RADIOACTIVE WASTE LANDFILL COVER ASSESSMENT: TEMPERATURE, MOISTURE, AND INFILTRATION EVALUATION

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ABSTRACT

Envirocare of Utah, Inc. has developed and constructed a test pad to evaluate infiltration through the cover system design incorporated over the low-level radioactive waste disposal embankments at the facility. The general design of the test pad follows the recommendations set forth in the Alternative Cover Assessment Program funded by the U.S. Environmental Protection Agency to assess alternatives to conventional landfill cover designs. The test pad cover is constructed identical to final cover used on the waste disposal embankments at the facility. The test pad is below grade with dimensions approximately 16 feet wide by 28 feet long. The base of the test pad is a lysimeter identical to compliance lysimeters within the disposal embankments. The purpose of the lysimeter is to collect and direct liquids through volumetric moisture monitoring instruments within a manhole outside the test pad. Permanent monitoring equipment has been placed during construction at specific intervals throughout the test pad. Monitoring equipment consists of water content reflectometers, matric water potential sensors (heat dissipation units), and temperature probes. The monitoring equipment provides cross-sectional data of the moisture content and temperatures throughout the constructed cover. Additionally, surface water runoff generated by precipitation is collected through a drainage trough and measured in order to perform a water balance over the entire test pad. Information generated from this test pad will be used to calibrate the performance modeling performed as part of the original design and permitting of the embankments. Temperature measurements were collected to evaluate whether freezing temperatures have not occurred within the clay layers. Heat dissipation unit and water content reflectometer moisture measurements indicate that the cover test cell is currently 'drying out' or, shedding water that was used during cover test cell construction for compaction purposes. Dose and tip data taken at the lysimeter corroborate heat dissipation unit and water content reflectometer measurements. A more rigorous analysis of moisture infiltration will be discussed in future technical papers, as the cover test cell continues to reach equilibrium.

INTRODUCTION

Envirocare of Utah, Inc. (Envirocare), is a commercially operated Low-Level Radioactive Waste (LLRW) disposal facility. Disposal is accomplished within engineered embankments consisting of a compacted clay liner, compacted waste layers, and a compacted clay/rock cover system designed to minimize water infiltration and reduce cover degradation to ensure long-term stability of the disposal site without the need for ongoing active maintenance (1). Infiltration fate and transport modeling (2) was conducted during Envirocare's licensing action to ensure that the design would contain radioactive contaminants for at least 500 years. Conservative parameters were chosen to ensure the modeling analysis would provide a conservative estimation of embankment performance. Infiltration modeling was performed using the Environmental Protection Agency (EPA) Hydrologic Evaluation of Landfill Performance (HELP) model. Moisture content and time of travel through the embankment components were assessed using the UNSAT-H computer model. Fate and transport of contaminates were evaluated using the PATHRAE model.

An "Unsaturated Flow Post-Model Audit Plan" had constituted part of Envirocare's compliance schedule since the inception of the GWQDP in 1993. Preliminary plans to perform this modeling called for intrusive moisture content monitoring of the cover systems atop the waste disposal embankments.

Envirocare and state regulators agreed that non-destructive testing was necessary to avoid compromising the integrity of the waste embankment and limit exposure to monitoring personnel.

Similar research is being conducted under the Alternative Cover Assessment Project (ACAP). The ACAP is an EPA grant funded research project initiated in 1998; an initial report on the research was prepared in 1999 (2). The ACAP research was initiated to examine alternatives to traditional landfill cover designs; additionally, the project examined the applicability of many computer code models including HELP and UNSAT-H. The ACAP research has assessed RCRA Subtitle C and D landfill covers at numerous sites across the nation; however, all of the cover systems examined to-date have included a vegetated component. Armored surface covers used at Envirocare have not been assessed.

The typical ACAP research project design includes a small test cell, with a built-in continuous soil moisture monitoring system, overlying a lysimeter designed to directly measure infiltration through the cover. Envirocare adopted a similar design. Additionally, ACAP projects construct weather stations near the test cells to attain the necessary parameters for model verification. Envirocare currently operates a weather station from which this data may be obtained.

