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Large-Scale Field Study of Landfill Covers at Sandia National Laboratories

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LARGE-SCALE FIELD STUDY OF LANDFILL COVERS AT SANDIA NATIONAL LABORATORIES

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ABSTRACT

A large-scale field demonstration comparing final landfill cover designs has been constructed and is currently being monitored at Sandia National Laboratories in Albuquerque, New Mexico. Two conventional designs (a RCRA Subtitle 'D' Soil Cover and a RCRA Subtitle 'C' Compacted Clay Cover) were constructed side-by-side with four alternative cover test plots designed for dry environments. The demonstration is intended to evaluate the various cover designs based on their respective water balance performance, ease and reliability of construction, and cost. This paper presents an overview of the ongoing demonstration.

INTRODUCTION

The US Department of Energy (DOE) is in the midst of a major clean-up effort of their facilities that is expected to cost billions of dollars. These cost estimates, however, are based on "state-of-the-art" technologies, of which many are inadequate. Consequently, work has begun on the development or improvement of environmental restoration and management technologies. One particular area being researched is landfill covers. As part of their ongoing environmental restoration activities, the DOE has many radioactive, hazardous, mixed waste, and sanitary landfills to be closed in the near future. These sites, as well as mine and mill tailings piles and surface impoundments, all require either remediation to a 'clean site' status or capping with an engineered cover upon closure (Hakonson et al. 1994). Additionally, engineered covers are being considered as an interim measure to be placed on contaminated sites until they can be remediated. The Alternative Landfill Cover Demonstration (ALCD) is a large-scale field test at Sandia National Laboratories, located on Kirtland Air Force Base in Albuquerque, New Mexico. The goal of the ALCD is to field test, compare and document the performance of alternative landfill cover technologies, of various complexities and costs, for interim stabilization and/or final closure of landfills, particularly in arid and semi-arid environments.

Traditional covers presently in use for Resource Conservation and Recovery Act (RCRA) Subtitle 'C' and 'D' regulated facilities as recommended by the US Environmental Protection Agency (EPA) are used throughout the US with little regard for regional conditions. Experience in the western United States has shown these designs to be vulnerable to such things as desiccation cracking when installed in arid environments. An EPA design guideline for final landfill covers states: "In arid regions, a barrier layer composed of clay (natural soil) and a geomembrane is not very effective. Since the soil is compacted 'wet of optimum', the layer will dry and crack" (Landreth et al. 1991). The clay barrier layer in the traditional Subtitle 'C' Cover must be constructed so as to yield a maximum hydraulic conductivity of 1×10^{-7} cm/sec. To achieve this, the soil often requires amendment (e.g. mixed with bentonite) and should be compacted 'wet of optimum'. Compacting this layer 'wet of optimum' in dry environments leads to drying and cracking of this layer. Desiccation, which can occur by several mechanisms, is an important failure mode for compacted soil hydraulic barriers, especially in arid environments (Suter et al. 1993). The basic soil cover used with Subtitle 'D' covers has a barrier layer that is also subject to desiccation cracking, as well as deterioration due to freeze/thaw cycles, among other problems.

These traditional covers such as the Subtitle 'C' Cover are not only inherently problematic but are very expensive and difficult to construct. A study (US EPA 1988) by the EPA of existing landfill performance revealed that current landfill technology is inadequate. Randomly selected landfills revealed that the vast majority are leaking. Many have serious problems including groundwater contamination and serious ecological impacts such as killing flora and fauna. Virtually all parts of the nation have experienced water contamination due to leachate leaking from landfills in some degree (US EPA 1988). Not all of these problems are the result of inadequate covers. Many older landfills were crudely installed (e.g., poor siting, inadequate or lack of liner) thus destined for failure, but these problems can be mitigated by capping the entire landfill with a properly designed cover.

Traditional designs were installed at the ALCD site to serve as baseline covers to compare and contrast alternative cover designs against. The baseline covers were installed to meet the minimum regulatory requirements set forth under the RCRA Subtitles 'C' and 'D', and the Comprehensive Environmental Recovery, Compensation, and Liability Act (CERCLA). Subtitle 'C' and 'D' sets forth performance standards but does not require the use of a specific cover design to comply with these standards. Subtitle 'C' and 'D' also allows the governing regulatory agency to consider and approve an alternative final cover design as long as it meets the general performance standards.

The objectives of the ALCD are to:

- demonstrate the construction and cost of cover design alternatives;
- measure the performance of the design alternatives using water balance and ancillary data as the primary evaluation criteria;
- validate predictive models for evaluating long-term performance of the cover designs; and
- document the results through presentations, reports, and peer-reviewed publications.

