United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

Research and Development

EPA-600/S2-81-098 July 1981

EPA

Project Summary

Effect of Flue Gas Cleaning Sludges on Selected Liner Materials

Clarence R. Styron, III, Zelma B. Fry, Jr., and Gordon L. Carr

This project examines the effects of two flue gas desulfurization (FGD) sludges on 18 liner materials used to contain them. Seventy-two special test cells were constructed 1 ft in diameter by 2 ft high. Devices were installed to collect the leachate from each test cell to determine the leakage and the leakage rate (permeability) and to provide storage for subsequent chemical analyses.

Ten admix liner materials were mixed with a clayey silt and compacted in the bottom 6 in. of the test cells. Six spray-on and two prefabricated membrane liners were placed over 6 in. of compacted silty sand. Four gal of sludge was then added to each test cell along with enough tap water to bring the liquid to within 4 in. of the top. Each test cell was covered and 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 after 12 and 24 months of exposure. Chemical tests for determining heavy metals were conducted on the two sludges as received and on the sludge liquor that passed through the lined test cells after 12 and 24 months.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at the back).

Introduction

Ground and surface water contamination resulting from improper disposal of hazardous wastes is a growing public concern. Controlling the leachate from such wastes by providing an impervious liner for the disposal area could be a solution to the problem, and it would allow for the use of more sites as disposal areas. The use of liners for such purposes is not a new concept, but knowledge is lacking on the compatibility of liner materials with certain toxic wastes and, particularly, on the life expectancy of such liners. Much information is needed to supply guidance and possible future regulations for using liners in waste disposal areas.

The objectives of this study were to determine the compatibility of liner materials with flue gas desulfurization (FGD) sludges, to estimate liner life, and to assess the economics of purchasing and placing various liners. To meet these objectives, specimens of a variety of potential liner materials were exposed to selected FGD sludges over a period of time under conditions that simulated disposal areas and changes in the physical properties of the liner material with exposure time were determined.

Considerations in selecting liner candidates were low cost and ease of placement and construction. Primary attention was focused on the use of admixed or stabilized in situ liner materials. Spray-on materials were also considered, and some use was made of prefabricated membrane liners (the latter are being tested extensively in other projects.[1-3]

The first step was to select two FGD sludges representative of those that would be found in disposal areas. Next, 18 types of liners (Table 1) were selected as potentially usable with FGD sludges. Test cells were then designed and constructed to simulate disposal conditions involving a sludge depth of at least 30 ft so that sludge could be applied in increments over time. Liners were then exposed for 12- and 24-month periods, after which physical tests were conducted to determine liner behavior over time. Any accumulated leachate was collected and measured for quantity and quality. Finally, cost data were developed for the liners.

Methods and Materials

Design and Construction of Test Cells and Ancillary Equipment

Design Factors

Factors considered in the design of the test cells were construction or installation methods,[4] size or amount of specimen required for physical tests after exposure periods, cell volume sufficient to contain the liner and sludge, and means of simulating a 30-ft sludge depth.

A decision was made to test each liner with 6 in. of compacted soil—the minimum practicable for stabilizing admixes and for limiting differential soil movement under spray-on and membrane liners. The size of each liner specimen was determined by the number and types of tests following the exposure period. Duplicate specimens were also used for determining unusual test results. Pressurization was considered the most feasible approach to simulating a 30-ft sludge depth. The use of pressure (20 psi) permitted minimum amounts of other materials to be used, including sludge.

