.S. Environmental Protection Agency and Washington State Regulations

Groundwater monitoring requirements at hazardous waste landfills applicable to the ERDF are contained in EPA regulations in 40 CFR Part 264 Subpart F. These regulations include no specific requirement for VZM at landfills. Land treatment facilities are the only types of "regulated units" specifically required to conduct VZM.

4.2 Other States' Regulations

Some other states require VZM at hazardous waste landfills. Chemical Waste Management's (CWM's) hazardous waste management facilities in Arlington, Oregon, and Kettleman Hills, California, are both implementing VZM programs. However, there is an explicit regulatory authority in both Oregon and California hazardous waste regulations that specify requirements for VZM. Oregon's requirements are found in Oregon Administrative Regulations 34 104-029 and California's requirements are found in 22 CCR 66264.97(d)(d)(5). Additional discussions of the CWM and Kettleman Hills landfills are presented below.

5.0 COMMERCIAL SITES USING VADOSE ZONE MONITORING

The information in this section was derived from interviews with operators of the facilities.

Central Waste Management Facility, Arlington, Oregon

Discussions with Waste Management Inc. (WMI) personnel at WMI's Columbia Ridge Landfill (municipal solid waste) in Arlington, Oregon, indicated that they are implementing VZM both at that facility and at the adjacent CWM hazardous waste Subtitle C landfill at Arlington, Oregon. At the Subtitle C facility, VZM is not implemented for existing units (which were constructed prior to the regulatory requirement), but it is being implemented in new landfill cells. The monitoring system consists of basin lysimeters installed beneath leak detection/collection sumps. The system is in operation. CWM also prepared a Response Action Plan, similar to that required in 40 CFR 264.304 for leak detection systems, in the event the VZM system detects leakage. The Response Action Plan describes different actions to be taken depending on the amount and quality of leakage detected.

Kettleman Hills, California

Personnel at the CWM Kettleman Hills, California, facility indicates that new landfills include a third geomembrane liner under the entire footprint of the landfill that functions as a large basin lysimeter. Initially, some water was collected that was attributed to consolidation of the overlying clay liner. Since that time, however, no water has been detected. In addition, the State Department of Toxic Substances Control has requested CWM to evaluate the use of neutron probes for VZM at previously closed, unlined landfills. However, such a program has not yet been implemented.

Roosevelt Regional Landfill, Roosevelt, Washington

This RCRA Subtitle D landfill has been built out in cells. The initial couple of cells had a large 20' wide free drainage lysimeter underneath the full length of the leachate collection system. The leachate collection system is simply a perforated pipe, which drains to a sump. The liner involved is a straightforward Subtitled D design. The only VZM, therefore, is simply a second liner strategically located under the leachate collection system with its own separate drainage and sump collection facilities. The original design utilized a trench to house the primary leachate collection system. This design was changed to a v-shaped notch rather than a trench design. As new cells are developed at this site, the state regulations under Subtitle D do not require the use of these free drainage basin lysimeters. The depth to water is 120', and the water bearing formation sits on a 340' layer of very thick clay. The logic expressed is that any leachate from the landfill will in fact perch on the clay and therefore the local groundwater monitoring system really acts as a VZM program. The drinking water aquifer is located below the clay layer.

Envirocare, Utah

The Envirocare facility is built out with individual cells that measure approximately 1500' by 900' each. There are two fundamental types of cells on site. One group consists of cells for radioactive waste only that are built according to Nuclear Regulatory Commission (NRC) requirements, which do not allow synthetic materials and which must satisfy the 500-year longevity requirement. Although methane is not an issue, these cells do in fact have caps that accommodate radon gas. Another group consists of standard RCRA subtitle C cells for mixed waste, with double liners and standard caps. The State of Utah required that a separate test cell be constructed in the identical manner as the operational cells. The test cell is highly instrumented with suction lysimeters, gypsum blocks, a metric potential probe, water content reflectometers, and temperature probes. The test cells, however, are not instrumented with neutron probes or any time domain reflectometry (TDR) systems. The rationale used is that NRC cells are designed to leak slowly to preclude any kind of bathtub effect. These designs are very different than the RCRA Subtitle C cells, which are designed not to leak. The RCRA cells have a third liner with a sump beneath the other liners that serves as a monitoring system for those cells.