The ALCD is not intended to showcase any one particular cover system. The focus of this project is to provide the necessary tools - i.e., cost, construction and performance data - to the public and regulatory agencies so that design engineers will have better, regulatory acceptable alternatives to the conventional cover designs.

The test covers are each 13 m wide by 100 m long. The 100 m dimension was chosen because it is representative of typical hazardous and mixed waste landfills found throughout the DOE complex (approximately 2 acres in surface area). All covers were constructed with a 5% slope in all layers. The slope lengths are 50 m each (100 m length crowned at the middle with half of the length - 50 m - sloping to the east and the other half toward the west). The western slope is monitored under ambient conditions (passive testing). A sprinkler system was installed in the eastern slope of each cover to facilitate stress testing of the covers (active testing).

Continuous water balance and meteorological data are currently being obtained. It will be actively collected for a minimum five-year post construction period. In addition, periodic measurements of vegetation cover, biomass, leaf area index, and species composition are being taken.

MATERIALS AND METHODS

Baseline Cover Designs

Baseline Test Cover 1 is a basic Soil Cover installed to meet minimum requirements for RCRA Subtitle 'D' governed landfills (US DOE 1993). These requirements apply to sanitary solid waste landfills to be closed using engineered covers and generally meet the following performance objectives:

- cover permeability less than or equal to the permeability of the bottom liner/subsoil or no greater than 10^{-5} cm/sec;
- minimize infiltration with a minimum of 45 cm of soil; and
- minimize erosion with a minimum of 15 cm of soil for plant growth.

The installed test cover is 60 cm thick (Figure 1). It is constructed of essentially two layers. The bottom layer is a 45 cm thick compacted soil layer. This barrier layer's primary purpose is to minimize the infiltration of water into the underlying waste. Only native soil was used in this layer. This soil met the criteria set forth in Table 1. The soil came from on-site cut excavations. The soil was compacted 'wet of optimum' as recommended by the EPA per ASTM D698. The barrier layer was installed in three six-inch lifts. Standard construction practices and equipment were used throughout the project. The lifts were compacted using a 18,200 kg smooth rolled vibratory compactor. Between lifts of soil, the prior lift was scarified before the next lift was installed. This was done to eliminate the potential for a seam between lifts that would allow for the passage of water along it. Soil density and water content readings were taken to ensure that the soil placed fell within the acceptable compaction zone as shown in Figure 9. The soil was placed as specified to meet the maximum 1×10^{-5} cm/sec requirement of Subtitle 'D' regulated facilities.

Laboratory test results yielded saturated hydraulic conductivity results on the barrier layer soil between 5.5×10^{-6} cm/sec and 5.1×10^{-7} cm/sec. The in-situ saturated hydraulic conductivity was determined to be about 4.9×10^{-7} cm/sec (Figure 8). A double-ringed infiltrometer was installed on a 7.3 m x 7.3 m test pad adjacent to the test cover constructed identically to the 45 cm thick soil barrier layer in the Baseline Test Cover 1 to measure the in-situ saturated hydraulic conductivity per ASTM D5093.

The top vegetation layer is 15 cm of loosely laid topsoil. The vegetation layer consists of topsoil cut from the site, stockpiled, and replaced. This layer provides for vegetation growth and erosion protection.

Figure 1. Baseline Test Cover 1

Baseline Test Cover 2 is a Compacted Clay Cover designed and constructed in accordance with minimum regulatory requirements for closure of hazardous and mixed waste landfills found in 40 CFR Parts 264 and 265, Subpart N. Under these regulations, owners/operators of landfills are required to perform landfill closures. The primary closure requirements of 264.310 and 265.310 require the owners/operators to design and construct a low-permeability cover over the landfill to minimize migration of liquids into the waste and to provide 30 years of post-closure monitoring and maintenance in order to prevent waste migration into the environment. The cover design must provide for the following:

- minimize liquid migration;
- promote drainage while controlling erosion;
- minimize maintenance;
- have a permeability equal to or less than the permeability of natural subsoil;
- account for freeze/thaw effects; and
- accommodate settling and subsidence so that the cover's integrity is maintained.

The recommended EPA RCRA Subtitle 'C' final cover design (Landreth et al. 1991) from bottom to top consists of:

1. Low hydraulic conductivity geomembrane/soil layer: a 60 cm layer of compacted natural or amended soil with a maximum saturated hydraulic conductivity of 1×10^{-7} cm/sec in intimate contact with a minimum 40 mil geomembrane.
2. Drainage layer: a minimum 30 cm sand layer having a minimum saturated hydraulic conductivity of 1×10^{-2} cm/sec, or a layer of geosynthetic material having the same characteristics.
3. Top vegetation/soil layer: a top layer with vegetation (or an armored top surface) and a minimum 60 cm of soil graded at a slope between 3 and 5 percent.

