

# CONTROL OF WATER INFILTRATION INTO NEAR SURFACE LLW DISPOSAL UNITS- PROGRESS REPORT ON FIELD EXPERIMENTS AT A HUMID REGION SITE, BELTSVILLE, MARYLAND

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## ABSTRACT

Three kinds of waste disposal unit covers or barriers to water infiltration are being investigated. They are: (1) resistive layer barrier, (2) conductive layer barrier, and (3) bioengineering management. The resistive layer barrier consists of compacted earthen material (e.g. clay). The conductive layer barrier consists of a conductive layer in conjunction with a capillary break. As long as unsaturated flow conditions are maintained the conductive layer will wick water around the capillary break. Below grade layered covers such as (1) and (2) will fail if there is appreciable subsidence of the cover. Remedial action for this kind of failure will be difficult. A surface cover, called bioengineering management, is meant to overcome this problem. The bioengineering management surface barrier is easily repairable if damaged by subsidence; therefore, it could be the system of choice under active subsidence conditions. The bioengineering management procedure also has been shown to be effective in dewatering saturated trenches and could be used for remedial action efforts. After cessation of subsidence, that procedure could be replaced by a resistive layer barrier, or perhaps even better, a resistive layer barrier/conductive layer barrier system. This latter system would then give long-term effective protection against water entry to waste and without institutional care. These various concepts are being assessed in six large (70' x 45' x 10' each) lysimeters at Beltsville, Maryland.

## INTRODUCTION

Infiltration of water into the waste is the foremost problem associated with near surface disposal of LLW. Up to this time, disposal unit covers have generally been constructed from soil materials. In the humid areas, these soil or clay covers have generally proved less than satisfactory; often the cover itself has served as the principal pathway for water entry into the waste (1). Water infiltrating to buried wastes, contacting the wastes, and then exiting the area can reasonably be expected to be the most important of radionuclide transport agents. Some radionuclides, such as tritium present as tritium oxide, and those present in anionic form, will essentially move with the flow of water; others present as multivalent cations will move much more slowly, but all will move to a greater or lesser degree. Clearly then, it is advantageous to reduce water infiltration to buried waste to as low a level as reasonably achievable. It is the purpose of this work to examine and demonstrate various approaches of achieving that goal.

Three kinds of waste disposal unit covers or barriers are being investigated in this work:

### 1. Resistive Layer Barrier

### 2. Conductive Layer Barrier

### 3. Bioengineering Management

The resistive layer barrier is the well known compacted clay layer and depends on compaction of permeable porous materials to obtain low flow rates. A simplified model is shown in Fig. 1. Flow through porous media is described by Darcy's law (2). Investigations on flow through such layers

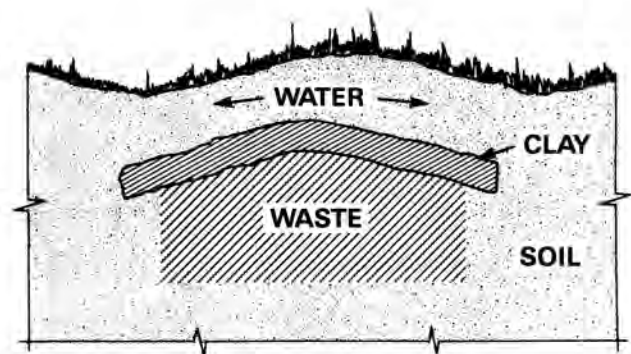


Fig. 1. Resistive Layer Barrier.

have gone on for over 100 years, so further progress in this area can be expected to be slow.

The conductive layer barrier (1) is a special case of the capillary barrier (3). Use is made of the capillary barrier phenomenon not only to increase the moisture content above an interface, but to divert water away from and around the waste. During such diversion water is at all times at negative capillary potential or under tension. A simplified model is shown in Fig. 2.

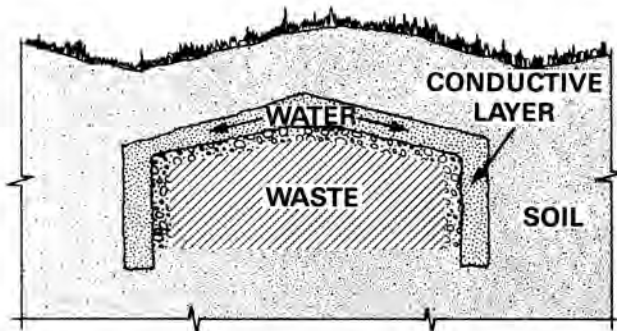


Fig. 2. Conductive Layer Barrier.

This system consists of a porous media underlain by a capillary break (rock layer). Infiltration barriers such as a conductive layer barrier or a clay layer barrier (or a combination thereof) must fail if subjected to substantial shearing caused by waste subsidence. Reestablishment of a layered system after subsidence failure is a difficult undertaking and is exacerbated by increasing complexity of the layered system.