City of Coalinga Landfill

The City of Coalinga landfills are a RCRA Subtitle D design. The Fresno County operators have implemented a perimeter soil gas monitoring series of air piezometers. The soil gas wells focus on the distribution of methane gas. These wells, however, do not penetrate through the cap and are located outside the landfill borders. No other VZM related to pore liquids is utilized at the site. The landfill is relatively small, and as such, groundwater monitoring has been found to be acceptable.

Triassic Park, New Mexico

The unique Triassic Park hydrogeology is compatible with a site-specific VZM design. Depth to water at the facility is greater than 600'. The aquifer, which contains non-potable water, has poor water production. Fine-grained materials underlie the landfill and the native soil is instrumented with neutron probes and lysimeters, which are used to focus on any potential perching of leachate on the fine grain sediments. Based upon the potential for perching and the use of suction lysimeters and neutron probes, the federal regulations on groundwater monitoring have been waived, and the groundwater monitoring requirements have been removed. The location of the lysimeters and the neutron probes however are completely outside the engineered liners. At this stage no monitoring is anticipated in the cap, and no monitoring is anticipated under the sumps at the facility.

U.S. Ecology, Hanford, Washington

This is an unlined facility built out in a series of trenches, each roughly 40' deep, 150' wide, and 400' long. It was begun in 1965 as an Atomic Energy Commission licensed site for radioactive waste. The license was transferred to the State of Washington when the State signed an agreement participating in the national regulation of radioactive material. It has been under the auspices of the State of Washington Department of Health since that time, with review and some oversight from the Department of Ecology. It is not regulated under RCRA, but attention is paid to some RCRA compliance parameters. A total of 16 trenches are currently in existence. None are capped, and none are lined. The material going into the landfill is required to be dry (anything wet must be accompanied by an excess amount of absorbent material). Although an earlier trench received hazardous waste, the facility has not accepted hazardous waste since 1985. The trenches are filled in layers, with dirt fill being put in place over each new layer of deposited waste. There is currently no significant concern that precipitation will drive the contaminants to the groundwater because it is believed that on average, the recharge rate is very low. The depth to groundwater is approximately 300'. A proposed closure plan is written every five years; the latest indicates a homogeneous final cover. There are currently three upstream groundwater monitoring wells and four downstream groundwater monitoring wells. There are a total of three vertical VZM wells. These are drilled adjacent to some of the trenches to a depth just below the trenches and are sampled on a regular basis determined by the fees that accrue as waste is received. These vertical wells are sampled for waste gas emission. A special study was conducted at the request of the State of Washington Department of Ecology to sample the vadose zone under some of the trenches. Two wells were slant drilled underneath the trenches. The samples from these wells indicated analyses that were very similar to those of the vertical well samples. The slanted wells are still available for sampling, but have not been used since the original study.

Solid Waste Landfill at Hanford

A basin lysimeter has been installed below the Solid Waste Landfill (SWL) at the Hanford Site. The SWL is located just off Army Loop Road, south and east of the 200 E Area. The SWL area is 65 acres. The content is "paper wastes and construction debris" but also includes asbestos, some million gallons of sewage and wash-water and "chemicals." The period of filling was 1973-1995. It was completely closed in 1996. There is no cover other than native backfill (no designed capillary breaks or lateral diversions). Simply a typical landfill without a "permanent" cover, soil-cover material 97-98% coarse (>2 mm) material, cobbles and gravel and sands. This is typical of the cribs and trenches in the 200 Areas but with no herbicide applied here. The bottom is unlined. The total area of the basin lysimeter is 80 square meters and was installed in 1993, below one of the last cells to be filled. This lysimeter has been continuously monitored on a regular basis from the summer of 1996, to the present. The lysimeter liquid volumes can be compared with precipitation values during this period of time. The liquid volumes collected in the lysimeter show two periods when it received increased rates of accumulation. These were (1) during the summer of 1996 and (2) during all of 1997. After that, the accumulation rate has been steady to the present. Integrating the accumulation over the period of time from the summer of 1996 to the present, one finds that the drainage through the landfill is approximately one fourth of the total precipitation that falls on the landfill.

In summary, the most common type of VZM at these commercial sites is the basin lysimeter located beneath the sump area. This is, of course, limited to sites that contain moisture. An instrumented test cell (without real waste) was constructed at one site, and sampling from vertical vadose zone wells was employed at the one landfill that was considered dry. In many cases the use of VZM eliminated some of the requirements of groundwater monitoring.

