United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/2-79-136
August 1979

Research and Development

Flue Gas Cleaning Sludge Leachate/ Liner Compatibility Investigation

Interim Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL PROTECTION TECHNOLOGY series. This series describes research performed to develop and demonstrate instrumentation, equipment, and methodology to repair or prevent environmental degradation from point and non-point sources of pollution. This work provides the new or improved technology required for the control and treatment of pollution sources to meet environmental quality standards.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

EPA-600/2-79-136
August 1979

FLUE GAS CLEANING SLUDGE LEACHATE/LINER COMPATIBILITY INVESTIGATION:

Interim Report

by

Clarence R. Styron III
Zelma B. Fry, Jr.
Geotechnical Laboratory
U. S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi 39180

Interagency Agreement No. EPA-IAG-D5-0785

Project Officer

Robert E. Landreth
Solid and Hazardous Waste Research Division
Municipal Environmental Research Laboratory
Cincinnati, Ohio 45268

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
CINCINNATI, OHIO 45268

DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory and the U. S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of the natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollution discharges from municipal and community sources for the preservation and treatment of public drinking water supplies and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research, a most vital communication link between the research and the user community.

This is an interim report presenting the results of physical tests and analyses of materials tested as liners for industrial waste. The tests followed 12 months inundation in actual wastes to simulated depths of 30 ft.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This project was initiated to study the effects of two industrial waste materials on 18 items used to contain these wastes. Seventy-two test cells, 1 ft in diameter and 2 ft high, were fabricated. Ten items were mixed with a clayey silt and compacted in the bottom 6 in. of the test cell; six spray-on and two prefabricated membrane items were placed over 6 in. of compacted soil. Four gallons of sludge were added to each test cell and enough tap water to bring the liquid to within 4 in. of the top of the test cell. Each test cell was covered and pressurized to simulate 30 ft of head.

This report lists and discusses the data following 12 months of inundation of each item with both sludges. Portland cement, cement plus lime, and C400 when mixed with the soil resulted in a significant reduction in permeability.

This report was submitted in partial fulfillment of the Interagency Agreement "FGD Waste Leachate/Liner Compatability Studies" IAG-D5/6-0785 between the U. S. Environmental Protection Agency (EPA) and the U. S. Army Engineer Waterways Experiment Station (WES). This report covers the period from April 15, 1975, through September 30, 1977. A subsequent report will include a 24-month data series and cost data where appropriate.

CONTENTS

FIGURES

TABLES

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

ASTM -- American Society for Testing and Materials
avg -- averages
°C -- degrees Celsius
cm/sec -- centimeters per second
cu ft -- cubic feet
diam -- diameter
EPA -- Environmental Protection Agency
°F -- degrees Fahrenheit
FGD -- flue gas desulfurization
ft -- foot/feet
gal -- gallon(s)
G_s -- specific gravity
hp -- horsepower
in. -- inch
lb/cu ft -- pounds per cubic foot
mg/l -- miligrams per liter
ML -- clayey silt
OD -- outside diameter
oz -- ounces
oz/sq yd -- ounces per sq yd
ppm -- parts per million
psi -- pounds per square inch
psig -- pounds per square inch gage
PVC -- polyvinyl chloride
SM -- silty sand
SLT -- standard laboratory techniques
TCA -- test cell apparatus
UC -- unconfined compression
USCS -- Unified Soil Classification System
WES -- Waterways Experiment Station

SYMBOLS

A -- area
As -- Arsenic
B -- Boron
Be -- Beryllium
Cd -- Cadmium
Cn -- Cyanide
Cr -- Chromium
Cl -- Chloride
Cu -- Copper

D	--	diameter
H	--	height
Hg	--	Mercury
i	--	average hydraulic gradient during t
Mg	--	Magnesium
Mn	--	Manganese
Ni	--	Nickel
NO_2, N	--	Nitrogen Nitrite
NO_3, N	--	Nitrogen Nitrate
Pb	--	Lead
Q	--	quantity of leachate collected
Se	--	Selenium
SO_3	--	Sulfite
SO_4	--	Sulfate
t	--	time period during collection of leakage
V	--	Vanadium
Zn	--	Zinc
ΔH	--	change in height

METRIC UNITS OF MEASURE

Multiply	By	To Obtain
cubic feet	0.028317	meters
Fahrenheit degrees*	5/9	Celsius degrees or Kelvins*
feet	0.3048	meters
gallons (U. S. liquid)	3.785412	cubic decimeters
gallons per square yard	4.5273	cubic decimeters per square meter
inches	25.4	millimeters
mils	0.0254	millimeters
ounces (U. S. fluid)	29.57353	cubic centimeters
ounces (mass) per square yard	33.90575	grams per square meter
poises (absolute viscosity)	0.1000	pascal seconds
pounds (mass)	0.4535924	kilograms
pounds (force) per square inch	6894.757	pascals
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
pounds (mass) per gallon (U. S. liquid)	119.826	kilograms per cubic meter
tons (2000 lb, mass per acre)	0.22417	kilograms per square meter

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9)(F - 32). To obtain Kelvin (K) readings, use: K = (5/9)(F - 32) + 273.15.

ACKNOWLEDGMENTS

The cooperation of Drs. Larry W. Jones and Philip G. Malone, Environmental Laboratory, WES, in providing an analysis and discussion of the chemical analysis, respectively, is gratefully appreciated.

Special thanks are also directed to Mr. Gerald T. Easley, Geotechnical Laboratory, WES, who designed the test cell and ancillary equipment and supervised all procurement and fabrication.

The authors wish to thank Messrs. Robert E. Landreth and Norbert B. Schomaker for their support and guidance during this phase of the subject project.

SECTION 1

INTRODUCTION AND OBJECTIVES

The industrialization of this country has had a very significant impact on the environment. Many industries produce wastes that may be highly toxic to the environment if proper controls are not used. As the volumes of these wastes increase, disposal problems are multiplied both in availability of land space and economics dictating development of new disposal technology. The Environmental Protection Agency's "Report to Congress on Hazardous Waste Disposal" in 1973 (1) concluded that the then existing management of hazardous wastes was generally inadequate and that the public health and welfare are now threatened by the uncontrolled disposal of such waste materials into the environment.

The potential environmental impact is the contamination of ground and surface waters, which can occur from improperly located, designed, or operated disposal sites. The potential exists because within a disposal site various physical, chemical, and biological processes occur from water or fluid percolating through the wastes, resulting in a leachate potentially hazardous to contamination of the groundwater. Controlling the leachate by lining the disposal area with an impervious material could be a solution to the problem, and it would allow the utilization of more sites for disposal areas. The use of liners for such purposes is not a new concept. However, there is a lack of knowledge concerning the compatibility of liner materials subjected to certain toxic wastes and particularly the life expectancy of the liners. In this respect, the Environmental Protection Agency (EPA) needs considerably more information in order to supply guidance and possible future regulation for use of liners for waste disposal areas.

This study was undertaken with the following objectives:

a. To determine the compatibility of liner materials with flue gas desulfurization (FGD) sludges and associated liquors and leachates.

b. To estimate the length of life for the liners.

c. To assess the economics involved with the purchase and placement (to include construction) of various liner materials.

To realize the study objectives, the liner materials were subjected to a simulated 30-ft* head (depth) of sludge, as would be expected in disposal ponds.

---

*A table for converting U.S. customary units of measure to metric (SI) units is given on page xii.

This interim report describes the following procedures:

a. The methodology and research approach.

b. The construction of the test cells and ancillary equipment.

c. The selection of the various liners and wastes (sludges).

d. The preparation of the liners and sludges and installation in the test cells.

e. Physical properties of the liners and chemical analyses of the sludges and leachates for zero time (unexposed) and for a 12-month exposure period.

The final report will present the results after the liners have been exposed to the sludges for a 24-month exposure period, along with estimates of liner life and an economic assessment of the various liners.

SECTION 2

SUMMARY

A total of 72 special test cells were constructed to study the compatibility of 18 liner materials and two selected FGD sludges. Devices were installed to collect the leachate from each test cell for quantity of leakage determination, rate of leakage determination (permeability), and storage for subsequent chemical analysis. The test cells were pressurized to simulate a disposal area approximately 30 ft deep. Physical tests of the 18 liner materials were conducted before exposure to the FGD sludges and again after 12 months exposure. These same tests will be conducted after 24 months exposure.

Five of the admix liner materials, which were Portland cement, lime, Portland plus lime, C400, and CST, were tested in unconfined compression (UC) following 12 months exposure to both sludges, and the UC values were approximately double the zero time (control) values. The asphaltic concrete liner exhibited extensive cracks whereas TACSS 020 and 025 suffered decreases in UC. Guartec UF and M179 proved incompatible with either sludge type and the testing of these two products was discontinued. The breaking strength of the spray-on and membrane liners decreased without exception. The percent elongation varied, increasing significantly for total liner, decreasing for DCA-1295 and Aerospray 70, and remaining essentially constant for T16, Dynatech, and Uniroyal. Since the AC40 liners could not be tested in this manner and only one Sucoat liner could be tested, evaluation of these liners will not be made until the 24-month data are received.

To determine the concentration of 20 heavy metals, chemical tests were conducted on the two FGD sludges as received and on the FGD sludge liquor that passed through the lined test cells, and the data were tabulated. Increasing concentrations of some of the heavy metals were indicative of liner breakdown and/or penetration by the sludge material in the case of Guartec UF and two TACSS materials. The chloride concentration of the liquor collected beneath each test cell is presented separately as an indication of how the sludge liquor moves through the liner/soil combination. For example, these data indicate that the AC40 and Sucoat both had liquor moving through the entire cross section of the liner. It is expected that should liquor continue to pass through these or similar liner materials in a real situation, the discharge from the test cells would approach the composition of the sludge liquor.

SECTION 3

APPROACH AND RESEARCH PLAN

To meet the objectives of this study, the overall experimental approach was to expose specimens of a variety of potential liner materials to selected FGD sludge wastes over a period of time under conditions that simulate disposal areas and to determine changes in the physical properties of the liner material with exposure time.

Due to the type of material to be disposed, the volume, and related economic considerations, the selection of potential liner candidates was initially limited to those that were relatively inexpensive. However, ease of placement and construction costs were also considered in selection criteria as a possible offset to high material costs. Primary consideration was placed on the use of admixed or stabilized in situ material; secondly, use of spray-on materials; and finally, limited use of prefabricated membrane-type materials. The membrane- or polymeric-type liners are being tested extensively in other EPA-supported projects (2-4). From the above categories, the requirement was to select a total of 18 liner materials to consist of ten admix, six spray-on, and two membrane types for inclusion in the study. Two FGD sludges were selected for the study.

Specifically, the plan has been

a. To select liner materials that have the potential for being used as liners for FGD sludge disposal areas.

b. To design and construct test cells simulating the conditions under which liner materials would exist in a disposal area. The test cells are to be capable of simulating a depth of sludge of at least 30 ft that can be applied in increments over a period of time.

c. To select the FGD sludge that would be representative of those expected to be encountered in disposal areas.

d. To characterize the FGD sludge so that behavior of selected liners can be predicted for required exposure periods.

e. To expose the liner materials for 12- and 24-month periods.

f. To subject the liner materials to physical tests to determine the characteristics of the liners at each of the data points (i.e. zero, 12, and 24 months) to provide three data points regarding behavior over a period of time.

g. To collect and measure the quality of permeate, if any, of the sludge leachate through the liners.

h. To analyze the permeate of the 12- and 24-month periods for the 20 parameters used to indicate water quality. The analyses will be conducted at a sensitivity equal to that obtainable by flame AA spectrophotometry.

SECTION 4

DESIGN AND CONSTRUCTION OF TEST CELLS AND ANCILLARY EQUIPMENT

The considerations for design of the test cells and the special equipment and materials required are discussed in this section.

GENERAL CONSIDERATIONS FOR DESIGN

Several factors were considered for the design of the test cells. These factors included the methods for constructing or installing liners for field installations (5), the size or amount of a specimen required for physical tests at the termination of exposure periods, a cell of sufficient volume to contain the liner and sludge, and a means of simulating a 30-ft depth of sludge.

The admix liners constitute the largest number of liners selected for this study. Admix materials are usually chemicals added to a road base or runway base soil in small quantities (normally 4 to 10 percent of the dry soil weight) to improve some particular physical quality(ies) of the soil. They can be mixed at the site by covering the area to be treated with the chosen amount of additive and then mixing it with the underlying soil using a mixing device such as the Pettibone mixer (Figure 1). This machine, along with other machines such as the road grader and dozer, is used to process and move large quantities of soil economically. Due to the size of these machines and the normally undulating terrain, 6 in. is judged to be the minimum practicable depth to stabilize. This is believed true even when the admix material is mixed with the soil at a batch plant and transported to the site for spreading and compacting.

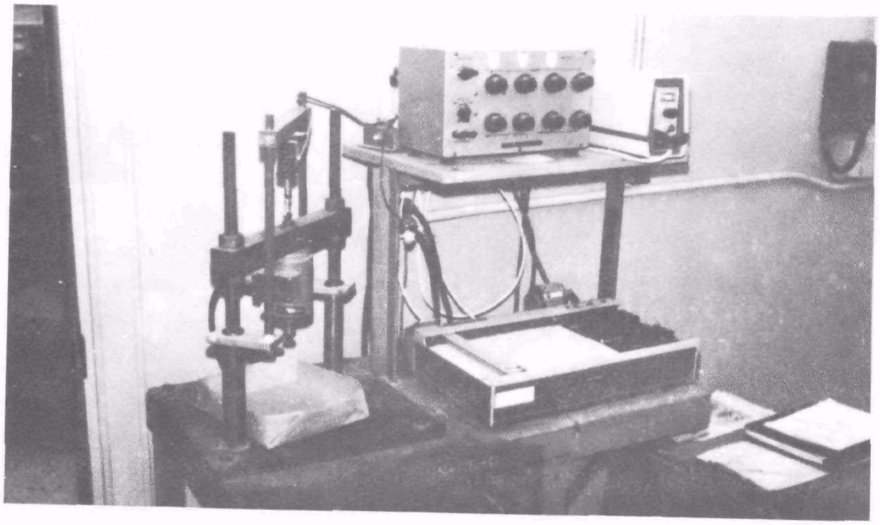
Spray-on materials should be applied to "level" areas or at least areas free of vertical or nearly vertical surfaces (i.e. wheel ruts). Usually some work is required to ready a site before a spray-on material can be applied. Ideally all vegetation, sticks, roots, and large rocks are removed, and the area rolled and prewet before the spray-on is applied.

Both spray-on materials and membranes require some protection against differential soil settlement. Membranes are simply left wrinkled with the idea that enough slack will be available to keep any resulting differential soil settlement from rupturing the membrane. Differential soil movement can easily rupture spray-on materials, rendering the liner ineffective.

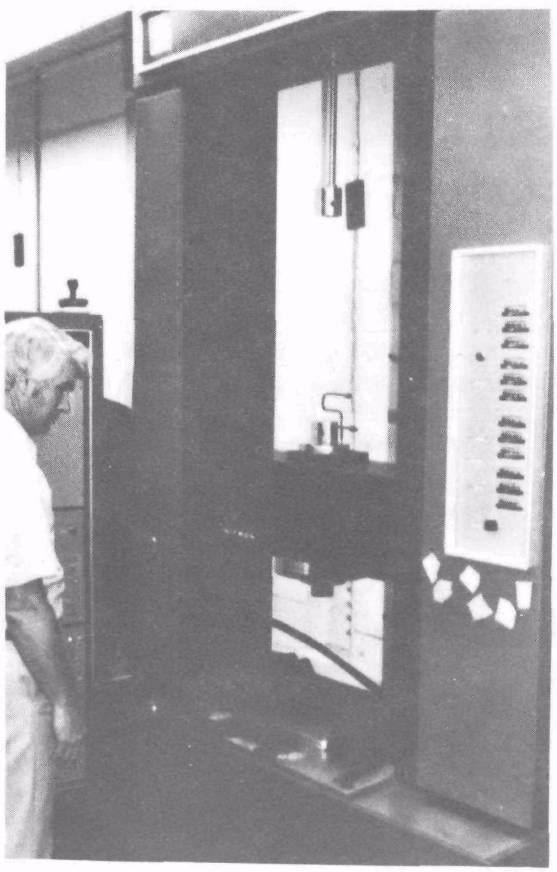
Figure 1. Pettibone mixer.

The best method for limiting differential soil movement is through compaction of the soil prior to placement of the spray-on material. From a practical standpoint, the minimum depth of compaction should be 6 in. Thus, it was decided that the liners would be tested with 6 in. of compacted soil in each case. In the admix materials, the liner is mixed with the compacted soil to a depth of 6 in., whereas the spray-on and membrane liners cover 6 in. of compacted soil. Any leachate would be forced to permeate a liner material and 6 in. of compacted soil, thus assuring comparable conditions.

The size of each liner specimen was determined by the number and type of tests following the exposure period. Nondestructive-type tests could only be used to detect swelling, shrinking, or obvious deterioration. Destructive-type tests were required to determine changes in liner strength and elasticity. The UC test was selected as a standard for the admix materials, and the grab test was chosen for the spray-on and membrane liners. Duplicate specimens were used for each test and the results averaged. Duplicate specimens were also valuable for determining unusual test results and for determining when additional testing was necessary. The UC test (American Society for Testing and Materials (ASTM) Method D 2166-66) (6) requires specimens approximately 1.2 in. in diameter by 2.8 in. high, whereas the grab test (ASTM D 1682-64) (7) requires 6- by 4-in. specimens. The UC and grab test equipment is pictured in Figure 2.



a. Unconfined compression machine and recorder.



b. Instron machine with grab test attachments.

Figure 2. UC and grab test equipment.

Pressurization was considered to be the most feasible approach to simulate a 30-ft depth of sludge. This necessitated an enclosed system and a pressure source sufficient to supply 20 psi to each test cell. The use of pressure permitted the use of minimum amounts of other materials, including sludge. Four gallons of sludge was arbitrarily chosen as a sufficient amount for a 2-year exposure period.