On October 15, 1999, a refined plan was submitted that utilized the concept of a separate "test pad" for infiltration and moisture content measurements throughout the cover design. To avoid confusion with the Construction Quality Assurance/Quality Control (CQA/QC) requirements for "test pads", this program has been formally named the "Cover Test Cell" (CTC). Construction was completed and data collection began on September 19, 2001. All functional instrumentation was calibrated by January 2002. The results, as of October 31, 2003, of the testing will be provided in this report.

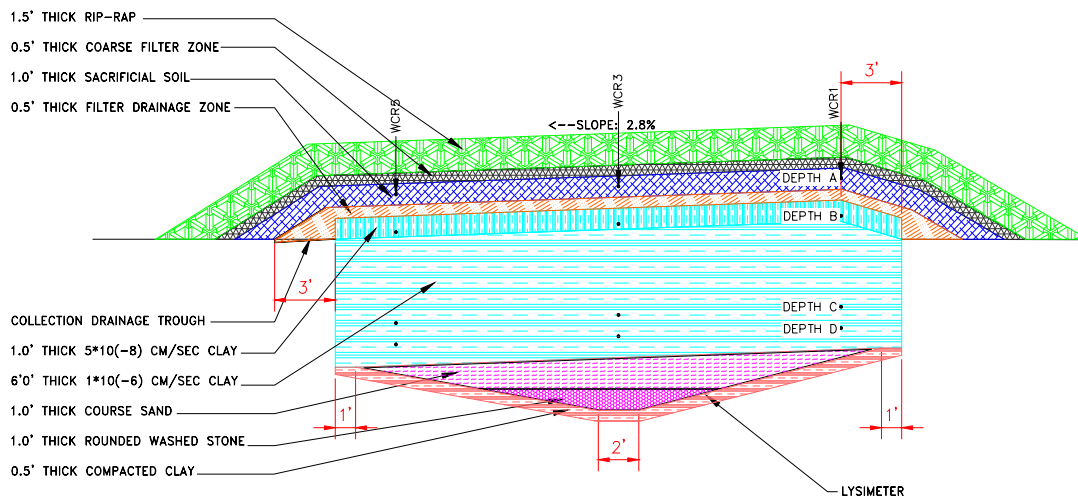Figure 1 provides the design and instrument locations for the CTC.

Fig, 1 Cross section: cover test cell

Design and Construction

Two primary functions are served by the rock cover design employed at Envirocare. First, the cover is constructed to prevent water infiltration, thereby minimizing the opportunity for groundwater contamination which is the focus of this paper; the cover also acts as a barrier against radon emission.

CTC Cross Section

The CTC can be broken down into six basic layers as shown in Figure 1. From top to bottom:

1. Type B Rip Rap: Consists of rock with diameters greater than 3/4 inches and less than 4 1/2 inches;

2. Type A Filter Zone: Consists of rock with diameters greater than 0.85 inches and less than 6 inches;

3. Sacrificial Soil: Gravel between 3/4 and 3/8 inches in diameter;

4. Type B Filter Zone: Gravel between 3/8 and 1 1/2 inches in diameter;

5. $5x10^{-8}$ cm/sec Clay: Native clay compacted in 6 inch lifts to a permeability of $5x10^{-8}$ cm/sec; and,

6. $1x10^{-6}$ cm/sec Clay: Native clay compacted in 6 inch lifts to a permeability of $1x10^{-6}$ cm/sec.

This design optimizes runoff, prevents desiccation, limits frost penetration, and limits biointrusion.

INSTRUMENTATION

Water Content Reflectometers (WCRs):

WCRs are used to measure moisture content within soils. They consist of two parallel, 30-centimeter stainless steel rods connected to a shielded circuit board to supply power and monitor the signal. The moisture content is measured by reading the frequency, or period, of a wave pulse sent down the rods. A higher dialectric material will have a slower response signal (longer period; lower frequency). Since water is more dialectric than most materials, a wet, or moist, material will reflect much slower than a drier material.

Heat Dissipation Units (HDUs):

HDUs are small, fragile instruments comprised of a ceramic cylinder approximately 1.5 cm in diameter and 3.2 cm long. Internally, the unit consists of a heating element needle and a thermocouple surrounded by the ceramic material. During data collection, a constant current source applies a 50-milliamp current to the heating element for 30 seconds while the thermocouple measures the temperature change in the area. This temperature increase can be correlated to the matric potential through fitted calibration curves.