**Caution-Buried Multi-layer Covers Must Fail If There Is Appreciable Subsidence**

The failure potential of in-ground layered systems during the subsidence period argues for development of an easily repairable surface barrier for use during that period. To that end a procedure called "bioengineering management" was developed (4). The bioengineering management technique utilizes a combination of engineered enhanced run-off and moisture stressed vegetation growing in an overdraft condition to control deep water percolation

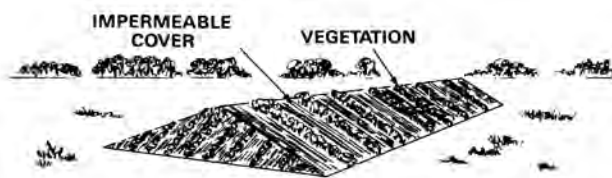


Fig. 3. Bioengineering Management.

through disposal unit covers. An artist's conceptual drawing is shown in Fig. 3.

**EXPERIMENTAL AND DEMONSTRATION**

In this section we will discuss experiments being conducted in large-scale lysimeters at a humid region site in Beltsville, MD (see Table I).

**TABLE I**  
Design Type and Completion Dates of Experimental Lysimeters Located at Beltsville, MD

Lysimeter		Date Completed
1	Bioengineering Management	5/87
2	Bioengineering Management	5/87
3	Vegetated Crowned Soil Cover	5/87
4	Rip-Rap over Resistive Layer Barrier	10/88
5	Resistive Layer Barrier over Conductive Layer Barrier	1/90
6	Vegetation over Resistive Layer Barrier	4/89

**Bioengineering Management**

In this section we will examine a procedure where the necessary run-off is provided by features installed at or above the soil surface rather than within the profile. The procedure has been described by Schulz et al. (4) and was designated bioengineering management. The principle advantage of the bioengineering management system is that subsidence can be easily managed by relatively simple, inexpensive maintenance of the above ground features rather than difficult reconstruction of below ground layers. It should be noted, that after a sufficient passage of time so that the organics have decayed out and the waste containers have completed failure, subsidence will cease and a layered system could be then installed which could last over geologic time periods.

In essence, the "bioengineering management" technique utilizes a combination of engineered enhanced run-off and stressed vegetation in an overdraft condition to control deep water percolation through disposal unit covers. To describe it further: if a waste burial site is selected so that incoming subsurface flow is negligible, then precipitation is the sole source of input water. In a simplified model, that water has three possible fates: (1) evapotranspiration, (2) run-off, and (3) deep percolation. Evapotranspiration has a definite limit governed by energy input. Ideally, deep percolation should be zero, leaving only the run-off component available for unlimited manipulation. Positive control of run-off becomes difficult with the use of compacted porous media trench caps as the sole barrier to water infiltration. The compacted material tends to become

more permeable with the passage of time, due to fractures caused by waste subsidence and from the inexorable process of root growth followed by death and decay of the roots, thus creating water channels. Evapotranspiration is then not adequate to use all of the infiltrating water, and water percolates downward to the waste. As stated before, evapotranspiration has a theoretical maximum dictated by solar energy input to the system; only run-off remains available for nearly unlimited management. This run-off can be surface or subsurface as long as it occurs before water reaches the waste.

Surface run-off can be managed to as high as 100 percent (perfect leak-proof roof, expensive and hard to guarantee). Alternately, adequate but not total run-off can be engineered rather inexpensively by using an impermeable ground cover over part of the surface to achieve high and controlled levels of run-off. Vegetation planted between areas of impermeable cover will extend over the cover to intercept incoming solar energy to evaporate water. Roots will extend under the cover in all directions to obtain water.

Such a system can be visualized by conceiving in one's mind a supermarket parking lot where trees are planted in islands among an extensive paved area with the islands having curbing around them. Utilizing this concept, it should be possible, by combining engineered run-off with vegetation, to maintain the soil profile in a potential overdraft condition on a yearly basis.

Initial investigations of the bioengineering management technique were carried out in lysimeters at Maxey Flats, KY. Results obtained in seasonal 1984-85 and 1985-86 were reported by O'Donnell et al. (5). In that work a fescue grass crop was used with an engineered cover of stainless steel. Following seasonal 1985-86 the grass cover was removed, a new stainless steel engineered cover was con-

structed and Pfitzer junipers were planted in the lysimeters. After establishment of the junipers, percolation data was again collected in 1988 and reported by Schulz et al. (6). The performance of the woody junipers was excellent in preventing deep percolation of water in the lysimeter.

The encouraging initial results obtained in the Maxey Flats lysimeter experiment has led to the establishment of a large scale field demonstration at Beltsville, Maryland. Fig. 4 shows the placement of the experimental lysimeters and Fig. 5 is a photograph of lysimeter 1, bioengineering management, taken in January 1990, three years after planting of the Pfitzer junipers. Alternating panels of aluminum and fiber glass were used as the hard cover. These plots or lysimeters are 70 ft long by 45 ft wide and the bottoms are 10 ft below grade. Figure 6 shows a side view of construction details of lysimeters 1 and 2 (bioengineering management). The only differences between the two was the initial level of the water tables. The water table was 90 cm above the bottom in lysimeter 1 and 190 cm above the bottom in lysimeter 2. In addition to the two bioengineered lysimeters, two reference lysimeters were initially constructed. The reference lysimeters were similar except that they were merely cropped with fescue grass. They were labeled lysimeter 3 and 4. No hard cover was present but surface slopes were similar. Performance data of the reference lysimeters are given in Fig. 7.