TEST CELL CONSTRUCTION

Polyvinyl chloride (PVC) was selected for construction of the test cells. PVC was considered to be an inert material that would not react chemically with the FGD sludge. Schedule 80 PVC pipe, ID 11-13/16 in. with a pressure tolerance of 130 psi was selected for the pressure cells. The base, also PVC, was 2-1/2 in. thick and 15 in. square. The base was tapped at the center to accommodate the drain port, and a special recess was provided to house a 6-in.-diam and 1/4-in.-thick porous plastic disc. The PVC top was 15 in. in diameter and 3/8 in. thick with a tap provided for pressure attachments. The top, flanges, and base were drilled to accommodate 3/8-in. bolts for connection purposes. A schematic drawing of the test cell with ancillary equipment is shown in Figure 3. An exploded view of the cell is shown in Figure 4, and an assembled cell is shown in Figure 5. An additional top plate of 1/4-in. aluminum was required to prevent buckling of the PVC top as pressure was increased in the cell.

A total of 72 cells were fabricated. The initial step in assembly was attachment of the base plate to the cylindrical body. A silicone sealant was applied at the interface of the flange and base plate and the bolts were secured. The same procedure was used for the coverplate after installation of the liner and sludge (the placement of liners and sludge is discussed elsewhere in this report). After assembly, the cells were placed in a holding room on racks previously constructed as shown in Figure 6. The holding room was capable of maintaining a constant temperature of 68°F and 40 percent humidity. In this manner, 18 liner types would be exposed to two sludge types for 12 months. This would require 36 test cells. A second set of 36 test cells was assembled at the same time for 24 months exposure.

ANCILLARY EQUIPMENT

The ancillary components consisted of a pressure system for pressurization of the test cells and a system to collect the leachate.

For the pressure system, a 2-hp compressor was used to supply compressed air through a piping system to a series of manifolds from which plastic tubing was used to connect to each individual cell (see Figures 3 and 6). Regulators and check valves were used between the compressor and manifolds for control of the desired pressure and as a safety measure against rapid depressurization should a failure occur. A second compressor was installed for use as required.

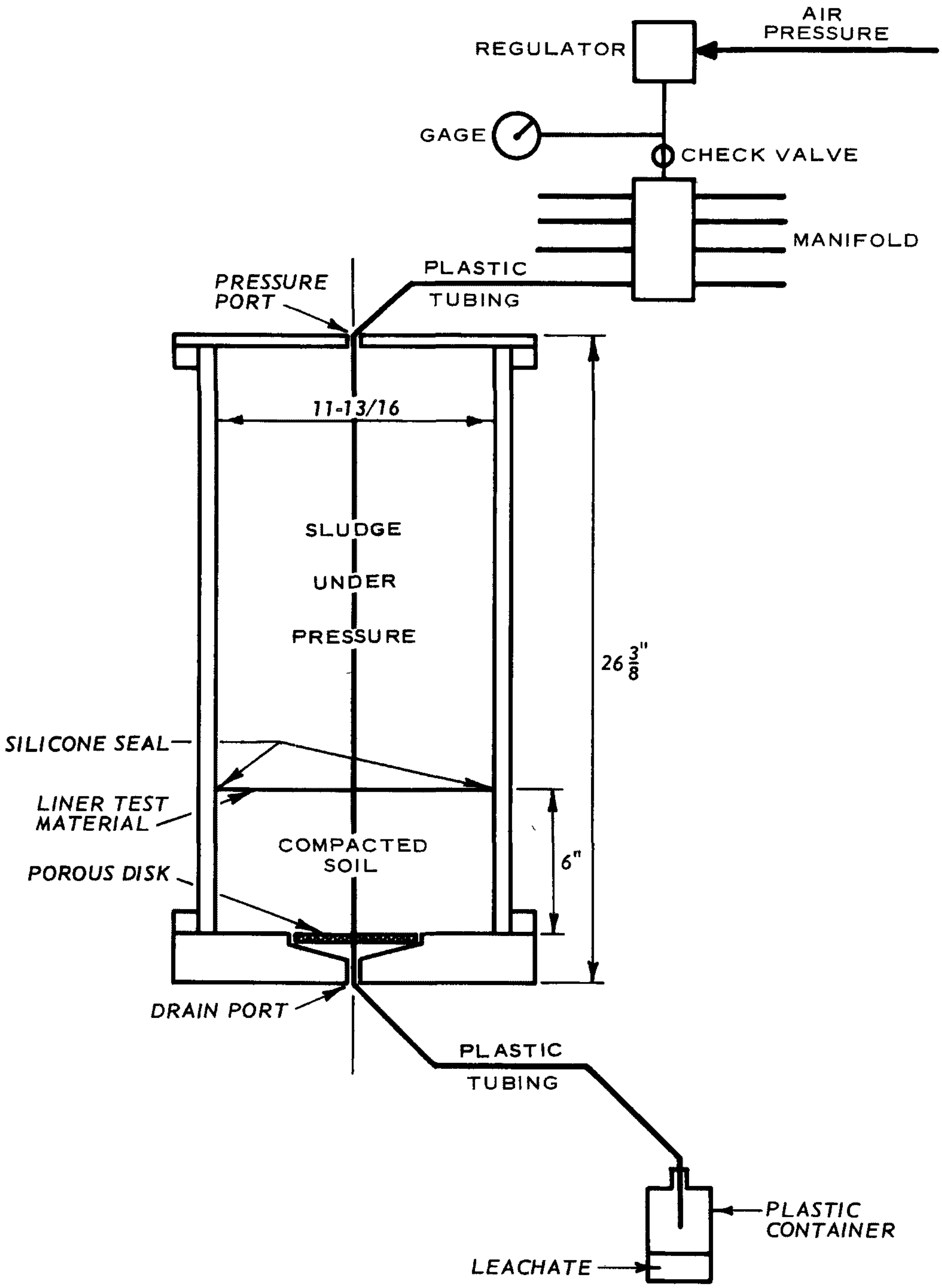


Figure 3. Schematic of a test cell section with a spray-on or membrane liner depicted and ancillary equipment.

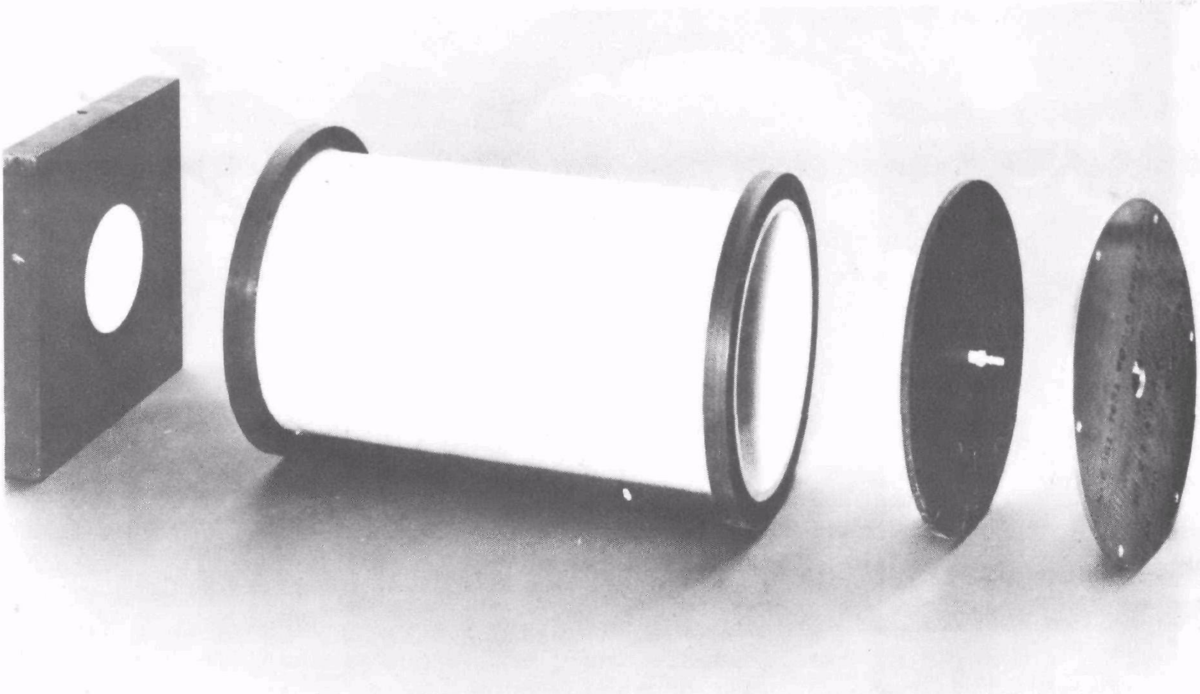


Figure 4. Exploded view of a typical test cell.

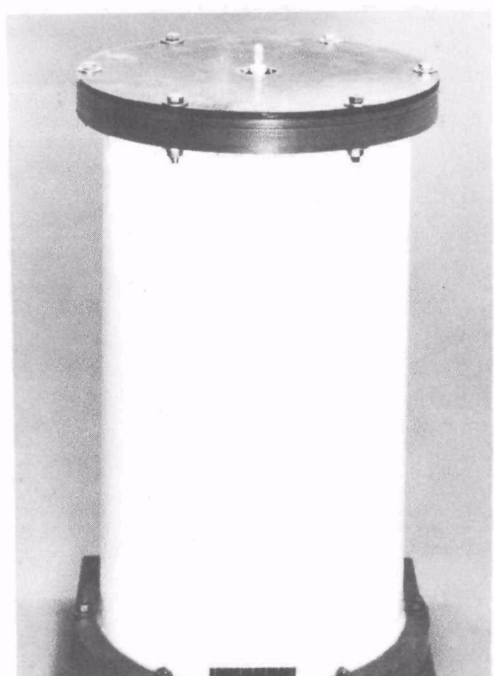


Figure 5. Assembled test cell.

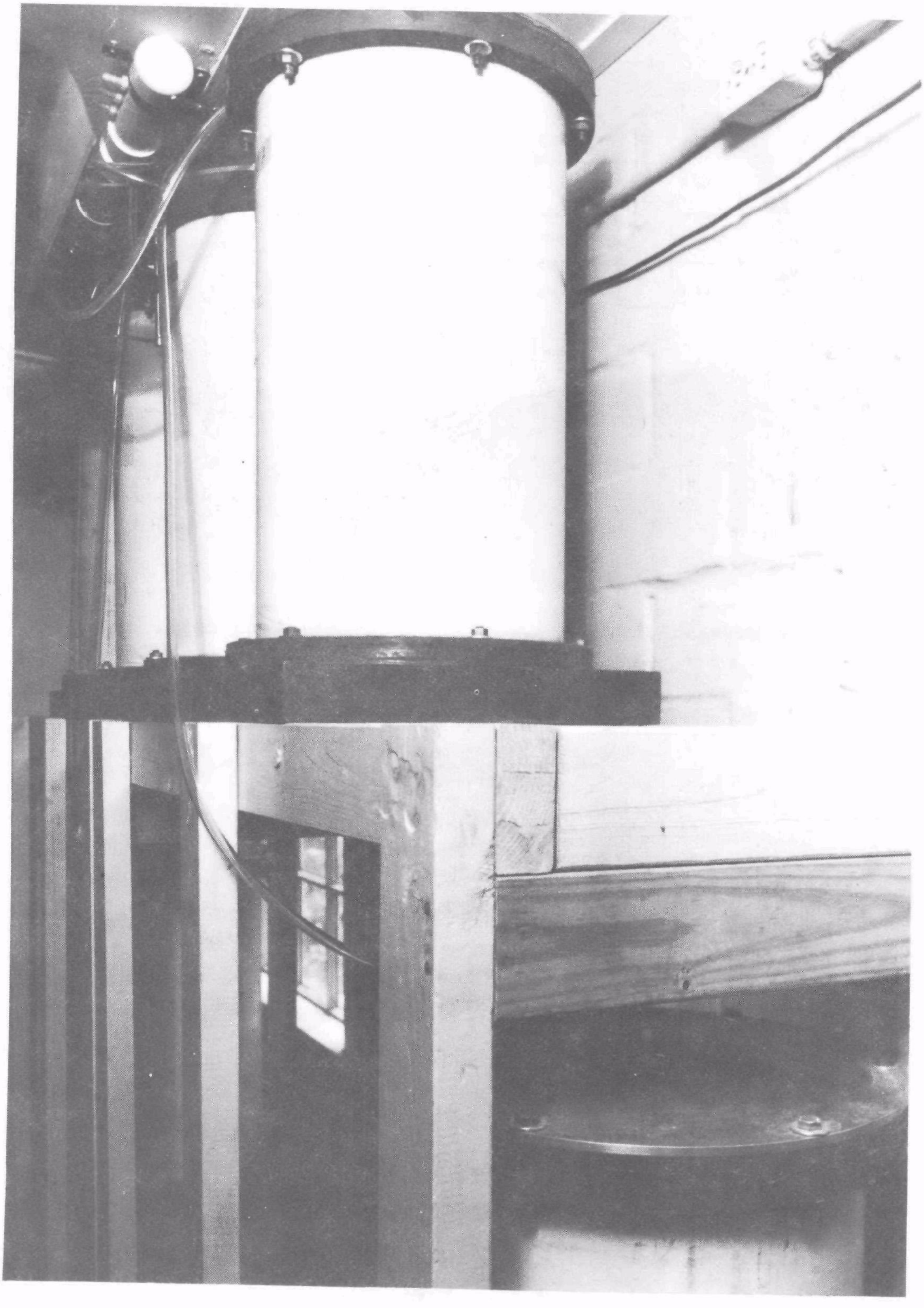


Figure 6. Assembled test cells on racks in holding area.

SECTION 5

SELECTION AND CHARACTERISTICS OF FGD SLUDGE

SELECTION

The two FGD sludges used in this study were selected from a group included in an EPA-supported research project at the WES (8). The group included FGD sludge from five different power plant locations from which samples had been previously obtained and characterized by chemical analyses (Table 1). Based on the available information, EPA recommended two sludges, one from an eastern coal lime-scrubbed process (Sludge A) and one from an eastern coal limestone-scrubbed process (Sludge B). The sludges were obtained from disposal ponds at the plant sites, placed in metal cans lined with heavy plastic bags, and transported to WES. The percent solids of Sludge A is 47.6, and the pH is 10.3; and the percent solids of Sludge B is 34.2, and the pH is 9.0.

TABLE 1. CHEMICAL ANALYSIS PARAMETERS AND TEST METHODS

Parameter	Test Method	Limit of Detection ppm
Arsenic (As)	Atomic absorption (AA), gaseous hydride method	0.002
Beryllium (Be)	Emission spectrophotometer	0.005
Cadmium (Cd)	AA, graphite furnace	0.001
Chromium (Cr)	AA, graphite furnace	0.001
Copper (Cu)	AA, graphite furnace	0.002
Mercury (Hg)	AA, cold vapor technique	0.0002
Magnesium (Mg)	AA, flame	0.1
Manganese (Mn)	AA, flame	0.01
Nickel (Ni)	AA, graphite furnace	0.005
Lead (Pb)	AA, graphite furnace	0.003
Selenium (Se)	AA, gaseous hydride method	0.003
Vanadium (V)	Emission spectrophotometer	0.005
Zinc (Zn)	AA, graphite furnace	0.001

(continued)

TABLE 1 (continued)

Parameter	Test Method	Limit of Detection ppm
Boron (B)	Standard methods* - 107B	0.3
Chloride (Cl)	Standard methods* - 112B	8.0
Cyanide (Cn)	Technicon autoanalyzer	0.005
Nitrite, nitrogen (NO_2,N)	Standard methods* - 134	0.01
Nitrate, nitrogen (NO_3,N)	Standard methods* - 213E	0.05
Sulfite (SO_3)	Standard methods* - 158	1.0
Sulfate (SO_4)	Standard methods* - 156C	4.0

* Standard Methods for the Examination of Water and Wastewater. 1976. 14th ed. American Public Health Association. Washington, D. C.

Table 2 shows the concentrations of 20 parameters for Sludges A and B with the sludge solids listed on the first line and the sludge liquor on the second line. The last tabulation provides the allowable limits for metal concentrations from the Journal of Water Technology and Quality 75-76, Maximum Allowable Domestic Water Supply Criteria (9, 10). As noted, some of the values are secondary standards (EPA) proposed for drinking water criteria.

CHARACTERISTICS

As can be noted from Table 2, the two FGD sludges are very similar in composition. Sludge A (lime-scrubber sludge) is generally high in trace metal content and has higher arsenic, beryllium, chromium, copper, manganese, nickel, lead, and vanadium than Sludge B. Boron and chloride levels are also higher in Sludge A than Sludge B. These differences probably reflect differences in the chemical composition of the coals burned at the two power plants. It can also be noted that Sludge B has more magnesium than Sludge A; this is probably due to the incorporation of dolomite in the limestone feed used for scrubbing. Lime usually has a lower magnesium content than scrubber limestone.

With few exceptions, the compositions of the sludge liquors are very similar. The scrubber liquor from Sample A has over twice the concentration of manganese than does liquor from Sample B. The scrubber liquor from Sample B has higher concentrations of copper, boron, cyanide, and sulfate.

TABLE 2. CHEMICAL ANALYSIS OF SLUDGE AND EPA ALLOWABLE LIMITS

Sludge and EPA Allowable Values	Material	Lab Symbol	Arsenic As	Beryllium Be	Cadmium Cd	Chromium Cr	Cyanide Cn	Copper Cu	Mercury Hg
Sludge A	Sludge Solids	mg/kg	0.28	6.8	0.005	133.0	--*	0.85	0.44
	Sludge Liquid	mg/ℓ	0.003	0.005	0.001	0.001	0.012	0.009	0.002
Sludge B	Sludge Solids	mg/kg	0.16	1.25	0.007	33.3	--*	0.38	0.84
	Sludge Liquid	mg/ℓ	0.003	<0.005	<0.001	<0.001	0.018	0.010	0.002
EPA	Values obtained from Ref. 9 and 10	mg/ℓ	0.05	0.011†	0.01	0.05‡	0.005	0.2§	0.002

* -- = Insufficient sample to analyze for all parameters.