The Baseline Test Cover 2 was designed with the following features. It is 1.5 m thick. The typical profile for this cover consists of three layers (Figure 2). The bottom layer is a 60 cm thick compacted soil layer. This layer's primary purpose is as a barrier layer to prevent the downward migration of water into the underlying waste. Laboratory tests revealed that the native soil at the ALCD site required amendment to meet the saturated hydraulic conductivity requirement (maximum of 1×10^{-7} cm/sec). The goal of the

laboratory testing was to find a combination of native soil and soil amendment, in this case sodium bentonite, that would yield a saturated hydraulic conductivity maximum of 1×10^{-8} cm/sec. Past experience has shown that laboratory testing of hydraulic conductivity yields results at least an order of magnitude better than in-situ soil measurements. Through laboratory testing using a rigid-wall permeameter (Daniels 1985), it was determined that a mixture of 6% by weight of sodium bentonite with the native soil compacted 'wet of optimum' to 98% of maximum dry density per ASTM D698 would be adequate. All permeameter tests in the 'wet of optimum' range yielded results between 10^{-8} to 10^{-9} cm/sec range. The soil was specified to be compacted 'wet of optimum' as recommended by the EPA so as to remold the soil to lower the hydraulic conductivity.

Table 1. Baseline Test Covers Soil Requirements				
Quality	Test	Frequency	Baseline Test Cover 1 - Subtitle 'D' Cover	Baseline Test Cover 2 - Subtitle 'C' Cover
Percent Fines	ASTM D1140	2/cover on different lifts	20 % minimum	20% minimum
Percent Gravel	ASTM D422	2/cover on different lifts	10% maximum	10% maximum
Water Content	ASTM D4643	1/lift	wet of optimum	wet of optimum
PI	ASTM D4318	2/cover on different lifts	0 to 35	10 to 35
Max. Clod/Stone Size	Observation	Continuous	None larger than 2"	None larger than 3/4"

The acceptable compaction zone was very similar to that seen in Figure 9 for Baseline Test Cover 1. The barrier layer was built in four equal 15 cm thick compacted lifts. Each lift was scarified prior to the next lift being installed to eliminate seams with the exception of the top lift which was smooth rolled. A visual walk-over was then performed on this top lift after it was compacted to remove all stones and debris larger than 1.5 cm in diameter. This was done to ensure no damage to the geomembrane to be placed on top and allow for intimate contact with the geomembrane to create a composite barrier layer. The combination of the compaction requirements, soil amendment, and placement ('wet of optimum') was done in hopes of yielding a maximum hydraulic conductivity of 1×10^{-7} cm/sec. The in-situ saturated hydraulic conductivity was determined to be 7.9×10^{-7} cm/sec (Figure 8). Desiccation cracking is believed to be the cause for the lower than anticipated hydraulic conductivity. The effects of desiccation cracking is not accurately represented in the laboratory.

This barrier layer was extremely difficult and expensive to install. The most economical means of purchasing the bentonite was to have it trucked in from Wyoming. It was trucked in two-ton bags. Approximately 100 tons were used in the 13 m x 100 m x 60 cm barrier layer and 7.3 m x 7.3 m x 60 cm test pad. The bentonite was mixed with the native soil dry, wetted, transported into place, and compacted. The compaction requirements were much more difficult to achieve than those for the barrier layer in Baseline Test Cover 1.

A 40 mil linear low density polyethylene geomembrane was placed directly on top of the clay barrier layer. The surface of the clay barrier layer was smooth-roll compacted and prepared to allow for intimate contact between it and the under-surface of the geomembrane to essentially obtain a composite barrier layer. Continuous contact was emphasized in an effort to eliminate gaps between the geomembrane and soil barrier layer where any water that has passed through the geomembrane would have a pathway to run and find a crack in the underlying soil layer. The geomembrane acceptance section of the QA plan was by far the most extensive. The acceptance of the earth surface was determined prior to placing the geomembrane

on it, panel layout and identification were recorded, and equipment used are just a few of the things recorded. All welded seams were air pressure tested for compliance. Destructive testing was also performed on all seams including shear strength and peel adhesion (ASTM D4437). Any defects found in the geomembrane were patched and extrusion welded. The patches were then vacuum tested for compliance.

