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FINDING A BETTER COVER

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A demonstration project in New Mexico is showing that some landfill covers that are less expensive and easier to create than those required by regulations can actually work better.

Stephen F. Dwyer

The U.S. Department of Energy (DOE) is in the midst of a major cleanup of its landfills and other contaminated sites that is expected to cost billions of dollars. Cost estimates for these efforts, however, are based on the cleanup technologies in current use, many of which have proved inadequate. Consequently, work has begun on the development and improvement of environmental restoration and management technologies, and the performance of landfill covers is an area of particular concern.

As part of its ongoing environmental restoration activities, the DOE plans to close many radioactive, hazardous, mixed waste, and sanitary landfills in the near future. These sites, as well as mine and mill tailings piles and surface impoundments, all require either remediation to "clean site" status or capping with an engineered cover upon closure. In addition, engineered covers are being considered as an interim means of confining contaminated sites until they can be remediated.

The Alternative Landfill Cover Demonstration (ALCD)

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[illegible]

[illegible] This [illegible] has [illegible] throughout the [illegible] with a 5 percent [illegible] layers.

[illegible] the weight of [illegible] cover degrees to the east and the [illegible] to the west. The [illegible] degree of the covers are [illegible] under [illegible] conditions with passive [illegible]. A sprinkler system was installed on each of the east [illegible] degree to facilitate stress testing with active monitoring of the covers.

Passive testing consists of daily on-site observations to [illegible] system performance and to correct problems as they develop. Continuous data are being obtained on soil moisture status, percolation and interflow runoff and [illegible] precipitation, wind speed and direction, relative humidity, solar radiation and air and soil temperatures. Periodic measurements are also made of vegetation cover [illegible] leaf area index, the amount of plant coverage and species composition.

Active testing includes the addition of supplemental precipitation to hydrologically stress the various cover [illegible]. Water applied with the sprinkler system is tested for rate and uniformity of application. All water is distributed through flowmeters that electronically control and [illegible] the quantities discharged. This system has the capability of applying water quantities that simulate worst-[illegible] precipitation events. All other measurements under [illegible] precipitation regime are the same as those described above for passive monitoring.

The baseline test cover 1 is a basic soil cover installed to meet minimum requirements for RCRA subtitle D (see Figure 1). These requirements apply to municipal solid waste sites to be closed using engineered covers and are designed to meet the following performance objectives: to have cover permeability less than or equal to that of the bottom liner or subsoil but in no case more than 0.00001 cm/s; minimize infiltration using no less than 45 cm of soil; and to minimize erosion using no less than 15 cm of topsoil for plant growth. The installed test cover is 60 cm thick and comprises two principal layers. The top vegetation layer consists of 15 cm of loosely laid topsoil, and the bottom layer is a 45 cm thick compacted soil barrier layer.

The focus of this project is to provide the necessary data on cost, construction, and performance to the public and regulatory agencies so that design engineers will have alternatives to conventional cover designs that cost less but nevertheless conform to regulations.

designs be less expensive to construct than traditional designs. The study has drawn no final conclusions yet because data are still being collected, but certain trends can be seen after three years.

The ALCD landfill covers were divided into two separate bid packages, known as phase I and phase II. The phase I covers, constructed in the summer of 1995, include a soil cover that meets the requirements of subtitle D of the Resource Conservation and Recovery Act (RCRA), a compacted clay cover that speaks to subtitle C of the act, and the first of four alternative covers—a geosynthetic clay liner cover.

The phase II covers, built in the summer of 1996, provide the three other alternatives: a capillary barrier, an anisotropic barrier, and an evapotranspiration cover (see "Alternative Landfill Covers Pass the Test," *Civil Engineering*, September 1996). The RCRA soil and compacted clay covers were constructed to serve as baselines in evaluating the alternative cover designs. Each phase of construction was carried out on the basis of competitive bidding, with the low bidder receiving a firm, fixed-price contract.

Fig. 1 Subtitle D RCRA Cover

Fig. 2 RCRA Subtitle C Compacted Clay Cover

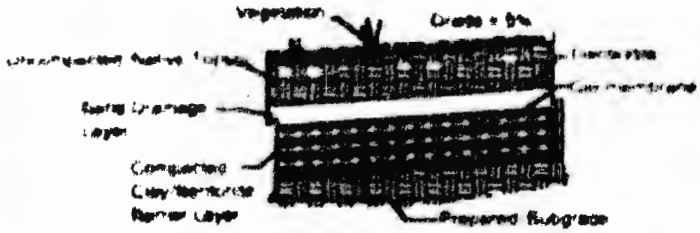
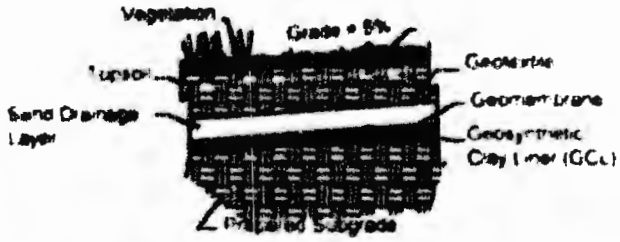