Table 1. *Selected Liner Materials*

ID No.	*Material Name and Type**	*Percent/Description/Type*
	Admix Liner Material:	
12	*Lime*	*Hydrated ASTM C 141-67†*
10	*Portland cement*	*Type I ASTM C 150-78‡*
15	*Cement with lime*	*4 percent Type I Portland cement* *6 percent hydrated lime*
11	*M179*	*4 percent polymer, bentonite blend*
08	*Guartec UF*	*4 percent light gray powder*
09	*Asphaltic concrete*	*11 percent asphalt cement* *1/2 in. (max.) aggregate*
14	*TACSS 020*	*6 percent blackish-brown liquid*
16	*TACSS 025*	*6 percent blackish-brown liquid*
17	*C400*	*15 percent finely ground powder*
18	*CST*	*15 percent finely ground powder*
	Spray-on Liner Material:	
03	*DCA-1295*	*3/4 gal/yd^2 polyvinyl acetate*
04	*Dynatech*	*3/4 gal/yd^2 natural rubber*
05	*Uniroyal*	*3/4 gal/yd^2 natural latex*
06	*Aerospray 70*	*3/4 gal/yd^2 polyvinyl acetate*
07	*AC40*	*3/4 gal/yd^2 asphalt cement*
13	*Sucoat*	*As-supplied molten sulphur*
	Prefabricated Membrane Liner:	
01	*Total Liner*	*As-supplied elasticized polyolefin*
02	*T16*	*As-supplied black chloroprene-coated nylon*

** For manufacturer/address, see Appendix A of full report.*

† Standard Specifications for Hydraulic Hydrated Lime for Structural Purposes. In: 1978 Annual Book of ASTM Standards, Part 13, Designation: C141-67 (rev 78). Philadelphia, Pennsylvania, 1978.

‡Standard Specifications for Portland Cement In: 1978 Annual Book of ASTM Standards, Part 14, Designation: C150-78. Philadelphia, Pennsylvania, 1978.

Test Cell Construction

Seventy-two test cells were fabricated from polyvinyl chloride (PVC), which was selected as an inert material that would not react chemically with the FGD sludge. Schedule 80 PVC pipe (ID 11-3/16 in.) with a pressure tolerance of 130 psi was selected for the pressure cells. The PVC base was 2-1/2 in. thick and 15 in. square. The PVC top was 15 in. in diameter and 3/8 in. thick. A schematic view of the test cell is shown in Figure 1. 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.

Ancillary Equipment

Ancillary equipment consisted of a system for pressurizing the test cells and a system for collecting the leachate (Figure 1).

FGD Sludge Selection and Characteristics

Sludges were selected from an eastern coal lime-scrubbed process (Sludge A) and from an eastern coal limestone-scrubbed process (Sludge B). Samples were obtained from disposal ponds at the plant sites. Sludge A had 47.6 percent solids and a pH of 10.3, and Sludge B had 34.2 percent solids and a pH of 9.0. A chemical analysis of the sludges appears in Table 2 along with EPA allowable limits. With few exceptions, the two sludges are very similar in composition.

Soil Material and Liner Selection and Properties

Soil selections were based primarily on results of previous investigations. A highly permeable soil was considered most applicable for evaluating membrane and spray-on liners because it would permit any leakage of the liners to be readily detectable. But the admix materials required a less permeable soil to minimize the amount of admix needed. A silty sand was thus selected to evaluate the membrane and spray-on liners, and a clayey silt was used to evaluate the admix liners. These soil types are considered representative of typical soils