HDUs are also known as matric potential probes or soil water potential probes, and are capable of measuring the matric potential of the media within which they are placed. Matric potential is defined as the amount of tension retained in the soil due to small amounts of water retained in the soil matrix; it corresponds to the pressure work required per unit quantity of water to move water within the system to a neighboring point at the same elevation (pressure head or pressure potential). Gradients in matric

potential are important because they measure movement of water within the system. In the CTC, matric potential is used as a redundant moisture content measurement and to provide moisture gradients throughout the cover.

Temperature Probes:

Temperature probes installed throughout the CTC are rugged instruments consisting of a thermister housed within an epoxy-filled aluminum case. Calibrations were not necessary for the temperature probes. No temperature probes, or any other monitoring devices, were placed in the riprap layer of the CTC.

Dosing Syphon Basins:
Dosing siphon basins are a part of the equipment used to measure lateral drainage from the lower, filter layer. They are completely enclosed, fixed volume cylindrical vessels with a dosing siphon mounted to the base. A dosing siphon is a device with no mechanical components, consisting of a trap with a vent pipe on one end and a "bell" covering the other end of the trap. When the fluid within the basin rises above the open end of the snifter pipe, air is sealed in the bell and trap. Once the fluid builds up to a level where the fluid pressure exceeds the pressure of the air in the trap, the air is forced through the trap and the siphon is "tripped", releasing fluid until the fluid level is equal to the open end of the snifter pipe. Therefore, a specific (fixed) quantity of liquid is released each time the siphon is "tripped". A mercury float switch is installed within the basin to provide a signal that counts each dose of the instrument.

Rain Gauge:

In order to measure the smaller flows associated with water infiltration, a 0.1-inch tipping bucket rain gauge has been installed in-line between the lysimeter collection pipe and the dosing siphon basin. Based on the area of the rain gauge collection pan, the tipping bucket volume has been calculated at 0.289 inches^3 (4.7 cm^3).

Data Collection and Peripheral Equipment:

Output signals from all measurement equipment are collected, monitored, and processed through a CR23X datalogger used solely for CTC-Project data. In addition to data collection, the datalogger also provides the stimuli necessary to create measurements (e.g. the constant current source needed for the HDU sensors).

The data logger is currently programmed to measure data at the following times and intervals throughout the day:

- Temperature is collected every minute and an hourly average is computed and stored as output within the datalogger;

- WCR data are collected once every hour, on the hour; and,

- HDU measurements are collected once every day at noon.

The datalogger has enough memory for at least six months of data storage however, data are collected on a monthly basis.

Campbell Scientific, Inc. created the datalogger software that enables it to communicate with data gathering equipment, a Toshiba Satellite computer dedicated solely to CTC Project data acquisition.

Peripheral devices associated with the CTC include a 12-volt battery and charge regulator continuously charged through a 20-watt solar panel, and used to power the datalogger and all monitoring equipment. A constant current excitation module is used for HDU sensor excitation. Peripheral equipment also consists of relay multiplexers, and a fixed, weather resistant enclosure.

INSTRUMENT PLACEMENT AND LOCATION

Locations of all CTC measurement devices are provided in Figure 1.

WCR-1 Through WCR-5:

All monitoring devices were placed at four different depths. Device depths are as follows:

- Depth D: located 1.5 feet above the top of the lysimeter in the $1x10^{-6}$ cm/sec clay layer;

- Depth C: located approximately 3.5 to 4 feet above the top of the lysimeter in the $1x10^{-6}$ cm/sec clay layer;

- Depth B: located approximately 6 feet above the top of the lysimeter in the $5x10^{-8}$ cm/sec clay layer; and,

- Depth A: located within the sacrificial soil layer, approximately at the mid-point.

Three instruments are located at each specific monitoring point within the depth layers described above; one WCR, one HDU, and a temperature probe. Instruments were placed radially around the surveyed monitoring points, and locations were noted to avoid placing the same instrumentation directly above each other.

Therm-1:

Therm-1 is a supplemental monitoring network and has been design to measure potential freeze and evaporative zone depths. Only temperature probes and WCRs are located within these monitoring stations. All of the specific monitoring stations associated with Therm-1 are located within the upper portions of the test cell.

