FINAL REPORT

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND INSTALLING COVER AND BOTTOM LINER SYSTEMS FOR HAZARDOUS WASTE FACILITIES

VOLUME I
DATA BASE DEVELOPMENT: PERSPECTIVES OF INDUSTRY EXPERTS, STATE REGULATORS, AND OWNERS AND OPERATORS

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ABSTRACT

This effort is part of a broader effort to collect "real world" and up-to-date information for use by EPA in its regulatory reform review of the sections of the July 1982 interim final land disposal regulations pertaining to liners for hazardous waste management facilities. Interviews were conducted with some 40 individuals/organizations representing a spectrum of viewpoints/interests and having expertise in various aspects of selection, design, manufacturing, fabrication, and installation of liners (primarily flexible membrane liner or FML and clay liner). This compendium presents the opinions expressed by those interviewed on topics which include: (1) clay and FML systems used in hazardous waste land disposal application; (2) factors/problems associated with manufacturing, fabrication, installation, etc., which impact liner performance, and recommended changes to mitigate problems; (3) research and development needs for addressing problems; and (4) role of regulations and regulatory needs. The information collected during the interviews is primarily the opinions of those interviewed and is reported here without any change or an attempt by the authors or EPA to interpret or analyze the opinions expressed or to present opposing views.

The opinions collected indicate a reasonable consensus on the following points:

- The technology and know-how currently exist to produce installed liners that will not fail. Such technology and know-how, however, are not necessarily always employed in actual practice primarily due to: (1) inadequate familiarity of many users and permitting agencies with potential problems and mitigation measures; (2) failure of the user to consider factors other than cost in selecting contractors; (3) lack of adequate communication among all parties involved; and (4) absence of an effective quality assurance/quality control program at all steps leading to the development of a completed installation.

- Because of the involvement of fewer steps/parties and the more developed state-of-the-art for clay liners, construction of such liners presents fewer and more manageable problems. There is a general

agreement, however, that a clay-FML combination system can offer the most protection.

- Most liner failures can be traced to inadequate designs. Next to design, installation (especially field seaming of FML sheets) is the most critical factor in developing an adequate installation.

- There is a lack of long-term engineering data on the performance of both clay and FML in field installations, and there exists a need for documentation and analysis of design and installation practices which have led to failures and successes of actual installations.

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This compendium presents the views of a sampling of liner material suppliers, manufacturers, fabricators, designers, and installers; technical experts and researchers at academic and research institutions; trade associations; technical staff at state regulatory agencies; and owners and operators of hazardous waste management facilities. TRW wishes to express its deepest gratitude to the individuals/organizations listed in Tables 2 through 6 who made this project feasible by fully cooperating with the study via granting of interviews and reviewing the draft interview reports.

Special thanks are due to Mrs. Monique Tholke for her invaluable secretarial support to the project.

1. BACKGROUND, OBJECTIVE, AND SCOPE

The Environmental Protection Agency's Office of Solid Waste is currently engaged in a review of the Part 264 land disposal regulations (promulgated in July 1982 as Interim Final Regulations) to determine if there are areas where regulatory reform would be appropriate. One of the areas which is being reviewed relates to the requirement for liners (and covers) for new land disposal facilities which stipulates prevention of the migration of waste during the active life of a facility and minimization of the migration during the post-closure care period. The liner requirement review effort involves primarily a detailed examination of the efficacy of flexible membrane liners (FML), clay and other types of liners (and caps) used in various locations to minimize groundwater contamination.

The present effort, which has been carried out under a work assignment contract for EPA's Office of Solid Waste, has had as its objective the development of a technical data base for the evaluation of the ability of current manufacturing, fabrication, design, construction, and installation practices to produce clay, FML, and other types of liners meeting the performance standards stipulated in the interim regulations. More specifically, the data base is to be used to answer the following:

- Can liners be installed near design conditions so that they will not fail?
- Are such liners actually installed near design conditions?

To ensure the incorporation of "real world" data and up-to-date information in the data base for liner capability evaluation, the data base development effort has emphasized data acquisition from technical experts and individuals/organizations engaged in actual manufacturing, fabrication, design and installation of liners, and in operation and regulation of hazardous waste management facilities. To this end, face-to-face discussions have been conducted with a relatively large sample of individuals/organizations representing

a spectrum of viewpoints/interests and having expertise in various aspects of liner selection, design, etc. This report presents the opinions of individuals/organizations interviewed on topics such as:

- Use of clay and FML systems in hazardous waste land disposal application.
- Factors/problems associated with manufacturing, fabrication, etc., which impact liner performance, and recommended changes to mitigate problems.
- Research and development needs for addressing problem areas.
- Role of regulations and regulatory needs.

Many of the individuals who were interviewed saw a great need for systematic and continual transfer of information on the latest developments in liner technologies, design advances, and R&D needs to the user community (designers, installers, permitting agencies, owners/operators of disposal sites, researchers, etc.). To this end, this compendium can serve as an important step toward the goal of promoting exchange of opinions among agencies/organizations with interest in various aspects of hazardous waste management. As a result of the preparation of this compendium, important contacts have been developed and a dialogue has been established with key experts and various interested parties. Steps should thus be taken to maintain and expand these contacts and dialogue so that this compendium can be periodically updated in the future.

This compendium is organized into four major sections: Section 1 (this section) reviews the background for and the intended use(s) of this document. Section 2 describes the methodology for data acquisition and identifies individuals/organizations providing input to the compendium. Section 3 is an overview of the information collected during interviews. Reports on individual interviews are presented in Section 4.

It should be noted that the perspectives expressed in this compendium constitute merely one input to an analysis which draws upon a much broader data base, including results of many recent EPA-sponsored studies and other published literature which might contradict (or support) certain opinions expressed by the interviewees. In line with this consideration and other

possible uses of the document, the opinions collected during the interviews are presented in this compendium without any change or discussion, and hence, no attempt has been made to analyze views expressed or to present opposing viewpoints on certain controversial assertions. Some technical analysis of a number of points raised relating to liner installation, compatibility, and failure mechanisms can be found in Volume II of this document and in the final reports being prepared for EPA by Research Triangle Institute (Research Triangle Park, NC) and Arthur D. Little, Inc. (Cambridge, MA) in connection with two companion liner studies.

2. INDIVIDUALS/ORGANIZATIONS INTERVIEWED AND DATA ACQUISITION METHODOLOGY

The initial identification of potential interviewees was via review of the literature and discussions with the EPA Project Officers and the technical staff at EPA's Solid and Hazardous Waste Research Division in Cincinnati, OH. The potential interviewees were then contacted ("screened") by telephone to gauge their interest in the study and the type and relative value of their potential inputs. Mutually agreeable dates for the interviews were then set and subsequently confirmed in formal letters. With each letter a copy of the "work plan", which provided a more elaborate description of the study and its objectives, was enclosed. A copy of the typical letter is reproduced as Table 1.

The individuals/organizations interviewed are listed in Tables 2 through 6, broadly grouped into the following categories:

- Suppliers, manufacturers, fabricators, designers, and installers of FML, clay, and other liners.
- Owners/operators of hazardous waste management facilities.
- State regulatory agencies.
- Researchers in academic and research organizations.
- Trade/professional associations and standards setting organizations.

The categorization in the tables is for presentation purposes only since, in some cases, an organization may be involved in or represent more than one category. Within each table, the interviewees are listed in chronological order of the interviews. Overall, a total of 39 interviews were conducted. Except for three telephone discussions, the interviews involved face-to-face discussions which took place in a very informal atmosphere. In most cases, more than one individual represented the participating organization.

TABLE 1. TYPICAL INTERVIEW DATE CONFIRMATION LETTER

TRW

T300-MG-83-008
19 January 1983

Mr. Gary Sherlaw
National Sanitation Foundation
3475 Plymouth Road
Ann Arbor, MI 48105

Dear Mr. Sherlaw:

This is with reference to our telephone conversation of today, confirming our meeting scheduled for 9 00 AM, 28 January 1983, in your office in Ann Arbor. Our purpose is to obtain technical information and your perspectives on various aspects of the manufacture, fabrication, and installation of liners. This information will be used in an EPA study, the work plan of which is enclosed for your review.

As mentioned to you in our conversation and described in more detail in the enclosed work plan, it is the objective of the subject study to develop the technical data base for use by EPA in its review of the Part 264 land disposal regulations promulgated July 26, 1982, to determine if there are areas where regulatory reform would be appropriate. The review would particularly address the requirements for liners and covers for new land disposal units. Under the new regulations, the migration of wastes must be prevented during the active life of a unit, and minimized during the post-closure care period.

The subject study will seek to develop the data base needed for the evaluation of the ability of current manufacturing, construction, and installation practices to produce clay, synthetic membrane, and other types of liners to meet the above performance standards. To ensure an objective evaluation based on "real world" data and sound technical rationale, in developing the data base we are supplementing the information in the published literature with updated data acquired through discussions with a spectrum of individuals/organications representing different viewpoints/interests and having expertise on various aspects of liner design, construction, and installation. It is to this end that we are soliciting your participation in and input to our data base development effort.

I trust that you will find the enclosed work plan of help to you in explaining the nature and objective of our study, and I look forward to meeting with you.

Sincerely,

Masood Ghassemi, Ph.D., P.E.
Senior Project Engineer
Mail Station: R4/1142

MG/mt

Enclosure

C: A. Otte (EPA/OSW; Washington, DC)
C. Wiles (EPA/MERL; Cincinnati, OH)

ENVIRONMENTAL DIVISION ENERGY DEVELOPMENT GROUP OF TRW INC. • ONE SPACE PARK REDONDO BEACH, CALIFORNIA 90278 • (213) 535-2107

TABLE 2. SUPPLIERS, MANUFACTURERS, FABRICATORS, DESIGNERS, AND INSTALLERS OF FML, CLAY, AND OTHER LINERS INTERVIEWED

Company and Address	Interviewee(s) and Telephone Number	Date of Interview	Background/Expertise	Interview No.
Schlegel Lining Technology, Inc. 200 S. Trade Center Parkway P. O. Box 7730 The Woodlands, TX 77380	James Price, Morris Jett, Robert Clarke, Jan Braun (713) 350-1813	14 December 1982	Manufacturer and installer of high density polyethylene FML.	A-1
Sta-Flex Corporation 4917 New Ramsey Court San Jose, CA 95136	Louis Peloquin (408) 224-0604	14 December 1982	FML installer.	A-2
Burke Rubber Company 2250 South 10th Street San Jose, CA 95112	D. Kutnewsky Ralph Woodley (408) 297-3500	16 December 1982	FML manufacturer and fabricator.	A-3
Gundle Lining Systems, Inc. 1340 East Richey Road Houston, TX 77073	Richard Schmidt (713) 443-8564	17 December 1982	FML manufacturer.	A-4
Watersaver Company, Inc. 5870 E. 56th Avenue P. O. Box 16465 Denver, CO 80216	Bill Slifer (303) 623-4111	17 December 1982	FML fabricator.	A-5
E.I. DuPont de Nemours & Co. 10 S. 224 Terry Trail Hinsdale, IL 60521	Gerald Fisher (312) 485-6881	18 January 1983 31 January 1983	Supplier of raw elastomers for FML.	A-6
M Putterman & Co. 2221 West 43rd Street Chicago, IL 60609	Jack Moreland (312) 927-4121	24 January 1983	FML fabricator.	A-7
American Colloid Company 5100 Suffield Court Skokie, IL 60077	Christopher Jepsen Robert Massini (312) 966-5720	26 January 1983	Supplier of bentonite clay; markets bentonite admixture liner.	A-8

