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Alternative Landfill Cover Demonstration

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Abstract

The Alternative Landfill Cover Demonstration is a large-scale field test to compare and document the performance of alternative landfill cover technologies of various costs and complexities for interim stabilization and/or final closure of landfills in arid and semi-arid environments. Test plots of traditional designs recommended by the US Environmental Protection Agency (EPA, 1991) for both RCRA Subtitle ‘C’ and ‘D’ regulated facilities have been constructed. These will serve as baselines for comparison to alternative covers. The alternative covers designed specifically for dry environments will be constructed in 1996. The covers will be tested under both ambient and stressed conditions. All covers will be instrumented to measure water balance variables and soil temperature. An on-site weather station will record all pertinent climatological data.

A key to acceptance of an alternative environmental technology is seeking regulatory acceptance and eventual permitting. The lack of acceptance by regulatory agencies is a significant barrier to development and implementation of innovative cover technologies. Much of the effort on this demonstration has been toward gaining regulatory and public acceptance. The demonstration is working with regulatory authorities and public interest groups toward the possibility of interstate permitting of alternative landfill cover technologies.

Introduction

The Departments of Energy and Defense have begun a clean-up of their facilities that is expected to cost hundreds of 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

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activities, the US Department of Energy (DOE) and the US Department of Defense (DOD) have thousands of radioactive, hazardous, mixed waste, and sanitary landfills to be closed in the near future (Hakonson et al., 1994). 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. 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 taking place at Sandia National Laboratories, located on Kirtland Air Force Base in Albuquerque, New Mexico. It will compare and document the performance of alternative landfill cover technologies of various costs and complexities for interim stabilization and/or final closure of landfills in arid and semi-arid environments.

Health and environmental risk assessment work is currently underway at the various federal facilities. These studies will almost certainly recommend capping technologies to be widely used rather than the remediation of landfill sites to a 'clean site' status. Early estimates to excavate buried hazardous waste and completely remediate the site to a clean position are about 20 times more expensive than capping it with an engineered cover in place. (Hakonson et al., 1994).

Traditional Cover Designs

The ALCD will install traditional designs as baseline covers to compare and contrast alternative covers against. The ALCD is comprised of phased construction due to funding limitations. Phase I constructed in 1995 consists of three covers.

1) a traditional Compacted Clay Cover meeting minimum requirements of Subtitle 'C' with the following profile - a 60 cm vegetation soil layer over a 30-cm sand drainage layer over a geomembrane over the 60 cm compacted clay barrier layer (EPA, “Construction...., 1994).

2) A basic Soil Cover that meets minimum requirements set forth in Subtitle ‘D’ - comprised of a 15 cm vegetation soil layer over an 45 cm compacted soil barrier layer (DOE, 1993).

3) A Geosynthetic Clay Cover identical to the traditional compacted clay cover with the exception that the problematic clay barrier layer will be replaced with a manufactured sheet installed in its place - a geosynthetic clay liner (GCL).

Phase II designs will be finalized in 1995 and are scheduled to be constructed in the summer of 1996. These designs include a capillary barrier, dry barrier, anisotropic barrier, and enhanced evapotranspiration cover.

Traditional covers presently in use for 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 environments. 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 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.” (EPA, 1991) The clay barrier layer in the traditional Subtitle ‘C’ cover must be constructed so as to yield a maximum hydraulic conductivity of $1 \times 10^{-7}$ 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. This desiccation cracking can cause serious problems with its ability to block the infiltration of water. 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 Compacted Clay Cover not only have inherent problems but are very expensive and difficult to construct.

A study by the EPA (EPA, 1988) of existing landfill performance revealed that many have serious problems, from groundwater contamination to 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 (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 good quality final cover.

Alternative Acceptance

Without regulatory acceptance, promising technologies will die with their inventors. The ALCD has been committed from the start to get regulatory and public acceptance of the project and the technologies presented in the demonstration.