The water table in the two reference plots or trenches, lysimeters 3 and 4, i.e. the plots cropped to fescue, rose until near the surface. At that time pumping of water from the water table was initiated to keep the plots (trenches) from running over. The graphs of the water tables in the bioengineered plots (lysimeters 1 and 2) show an entirely different story as evidenced in Fig. 8. Here, in both cases, the water table has been eliminated. It appears that the bioengineering approach not only could be used to prevent water infiltration to a disposal unit; it also could be used for a remedial action in dewatering existing problem sites such as Maxey Flats.

On February 4, 1988, lysimeter 4 was pumped out to prevent overflow. It was then discontinued as a reference lysimeter and converted to a rock surfaced resistive layer barrier plot. Lysimeters 1 and 2 (bioengineered) and lysimeter 3 have been continued. A summary of run-off, evapotranspiration and pumping from those three lysimeters is given in Fig. 9.

Figure 9 shows that there was very little run-off from the grass covered plot. The bulk of the precipitation was disposed of by evapotranspiration by the fescue crop but this was not adequate to prevent rise of the water table. During the past year about 74% of the precipitation was disposed of as run-off in the bioengineering plots and only about 26% as evapotranspiration. However, that combina-

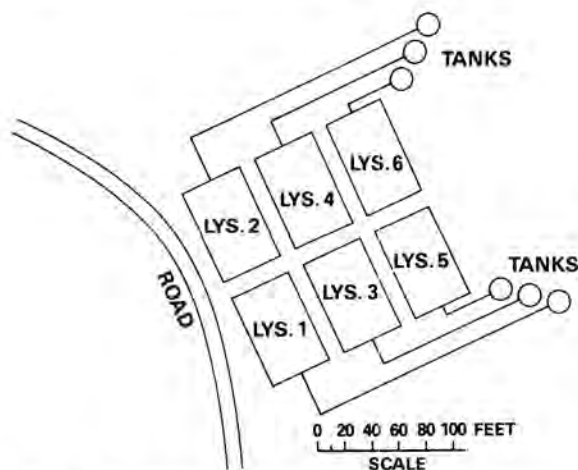


Fig. 4. Plan View Showing Placement of Experimental Lysimeters at Beltsville, MD.





Fig. 5. Bioengineering Plots at Beltsville. Photo Taken in January of 1990, Three Years After Planting of Pfitzer Junipers. Run-off is 74% of Precipitation.

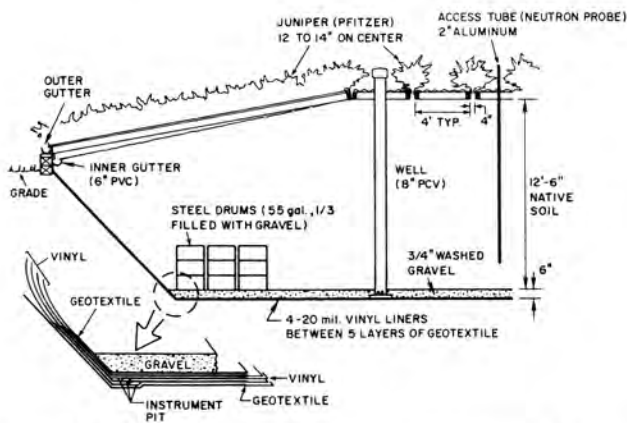


Fig. 6. Side View of Bioengineered Lysimeter. Surface Run-Off is Collected from Both Engineered Surface and Soil Surface. Soil Moisture Content is Measured with Neutron Probe. Water Table is Measured in Well.

tion eliminated the water table as shown previously in Fig. 8.

**Resistive Layer Barrier**

As previously mentioned, on February 4, 1988, lysimeter 4 was pumped out, discontinued as a reference lysimeter,

WATER TABLES  
HEIGHT ABOVE BOTTOM OF LYSIMETER

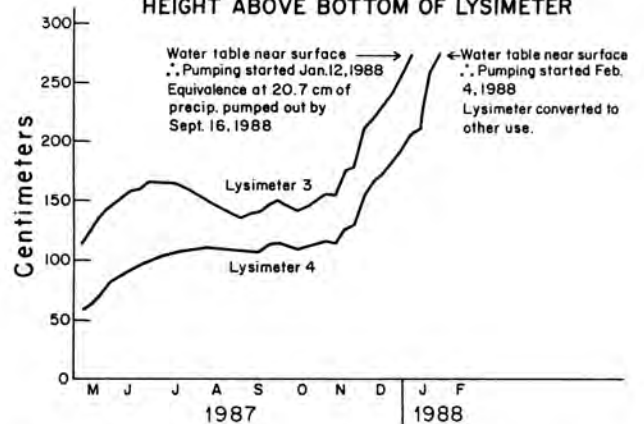


Fig. 7. Water Table vs. Time in Reference Lysimeters. The Crowned Surface is Cropped with Fescue Grass. Water Table Increased with Time until Pumping of Water Table was Necessary to Keep Trench from Running Over. Surface Run-Off was 8% of Precipitation.

and converted to a rock surfaced resistive layer barrier plot. The primary reason for constructing that particular cover is the likelihood of such covers being used for uranium mill tailings. An end view of that plot or lysimeter is shown in Fig. 10. This lysimeter was completed in the fall of 1988 and data collection, i.e., measuring performance, has begun.