(Continued)

TABLE 2. (Continued)

Company and Address	Interviewee(s) and Telephone Number	Date of Interview	Background/Expertise	Interview No.
Woodward-Clyde Consultants 11 East Adams Chicago, IL 60603	Jean-Pierre Giroud (312) 939-1000	27 January 1983	Dr Giroud is a leading expert on FML design.	A-9
Roy F Weston* Weston Way Westchester, PA 19380	Amir Metry (215) 692-3030	31 January 1983	Liner design experience.	A-10
Slurry Systems 7100 Industrial Avenue Gary, IN 46406	Frank Zlamal (219) 949-0561	2 February 1983	Designer, constructor, and installer of bentonite liner and asphalt emulsion slurry walls and spray-on liners.	A-11
B.F Goodrich P. O. Box 657 Marietta, OH 45750	Richard Ward (614) 373-6611	4 February 1983	Material supplier, manufacturer, fabricator, and installer of FML.	A-12
The Pantasote Company of New York, Inc * 26 Jefferson Street Passaic, NJ 07055	Larry Kamp (201) 277-8500	6 February 1983	FML manufacturer.	A-13
Gulf Seals 601 Jefferson, Suite 558 Houston, TX 77002	William Way Ralph Crumbliss (713) 759-0861	7 February 1983	FML installer.	A-14
Arizona Refining Co P O Box 1458 Phoenix, AZ 85001	William Hamlin Elizabeth Wilkes William Ham (800) 528-5305	8 February 1983	Manufacturer and installer of asphaltic rubber liner.	A-15

*As of 25 April 1983, no comments have been received on the draft interview reports submitted to these companies for review.

TABLE 3. OWNERS/OPERATORS OF HAZARDOUS WASTE MANAGEMENT FACILITIES INTERVIEWED

Company/Organization and Address	Interviewee(s) and Telephone Number	Date of Interview	Interview No.
CECOS International, Inc. 2321 Kenmore Avenue Kenmore, NY 14217	Frank Nero Robert Stadelmaier Kenneth Malinowski Peter Tarnawskyj Ernest Gedeon Anne Burke (716) 873-4200	14 December 1982	B-1
Gulf Coast Waste Disposal Authority P. O. Box 1026 La Marque, TX 77568	Robert Dyer (713) 935-4783	15 December 1982	B-2
Browning-Ferris Industries 14701 St. Marie's, P. O. Box 3151 Houston, TX 77001	Robert Johnson Jerry Duggan (713) 870-7913	17 December 1982	B-3
Waste Management, Inc.* 3003 Butterfield Road Oakbrook, IL 60521	John Rohr Steven Menoff Don Wallgreen (312) 654-8800	27 January 1983	B-4
Lanchester Corporation* P. O. Box 490 Honeybrook, PA 19344	Morris Holman, Jr. (717) 354-4351	1 February 1983	B-5
Monsanto Polymer Product Co. 800 North Lindberg St. Louis, MO 63166	Jerry McGuire (314) 694-5262	2 February 1983	B-6

*As of 25 April 1983, no comments have been received on the draft interview reports submitted to these companies for review.

TABLE 4. STATE REGULATORY AGENCIES INTERVIEWED

Agency and Address	Interviewee(s) and Telephone Number	Date of Interview	Comments	Interview No.
NY State Dept. of Environmental Conservation 600 Delaware Street Buffalo, NY 14202	Mark Hans (716) 847-4585	13 December 1982	Agency has permitted and inspected a number of major lined facilities.	C-1
PA Dept. of Environmental Resources Bureau of Solid Waste Management 200 Pine Street Williamport, PA 17701 and Lycoming County Planning Commission 48 W. Third Street Williamport, PA 17701	Richard L Bittle (717) 327-3653 and Jerry S. Walls (717) 327-2230	15 December 1982	Lycoming County also owns/operates a landfill with FML.	C-2
PA Dept. of Environmental Resources Bureau of Solid Waste Management 1875 New Hope Street Norristown, PA 19401	Dennis C Orenshaw (215) 631-2420	16 December 1982	The Norristown Region has jurisdiction over several landfills using different liner types.	C-3
PA Dept. of Environmental Resources Bureau of Water Quality Management 100 Forbes Ave.; Kossman Bldg., Room 600 Pittsburgh, PA 15222	Michael Hospodar Andrew Kondis Scott McDougall (412) 565-5091	17 December 1982	Department has jurisdiction over several clay-lined landfills.	C-4
NJ Dept. of Environmental Protection - Division of Water Resources 1474 Prospect Street, CN029 Trenton, NJ 08625 - Solid Waste Administration 1474 Prospect Street, CN029 Trenton, NJ 08625 - Bureau of Hazardous Waste 32 E. Hanover Street, CN027 Trenton, NJ 08625	Merry Morris David Kaplan William Brown (609) 292-0424 John Castner (609) 292-7744 Ernest Kuhlwein (609) 984-4061	20 December 1982	Department has jurisdiction over a large number of clay- and FML-lined landfills.	C-5
MD Dept. of Health and Mental Hygiene Office of Environmental Programs 201 W. Preston Street Baltimore, MD 21201	Robert M. Byer Reid J. Rosnick (301) 383-5736	21 December 1982	Clay-lined landfills are common in state.	C-6
WI Dept. of Natural Resources Bureau of Solid Waste Management 101 S Webster Street, GEF-11, Box 7921 Madison, WI 53707	Peter Kmet (608) 266-8804	14 January 1983	Department has strong preference for clay over FML.	C-7

TABLE 5. RESEARCHERS IN ACADEMIC AND RESEARCH ORGANIZATIONS INTERVIEWED

Organization	Interviewee(s) and Telephone Number	Date of Interview	Background/Expertise	Interview No.
Southwest Research Institute 6220 Culebra Road San Antonio, TX 78284	David Shultz (512) 684-5111	13 December 1982	Problems of liner installation, testing, and performance.	D-1
University of Texas ECJ 6.2 Austin, TX 78712	David Daniel (512) 471-1555	13 December 1982	Leakage through compacted clay liners; laboratory vs. field permeabilities.	D-2
Texas A&M University Soil and Crop Sciences Dept. College Station, TX 77843	Kirk Brown (713) 845-5286	14 December 1982	Waste impact on clay permeability.	D-3
Matrecon, Inc. 2811 Adeline Oakland, CA 94623	Henry Haxo (415) 451-2757	15 December 1982	Compatibility of waste with FML materials; developed Technical Resource Documents on Liners for EPA.	D-4
Denver Research Institute University of Denver Denver, CO 80208	William Culbertson Charles Habenicht (303) 753-2911	16 December 1982	Development of liner material from spent shale.	D-5
U.S. Army Corps of Engineers Waterways Experiment Station Geotechnical Laboratory Vicksburg, MS 39180	Michael Kelley (601) 634-3378 Patrick Tucker Paul Miller Colin McAneny George Regan Phil Malone Robert Larson Richard Lutton William Murphy Gordon Carr	16 December 1982	Research on liners and covers for waste disposal sites.	D-6
U.S. Bureau of Reclamation P. O. Box 25007 D 1520, Denver Federal Bldg. Denver, CO 80225	Bernard Jones Ron Forbel Chester Jones (303) 234-7044	16 December 1982	Studies of compacted earth, asphalt, and FML as liner in water projects.	D-7
Illinois State Geological Survey* The Natural Resources Building 615 E. Peabody Drive Champaign, IL 61820	Keros Cartwright (217) 333-5113	25 January 1983	Research on clay permeability.	D-8

*As of 25 April 1983, no comments have been received on the draft interview report submitted for review

TABLE 6. TRADE/PROFESSIONAL AND STANDARDS SETTING ORGANIZATIONS INTERVIEWED

Organization and Address	Interviewee(s) and Telephone Number	Date of Interview	Background/ Expertise	Interview No.
American Water Works Association 6666 W. Quincy Avenue Denver, CO 80235	John Capito George Craft (303) 794-7711	15 December 1982	Developed manual on FML in potable water application; standards under development.	E-1
Electric Power Research Institute P. O. Box 10412 3412 Hillview Avenue Palo Alto, CA 94303	Dean Golden (415) 855-2516	17 December 1982	Studies in liner evaluation.	E-2
National Sanitation Foundation P. O. Box 1468 3475 Plymouth Road Ann Arbor, MI 48105	Gary Sherlaw (313) 769-8010	28 January 1982	Developing standards for FML.	E-3

Following each interview, an interview summary report highlighting the key and relevant points of the discussion was drafted, based on notes taken during the interview. The draft interview summary report was then forwarded to the interviewee for review to assure accuracy and completeness, and to provide the interviewee with an opportunity to expand or supply additional information/clarification on various issues discussed. To meet the very stringent project schedule, the draft interview reports were mailed via an overnight commercial delivery service and the interviewees were requested to submit their comments by a specified date (usually about two weeks). It was stated in the transmittal letter that if no comments were received before the indicated date, it would be assumed that the draft report is correct and meets the approval of the interviewee. Since no response had been received by the requested dates from about 34 percent of the interviewees to whom the draft interview reports had been sent for review, it was assumed that certain of the non-respondents may have found it very difficult to comply with our quick turn-around review request. Accordingly, while the first draft of this compendium was under review at EPA, all non-respondents were recontacted and given additional time to submit comments (if any). As of 25 April 1983, comments on or approvals of the as-submitted drafts have been received on 34 of the 39 interview reports (an 87 percent response). The changes suggested by the interviewees were generally minor and were incorporated in the final interview reports which are presented in Section 4. A typical letter requesting review of the draft interview report from a group of interviewees is reproduced as Table 7.

TABLE 7. TYPICAL LETTER REQUESTING REVIEW COMMENTS ON DRAFT INTERVIEW REPORTS

ENERGY AND ENVIRONMENTAL DIVISION
ONE SPACE PARK - R4/1142
REDONDO BEACH, CA 90278

Date 20 January 1983
T300-MG-83-009

TRW

To Distribution

From Masoud Ghassemi
213-535-6219

CC

Subject Request for Review of the Draft Interview Summary Report; EPA Contract No. 68-02-3174, Work Assignment No. 109, "Assessment of Technology for Constructing and Installing Cover and Bottom Liner Systems for Hazardous Waste Facilities".