Eight depths have been included at this monitoring location to provide eight specific measuring points. The following specific measuring points and corresponding instruments are associated with Therm-1, and are found in Table I:

Table I Therm Locations

Therm 1	Location:	The interface between the 1.0×10^{-6} and 5.0×10^{-8} cm/sec clay radon barrier layers.
	Instrument:	One temperature probe.
Therm 2	Location:	Approximately 0.3 feet above the surface of the 1.0×10^{-6} cm/sec layer in the 5.0×10^{-8} cm/sec layer .
	Instrument:	One temperature probe
Therm 3	Location:	Approximately 0.7 feet above the surface of the 1.0×10^{-6} cm/sec layer in the 5.0×10^{-8} cm/sec layer.
	Instrument:	One WCR and one Temperature probe.
Therm 4	Location:	The surface of the 5.0×10^{-8} cm/sec layer.
	Instrument:	One temperature probe.
Therm 5	Location:	Approximately 0.125 feet into the Type B filter layer.
	Instrument:	One WCR and one temperature probe.
Therm 6	Location:	Approximately 0.25 feet into the Type B filter layer.
	Instrument:	One WCR and one temperature probe.
Therm 7	Location:	Approximately 0.375 feet into the Type B filter layer.
	Instrument:	One WCR.
Therm 8	Location:	Approximately the midpoint of the sacrificial soil layer.
	Instrument:	One temperature probe and one WCR.

MODELING

In order to determine the data quality objective required for this project, an understanding of the associated models, along with their input parameters and assumptions, is necessary.

The HELP model (3, 4) is the most widely used model for landfill design due to its availability, comprehensive process incorporation, regulatory acceptance, and ease of use. The HELP code was written for the EPA specifically to evaluate landfill cover designs. This model is a quasi-two dimensional computer code that generally tends to over-predict the amount of drainage (infiltration) through the modeled cover layers (2).

The HELP model uses a simple water mass balance to estimate the drainage out of the system (infiltration; D). This mass balance may be defined mathematically:

$$D = P + SM - R_0 - ET - \Delta S \tag{Eq. 1}$$

where P is the precipitation, SM is additional water input from snow melt, R_0 is runoff, ET is evapotranspiration, and ΔS is the change in water storage within the soil (and on the surface). From the input weather data, the code generates daily mean values for precipitation, temperature, and solar radiation. This weather data is then used to compute the variables in Equation 1 and calculate daily drainage values which are then summed to obtain an average annual infiltration through the cover system. In order to use the HELP model, it is assumed that the clay layers do not undergo freeze thaw

temperatures. Freeze thaw conditions within the clay layers would increase clay permeability and negate the covers ability to prevent water infiltration.

Inputs for the HELP model include the porosity, field capacity, wilting point, and saturated hydraulic conductivity for each layer within the system. Additionally, weather data may be input or taken from a national Oceanographic and Atmospheric Administration (NOAA) database.   The field capacity is defined as the volumetric water content at a soil water suction of 0.33 bars. The wilting point is defined as the volumetric water content at a soil water suction of 15 bars. These two parameters are used to estimate water storage and relative unsaturated hydraulic conductivity within the cover system.

In the situation modeled by Envirocare, the UNSAT-H model (5) uses the HELP model infiltration predictions to estimate moisture content and flow velocity profiles through the cover system clays, waste layers, clay liner, and native soils to the surface of the water table underlying the embankment. The UNSAT-H code uses an implicit finite difference method to solve Richard's equation in one-dimension (vertical). The one-dimensional Richard's equation is:

$$C(\theta)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left(K(h)\frac{\partial H}{\partial z} \right)$$
(Eq. 2)

where $C(\theta)$ is the specific moisture capacity (defined as the slope of the moisture retention curve, $\theta(h)$), $K(h)$ is the unsaturated hydraulic conductivity, h is the matric potential (pressure head) of the soil, H is the total hydraulic head, t is the time, and z is the vertical distance. Analytically established water retention data is used to empirically determine the $\theta(h)$ function using a van Genuchten water retention model.

In addition to the HELP model infiltration predictions, inputs for the UNSAT-H model include the specific node geometry used to solve the Richard's equation, boundary conditions (head and infiltration), initial conditions (head), and material properties for each layer (moisture retention data, saturated hydraulic conductivity, van Genuchten parameters).