† Fresh water-aquatic life criteria.

‡ Freshwater and marine organisms criteria.

§ Secondary standards proposed for drinking water criteria (EPA).

(continued)

TABLE 2 (continued)

Sludge and EPA Allowable Values	Material	Lab Symbol	Magnesium Mg	Manganese Mn	Nickel Ni	Lead Pb	Selenium Se	Zinc Zn	Sulfite SO_3
Sludge A	Sludge Solids	mg/kg	3030.0	84.8	0.84	1.08	1.38	135	190
	Sludge Liquids	mg/ℓ	10.1	2.3	<0.003	<0.003	<0.003	0.002	<1.0
Sludge B	Sludge Solids	mg/kg	5160	43.7	0.38	0.68	2.15	278	200
	Sludge Liquids	mg/ℓ	13.8	0.95	0.003	0.003	0.007	0.002	<1.0
EPA	Values obtained from Ref. 9 and 10	mg/ℓ	n/a	0.05	0.1*	0.05	0.01	5.0†	n/a

* Freshwater and marine organisms criteria.

† Secondary standards proposed for drinking water criteria (EPA).

(continued)

TABLE 2 (continued)

Sludge and EPA Allowable Values	Material	Lab Symbol	Sulfate SO_4	Boron B	Chloride Cl	Vanadium V	Nitrogen Nitrite NO_2, N	Nitrogen Nitrate NO_3, N
Sludge A	Sludge Solids	mg/kg	--*	385	1330.0	162	<0.04	3.0
	Sludge Liquids	mg/ℓ	1281.0	14.0	675.0	--*	<0.01	0.5
Sludge B	Sludge Solids	mg/kg	68750	185	300	53	<0.04	3.0
	Sludge Liquids	mg/ℓ	2100	71.2	670	--*	<0.01	0.51
EPA	Values obtained from Ref. 9 and 10	mg/ℓ	250†	0.75‡	250†	n/a	10.0	10.0

* -- = Insufficient sample to analyze for all parameters.

† Secondary standards proposed for drinking water criteria (EPA).

‡ Irrigation criteria.

SECTION 6

SELECTION AND PROPERTIES OF SOIL MATERIALS AND LINERS

The soil and the liner materials selected for use, including their physical properties, are described in this section. Emphasis was placed on the use of admix and spray-on type materials for liners. The selection of candidate liners was based on prior experience with the materials; however, a screening process that included a permeability test as a basic requirement resulted in deletion of many of the materials due to a very highly permeable condition. Similar screening processes were used to select a soil type for the admix and spray-on materials. For the soil selection, permeability was a major requirement, but the soil had to have the capability of being admixed on an economical basis with a particular selected candidate material.

SELECTED SOIL MATERIALS

The selection of soil types for use in the study was primarily based on experience gained during soil stabilization, dust pallation, and waterproofing. A soil of high permeability ($>10^{-4}$ cm/sec) was considered to be the most applicable for evaluating the membrane and spray-on liners in that it would permit any leakage of the liners to be readily detectable. However, from an economical standpoint, the high permeability soils are not suitable for the admix materials because of the high percent of admix that would be required. Therefore, a less permeable (finer-grained) soil was used with the admix materials. Based on this rationale, a silty sand was selected for evaluation of the membrane and spray-on liners and a clayey silt was selected for evaluation of the admix liners. The two soil types are considered representative of typical soils that might be encountered in a disposal area.

Silty Sand

A brown, nonplastic, silty sand (SM) with a specific gravity (G_s) of 2.68 (Unified Soil Classification System (USCS)) was selected. The gradation curve is shown in Figure 7. The standard compaction test procedure indicated the optimum water content to be 12.7 percent and the maximum dry density to be 111 lb/cu ft (Figure 8).

Clayey Silt

A light brown, slightly plastic, clayey silt (ML) with a G_s of 2.71 (USCS) was selected. The gradation curve is shown in Figure 7 also. The standard compaction test procedure (11) indicated the optimum water content to be 17.3 percent and maximum dry density to be 106 lb/cu ft (Figure 8).

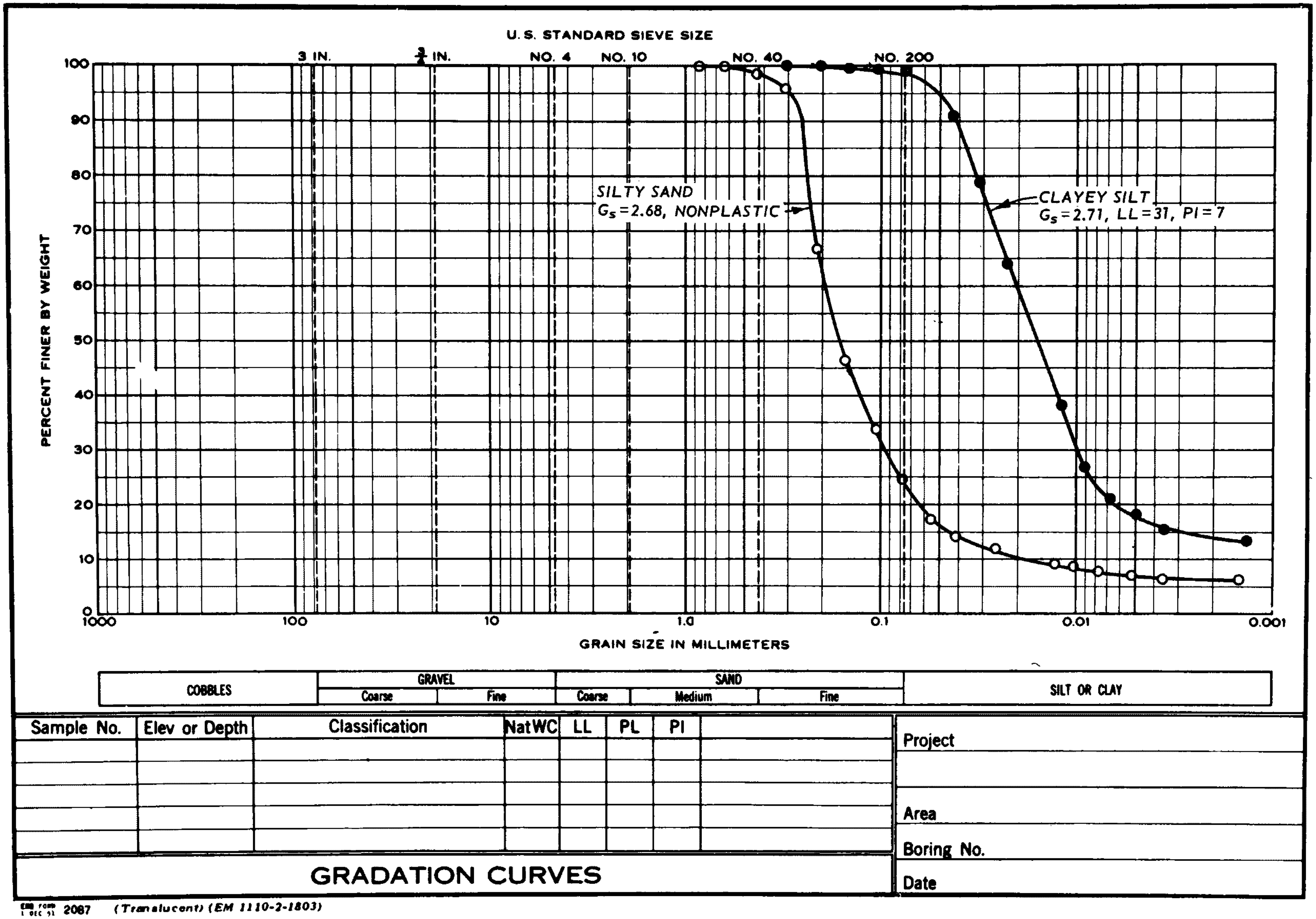


Figure 7. Gradation curves for soil materials.

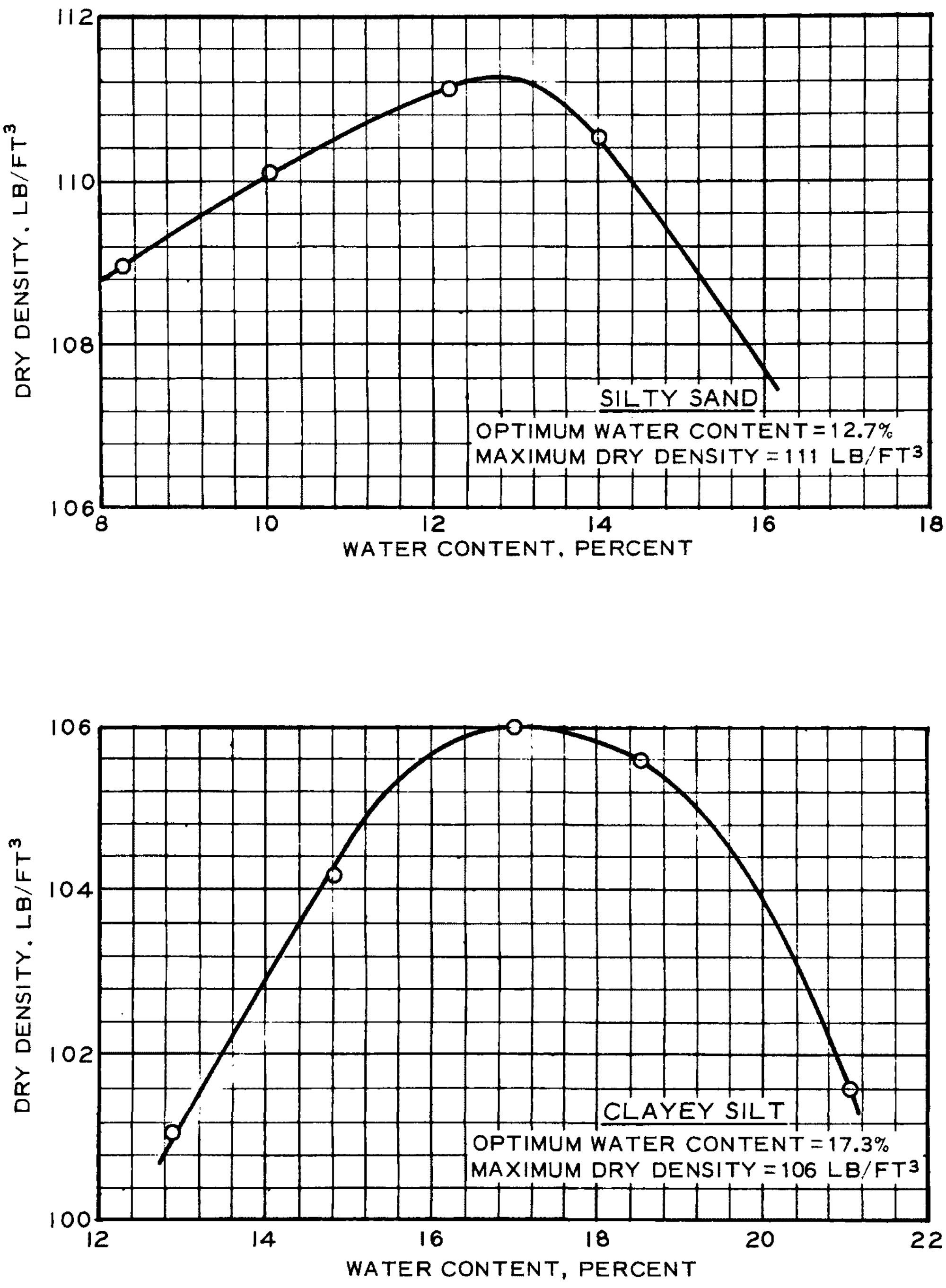


Figure 8. Moisture-density curves for test soils.

SOIL PERMEABILITIES

The permeability of the two soil types was determined using standard laboratory techniques (SLT) (11). These values are presented in Table 3. The permeability determined using SLT would identify these two soil types further. Of more immediate importance, these values would be compared with that value determined using a typical test cell apparatus described in Section 4 under conditions as outlined below. It should be pointed out that some very important differences exist between the two test methods: the SLT procedure called for deaired, distilled water, the test cell apparatus (TCA) did not; the SLT procedure called for an oven-dried sample that is saturated before the test begins, the TCA did not; the SLT procedure called for the entire specimen to be vibrated to the correct thickness/density in one layer, the TCA did not; and the SLT procedure called for the head to be regulated to avoid high/large hydraulic gradients, the TCA did not. These differences indicate the inherent strength and/or weakness of this particular test situation. It was the intent of this investigation to use the TCA instead of SLT to duplicate insofar as possible the expected field test conditions.

TABLE 3. SLT AND TCA PERMEABILITY VALUES

Conditions	Permeability cm/sec X 10^{-6}
SLT Values	
Silty sand - constant head method	460
Clayey silt - falling head method	0.57
TCA* Values	
Water (only)	28,500
6-in. compacted silty sand, water	81
6-in. compacted clayey silt, water	16
6-in. compacted silty sand,	
5-gal Sludge A plus water	49
5-gal Sludge B plus water	47
6-in. compacted clayey silt	
5-gal Sludge A plus water	7
5-gal Sludge A plus water	1

* Test cells filled as noted, with porous plate and drain tube in place.

The permeability of a typical TCA was determined to ensure that this value was at least as great as the permeability of either test soil selected. To do this, a test cell with porous plate, drain port, and drain tube in place was filled with tap water to a level 4 in. below the top of the test cell and allowed to drain freely into a collection device. The permeability was calculated by measuring the amount collected and the time during which it was collected. (See Section 8 for other test results data.) The permeability value obtained in this way (Table 3) indicated that the TCA would not interfere with subsequent similar measurements described below.

Each test soil was compacted 6 in. deep at optimum density in separate test cells (see Section 7 for compaction techniques). Each test cell was carefully filled with tap water, and the permeability was calculated and listed (Table 3). The permeability of the silty sand is almost six times less in the test cell than that determined by the SLT, whereas the clayey silt is 16 times greater than its corresponding SLT value. The permeability value of silty sand is less when obtained in the test cell primarily because the water level was not held constant; however, the clayey silt value is greater because the soil was not saturated prior to testing. The test started when the water level reached 4 in. from the top of the test cell.

A comparison of the selected soil permeability values determined by SLT and TCA was discussed previously. These TCA values also provided an intermediate point (permeability value) for the same setup as before with sludge added. The next test series would determine whether the sludge/sludge liquor increases or decreases the permeability of the TCA.

Six inches of compacted silty sand was placed in each of two test cells and 6 in. of compacted clayey silt was placed in each of two test cells. Approximately 4 gal of Sludge A was added to the test cells, one with compacted silty sand and one with compacted clayey silt. Approximately 4 gal of Sludge B was added to the remaining two test cells. The tap water was added until the liquid reached a level 4 in. below the top of each test cell and was allowed to drain freely as before. Adding sludge to a particular test cell/compacted soil combination reduced the permeability value of that system by about one half. Actual values are listed in Table 3.

The permeability values listed in Table 3 show how each succeeding step of adding compacted soil and sludge reduced the permeability of the test cell apparatus. The table was important in that it would indicate whether or not the final variable, the liner itself, was reducing the TCA permeability. Table 3 thus became the data base for all liners. Any liner in a test cell/soil/sludge exhibiting permeability the same as or greater than that of a similar although linerless configuration in Table 3 would be closely examined and probably rejected.

LINER SELECTION AND TESTING

In the past, admix materials were added to roadway/runway soil primarily to increase the base or subbase bearing capacity (soil strength). More recently, admix materials have found increasing use as modifiers to improve the workability of a soil or to substantially reduce its susceptibility to water. Similarly, spray-on materials are applied to control dust or prevent weathering cycles including rainfall from eroding the soil surface, but the more expensive, more time-consuming permeability tests normally have not been conducted. It became apparent that a reasonably fast method of determining permeability for various admix and spray-on materials at various application rates would be necessary to achieve the objectives of this study.

The procedure used for the admix liners consisted of preparing the test specimens and compacting the material in a Harvard miniature test apparatus (11). For the spray-on liners, soil specimens were prepared and compacted in the Harvard miniature mold, and the spray-on materials were applied to the top surface of the soil specimen. Both admixed and spray-on specimens were allowed to cure for 7 days under humid conditions. Following the curing period, a rubber membrane was placed around the top of the mold to form a watertight connection to a tube. Water was introduced into the tube to provide a 2-ft constant head on the liner materials. The water permeating through the specimen was collected and measured over a known period of time and from this the permeability was determined.

A deviation from this procedure was required for screening the asphaltic concrete mix because of the size of aggregate in the mix. All admix specimens were prepared 2 in. thick by 11-5/8 in. in diam and placed in a test cell. The test cell was filled with water, and the permeability of a particular mix design was determined in the same manner as for the selected conditions described above and listed in Table 3.

The prefabricated membrane materials were tested for leakage (pinholes) or other abnormalities by the use of a 21-in. standpipe with a bell shape on the lower end as shown in Figure 9. The membrane was placed on the bell end, sealed with silicone, and secured with a ring and "C" clamps. The standpipe was filled with water that was allowed to remain for an extended period of time, usually 15 to 20 days. Leakage was detected by the accumulation of moisture in a container beneath the device.

Results of the screening process and selection of liner materials are discussed in the following paragraphs.

SELECTED LINER MATERIALS

The items selected for exposure testing as liners in cells containing sludge are listed in Table 4.

Admix Liners

The quantity of admix to be added to the soil for preparation of the liners was based primarily upon experience with the use of admixtures to improve the strength, durability, or workability of soils in various civil engineering projects. In some cases, the admix quantity used was recommended by the admix procedures. Although several tests, including permeability, density, compressive strength, penetration of asphalt, and viscosity of asphalt, were performed on the admix liners, permeability was the prime measurement used to select the percentage of an admix.