Fig. 3 Geosynthetic Clay Liner (GCL) Cover



The baseline test cover 2 is a compacted clay cover designed and constructed in accordance with the minimum requirements of regulations for the closure of hazardous and mixed waste landfills. These regulations do not specify the cover profile for an RCRA C cover in as much detail as those for an RCRA D cover.

The Environmental Protection Agency (EPA) recommended a RCRA C cover composed of, from bottom to top, a composite barrier layer consisting of at least 60 cm of compacted natural or amended soil with a maximum saturated hydraulic conductivity of 1×10^{-7} cm/s in intimate contact with an overlying geomembrane; a drainage layer consisting of at least 30 cm of sand with a minimum saturated hydraulic conductivity of 0.01 cm/s or a layer of geosynthetic material with the same characteristics; and a top vegetation and soil layer consisting of at least 60 cm of soil graded at a slope between 4 and 5 percent with vegetation on an exposed top surface (see figure 2).

The installed compacted clay cover is 1.5 m thick, which basically matches the recommended EPA design as stated above. This cover consists of three layers. The bottom layer is a 60 cm thick compacted soil barrier. The native soil required amendment to meet the saturated hydraulic conductivity requirement for this barrier layer. Laboratory tests determined that a mixture of 6 percent by weight of sodium bentonite with the native soil, compacted wet to achieve a low permeability, would be adequate. A linear low-density polyethylene geomembrane was placed directly on the compacted soil barrier layer to create a composite barrier layer, the purpose of which is to create an impermeable barrier that blocks the infiltration of water. Eight 1 cm^2 defects (puncture holes) were randomly placed in this geomembrane to be representative of a geomembrane installation with average quality control conditions.

Above that is a 30 cm thick drainage layer that minimizes the time any infiltrated water is in contact with the underlying barrier layer by quickly routing the water that has passed through the vegetation layer laterally to collection drains. This layer was constructed of sand and placed directly on the geomembrane.

On top is a 60 cm thick vegetation layer composed of uncompacted soil that provides a medium for vegetation growth and to protect the underlying layers from erosion and freeze-thaw cycles. The vegetative layer allows for storage of infiltrated water that can be removed by evaporation or transpired by vegetation.

All soil used in the construction of the alternative test landfill covers came from excavation done on-site. The materials acquired off-site—such as sand and gravel—were readily available because they are commonly used in construction. The soil for the alternative covers was compacted in as dry a condition as possible to minimize the potential for cracking from desiccation and to allow a larger initial water storage capacity.

Alternative test cover 1 is a geosynthetic clay

Fig. 4 Capillary Barrier

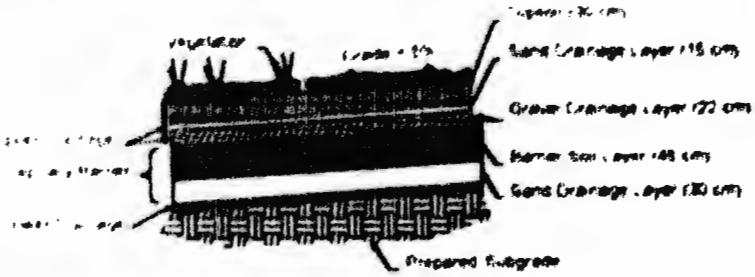


Fig. 5 Anisotropic Barrier

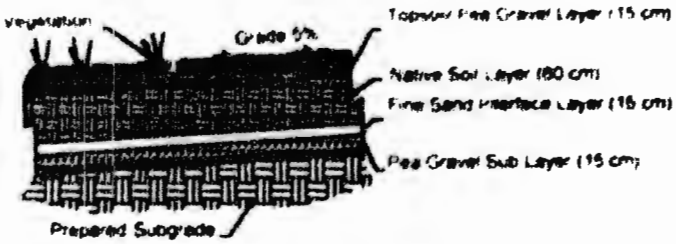
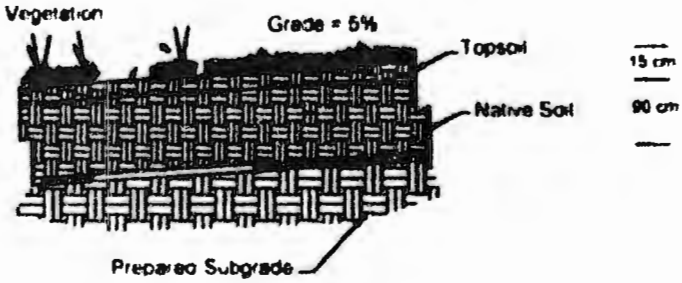