6.0 DETECTION METHODS FOR VADOSE ZONE MONITORING

Methods for VZM generally fall into broad classes such as measurement of moisture change, collection of moisture and gas samples, temperature, flow/velocity, barometric pressure, settlement, etc. A complete evaluation of the development of VZM science and technology is found in the National Department of Energy Vadose Zone Science and Technology Roadmap (Idaho National Engineering Laboratory, S. J. Kowall, ed.). For purposes of this study, it is assumed that VZM would be performed in the sub grade beneath the construction of the new cells, within the new cells, or within the final cap covers.

6.1 Moisture Change Methods

A number of methods are available for monitoring moisture change in soils (Everett et al., 1984, Wilson et al., 1995, Looney & Falta, 2000). Many of these measurement techniques require laboratory testing to develop calibration curves relating instrument output to soil moisture content. Several of the more commonly used methods are described below:

6.1.1 Neutron Probe

The neutron probe contains a source of neutrons and detectors to measure backscattered neutrons. The magnitude and energy of backscattering is primarily a function of the hydrogen content of the material surrounding the probe. To take readings, the neutron probe is lowered into the pipe and a continuous record of the response is obtained. Changes in the readings over time at a particular depth indicate changes in the number of hydrogen atoms, i.e., water content. The neutron probe must be calibrated for specific soils.

6.1.2 Time Domain Reflectometer

In this method, an electromagnetic wave is transmitted along a transmission cable buried in soil. At the end of the cable, a portion of the signal is reflected. The amplitude and travel time of the reflected portion depend on the dielectric properties of the soil, which in turn are strongly dependent on soil moisture content. The output is typically monitored on an oscilloscope or cable tester. These probes can be monitored remotely and have no direct analytical costs associated with them other than initial calibration. This tends to minimize life-cycle costs.

6.1.3 Thermocouple Psychrometer

This instrument measures relative humidity within the soil pores, from which soil water potential, and therefore moisture content, can be calculated. Humidity is determined by the observed difference in temperatures between two thermocouples, one of which is exposed to the humidity in the surrounding soil and experiences cooling; the other thermocouple is located adjacent to the first but is isolated from the humidity. Moisture content is determined from relative humidity on the basis of laboratory calibration.

6.1.4 Electromagnetic Induction

Electromagnetic Induction (EMI) is a standard geophysical technique that is used to measure the conductivity of soil mass. At the ground surface, a transmitter coil generates an electromagnetic field that induces eddy currents in the underlying sub grade. Secondary electromagnetic fields created by the eddy currents are measured by a receiver coil that produces an output voltage related to the subsurface conductivity. EMI is a rapid technique that is often used to delineate contaminant plumes, buried wastes, and other features that have conductivity contrasts with the surrounding soil.

6.1.5 Electrical Resistivity Tomography

Electrical resistivity tomography (ERT) is based on a large number of soil resistance measurements analyzed by mathematical methods (e.g., finite difference models employing inversion techniques). Each resistance measurement involves several electrodes, some to apply a current through the soil and some to measure the voltage drop. The location and spacing of the electrodes determines the soil volume being measured; in general, larger electrode spacings are used at greater depth. Commonly a linear series of electrodes is placed on the ground surface or beneath a landfill. An automatic monitoring system excites various pairs of electrodes according to a programmed sequence and measures the resistance between other pairs. When all desired combinations have been read, the resulting data are analyzed. The result is a two-dimensional contour map (i.e., a vertical or horizontal slice) of soil resistivity along the electrode line. Changes in moisture content over time would appear as changes in resistivity. Laboratory calibration of sub-grade soil would be required to develop quantitative relationships. High-resolution resistivity has shown particular merit in both cap and subsurface liner monitoring but is not developed to a stage where it can be recommended in the next few months.

6.1.6 Fiber Optic Cable

Fiber optic systems could be considered as one of the latest improvements in vadose zone sensor systems. Fiber optic systems already are measuring strain, temperature, acoustics, moisture, pH, flow, and chemicals. Fiber optic cable could be included in the future applications of a monitoring system. The cable could be deployed in the perforated stainless steel tubing laid down below the bottom liner during construction. Consideration could be given to including fiber optic cable in the horizontal and vertical monitoring orientations. The cost advantages expected with the use of fiber optic sensors are substantial. The risk of causing preferential flow paths associated with installing a very small diameter fiber cable is small relative to the other technologies.