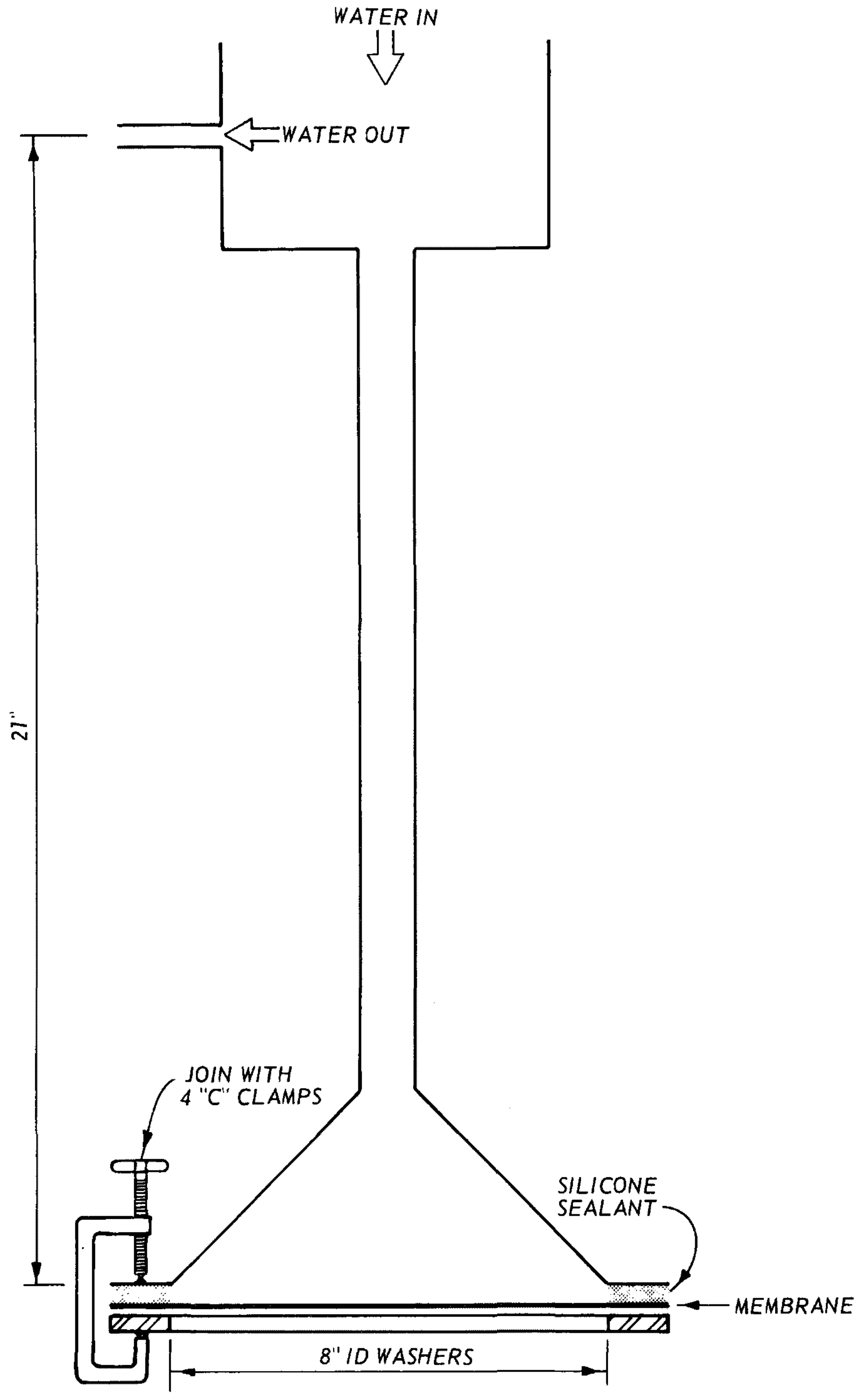


Figure 9. Pinhole test device for membrane liners.

TABLE 4. SELECTED LINER MATERIALS

Material Name	Percent/Description/Type
	Admix Liner Material
Lime	Hydrated ASTM C 141-67*
Portland cement	Type I ASTM C 150-78†
Cement with lime	4 percent Type I Portland cement 6 percent hydrated lime
M179	4 percent polymer, bentonite blend
Guartec UF	4 percent light gray powder
Asphaltic concrete	11 percent asphalt cement 1/2 in. (max.) aggregate
TACSS 020	6 percent blackish-brown liquid
TACSS 025	6 percent blackish-brown liquid
C400	15 percent fine-ground powder
CST	15 percent fine-ground powder
	Spray-on Liner Material
DCA-1295	3/4 gal per sq yd polyvinyl acetate
Dynatech	3/4 gal per sq yd natural rubber
Uniroyal	3/4 gal per sq yd natural latex
Aerospray 70	3/4 gal per sq yd polyvinyl acetate
AC40	3/4 gal per sq yd asphalt cement
Sucoat	As-supplied molten sulphur
	Prefabricated Membrane Liner
Total liner	As-supplied elasticized polyolefin
T16	As-supplied black chloroprene-coated nylon

NOTE: For manufacturer/address, see Appendix A.

* ASTM. 1978. Standard Specifications for Hydraulic Hydrated Lime for Structural Purposes. In: 1978 Annual Book of ASTM Standards, Part 13, Designation: C 141-67 (rev 78). Philadelphia, Pennsylvania.

† ASTM. 1978. Standard Specifications for Portland Cement. In: 1978 Annual Book of ASTM Standards, Part 14, Designation: C 150-78. Philadelphia, Pennsylvania.

Admix materials produced by Takenaka Komuten Company (Japan) are identified as TACSS 020, TACSS 025, C400, and CST. They were included in the study based upon data presented by the company that the admixtures had a high potential for creating an impermeable condition. The Takenaka Company provided the materials and personnel to assist in formulating the mixes used as liner specimens.

Asphaltic Concrete--

The asphaltic concrete mix used consisted of 1/2-in. maximum-size aggregate with an 11 percent asphalt content. The material was compacted in 2-in.-thick by 11-5/8-in.-diam specimens for installation in the test cells. The 11 percent asphalt content is not unusual in preparing mixes for pond and canal liners where impermeable mixtures are desired.

Portland Cement--

Type I Portland cement, which is readily available in most areas, was selected as an admix to produce higher strength in otherwise acceptable soils. Trial applications of 6, 8, and 10 percent cement admix were prepared and subjected to permeability tests. The specimens with 6 and 10 percent admix did not leak whereas the specimen at 8 percent had slight leakage. No reason for the slight leakage could be found; however, the larger application rate of 10 percent of the dry weight was selected.

Portland Cement with Lime--

Lime or calcium hydroxide, commonly called hydrated lime, is readily available and can be added to soil to reduce the volume change potential and render the soil easier to compact. Although both cement and lime have been used separately in large quantities to stabilize soil, very little has been done with these two materials in combinations. It was believed that some combination of the two materials would produce the desired benefits of both materials: an increase in strength and a decrease in volume change potential. It is known that some percentage of lime (approximately 1 percent) is lost due to carbonation, which is the reaction of calcium with carbon dioxide in the air, so an arbitrary combination of 4 percent Type I Portland cement and 6 percent hydrated lime was selected and tested. When the test specimen failed to leak, this application rate (both percents of the dry soil rate) was accepted, and the combination of the two materials was used as one of the admix materials.

C400--

The C400 material is a fine-ground powder produced in Japan. It is reported to be very similar to cement with additional (unspecified) additives. A large variety of uses is well documented by the Japanese. This material was applied at 15 percent of dry soil weight following tests of 5, 10, and 15 percent.

CST--

There were no essential differences noted between the CST material and C400 described above. It was applied at the same rate as the C400.

Guartec UF--

Guartec UF is a highly refined, unmodified gum produced by grinding the guar bean into a fine powder. The guar bean is a legume plant that is native to India but is now grown in northern Texas and southern Oklahoma. Typical properties are a free-flowing powder, 12 percent maximum moisture with 99 percent passing the 100 mesh screen. The bulk density (packed) is 55 lb/cu ft. It is described as having five to eight times the thickening power of starch. It was reasoned that this material would swell to fill the soil voids. The application rate of 4 percent of the dry soil weight resulted in a specimen which did not leak and was used in the test cells.

Lime--

Lime was tested and applied at the rate of 10 percent of the dry soil weight for comparison with Portland cement.

M179--

M179 is a preblended mixture of water-swellable polymers and bentonite. This material has been widely used as a sealant for reservoirs and is reported effective in all soil types ranging from sand to clayey soils. The material was applied at the rate of 45 tons per acre, approximately 4 percent of the dry soil weight, as suggested by the supplier.

TACSS 020--

TACSS 020 is a blackish-brown transparent liquid (G_s = 1.115) produced in Japan. A proprietary liquid catalyzer may be used to adjust the cure time. This material was applied at the rate of 6 percent of the dry soil weight as suggested by the supplier.

TACSS 025--

TACSS 025 is a blackish-brown liquid (G_s = 1.120) produced in Japan. A proprietary liquid catalyzer may be used to adjust the cure time. This material was also applied at the rate of 6 percent of the dry soil weight as suggested by the supplier.

Pertinent physical data for the admix materials prior to being subjected to the sludge (zero time data) are presented in Table 5.

Spray-on Liners

The materials used for spray-on liners were selected primarily from items previously evaluated for dust control for military applications (13). The selection was based on experience in regards to ease of application, danger to personnel in applying or using, and subsequent behavior when exposed to climatic conditions. One material, a molten sulfur product that EPA suggested as a candidate material, was supplied by the Chevron Company in a premolded specimen made the size for installation in the test cells.

Other than the molten sulfur product, the materials were applied at a uniform rate of 3/4 gal/sq yd based on experience gained in use for dust control. This rate was considered adequate to provide complete coverage, preclude thin areas where pinholes or air bubbles might develop, and would not be of sufficient quantity so that flow would occur. Experience indicates that greater application tends to flow.

TABLE 5. PHYSICAL TESTS - ADMIX LINERS
Zero Time (Control Data)

Liner Material	Application* Rate, %	Water Content %	Dry Density lb/cu ft	Height/Diameter H/D	Axial Strain ΔH/H, %	Unconfined Compression lb/sq in.
Clayey silt	n/a	16.6	103.5	2.051	3.1	38.4
Guartec UF	4	17.4	90.0	2.042	5.9	13.9
Portland cement	10	16.6	102.8	2.155	1.0	663
M179	4	13.2	103.9	2.009	n/a	<5
Lime	10	17.3	101.0	2.153	1.0	242
TACSS 020	6	16.2	106.3	2.154	6.3	179
Cement plus lime	4, 6	16.1	104.1	2.172	1.0	503
TACSS 025	6	16.4	104.6	2.173	5.0	164
C400	15	15.9	105.4	2.111	1.0	721
CST	15	14.4	105.2	1.792	1.0	1160

Liner Material	Application* Rate, %	Asphalt Content %	Penetration 0.1 mm	Viscosity Passes
Asphalt concrete	11% asphalt 1/2-in. aggregate	10.4	60	2959

NOTE: UC tests followed seven days humid cure.

* The application rate is based on the percent of dry soil weight or dry aggregate weight.

The spray-on liners were subjected to permeability, density, and tensile strength/elongation tests.

AC40--

AC40 is an asphalt material refined to meet specifications for paving, industrial, and special purposes. Specifications for this material require a viscosity of 4000 ± 800 poises at a temperature of 135°C (275°F) and a penetration of 20 (minimum) at 25°C (77°F) for 100 grams for 5 sec. This material requires a high temperature to flow (300 to 400°F), and it was applied at the rate of 3/4 gal/sq yd.

Aerospray 70--

Aerospray 70 is a polyvinyl acetate material weighing about 9.2 lb/gal. This liquid is white and cures to form a clear flexible film. The application rate was 3/4 gal/sq yd. This material has been used to control erosion in areas of new vegetation.

DCA-1295--

DCA-1295 is similar to Aerospray 70 with additional plasticizers and other additives to increase shelf life and help produce a more flexible film. The application rate was 3/4 gal/sq yd. This material was developed to control dust during military operations.

Dynatech--

Dynatech is a natural rubber latex compound designated 1-H-10 formulation No. 267. It was applied at a rate of 3/4 gal/sq yd. An experimental product, it is one of the materials considered for the military dust control program.

Sucoat--

Sucoat is a molten sulfur product which is placed at high temperature (300 to 400°F) and forms a strong solid upon curing. Four 3/8-in.-thick discs, approximately 11-5/8 in. diam, were supplied by the manufacturer for testing, and they were installed in the cells as received. This is a new product described as a quick setting, watertight, coating compound.

Uniroyal--

Uniroyal is a black natural latex designated L9241 by the manufacturer. It was applied at the rate of 3/4 gal/sq yd. This experimental product was one of the materials that passed the traffic phase of the dust control program.

Pertinent physical data for the spray-on liner material for zero time are presented in Table 6. Figure 10 shows a typical spray-on material (AC 40) being cured in the laboratory. All spray-on materials were cured for 0-time physical testing in a similar fashion.

Prefabricated Membrane Liners

The following prefabricated liners were selected for evaluation and were subjected to permeability, density, and tensile strength/elongation tests.

Total liner--

Total liner is an elasticized polyolefin approximately 20 mils thick. The membrane was applied as received. This material was furnished by the manufacturer at the request of the EPA.

T16--

T16 is a chloroprene-coated nylon approximately 18 mils thick. This composite material is formed from a single-ply nylon fabric coated with neoprene and weighs 18.5 oz/sq yd. This membrane was developed at WES as an expedient airfield pavement surfacing material. The membrane was applied as received from the producer.

Pertinent physical data for the prefabricated membrane liner material for zero time are presented in Table 6.

TABLE 6. PHYSICAL TESTS - SPRAY-ON AND MEMBRANE LINERS
Zero Time (Control Data)

Liner Material	Thickness in.	Weight grams	Density lb/cu ft	Application Rate lb/sq yd	Apparent Elongation %	Breaking Strength lb
Total liner	0.023	7.77	54.48	0.92	136	544
T16	0.018	8.95	75.75	1.04	26	482
DCA-1295	0.219	112.44	81.42	13.42	172	127
Dynatech	0.093	29.98	55.50	3.87	486	128
Uniroyal	0.111	35.39	53.45	4.43	615	122
Aerospray 70	0.158	80.77	82.27	9.74	235	106
Sucoat*					NOT AVAILABLE	

Liner Material	Asphalt Content	Penetration 0.1 mm	Viscosity Passes
AC40	n/a	49	8237

* Four discs 3/8 in. thick received from manufacturer. All four used in test cells.

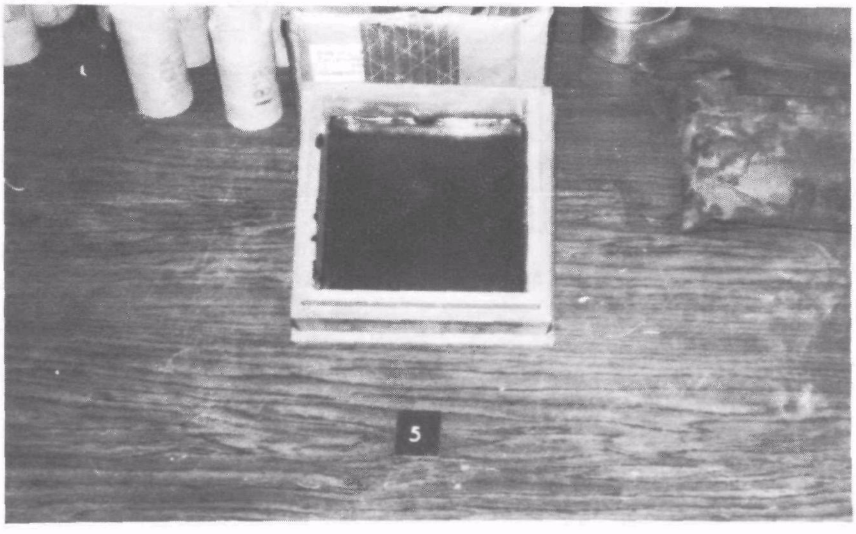


Figure 10. AC40 curing in a plastic mold.

SECTION 7

PREPARATION AND INSTALLATION OF LINER AND SLUDGE MATERIALS ON TEST CELLS

GENERAL PROCEDURES

The sequence for fabrication of the test cells was basically the same for all cells and followed the routine presented in Section 4. The method of preparing and installing the liners is discussed in this Section. Since compaction of the soil materials (and liners in the case of the admixed materials) was a pertinent part of the preparation of all of the liner/cell combinations, the details of the procedure are presented initially to obviate further discussion per individual liner types.

COMPACTION DEVICES AND METHODS

Compaction devices consisting of two different size footings were prepared for the Instron machine (Figure 11). These devices were used to statically compact soil in the test cells in 2-in.-thick layers. The surface of the compacted layer was scarified and another layer added. In this manner, three layers of a predetermined weight of soil were compacted using a procedure that closely parallels the one used in preparing Harvard miniature specimens (Figure 12). Finally, an 11.5-in.-diam compaction foot was attached to the Instron machine, and the soil surface was leveled throughout to a 6-in. depth, assuring the desired optimum density. The footings were mounted on shafts of sufficient length to reach the lowest part of the cell.

LINER PREPARATION

Admix Liners

The admix-type liners were prepared in accordance with the proportions discussed in Section 6. Each admix material was thoroughly mixed with the clayey silt, placed in a test cell, and compacted; then liners were allowed to cure for seven days at 78°F and 50 percent humidity. The only deviation was the asphaltic concrete, which was prepared separately in a special mold having the same diameter as the test cell. This was necessary in order to obtain sufficient density of the mix during compaction and also prevent any damage to the underlying silty sand soil on which it was placed. This resulted in a 2-in. thickness of asphaltic concrete over a 6-in. layer of compacted silty sand. This was the only admix material used in conjunction with the silty sand soil. All others were mixed with the clayey silt soil and compacted in a test cell.