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

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

A commercialization plan written for the ALCD concluded that for the technologies in the project to be accepted, the demonstration must meet several criteria (Dwyer, 1994). The covers must be readily comparable. The data must be real and obtained fairly. Key individuals and groups, independent to the project design, serve as reviewers to ensure the criteria is met. The Phase I designs were
sent out for review first to a group of technical peers that were independent of the project and deemed industry experts. This review helped ensure the technical validity of the designs to be constructed in Phase I. Comments were gathered from the reviewers and included in the designs.

This revised test plan was then sent to regulatory representatives from Environmental Departments from many of the western states including New Mexico, Arizona, California, Nebraska, Nevada, South Dakota, Texas, and Utah. It was also sent to representatives from the EPA Regions VI and VIII offices. Comments from this review were also incorporated into the design package.

Politicians and thus regulators are becoming more sensitive to special interest groups concerns and are therefore encouraging participation with these groups when permitting projects. The ALCD has received endorsement by a committee from a western states’ and federal government initiative to accelerate and improve clean up 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 inter-state 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 a package. 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 meetings were held with these representatives of some of the special interest groups, Western Governor’s Association, regulatory agencies (predominantly from New Mexico), New Mexico State Legislature, and Sandia National Laboratories. These meetings kept interested parties apprised of advancements, progress, and answered questions and concerns. These meetings continue on about a bimonthly basis.
Demonstration Description

The ALCD is a series of large-scale landfill test covers constructed side-by-side for comparison. (see figure 1). Future test cover construction will continue this side-by-side arrangement. The various covers will be compared based on their performance, cost, and ease of construction.

The ALCD is not intended to showcase any one particular cover system. It is intended to compare and contrast different cover systems in a dry environment. Information gained from the demonstration can then be used by others when choosing between cover designs or when applying for the permitting of one of the cover systems.

The covers are each 13 m wide by 100 m long. The 100 m dimension was chosen because it is fairly representative of hazardous and mixed waste landfills found throughout the DOE complex (approximately 2 acres in surface area).
General site preparation included bringing utilities (water and power) to the site for the instrumentation and stress testing. The site was cleared and grubbed after which the top 15 cm of topsoil was excavated and stockpiled. This topsoil was reused as the top 15 cm of the covers. The covers were designed so that the site cut excavations were approximately equal to the soil requirements for the covers. The subgrade below each cover was compacted to 95% of maximum dry density (ASTM D698). The only soil hauled in from off-site used in the construction of the covers was the bentonite added to the barrier layer in the Compacted Clay Cover and the sand for the drainage layers. All covers were constructed with a 5% slope in all layers.

**Phase I Cover Descriptions**

The Compacted Clay Cover installed was designed to meet minimum requirements from Subtitle ‘C’ regulated landfills (EPA, 1991). It is 1.5-meters thick. The typical profile for this cover consists of three layers (see figure 2). The bottom layer is a 60 cm thick barrier layer. The barrier layer’s primary purpose is to prevent the downward movement of water into underlying waste. It was constructed of native soil mixed with 6% bentonite. The bentonite was required because the native soil used did not have an adequate amount of fines in it. The lifts were installed in maximum 22 cm loose lift thicknesses and compacted to 98% of maximum dry density (ASTM D698). The soil during fill and compaction was kept at a water content two to four percent ‘wet of optimum’. The soil was compacted ‘wet of optimum’ so as to remold the soil. The combination of the compaction requirements, soil amendment, and placement ‘wet of optimum’ was done to yield a maximum hydraulic conductivity of $1 \times 10^{-7}$ cm/sec. Laboratory soil tests revealed that the amended soil compacted to these requirements had a hydraulic conductivity lower than $1 \times 10^{-8}$ cm/sec. A lesser percent of bentonite would have been acceptable based on laboratory tests but it was decided, based on past experience and discussions with colleagues, that 6% bentonite is probably the minimum practical amount that one can add to get a fairly uniform application and mix. Partial penetrating kneading compaction was used rather than full penetrating so as not to damage instrumentation (TDR probes, thermocouples and associated cable) placed on or in the preceding lift. Each lift was scarified an inch or two prior to placement of the next lift. This was done in an effort to eliminate the interface between lifts. An interface left could provide a pathway for water to run along until it found a crack in the underlying lift. Organic material and stones larger than 2 cm in diameter were removed from soil prior to placement. This was done in order to remain consistent with the soil preparation for the hydraulic conductivity laboratory tests. The top lift of the barrier layer was compacted smooth. Objects larger than 13 mm were removed from the surface or near the surface so as not to damage the geomembrane that was placed on top of this barrier layer.