Fig. 6 Evapotranspiration Soil Cover



lined cover (see figure 3) is identical to the traditional compacted clay cover used as baseline test cover 2 except that the expensive and problematic clay barrier layer was replaced with a geosynthetic clay liner or manufactured sheet. The overall thickness of this cover was 90 cm. The cover's component layers from bottom to top consist of a barrier layer (the geosynthetic clay liner membrane covered with a geomembrane that comprises the composite barrier layer), a 30 cm sand drainage layer; a geotextile filter fabric, and a 60 cm vegetation soil layer. The installed geomembrane also included eight 1 cm^2 randomly placed defects similar to those inflicted on the compacted clay cover's geomembrane.

The geosynthetic clay liner consists of two nonwoven fabrics that sandwich a thin layer of bentonite. The liner's hydraulic conductivity was specified by the manufacturer as 5×10^{-9} cm/s.

Alternative test cover 2 is a capillary barrier. This cover system consists of four primary layers from bottom to top: a lower drainage layer, a barrier soil layer, an upper drainage layer; and a topsoil layer (see figure 4). The barrier soil layer and lower drainage layer constitute the capillary barrier. The lower drainage layer is composed of 30 cm of washed clean sand.

The 45 cm barrier soil layer was installed directly on the sand and the upper drainage layers were placed over the barrier soil layer. This upper drainage layer consists of 22 cm of clean pea gravel overlain by 15 cm of clean sand. Finally, a layer of topsoil 40 cm thick was placed on the sand.

Alternative test cover 3 is another capillary barrier system, this one referred to as the anisotropic barrier, that is designed to limit the downward movement of water while promoting its lateral movement. This cover is composed of a layering of capillary barriers.

The cover system contains four layers: a top vegetation layer, a cover soil layer; an interface layer, and a sublayer (see figure 5). The vegetation layer is 15 cm thick and is composed of a mixture of local topsoil and pea gravel. The gravel-to-soil mixture ratio by weight was 25 percent. The gravel was added to assist in minimizing surface erosion caused by runoff. This layer encourages evapotranspiration, allows for vegetation growth, and reduces surface erosion. The native soil cover layer is 60 cm thick. Its function is to allow for water storage and eventual evapotranspiration and to serve as a rooting medium. 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 to collection areas. The sublayer comprises 15 cm of pea gravel. The native soil overlying the sand layer

Manual backup systems are available for use in the event of failure in one or more of the automated measurements systems or to verify the systems' accuracy.

[illegible] capillary barrier while the [illegible] the [illegible] a second capillary break.

Alternative test cover 4, referred to as an evapotranspiration cover, consists of a single vegetated soil layer constructed to represent an optimum mix of soil texture, soil thickness, and vegetation cover. (See figure 6.)

The installed test cover is a [illegible] cm thick monolithic soil cover. The bottom 90 cm of native soil was compacted while the top 15 cm of topsoil was loosely placed. A thin gravel veneer (2 to 4 cm) was placed on the surface after the cover was seeded. The objective of the gravel veneer was to promote vegetation and minimize erosion.

After the covers were constructed, they were drill seeded with native rangeland vegetation. The choice of seed mix was based on finding an acceptable type of native vegetation that would provide adequate coverage during both warm and cool growing seasons. The warm season grasses chosen were *Bouteloua gracilis* (blue grama), *Hilaria jamesii* (galleta), and *Sporobolus cryptandrus* (sand dropseed). The cool season grasses were *Oryzopsis hymenoides* (indian ricegrass) and *Stipa comata* (needle and thread).

The water balance variables obtained with the monitoring systems are precipitation, plus applied water, if any, surface runoff, lateral drainage, soil water storage, and percolation or infiltration. The variables are used to solve for evapotranspiration. All measurements are made with automated monitoring systems to provide continuous data. Manual backup systems are available for use in the event of failure in one or more of the automated measurements systems or to verify the systems' accuracy.

Time-domain reflectometry and an associated data acquisition system are used to provide a continuous record of soil moisture status at various plan locations and depths within each cover profile. Each time-domain reflectometry probe was individually calibrated to achieve the highest degree of accuracy possible. Polyvinyl chloride pipes were installed strategically in the covers as ports so that frequency-domain reflectometry could be used as a backup.