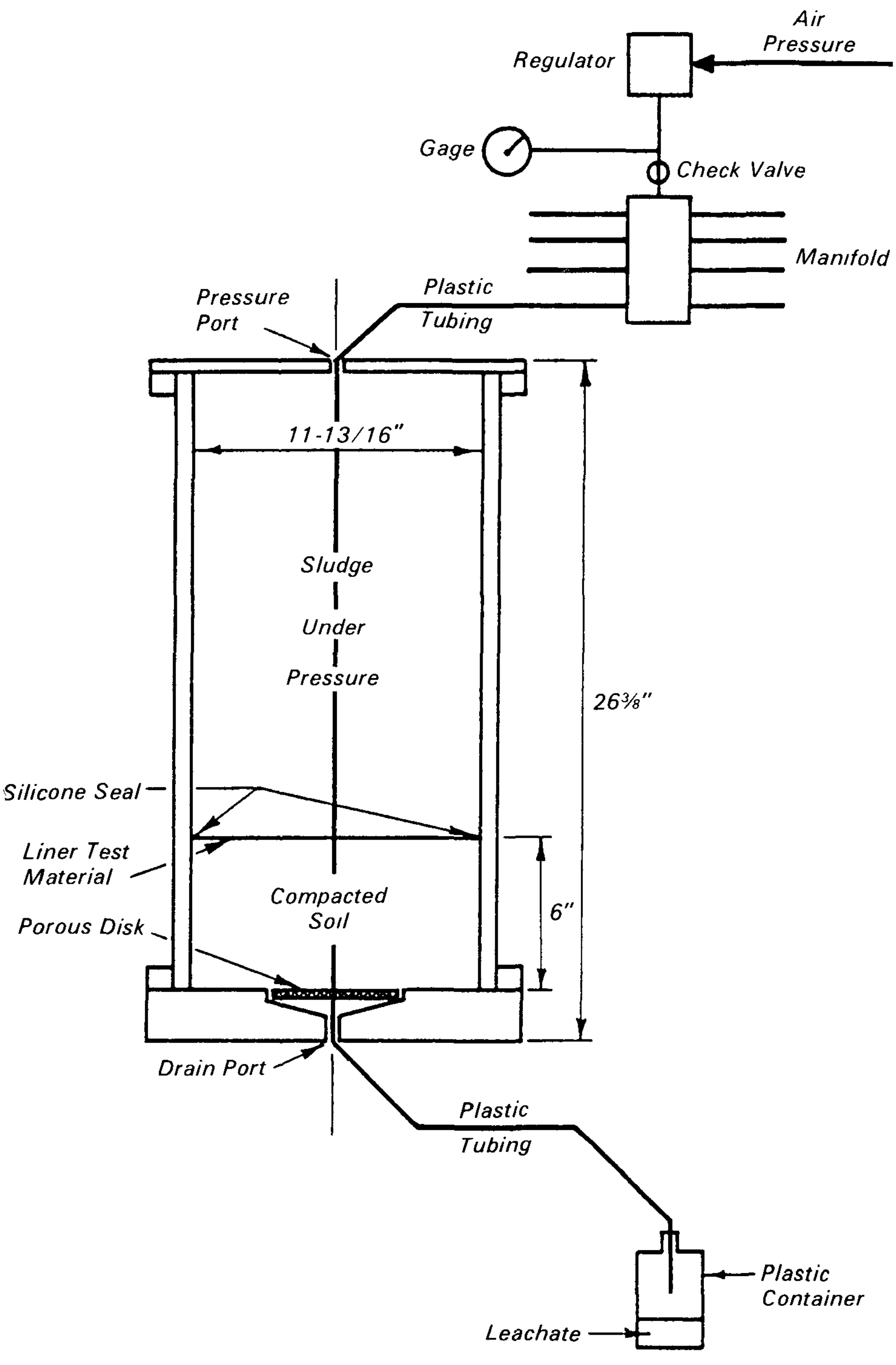

Figure 1. *Schematic of a test cell section with a spray-on or membrane liner depicted and ancillary equipment.*

that might be encountered in a disposal area.

Liner selection was based on results of permeability tests. Admix liner materials were prepared and compacted in a Harvard miniature test apparatus.[5] Spray-on liners were applied to the surface of soil specimens that had been prepared and compacted in the Harvard miniature mold. Both admix and spray-on liners were allowed to cure for 7 days under humid conditions. A 2-ft constant head was maintained on the liners, and permeability was measured by collecting water that permeated through the specimen over a period of time. The prefabricated membrane materials were tested for leakage (pinholes) or other abnormalities by covering the bell-shaped end of a 21-in. standpipe with a sample of each liner and allowing water to stand in it for 15 to 20 days. Leakage was collected in a container beneath the device.

Results

Physical Tests

Unconfined compression (UC) tests were used to study the effects of 12- and 24-month inundation/pressurization of the admix liners, and grab tests were used to study these effects on the spray-on and prefabricated membrane liners.

Admix Liners

Physical tests of the admix liners were made for the 0-, 12-, and 24-month exposures. Two of the materials (Guartec UF and M179*) suffered a complete breakdown at the end of 12 months and further testing was discontinued.

Moisture contents in all samples increased slightly during the first 12 months and generally remained about constant at 24 months, indicating some initial liquid infiltration. But the dry density remained about the same during the 2-year period, which would indicate that the soil structure had not changed.