The 30 cm thick middle drainage layer was constructed of sand placed directly on the geomembrane. The purpose of the drainage layer is to minimize the time any infiltrated water is in contact with the underlying barrier layer by quickly routing this water that has passed through the vegetation layer laterally to collection drains. The average saturated hydraulic conductivity of the sand installed was 1×10^{-1} cm/sec which is an order of magnitude better than the minimum 1×10^{-2} cm/sec specified. The only other physical requirement for the sand in this cover was that there be no more than 5% fines passing the no. 200 sieve after installation. A nonwoven polyester needlepunched geotextile was placed directly on top of the sand drainage layer. This served as a filter between the drainage layer material and top vegetation layer. The geotextile joints were overlapped with no physical attachment.

This entire layer was placed and left uncompacted. The top layer is a 60 cm thick vegetation layer comprised of uncompacted soil. This layer's primary purpose is to provide for vegetation growth, erosion protection, and protect the underlying layers from such things as harmful freeze/thaw cycles. It allows for storage of infiltrated water that can later be evaporated. It is 45 cm of native fill soil covered by 15 cm of topsoil.

The covers were drill seeded upon completion of construction. The seed mix was obtained from the New Mexico Highway Department's recommendation list. The mix included: crested wheatgrass, indian ricegrass, alkali sacaton, sand dropseed, and four-wing saltbrush.

Figure 2. Baseline Test Cover 2

Alternative Designs

Design criteria for the alternative cover designs were very basic. The covers were to be (1) less expensive than Baseline Test Cover 2; (2) more effective than the baseline covers at preventing the infiltration of water into the underlying waste; and (3) easier and more reliable to construct. The native soil used came from on-site cut excavations. Other materials to be purchased off-site such as sand and gravel used must be common and readily available (i.e., no exotic grain-size distributions, etc.).

All compaction of soil required by design in the alternative covers was compacted 'dry of optimum' rather than 'wet of optimum' as currently recommended by the EPA with the traditional covers. Dry-side compaction should result in a compacted barrier soil that is less susceptible to potential desiccation cracking due to the molding water content relative to wet-side compaction. Dry-side compaction also made construction easier and therefore, less expensive and should provide more soil water storage capability than

wet-side storage due to the lower initial degree of saturation associated with dry-side compaction relative to wet-side compaction.

The determination to compact soil 'dry of optimum' for all the alternative covers was confirmed by laboratory testing that showed the saturated hydraulic conductivity of the soil is relatively insensitive to the molding water content. The hydraulic conductivities of three soil test specimens were determined. One of the specimens was compacted 'wet of optimum', one was compacted at the optimum water content, while the third was compacted 'dry of optimum'. The standard Proctor curves revealed the relative insensitivity of the hydraulic conductivity to the water content (Shackelford 1995).

Alternative Test Cover 1 is a Geosynthetic Clay Cover (Figure 3) identical to the traditional compacted clay cover with the exception that the problematic clay barrier layer was replaced with a manufactured sheet installed in its place - a geosynthetic clay liner (GCL). All other aspects of the cover are identical to Baseline Test Cover 2. The overall thickness of this cover is 90 cm. The cover layers are, from bottom to top: the barrier layer (the GCL membrane covered with a geomembrane comprises the composite barrier layer), sand drainage layer, geotextile filter fabric, and vegetation soil layer, respectively. The GCL sheet is a composite of two nonwoven fabrics sandwiching a layer of bentonite. The saturated hydraulic conductivity of the GCL per the manufacturer (Claymax) is 5×10^{-9} cm/sec.

The GCL was installed as recommended by the manufacturer on a smooth clean base free of any debris larger than half-inch in diameter. It was simply placed on the site and rolled out. At joints, the GCL panels were overlapped with no physical seaming.

A geomembrane was then installed on the GCL. Its installation, as well as, that of the sand drainage layer, geotextile, and topsoil were installed identically to those similar layers in the Compacted Clay Cover.

Figure 3. Alternative Test Cover 1

Alternative Test Cover 2 is a Capillary Barrier. Differences in pore size distribution and, thus, differences in suction between two soil layers under unsaturated flow conditions cause water to be retained in the upper soil layer as long as the contrast in unsaturated properties (e.g., soil-moisture characteristic curves and unsaturated hydraulic conductivities) of the soils in the two soil layers is sufficiently large. In general, the upper soil layer must consist of a soil with a significantly larger suction than the lower soil layer at the same water content. Thus, a capillary barrier effect results when a 'relatively fine-grained soil' overlies a 'relatively coarse-grained soil'. The capillary pressure head in the fine-grained upper soil layer must approach a value near zero (i.e., saturated conditions) before any appreciable flow occurs into the lower lateral drainage layer.