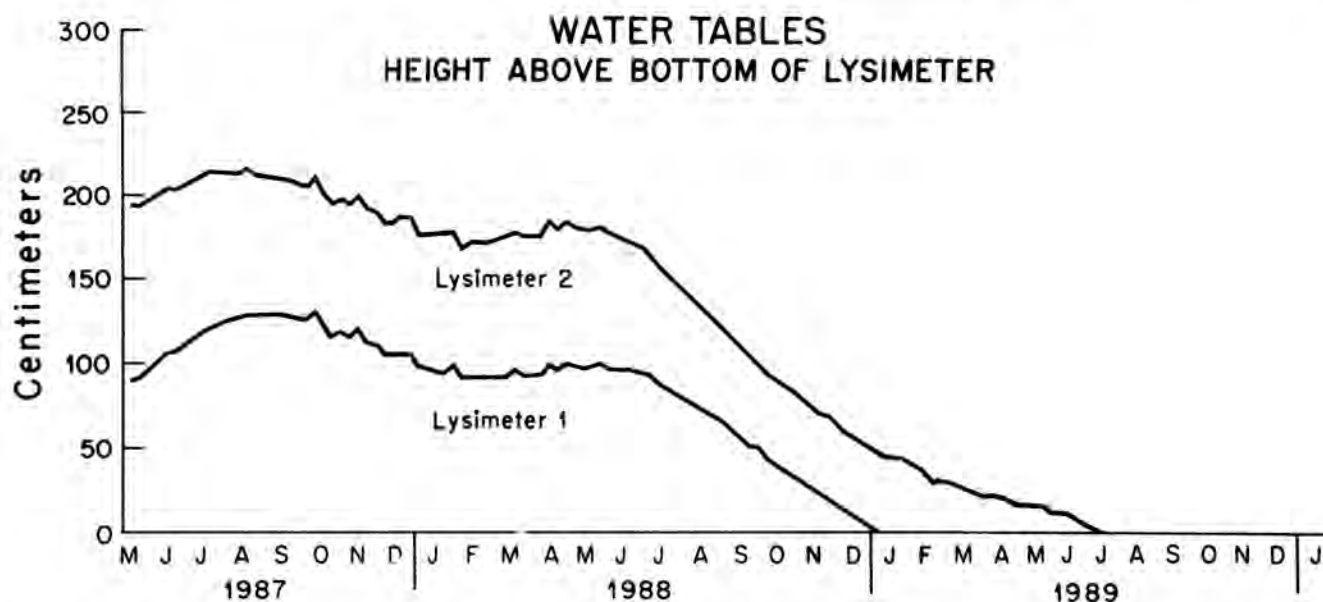


Fig. 8. Water Table vs. Time in Bioengineered Lysimeters. Decline of Water Table Levels with Passage of Time Shows Bioengineered Covers were Very Effective in Preventing Water Percolation. Elimination of Water Table Shows that this Procedure Could be Used for Remedial Action ("drying out") of Existing Water Logged Burial Sites. Contrast this with Fig. 7.

The most important information to be gained here will be the relative weighing of the advantages and disadvantages of rock surface vs. a vegetated surface. Performance of that lysimeter during 1989 is given in Fig. 9. So far, the clay layer has operated perfectly; no measurable water has percolated through the clay layer to the pan shown in the diagram.

In addition to the UMTRA or rock surface-resistive layer barrier plot, construction of a vegetated resistive layer barrier plot was carried out. The primary purpose of this plot is for comparative measurements. Essentially this plot is similar to the rock surfaced plot except that topsoil replaces the rock layer and the plot is planted to fescue grass. Less than one year's data has been collected to date; therefore, results are not shown in Fig. 9, but so far there has been no leakage through the clay layer to the pan. A diagram of this plot is given in Fig. 11.

#### Conductive Layer Barrier

If we consider the case of water flowing downhill in an unsaturated porous media we have the case shown in Fig. 12. The "holes" shown in the diagram could be a rock layer affording a capillary break or capillary discontinuity. This is illustrated in Fig. 13. Under appropriate conditions, water everywhere in these cross-sections will be under tension and there will be no leakage. This might then serve as an excellent means of protecting waste by conducting water around the waste. Figure 12 simulates a conducting porous media such as a fine sandy loam soil smoothly laying on top of a rock layer. Problems with water flow under saturated con-

ditions will certainly arise where a less than smooth surface ends up being constructed as depicted in Fig. 14. That is, what happens if imperfections are constructed so that "pockets" of soil extend down into the rock layer? Figure 14 represents that case. Again, there will be no leakage, provided conditions are such that the water in all parts of the conductive layer remain under tension.

The big question is, can conditions required to maintain the necessary soil water tension be practically maintained while using this procedure to effectively protect waste disposal units? To answer this question an apparatus schematically depicted in Fig. 15 was constructed.