6.1.7 Limitations of Moisture Change Monitoring

There are processes other than leakage through the liner system that could cause changes in moisture content of the vadose zone. Examples include moisture release from the admix layer as it consolidates under the load of the waste, and vapor migration due to temperature changes caused by excavation, lateral moisture or vapor movement into the trench (from outside the trench), and removal of sub-grade soils. Moisture change resulting from such processes could be difficult to distinguish from leachate. In addition, those methods described above which utilize electrical properties of the soil would be influenced by dissolved constituents as well as moisture content alone. In spite of these limitations, in the case of a RCRA cap, which is designed as an impermeable cap, elevated moisture migration rates alone can be used as an indicator of increased infiltration through the cap.

6.2 Moisture Sampling Methods

To determine whether moisture is the result of leakage through the liner, samples are collected and analyzed for constituents known to occur in the waste material. A number of techniques are available and are described in the literature (Everett 1980, Everett et al 1984, Wilson et al 1995, Looney & Falta 2000).

6.2.1 Suction Lysimeter

The suction lysimeter consists of a porous cup or plate attached to a small diameter tube leading to a sampling chamber. The lysimeter is buried in the soil at the location where a sample is desired, and the tubing leads to an accessible location. To obtain a sample, a reduced pressure is applied to the lysimeter. Water in the soil matrix is sucked into the lysimeter and accumulates in the sampling chamber. There are various modifications utilizing additional tubes, check valves, and other components to allow samples to be retrieved from depth, but the basic operating principle is the same.

6.2.2 Absorbent Pads

This method utilizes pads of absorbent material, such as felt, to collect soil moisture. One commercially available system (Flute), which has been used to collect samples beneath a radioactive waste landfill at Los Alamos National Laboratory, utilizes a cylindrical flexible membrane, which holds the pads. The membrane is initially inside out, or inverted, and is "everted" as it is placed in the borehole so that the pads contact the borehole wall. After a period of time, when the pads have reached equilibrium with the surrounding material, the membrane is withdrawn, being inverted again during this process so that the pads are not contaminated. In soil materials, where an open borehole cannot be maintained over the long term, a permeable casing would be required.

6.2.3 Sodium Iodide Gamma Detector

This is a radiation-measuring instrument that would be lowered down an access pipe. Rather than returning a sample to the ground surface, the detector measures the radioactivity of the surrounding soil. This method identifies contaminants, which are gamma emitters in sufficient concentrations to be clearly detectable.

6.2.4 Basin Lysimeter

The basin lysimeter consists of a broad, shallow basin several feet in dimension. It is lined with a geomembrane and backfilled with vadose zone soil. The floor of the basin slopes to a collection point, and a pipe leads from this point up to the ground surface. When a sample is required, a sampling pump is lowered down the pipe, where quantifiable measurements can be obtained.

6.2.5 Chemical Analysis

In addition to capital costs, moisture sampling has ongoing operating costs related to the sampling process and the associated chemical analysis.

7.0 DEPLOYMENT OF DETECTION METHODS

The following is a discussion of how the above-mentioned detection methods can be deployed. This list of deployment methods is not meant to be exhaustive, but represents some of the possible configurations for potential deployment. The DQO of the monitoring systems would be clearly identified, and the methods applied would provide a means of monitoring a landfill after closure in lieu of certain groundwater monitoring.

7.1 Basin Lysimeter

A review of other hazardous waste facilities, as discussed earlier, shows that where VZM is applied below the liner system, the primary method utilizes basin lysimeters of variable sizes. Basin lysimeters generally have proven regulatory acceptance, reduced cost, ease of installation, and the ability to collect quantifiable results. A typical design would be a basin lysimeter made up of 100-mil HDPE installed under the bottom sump. The lysimeter can extend five feet beyond the perimeter of the bottom sump and can be designed with an access pipe that will allow the removal of any liquid collected. Due to the lateral flow patterns normally generated near capillary barriers and those that exist at the interface between contrasting soil textures, such a basin lysimeter could be expected to detect most leaks in the bottom liner of a landfill.