Enclosed is a "trip report" which summarizes the highlights of the discussions which our representative(s) recently had with you for the purpose of acquiring first hand/"real world" technical data for use in the subject assignment for EPA. The report is based on notes taken during the "interview" and does not contain our analysis of the various topics discussed which we plan to carry out in connection with the preparation of the final report for the project. The trip report is being forwarded to you for review to assure accuracy and completeness, and to provide you with an opportunity to expand or supply additional information/clarification on the various issues discussed. Where applicable, we would appreciate receiving any quantitative engineering and technical data ("facts and figures") which you might have since identified to support some of the statements and assertions which appear somewhat qualitative. Until we receive your review comments, we will continue to treat the enclosed report as preliminary draft and subject to change. To meet our very stringent project schedule, we would very much like to receive your review comments on the report no later than February 4, 1983. Unless we hear from you by that date, we will assume that the material meets with your approval.

On behalf of the TRW project staff and EPA, I want to thank you for your time and courtesy. The incorporation of the information that you have provided us in the data base for our study will significantly improve the quality of the data base which will be used by EPA in its regulatory reform analysis effort.

Distribution:

Robert Byer, MD Department of Health and Mental Hygiene
John Capito, American Water Works Association
John Castner, NJ Dept. of Environmental Protection, Solid Waste Adm.
William Culbertson, Denver Research Institute
Henry Haxo, Matrecon, Inc.
Michael Hospodar, PA Dept. of Environmental Resources, Water Quality Mgmt.
Robert Johnson, Browning-Ferris Industries
Capt Michael Kelley, USAE Waterways Experiment Station
Peter Knet, WI Department of Natural Resources
Ernest Kuhlwein, NJ Dept. of Environmental Protection, Hazardous Waste
D. Kutnewsky, Burke Rubber Company
Merry Morris, NJ Dept. of Environmental Protection, Water Resources
Dennis Orenshaw, PA Dept. of Environmental Resources, Solid Waste Mgmt.

3. OVERVIEW OF THE COLLECTED OPINIONS

This section of the report, which is based on the individual interview reports presented in Section 4, is an overview of the opinions collected from technical experts, industry representatives, and state regulatory agencies on the relative effectiveness of clay and FML, factors affecting liner performance, research and development needs, and regulatory concerns/needs. This overview is primarily intended to provide insight as to the type and significance of the collected perspectives and is, by no means, a summary of all the material contained in the interview reports for which separate individual summaries are also included in Section 4. This overview also does not include many of the general information items (e.g., descriptions of various seaming methods) which are contained in the interview reports and for which considerable data are also available in the open literature.

It should be emphasized that the material presented here in this section and in the interview summary reports contained in Section 4 represents the opinions of the individuals interviewed. As would be expected in any survey of a diverse group of individuals representing a range of interests, there are some conflicts in the opinions expressed. These opinions are presented here without any change or discussion and no attempts have been made by the authors or EPA to analyze the views expressed or to present opposing viewpoints. Some technical analysis of a number of points raised relating to liner installation, compatibility, and failure mechanisms can be found in Volume II of this document and in the final reports being prepared for EPA by Research Triangle Institute (Research Triangle Park, NC) and by Arthur D. Little, Inc. (Cambridge, MA) in connection with two companion liner studies.

3.1 OPINIONS ON CLAY AND FML SYSTEMS USED IN HAZARDOUS WASTE LAND DISPOSAL APPLICATION

Proper and objective assessment of the relative merits and demerits of FML and clay in hazardous waste disposal application is hindered by a fundamental

lack of long-term performance data (successes and failures) on engineered sites using either type of liner. While there appears to be plenty of statements and assertions as to the actual or expected liner performance, such statements and assertions are primarily opinions (often motivated by self-interests) and are not supported by technical data. Because of the difficulty of assessing liner performance (e.g., seam integrity for FMLs) under actual use conditions, liner failures which have been documented generally represent cases of catastrophic failures and not failures which would ordinarily go undetected with the presently available monitoring systems (e.g., cases of slow leaks). There also appears to be a lack of agreement as to what constitutes a failure. According to some designers, a leaking liner is not a failure per se since "all liners leak to a certain extent"; a leakage would be considered a failure if it exceeds the rate stipulated in the design.

In general, people in the FML industry are of the opinion that if FML is properly selected, manufactured, fabricated, designed, and installed, it should outperform clay in the long run. Owners and operators of hazardous waste management facilities who are the actual users of liners and who would have first-line liability responsibility for their performance, as well as state regulatory agencies who issue operating permits for such facilities, generally do not argue the point that FML can be installed to perform satisfactorily, but insist that the present practices of manufacturing, design, installation, etc., are largely inadequate and cannot be relied upon to consistently produce quality installation. They argue that there are simply too many things which can go wrong with FML. In general, less objection is expressed for the use of FML as caps than as bottom liners because of the greater accessibility of caps for repair, absence of contact with waste and leachate, and the superior ability of certain FMLs to absorb subsidence under certain conditions.

The manufacturers, fabricators, and installers of FML who were interviewed generally consider their own operation of very high standards and blame the "other guys" for heretofore incidences of bad performance which have generated some of the current negative image for FML. In defending FML, they point to some of the shortcomings of clay, including reported increases in permeability upon prolonged contacts with concentrated solvent wastes and the difficulty of predicting the performance of the installed liner based on laboratory permeability tests.

Those interviewees expressing a strong preference for clay over FML admit to the fact that the installation of clay liners also presents opportunities for mistakes and poor quality work. They, however, consider that the problems with clay installation are fewer and more manageable than those for FML. Their preference for the use of clay also appear to stem from a presumed greater body of knowledge and experience which currently exists for clay (largely as the result of extensive design and construction experience with clay structures such as dams and embankments). The clay proponents cite published literature which indicates deterioration of the physical properties of certain FMLs when exposed to municipal waste leachate and a range of other chemicals. The ability of clay to attenuate pollutant movement is considered a very desirable safety factor and, hence, a definite advantage of clay over FML. Indeed, some researchers believe that the landfill liner should be capable of absorbing all the leachate which is generated in a landfill, and that the removal of leachate which necessitates perpetual care connotates waste storage and not disposal.

Because of a lack of trust in FML which is in some cases reinforced by bad experience with a company's own facilities lined with FML, owners and operators of major commercial hazardous waste management facilities prefer the use of clay-FML combination or clay over FML alone. The concern for safe operation and avoidance of potential liability is reflected in the apparently significant overdesign which is typical of many such facilities. Thus, the liner system at one facility consists of 10 feet of compacted clay, topped by an HDPE liner which is, in turn, covered by 2-foot thick clay. Certain state regulatory agencies (most notably, Wisconsin Department of Natural Resources) also have a strong preference for clay over FML.

Generally, considerably less information is available on the characteristics and performance of admixes and spray-on liners than on FML and clay. Some of the information obtained from different sources on the performance of specially-treated bentonite clay was also contradictory (e.g., from the standpoint of compatibility with leachate).

3.2 FACTORS AFFECTING FML PERFORMANCE AND MEASURES FOR MITIGATING PROBLEMS

3.2.1 General Considerations

Because a relatively large number of steps and parties are involved in producing the final product (i.e., an installed FML), a range of problems

present themselves during the sequence of raw material preparation, manufacturing, fabrication, transportation, design, site preparation, and field installation. Although certain steps (e.g., design and field installation) are considered more critical than others to the performance of the final product, there is generally a concensus of opinion among the individuals/organizations interviewed that failure to properly address the problems at each and all of the steps can lead to inadequate liner performance. Thus, a weak or broken link in the required chain of custody for quality control and quality assurance (QC/QA) is believed to be conducive to poor liner performance. Given the standard business practice of selecting contractors based on evaluation of the bids submitted, cost consciousness, and the intense competition which often promotes underbidding, there exists, therefore, an ample opportunity for the occurrence of weak links and hence inadequate liners.

Educating customers to recognize the importance of and the need for maintaining an unbroken chain of QA/QC, to demand comprehensive QA/QC programs at all stages of design, manufacturing, etc., and, above all, to consider factors other than cost in selecting contractors was most often cited as perhaps the only practical solution to the liner installation problem. The very slow nature of such an education process, however, is recognized and measures such as organization of the profession and dissemination of information on the latest developments in liner technology (e.g., via the holding of technology transfer seminars, training sessions, etc.) are suggested as means for speeding up the process. The use of a turn key contract management system which makes a single party responsible for the performance of the installed liner, or the development and enforcement of performance standards, is considered appealing but impractical. These approaches would increase the cost and are fraught with technical and legal problems. These difficulties, which could promote unwillingness on the part of contractors to bid on liner jobs, can best be illustrated by the reluctance of liner manufacturers to offer meaningful and extended warranties on their products. Even when every conceivable precaution is taken, including extensive overdesign, there is an inherent statistical risk that cannot be overcome completely. In many cases, it would also be almost impossible to pinpoint specific causes for observed failures.

The problem of lack of a QA/QC chain of custody is addressed in part by some firms/contractors which take upon themselves to "police" the operations at certain steps which preceed or follow their own. Thus, one liner fabricator indicated that it requires the material suppliers to certify their product based on certain tests which it specifies, and provides field seaming specifications based on its assessment of the capability of the installer. In one installation case, the site owner inspected the manufacturer's and fabricator's facilities and operations as well as those of the independent laboratories they hired. The qualifications and experience of the installers were also considered before selecting an installation contractor.

3.2.2 Design Considerations

Design engineers who were interviewed consider proper design as the most important single factor in developing a successful installation. They believe very strongly that many of the documented cases of liner failures can be traced to improper design and could have been avoided with the proper approach and supporting investigations. Thus, identification of conditions which may lead to failure and hence developing the basis for design is considered the first and most important design element. Because the conditions vary significantly from job to job, the design must be tailored to the specific requirements of the site which must be defined in terms of the characteristics of the waste to be handled (liner-waste compatibility), expected waste/equipment load on the liner, site climate (wind, temperature, precipitation), and soil stability and subsurface characteristics. The identification of the many site-specific conditions often requires an extensive geotechnical investigation which is, however, seldom undertaken.

The designers consider sound structural design an important factor in determining the success or failure of an installation. Important design aspects are considered to include proper siting, use of a suitable side slope (2:1 is the limit and 3:1 is preferred), preparation of the soil support to ensure proper and uniform compaction, use of geotextiles or other suitable materials when rocks are likely to be a problem in the finished subgrade, backfilling to provide adequate protection against damages from equipment and weathering, use of protective measures (e.g., fences, intentional alternate watering and feeding areas) to keep animals away from the operational areas,

and installation of gas vents to release gas generated by the decomposition of the residual organics in the subsoil. While one liner manufacturer believes that the thickness of its liners allows for equipment operation on the liner without damage to the liner material, one designer feels that under no circumstances should operation of equipment on the unprotected liner be permitted, irrespective of how thick the liner is.

Taking full advantage of favorable geological conditions (e.g., natural cut-off walls and thick and homogenous clay strata) should be an important consideration in siting disposal facilities. Other important siting considerations mentioned by interviewees included availability of adequate supply of cover material, and local sentiment and political factors. Political opposition can be a formidable force and, in some instances, has forced owners/operators to expand existing facilities rather than seeking additional sites in new locations. In some areas, a facility has been located in the groundwater table (the "intragradient" design) with the objective of providing a hydraulic gradient against leachate movement into the groundwater.