The apparatus constructed to make the necessary measurements were called soil beams. Several "mini-soil beams" were constructed for use in the laboratory so a variety of candidate conductive layer materials could be quickly evaluated. A photograph of a laboratory scale "mini-soil beam" is shown in Fig. 16.

A number of materials were evaluated using the mini-soil beams. It was quickly established that it would be necessary to construct a resistive layer barrier above the conductive layer barrier to have a practical system. The standard was set that the resistive layer barrier have an easily achievable conductivity of not greater than 10-6 cm/sec. On this basis it was found that soil material such as fine sandy loam could provide an effective conductive layer barrier. That is, conduct around the waste 100% of water percolating through the resistive layer. However, the mea-

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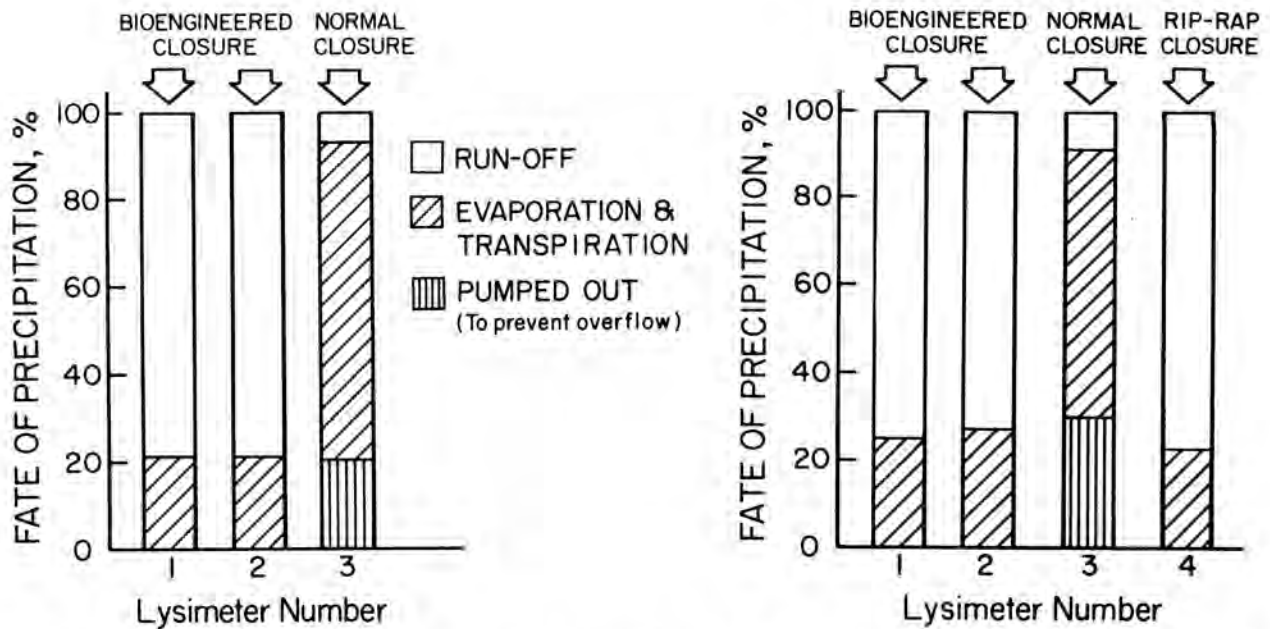


Fig. 9. Fate of Precipitation in Bioengineered, Reference, and UMTRA Lysimeters. Pumping to Prevent Overflow was Required in Reference Lysimeter but Not Needed in Bioengineered or UMTRA Lysimeters.

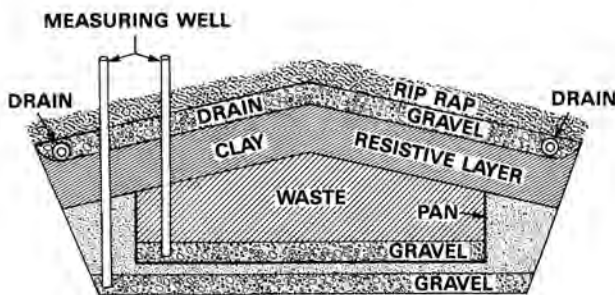


Fig. 10. Resistive Layer Barrier with Rock Cover. No Vegetation. Possible UMTRA Cover. Possible Advantages Over Vegetated Resistive Layer Barrier. (1) Clay Layer Remains Wet and More Efficient Barrier to Escape of Radon. (2) Initially, Superior Erosion Protection, and (3) No Root Penetration of Waste. Major Disadvantage: No Plant Transpiration, therefore Requiring a Clay Barrier of Extremely Low Hydraulic Conductivity. For Clarity, Most Instrumentation and Some Details Not Shown.