Site Meteorological Conditions

The meteorological (weather) data used in the infiltration and transport modeling was generated in the HELP module of the modeling software. The HELP software uses a synthetic weather generator based on site-specific data for evapotranspiration, precipitation, temperature, and solar radiation input. This weather data generator routine, developed by the USDA Agricultural Research Service, generates 100 years of daily climate distribution parameters used as model input parameters.

Since 1992, Envirocare has been collecting and analyzing stability, temperature, wind speed and direction, pan evaporation, solar radiation, and precipitation data at the Clive facility with a site weather monitoring station. This data has been collected annually and compared with modeling results generated by the weather data generator routine. Recently, all of the data collected from July 1992 through June 2002 was compiled, averaged, and compared to meteorological modeling results.   Although meteorological data reported for the years 1992–2002 are statistically insignificant when compared to the 100 years of data used for model input, comparison of key parameters (temperature, precipitation, and wind speed) have been completed determining that the model represents site conditions.

DISCUSSION

The information for this section was taken from data acquired by the CR23X datalogger, between September 19, 2001 and October 31, 2003. Data were tabulated and organized in a series of graphs, provided as Figure's 2, 3, and 4, and combined with data acquired from the Clive facility weather monitoring station. Figure 2 has hourly temperature data imposed in the background. Figures 2, 3, and 4 are titled as follows:

1. Figure 2: Temperature History;

2. Figure 3: Volumetric Moisture History;
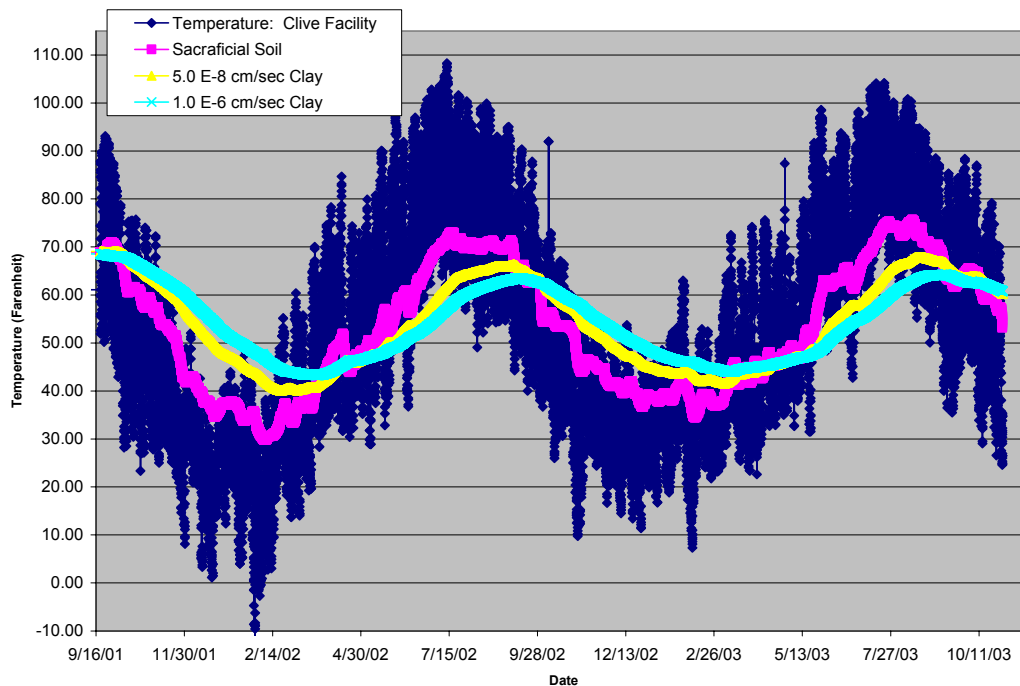
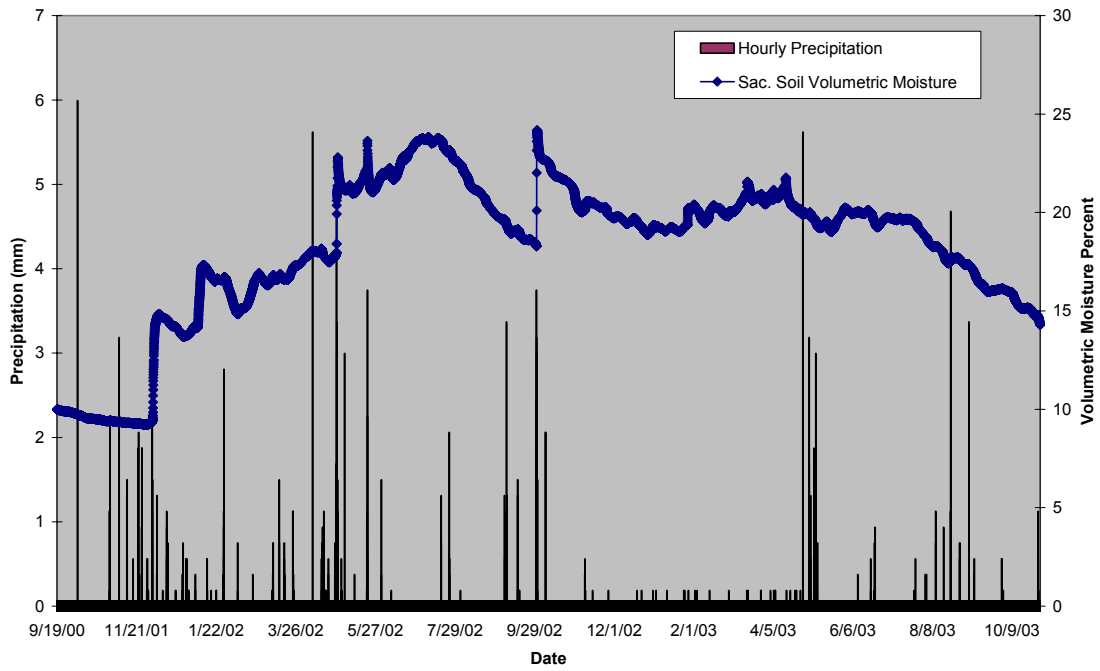3. Figure 4: Dosing Tips per day;