During the first 12 months, the UC strength of the Portland cement, Portland cement plus lime, C400, and CST almost doubled, whereas the lime strength increased nearly six times. At 24 months, the UC strength of the Portland cement and CST remained unchanged; but the Portland cement plus lime and the C400 increased an additional 8 to 10 percent, and the lime increased an additional 20 percent. Thus the results indicated that the performances of the C400 and CST liners were similar to that of Portland cement.

Increases in UC strength after curing time would be expected for silty clay and lime as well as for other soil types, but the TACSS 020 and 025 lost 14 and 12 percent UC strengths, respectively, at the end of 12 months. At the end of 24

*Mention of trade names of commercial products does not constitute endorsement or recommendation for use by the U S Environmental Protection Agency

Table 2. Chemical Analysis of Sludges and EPA Allowable Limits

	Sludge A		*Sludge B*		
Parameter	*Sludge Solids (mg/kg)*	*Sludge Liquid (mg/L)*	*Sludge Solids (mg/kg)*	*Sludge Liquid (mg/L)*	*EPA Allowable Limits* (mg/L)*
Arsenic	*0.28*	*0.003*	*0.16*	*0.003*	*0.05*
Beryllium	*6.8*	*0.005*	*1.25*	*<0.005*	*<0.011†*
Cadmium	*0.005*	*0.001*	*0.007*	*<0.001*	*0.01*
Chromium	*133.0*	*0.001*	*33.3*	*<0.001*	*0.05‡*
Cyanide	*—§*	*0.012*	*—*	*0.018*	*0.005*
Copper	*0.85*	*0.009*	*0.38*	*0.010*	*0.2***
Mercury	*0.44*	*0.002*	*0.84*	*0.002*	*0.002*
Magnesium	*3030.0*	*10.1*	*5160.0*	*13.8*	*NA††*
Manganese	*84.8*	*2.3*	*43.7*	*0.95*	*0.05*
Nickel	*0.84*	*<0.003*	*0.38*	*0.003*	*0.1‡*
Lead	*1.08*	*<0.003*	*0.68*	*0.003*	*0.05*
Selenium	*1.38*	*<0.003*	*2.15*	*0.007*	*0.01*
Zinc	*135.0*	*0.002*	*278.0*	*0.002*	*5.0***
Sulfite	*190.0*	*<1.0*	*200.0*	*<1.0*	*NA*
Sulfate	*—*	*1281.0*	*68750.0*	*2100.0*	*250.0*
Boron	*385.0*	*14.0*	*185.0*	*71.2*	*0.75‡‡*
Chloride	*1330.0*	*675.0*	*300.0*	*670.0*	*250.0***
Vanadium	*162.0*	*—*	*53.0*	*—*	*NA*
Nitrite, nitrogen	*<0.04*	*<0.01*	*<0.04*	*<0.01*	*10.0*
Nitrate, nitrogen	*3.0*	*0.5*	*3.0*	*0.51*	*10.0*

**From References 9 and 10 in full report.*

†Freshwater aquatic life criteria.

‡Freshwater and marine organisms criteria.

§— = Insufficient sample to analyze for all parameters.

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

††NA = Not available.

‡‡Irrigation criteria

months, the TACSS 020 lost an additional 11 percent (a total of 25 percent, based on zero-time data), and the TACSS 025 dissociated when cored, thus yielding no data.

The penetration of the asphaltic concrete increased approximately 10 percent at 12 months and remained constant at 24 months. The viscosity, however, increased approximately 13 percent at 12 months but decreased more than 16 percent after 24 months. Extensive surface cracks developed in this liner after 12 months.

Spray-On and Prefabricated Membrane Liners

Physical test results of the spray-on and membrane liners indicated that after 12 months of exposure, the breaking strength of all the liners decreased, and the DCA-1295 continued to lose strength at 24 months. Although the overall strength of the liners had decreased considerably by the end of the 24-month period, values were slightly higher at the end of 24 months than they had been at 12 months for the Total Liner, T16, Uniroyal, and Dynatech.