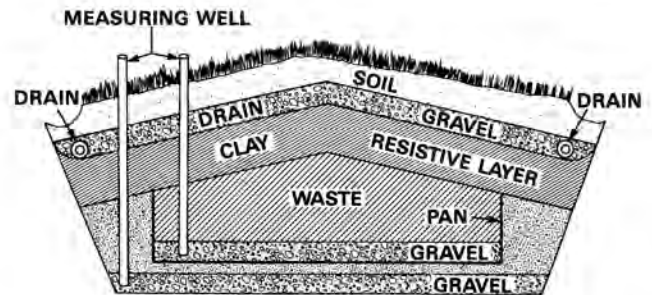


Fig. 11. Resistive Layer Barrier with Grass Cover. Similar to UMTRA Cover but Has Vegetation in Place of Rip-Rap. See Fig. 10.

FLOW UNDER NEGATIVE MATRIC POTENTIAL

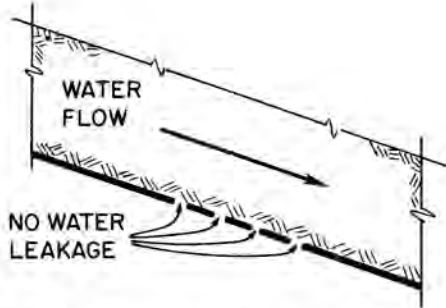


Fig. 12. Water Flow in an Unsaturated Porous Media. If a Drop of Water were to be Placed at One of the Holes Shown, it Would Flow Upward into the Soil.

FLOW UNDER NEGATIVE MATRIC POTENTIAL

CONDUCTIVE LAYER IMPERFECTLY CONSTRUCTED

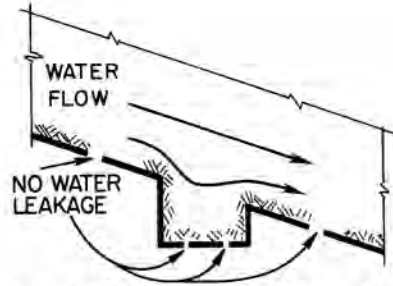


Fig. 14. Imperfectly Constructed Conductive Layer with "Pocket" Extending Down into Rock (or Capillary Break) Layer. No Leakage if Conditions Required to Maintain Tension are Met.

WATER PRESSURE DISTRIBUTION (VERTICAL)

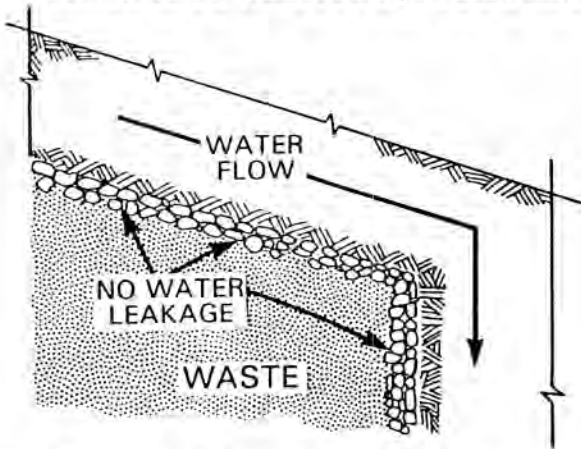


Fig. 13. Substitution of Rock Layer for Holes Shown in Fig. 12. Voids Between Rocks Act Exactly like Holes Shown in Fig. 12 in Forming a Capillary Discontinuity, therefore, Preventing Leakage Downward Under the Influence of Gravity.

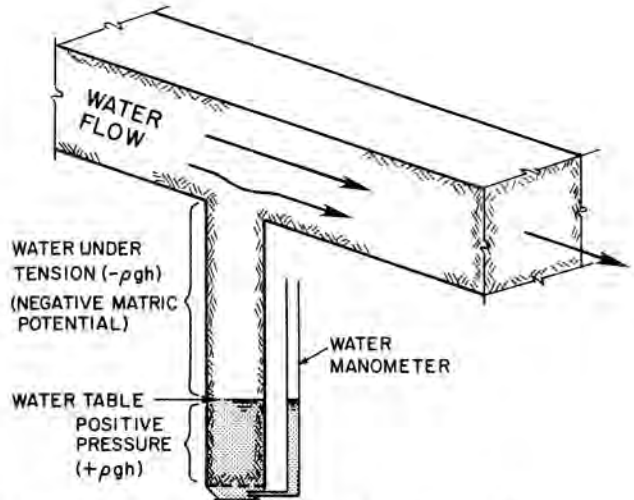


Fig. 15. Schematic of Laboratory Apparatus for Measurement of Water Tension Measurement with Different Materials and Varying Flow Rates.

measurements showed that such materials would not provide the desired (factor of 10) safety margin.

Further investigations turned up a material, diatomaceous earth, that would fit these requirements. Measurements of tension vs. distance of flow are shown in Fig. 17.

The results of this experiment in the 4.5 ft long beam suggest that as long as the flow rate is no greater than  $4.2 \times 10^{-4}$  cm/sec the soil water will remain under tension regardless of the soil beam length. These results show that with the use of diatomaceous earth for the conductive layer and following the easily achievable standards set above for the resistive layer, it should be possible to construct a barrier that would allow no water leakage to a waste disposal unit. However, before final selection of the diatomaceous earth as the conductive layer material was made, it was felt prudent to conduct tests in a large scale soil beam. A large beam

was constructed and used for this purpose. The large beam is shown in Fig. 18 and has a soil beam length of 21 ft. As shown in Fig. 19, a matric potential of about -15 to -20 cm of water is maintained over the entire 21 ft length of the beam when the flow rate does not exceed  $3.1 \times 10^{-4}$  cm/sec.