Design considerations for this cover system included determining the proper soil layer thicknesses and slope to minimize the percolation of water through it. In general, layer thicknesses and slope depend on (1) climatological information for the site at which the cover is to be constructed (e.g., precipitation, temperature, humidity), (2) the characteristics of the soils used in the cover (e.g., hydraulic conductivity,

moisture content), and other factors (e.g., slope stability, desiccation considerations). Case studies (e.g., Melchoir et al. 1994, Benson and Khire 1995) were also used to assist with design considerations.

This cover system consists of four primary layers: (1) a surface or topsoil layer; (2) an upper drainage layer; (3) a barrier soil layer; and (4) a lower drainage layer (Figure 4).

The lower drainage layer was installed in one lift and left uncompacted. The basic construction requirement for this layer other than thickness and slope was particle size distribution (PSD). A material representative of that tested in the laboratory was warranted. Therefore the PSD had to meet the criteria shown in Figure 10. A washed concrete sand, a common construction material, was used and easily met the specified criteria. A 45 cm thick layer of compacted soil was installed on top of the lower sand drainage layer. The barrier soil layer and lower drainage layer comprise the capillary barrier. Care was taken in placing the first lift of soil. It was important to maintain a clean interface between the sand and soil for optimum performance of the capillary break. A loader placed the soil over the sand always driving on previously placed soil, never on the sand. Native soil taken from on-site cut excavations was used. A small bulldozer with steel tracks was used to spread the soil forward and evenly. The steel tracks allowed for the distribution of the weight of the bulldozer over a larger area to mitigate any disturbance to a clean interface between the sand and soil underneath the tracks. This process was used for materials placed directly on a dissimilar material. The compacted soil layer was placed in three approximately equal lifts. The soil was compacted within an acceptable compaction zone as shown in Figure 11. An 18,200 kg smooth rolled vibratory compactor was used to compact the soil. All lifts were scarified prior to the placement of the next lift to eliminate seams between lifts with the exception of the top lift which was left smooth rolled.

On top of the soil barrier layer, the upper drainage layer was installed. The bottom layer of the upper drainage layer was a 22 cm thick lift of gravel meeting the particle size distribution (PSD) shown in Figure 12. Clean pea gravel was used. It was placed in one uncompacted lift. Above this was a sand layer designed to meet filter criteria between the soil and gravel. Its PSD met that shown in Figure 12. It was originally designed to be only 8 cm thick, but the thinnest practical lift turned out to be 15 cm which is what was installed. This sand layer was also left uncompacted. The sand serves as a graded filter to prevent topsoil from clogging the drainage layer. The gravel allows for lateral drainage of any water that has percolated through the topsoil. The 30 cm thick topsoil layer was then installed on top of the sand. This surface layer is placed to enhance evapotranspiration (ET), protect against desiccation of the barrier soil layer, and provide a medium for growth of vegetation. Vegetation increases ET and protects against surface erosion. The layer was topsoil cut from the site, stockpiled and then replaced. It was placed in one uncompacted lift.

Figure 4. Alternative Test Cover 2

Alternative Test Cover 3 referred to as the Anisotropic Barrier attempts to limit downward movement of water while encouraging lateral movement of water. This cover is composed of a layering of capillary

barriers. The various layers are enhanced by varying soil properties and compaction techniques that lead to the anisotropic properties of the cover.

This cover system consists of 4 layers: (1) a top vegetation layer; (2) a cover soil layer; (3) an interface layer; and (4) a sublayer (Figure 5). The vegetation layer is 15 cm thick. It is comprised of a mixture of local topsoil and pea-gravel. The gravel to soil mixture by weight is 25%. The gravel and soil were mixed adjacent to the site, then placed on the cover in one uncompacted lift. The gravel was added primarily to assist in minimizing surface erosion to runoff. This layer encourages evapotranspiration, allows for vegetation growth, and reduced surface erosion. The cover soil layer is 60 cm of native soil. Its function is to allow for water storage and eventual evapotranspiration and to serve as a rooting medium. It was placed in four 15 cm thick lifts. It met the density and moisture criteria for installation shown in Figure 13. The densities were met by allowing compaction through normal construction activities, not by the use of a compactor. By normal construction activities, I mean the loaders and tractors used to install the soil compacted the soil enough to meet the density criteria. The interface layer is 15 cm of fine sand that serves as a filter between the overlying soil and the underlying gravel. It also serves as a drainage layer to laterally divert water that has percolated through the cover soil. The sand meets the PSD shown in Figure 12. It was also clean washed concrete sand. The sand was placed in one uncompacted lift. The sublayer is 15 cm of pea-gravel. It meets the PSD criteria shown in Figure 12. This layer was installed in one uncompacted lift. The soil over sand layers create one capillary barrier while the sand over gravel creates a second capillary break. The interface layer and sublayer combined also serve a dual purpose as bio-barriers to reduce the penetration or intrusion of roots and burrowing animals into the underlying waste.