Clear and easily understood design specifications are considered by some designers and installers as an important contribution to an adequate installation job. According to one expert, the wide differences which are observed among bids for the same job would be substantially reduced if specifications were written in a concise and unambiguous language. This expert also felt that specifications requiring goals which are unrealistic or very costly to achieve may favor low bidding by unscrupulous firms or by firms who, because of the lack of appropriate expertise, may not recognize the difficulties involved in meeting the stated goals. The term "or equal" which is often included in specifications essentially nullifies any intent for securing a specific product or contractor. Some experts questioned the competency and practices of many of the design engineering firms which they hold responsible for some of the heretofore cases of liner failure. Examples noted include the "recycling" of certain construction drawings (e.g., detailed drawings for liner anchor trenches) from previous projects, and reliance on inputs from sales personnel who may lack objectivity or necessary design expertise. One waste management company who operates a number of facilities indicated that, because of its poor experience with design/construction companies, it has been forced to develop its own in-house design capabilities.

Many of the individuals/organizations interviewed elaborated on a key design problem, namely that of liner material selection. In evaluating prospective liners, the designers generally rely on the manufacturers' literature on liner properties (e.g., sheet/seam strength, high and low temperature resistance, compatibility with various chemicals, and costs). In this connection, one interviewee indicated that compatibility testing should indeed be solely the responsibility of the supplier/manufacturer. Most of the manufacturers' literature are derived from short-term tests carried out under controlled conditions and, hence, may not represent the actual field environment, especially from the standpoint of liner-waste compatibility. According to one designer, these tests are primarily suitable for ranking materials for use in a specific application and, even at that, the results can be misleading insofar as a fully suitable material may be eliminated from further consideration. The problem is further complicated by a lack of uniform standards for compatibility testing and on the interpretation of the test results. Thus, one manufacturer considers a sample which deforms to greater than 10 percent of its original weight and tensile strength to be incompatible with the waste tested, but a strong technical basis has not been developed for this and other arbitrary values which are in common use. Because of the shortcomings of the compatibility tests, one owner/operator felt that the selection of suitable material for a specific application can best be made by relying upon any experience available from parallel field situations.

The selection of a suitable liner is also complicated by the extreme difficulty in defining the average as well as the range of fluctuations in the waste/leachate characteristics. One designer indicated that it uses the manufacturers' literature to select a liner; once the liner is selected, it conducts its own compatibility tests to identify incompatible wastes which will then be required to be excluded from the facility.

There is no single liner material which would be compatible with the combination of wastes encountered in a hazardous waste disposal site. Based on the results from in-house laboratory tests, one supplier concludes that the range of wastes encountered in a disposal site can be handled by no more than 3 or perhaps even 2 FMLs. Segregation and screening of wastes (especially that which is placed in direct contact with the liner), banning or pretreat-

ment of certain problem wastes, the use of multiple liners to compensate for single liner deficiencies, minimizing opportunities for contact with the leachate (via removal of the leachate), and monitoring changes in liner characteristics using coupon programs are some of the suggested approaches to mitigating the liner compatibility problem. Some designers consider a 2 percent bottom slope, which is commonly used in design, inadequate in preventing ponding and hence extended liner contact with high strength leachate.

An inadequate data base currently exists for judging the longevity of FML under full scale use conditions. In one county installation where the liner adequacy has been contested, the testing of the PVC liner after 4 years of service showed no difference in characteristics when compared to the unused material. Because of the uncertainties as to the long-term integrity of FML, some designs have intentionally promoted infiltration into the facility and incorporate leachate recirculation during the operational life of the site, thus accelerating the process of waste stabilization. This, it is believed, will result in the formation of the largest volume of leachate when the liner is new and probably better able to resist the corrosive characteristics of the leachate.

The connections between the liner and the structure is an important but often overlooked problem in design. The liner is especially susceptible to failure at such connections due to heavy stresses resulting from differential settlement, gravity pull on slopes, and incompatible expansion/contraction characteristics. Since connecting to structures is usually one of the last items of field activity (and hence is often done in a hurry), the connections generally also receive inadequate quality control. The designer can address the connection problems by avoiding certain geometries (e.g., sharp corners which are not easily handled), specifying compatible materials, and requiring greater quality control. One interviewee suggested doubling the thickness of the liner at connections to better resist abrasion around structures.

3.2.3 Installation (Seaming Problems)

Next to poor design, inadequate seams (especially field seams) are cited as the most common cause of liner failure. The people associated with the liner industry and the design engineers are generally in agreement that, with

the present equipment and technology know-how, field seams can be made so that they will not fail. They, however, also agree that in actual practice there is not always an adequate QA/QC program in effect to ensure compliance with the recommended seaming procedures, and the seaming is not done under specified weather conditions. The owners and operators of hazardous waste disposal facilities cite from their own experience specific cases of liner failure to support their assertion that the present practice and technology cannot in all cases guarantee installation of liners that will not fail. The large number of factors which affect seam integrity (and, hence, necessitate the use of experienced labor), the lack of adequate quality control and quality assurance on many installation jobs, inadequacies of some of the seam testing methods, and poor seaming specifications are among the factors most often cited by the interviewees as the causes of poor field seams. Although the impact on seam quality varies somewhat with the specific seaming method used (e.g., solvent seaming vs. heat welding), extremes of temperature, high wind and precipitation ("wet jobs") can result in poor bonding and, hence, inadequate seams. There appears to be some differences of opinion regarding the suitability of solvent seaming. Thus, while one designer indicated a preference for solvent seaming because of its ability to consistently produce high quality seams and to enable easy visual inspection of the finished seams, another interviewee felt that in the solvent seaming process the solvent attack might become excessive and, hence, possibly damaging to the liner.

The ability to recognize job-specific requirements and to pass on-the-spot judgement as to the adequacy of the field procedures and, hence, of the resulting seams, requires that the workers assigned to the seaming jobs have some prior seaming experience or be at least supervised by very experienced foremen. Most interviewees, however, point out that in actual practice this is seldom possible and, in most cases, economic considerations force many installers to hire untrained local labor, often directly from the unemployment line. (The use of local labor is also often a deliberate act to get around some of the labor union restrictions.) The problem of finding experienced seamers is compounded by the fact that the type of seams and the skills required for each type vary with the type of lining material which, in turn, changes from job to job. There are also variations in the seaming specifications for the same material supplied by different manufacturers.

The issue of suitable supply of skilled and reliable labor force at a reasonable price for seaming tasks has been addressed, at least in part, by a number of installers who report successful experience with training and use of off-duty firemen and policemen. To provide for continuity of service and hence accumulation of experience, one installer in the Southwest has successfully used a group of so-called "camp followers" who are encouraged to follow the installer from job to job; the camp followers themselves usually spread the word as to the location of a forthcoming job and, because of the reasonably high pay which is sometimes involved with contracts requiring a "prevailing wage clause", are willing to provide their own transportation to relatively distant new job sites. Some fabricators who also provide installation service have successfully engaged their factory personnel in the actual installation work.

The importance of adequate supervision and use of capable foremen who can guide/teach the individuals carrying out the actual seaming was pointed out by several of the installers and designers. It is generally considered that a good foreman can adequately compensate for the lack of previous experience of the crew members. For this reason, and because it is not practical to require previous experience from all individuals engaged in seaming, there were a number of suggestions that any training/certification program should be directed at the foreman level. One expert expressed some skepticism as to the effectiveness of a certification/licensing program to weed out poor installers. One interviewee suggested that any training, certification, or licensing program could probably be financed via a user fee attached to the facility permit.

The question of material compatibility with the waste is considered somewhat less critical in designing covers than liners. Weathering and uv resistance are considered the important criteria in the selection of material for caps. While most designers recommend only the use of unreinforced material for caps (to provide ability to elongate in response to any subsidence), another expert considers reinforced material more suitable. A 2 percent slope is considered an adequate design for preventing ponding on the top surface of the cap. Proper design also requires adequate prior compaction to prevent extensive subsidence, and use of protective cover material (gravel or soil).

To reduce potential for slippage of the soil cover, some designers suggest the use of a geotextile at the FML-clay interface.

According to one fabricator, only few installers can be "trusted" with simple overlap field seams, which presents the greatest opportunity for mistakes. For most installers, this fabricator specifies tongue-and-groove seams which it fabricates for field installation. A number of contractors and owners/operators of disposal sites have used various criteria to screen potential installers. These criteria include passage of written and mock seaming tests, and the extent of previous experience (judged, for example, by the square footage of liner installed). One designer indicated a noticeable improvement in seam quality by numbering the seams on design drawings and recording the individual assigned to specific seams. In the opinion of one expert, firms specializing in installation would generally have a wider range of installation experience, including involvements in some very difficult installation jobs, than firms which are engaged in manufacturing and fabrication as well as installation. One interviewee pointed out that on occasions some dirt contractors who have not been very experienced in liner installation have been hired to also do the actual installation, and the outcome has been less than satisfactory. Some opinions were expressed as to the quality of work and stability of small vs. large installers. One interviewee indicated a preference for smaller contractors which he characterized as being more anxious to do a quality job and more receptive to technical inputs from manufacturers, designers, and fabricators. Large installers, however, are viewed as being financially more stable and better equipped to handle business fluctuations than smaller contractors and, hence, more likely to remain in business after a work is completed and their services may be needed for follow-on or repair works.

The many job-specific factors which can affect seam properties in particular, and liner integrity in general, underline the need for an effective QA program during liner installation. It should be the responsibility of the QA inspector to ensure compliance with design specifications, including testing of seams in the manner specified. To be effective, the inspection should be carried out by an independent party not affiliated with the installation contractor. The presence of an inspector on site would also discourage sloppy operation and unauthorized deviations from the design specifications. Some

interviewees indicated that the competency of the inspector is very essential and cited a number of examples where the inspector assigned to a job lacked credentials and technical expertise to properly discharge his QA/QC responsibility. One interviewee indicated that, on occasions, installers have raised their price or modified their contract after learning that a particular inspector with the reputation of being very thorough and critical had been assigned to a specific job.

Although there is agreement among the industry representatives and experts interviewed as to the need for a comprehensive QA/QC program, the scope of such a program is not clearly defined and its impacts on the overall cost of installation is not quantified. For example, there are some uncertainties as to the effectiveness of a number of seam testing methods (e.g., visual inspection or ultrasonic test) and the material-specific applications and significance of methods for testing seam strength and integrity. In a number of cases, experience seems to indicate a preference for the peel test over the shear test. It is also noted that the effectiveness of various tests vary with the liner thickness, and field temperature and humidity conditions. Some installers have developed and used patented seaming methods which they claim are superior to the standard technology. One expert pointed out that a sufficient number of seam testing units are not always available at the job site, and this can result in testing to significantly lag seam construction, thereby promoting less than proper testing of seams.