Runoff and erosion are measured on an event basis. Surface runoff is collected with a gutter system located at the bottom of each of the two slope components of each cover. The collected water is routed to instrumentation that quantifies the amount, and a data acquisition system is linked to the instrumentation to automatically record and store the data.

Table 1

Year	Precipitation Volumes Collected (L)	Flux rates (cm/year)				
		Subtitle D	GCL	Subtitle C	Capillary Barrier	Evapotranspiration Barrier
1997 (May 1 - Dec. 31)	[illegible]	10.82	1.81	0.12	[illegible]	[illegible]
1998	[illegible]	4.00	0.30	0.30	[illegible]	[illegible]
1999	[illegible]	3.12	4.31	0.04	[illegible]	[illegible]
2000 (Jan. 1 - Aug. 31)	[illegible]	0.00	0.00	0.00	[illegible]	[illegible]
Average		4.82	1.81	0.13	[illegible]	[illegible]

Table 2

Year	Cover Efficiency (1 - Percolation/Precipitation) (%)				
	Subtitle D	GCL	Subtitle C	Capillary Barrier	Evapotranspiration Barrier
1997	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1998	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1999	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2000	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Average	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

The evapotranspiration cover appears to be leading the way in the third year of testing. This is encouraging because there have been many permit applications for this simple soil cover design for final landfill closures.

Subsurface percolation and interflow are measured, and lateral drainage from each layer is collected using underdrain systems placed at the bottom of each slope component of each cover. The water is routed to measurement instruments that are linked to a data acquisition system. Percolation through the barrier layer within 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. Measurement redundancy is built into the system to reduce the probability of losing data because of equipment failure or power loss and to verify the accuracy of the results. All monitoring instrumentation is housed in a shelter.

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

Attributes of the vegetation on each landfill cover are measured yearly to relate vegetation characteristics to potential changes in erosion and evapotranspiration. Several point frames—which mark where measurements were taken—are used to evaluate total cover, species count, and vegetation biomass.

The data presented in this article are those obtained at the ALCD site between May 1997 and June 2000 and represent the first three years of data collection in a period that will last at least five years.

The measured percolation and precipitation data collected so far are presented in table 1. The first year in which monitoring was done (the second half of 1997) was relatively wet, whereas the two final years (1999 and 2000) were extremely dry. The percolation data were converted into a flux rate—the rate at which moisture moves through the landfill cover—for each cover.

The first year of testing revealed that the RCRA subtitle D cover generally used for municipal landfills was by far the worst design. Generally, a flux rate of 3 mm/year is a good target for a cover design. The RCRA D cover exceeded this rate in each year except for 2000, which was a year of extreme drought and is therefore not representative. The cover does, however, seem to be improving as the vegetation on it matures.

The only cover that appears to be degenerating with time is the geosynthetic clay liner cover. Four hypotheses for this are currently being tested in side experiments at the site: The bentonite within the geosynthetic clay liner has desiccated and does not fully repair itself after rewetting, the soils in the Southwest or dry environments are susceptible to ion exchange problems that increase the permeability of the liner; the liner is susceptible to damage from root intrusion; and the liner is susceptible to damage during construction. The results will be available once the tests are completed.

The evapotranspiration cover appears to be leading the way in the third year of testing. This is encouraging because there have been many permit applications for this simple soil cover design for final landfill closures. This test reveals that in dry environments a well-designed simple soil cover is not only the cheapest alternative but also the most effective at controlling infiltration. The EPA is currently rewriting its RCRA and Comprehensive Environmental Response, Compensation, and Liability Act landfill cover design guidelines so as to outline what constitutes an effective design. Guidance will be provided on both capillary barriers and evapotranspiration covers.

Estimates of the efficiency of each cover are listed in table 2. In essence, the efficiency value quantifies how well the covers prevent precipitation moisture from infiltrating into the underlying waste.

The ALCD project is expected to provide performance and cost data for landfill cover components and systems that are more applicable to climatic conditions in the western part of the country than current prescriptive designs. 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 provide those responsible for landfill cover designs with a defensible basis for moving from designs suited for the eastern United States to those that will give better results on the other side of the country.

The probable outcome of this demonstration is the acceptance of alternative cover designs that cost much less but are more effective than conventional designs. Given the vast number of buried waste sites to be covered, the payoff from this demonstration may wind up saving taxpayers billions of dollars. ▼

Stephen F. Dwyer is a principal investigator with the Environmental Restoration Technology Department of Sandia National Laboratories, Albuquerque, New Mexico.

REFERENCE SET FOR TECHNICAL AREA 54
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Documents use ER ID numbers to track reference items through its Records-Processing Facility. Because ER ID numbers are issued on an ongoing basis throughout the entire RRES-R Program, gaps may be present in the numbers included in this table of contents.

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