Fig. 2 Temperature history

Fig. 3. Cover Test Cell. Precipitation & Volumetric Moisture History (Sacrificial Soil).
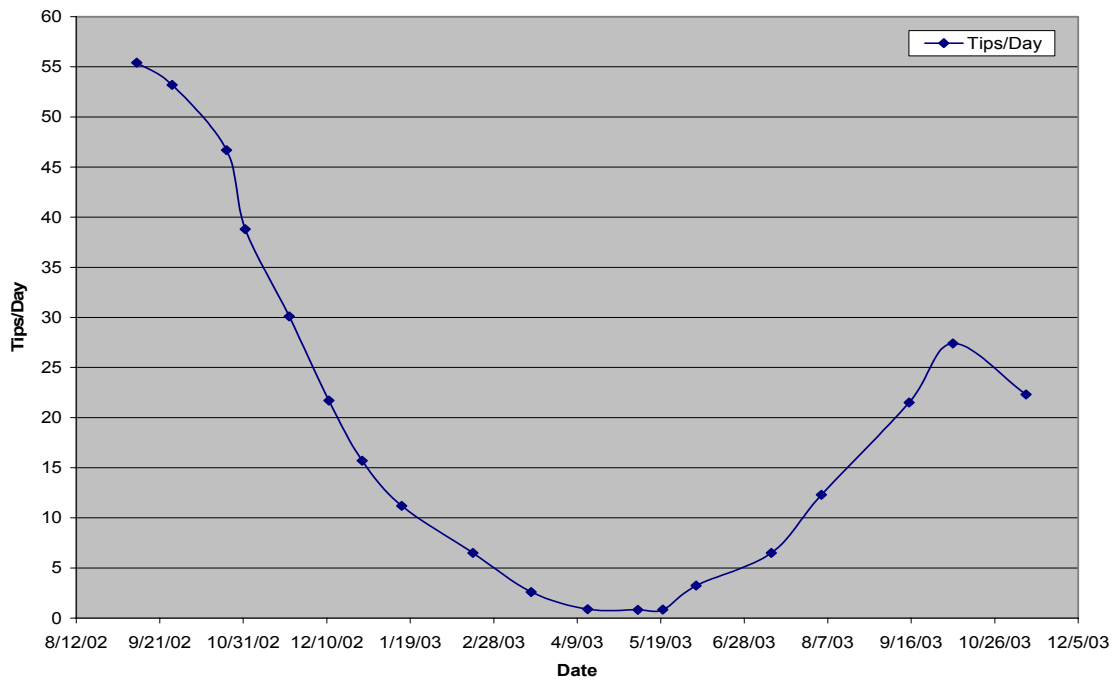

Fig. 4 Average Tips-Per-Day

Temperature Measurements

Table II provides minimum and maximum temperatures that were attained throughout the placement layers in the CTC, the dates they occurred on, and temperature measurements made by the weather monitoring station at the Clive facility.