In general, a good quality assurance check for seams is considered to include nondestructive testing of 100 percent of the seams. Unless certain precautions are observed (e.g., in unannounced inspections, requiring the seaming crew to construct a test seam on scrap material using the exact technique that was just being used on the liner), mock seams constructed especially for QA testing would not be representative of the quality of the installed seams. In one field installation, the peel failure rate for cut-out peel samples was significantly lower than for the mock seams. While some researchers see no reason why the patches installed to fill in where the cut-out samples were taken should create a lower quality material, others believe that destructive testing can be detrimental to the liner integrity. To be effective for quality assurance purposes, cut-out samples should be taken from

unspecified locations (unknown to the seaming crew) and not only from the edges of the liner, as has sometimes been suggested to limit any possible liner damage to the less critical areas. Quality assurance programs should especially address quality of liner connections to structures. Since these connections are usually made last, and the contractor is anxious to move its crew to another job, either the work is done in a hurry or an inexperienced crew is sent to finish the project.

At least from the incompatibility standpoint, seams in the FML caps present less critical problems than those in the bottom liners. Cap seams are not subject to as severe incompatibility conditions as the bottom liner seams, and would be accessible for repair in case of failure. Seaming new liner caps to old (aged) bottom liners (or seaming of different liner materials) is considered to present some installation problems. Good seams, however, can be achieved by removing the surface cure from the old material prior to bonding.

Even though factory seams are generally considered superior to field seams, in the view of at least one expert, this is not necessarily always the case. This expert also believes that, compared to the European practice, field installation techniques and quality control are superior in the U.S.

Poorly written seaming specifications which are difficult to follow are considered by some experts as a major problem area in liner installation. For example, it is pointed out that for a reinforced liner the specifications frequently give the "scrim-to-scrim" overlap requirement. This, however, is difficult to maintain since the distance between the end of the scrim and the edge of the sheet always varies widely because the scrim is very flexible and, during manufacturing, it cannot be held in place when it is laminated between the panels.

3.2.4 Raw Materials and Manufacturing Considerations

Few companies can be considered as major suppliers of raw elastomers (in the form of latex or chips) for the manufacture of FML. With some exceptions, the suppliers are not generally involved in and have no direct control over the subsequent manufacturing, fabrication, and installation steps. Suppliers and, to a lesser extent, the manufacturers, however, are major companies with assets which are generally substantially higher than those of a typical

fabricator or installer, and hence are attractive targets for any litigations stemming from damages from liner failures in waste disposal application. Because of this and their desire to avoid bad publicity which could be damaging to their markets, suppliers and manufacturers generally feel some corporate responsibility for the ultimate performance of their products. Some suppliers thus have active programs to interface with and advise manufacturers, fabricators, designers, and installers on such topics as material compatibility, proper design and installation procedures. One supplier interviewed has extensive R&D effort for testing, screening, and improving product quality.

Unless involved in the manufacturing step, suppliers exert no control over the selection of compounding ingredients (e.g., carbon black, pigments, fillers, plasticizers, accelerators, and antioxidants) used in manufacturing to impart various properties to the finished product. The current material specifications are too broad and hence permit significant variations in the properties of the same liner type from different manufacturers. Thus, specifications for Hypalon merely require that the material contains at least 45 percent by weight of Hypalon 45 as the sole elastomer, and meets certain physical criteria. Consequently, as with all generic classes of liners (e.g., PVC, HDPE, EPDM, etc.), Hypalon liners available from different manufacturers may vary widely in properties. Beyond requiring compliance with this minimal specification, the suppliers exert no control over manufacturing and cannot refuse to sell their elastomer products to any manufacturer. Several interviewees, however, indicated that withholding of the product from unscrupulous customers can be an effective quality control measure and should be exercised by responsible suppliers, manufacturers, and fabricators. This variation in product quality has been a major impetus for the current effort of the National Sanitation Foundation to develop liner standards applicable to the manufacturers (and fabricators) of FML.

In addition to the specific formulation which affects liner properties, the method and equipment used in manufacturing also have significant impacts on the properties of the finished sheets. One expert compared calendering and spread coating methods of sheet manufacturing from the standpoint of product quality and quality control. Spread coating, which involves building up of the sheets from layers of material applied as liquid coats, is considered to

provide less opportunity for pinhole development and to allow the use of higher scrim densities for reinforced products. The extent of recycling scraps (especially reinforced material scraps which contain scrims) to the polymer melting pot also impacts product quality, and there is currently no standards governing the extent of recycling which can be tolerated. One owner/operator who also manufactures synthetic sheet materials for miscellaneous uses indicated some quality assurance problems in the manufacturing of synthetic liners; the company, for example, has experienced difficulties with thickness, reinforcing scrim, and material uniformity.

One FML manufacturer indicated that its QA/QC program includes: (a) sampling at top and bottom of each raw material rail car; (b) visual inspection of product as it rolls off the production machine; (c) laboratory testing of at least two samples of the finished product per shift; (d) documentation, including batch coding, date coding, and numbering of each role; and (e) issuance of a quality control certificate to the customer. One interviewee suggested that quality control in the manufacturing step is often inadequate and that several new and potentially very effective techniques such as spark-gap and vacuum testing are not yet in widespread use.

There appears to be significant differences of opinion among the experts interviewed on the pinhole problem and its significance in liner performance. Thus, while some indicate that it is not possible to produce pinhole-free liners, there are others who believe that pinholes in liner sheets is a problem of the past and that the present manufacturing methods, and the quality control which is exercised in the manufacturing step, can guarantee liners without pinholes. There appears to be a lack of technical data to support either assertion. Some manufacturers which were interviewed indicated that their material would be "nominally" pinhole-free and that they "would be hard put" to guarantee that their product is completely free of pinholes. Pinholes which penetrate the liners are considered less of a problem for multi-ply than for single-ply liners because the chances of a pinhole in one ply matching up with pinholes in a second ply are very small. There might be some potential problems, however, if a pinhole exposes the scrim such that contact with waste fluids could cause wicking along the scrim, build-up of fluid between plies, and eventual delamination. The probability of this happening, however, is

very small and it might only be a potential problem with tightly-woven scrims and thick yarns.

Pinholes can originate during the calendering process where air bubbles, contaminant particles, or poorly dispersed granules (e.g., unmelted modules of carbon black or scrim scrap) in the mixed stock can mar the otherwise smooth surface between rollers and result in indentations which pass through the liner. The pinholes can vary in size, from a few microns in diameter to a size which can be spotted by the naked eye when the sheet is held against light (e.g., passed over a light bar). Quality control for pinhole prevention during manufacturing can include fine screening of the mixed stock before calendering or extrusion, limiting the amount of scrap recycling, and visual inspection of the sheets on both sides to identify and repair pinholes.

Technical data have not been generated through any systematic studies to enable quantitative assessment of the significance of and the extent of problem with pinholes in liner performance. Liner designers and installers generally down-play the significance of pinholes in liner performance and find little evidence indicting pinholes in liner failures. One designer reports that, based on one study with a water containment system, 2000 pinholes may be considered equivalent to one hole of 10 mm diameter or ten holes of 3 mm diameter. The amount of weepage through pinholes would probably be orders of magnitude less than through a bad seam or a substantial tear. Moreover, since all liners possess sufficient puncture resistance, pinhole enlargement during actual use would be unlikely.

One expert pointed out a general misconception that the thickness of a liner is the principal factor determining its performance. He indicated that he has actual comparative test data which prove, at least from the viewpoint of resistance to puncturing, that the "thicker is not always the better".

Most warranties offered by manufacturers are generally very limited in scope and, in the opinion of some, are "full of holes" (especially the extended warranties). In most cases, exceptions are taken to incidental and consequential damages which could occur as the result of liner failure. These warranties generally limit liability to a dollar amount which does not exceed the selling price of a particular project.

The technical experts most familiar with the European technology indicated that overall, the quality of the liner products manufactured in the U.S. are superior to those of European counterparts.

3.2.5 Fabrication and Transportation

Transportation of the liner material from the manufacturing facility to the fabricating plant, and from the fabricating plant to the installation site offers opportunities for damage to the liner product. Visual inspection at the fabrication plant (both before and after seaming) as well as at the installation site as the material is unloaded is generally considered necessary to detect transportation-related damages (or other faults). There are generally two methods of transportation which can be specified in the bid specifications: "FOB plant" and "FOB site". It would be to the advantage of the site owner to select "FOB site", as this would transfer the responsibility for transportation to the job site, including writing of all specifications (e.g., crate specs) and handling all damage claims, to the shipper. If damages are substantial and cannot be repaired on site, the shipments should be rejected.

The factory seams are developed by a number of methods, with the choice being dependent on the liner material. Some fabricators have developed special modifications to the standard equipment designs which they claim enable them to improve seam quality. One fabricator which uses heat-weld seams indicates that, with reinforced thermoplastic material and 2-inch overlap, its particular techniques can duplicate the strength of the material in the seam. The QA/QC program employed by this fabricator reportedly includes the use of "peel test" on test seams to establish optimum seaming conditions (temperature, pressure, and speed), use of experienced operators/technicians, visual inspection of seams for extrusion of material at the interface of the welded sheets, stress and creep testing of seam samples, and use of tick marks to ensure proper lining of sheets prior to feeding into the seaming machine (to avert stresses being built into the seams).

3.2.6 Research and Development Needs

Many of the comments received from the interviewees on FML-related R&D needs pertained to: (a) establishment of a better basis for design through systematic and "real world" studies; (b) development of improved seaming methods, compatibility tests, and liner materials for specific applications;

and (c) investigation of new concepts and approaches to seaming. Some experts, particularly those confronted with the "real world" problems, see laboratory test results as a poor substitute for design data collected through systematic studies of the performance of liners and design approaches in full-scale applications. Thus, while research to date is considered very fruitful, it is suggested that it be extended to also address some of the practical concerns of the design. Some of these concerns relate to the following:

- Development of better design/construction criteria for connecting liner to concrete structures in liquid impoundments.
- Development of better sump systems for landfills to allow more durable connections (the concept of a prefabricated unit is considered worth investigating).
- Definition of conditions where geotextiles can be cost-effectively used in conjunction with reinforced and unreinforced FML.
- Observation of the performance of liner in actual field installations or in "prototype" cells dedicated to systematic studies. These studies could, for example, address the behavior of liners and seams in deep and shallow ponds and under a range of exposure conditions.
- Scientific cause-and-effect investigation and documentation of the reported cases of liner failures (and successes).
- Investigation of new concepts to seaming (e.g., use of a "mechanical zipper"), development of new seaming methods, and test and evaluation to generate the technical basis for more concise seaming specifications (e.g., as to the required overlap width).