The studies carried out in the large soil beam verified closely the data obtained in the mini-beam. Accordingly, diatomaceous earth was used as the conductive layer material in the demonstration lysimeter (lysimeter 5). It has been estimated that purchasing and shipping the diatomaceous earth to a job site any place in the U.S. will add about \$0.50



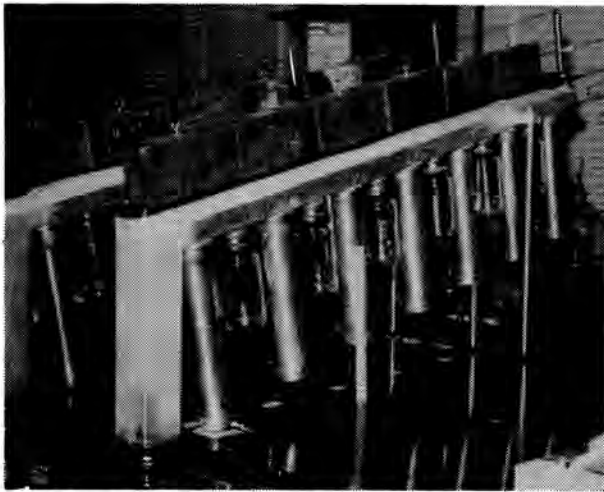


Fig. 16. Mini-soil Beam Used for Evaluation of Materials for Possible Use in Conductive Layer Barrier Application. This Soil Beam has a Total Length of 4.5 ft.

SOIL WATER TENSION AT VARIOUS FLOW RATES, (cm/sec)  
TENSION vs HORIZONTAL DISTANCE FROM DISCHARGE POINT

DIATOMACEOUS EARTH (P-171)

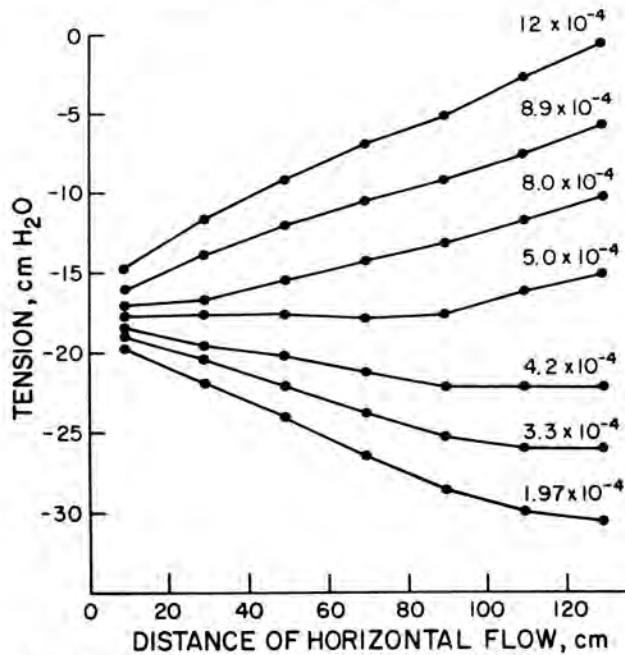


Fig. 17. Soil Water Tension at Various Flow Rates. Tension vs. Horizontal Distance from Discharge Point. Results Suggest that at Rates of  $4.2 \times 10^{-4}$  cm/sec or Less, Water Would Remain under Tension at any Beam Length.

per cubic feet of disposed waste. This is over the cost of using locally obtained soil and based on waste being 10 ft. deep.



Fig. 18. Large Soil Beam Used for Final Selection of Diatomaceous Earth as Conductive Layer Material.

SOIL WATER TENSION AT VARIOUS FLOW RATES, (cm/sec)  
TENSION vs HORIZONTAL DISTANCE FROM DISCHARGE

DIATOMACEOUS EARTH (P-171)

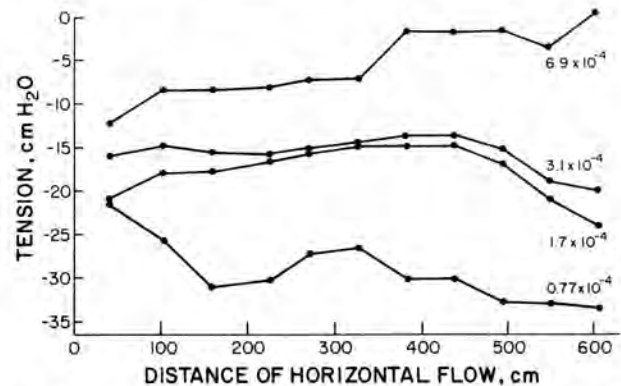


Fig. 19. Soil Water Tension at Various Flow Rates and as Determined Over a 21 ft. Long Flow Distance. At -15 to -20 cm Matric Potential Water Flow Rate is Approximately  $3 \times 10^{-4}$  cm/sec.