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 get 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 middle layer is a 30 cm thick drainage layer. The primary purpose of the
drainage layer is to quickly route any water that has passed through the vegetation
layer laterally to collection drains normally located at the perimeter of the landfill.
This layer was constructed of sand placed directly on the geomembrane. It was not
compacted to a level beyond that received as a result of ordinary construction
activities. The average hydraulic conductivity of the sand installed was $1 \times 10^{-1}$
cm/sec which is an order of magnitude better than the minimum $1 \times 10^{-2}$ cm/sec
called for in Subtitle ‘C’. 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 layer.

The top layer is a 60 cm thick vegetation layer. 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 soil covered by 15
cm of topsoil. This entire layer was placed and left uncompacted. Stones larger than
50 mm in diameter were removed from this soil prior to replacement.

After completion of all covers, the surfaces were seeded with native grasses.
A cereal straw mulch was spread over the seed with a tackifier applied to help
prevent the wind from blowing it away. The seed and fertilizer mixture applied was
chosen with the assistance of the New Mexico State Highway Department and is
consistent with vegetation found in the immediate area. The vegetation provides for
erosion control and transpiration of water through the plants from the vegetation
layer.

Subtitle 'C' RCRA Cover
Figure 2 - Compacted Clay Cover typical section.

The basic Soil Cover installed met minimum requirements for Subtitle ‘D’ governed landfills (DOE, 1993). This cover is 60 cm thick (see figure 3). It is constructed of essentially two layers. The bottom layer is a 45 cm thick compacted soil barrier layer. Only native soil was used in this layer. Organics and objects larger than 50 mm in diameter were removed prior to placement. This barrier layer was constructed by placing loose lifts no thicker than 22 cm. The soil was compacted to 95% of maximum dry density (ASTM D698). Partial rather than full penetrating kneading compaction was used so as not to damage underlying instrumentation. The soil was placed as specified to meet the maximum $1 \times 10^{-5}$ cm/sec requirement of Subtitle ‘D’ regulated facilities. Laboratory test results yielded saturated hydraulic conductivity results on the barrier layer soil between $5.5 \times 10^{-6}$ cm/sec and $5.1 \times 10^{-7}$ cm/sec.

The top vegetation layer is 15 cm of topsoil loosely laid. This layer provides for vegetation growth and erosion protection.

Figure 3 - Soil Cover typical section.

The third cover is called a Geosynthetic Clay Liner (GCL) cover (see figure 4). It is identical to the Compacted Clay Cover installed with one exception. The

Geosynthetic Clay Liner Cover

Figure 4 - GCL Cover typical section.
compacted clay barrier layer was replaced by a single manufactured sheet known as a GCL. Therefore the GCL is the bottom layer covered with a geomembrane, drainage layer and vegetation layer, respectively. The GCL sheet installed is a composite of two nonwoven geotextile fabrics sandwiching a layer of bentonite. The hydraulic conductivity of the GCL is $5 \times 10^{-9}$ cm/sec.

Apart from the three covers installed, two smaller test pads were also constructed adjacent to the test pads. The test pads are 7.3 m by 7.3 m. One pad is a Subtitle 'C' compacted clay barrier layer with the other being a Subtitle 'D' compacted soil barrier layer. They were constructed exactly like the barrier layers in the full size test plots. A double-ring infiltrometer was installed on each test pad to measure in-situ hydraulic conductivity (ASTM D5093). These infiltrometers will be left in-place to measure hydraulic conductivity throughout the duration of the experiment.

**Phase I Construction Quality Assurance**

A detailed Quality Assurance (QA) Plan was prepared for this demonstration. It adheres closely to that recommended by the EPA (EPA, 1993). The major purpose of this QA process was 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.