In underlining the need for documentation of liner failures and successes, several interviewees pointed out that some data currently exist in the files of manufacturers, designers, and installers, but such data are considered confidential and hence not releasable. Several interviewees emphasized the need for improvements in liner performance tests (in particular compatibility and permeability tests), and for quantification of the credibility of the test results in predicting performance under field conditions. Especially needed are accelerated tests which can condense 25 years or more of service into a short period of laboratory tests. To be of greater value, compatibility tests should utilize actual leachate solutions representative of leachate characteristics. To this end, information is needed on the characteristics of leachate from large-scale facilities and the time variance and waste source dependency of such characteristics.

Two interviewees saw a great demand for developing suitable liner materials for certain specific service requirements (e.g., containment of brine and low pH wastes). Although compatibility with waste generally has been considered of little concern in selecting liner material for covers, the magnitude of the problem (especially in cases involving volatile wastes) has not been addressed and must be researched. One interviewee pointed out a much broader need for an investigation of viable alternatives to landfilling or restricting the use of landfills to those wastes which cannot be handled by other disposal methods. He also suggested investigating the technical and economic merits of using above-ground containment systems where any liner used would be more easily accessible for observation and repair.

3.3 FACTORS AFFECTING CLAY LINER PERFORMANCE AND MEASURES FOR MITIGATING PROBLEMS

3.3.1 General Considerations

Some of the problems associated with producing a quality FML installation (e.g., deficiencies in design, inadequate QA/QC, material incompatibility, etc.) also apply to clay installations. Additional problems with clay liners which were pointed out by a number of interviewees related to general over-reliance on construction techniques and experience from other geotechnical projects and the inadequacies of the data presented to support the asserted good performance of certain operating clay-lined facilities. Thus, it is stated that not all practices and experience from dam and embankment construction would be applicable to or should be used in constructing clay liners. For example, the degree of compaction used in the construction of large embankments may not be suitable for liners. Some of the problems with clay liners have indeed been attributed to faulty designs developed by engineers and hydrologists who are familiar with saturated flows when in liner/cap application, the clay is, in fact, placed in an unsaturated condition. One expert suggested that input of a soil scientist might be helpful to avoid certain design problems and pointed out that various properties of clay, especially under varying conditions of moisture content, are very poorly understood. In this connection, one owner/operator indicated that because of the inexact nature of the soil science in designing his facility, he solicited inputs/opinions from two different geotechnical consultants.

Some experts question the validity and comprehensiveness of some of the data which are presented to indicate adequate performance of operating clay-lined facilities; it is felt that, unless support data are obtained through systematic and well-designed extended studies, the long-term performance of clay liners (as well as FMLs) in hazardous waste disposal site application will continue to remain a matter of speculation and controversy. Thus, while clay-lined facilities for which there is no apparent evidence of failure are cited by some to indicate a lack of incompatibility problem, others make references to documented cases of clay liner failure due to incompatibility and cite the research carried out by Dr. Kirk Brown of Texas A&M University indicating marked increases in clay permeability upon exposure to high-strength organic solvents. Both Dr. Brown and other researchers, however, point out that the referenced research results are preliminary and that the test conditions used to obtain data (i.e., high pressures and use of concentrated waste streams) do not represent all field conditions.

As noted previously, and despite the above-listed shortcomings, a segment of the individuals/organizations interviewed (particularly those associated with the operation of waste disposal sites) indicated a very strong preference for clay. Even those associated with the FML industry see justifiable uses for clay and there seems to be a consensus of opinion that a clay-FML combination offers the best protection. Some of the advantages cited for the use of clay over FML were reviewed in Section 3.1; these and other asserted advantages, some of which are not supported by technical data, include the following:

- Fewer steps and parties involved, and simpler procedures for developing a completed installation. There is thus less opportunity for mistakes and the problems are more manageable.
- More developed state-of-the-art due to considerable experience with other geotechnical projects (e.g., construction of dams and embankments).
- Favorable operating experience with sanitary landfills sited on native clay deposits and from limited sites lined with recompacted clay.
- Less catastrophic failures and the ability of clay to attenuate pollutant migration in case of failure.
- Better ability to resist mechanical damage due to the much greater thickness of the clay liner.

As with FML, two problems which were cited as being most important in producing a quality installation relate to deficiencies in design and inadequate QA/QC during clay liner installation. These are briefly reviewed below.

3.3.2 Design Considerations

The importance of design and some of the general design considerations discussed in Section 3.2.2 in connection with FML are also applicable to clay liners. These common factors, which will not be elaborated upon here, include identification of conditions which may lead to failure through site surveys and geotechnical investigations, tailoring design to meet the identified conditions of failure and site-specific requirements, proper siting of the facility, use of suitable slopes, preparation of adequate support for recompacted clay liner, use of clear and easily understood specifications, and design of suitable structures for leachate collection and removal.

Except where a facility is underlaid by a relatively thick and homogenous clay stratum, native clay is not generally considered a suitable liner because of the presence of discontinuities (sand and silt lenses, roots, and debris). Some of these discontinuities can escape even the most comprehensive geological investigations. Some concern was also expressed about the wisdom of undertaking an extensive geological investigation involving soil borings, as such borings can introduce their own discontinuities and hence promote downward movement of leachate. When clay is available at a site, it should thus be recompacted to improve uniformity and eliminate major discontinuities. Although there are some state guidelines as to the thickness or the permeability of clay liner (e.g., Louisiana requires a minimum 3-foot clay liners for hazardous waste facilities), such guidelines generally vary.

Based on the interviews, there appear to be two distinct design philosophies for the management of leachate in a clay-lined facility. One school of thought, which is promoted by designers, sees a need for the removal of leachate for above-ground treatment and disposal. Leachate removal is considered necessary to reduce potential for liner deterioration due to incompatibility with waste, and to reduce the hydraulic head which can promote liquid penetration. The concept of intentionally allowing the leachate to percolate into and be absorbed by the liner, as is advanced by a second group of experts (represented by certain researchers), is considered a potentially dangerous

proposition and contrary to the goal of protecting groundwater. It is thus pointed out that the poorly understood chemistries and transport mechanisms involved preclude proper assessment of the capacity of clay to absorb various chemicals present in a complex leachate solution and, hence, it is not possible to develop the proper basis for liner design to accommodate leachate. The objective of leachate collection and removal is viewed as one of transferring hazardous and potentially mobile material from a difficult-to-control environment (i.e., the landfill) to a more easily controlled environment (e.g., an above-ground treatment system).

Those who promote the deliberate percolation of leachate into the clay liner view any effort at leachate removal contrary to the concept of permanent waste disposal, since it implies perpetual care. These experts contend that leachate collection is neither needed nor desirable, and that clay liners should be designed to accommodate leachate absorption. To avoid accumulation and overflow, it is also recommended that the cap for a facility be designed to be less permeable than the bottom liner. One interviewee, however, pointed out that this might not be practical in all cases since permeabilities less than that for commonly developed bottom liners (10^{-8} to 10^{-7} cm/sec) may not be readily achievable. To lessen the strength of leachate and hence the load on the liner, it is further suggested that disposal of liquids and very troublesome wastes in landfills should, with only few exceptions, be eliminated.

Perspectives expressed regarding cap designs generally point out the difficulty of developing a system (clay, FML, or other materials) that can remain viable over a long period. While some experts favor caps constructed of clays or other natural materials, most agree that all caps are subject to deterioration due to subsidence and erosion and must be repaired. Although subsidence will occur in every case, it can be minimized by proper design which will reduce the amount of moisture entering the facility. One researcher cited that in Northern Illinois where there are only 30 to 34 inches of rain per year, only 2 percent of the precipitation normally reaches the groundwater. By comparison, infiltration into poorly designed/constructed caps can exceed 60 percent. A different philosophy on cap design was expressed by some state regulatory agencies who favor design to intentionally promote infiltration to

accelerate waste stabilization which is further aided by leachate recirculation during the operational life of the facility and before placement of the cap.

Commenting on regulations requiring a specific thickness for clay caps, one researcher pointed out that a uniform requirement would not be applicable to all sites. Thus, a 2-foot compacted clay would not be sufficient in certain cold climates where, in winter, the frost line may extend to more than 30 inches deep. The thickness of clay caps which have been used in actual installations has varied and depths of up to several feet were reported. The wisdom of planting grass in the soil cover for the cap was questioned by one researcher on the grounds that while such practice might minimize erosion, by holding water it can increase infiltration. It is cited that compared to row crops such as corn, infiltration with a grass cover may be four to five times higher.

One researcher is investigating a cap design with a gravel layer sandwiched between two clay layers. In this system, which is believed to offer good long-term performance, the gravel layer perches the water in the upper clay layer where it is removed by evapotranspiration during dry weather conditions. During the wet weather conditions, when the storage capacity of the top layer is exceeded, some of the water would be transmitted to the gravel layer and drained out and away from the site.

3.3.3 Installation Considerations

As with FML, inadequate installation is ranked next to poor design as the most common cause of failure of clay liners. Elements of good installation practice include proper care to identify and eliminate discontinuities in clay during excavation, use of acceptable equipment operating practices during liner emplacement and compaction, development of proper and uniform moisture level during compaction, and use of protective measures to minimize dessication and cracking prior to use. A quality assurance program which will ensure compliance to recommended procedures during each step of installation is essential to the development of an adequate installation.

Removal of discontinuities in clay (sand and silt lenses, roots, etc.) is very essential to ensure the integrity of a recompacted clay liner developed

from clay excavated from the site. (One interviewee, however, indicated that sand lenses would only present problems if they are hydraulically connected). In practice, however, the critical task of removing discontinuities has often received inadequate attention due to time and hence cost considerations. According to one expert, failure to eliminate silt lenses have been responsible for inadequate performance of several surface impoundments, and similar cases of landfill failures have been attributed to such discontinuities in the finished liner although, in the case of landfills, the cause-and-effect relation is more uncertain due to the inaccessibility of the buried liner. Because of the inability of an average equipment operator to identify subtle discontinuities (in particular, presence of silt lenses since they generally resemble the surrounding clay in color and texture), one expert feels that the presence of a highly qualified inspector at the site during excavation to watch for sand and silt lenses is almost mandatory.

Use of proper construction techniques and adherence to acceptable equipment operating practices during liner emplacement and compaction are considered necessary to avoid possible damage to the finished liner. Thus, use of inappropriate techniques (e.g., use of standard road construction practices) and careless equipment operation (e.g., dead standing turns) which could wreck, to varying degrees, work that is supposedly completed, should be avoided. This, however, is considered to be much less of a problem than with an FML since, because of the thickness of the clay liner, damage would be limited to the surface (it will not penetrate through the liner) and can be more readily spotted.

Development of proper and uniform moisture level in clay during compaction is very essential to the performance of a finished clay liner. Case study research data developed by one interviewee indicate that soil compacted "dry" of optimum can be several orders of magnitude more permeable than soil compacted at or greater than optimum. The recommended practice is to compact the clay wet of optimum to about 95 percent of Proctor test density. Nonuniform addition or distribution of water and failure to break up large clods during compaction can result in the formation of cracks and clods with wet surfaces, but dry, cracked interiors that will allow rapid leachate migration. Thus, during compaction, large clods of clay must be broken up. It is consi-

dered that clods larger than 3 inches should be eliminated, but a maximum of 6 inches may have to be tolerated due to the limitations of current technology and equipment. Nonuniform and inadequate moisture level can also result from inadequate time allowed for water to penetrate clay. The difficulty is especially pronounced on side slopes where much of the water may run off, sometime forming pools at the bottom of the slopes.