Figure 11. The Instron machine with both compaction footings.

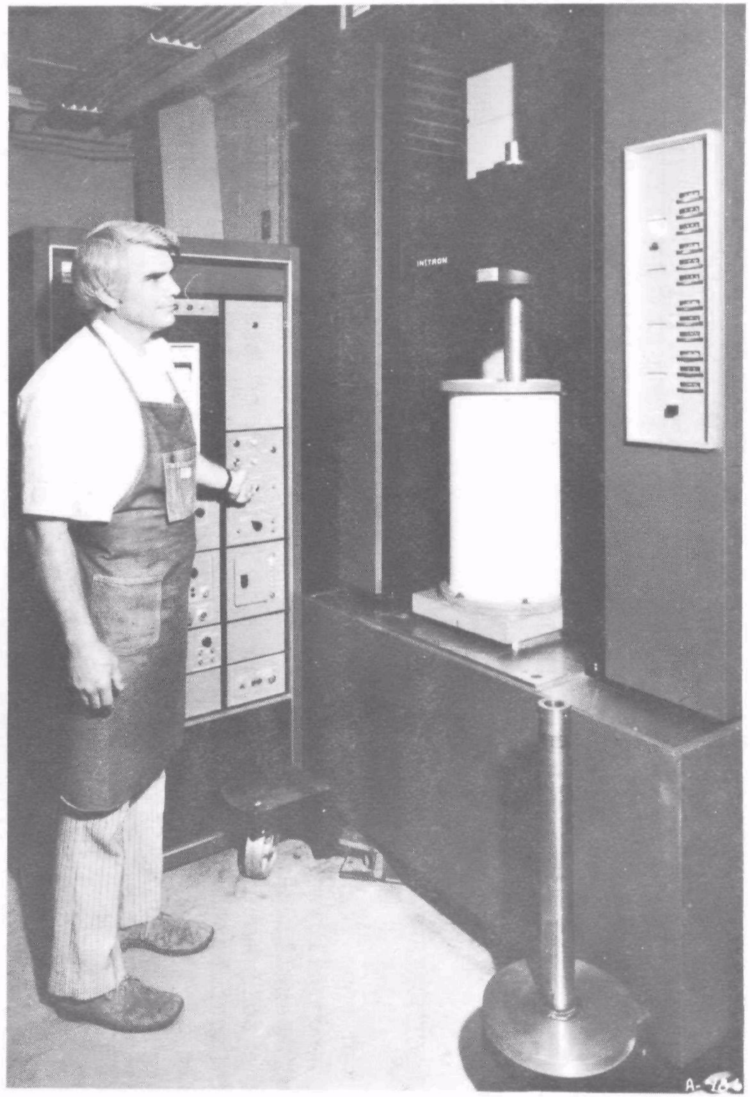


Figure 12. Typical operation using Instron machine and 4.5-in.-diam footing to compact soil layer in a test cell.

Spray-on Liners

The spray-on liner materials were applied to the surface of the silty sand soil. The silty sand was compacted 6 in. deep in the test cell at optimum moisture and density and was allowed to cure (normally two to three days) at 78°F and 50 percent humidity. The spray-on materials were placed on the surface (3/4 gal/sq yd) and allowed to cure in accordance with the manufacturer's recommended time. The cure time was usually about four hours or less.

Prefabricated Membrane Liners

The prefabricated membrane liners were prepared to include a seam or joint in the mid-portion of the specimen, which was then cut to the diameter of the test cell. The seam was considered to be a necessary part of the test as one would certainly be encountered in covering a large area. The liners were placed on 6 in. of compacted silty sand in the test cell.

SEALANT

A silicone sealant was used to seal around the periphery of the liner and test cell wall. The sealant was used with a primer for best results. The primer was placed only on the PVC test cell walls in bands approximately 3 in. wide in the area where the sealant would be placed to help assure a good bond between the primed test cell wall, forming a triangular-shaped wedge that extended approximately 1 in. out on the liner and 1 in. up the test cell wall. The sealant was allowed to cure until it was dry to the touch.

FGD SLUDGE

The FGD sludges were collected and transported in metal cans lined with heavy vinyl bags. Prior to placement in the cells, the sludge was thoroughly mixed using a portable mixer with extended mixing blades (Figure 13). After they were mixed, the sludges were added to the test cells at a rate of approximately 4 gal per test cell.

CHEMICAL ANALYSIS DATA BASE

A chemical analysis of the sludge solids and sludge liquids was conducted on both Sludges A and B "as received." The analysis included measurement of the concentration in mg/ℓ for 20 parameters (see Table 1) and further identification of the sludges used. (See Section 5 and Table 2.) It was also deemed desirable to establish a chemical analysis data base for each different testing situation. Therefore, a chemical analysis was conducted on the leachate from unlined test cells loaded as follows:

Lab Symbol	Sludge Type	Soil Type
1-100	A	Clayey silt
2-100	A	Silty sand
1-400	B	Silty sand
2-400	B	Clayey silt

Additionally, each test cell was filled with tap water to a level 4 in. from the top. By comparing this chemical analysis with the analysis taken after the liquid passes through the liner, these initial data (Table 7) will serve to indicate whether a liner that passes liquid is helping solve a potential problem or contributing to the problem.

Figure 13. Portable mixer with extended mixing blades.

TABLE 7. CHEMICAL ANALYSIS DATA
Leachate from Unlined Test Cells and EPA Allowable Values mg/ℓ

Sludges and EPA Allowable Values	ID No.	Arsenic As	Beryllium Be	Cadmium Cd	Chromium Cr	Cyanide Cn	Copper Cu	Mercury Hg	Magnesium Mg	Manganese Mn	Nickel Ni
Sludge A	2-100	0.003	0.005	0.002	0.001	0.029	0.013	0.0002	65.1	0.01	0.005
	1-100	0.002	0.005	0.002	0.001	0.01	0.001	0.0002	22.2	0.35	0.005
Sludge B	1-400	0.004	0.005	0.003	0.001	0.034	0.003	0.0002	74.1	0.01	0.005
	2-400	0.004	0.005	0.003	0.001	0.01	0.003	0.0002	20.0	0.01	0.005
EPA	*	0.05	0.11†	0.01	0.05	0.005‡	0.2‡	0.002	n/a	0.05	0.1†

* Values obtained from References 9 and 10.

† Freshwater aquatic life criteria.

‡ Freshwater and marine organisms criteria.

(continued)

TABLE 7 (continued)

Sludges and EPA Allowable Values	ID No.	Lead Pb	Selenium Se	Zinc Zn	Sulfite SO_3	Sulfate SO_4	Boron B	Chloride CL	Vanadium V	Nitrogen Nitrite NO_2, N	Nitrogen Nitrate NO_3, N
Sludge A	2-100	0.006	E*	0.020	1.0	241.0	14.7	83.0	0.021	14.3	75.6
	1-100	0.010	E*	0.020	1.0	42.0	1.1	95.0	0.005	0.01	0.33
Sludge B	1-400	0.005	E*	0.016	1.0	297.0	7.4	78.0	0.018	31.6	47.5
	2-400	0.005	E*	0.026	1.0	36.0	0.6	79.0	0.005	0.001	0.05
EPA	†	0.05	0.01	5.0‡	n/a	250‡	0.75§	250‡	n/a	10.0	10.0

* E = equipment being repaired.

† Values obtained from References 9 and 10.

‡ Secondary (EPA) standards proposed for drinking water criteria.

§ Irrigation criteria.

COMPLETION OF ASSEMBLY

The top plates were attached, and the cells were placed in the holding area. The pressurization system was installed and attached to the cells. The system for collection of the leachate was assembled, and the exposure test was commenced. Following the first month of 0 psig (atmospheric pressure), the pressure system was activated and the pressure was increased to 2 psig, simulating placement of approximately 3 ft of sludge. Similarly, the pressure was increased 2 psig each month for a total of 10 months (30 ft of head). It was reasoned that a disposal area of a size less than 1-year capacity probably would not be economically feasible, yet one half the test cells would be removed after only 12 months duration, and it seemed desirable to have some portion of that period at the full "design" condition, i.e., 30 ft of head.

IDENTIFICATION SYSTEM

A method to identify the test cell sludge/liner combination was developed. Each liner material was assigned a number from 01 to 18; these two numbers were followed by either a 1 (for 12 months exposure time) or a 2 (for 24 months exposure time); and finally this number was followed by a letter (A for Sludge A, or B for Sludge B). Thus, each test cell was assigned an identification number and all particulars were noted on a master sheet. For example, 121B on a test cell indicates that the liner is lime, the test duration is 12 months, and the sludge is "B", a FGD sludge from an eastern coal limestone-scrubbed process.

SECTION 8

TEST DATA

At the end of the first 12-month period, 36 test cells were depressurized at the rate of 2 psig per hour and removed from the holding areas for disassembly. All remaining liquid and sludge solids were removed from the liner in a way that would not damage the liner or test cell.

ADMIX LINER MATERIALS

Admix liner materials were removed for testing by coring with a 3-in.-OD diamond-studded, hollow-core bit. It was necessary to core each admix liner three times to help ensure duplicate test specimen values for each situation (test cell) because it was not possible to determine if a cored sample sheared during coring. This was not immediately detectable for two reasons: there was no discernible difference in the coring machine operation when shearing occurred and because the test cell had to be transported to an area where the base plate could be removed and the cored samples extracted. Since the bit was not allowed to penetrate the 6-in. soil layer more than 5-3/4 in. (to prevent damage to the base plate), the base plate had to be removed and 1/4 in. of the soil scraped away before the cored specimen could be removed and examined (Figure 14). Each specimen was trimmed as necessary for the

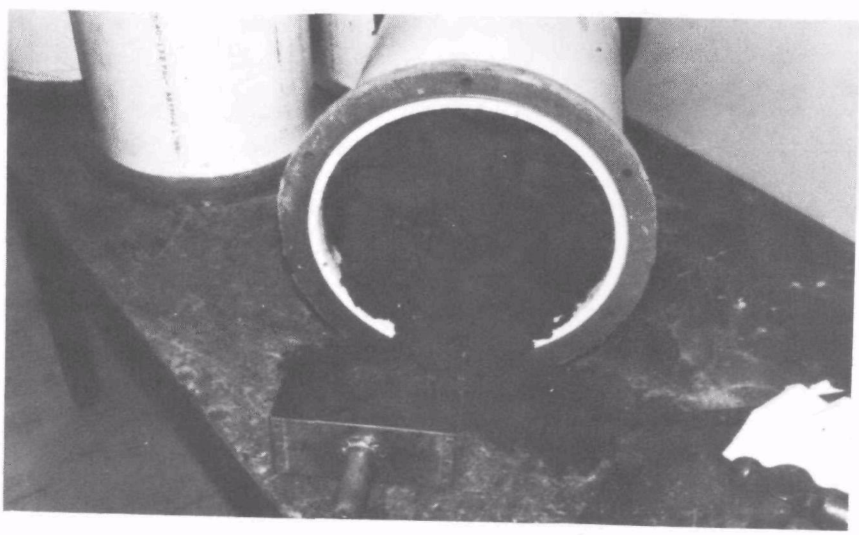


Figure 14. Soil being removed from bottom of test cell lined with TACSS 025.

unconfined compression test and the specimen was measured, weighed, and tested. Water contents were determined after testing in unconfined compression (Figure 15). These values and any pertinent observations are listed in Table 8. The zero time data for each liner are presented in Table 8 for ease of comparison with the 12-month data.

Nine of the admix liner materials were handled in this fashion. The tenth admix liner material, asphaltic concrete, was cored and the asphalt material was extracted (from the aggregate added initially and whatever infiltrated the liner). The percent asphalt was determined and the asphalt was examined for penetration and viscosity values. These data are listed in Table 8 with the corresponding zero times values. The permeability values of the admix liners will be discussed along with the spray-on and membrane liners since the permeability remarks apply to all three liner types.

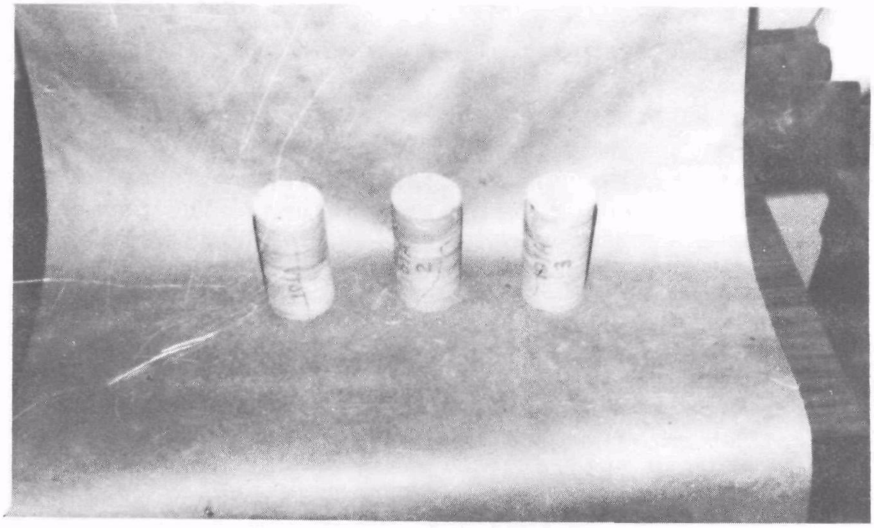
SPRAY-ON AND PREFABRICATED MEMBRANE LINERS

Following depressurization and the liquid/sludge removal above the spray-on and prefabricated membrane liner material, the silicone edge sealer was peeled from the test cell wall, and in the case of the prefabricated membrane, the liner was rolled back from the walls and removed. This was somewhat more difficult with the spray-on liners because the liquid penetrated the soil surface and formed a film that bonds to the soil. However, with care, it was possible to remove the spray-on liner from the soil surface. Gently washing the spray-on liner with aerated tap water removed the remaining loose soil particles and the sludge solids. Some soil particles were completely encapsulated and became part of the liner, and probably other soil particles/sludge solids not so completely bound resisted the cleaning efforts described above, but no further attempts were made to dislodge them for fear of inadvertently damaging the liner itself. The washed samples were cut into 4- by 6-in. grab test samples, measured (thickness) and weighed, and kept under tap water until four hours or less before the time of the actual grab test. These results are presented in Table 9.

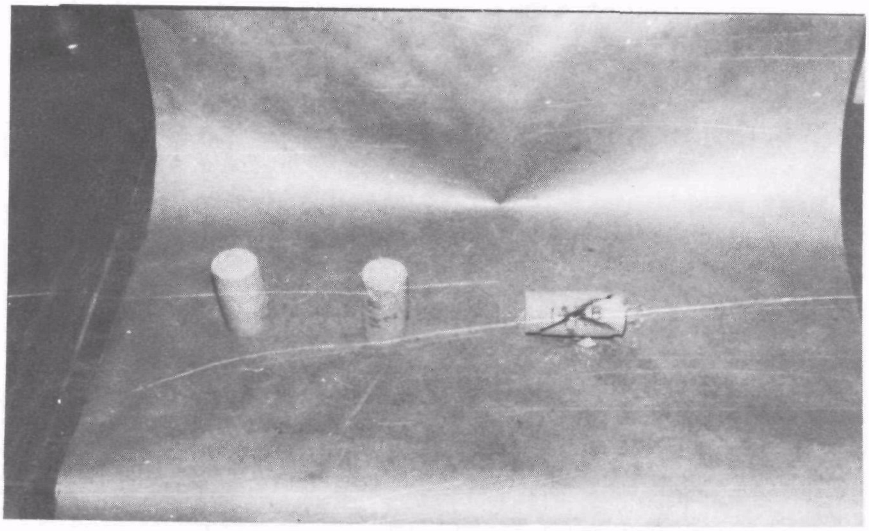
Five of the spray-on and two of the prefabricated membrane liners were handled in this fashion. The AC40 spray-on material formed a highly flexible film that could not be tested by the grab test method. Since the AC40 is an asphalt material, samples of it were taken and the asphalt content, penetration, and viscosity values determined (Table 9).

PERMEABILITY

Each test cell had its own collection system (see Figure 3), and any leachate from a test cell would exit through the drain port and proceed via plastic tubing to a plastic container. Each container was checked regularly, and the contents were noted for several reasons. First, even though a liner material might prove permeable, the permeability might be so low that the environment would remain essentially unaffected. Secondly, a permeable liner material could be a very effective filter and the chemical analysis of the leachate could show it to be of no consequence to the environment.



a. Portland cement



b. TACSS 020

Figure 15. Admix liner materials following 12 months of inundation and unconfined compression test.