The percent of elongation values for the Total Liner material increased approximately 400 percent the first year and remained constant during the second year. The elongation values for the T16, Dynatech, and Uniroyal generally remained constant throughout the 2-year test period. At 24 months, the Aerospray 70 reversed its 12-month pattern by increasing, and the DCA-1295 continued decreasing the second year.

Chemical Tests

The first 32 oz of liquid issuing from each test cell was collected and analyzed chemically to assess the gross effects of liner behavior and liner composition. These initial liquid samples consisted of a mixture of soil pore water, material from the liners, and sludge liquor.

Material lost from the liners cannot be seen in most cases because of the concentrated liquor from the FGD sludges and normal background chemistry of the water associated with the soils. Some exceptions, however, include Guartec UF, TACSS 020, and TACSS 025, all of which released levels of magnesium and manganese higher than those observed in most samples. This release may have resulted from acidic conditions that developed in these admixes because of decay (in the case of Guartec) or from reactions with plasticizers (in the cases of TACSS 020 and 025).

The concentration of a chemical constituent such as chloride, which is not effectively attenuated by soil, is an important indicator of how the sludge liquor is moving through the membrane. Low chloride levels suggest that the sludge liquid is moving uniformly through the membrane along the entire cross section of the test cell. This hypothesis is borne out by observations made on the liner conditions after 12 months.

Permeability

Because some leakage was caused by the silicone seals, permeability values were influenced and in many cases invalidated. Thus the only permeability data reported are those for liners that permitted no leachate to pass or for liners that were obviously attacked by the chemical sludges.

Summary of Liner Performance

Recorded data for physical tests and chemical analyses indicate that the following comments are valid and pertinent.

1. *Total Liner.* The density increased 26.2 percent following exposure, and the breaking strength decreased 72 percent. These figures indicate that the polymer was compacted and its strength was greatly reduced. The liner material was still soft and pliable, and it appeared to be in good condition.
2. *T16.* The density increased 14.5 percent, indicating some compaction of the polymer; but there was little or no change in the breaking strength. Some small, crusty formations were observed on the liner/sludge interface.
3. *DCA-1295.* The average density of this liner material decreased slightly (3.3 percent), but both the elongation and the breaking strength decreased significantly. Visual inspection revealed that this liner was discolored and very

thin. The liner was very easily torn while it was being removed from the test cell.

4. *Dynatech.* A 17.3-percent increase in density indicates some sludge infiltration into the sprayed material or compression of the polymer, but the other physical data remained essentially unchanged. Discoloration noted could be due to chemical attack during the testing.
5. *Uniroyal.* A 17.2-percent increase in density indicates some compression of the polymer and incorporation of sludge; the breaking strength decreased 40 percent. Liner discoloration noted could indicate susceptibility to chemical attack.
6. *Aerospray 70.* A 33.3-percent increase in density indicates considerable sludge incorporation and polymer compaction. The breaking strength decreased 57 percent, although one of these test cells did not pass any leachate. Discoloration and thin spots were observed throughout the liner. Decomposition was noted on the membrane/soil interface.
7. *AC40.* The physical tests performed on this liner material made it difficult to detect any chemical degradation of the liner. The average viscosity appeared to be very high at the end of the first 12 months, but this figure had returned to nearly the original value by the end of 24 months. Leachate from these test cells was passing through the liner material itself. Chemical data indicate that this leachate contained four to six times the concentrations of chromium, selenium, boron, and sulfate at 24 months than at 12 months.
8. *Asphaltic concrete.* These physical tests were identical to those for AC40 and essentially the same comments are appropriate.
9. *Portland cement.* The density of this liner material remained essentially unchanged, but the UC strength increased 175 percent. Chemical data indicate that leachate from the test cell contained approximately seven times higher concentrations of sulfite and sulfate at 24 months. The liner was soft and friable in isolated areas.
10. *Lime.* The 1.1-percent increase in density of this liner material may indicate slight sludge infiltration or compaction of the liner, but it is more likely that this change represents a normal variation in density across the specimen. The UC values of this liner increased 464 percent. Chemical data indicate the leachate from the test cell contained 5 to 20 times higher concentrations of chromium and boron after 12 months, whereas the concentrations of magnesium, sulfate, nitrite, and nitrate were as much as 150 times lower.
11. *Sucoat.* This liner was supplied preformed by the manufacturer, and it apparently suffered no chemical decomposition. One test cell ruptured under pressure and was discontinued. Chemical data indicate that leachate from the test cell contained twice the concentrations of magnesium and sulfate, five times the concentration of boron, and 100 times the concentrations of nitrite and nitrate at 24 months than at 12 months. The breaking strength was reduced 16 percent at the end of 24 months.
12. *TACSS 020 and TACSS 025.* Neither of these two liner materials evidenced any change in density other than the change normally expected during a typical construction procedure. Sludge penetrated the surface of the liner more than 3/8 in. on each liner type.
13. *Portland cement plus lime.* No significant change in density occurred during the 24-month test (+0.3 percent). Chemical data indicate that the leachate through the liner contained approximately 40 times the concentration of chromium at 12 months than at 0 months, whereas the concentration of magnesium decreased approximately 0.01 times, and the concentrations of nitrite, nitrate, and sulfate decreased 0.01 to 0.001 times. The UC strength increased 187 percent.
14. *C400.* No significant change in density occurred during the 24-month test (+0.3 percent). The UC strength increased 106 percent. The chemistry of the leachate through the test cell indicates that approximately three times the concentrations of arsenic and boron and 20 times the concentrations of chromium and selenium were detected at 24 months than at 12 months. Indications were that the copper and lead concentrations also increased.
15. *CST.* No significant change in density occurred during the 24-month test (+0.3 percent). The UC strength increased 63 percent. The chemical concentration of the leachate at 12 months increased approximately 20 to 100 times for sulfate and nickel, respectively. Concentrations decreased by a factor of 0.001 for nitrite and nitrate and by approximately 0.01 for magnesium.