Table II Temperature Extremes

	High		Low	
	Date	**Temp ($^oF/^oC$)**	**Date**	**Temp ($^oF/^oC$)**
Weather Station	7/13/02	108.28/42.38	1/30/02	0.55/-17.47
Sac. Soil	7/18/02	73.00/22.77	2/8/02	29.80/-1.22
5.0 E-8 Clay	10/3/01	69.08/20.6	2/21/02	40.14/4.52
D Level 1.0 E-6 Clay	9/19/01	68.86/20.48	4/2/02	46.46/8.03
THERM-1	9/20/00	69.99/21.11	3/8/01	42.76/5.98
THERM-2	9/20/00	70.14/21.19	2/20/01	41.70/5.39
THERM-3	10/3/00	70.25/21.25	2/20/01	41.25/5.14
THERM-4	10/2/00	70.61/21.45	2/17/01	39.42/4.12
THERM-5	10/1/00	70.65/21.47	2/15/01	38.18/3.43
THERM-6	10/1/00	70.81/21.56	2/14/01	36.91/2.73
THERM-8	7/17/01	72.55/22.53	2/8/01	31.10/-0.5

The high and low temperatures in the CTC occurred in the sacrificial soil (as would be expected), on July 18, 2002 and February 8, 2002, and were 73 ^oF and 29.80 ^oF, respectively. Neither clay layer experienced freezing conditions during the 18 months that data has been collected thus far. A discussion of Therm results follows.

Freeze Layer Determination

Figure 2, Temperature History, delineates the temperature cycle experienced by the sacrificial soil layer, the $5x10^{-8}$ cm/sec clay layer, and the $1x10^{-6}$ cm/sec clay layer. These data lines are superimposed on the site weather data line recorded by the Clive facility weather monitoring station. These data establish two items of discussion; One, the temperature probes throughout the Test Cell are taking data that corresponds with the hot and cold cycles measured at the facility. This suggests that the temperature probes were adequately calibrated and are performing to required specifications; and two, the clay layers have not experienced freezing temperatures since data acquisition began.

Data measured at the locations of Therm's 3 and 6 show slightly cooler (in the winter) and warmer (in the summer) trends than the other temperature probe measurements in the graphs. These two Therm's are the shallowest monitoring points on their respective graphs, therefore these trends are to be expected.

Therm 8 (Figure 2), located at the midpoint of the sacrificial soil layer, 2.5 feet beneath the upper surface of the cover, is the only Therm-monitoring location that experienced freezing temperatures (early February 2002) over the time of data collection. This is the only time since data acquisition began that freezing temperatures were measured in the sacrificial soil. This is not to suggest that the sacrificial soil layer will not experience freezing temperatures in the future, merely that freezing temperatures are experienced at this depth on an infrequent basis. Data taken thus far seem to suggest that the CTC will experience freezing up to the midpoint (~6 inches) of the sacrificial soil layer, but not at a depth of 9 inches into this layer (Therm 6). The data also indicate that freezing temperatures are not achieved within the clay layers. This preliminary data confirms that the sacrificial soil layer is performing as designed to

protect the clay layers from freezing and compromising the protection afforded by these layers. Further monitoring and data acquisition will be necessary to make any conclusive determinations.

Dosing and HDU Moisture Data

This section discusses the HDU data gathered in all layers (A-D) of the CTC, and provides a summary of the amount of water exiting through the lysimeter pan. Figure 4 illustrates the volumetric moisture content of the sacrificial soil layer compared to hourly precipitation events measured by the Clive facility weather monitoring station. It is interesting to note that the volumetric moisture content of the sacrificial soil layer has remained relatively independent of the precipitation events on site. This suggests that the majority of the precipitation falling on the CTC is evaporating instead of penetrating the cover, or running off. Data for each individual HDU measurement device in the A-layer was averaged and compared to daily precipitation amounts measured at the Clive facility weather monitoring station.