TABLE 8. PHYSICAL TESTS - ADMIX LINERS

ID No.	Liner Material	Application Rate %	Water Content %	Dry Density lb/cu ft	Sample Height / Diameter H/D	Axial Strain ΔH/H, %	Unconfined Compression lb/sq in.	Permeability cm/sec x 10^{-6}	Remarks
000*	Clayey silt	n/a	16.6	103.5	2.051	3.1	38.4		Untreated soil - tested following 7 days humid cure.
080	Guartec UF	4	17.4	90.9	2.042	5.9	13.9		Eight test cells attempted - all leaked. Horrible odor developed, probably indicative of material breakdwon. Liner material poured from test cell - rejected. Too soft to test.
081A				TOO SOFT TO TEST				0.117	
081B									
100	Portland Cement	10	16.6	102.8	2.155	1.0	663		Very hard to core samples.
101A			21.0	103.0	2.094	1.0	1779	0.006	
101B			20.3	103.6	2.111	1.0	1893	0.001	
110	M179	4	13.2	103.9	2.009	n/a	<5		Same as Guartec above.
111A								0.156	
111B								0.084	
120	Lime	10	17.3	101.0	2.153	1.0	242		Very hard to core samples.
121A			20.1	100.8	2.073	1.0	1294	0.008	
121B			22.3	101.7	2.073	1.0	1200	0.010	
140	TACSS 020	6	16.2	106.3	2.154	6.3	179		Very hard to core samples.
141A			16.7	105.9	2.153	6.6	148	0.044	
141B			16.5	105.9	2.159	6.3	162	0.052	
150	Cement plus lime	4	16.1	104.1	2.172	1.0	503		2-psi back pressure failed to produce any bubbles that would indicate leaks.
151A		6	20.4	103.7	2.118	1.0	1297	0.009	
151B			20.1	104.4	2.063	1.0	1496	0.007	
160	TACSS 025	6	16.4	104.6	2.173	5.0	164		
161A			17.1	104.8	2.157	7.0	147	0.071	
161B			18.3	104.0	2.160	7.0	144	0.038	
170	C400	15	15.9	105.4	2.111	1.0	721		Very hard to core samples.
171A			20.3	104.2	2.106	1.0	1510	none	
171B			19.8	105.6	2.171	1.0	1294	0.003	
180	CST	15	14.4	105.2	1.792	1.0	1160		Very hard to core samples.
181A			19.0	106.2	2.118	1.0	1792	0.011	
181B			19.9	105.3	1.953	1.0	2091	0.004	

ID No.	Liner Material	Asphalt Content	Penetration, 0.1 mm	Viscosity, poises	Permeability, cm/sec x 10^{-6}
090	Asphaltic concrete	10.4%	60	2959	
091A	11% asphalt	11.2%	68	3749	0.298
091B	1/2-in. aggregate	10.3%	82	2945	2.805

* 0 - Control data, zero time.

TABLE 9. PHYSICAL TESTS - SPRAY-ON AND MEMBRANE LINERS

ID No.	Liner Material	Thickness in.	Weight gms	Density lb/cu ft	Application Rate lb/sq yd	Apparent Elongation %	Breaking Strength lb	Permeability cm/sec x 10^{-6}	Remarks
010*	Total liner	0.023	7.77	54.58	0.92	136	544		Leakage apparently developed between liner and
011A		0.022	9.10	63.66	1.07	573	158	0.120	sealant along 1/2-in. strip.
011B		0.025	9.80	62.98	1.15	464	134	0.265	
020	T16	0.018	8.95	75.75	1.04	26	482		Leakage developed in two places between liner
021A		0.018	15.38	88.77	1.77	25	345	0.226	and sealant. Total length of leaking strip
021B		0.017	16.62	94.35	1.95	28	374	0.063	approximately 1/2 in.
030	DCA-1295	0.219	112.44	81.42	13.42	172	127		The liner was discolored and apparently dis-
031A		0.177	65.14	88.95	7.76	95	47	0.368	solving from chemical attack; two small holes
031B		0.103	34.08	55.40	4.06	52	22	0.066	at liner edge, liner very thin elsewhere.
040	Dynatech	0.093	29.98	55.50	3.87	486	128		Liner and sealer separated and leak developed
041A		0.100	40.79	64.23	4.79	496	82	0.044	although sealer/cylinder bond was good.
041B		0.113	41.99	58.72	4.95	521	118		
050	Uniroyal	0.111	35.39	53.45	4.43	615	122		Liner and sealer separated approximately 3/4
051A		0.088	34.31	60.83	4.04	584	68	none	of the circumference of the liner.
051B		0.086	32.93	60.26	3.89	607	70	0.344	
060	Aerospray 70	0.158	80.77	82.27	9.74	235	106		Liner badly discolored and very thin in spots
061A		0.071	38.61	83.11	4.36	174	37	0.034	apparently due to chemical attack.
061B		0.096	96.00	165.88	11.34	55	34	0.040	
130	Sucoat				NOT AVAILABLE				Four discs 3/8 in. thick received from manu-
131A		0.420	320.83	120.32	37.88	6	225	0.085	facturer. All four used in test cells.
131B				LINER SHATTERED WHEN TEST CELL RUPTURED UNDER PRESSURE				0.064	

ID No.	Liner Material	Asphalt Content	Penetration, 0.1 mm	Viscosity, poises	Permeability cm/sec x 10^{-6}	Remarks
070	AC40	NA	49	8237		Leaked near the center of the liner. No
071A		19.5	42	14752	0.067	apparent leaks around sealant. Liner ruined
071B		27.6	42	13644	0.105	when removed.

* 0 - control data, zero time.

The coefficient of permeability of each liner material, k , was approximated using the formula $Q = kiAt$ where Q is the quantity of leachate collected; A, the area of the liner material exposed (for simplicity, the gross sectional area of the test cell was used, diameter = 11-13/16 in.); t , the time period in which leakage was collected; and i , the average hydraulic gradient during the time period t. The permeability values are tabulated in Tables 8 and 9.

FILTERABILITY

In order to assess the gross effects of liner behavior and liner composition on the liquid first released from a lined or unlined sludge pond, the first 32 oz of liquid issuing from each test cell was collected and analyzed chemically. Since duplicate test cells had been constructed for each liner, duplicate samples were available for each membrane type that passed liquid. The samples were collected over varying lengths of time, but care was taken to avoid contamination of samples from dust or evaporation by using narrow-necked plastic bottles with close-fitting collection tubes. Each sample was submitted for analysis as soon as 32 oz had been collected. The methods of chemical analysis are listed in Table 1. The chemical analyses of samples are given in Tables 10 and 11. Conductivity and pH values for the samples are given in Table 12.

These initial liquid samples (permeate water) consisted of a mixture of soil pore water, material from the membrane, and sludge liquor (the liquid that is a result of and saturated with the FGD sludges). Factors that affected the composition of the initial permeate water samples were the following:

a. Initial composition of the pore water in the soil.

b. Composition of any additional water added to the soil during the application of the liner material to be tested.

c. Composition of the sludge liquor.

d. Composition of material leached from or generated by the decomposition of the liner material.

e. Degree of mixing of soil pore water and permeating sludge liquor in the water sample.

The soil pore water had considerable effect upon the permeate composition. Approximately 0.4 cu ft of soil (40 to 50 lb) was used in each test cell. Moisture contents for the soils as used were between 13 and 17 percent by weight. Each soil sample, therefore, initially contained 96 to 128 oz of water. Two different soil samples were used. The composition of the pore water in the soils is best shown in the initial sample taken from linerless test cells (see Table 7).

During the installation of some spray-on or admixed liners, additional water was added to the soil. Part of this liquid was also expelled in the

TABLE 10. SUMMARY OF CHEMICAL ANALYSIS DATA
Sludge A
Leachate from Unlined Test Cells, Lined Test Cells, and EPA Allowable Values, mg/ℓ

Material	ID No.	Arsenic As	Beryllium Br	Cadmium Cd	Chromium Cr	Cyanide Cn	Copper Cu	Mercury Hg	Magnesium Mg	Manganese Mn	Nickel Ni
Silty sand											
No liner	2-100	0.003	<0.005	0.002	<0.001	0.029	0.013	<0.0002	65.1	<0.01	<0.005
Total liner	011A	<0.002	<0.001	<0.001	0.001	<0.005	0.003	<0.0002	82.4	<0.01	<0.005
	012A	0.007	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	108.5	19.3	0.022
T16	021A	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	111.3	15.3	0.019
	022A	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	103.4	<0.01	<0.005
DCA-1295	031A	<0.002	<0.005	<0.001	<0.001	0.010	<0.001	<0.0002	94.0	0.13	<0.005
	032A	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	123.8	<0.01	<0.005
Dynatech	041A	0.004	<0.001	<0.001	<0.001	0.055	<0.002	<0.0002	161.4	7.6	0.035
	042A	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	144.4	8.1	0.021
Uniroyal	051A	<0.002	<0.001	0.040	<0.001	<0.005	<0.002	<0.0002	83.3	8.0	0.019
	052A	<0.002	<0.005	<<0.001	<0.001	<0.010	0.001	<0.0002	106.0	0.06	<0.005
Aerospray 70	061A	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	0.0008	111.2	<0.01	<0.005
	062A	?*									
AC40	071A	<0.002	<0.001	<0.001	<0.001	<0.005	0.002	0.0004	95.7	<0.01	<0.005
	072A	?*									
Asphaltic Concrete	091A	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	167.0	10.6	0.023
	092A	?*									
Sucoat	131A	<0.002	<0.005	<0.001	<0.001	CI	0.001	<0.0002	100.0	<0.01	<0.005
	132A	<0.002	<0.005	<0.001	<0.001	CI	0.002	<0.0002	88.4	<0.01	0.013
Clayey silt	1-100	0.002	<0.005	0.002	<0.001	<0.01	<0.001	<0.0002	22.2	0.35	<0.005
Guartec UF	081A	<0.002	<0.001	0.042	0.056	CI	0.500	<0.0002	1431.0	1955.0	4.23
	082A	<0.002	<0.001	0.045	0.038	0.045	0.550	0.0002	1259.0	1788.0	3.46
Cement	101A	0.004	<0.005	<0.001	0.966	0.034	0.003	<0.0002	<0.10	<0.01	<0.005
	102A	0.003	<0.005	<0.001	0.769	0.079	0.015	<0.0002	<0.10	<0.01	<0.005
M179	111A	<0.002	0.010	<0.001	<0.001	<0.005	<0.002	<0.0002	101.5	1.3	0.025
	112A	<0.002	0.003	<0.001	<0.001	<0.005	<0.002	<0.0002	94.3	3.6	0.038
Lime	121A	<0.002	0.010	<0.001	0.015	0.048	0.013	<0.0002	<0.10	0.01	0.044
	122A	<0.002	<0.001	<0.001	0.029	0.065	0.015	0.0030	<0.10	0.01	0.044
TACSS 020	141A	0.002	0.008	0.004	<0.001	0.045	<0.002	<0.0002	263.3	23.8	0.025
	142A	<0.002	0.010	<0.001	<0.001	<0.005	<0.002	<0.0002	206.5	14.6	0.046
Cement/Lime	151A	0.004	0.011	<0.001	0.012	<0.005	0.030	<0.0002	<0.01	<0.01	0.052
	152A	0.002	<0.001	<0.001	0.042	0.035	0.014	<0.0002	<0.10	<0.01	0.042
TACSS 025	161A	0.002	0.013	<0.001	<0.001	<0.005	0.002	<0.0002	271.0	28.9	0.033
	162A	0.014	0.011	<0.001	<0.001	<0.005	<0.002	<0.0002	280.3	44.4	0.033
C400	171A	?*									
	172A	?*									
CST	181A	<0.002	0.012	<0.001	<0.001	0.151	0.093	<0.0002	<0.01	0.01	0.058
	182A	0.003	<0.005	<0.001	<0.019	0.150	0.188	<0.0002	<0.10	0.01	0.120
Values obtained from Ref. 9 and 10		0.05	0.11†	0.01	0.05	0.005‡	0.2§	0.002#	N/A	0.05	0.1†

* ? = Insufficient leakage to date (<<32 oz).
† Freshwater aquatic life criteria.
‡ Freshwater and marine organisms criteria.
§ Secondary standards proposed for drinking water criteria (EPA).
# Irrigation criteria.

(continued)

TABLE 10 (continued)

Material	ID No.	Lead Pb	Selenium Se	Zinc Zn	Sulfite SO_3	Sulfate SO_4	Boron B	Chloride Cl	Vanadium V	Nitrogen Nitrite NO_2, N	Nitrogen Nitrate NO_3, N
Silty sand											
No liner	2-100	0.006	E*	0.020	<1.0	241.0	14.7	83.0	0.021	14.3	75.6
Total liner	011A	0.01	<0.003	<0.001	<1.0	210.0	0.3	52.5	0.016	<0.01	18.0
	012A	<0.003	<0.003	0.002	<1.0	1320.0	5.8	150.9	0.035	<0.01	<0.05
T16	021A	0.014	<0.003	<0.001	1.0	1420.0	5.9	202.6	0.029	<0.01	<0.05
	022A	<0.003	<0.003	<0.001	<1.0	442.0	0.4	221.5	0.018	<0.01	0.15
DCA-1295	031A	0.019	E*	0.003	<1.0	371.0	1.4	209.0	0.020	<0.01	0.30
	032A	<0.003	<0.003	0.007	<1.0	624.0	0.6	170.0	0.016	<0.01	8.7
Dynatech	041A	<0.003	<0.003	0.001	1.0	1330.0	0.4	192.0	0.030	<0.01	<0.05
	042A	0.018	<0.003	0.001	<1.0	1190.0	6.6	236.3	0.038	<0.01	1.14
Uniroyal	051A	0.005	0.009	<0.001	<1.0	1430.0	5.5	204.7	0.031	<0.01	<0.05
	052A	0.008	E*	0.008	<1.0	346.0	<0.3	148.0	0.025	<0.01	0.22
Aerospray 70	061A	<0.003	<0.003	<0.001	<1.0	400.0	<0.3	108.8	0.011	0.15	5.0
	062A										
AC40	071A	0.008	<0.003	0.017	<1.0	218.0	<0.3	62.2	0.012	<0.01	<0.05
	072A										
Asphaltic Concrete	091A	<0.003	<0.003	0.004	<1.0	1080.0	6.5	460.5	0.040	<0.01	0.12
	092A										
Sucoat	131A	<0.003	E*	0.004	<1.0	615.0	<0.3	66.0	0.020	<0.01	<0.05
	132A	<0.003	E*	<0.001	<1.0	568.0	0.6	63.0	0.015	0.02	0.06
Clayey silt	1-100	0.010	E*	0.020	<1.0	42.0	1.1	95.0	<0.005	<0.01	0.33
Guartec UF	081A	0.074	<0.003	3.45	12.0	68.0	6.5	1495.0	0.410	CI	CI
	082A	0.095	<0.003	2.86	18.1	7.6	36.5	739.0	0.521	CI	CI
Cement	101A	<0.003	E*	<0.001	6.0	1079.0	<0.3	127.0	0.056	0.03	<0.05
	102A	0.017	E*	0.001	<1.0	7.0	<0.3	156.0	<0.005	0.53	0.20
M179	111A	0.005	<0.003	0.005	<1.0	1420.0	2.5	525.4	0.023	<0.01	0.38
	112A	<0.003	<0.003	0.004	<1.0	1430.0	3.4	348.1	0.026	<0.01	0.12
Lime	121A	<0.003	0.003	0.004	3.0	13.0	<0.3	32.1	<0.005	0.59	<0.05
	122A	<0.003	<0.003	0.004	4.0	>4.0	0.4	57.3	<0.005	1.00	0.42
TACSS 020	141A	<0.003	<0.003	<0.001	<1.0	460.0	2.8	485.3	0.042	<0.01	0.10
	142A	<0.003	<0.003	<0.001	<1.0	320.0	<0.3	504.3	0.033	<0.01	<0.05
Cement/Lime	151A	0.098	<0.003	<0.001	<1.0	<4.0	<0.3	10.6	0.040	<0.01	0.12
	152A	<0.003	<0.003	0.002	5.0	>4.0	0.4	23.3	<0.005	0.95	0.14
TACSS 025	161A	<0.003	<0.003	<0.001	3.6	640.0	4.6	490.6	0.053	<0.01	0.32
	162	<0.003	<0.003	<0.001	2.4	620.0	4.6	356.6	0.054	<0.01	0.38
C400	171A										
	172A										
CST	181A	<0.003	<0.003	<0.001	<1.0	6.0	<0.3	33.8	0.024	0.01	<0.05
	182A	<0.003	<0.003	0.006	<1.0	16.0	0.6	42.7	0.008	0.46	0.09
Values obtained from Ref. 9 and 10		0.05	0.01	5.0† Prop.	N/A	250.0† Prop.	0.75‡	250.0† Prop.	N/A	10.0	10.0

* E = equipment being repaired.
† Secondary standards proposed for drinking water criteria (EPA).
‡ Irrigation criteria.