7.2 Access Tubes

Time proven technologies like neutron moderation could be considered now below the liner systems of cells. As new technologies are developed and old technologies improved, consideration should be given to deploying or improving these new options. Particular reference could be made to emerging volume-integrating technologies like high-resolution resistivity and cross bore hole electrical resistive tomography. This strategy of being prepared to employ future technologies as they develop, could be facilitated by installing access tubing (probably perforated) beneath the bottom liners of new construction. This would provide a relatively inexpensive method of accommodating new technologies as they become available. Of the new technologies, those giving volumetric information seem to be the most promising. The main advantage of such a tubing network would be that tomographic methods could be used to provide a spatial distribution of any detected leakage.

Even with today's technologies, horizontally emplaced perforated access tubes could be used for measuring soil moisture movement, gamma detection, soil pore water sampling, soil gas, etc. The perforated tool access tubes should span the entire length a cell buried in a four to six foot deep trenches along the bottom of each cell and located in areas of potential liner failure. The multi-purpose, perforated access tubes could use the following types of monitoring technologies in measuring the above-mentioned parameters: a neutron probe, a sodium iodide gamma detector, and absorbent pads for evaluating soil pore water quality. The value of this monitoring approach is that it represents a cost effective graded method that would allow spatial monitoring below the landfill in order to locate liner failure positions. Soil moisture alone could be used as a cost effective sentinel parameter, which could be backed up with other supporting parameters if required. Perforated casing below the landfill might permit the collection of soil gas samples and could be used as part of a leakage or performance check of both the liner and the caps.

7.3 Measurements Systems Inside a Landfill

Vertically emplaced perforated access tubes (open-holed at bottom) could be installed (for measuring soil moisture movement, gamma detection, and for collecting soil pore water samples). The access tubes would extend from the surface, through the closure cover and the waste, but not through the bottom liner. These access tubes could be used for detecting vertical moisture changes throughout the waste, function as an access port for various other types of geophysical tools (e.g., neutron and gamma logging tool), provide access for absorbent pads, and the open hole at the bottom permits access for direct soil sampling. It would be imperative that a good seal be completed around the perimeter of the access tubes to prevent preferential flow between the access tubes and soil material. The following are other sensors that could be used with such a vertical tube system:

- TDR probe monitoring stations for each vertical access casing could be installed for measuring volumetric soil moisture.
- Heat dissipation probe monitoring stations (co-located with the TDR probes) for measuring matrix potential, which is the driving force for unsaturated moisture movement could be installed on each of the vertical access casings.
- Suction lysimeters in a vertical profile for collecting soil pore-water samples for chemical and radiological analysis could be installed.

7.4 Cap Monitoring

At closure, instruments should be installed in the final cover to measure its effectiveness in restricting moisture movement. There are many potential designs. Some would involve instrumentation of just the cap and some schemes could involve vertical neutron access tubes installed in the cover and through the waste to the bottom of the trench. Regardless of the approach taken, once the trench is closed with a final cover, there would likely be a period (two or more years) where existing moisture under the closure cap would be redistributed. Therefore, meaningful, post-closure, performance VZM data would not be relied upon until a baseline has been established and moisture equilibration has stabilized. Once stabilization has been achieved in the post closure VZM system, it is anticipated that much of the ground water monitoring specific to a facility could be eliminated or reduced in scope.

Settlement is an important long-term risk associated with the performance of both the liner and the cap. A system of determining settlement by using either survey stakes, topographic remote sensing, fiber optic cables, ground-penetrating radar for settlement plates, or visual inspection should be considered. The need is for a time consistent topographic survey of the cap to be conducted to identify any settlement depressions, erosion features, vegetative features, etc., that may develop over time. This could give early warning to possible (but not certain) future water leaks. The indication of subsidence could trigger monitoring in more localized areas.

8.0 VADOSE ZONE MONITORING CONSIDERATIONS

8.1 Consultation with members from the National Academy of Engineering

Conversations with members of the National Academy of Engineering (Dr Frank Parker, Dr Jim Clark) on the subject of monitoring through caps and through liners were held. The consensus appears that any monitoring system, which penetrated through the bottom liner would be unacceptable. Discussions related to monitoring systems which breach the surface cap were found to be troubling, although the concern related to breaching the cap diminished as the size of the access holes were reduced. Neutron access holes in the cap present some problems due to potential preferential flow between the soil and the casing tubing. Horizontally installed TDR wave-guides and dissipation probes, however, do not present these problems. Monitoring below the liners did not appear to be a problem.