Data suggests that the CTC is still trying to achieve soil-moisture equilibrium, as indicated by cyclical pressure increases and decreases in the matric potential measurements. It should be noted that it will take several more years to determine when, and if, the CTC will reach equilibrium.

Despite cyclical pressure activity in the CTC, a drying trend can be corroborated by the information acquired from the lysimeter-pan dosing basin, although it is still too early to conclusively establish. To date (October 31, 2003), there have been 8,889 tips, resulting in 2569 in^3, or 11.1 gallons of water come through the lysimeter pan. With the exception of system testing, no tips were recorded between the set-up of the system and early-August, 2002. As shown in Figure 4, the majority of this water came through in the months between early-August, 2002 through November 2002. Since that time, the numbers of tips recorded have fluctuated, but the overall tips-per-day pattern is beginning to exhibit a downward trend. Further monitoring of this data point will be required before any conclusions can be established. Coupling of preliminary results indicating a drying trend on the C and D levels, and a decreasing number of tips-per-day suggest that water coming through the CTC is water that was laid down during construction; not precipitation infiltrating the cover. Furthermore, the tip pattern does not correspond with measured meteorological conditions (precipitation) at the site.

The B level HDU devices are not exhibiting a drying trend as pronounced as the C and D level HDU devices, probably due to the slower diffusivity associated with this clay layer.

It is important to draw a comparison between the amount of precipitation falling on the CTC, the matric potential of the sacrificial soil and of the B level HDU devices, and the amount of water being collected in the dosing siphon basin through the drainage trough. A significant change in water elevation in this basin has not been measured, suggesting that no water is coming through the drainage trough. Furthermore, the outlet for the drainage trough, upon visual inspection, is dry most of the time, suggesting that no precipitation is gathered from lateral drainage. As the matric potential in the B-level HDU devices are undergoing wet/dry cycles, the A-level sensors in the sacrificial soil varies depending on the precipitation, and the C and D level sensors show drying activity, it is logical to conclude that water falling on the cover is evaporating, and/or running off, rather than penetrating into the clay level radon barrier. It is not expected that this result will change since the matric potential (pressure head) will continue to build as the cover dries out, making the CTC more prone to shed water than to allow penetration into the cover layers.

This is also substantiated through data measured by the water content reflectometers (WCRs). As previously mentioned, the HDU units measure moisture content as well as the WCRs, both systems acting to verify the other's results.

Modeling Comparison

The information in this section comes from infiltration modeling performed by Adrian Brown for the LARW embankment, dated December 4, 1997, and Infiltration and Transport Modeling performed by Whetstone Associates for the Western LARW embankment, dated July 19, 2000. Dose data acquired from the CTC was used to determine water infiltration to date (October 31, 2003).

Average water flow rate through the CTC has been measured to be 0.019 in/year, based on a flow rate of 5.29 gal/year and a CTC top slope area of 448 ft^2. Modeling performed by Adrian Brown for the LARW embankment predicted water infiltration at 0.078 in/year. Modeling performed by Whetstone Associates for the Western LARW embankment predicted water infiltration at 0.104 in/year. Since the CTC has not yet reached equilibrium, this data is provided for informational purposes; no conclusions can be drawn at this time.

CONCLUSION

Data taken over nearly two years indicate that the rip rap, sacrificial soil, and filter zone materials appear to protect the clay liner layers from freezing temperatures. This is important in as much as the mechanical stresses induced by freeze-thaw events are capable of producing cracks in the liner large enough to initiate water infiltration into the waste. Water measured through the dosing basin suggests that the amount of water leaving the test cell through the lysimeter is below the expected values determined by modeling. It should be noted, however, that HDU and WCR data suggest that the test cell is still in flux, having not yet achieved soil-moisture equilibrium within the cover. HDU and WCR data also suggests that the test cell is in the process of 'drying out', or, shedding water laid down for engineering purposes during test cell construction. Further test cell monitoring and data acquisition will be necessary before cover test cell infiltration barrier performance can be compared with any amount of confidence to the values produced using current modeling techniques.

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