After the time-consuming task of selecting the conductive layer material was accomplished, a resistive layer barrier over a conductive layer barrier was constructed in lysimeter 5. It was completed in January 1990. A local clay from Beltsville, Maryland, the Christiana clay, was selected as the resistive layer barrier. Testing has shown this material



more than meets specifications. A cross section of the cover system is shown in Fig. 20.

**APPLICATION**

The three procedures described in the Introduction may be used singularly or in combination to protect disposal units from percolating water. The principles apply equally to above-ground or below-ground disposal. For example, a combination of covers [1] and [2] described in the introduction of this article could be ideal for a stabilized shallow land burial facility whether it is above or below ground; e.g., the subsurface disposal could be in below-ground vaults and the above-ground disposal unit could be earth-mounded concrete bunkers. A drawing showing a combination of a resistive layer over a conductive layer in a "tumulus" or above-ground application is shown in Fig. 21. The resistive (clay) layer is the primary barrier. The small amount of water passing through the clay layer will be diverted around the waste by the conductive layer. This cover over the waste can be, in theory, 100% effective. A resistive layer alone must leak somewhat due to the nature of construction of compacted porous material (clay). The bioengineering concept could be advantageous for either a tumulus or shallow land burial unit that would be likely to exhibit subsidence. If desired, and after subsidence had ceased, covers 1 or 2 could be constructed with geological materials to give extremely long-term isolation without further maintenance.

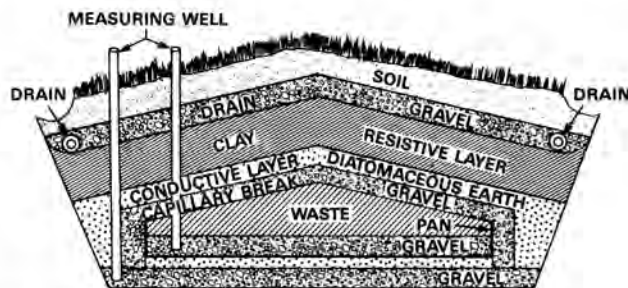


Fig. 20. Combination Resistive Layer Barrier over a Conductive Layer Barrier. The Clay Barrier (Resistive Layer Barrier) Needs Only to Provide Protection to Approximately  $10^{-6}$  cm/sec. Conductive Layer Barrier of Diatomaceous Earth will Readily Transport Percolating Water Around Waste.

**ACKNOWLEDGEMENTS**

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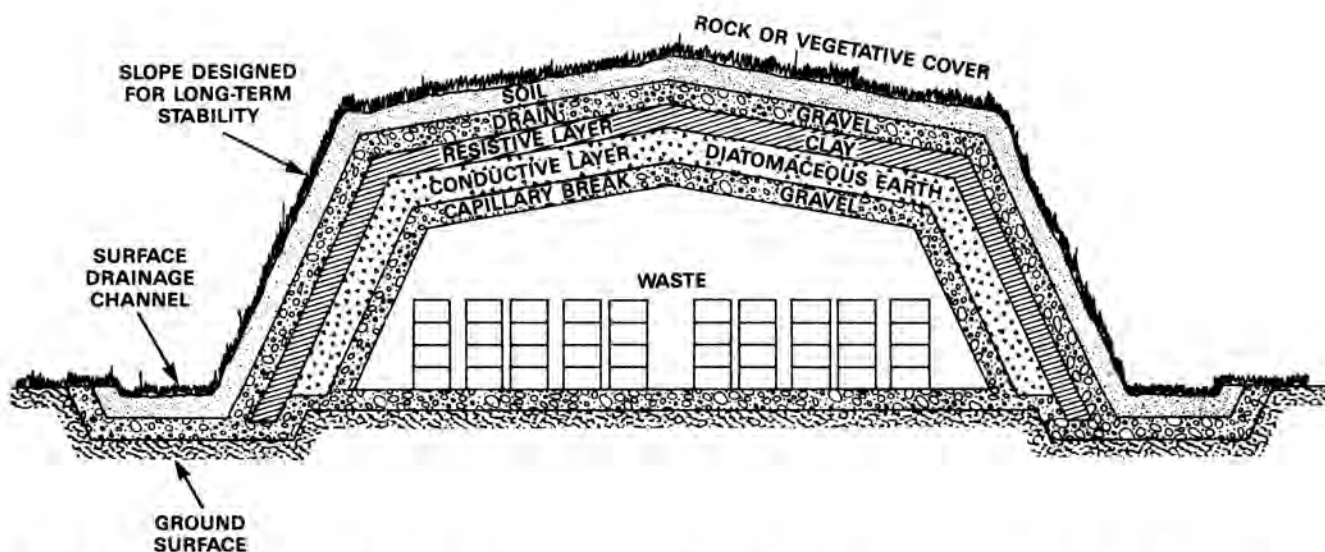


Fig. 21. Resistive Layer Barrier Overlying a Conductive Layer Barrier. Used in an Aboveground or "Tumulus" Application. Any Water Leaking Through the Clay Layer Will be Transported Around the Waste by the Conductive Layer.

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