Figure 5. Alternative Test Cover 3

Alternative Test Cover 4 is referred to as an Evapotranspiration (ET) Cover (Figure 6). The ET Cover consists of a single, vegetated soil layer constructed to represent an optimum mix of soil texture, soil thickness, and vegetation cover. Case studies were used to assist with design considerations (Nyhan et al. 1986, Nyhan et al. 1990). These studies showed that a well designed simple soil cover can be very effective in preventing excessive erosion due to runoff and percolation, particularly in dry environments. The vegetation cover serves as the principal mechanism inhibiting soil moisture movement through the cover and into the waste. However, the texture and depth of soil provide the means of storing soil moisture in the zone where it is available to plants. Many studies have shown that vegetation in arid and semiarid environments has the potential to remove nearly 100% of the moisture that infiltrates into the soil as long as plant roots can access the moisture. Under these conditions, this means that the potential for deep percolation of soil moisture is very low. Ideally, the vegetation cover should consist of an optimum mixture of species, including cool season and warm season species. Additionally, species with different growth forms (such as grasses, shrubs, or trees) should be used to revegetate the site in order to spread ET over as much of the growing season as possible. The average annual rainfall in Albuquerque, NM is 20.6 cm/yr. The following estimates of annual ET, expressed as a percentage of annual precipitation, are based on model output (Hakonson 1996). At normal precipitation for Albuquerque, NM, ET uses nearly 100% (averages 99.9%) of the precipitation that infiltrates into the soil.

This cover encourages water storage and enhances ET. The cover is a monolithic soil cover. The soil came from on-site cut excavations. It is 90 cm thick. The bottom 75 cm was compacted while the top 15 cm of topsoil was loosely placed. The bottom 75 cm was placed in 15 cm deep lifts and compacted to meet the acceptable compaction zone requirements in Figure 11. Each lift was scarified prior to placement of the next lift to eliminate seams between lifts. The soil allows for water storage which combined with the vegetation will increase ET. The top 15 cm of soil is loosely placed topsoil.

After completion of earthwork activities, the cover was drill seeded with a mixture of native seed designed specifically for the area. The New Mexico Highway Department mix of seed can often be impractical for landfill application. It is generally designed for roadside use where there is actually more precipitation due to runoff from the highways. This is not the case with landfills. The seed mix used was of species native to the immediate area. The mix ensured a good blend of cool and warm weather plants, primarily native grasses.

A side study was created and has been installed to assist with the ET cover. Twenty-four 10 m x 10 m plots were installed adjacent to the test covers. The plots are soil that was excavated to a depth of about 90 cm, stockpiled, and then replaced. They were drill seeded with the same grass seed mix used on the ET cover. After seeding they were each treated with one of eight surface treatments. So there are three sets of eight different surface treatments to allow for statistical analysis. The eight surface treatments are: (1) the addition of green waste compost at 2.5 kg/m³, (2) green waste compost at 1.2 kg/m³, (3) dairy manure compost at 1.2 kg/m³, (4) biosolids compost at 1.2 kg/m³, (5) biosolids at 2.5 kg/m³, (6) 2 cm cobble mulch, (7) a control plot with no surface treatment, and (8) a control plot where water is simply added to induce vegetation growth. Each plot has a PVC port vertically installed in it to allow for soil moisture measurements to a depth of 1.2 m using frequency domain reflectometry. These soil measurements will be taken periodically to evaluate the effect of the surface treatment on ET and thus on reducing the amount of infiltration.

Figure 6. Alternative Cover 4

A detailed Quality Assurance (QA) Plan was prepared for the construction of the demonstration. The QA requirements for the baseline test covers closely adhered to that recommended by the EPA (US EPA 1993). Revisions in the QA plan were made for the alternative covers on an individual basis. The QA process was intended to ensure that the covers were constructed as specified and that the design intent was in fact achieved. Other reasons for such a detailed and time intensive QA process was to record key variables during construction to allow for future repetition if warranted and to provide documentation for those individuals who were unable to observe the entire construction process (e.g., representatives of regulatory agencies, etc.) so that these individuals can make informed judgments about the quality of construction of the ALCD. QA procedures and results were thoroughly documented.

Materials quality assurance was of utmost importance. Materials and their installation were tested to ensure compliance with the design and recorded throughout the construction process. These items included such

things as plasticity index, sieve analysis, maximum size stone or debris, placement and compaction, moisture content, bond between lifts, in-situ hydraulic conductivity, bentonite content, water content, lift thicknesses, etc. Geosynthetic installations were also inspected and recorded

Performance Monitoring and Instrumentation

Passive testing consists of daily on-site observations to validate system performance and to correct problems. Continuous data is being obtained for soil moisture status, percolation and interflow, runoff and erosion, precipitation, wind speed and direction, relative humidity, solar radiation, air and soil temperature. Periodic measurements are being obtained on vegetation cover, biomass, leaf area index, and species composition.