Unless adequate measures are taken to prevent moisture loss, an installed clay liner is subject to dessication and cracking. It was cited that cracks extending 6 to 8 inches can form following a single day's exposure to ambient conditions. Conflicting views were expressed as to whether or not in actual practice necessary precautions are taken to protect the liner. Thus, while one interviewee indicated that installers are not generally careful about protecting the newly constructed portions of a liner, a number of other interviewees disagreed. In any event, there is a general agreement that protective measures are very effective and easy to implement. These measures include use of a temporary cover such as a thin layer of asphalt, a layer of soil, a plastic sheet, or even a layer of rock rubble. Alternatively, the liner can be constructed a foot or so thicker than required with the extra thickness scraped off before the liner is placed into service.

Laboratory permeability tests have been shown to be inadequate for assessing the quality of an installed clay liner. Based on a thorough evaluation of design and actual performance of several clay-lined impoundments, one researcher showed that the actual permeability of an installed liner may be 2 or 3 orders of magnitude greater than that predicted by laboratory permeability tests. In addition to possible dessication which may have occurred between the end of construction and beginning of operation, the differences were attributed to the inadequacy of laboratory tests to simulate field conditions. The problem was attributed to: (a) differences in compactive effort between laboratory and field conditions; (b) the small samples used in laboratory not being representative of the overall liner; and (c) laboratory samples being uniformly moistened prior to compaction whereas uniform moisture distribution may not be attainable in the field. One research group indicated that it does not use permeability tests on installed liners, but rather conducts soil density tests to ensure compaction to 95 or 98 percent of Proctor test density.

3.3.4 Research and Development Needs

Some of the general R&D needs discussed in Section 3.2.6 in connection with FML (e.g., development of a more extensive data base for design through systematic studies of long-term performance of actual facilities, investigation of alternatives to landfilling of certain wastes, and transfer of technical information to field personnel and permit writers) are also applicable to clay-lined facilities. Suggested R&D works more specific to clay include the following:

- Development of better design/construction criteria for clay liners (e.g., lift thickness, method of moisture distribution, compaction, etc.).
- Assessment of liner compatibility (long-term changes in permeability) with actual leachate and model wastes or simulated leachate.
- Development of laboratory permeability tests which would more closely correlate with actual fiel data.
- Additional studies of clay/natural soils attenuation with organic chemicals.
- Assessment of contaminant transport in fine grain sediments, including in fracture networks.
- Studies of the validity of Darcy's law at permeabilities of 10^{-7} to 10^{-8} cm/sec, including the effect of the porosity term used in the relationship.
- Investigation of the bonding energies of clays with organics versus water.
- Assessment of the effect of subsidence on rate of infiltration through clay caps.
- Standardization and survey of methods used to measure design parameters and assembling of information on current practice in one location.
- Investigation of use of chemicals such as lime or limestone on top of the liner to effect in-situ neutralization of leachate.

One research group with extensive experience with soil liners used in potable water applications suggested the following two research which could have applications to engineered clay liners for waste disposal: (1) use of dispersants to compact soils to higher densities, and (2) development of methods to evaluate soil liners after placement without violating liner integrity.

3.4 PERFORMANCE CONSIDERATIONS AND PROBLEM MITIGATION MEASURES FOR OTHER LINER TYPES

3.4.1 General Considerations (Comparison with FML and Clay)

Reflecting the lesser uses of liners other than FML and clay, a considerably smaller data base exists for these other liner types. There are usually only a few suppliers for each type of these "specialty products" and, with some exceptions, the suppliers seem to hold a monopoly on the available experience. The key exception is the asphaltic concrete, where the product and the method of its use are the same or modifications from pavement/highway construction, and this is cited both as an advantage (existence of extensive experience) as well as a disadvantage (not taking into account unique liner application requirements) of these products. In general, what little performance data that have been made public by the suppliers appear to be aimed primarily at promoting the product and, hence, may not be objective; the data also appear contradictory and have not been independently verified.

The specialty products for which varying amounts of information were collected in the interviews are asphaltic rubber, asphaltic cement, asphaltic emulsion spray-ons, and bentonite soil admixture. In general, the suppliers of these liners claim the following advantages for their products:

- Absence of seams - The installed material forms a continuous liner, thus eliminating the seaming problem which is a major drawback for FML.

- Involvement of fewer parties in steps leading to and including installation - Because only one or two firms are usually involved in the design of the mix and in the actual installation, there is probably less opportunities for mistakes and for quality compromises, and the supplier can also exercise tighter control to ensure proper product use.

- Formulation to accommodate site-specific variations - Based on previous experience and some laboratory tests, the mix of ingredients for bentonite and asphaltic rubber can reportedly be adjusted to respond to specific application conditions (e.g., type of soil and waste characteristics).

- Suitability for caps - Since bentonite is reportedly more flexible than clay or soil, and asphaltic liners can undergo a substantial elongation (perhaps in excess of 300 percent), both materials should be suitable for caps. One firm also claims better uv-resistance and chemical-resistance properties for asphaltic emulsion than for most FMLs.

Many of the obstacles to producing quality installation with FML and clay are also applicable to the specialty liners. Most noteworthy of these relate to deficiencies in design and lack of quality control during installation. Quality control is especially important with these products because conformance with the supplier's recommended procedures is very necessary to ensure a quality product. Inadequate cover protection for liner, reliance on liner to provide structural support (instead of the subgrade) are two common design pitfalls.

3.4.2 Asphaltic Concrete

The difficulty in developing adequate impermeability and potential incompatibility of the material with the harsh nature of waste/leachate are the two main concerns expressed by those providing information on asphaltic concrete liners. Most asphaltic concrete liners are constructed by general asphalt contractors whose experience might be exclusively with highways, parking lots, or similar applications of the material. While this considerable experience is cited by some as a decisive advantage for using asphaltic concrete, there are others who point out distinct differences between the two types of applications and note that the standard procedures might be inadequate to develop the characteristics needed of the material in a liner application. To develop the lower permeability needed for use as a liner, the mix should be modified to increase the asphalt and fines contents; a higher degree of compaction should also be used (via increasing the number of roller passes over the material). These required adjustments to the mix and the installation procedures, however, are not generally done (one interviewee indicated that the asphaltic concrete liner at his facility was based on a standard mix established by the state for highway construction).

Even though impermeability is of significantly less concern for the slopes than for the bottom, the difficulty in operating equipment on slopes can lead to inadequate compaction which can threaten the integrity of the material on steep slopes.

Those interviewed were also in reasonable agreement that asphaltic concrete would not be suitable in applications where ground movement is a distinct possibility.

3.4.3 Asphaltic Rubber

Better resistance to chemical attack and weathering are considered two major advantages of asphaltic rubber over many FMLs. Tests indicate that exposure to uv or ozone, for example, results only in surface degradation of the entrained asphalt and the formation of a protective layer on the surface which prevents degradation of the asphalt-rubber matrix of the interior. Asphaltic rubber, however, is a relatively new product and has not received as much attention as FML. Based on its apparently desirable properties, one supplier predicted that it is only a matter of time before asphaltic rubber is widely used in liner applications.

Although long-term data on the performance of asphaltic rubber in waste disposal applications are unavailable, one interviewee indicated that based on compatibility tests in which the time factor was compressed, asphaltic rubber is at worst more durable than other asphaltic-based products. Asphaltic-based products in general have registered long-term durability in a variety of potable water applications (e.g., lining of canals). One supplier/installer of asphaltic rubber liners indicated that as part of its R&D program (and as a matter of policy for new applications), it routinely carries out compatibility testing using a range of chemicals at varying concentration levels; the company believes that major incompatibility problems would surface within 30 days.

Although somewhat more of an economic/political factor than a performance consideration, asphaltic rubber can often be formulated to utilize some local sources of raw materials (especially the asphalt), thus reducing cost and enhancing the acceptance of the project by the local community.

3.4.4 Asphaltic Emulsion Spray-on

One interviewee who has carried out extensive R&D work and developed a soon-to-be-marketed asphaltic emulsion spray-on product, believes that its product will be superior to most currently available FMLs. The product will have as its ingredients elastomers, diluters, fillers, urethane, polybentylene, and a number of other proprietary additives. The recommended installation will consit of compaction of support soil and placement of a fiberglass mesh on top of the compacted soil onto which the emulsion will be sprayed to form

a 1/16 inch thick layer. A double liner system can be installed by sandwiching 18 inches to 2 feet of graded material (containing the leachate detection system) between the two spray-on liners. Excellent puncture resistance, resistance to degradation by chemicals and sunlight, quick setting properties, and absence of seams are claimed to be the major desirable features of the new product. Although no independent data are available to confirm or disprove the supplier's claims, one firm could foresee no liner application for asphaltic emulsion spray-ons.

3.4.5 Bentonite-Soil Admixture

One major supplier of bentonite (sodium montmorillonite) and a company providing engineering and construction services for specialty-type liners (including bentonite) were interviewed. The bentonite supplier considers its product distinctly superior to common clay for use as a waste disposal site liner because of the more desirable characteristics of sodium montmorillonite and the contaminant resistance properties which are imparted to the product by treatment with certain proprietary chemicals. According to the supplier, low-head permeability tests conducted using a range of solutions (generally containing about 10 percent of a contaminant) have indicated no change in bentonite permeability upon prolonged contact with the tested solutions. The supplier also notes that bentonite has been successfully used in tank farm spills containment applications involving short term contacts with organic solvents and industrial grade chemicals. Theoretically, polar compounds such as acetone and lower alcohols at high concentration levels would be expected to displace the bound water, thereby causing the collapse of the bentonite structure and hence increased permeability.

The supplier's view (and data) on the contaminant resistance property of bentonite is challenged by one engineering/installation company who recommends bentonite only for potable water liner applications. This company indicates that, based on the results from its own testing effort, even the so-called contaminant resistance material would be incompatible with waste/leachate and that failure of the bentonite liner (i.e., increase in permeability) in a full-scale application would just be a matter of time (most likely after the first or second year of installation).

As with clay liners, a bentonite liner is susceptible to dessication and cracking. The dessication potential, however, can be minimized during installation by quickly covering the bentonite with soil (usually about 6 inches thick) or with a sheet of plastic. According to the supplier, a successful bentonite liner installation requires: (a) prior site surveillance and laboratory testing to determine the required bentonite-soil mixture and the suitability of the site soil for use in the admix, and (b) strict work supervision to ensure adherence to the recommended installation procedures. A liner thickness of 6 to 12 inches is generally considered satisfactory.

Even if bentonite exhibited excellent performance characteristics, its use as a liner material would be limited only to certain geographic areas where the cost of transporting the material from mines and processing facilities in Wyoming and Dakota would be acceptable.