Daily Inspection Reports were prepared that included information about work that was accomplished, tests and observations that were made, and descriptions of the adequacy of the work that was performed. Daily Summary Reports provided a chronological framework for identifying and recording all other reports and aided in tracking what was done and by whom. Inspection and Testing Reports noted field observations, results of field tests, and results of laboratory tests performed on- or off-site. These observations took the form of notes, charts, sketches, or photographs, or a combination of these. Problem Identification and Corrective Measures Reports identified and recorded fixes of problems with material or workmanship that did not meet the requirements of the plans, specifications, or QA Plan. Drawings of Record ('as-built' drawings) were prepared and continually updated to document actual field installations. Final Documentation and Certification took the form of a final report that included all of the aforementioned.

Key meetings were essential to the successful construction of the ALCD. These meetings included a pre-bid meeting held prior to bidding of the contract, a pre-construction meeting held in conjunction with a resolution meeting after the contract was awarded but prior to the start of actual construction activities.
The pre bid meeting was used to discuss the QA Plan and resolve differences of opinion before the project was let for bidding. It also gave the bidders a chance to ask questions and problems which were therefore rectified early on. The resolution / pre-construction meeting allowed for lines of communication, review of construction plans and specifications, emphasize the critical aspects of a project necessary to ensure proper quality, begin planning and coordination of tasks, and anticipate any problems that might cause difficulties or delays in construction. It also allowed for the review of the QA Plan, to make sure that the responsibility and authority of each individual was clearly understood, where procedures to resolve construction problems were established. Periodic progress meetings were held at the job site. These meetings were helpful in maintaining lines of communication, resolving problems, identifying action items, and improving overall quality management.

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 (ongoing), bentonite content, water content, lift thicknesses, etc. Geosynthetic installations were also inspected and recorded.

Performance Monitoring and Instrumentation

Objectives to be achieved through monitoring are to: (1) collect continuous water balance data from each cover design and ancillary supporting data for a minimum five-year post-construction period, (2) periodically measure characteristics of the vegetation cover on each plot, and (3) manage the automated computer database.

The test covers were built with half of their length (150 m) sloping at 5% toward the east with the other half sloping toward the west (see figure 1). The western slope will be monitored under ambient conditions (passive monitoring). A sprinkler system was installed in the eastern slope of each cover. This will allow for stress testing of the covers (active monitoring).

Passive monitoring for the first few months will consist of daily on-site observations that will be required to validate system performance and to correct problems. As the bugs in the system are worked out, on-site observations will be necessary less frequently. Continuous data will be obtained for soil moisture status, percolation and interflow, runoff and erosion, precipitation, wind speed and direction, relative humidity, air and soil temperature. Periodic measurements will be obtained on vegetation cover, biomass, leaf area index, and species composition.

Active monitoring will include supplemental precipitation added to hydrologically stress the various barriers systems. Water will be applied using the
sprinkler system tested for rate and uniformity of application. All water will be distributed through electronically controlled flowmeters where quantities discharged will be controlled and measured. Worst case precipitation events such as a 10-, 50-, or 100-year storm can be applied. All other measurements under this precipitation regime would be the same as described above for passive monitoring.

The success of the ALCD will depend heavily on the quality of the monitoring systems and the care taken in their installation and follow-on maintenance. The monitoring equipment was designed for measuring the components of water balance and additional ancillary variables. All monitoring equipment was also designed with a backup for each.
The water balance equation to be used is:

\[ E = P - I - R - D - S; \]  
(Equation 2)

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', estimates of all terms in Equation 2 will be obtained with the monitoring systems. Evapotranspiration will be estimated by solving Equation 2 for 'E'. Other measurement variables include erosion,
precipitation, relative humidity, barometric pressure, soil temperature with depth, vegetation biomass and cover, and wind speed and direction. Most of the physical attributes will be measured with automated monitoring systems to provide continuous data (see figure 5).