Active testing includes supplemental precipitation added to hydrologically stress the various barriers systems. Water applied using the sprinkler system is tested for rate and uniformity of application. All water is distributed through electronically controlled flowmeters where quantities discharged are controlled and measured. This system has the flexibility to apply worst case precipitation events. All other measurements under this precipitation regime are the same as described above for passive monitoring.

The water balance equation being used is:

$$E = P - I - R - D - \Delta S;$$

where: precipitation (P), surface runoff (R), lateral drainage (D), evapotranspiration (E), soil water storage (S), and percolation or infiltration (I) are the six water balance variables. With the exception of 'E', quantities of all terms in the water balance equation are being obtained with the monitoring systems. Evapotranspiration is determined by solving the water balance equation for 'E'. All measurements are made with automated monitoring systems to provide continuous data. Manual backup systems are available in case of failure in one or more of the automated measurements systems and/or to verify accuracy of the automated systems.

Soil Moisture: Time Domain Reflectometry (TDR) and an associated data acquisition system is used to provide a continuous record of soil moisture status at various plan locations and depths in each cover profile. PVC pipes were installed strategically in the covers to be used as ports to allow for the use of frequency domain reflectometry as a backup. The process of sending pulses and observing the reflected waveform is called TDR. A waveform traveling down a coaxial cable or waveguide is influenced by the type of material surrounding the conductors. If the dielectric constant of the material is high, the signal propagates slower. Because the dielectric constant of water is much higher than most materials, a signal within a wet or moist medium propagates slower than in the same medium when dry. Ionic conductivity affects the amplitude of the signal but not the propagation time. Thus, moisture content can be determined by measuring the propagation over a fixed length probe embedded in the medium being measured.

Soils with a high water content lengthen the propagation time and this is reflected as an apparent increase in the distance traveled by the pulse. Soils with a high water content and a high electrical conductivity rapidly attenuate the voltage pulse before it is reflected back to the source. Each probe was individually calibrated to achieve the highest degree of accuracy possible. This calibration process was extremely lengthy and time consuming. Each probe as it would be assembled in the field was inserted in representative soil under a range of moisture contents to develop an algorithm that would yield an accurate moisture content. The TDR system was calibrated to measure the soil moisture content to within +/- 1% of actual gravimetric moisture content.

Soil Temperature: Thermocouples placed strategically throughout each cover are measuring the soil temperature. These data will be used to assist with evapotranspiration studies and for monitoring frost penetration and its effect on the hydraulic conductivity of the soils.

Runoff and Erosion: Runoff and erosion are measured on an event basis. Surface runoff water is collected with a gutter system located at the bottom of each slope of each cover. The collected water is routed to instrumentation that quantifies it. A data acquisition system is linked to the instrumentation to automatically record and store data. Sediment will be separated from runoff in a settling tank located downstream from the runoff measuring system to provide total soil loss for each runoff event.

Percolation and Interflow: Subsurface flows are measured. Lateral drainage from each drainage layer is collected using underdrain systems placed at the bottom of each slope of each cover. The water is routed to instrumentation that quantifies it. The instrumentation is linked to a data acquisition system to continuously record flow events. Percolation through the barrier layer for each cover is collected using a geomembrane under a geonet that routes the water to an underdrain collection system. Both percolation and interflow is routed via drains to the flow monitoring system. Measurement redundancy is built into the system to reduce the chances of losing data due to equipment failure or power loss and to verify correctness of results obtained. To avoid problems with inclement weather, all monitoring instrumentation is housed in a shelter.

Meteorology: A complete weather station was installed at the ALCD site. Precipitation, air temperature, wind speed and direction, relative humidity, and solar radiation are continuously recorded. The meteorological measurements are made with automated equipment coupled to the data acquisition system.

Vegetation: Attributes of the vegetation are measured seasonally throughout the study to relate to changes in erosion and evapotranspiration. A point frame is used to evaluate cover and leaf area. Biomass is determined by clipping and weighing oven-dried samples collected from subplots within each cover design. Species composition is measured using line transects and/or quadrates.

RESULTS

The construction costs of the covers are presented in Table 2. These costs represent only costs associated with the construction of the cover. They do not include instrumentation and monitoring equipment or anything installed for the testing of the covers.

