LANDFILL COVERS FOR DRY ENVIRONMENTS

Stephen F. Dwyer
Sandia National Laboratories
P.O. Box 5800, MS-0719
Albuquerque, NM 87185
(505)844-0595

ABSTRACT

A large-scale landfill cover field test is currently underway at Sandia National Laboratories in Albuquerque, New Mexico. It is intended 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 for both RCRA Subtitle ‘C’ and ‘D’ regulated facilities have been constructed side-by-side with the alternative covers and will serve as baselines for comparison to these alternative covers. The alternative covers were designed specifically for dry environments. The covers will be tested under both ambient and stressed conditions. All covers have been instrumented to measure water balance variables and soil temperature. An on-site weather station records 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.

INTRODUCTION

The ALCD is a series of large-scale landfill test covers constructed side-by-side for comparison. 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. Its intent is 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). 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 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).

Continuous data will be obtained for soil moisture status, percolation and interflow, runoff, 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 includes supplemental precipitation added to hydrologically stress the various barriers systems. Water is applied using the sprinkler system tested for rate and uniformity of application. All water is distributed through electronically controlled flowmeters where quantities discharged are 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 are the same as described for passive monitoring.

Objectives to be achieved through performance 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 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. This data collection system is automated with manual backup for each system.

A detailed Quality Assurance (QA) Plan was prepared for the construction of each test cover. It adheres closely to that recommended by the EPA. A 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.

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.

TRADITIONAL COVER DESIGNS

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." 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 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. 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.

The ALCD installed traditional designs as baseline covers to compare and contrast alternative covers against.

Traditional Test Cover 1 is a basic Soil Cover installed to meet minimum requirements for Subtitle 'D' governed landfills. This cover is 60 cm thick (see figure 1). It is constructed of essentially two layers.

![Figure 1 - Traditional Test Cover 1](image.png)

The bottom layer is a 45 cm thick compacted soil barrier layer. Only native soil was used in this layer. The soil was compacted 'wet of optimum' to 95% of maximum dry density (ASTM D698). 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 $5.1 \times 10^{-6}$ cm/sec. The top vegetation layer is 15 cm of topsoil loosely laid. This layer provides for vegetation growth and erosion protection.

Traditional Test Cover 2 is a Compacted Clay Cover designed and installed to meet minimum requirements from Subtitle ‘C’ regulated landfills. It is 1.5 m 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. Laboratory tests revealed that the native soil required amendment to meet the saturated hydraulic conductivity requirement (maximum of $1 \times 10^{-6}$ cm/sec). The lifts were compacted to a minimum of 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 $1 \times 10^{-6}$ 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.

Alternative Designs

Any and all compaction of soil in the alternative designs was compacted ‘dry of optimum’ rather than ‘wet of optimum’ as currently recommended with the traditional covers. This was done in an effort to mitigate the potential for desiccation cracking.

Alternative Test Cover 1 is a Geosynthetic Clay Cover (see 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).

Therefore the GCL is the bottom layer covered by a 40 mil linear low density polyethylene geomembrane 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 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. 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 $1 \times 10^{-5}$ 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 comprised of loosely laid 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 soil covered by 15 cm of topsoil. This entire layer was placed and left uncompacted.

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. 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 $1 \times 10^{-5}$ 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 comprised of loosely laid 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 soil covered by 15 cm of topsoil. This entire layer was placed and left uncompacted.

ALTERNATIVE DESIGNS

Any and all compaction of soil in the alternative designs was compacted ‘dry of optimum’ rather than ‘wet of optimum’ as currently recommended with the traditional covers. This was done in an effort to mitigate the potential for desiccation cracking.

Alternative Test Cover 1 is a Geosynthetic Clay Cover (see figure 3) identical to the traditional

Geosynthetic Clay Liner (GCL) Cover

![Figure 3 - Alternative Test Cover 1](image-url)
with a geomembrane, drainage layer and vegetation layer, respectively. The GCL sheet installed is a composite of two nonwoven fabrics sandwiching a layer of bentonite. The hydraulic conductivity of the GCL is $5 \times 10^{-9}$ cm/sec.

Alternative Test Cover 2 is a Capillary Barrier. The Capillary Barrier comprised of a fine-grained layer of soil placed over a coarse-grained layer emphasizes a sufficient contrast between the hydraulic conductivity’s 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 lower than that of the fine-grained soil layer.

This cover system consists of 4 primary layers: (1) a surface or topsoil layer, (2) an upper drainage layer, (3) a barrier soil layer, and (4) a lower drainage layer (see figure 4). The topsoil layer is 30 cm thick. 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. This vegetation increases ET and protects against surface erosion. The upper lateral drainage layer is 22 cm of gravel overlain by 8 cm of sand. The gravel allows for lateral drainage of any water that has percolated through the topsoil. The barrier soil layer and lower drainage layer comprise the capillary barrier. The barrier soil layer is compacted soil 45 cm thick. The lower drainage layer is 30 cm of sand.

![Figure 4 - Alternative Test Cover 2](image)

Alternative Test Cover 3 is another capillary barrier referred to as the Anisotropic Barrier. The design of 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 (see 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%. This layer encourages evapotranspiration, allows for vegetation growth, and reduce surface erosion. The cover soil layer is 60 cm of native soil. Its function is to allow for water storage and eventual evapotranspiration, as well as, serve as a rooting medium. The interface layer is 15 cm of fine sand. This layer 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 sublayer is 15 cm of pea-gravel. It serves as a capillary break. The interface layer and sublayer combined also serve a dual purpose as bio-barriers.

![Figure 5 - Alternative Test Cover 3](image)

Alternative Test Cover 4 is referred to as an Evapotranspiration (ET) Cover. The ET Cover is a soil cover with an engineered vegetative covering. This cover encourages water storage and enhances ET (see figure 6). The cover consists of only one layer - soil. It is 90 cm thick. The bottom 75 inches was

![Figure 6 - Alternative Cover 4](image)
compacted while the top 15 cm of topsoil was loosely placed. The soil allows for water storage which combined with the vegetation will increase evapotranspiration.

WATER BALANCE PERFORMANCE

Adjacent to the two aforementioned traditional test covers installed, two smaller test pads were also constructed. 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 traditional test cover plots. A double-ring infiltrometer was installed on each test pad to measure in-situ hydraulic conductivity (ASTM D5093).

The covers' water balance performance will be based on the mass balance equation at a given time interval:

\[ E = P - I - R - D - AS; \]  
(Equation 1)

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 1 will be obtained with the monitoring systems. Evapotranspiration will be estimated by solving Equation 1 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. The physical attributes are being measured with automated monitoring systems to provide continuous data.

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 frequency domain reflectometry (FDR) as a backup to the TDR system and to verify accuracy.

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

Runoff: Runoff is 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. 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.

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 are routed via drains to the flow monitoring system.

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. Point frames are 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 quadrants.

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 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.

The test cover 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. Comments were gathered from the reviewers and included in the designs.

The revised test plan was then sent to regulatory representatives from Environmental Departments from most of the western states. It was also sent to representatives from several EPA Region 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 expedient 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.

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 HELP Modelv3. 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).

ACKNOWLEDGMENTS

The work was supported by the United States Department of Energy Office of Technology Development through the Landfill Stabilization Focus Area product line. Special acknowledgments also go to those who assisted with alternative cover designs: Dr. Charles Shackleford, Colorado State University for the design of the Capillary Barrier, Dr. Tom Hakonson, Colorado State University for the design of the ET Cover, and Dr. John Stormont, University of New Mexico for the design of the Anisotropic Barrier.

REFERENCES