No definite trends were established from these tests that would permit the projection of liner life with any degree of accuracy.

Economic Assessments

Assessments were made of costs involved with purchase and placement of various liner materials. Estimates were based on a typical 15-acre lagoon that can accommodate 30 ft of water. The• cost of the land and the initial preparation (grubbing, clearing, digging, etc.) are not considered here, as they are site specific. For the 15 acres, costs for admix liner materials ranged from $150,000 for Portland cement, lime, and Portland cement plus lime to $4,300,000 for TACSS 025. Costs for spray-on and membrane liner materials ranged from $33,000 for AC40 to $1,350,000 for Sucoat. Total installation cost for placing the prefabricated membrane liners was estimated at $38,154. This cost included laborers, operators, equipment, fuel, and mobilization. The largest part of this cost occurred in unfolding, stretching, and placing the liners—30 laborers at a cost of $10,080. Construction costs for admix liners vary with the type of material and location.

The full report was submitted in fulfillment of Interagency Agreement EPA-IAG-D5/6-0785 between the U.S. Environmental Protection Agency and the U.S. Army Engineer Waterways Experiment Station.

References

1. 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.

2. 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.
3. 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.
4. Geswein, A.J. Liners for Land Disposal Sites; An Agreement. EPA-530/SQ-137, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975.
5. Wilson, S.D. Small Soil Compaction Apparatus Duplicates Field Results Closely. Soil Testing Services, Inc., Chicago, Illinois (undated).

Clarence R. Styron, III, Zelma B. Fry, Jr., and Gordon L. Carr are with the U.S. Army Engineers Waterways Experiments Station, Vicksburg, MS 39180.
***Robert E. Landreth** is the EPA Project Officer (see below).*
The complete report, entitled "Effect of Flue Gas Cleaning Sludges on Selected Liner Materials," (Order No. PB 81-213 365; Cost: $9.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
Municipal Environmental Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

☆ U S GOVERNMENT PRINTING OFFICE 1981 757-012/7246

United States
Environmental Protection
Agency

Center for Environmental Research
Information
Cincinnati OH 45268

Postage and
Fees Paid
Environmental
Protection
Agency
EPA 335

Official Business
Penalty for Private Use $300

RETURN POSTAGE GUARANTEED

[redacted]

PS 0000329
U S ENVIR PROTECTION AGENCY
REGION 5 LIBRARY
230 S DEARBORN STREET
CHICAGO IL 60604