Table 2. Construction Costs		
Cover	Description	Cost / m ²
Baseline Test Cover 1	Subtitle 'D' Soil Cover	\$52.42 / m ²
Baseline Test Cover 2	Subtitle 'C' Compacted Clay Cover	\$92.89 / m ²
Alternative Test Cover 1	GCL Cover	\$157.58 / m ²
Alternative Test Cover 2	Capillary Barrier	\$96.45 / m ²
Alternative Test Cover 3	Anisotropic Barrier	\$74.92 / m ²
Alternative Test Cover 4	ET Cover	\$72.66 / m ²

Water balance performance data will be released annually at the end of the fiscal year for each of the next five years.

DISCUSSION

Without regulatory and public acceptance, promising environmental technologies have little chance for successful implementation. Also very important to the acceptance of new environmental technologies is their cost. A study performed by the University of North Dakota (Wentz 1989) concluded that the deciding factors affecting which hazardous waste management technology is to be used are from most important to least important: 1) government regulations, 2) economics, 3) public relations, and 4) process/technology. The ALCD has been committed from the start to get regulatory and public acceptance of the project and the technologies presented in the demonstration. The design criteria for the alternative cover designs as stated earlier in this paper required that the new designs be less expensive to construct than the traditional designs.

Because permits can be difficult to get and there has been only minimal work done promoting alternative covers based on regional environmental requirements, many design engineers are reluctant to deviate far from conventional designs.

The test cover designs were sent out for review first to a group of technical peers who were independent of the project and deemed industry experts. This review helped ensure the technical validity of the proposed cover designs. Comments were gathered from the reviewers and incorporated in the designs.

The revised test plan was then sent to regulatory representatives from environmental departments throughout most of the western states. It was also sent to representatives from several EPA regional offices. Comments from this review were also incorporated into the design package.

Law makers and regulators have become more sensitive to special interest groups concerns and are consequently encouraging these groups inclusion in the permitting process. The ALCD has received endorsement by a committee from a western states' and federal government initiative to accelerate and improve cleanup of federal lands. This initiative originated in 1992, when the Western Governors Association, the Secretaries of Defense, Energy, and Interior, and the Administration of the Environmental Protection Agency formed a federal advisory committee to cooperate on the cleanup of federal waste management sites in the region. This committee, known as the Committee to Develop On-Site Innovative Technologies (DOIT Committee), has sought the guidance of key players to help identify, test and evaluate more cooperative approaches to deploying promising innovative waste remediation and management technologies in order to clean up federal waste sites in an expeditious and cost-effective manner.

The DOIT Committee's primary goal with regard to the ALCD is to assist with the eventual acceptance of new technologies that come from the demonstration and inclusion of landfill permitting in an interstate reciprocity program the Committee is attempting to finalize.

Yet another review process included sending a general overview of the demonstration to members of the DOIT Committee and special interest groups identified by the DOIT Committee. These interest groups included representatives from such entities as environmental activist groups like the Sierra Club, Indian tribes, government agencies, neighborhood associations, local businesses, engineering firms, and politicians. Over 1000 groups received information. Comments were forwarded through the Western Governors Association for consideration. The majority of these comments centered on questions rather than comments and on praise for getting them involved early in the process. Much interest was invoked as a result of this. Periodic progress meetings were held with these representatives of some of the special interest groups, Western Governors Association, regulatory agencies (predominantly from New Mexico), New Mexico State Legislature, and Sandia National Laboratories.

EXPECTED BENEFITS

The demonstration is expected to provide performance and cost data for cover components and systems that are more applicable to western climatic conditions. A direct comparison between conventional and alternative designs will be available. The "active" testing will permit data to be collected under extreme and accelerated conditions. This information will allow those responsible for the development of landfill cover design guidance to have a defensible basis for the transition from designs suited for the eastern US to those more suited to the western US.

This demonstration project will make field data available for validation of the EPA's HELP (Hydrologic Evaluation of Landfill Performance) model (Schroeder et al. 1994). This model is a quasi two-dimensional water balance model whose primary purpose is to quantify the amount of runoff, ET, moisture storage, lateral drainage, and vertical percolation for cover systems based on site-specific climatological data, soil properties, and cover design information. The demonstrations will provide data from extreme conditions (arid and high-precipitation) that can be used to test the capabilities of the HELP model. This computer program by the EPA is routinely used by practicing engineers to assist with design and application for permits.

The probable outcome of this demonstration is the acceptance of alternative cover designs that are significantly less costly than conventional designs. Given the thousands of acres of buried waste sites to be covered, the payoff from this demonstration may be on the order of many millions of dollars in savings to taxpayers.

Future papers will discuss the results comparing and contrasting the water balance variables between the covers as well as how well field results compared with predictive models such as the HELP model.

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