TABLE 11. SUMMARY OF CHEMICAL ANALYSIS DATA
Sludge B
Sludge Solids, Sludge Liquid, Leachate from Lined
and Unlined Test Cells, and EPA Allowable Volumes, mg/ℓ

Material	ID No.	Arsenic As	Beryllium Be	Cadmium Cd	Chromium Cr	Cyanide Cn	Copper Cu	Mercury Hg	Magnesium Mg	Manganese Mn	Nickel Ni
Silty sand											
No liner		0.004	<0.005	0.003	<0.001	0.034	0.003	<0.0002	74.1	<0.01	<0.005
Total liner	011B	<0.002	<0.001	<0.006	<0.001	<0.005	0.002	<0.0002	136.5	0.4	0.015
	012B	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	140.6	3.9	0.008
T16	021B	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	158.5	1.0	0.007
	022B	?*									
DCA-1295	031B	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	87.4	<0.01	<0.005
	032B	0.006	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	131.8	13.3	0.019
Dynatech	041B	0.006	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	141.1	<0.01	<0.005
	042B	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	149.7	0.06	0.007
Uniroyal	051B	--†	<0.001	<0.001	<0.001	0.016	0.007	--†	59.0	0.54	0.020
	052B	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	70.3	9.9	0.019
Aerospray 70	061B	<0.002	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	108.4	0.04	0.005
	062B	<0.002	<0.001	<0.001	<0.001	<0.005	0.002	0.0008	133.3	<0.01	0.005
AC40	071B	<0.002	<0.005	<0.001	<0.001	<0.01	<0.001	<0.0002	103.0	<0.01	<0.005
	072B	<0.002	<0.005	<0.001	<0.001	<0.01	0.001	<0.002	92.6	<0.01	<0.005
Asphaltic Concrete	091B	0.004	<0.001	<0.001	<0.001	<0.005	<0.002	<0.0002	99.0	11.6	0.021
	092B	<0.002	0.004	<0.001	<0.001	<0.005	<0.002	<0.0002	122.7	0.5	0.010
Sucoat	131B	0.002	<0.005	<0.001	<0.001	CI	0.003	<0.0002	102.0	1.4	<0.005
	132B	?*									
Clayey silt	2-400	0.004	<0.005	0.003	<0.001	<0.01	0.003	<0.0002	20.0	<0.01	<0.005
Guartec UF	081B	0.006	<0.001	0.014	0.044	<0.005	0.450	<0.0002	1197.0	1766.0	5.0
	082B	0.007	<0.001	0.017	0.040	<0.005	0.467	<0.0002	1020.0	1416.0	2.05
Cement	101B	0.005	<0.005	<0.001	0.340	0.032	0.025	<0.0002	<0.10	<0.01	<0.005
	102B	?*									
M179	111B	<0.002	0.005	<0.001	<0.001	<0.005	0.005	<0.0002	113.3	0.06	0.029
	112B	<0.002	0.009	<0.001	<0.001	<0.005	0.003	<0.0002	109.4	1.1	0.031
Lime	121B	0.004	<0.005	<0.001	0.538	0.033	0.020	<0.0002	<0.10	<0.01	0.012
	122B	0.004	<0.005	<0.001	0.205	0.025	0.013	<0.0002	<0.10	<0.01	0.023
TACSS 020	141B	0.028	0.009	<0.001	<0.001	<0.005	<0.002	<0.0002	229.1	28.3	0.003
	142B	0.009	0.010	<0.001	<0.001	CI	<0.002	<0.0002	253.7	34.4	0.010
Cement/Lime	151B	0.002	<0.001	<0.001	0.039	0.022	0.017	0.0004	<0.10	<0.01	0.052
	152B	0.002	<0.005	<0.001	0.026	0.033	0.010	<0.0002	<0.10	<0.01	0.039
TACSS 025	161B	0.006	0.013	<0.001	<0.001	CI	<0.002	<0.0002	261.0	39.5	0.031
	162B	0.011	0.011	<0.001	<0.001	0.023	<0.002	<0.0002	299.2	50.1	<0.005
C400	171B	0.050	<0.005	<0.001	0.120	0.103	1.23	<0.0002	<0.10	<0.01	0.052
	172B	?*									
CST	181B	0.004	<0.005	<0.001	0.008	0.094	0.259	<0.0002	<0.10	<0.01	0.090
	182B	0.002	<0.005	<0.001	0.029	0.082	0.200	<0.0002	<0.10	<0.01	0.120
Values obtained from Ref. 9 and 10		0.05	0.011‡	0.01	0.05	0.005§	0.2	0.002#	n/a	0.05	0.1‡

NOTE: Chemical insufficient, could not be determined.
* ? = Insufficient leakage to date (<<32 oz).
† -- = Insufficient sample to analyze for all parameters.
‡ Freshwater aquatic life criteria.
§ Freshwater and marine organisms criteria.
# Secondary standards proposed for drinking water criteria (EPA).

(continued)

TABLE 11 (continued)

Material	ID No.	Lead Pb	Selenium Se	Zinc Zn	Sulfite SO_3	Sulfate SO_4	Boron B	Chloride Cl	Vanadium V	Nitrogen Nitrite NO_2, N	Nitrogen Nitrate NO_3, N
Silty sand											
No liner		0.005	E*	0.016	<1.0	297.0	7.4	78.0	0.018	31.6	47.5
Total liner	011B	<0.003	<0.003	0.002	<1.0	1510.0	46.1	204.7	0.036	<0.01	<0.11
	012B	<0.003	<0.003	0.001	<1.0	1280.0	35.6	200.2	0.030	0.12	0.08
T16	021B	<0.003	<0.003	<0.001	<1.0	1230.0	32.9	229.0	0.031	<0.01	<0.05
	022B										
DCA-1295	031B	<0.003	<0.003	<0.001	<1.0	167.0	3.8	135.0	0.013	0.30	<0.05
	032B	0.005	<0.003	0.002	<1.0	1490.0	28.2	135.0	0.034	<0.01	0.26
Dynatech	041B	0.006	<0.003	<0.001	1.0	910.0	18.8	170.9	0.027	<0.01	<0.05
	042B	0.016	<0.003	0.004	1.0	1300.0	44.0	208.9	0.037	<0.01	<0.05
Uniroyal	051B	0.008	<0.003	<0.001	<1.0	--†	22.5	--†	0.042	--†	--†
	052B	<0.003	<0.003	<0.001	<1.0	1520.0	33.2	181.5	0.044	<0.01	<0.05
Aerospray 70	061B	<0.003	<0.003	0.002	1.0	530.0	13.8	95.0	0.021	<0.01	0.10
	062B	<0.003	<0.003	<0.001	<1.0	226.0	4.3	135.9	0.013	<0.01	0.12
AC40	071B	0.005	E*	0.005	<1.0	342.0	2.7	73.0	0.025	0.66	1.41
	072B	0.017	E*	0.005	<1.0	340.0	2.1	50.0	0.019	<0.01	0.31
Asphaltic Concrete	091B	<0.003	<0.003	0.004	1.0	1500.0	37.8	227.9	0.045	<0.01	0.30
	092B	0.005	0.005	0.006	1.0	494.0	8.8	164.6	0.024	0.02	4.82
Sucoat	131B	<0.003	E*	0.009	<1.0	872.0	0.8	68.0	0.027	<0.01	<0.05
	132B										
Clayey silt	2-400	0.005	E*	0.026	<1.0	36.0	0.6	79.0	0.005	<0.01	<0.05
Guartec UF	081B	0.048	<0.003	2.79	10.1	100.0	28.0	685.7	0.500	CI	CI
	082B	0.030	<0.003	2.26	12.0	92.0	37.5	597.8	0.565	CI	CI
Cement	101B	<0.003	E*	<0.001	<1.0	117.0	0.3	151.0	0.013	0.05	<0.05
	102B										
M179	111B	0.009	<0.003	0.005	<1.0	1750.0	21.6	423.0	0.042	<0.01	0.11
	112B	0.009	<0.003	0.007	1.0	1560.0	10.7	580.2	0.039	<0.01	0.12
Lime	121B	0.007	E*	0.001	1.0	194.0	0.3	150.0	<0.005	0.07	<0.05
	122B	0.006	E*	<0.001	1.5	833.0	0.3	153.0	0.018	0.04	<0.05
TACSS 020	141B	<0.003	<0.003	0.001	1.0	340.0	6.1	622.4	0.041	<0.01	0.26
	142B	<0.003	<0.003	0.001	38.4	570.0	18.6	736.4	0.048	<0.01	0.38
Cement/Lime	151B	<0.003	<0.003	0.004	<1.0	4.0	0.4	19.4	0.006	0.15	<0.05
	152B	0.022	<0.003	0.002	5.0	20.0	0.4	29.1	0.006	0.03	<0.05
TACSS 025	161B	<0.003	<0.003	0.001	22.8	570.0	25.4	379.9	0.056	<0.01	<0.05
	162B	0.014	0.004	0.002	140.6	1290.0	45.4	643.5	0.090	<0.01	0.97
C400	171B	0.042	0.005	0.021	365.0	4560.0	1.4	462.1	0.271	<0.01	<0.05
	172B										
CST	181B	0.045	<0.003	0.003	10.0	29.0	0.3	77.7	0.007	0.57	0.15
	182B	0.007	<0.003	0.003	25.0	21.0	0.3	71.9	0.008	0.37	0.27
Values obtained from Ref. 9 and 10		0.05	0.01	5.0‡	n/a	250.0	0.75§	250.0‡	n/a	10.0	10.0

NOTE: Chemical insufficient, could not be determined.
* E = Equipment being repaired.
† -- = Insufficient sample to analyze for all parameters.
‡ Secondary standards proposed for drinking water criteria (EPA).
§ Irrigation criteria.

TABLE 12. SPECIFIC CONDUCTANCE AND pH VALUES

ID No.	Liner Material	Sludge A Specific Conductance µmhos/cm	Sludge A pH	Sludge B Specific Conductance µmhos/cm	Sludge B pH
	Silty sand (no liner)	1423	7.33	1642	8.18
011*	Total liner	2525	7.59	3061	7.43
012		2658	7.18	2928	7.81
021	T16	2729	7.16	2729	7.60
022		1683	7.86	†	†
031	DCA-1295	2104	7.51	1263	7.96
032		2020	7.70	2805	7.36
041	Dynatech	2623	7.50	2195	7.41
042		2885	7.40	2805	7.60
051	Uniroyal	1683	7.99	‡	‡
052		2805	7.46	3015	5.43
061	Aerospray 70	1712	7.80	1507	7.99
062		†	†	1629	7.67
071	AC40	1578	7.30	3061	7.36
072		†	†	1683	7.76
091	Asphaltic concrete	3367	7.48	3206	7.30
092		†	†	2104	7.50
131	Sucoat	1741	7.64	1870	7.72
132		1507	7.83	†	†
	Clayey silt (no liner)	721	7.42	652	7.39
081	Guartec UF	n/a	n/a	n/a	n/a
082		n/a	n/a	n/a	n/a
101	Cement	3150	11.65	4810	7.85
102		1485	11.13	4698	8.16

NOTE: 1. California Consumer-Acceptance Limits (1972) recommend a specific conductance of 800 with an upper limit of 1600 and maximum short term of 2400 µmhos/cm.

2. EPA water-quality criteria for Marine Aquatic Life require the pH range to be from 6.5 to 8.5.

* The A (e.g., 011A) values are in the column headed Sludge A and the B (e.g., 011B) are in the column headed Sludge B.

† Insufficient leakage for test.

‡ Insufficient sample.

(continued)

TABLE 12 (continued)

ID No.	Liner Material	Sludge A Specific Conductance µmhos/cm	Sludge A pH	Sludge B Specific Conductance µmhos/cm	Sludge B pH
111	M179	4391	7.83	4810	7.85
112		3885	7.69	4698	8.16
121	Lime	2730	11.71	3156	11.85
122		2149	11.29	3156	11.73
141	TACSS 020	3675	7.22	3741	7.40
142		2928	7.50	4040	7.28
151	Cement/lime	2525	11.50	1443	9.08
152		1804	10.41	1942	7.92
161	TACSS	3483	7.28	3258	7.66
162		2886	7.27	4122	7.19
171	C400	*	*	19423	12.00
172		*	*	*	*
181	CST	4810	11.20	5050	9.35
182		3607	9.57	4591	9.30

* Insufficient sample.

first 32-oz sample submitted for analysis. The composition or amount of additional water is not directly determinable, and it varied with the nature of the liner and the application rate of liner material.

During the testing of the liner materials, the simulated head (compressed air) was forcing the liquid or liquor associated with the FGD sludges through the liner and into the soil. Two different FGD sludges were used in this testing program, but the liquids associated with them were quite close in composition. The liquid was alkaline (pH 9-10.3) and saturated with gypsum and calcium carbonate. The chemical compositions of these liquids are given in Tables 10 and 11.

SECTION 9

ANALYSIS AND DISCUSSION OF RESULTS

This section presents the results of the project at the midpoint of the study. The discussion includes results of physical tests and chemical analyses at the initial stage (zero time) and at the end of the 12-month exposure period.

PHYSICAL TESTS

General

In reviewing the physical test data, the three types of liner materials should be kept in mind: admixed materials, spray-on materials, and prefabricated membrane materials. Unconfined compression tests (6) were used to study the effects of 12-month inundation/pressurization of the admixed liners, whereas grab tests (7) were employed to study similar effects on the spray-on and prefabricated membrane liners. Neither of these tests would yield very meaningful data for asphaltic concrete or asphalt cement liners. Tests of these two liner materials were concentrated on the asphalt cement itself. Density, penetration, and viscosity of the asphalt cement were determined as a means of ascertaining deterioration.

Admix Liners

The results of the physical tests on the admix liners are shown in Table 8. The results shown are for both the zero and 12-month exposure times. Two of the materials, Guartec UF and M179, were obviously incompatible with either of the sludges as a complete breakdown of the liners occurred. The two materials are considered unsatisfactory for the stated use, and further tests have been discontinued. The moisture content in all samples increased slightly, indicating some liquid infiltration, although the dry density remained about the same during the 12-month period, which would indicate that the soil structure was not changed. Five of the materials, Portland cement, lime, Portland cement plus lime, C400, and CST, exhibited considerable increases in unconfined compressive strengths. The strength in general almost doubled; however, in the lime admix, the strength increased almost six times the initial strength.

Normally, at least in the case of silty clay stabilized with 10 percent lime, the UC strength can be observed to increase from 150 psi after a 7-day cure to approximately 400 psi after 36 weeks cure (14). Undoubtedly, other soil types would also have similar UC versus cure time curves with greater UC values. Although very little is known about the C400 and CST materials, they were reported to be very similar to cement with additional additives. These unusually high strengths will be closely compared with the 24-month data.

A photo series (Figures 16, 17, and 18) of the asphaltic concrete liner shows two extensive surface cracks (Figure 16). Covering the liner with water and applying back pressure only produced bubbles at the intersection of the two cracks (Figure 17). A close-up of this liner shows the relative size of the two cracks (Figure 18).

Figure 16. Asphaltic concrete liner surface showing extreme cracking.

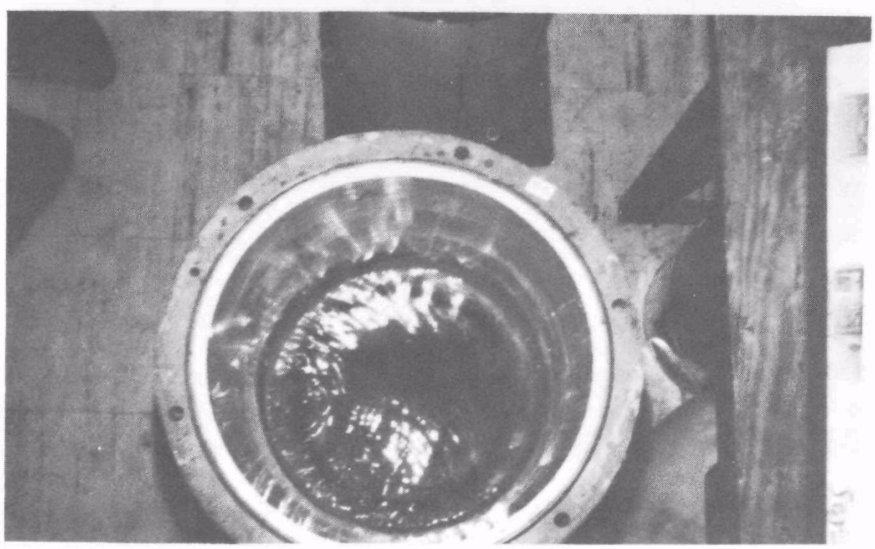


Figure 17. Asphaltic concrete liner with sludge removed, approximately 1-in. water added, and 2-psi back pressure applied.

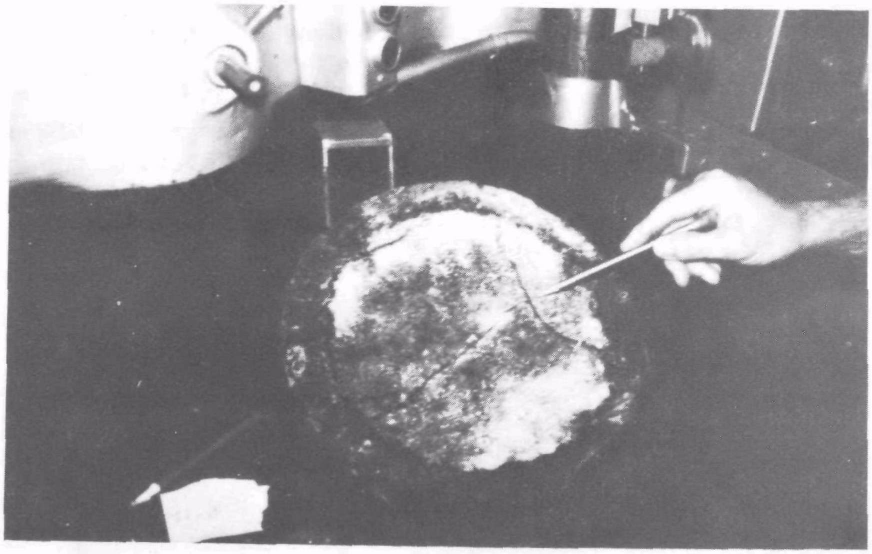


Figure 18. Close-up of cracks in asphaltic concrete liner. Discolored area around periphery indicates area covered by silicone sealant.

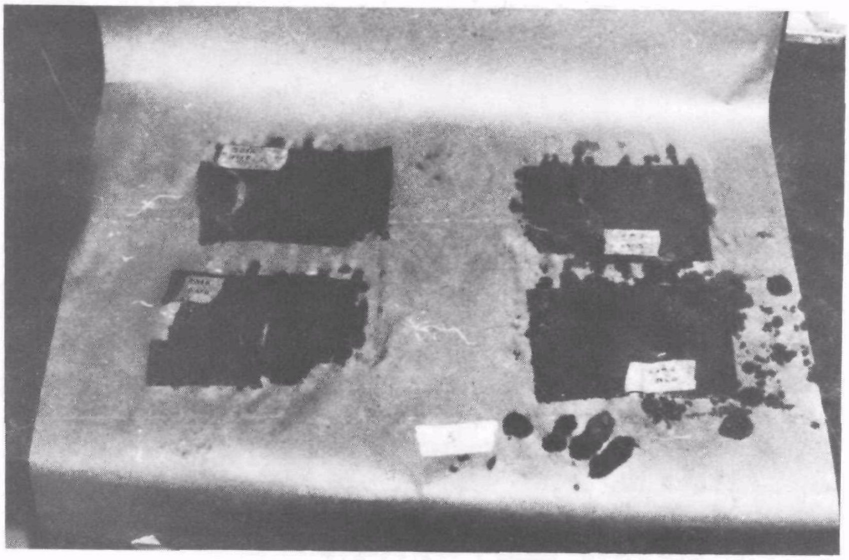
TACSS 020 and 025 both suffered 5 to 25 percent decrease in UC, which would seem to indicate some degree of susceptibility to continuous exposure that could only be expected to get worse with time. Much more can be determined when the 24-month test results are analyzed.