8.2 Discussions with noted soil physicists and regulators

Discussions with selected individuals within the Soil Physics Community, including Dr. Rein van Genuchton, have indicated that selected VZM instrumentation which have been tested over time are ready for application in long term monitoring at landfill facilities. Dr. Glendon Gee has indicated that the limited spatial coverage of many current technologies, however, encourages the development of volume integrating technologies such as Electrical Resistivity Tomography. Discussions with EPA Region 10 regulators have indicated that only time proven technology should be considered under existing landfills and that evolving technology could be considered in and below the landfill caps.

8.3 Redundancy

Another possible consideration for monitoring systems is redundancy (i.e., a system that doesn't rely on only one type of VZM system). The following are some possible benefits:

- The redundancy provides a back-up system in the event of instrument failure.
- The redundancy provides a mechanism to crosscheck instrument accuracies.
- The redundancy provides more confidence in the data.
- The redundancy provides a method for identifying false positives.
- It can assist in applying the graded approach utilizing an automated monitoring systems first, and then if necessary, using a manual system that may include analytical costs.
- It should extend the life expectancy of the entire monitoring system by providing back-up systems in the event of instrument failure. This is especially the case for the "non-retrievable" elements of the monitoring system.

8.4 Instrumentation Standards

The American Society for Testing and Materials International (ASTM) has standards pertaining to VZM. Reference to these standards should be made in considering potential VZM. The ASTM D18.21.02 committee on Vadose Zone Monitoring standards is responsible for publishing the following list of vadose zone standards (Table 1):

Table 1

ASTM INTERNATIONAL VADOSE ZONE MONITORING STANDARDS
VADOSE ZONE TERMINOLOGY (FINAL)
SOIL PORE-LIQUID MONITORING (D 4696-92)
SOIL CORE MONITORING (D 4700-91)
MATRIC POTENTIAL DETERMINATION (D 3404-91)
NEUTRON MODERATION (D 5220-92/97)
SOIL GAS MONITORING (D 5314-93)
HYDRAULIC CONDUCTIVITY (D 5126-90)
DECONTAMINATION OF FIELD EQUIPMENT (D 5088-90)
FLUX DETERMINATION BY TIME DOMAIN REFLECTOMETRY (D 6565)
DETERMINING UNSATURATED AND SATURATED HYDRAULIC CONDUCTIVITY IN POROUS MEDIA BY STEADY STATE CENTRIFUGATION (D 6527)
HORIZONTAL APPLICATIONS OF NEUTRON MODERATION (D 6031)
FREQUENCY DOMAIN CAPACITANCE (Z4302Z)
FIELD SCREENING GUIDANCE STANDARD (Final)
WATER CONTENT DETERMINATION (DRAFT)
VADOSE ZONE BOREHOLE FLOW RATE CAPACITY TEST (DRAFT)
AIR PERMEABILITY DETERMINATION (OUTLINE)
THERMALCOUPLE PSYCHROMETERS (OUTLINE)

9.0 CONCLUSIONS

If VZM were to be implemented by DOE at the Hanford Site, there would be multiple reasons for deployment that would vary depending upon the application and the associated facility. The rationale for utilizing vadose monitoring includes, but is not limited to, the following: landfill cap/barrier performance monitoring, compliance with DOE Order 435.1, and early warning detection system with the primary objective of preventing or mitigating future groundwater contamination. Current environmental regulations in some states (not Washington State) call for monitoring the vadose zone. In some cases, VZM activities provide sufficient strategic monitoring capability that other more expensive monitoring activities have been eliminated or reduced. DOE could take advantage in such situations of early detection of contaminant migration in the vadose zone to instigate evaluation and possibly intervening actions before migration to the groundwater.

Any VZM system at the ERDF should be cost effective, support the evaluation of the engineered barriers, tie into the models for containment, satisfy long term monitoring goals, identify action levels for management response, and work within the DOE Complex Wide Vadose Zone Science and Technology Roadmap and the DOE Long Term Stewardship Science and Technology Roadmap. Because of the uncertainty with respect the performance and interpretation of data from VZM additional long term Hanford specific data on VZM is needed. For application at the ERDF, the installation of VZM capabilities should serve as a method of evaluating vadose zone monitoring in a well-engineered and well-controlled facility. The purpose of the installation would not be to monitor the facility itself but would be used to evaluate the technology for possible future deployment. The national trend, as well as the trend observed in DOE's own studies and recommendations, points toward increasing use of vadose zone monitoring to establish performance data on various remediation and containment actions.