Soil Moisture: Time Domain Reflectometry (TDR) and an associated data acquisition system will be used to provide a continuous record of soil moisture status at various plan locations and depths in each cover profile. The soil moisture will be measured using TDR. PVC pipes were installed strategically in the covers to be used as ports to allow for the use 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. If the attenuation is great enough there is no return signal and the probe cannot be used. This is essentially what happened when commercially available probes were tested in soils representative of the barrier layer in the Compacted Clay Cover — no useful signal was reflected back. The high density, water content and sodium bentonite addition made TDR a challenge to use. Because of the problems with the commercially available TDR systems, a system was designed to overcome these problems. The design began with perhaps the single most important element and weak link - the probe. Such things as: rod length, rod spacing, number of rods (2 or 3), coating the rods (with several different types of coatings, coating thicknesses, and surface preparation), total coax cable lengths, rod diameter, low loss coaxial cable, and inserting diodes were experimented with to perfect the probes.

The final design yielded excellent waveforms under the most trying of circumstances. 256 probes were fabricated, installed in the three covers, and multiplexed (SDMX50 by Campbell Scientific) back to a set of Cable Testers (Tektronix 1502B). After fabrication of the probes but prior to their installation, each probe was individually calibrated. 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 moisture content.

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

Runoff and Erosion: Runoff and erosion will be measured on an event basis. Surface runoff water will be collected with a gutter system located at the bottom of each slope of each cover. The collected water will be routed to instrumentation that quantifies it. All instrumentation is set up so as to have redundancy in case of a failure in the primary measurement. 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 will be measured. Lateral drainage from each drainage layer will be collected using underdrain systems placed at the bottom of each slope of each cover. The water will be 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 will be collected using a geomembrane under a geonet that routes the water to an underdrain collection system. Both percolation and interflow will be 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 will be continuously recorded. The meteorological measurements will be made with automated equipment coupled to the data acquisition system.

Vegetation: Attributes of the vegetation will be measured seasonally throughout the study to relate to changes in erosion and evapotranspiration. A point frame will be used to evaluate cover and leaf area. Biomass will be determined by clipping and weighing oven-dried samples collected from subplots within each cover design. Species composition will be measured using line transacts and/or quadrants. This activity commences upon completion of each respective test plot.

Phase II Designs

(1) A Capillary Barrier primarily comprised of a fine-grained layer of soil placed over a coarse-grained layer. The design emphasizes a sufficient contrast between
the hydraulic conductivities of the fine-grained layer versus the coarse-grained layer. This contrast lends to the effect that flow through the cover is greatly slowed under unsaturated conditions. Also, under unsaturated conditions, the hydraulic conductivity of the coarse-grained soil is significantly lower than that of the fine-grained soil layer. If saturation is reached however, the cover fails.

(2) An Anisotropic Barrier that 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.

(3) A Dry Barrier which is an enhanced capillary barrier. It is comprised of a fine-grained soil over a coarse-grained material. The preferred coarse-grained material is volcanic tuff as found in the Los Alamos, NM area or scoria. This material lends to water storage in the coarse-grained layer. The design assumes that the first layer will store water and allowed to evaporate. A capillary barrier exists with the contrast in hydraulic conductivity between the two materials. Any water entering the coarse layer where it is stored in the material will be dried by air that enters the coarse layer through supply vents strategically located through the cover (goose-necked pipes). The air then exits through passive air vents such as a common roof turbine secured to a return pipe that extends from the coarse layer and are strategically located throughout the cover.

(4) An enhanced evapotranspiration (ET) Cover that is a soil cover with an engineered vegetative covering. This cover encourages water storage and enhanced ET year-round rather than just during the growing seasons.

**Expected Benefits of the ALCD**

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 should provide valuable field data for validation of the HELP Modelv3 (EPA, "HELP..., 1994). The demonstrations will provide data from extreme conditions (arid and high-precipitation) that will be used to test the capabilities of the HELP Modelv3. 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.

Future papers will discuss the comparison of construction specifics and costs between the various covers. Also, 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 Hydrologic Evaluation of Landfill Performance (HELP).

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