Spray-on and Prefabricated Membrane Liners

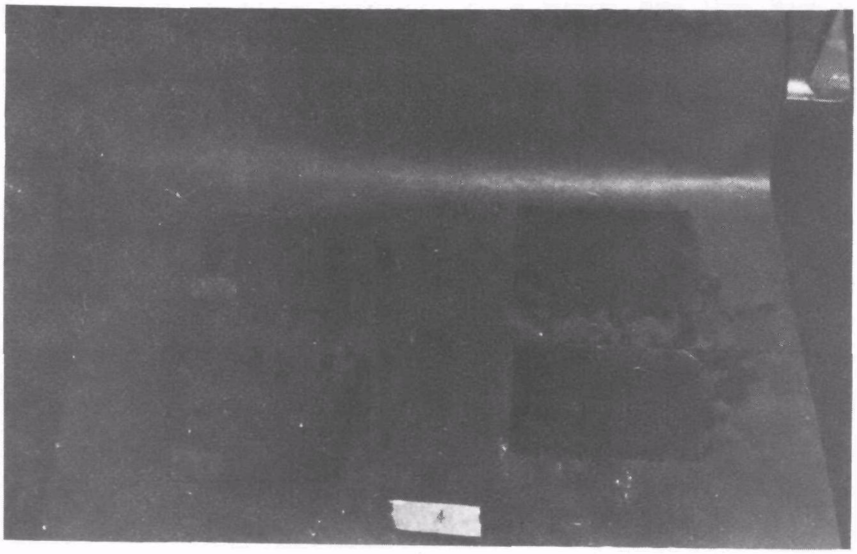
The results of the physical tests on the spray-on and membrane liners are shown in Table 9. Without exception, the breaking strengths of the liners decreased with exposure time. The percent elongation varied somewhat; it increased significantly for total liner and decreased significantly for DCA-1295 and Aerospray 70. It remained essentially constant for T16, Dynatech, and Uniroyal. Figure 19 shows DCA-1295 and Uniroyal after 12-month grab tests. The AC40 test cells did not pass any liquid until two-thirds of the way through the test period. Following teardown, a hole was observed in one liner near the center. The liner fell apart while it was being removed from the test cell. No zero data have been obtained for the Sucoat liner materials, and one test cell ruptured during the 12-month period. No evidence of chemical attack could be observed on the one remaining liner. Figure 20 shows the prefabricated membrane total liner after 12-month grab test.

CHEMICAL TESTS

The initial permeate water samples taken during this testing program also may contain any leachable constituents from the liners. In many cases, the effects of material lost from the liners cannot be seen because of the very concentrated liquor from the FGD sludges and normal background chemistry of the water associated with the soils. There are, however, some exceptions. For example, Guartec, an organic product derived from the guar bean, obviously decomposed and became putrescent. The resulting reducing conditions appear to have released manganese, or caused manganese in the soil to go into



a. DCA-1295



b. Uniroyal

Figure 19. Spray-on liner materials samples following 12 months of inundation and grab test.

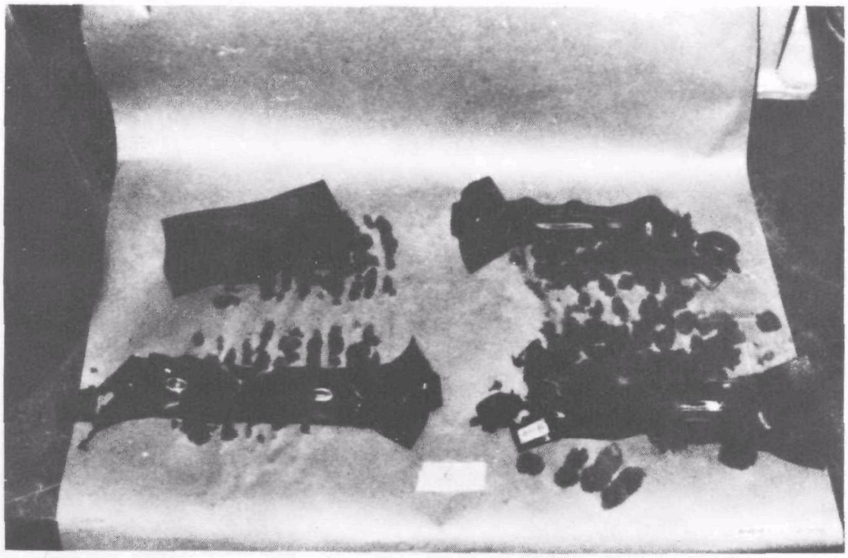
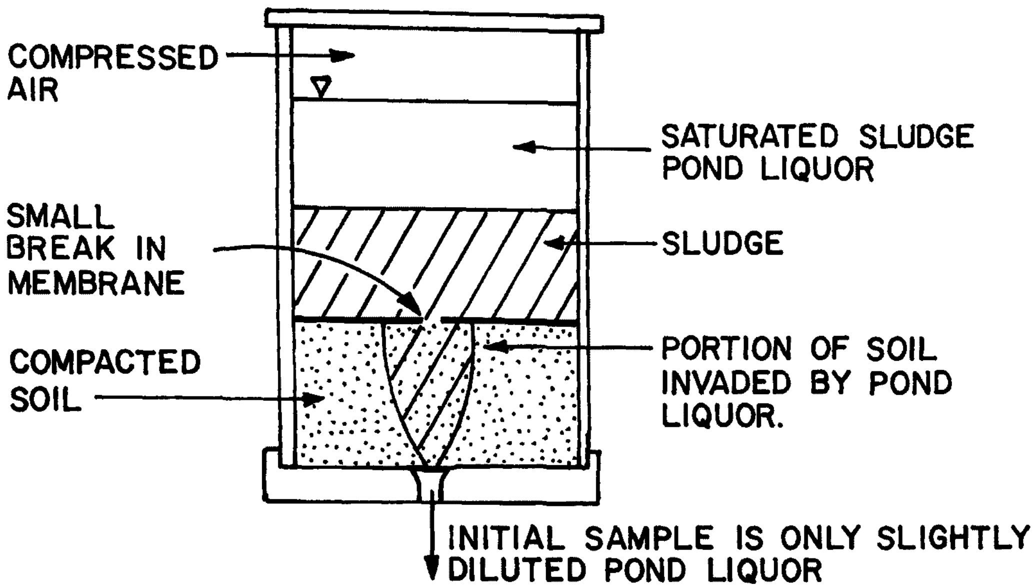


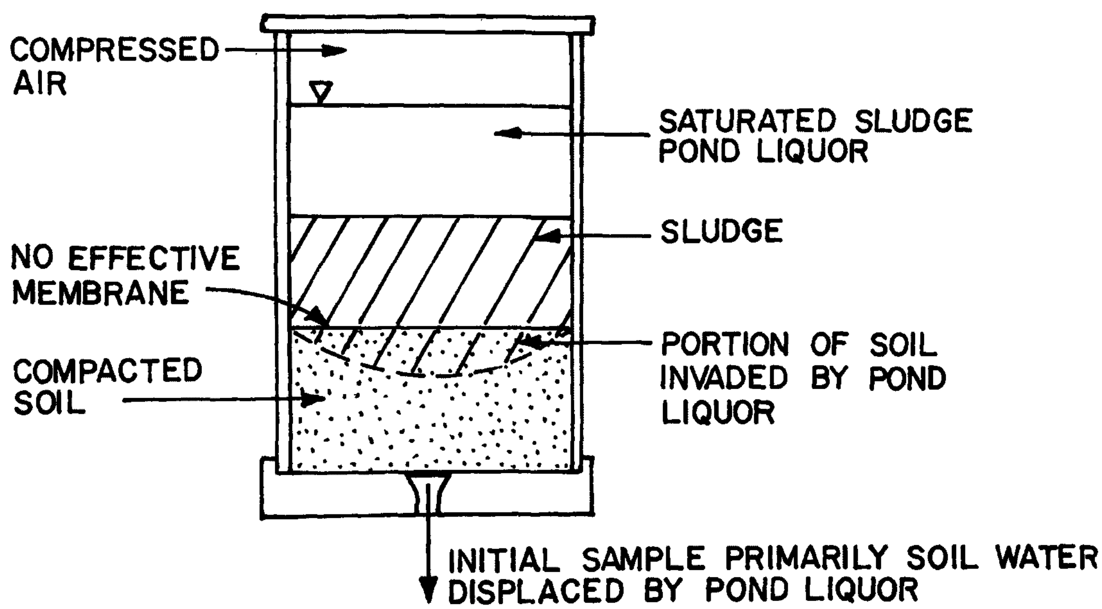
Figure 20. Prefabricated membrane total liner material samples following 12 months of inundation and grab test.

solution. The manganese levels in the liquid from the Guartec UF test cells are an order of magnitude greater than those of other test cells. This occurred in all sets of test cells with both Sludges A and B. Guartec UF, along with TACSS 020 and TACSS 025, released levels of magnesium higher than observed in other samples. Locally, acidic conditions may have developed in these admixes due to decay (in the case of Guartec UF) or reactions with plasticizers (in the case of TACSS 020 or TACSS 025).

The first 32 oz of water collected from each test cell represents the first liquid that would be passing down into the saturated zone and mixing with the groundwater. This initial contribution arriving at the water table is a mixture of sludge liquor, materials from the liner, and displaced interstitial water (pore water) from the soil. The extent of mixing of the concentrated solution from the sludge and soil water is directly related to the location of the soil mass that is invaded by the infiltrating sludge liquor. The leakage from a small rupture in a test membrane will seep directly through the soil under the leak (Figure 21a), and by displacing only small amounts of soil pore water, will have a composition near to that of the sludge liquor plus any contaminants from the membrane. For a test cell with no membrane or with a membrane passing liquid over a broad area, a shallower mass of soil is invaded initially, and the first liter of liquid reaching the test cell outlet is primarily displaced soil pore water (Figure 21b). Thus, if the membrane passes water over the entire cross section of the test cell and sludge liquor moves through the entire soil/sludge interface, the initial permeated water sample will be very close to pore water in composition. The configuration of the leak by which sludge liquor passes through the membrane is probably the most decisive factor in determining the composition of the initial 32-oz water sample.



a. Small rupture in membrane.



b. Large rupture in membrane.

Figure 21. Pattern of leakage from membrane ruptures.

The concentration of a chemical constitutent such as chloride, which is not effectively attenuated by soil, is an important indicator of how the sludge liquor is moving through the membrane. Tables 13 and 14 list the liners in order of increasing chloride content from initial permeate water samples. The spray-on liners AC40 and Sucoat both show low chloride levels in the intial liquid samples from Sludges A and B, suggesting that liquid was moving through the membrane along the entire cross section of the test cell. This hypothesis is borne out by observations made on the condition of the liners after the 12-month exposure. The AC40 liner developed a large leak in the center and had deteriorated so badly that it could not be removed intact from the test cell. The Sucoat liner had fractured and too little material was available for postexposure testing. In the admixed materials, the cement/lime and CST liners show very low chloride levels with Sludges A and B, again suggesting uniform permeation across the area of the test cell. Neither of these materials showed evidence of local small leakage when the cells used for 12-month exposure were examined.

As liquor continues to pass through these liner materials, the composition of the discharge from the test cells will approach the composition of the sludge liquor. In a typical sludge pond situation the decomposition products from the liner should be a minor problem compared to the high levels of pollutants in the ponded sludges. This study indicates that the characteristics of the leak are an important facet of the initial effect of the contained sludge liquor on the groundwater. However, if the liner fails, ultimately the full impact of sludge contamination will be felt.

TABLE 13. LINER MATERIALS ON SILTY SAND LISTED IN ORDER OF INCREASING CHLORIDE CONTENT

Liner Material	Test Cells for Sludge A Avg Cl, ppm	Liner Material	Test Cells for Sludge B Avg Cl, ppm
AC40	62	AC40	62
Sucoat	65	Sucoat	68
No liner	83	No liner	78
Total liner	102	Aerospray 70	115
Aerospray 70	109	DCA-1295	135
Uniroyal	176	Uniroyal	182
DCA-1295	190	Dynatech	190
T16	212	Asphaltic concrete	196
Dynatech	214	Total liner	202
Asphaltic concrete	460	T16	224
Sludge liquor	675	Sludge liquor	670

TABLE 14. LINER MATERIALS ON CLAYEY SILT LISTED IN ORDER OF INCREASING CHLORIDE CONTENT

Liner Material	Test Cells for Sludge A Avg Cl, ppm	Liner Material	Test Cells for Sludge B Avg Cl, ppm
Cement/lime	17	Cement/lime	24
CST	38	CST	75
Lime	45	No liner	79*
No liner	95*	Cement	151
Cement	142	Lime	152
TACSS 025	424	C400	462*
M179	437	M179	502
TACSS 020	495	TACSS 025	512
Sludge liquor	675	Guartec UF	642
Guartec UF	1117	Sludge liquor	670
		TACSS 020	679

* Single sample.

REFERENCES

1. U. S. Environmental Protection Agency. Report to Congress on Hazardous Waste Disposal. SW-115, Cincinnati, Ohio, 1973.

2. Haxo, H. E., and R. M. White. First Interim Report, Evaluation of Liner Materials Exposed to Leachate (unpublished). U. S. Environmental Protection Agency, Cincinnati, Ohio, 1974.

3. Haxo, H. E., and R. M. White. Second Interim Report, Evaluation of Liner Materials Exposed to Leachate. EPA-600/2-76-255, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1976.

4. Haxo, H. E., R. S. Haxo, and R. M. White. First Interim Report, Liner Materials Exposed to Hazardous and Toxic Sludges. EPA-600/2-77-081, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1977.

5. Geswein, A. J. Liners for Land Disposal Sites, An Agreement. EPA-530/SQ-137, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1975.

6. American Society for Testing and Materials. Tests for Unconfined Comprehensive Strength of Cohesive Soils. In: 1978 Annual Book of ASTM Standards, Part 19, Designation: D 2166-66, Philadelphia, Pennsylvania, 1978.

7. American Society for Testing and Materials. Tests for Breaking Load and Elongation of Textile Fabrics. In: 1978 Annual Book of ASTM Standards, Part 32, Designation: D 1682-64, Philadelphia, Pennsylvania, 1978.

8. Mahloch, J. L., D. E. Averett, and M. J. Bartos, Jr. Pollutant Potential of Raw and Chemically Fixed Hazardous Industrial Wastes and Flue Gas Desulfurization Sludges. EPA-600/2-76-182, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1976.

9. Tate, C. H., and R. R. Trussell. Developing Drinking Water Standards. Journal of the American Water Works Association, 69(9): 489-492, 1977.

10. Quality Criteria for Water. EPA-440/9-76-023, U. S. Environmental Protection Agency, Cincinnati, Ohio, 1976, 500 pp.

11. Department of the Army. Engineer Manual EM 1110-2-1906: Laboratory Soils Testing. Prepared by U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1970

12. Wilson, S. D. Small Soil Compaction Apparatus Duplicates Field Results Closely. Soil Testing Services, Inc., Chicago, Illinois (undated brochure).

13. Styron, C. R., III, and R. C. Eaves. Investigation of Dust-Control Materials. Prepared by U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi, 1973.

14. Yoder, E. J., and M. W. Witczak. Principles of Pavement Design. John Wiley and Sons, Inc., New York, 1975.

APPENDIX A

MANUFACTURER/ADDRESS FOR THE SELECTED LINER MATERIALS

Material	Manufacturer/Address
Type I Portland Cement	Local Distributor
Hydrated Lime	Local Distributor
Cement with Lime	Local Distributor
M179	Dowel Division of Dow Chemical
Guartec UF	General Mills
Asphaltic Concrete	Local Contractor
TACSS 020	Takenaka Komuten Co. (Japan)
TACSS 025	Takenaka Komuten Co. (Japan)
C400	Takenaka Komuten Co. (Japan)
CST	Takenaka Komuten Co. (Japan)
DCA-1295	Union Carbide
Dynatech Formulation 267	Dynatech R&D Co.
Uniroyal	Uniroyal Inc.
Aerospray 70	American Cyanamid
AC40	Globe Asphalt
Sucoat	Chevron Chemical Co.
Total liner	Goodyear Tire & Rubber Co.
T16	Reeves Brothers, Inc.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-79-136	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE FLUE GAS CLEANING SLUDGE LEACHATE/ LINER COMPATIBILITY INVESTIGATION Interim Report		5. REPORT DATE August 1979 (Issuing Date)
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Clarence R. Styron III and Zelma B. Fry, Jr.		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Geotechnical Laboratory U.S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi 39180		10. PROGRAM ELEMENT NO. 1DC818, SOS1,Task27;1NE624,COS,SOX 4
		11. CONTRACT/GRANT NO. IAG-D5-0785
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory--Cin.,OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		13. TYPE OF REPORT AND PERIOD COVERED Interim April 15-September 77
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer: Robert E. Landreth (513) 684-7871

16. ABSTRACT

This project was initiated to study the effects of two industrial waste materials on 18 items used to contain these wastes. Seventy-two test cells, 1 ft in diameter and 2 ft high, were fabricated. Ten items were mixed with a clayey silt and compacted in the bottom 6 in. of the test cell; six spray-on and two prefabricated membrane items were placed over 6 in. of compacted soil. Four gallons of sludge were added to each test cell and enough tap water to bring the liquid to within 4 in. of the top of the test cell. Each test cell was covered and pressurized to simulate 30 ft of head.

This report lists and discusses the data following 12 months of inundation of each item with both sludges. Portland cement, cement plus lime, and C400 when mixed with the soil resulted in a significant reduction in permeability.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Linings Permeability Waste Disposal Air Pollution Electric Power Generation Sludge	Soil Sealants Emission Control Membrane Liners Solid Waste Management	13B

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS *(This Report)* UNCLASSIFIED	21. NO. OF PAGES 75
	20. SECURITY CLASS *(This page)* UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

☆ U.S. GOVERNMENT PRINTING OFFICE: 1979 -657-060/5410