The above survey indicates that VZM has been used at several commercial landfill sites in the western part of the United States, where arid conditions guarantee the existence of a relatively deep vadose zone. These applications of VZM are generally kept simple and reasonably inexpensive. They have generally been employed to give an early warning of leakage and thus have resulted in a reduction in required groundwater monitoring. It is noted that the two states south of Washington require vadose zone monitoring, and there is an indication of its increased popularity.

VZM is used specifically in two general areas of a landfill, beneath the bottom layer of the landfill and in the final cap. These correspond to the use of VZM at two distinct stages of the landfill's life cycle. The first is during the operation of the landfill, while it is being filled and before the final cap is installed. The second is during the long-term storage phase, while the final cap is in place. Thus, the most appropriate monitoring for the first operational phase is a system installed below the bottom of the landfill, whereas the most appropriate monitoring for the long-term phase is one that monitors the integrity of the cap. The above analysis gives potential candidates for use in either of these cases.

10.0 RECOMMENDATIONS FOR NEW CELLS

Because of the national trend toward increased vadose zone monitoring, as well as the DOE trend in the same direction, it is recommended that vadose zone monitoring be included in the design of future cells of the ERDF. The recommendation is that the instrumentation be used only for the study and technical advancement of VZM methods and *not* for monitoring the performance of this facility. Because ERDF is a well-designed and well-controlled facility operating within design specifications, it makes a good test location for VZM to be used in the evaluation of the important parameters and to establish the base values for future employment of VZM. The VZM at the ERDF, thus, is to be used as a valuable tool in determining future vadose zone monitoring and not for monitoring the facility itself. For example, the operation of a basin lysimeter beneath this modern lined facility could be compared with the operation of the basin lysimeter already in place beneath the Solid Waste Landfill. If it is possible at this date to include the design of VZM in the design of the new cells 5 and 6, then this should be carried out.

Although several reasonable candidates for VZM were presented above, there are some that are more reasonable for application at the ERDF than others. For all the ERDF cells, when they are closed, VZM of the caps is strongly recommended. The most cost-effective approach to use during the operational phase of the landfill, however, would be to instrument new cells with basin lysimeters below the secondary leachate sumps. Because of the proven regulatory acceptance, reduced cost considerations, ease of installation and the ability to collect quantifiable results, a basin lysimeter made up of 100 mil HDPE installed under the secondary sump and beneath the lower compacted low-permeability soil layer in each new cell is the first recommendation. This lysimeter would extend five feet beyond the perimeter of the secondary sump and would be designed with an access pipe that allows the removal of any liquid collected. It is important that the basin lysimeter be placed beneath the lowest point of the low permeability layer.

In addition to the basin lysimeter, it is recommended that access tubes be laid down beneath the secondary liner. These will be used to create a "test" cell or representative cell. The access tubes will run the full length of each cell with spacing sufficient to allow future cross borehole tomography. Since these would be laid down during construction of the new cells, the costs would be minimal. These access tubes will provide access for a variety of instruments and would accommodate new technologies as they are developed. Installation at cells 5 and 6 or future ERDF cells will provide a relatively controlled setting for evaluating the performance and utility of access tubes at future multi-use facilities.

During the capped long-term storage period of the landfill instrumentation should be used for maintaining surveillance of the integrity of the cap. Non-invasive methods can be of various types, including lysimeters around the edge of the cap, subsidence monitoring of the cap structure, and tomographic methods for the spatial resolution of possible failure points. Invasive methods would entail establishing entry points through the cap into the interior of the landfill. Since access to the cap is easier and more readily modified, the latest technologies will be applied to the caps when they are designed and constructed. Since the caps have not yet been designed for the ERDF, we do not give any specific recommendations for what instrumentation would be the best at the time of implementation of monitoring of the cap's integrity. In addition to instrumentation of the cap, there would also be the possibility of implanting sensors in the body of the landfill in order to monitor its state. Also, any tomographic methods at the surface could be combined with the underlying access tubes to give tomographic data on the interior of the landfill. Several possible current technologies for the cap are given above.

The approach outlined above is consistent with other accepted programs, with additional emphasis placed on access to below the new cells during the operational phase and cap integrity monitoring of final coverings. Almost all monitoring methods are expected to be become obsolete or to have some aspect fail over time; thus, it is prudent to consider new technologies and new testing protocols as they are developed and to allow for the possibility of changing out instrumentation components.

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