3.4.6 Research and Development Needs

The following areas were suggested for further research and development:

- Evaluation of the effects of heavy metals and aromatics on the permeability of bentonite, and elucidation of the reaction mechanisms involved.
- Development of specific tests for and determination of those characteristics of asphaltic rubber most important to liner performance. Any independent effort should enlist the assistance of principal suppliers who are most familiar with the product.

3.5 PERSPECTIVES ON REGULATIONS

While a number of individuals interviewed considered the July 1982 interim final land disposal regulations adequate, a number of criticisms were also raised on certain specific points in the regulations. There were also a number of suggestions for incorporating some sort of QA/QC requirements in the regulations.

3.5.1 Limitations of the Interim Final Regulations

There appears to be a consensus of opinion that land disposal regulations should not disallow the use of clay liners, that under most conditions a clay-FML combination system could provide the most protection, and that there must be a greater emphasis on siting factors since under certain circumstances a

clay liner can prove very suitable. Some experts believe that the EPA's decision to disallow the use of clay liners in favor of FML was very premature and was apparently prompted by research results from the work of Dr. Kirk Brown of Texas A&M University which indicated that under certain conditions some organics can increase clay permeability. It is, however, pointed out (by Dr. Brown, among others) that the test conditions used in Brown's experiments (i.e., pure solvents and high pressures) are in no way representative of the actual landfill environment.

There were a number of comments on the desirability of expanding monitoring requirements of the existing regulations and the possible pitfalls of exempting double-lined facilities from monitoring. One designer pointed out that such an exemption would provide incentive to intentionally construct an inadequate lower liner so that any leachate passing through the first liner would pass through the second liner, thus escaping detection by any leachate detection system placed between the two liners. Since monitoring wells would not be required for double-lined facilities, the escaping leachate would move unnoticed into the ground. For this reason, and because of the general difficulty of defining and determining liner failure, performance standards are thus not favored. Performance standards, however, were considered desirable by some interviewees as a mechanism for enforcing compliance and for enticing owners/operators to seek quality contractors/installers.

With respect to FML standards, the requirement for a minimum liner thickness (e.g., 30-mil) is generally considered inappropriate and a preference is expressed for stating the requirements in terms of liner permeability. The general difficulty of setting standards to cover all types of FML is also acknowledged.

One owner/operator pointed out the need for writing clearer regulations. He believes, for example, the statement limiting the depth of leachate over the liner to a maximum of 30 cm is somewhat confusing without defining what constitutes the bottom since the liners are designed with a slope and some siltation occurs in the leachate collection reservoirs during the service life of a facility. Also, the provision requiring operation of the leachate and detection system until leachate is no longer detected needs some clarification

to define, in quantitative terms, as to what would constitute "no leachate detected" since a very low level of leachate generation would be expected for a significant length of time.

3.5.2 QA/QC Requirements

The need for incorporating some kind of QA/QC requirements in the regulations was pointed out by several of the interviewees. It was suggested, for example, that the submission of a comprehensive QA/QC program be required as part of the permit application for hazardous waste land disposal facilities. The QA/QC programs should be so designed and implemented that they would force owners/operators of facilities to hire competent contractors and reputable suppliers, and to consider factors other than cost in evaluating and awarding construction bids. This objective could be aided significantly by EPA educational programs (e.g., training sessions and technology transfer seminars) aimed at elevating the technical familiarity of the personnel at permit issuing agencies on various aspects of site design, construction, and operation. It was also suggested that QA/QC programs be designed and run, not necessarily by EPA, but by a team of qualified independent experts.

3.5.3 Miscellaneous

There appears to be a consensus of opinion that education, and not necessarily only regulations, is the key to ensuring environmentally adequate waste disposal facilities. This education would also be very conducive to improving communication between regulators, designers, material suppliers, liner manufacturers, fabricators, installers, etc., which is so essential to developing adequate facilities. Improved communication can publicize cases of failure (and success) and expose incompetent contractors, unscrupulous suppliers, manufacturers, etc.

Although admitting that perhaps somewhat impractical and contrary to the present trend, one researcher suggested that regulations should promote construction of more smaller landfills over construction of fewer but larger landfills; the failures of smaller landfills would not have very catastrophic environmental impacts and, in most cases, the resulting damages can be corrected.

Some interviewees attributed the shortcomings of the existing environmental regulations to what they perceive as a lack of technical competence and "real world" experience on the part of individuals writing regulations. It is also pointed out that a very high staff turn-over, which is characteristic of regulatory agencies, prevents the individuals drafting regulations (who are asserted to be largely administrative personnel) to accumulate and apply experience on any given subject matter.

4. INTERVIEW REPORTS

- Suppliers, Manufacturers, Fabricators, Designers, and Installers of FML, Clay, and Other Liners.
- Owners/Operators of Hazardous Waste Management Facilities.
- State Regulatory Agencies.
- Researchers in Academic and Research Organizations.
- Trade/Professional and Standards Setting Organizations.

4.1 INTERVIEW REPORTS WITH SUPPLIERS, MANUFACTURERS, FABRICATORS, DESIGNERS, AND INSTALLERS OF FML, CLAY, AND OTHER LINERS

A-1. Schlegel Lining Technology, Inc.

A-2. Sta-Flex Corporation

A-3. Burke Rubber Company

A-4. Gundle Lining Systems, Inc.

A-5. Watersaver Company, Inc.

A-6. E.I. DuPont de Nemours & Co.

A-7. M. Putterman & Co.

A-8. American Colloid Co.

A-9. Woodward-Clyde Consultants

A-10. Roy F. Weston

A-11. Slurry Systems

A-12. B.F. Goodrich

A-13. The Pantasote Company of New York

A-14. Gulf Seals

A-15. Arizona Refining Company

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-1

Schlegel Lining Technology: Inc., The Woodlands, TX

James Price
Morris Jett
Robert Clarke
Jan Brunn
713-350-1813

TRW: Michael D. Powers
Michael T. Haro

14 December 1982

Summary

- Schlegel is attempting to change the historically negative image of synthetic liners by marketing a high quality, high technology product. They offer a competitively priced product when viewed from a life-cycle cost benefit analysis.

- Schlegel has demonstrated that it is possible to install a 100 percent leak proof liner. There are several installations of double liner containment with monitoring systems that have passed stringent long term testing to ensure a 100 percent leak proof system.

- Schlegel controls and performs QA/QC, for all operations, from receipt of raw polymer to installation.

- QA/QC procedures should be specified in regulations and include a requirement for a third party QA/QC audit. Standards-setting organizations such as ASTM take too long to reach a concensus.

Background

Schlegel Lining Technology, Inc. is a subsidiary of Schlegel Corporation, a Rochester based company. Other lining divisions with manufacturing capabilities are located in Hamburg, West Germany, and Waterford, Ireland. Schlegel manufactures, tests, and installs high density polyethylene (HDPE) liners in 60, 80, and 100 mil thicknesses.

The following are perspectives of the company on: (a) various aspects of their operating philosophy; (b) installation procedures; (c) quality assurance/quality control procedures; (d) warranties; (e) major causes of liner failures; and (f) adequacy of regulations and regulatory reform needs. The statements and assertions, which are largely qualitative, reflect the extensive experience of the company; quantitative technical and engineering data to support the statements and assertions were not provided.

Schlegel's General Operating Philosophy

- Historically, the synthetic liner industry has a very negative image. There are a lot of fly-by-night operators who do sloppy work, as well as other more-or-less reputable firms whose products do not perform satisfactorily.

- Schlegel is trying to change the negative image of the liner industry. They put out a product that they regard as being high quality, high technology, and consequently higher priced. They are not in the "thin membrane" market; while some companies manufacture a 30, or even 20, mil liner sheet, Schlegel's material comes in 60, 80, and 100 mil thicknesses.

- There often are problems with synthetic liner installation. A "totally leak-proof" liner system is possible. Only when the most stringent controls are exercised during design and installation can a system be considered as 100 percent leak-proof. Post completion monitoring is essential to establishing a totally leak-proof installation.

  Schlegel continually strives to improve their practices in order to achieve the leak-proof installation.

- Schlegel believes that because the regulations allow liners as thin as 30 mil, other manufacturers and installers have greater difficulty in providing a leak-proof system. Physical properties such as tear and puncture resistance are directly related to thickness and significantly affect the liner installation by providing a factor of safety for damage from external forces imposed on the liner.

- Although Schlegel's first contact with a customer is usually through a design or engineering consultant, the final contact is directly with the end user of the liner in 95 percent of their business. In this way, Schlegel is responsible only to the end user of the liner, rather than to some contractor. Schlegel does advise the engineer and influence design, but it does not do any of the civil engineering work for a facility, nor does it stamp plans for dirt work or piping.

- Schlegel carefully tests compatibility of the liner material with the waste to be contained, working in close cooperation with the owner's design engineers. They run a high temperature immersion test at 158°F (70°C) for 28 days in the customer's waste, or until the weight of the sample stabilizes. Changes in weight and tensile strength are determined; weight changes greater than $\pm$ 3 percent and changes in tensile properties greater than $\pm$ 10 percent indicate that the liner is deleteriously affected by the waste.

Schlegel's Liner Installation Procedures

- All welding and QA/QC testing is performed by independent Schlegel personnel. Schlegel uses a year-round core group of welding technicians, adding trainees as the need arises. The usual company crew consists of a site superintendent, a senior welding technician, and three or four other welding technicians. Non-welding laborers are hired locally to perform such duties as unloading, cutting, and positioning the liner sheeting, sand bagging it to prevent wind damage or movement, and surface grinding in the areas to be welded.

- Usual procedure for installation is to position, cut, and prepare liner surfaces during the day, and then do the actual welding at night when the material has contracted.

- Because of the thickness of Schlegel's material, heavy rubber-tired equipment can work on top of the liner. This allows grading during the placement of a soil cover. Schlegel does insist on having a welding technician on-site to watch for punctures or other damage during the placement of soil cover.

- Schlegel feels that their patented extrusion welding process is critical to the success of their liners. This process extrudes a ribbon of molten HDPE between the liner sheets, and then pressure rollers force the sheets together. This method of joining sheets results in a seam with physical and chemical properties identical to that of the sheet itself, as opposed to solvent or contact cement joints common to other materials.

Schlegel's QA/QC Practices

- Schlegel tests each shipment of raw polymer prior to unloading; it is unloaded only if it meets specifications.

- During the manufacturing process, the sheeting is visually inspected for flaws and holes; imperfections are marked and noted for repair in the field.

- Field welds are tested in several ways:

  - Visual.
  - "Point-stress test apparatus". A screwdriver is inserted and twisted to see if a spot on a weld fails.
  - Ultrasonic. Because Schlegel's welds are designed to be homogeneous, inhomogeneities such as gaps, bubbles, and holes in the welds are easily detected.
  - Vacuum box. For testing fillet welds.

- Tensile and peel strength. Samples are taken and tested in field prior to welding. Post-installation samples are also sent to the Schlegel Lab for confirmation testing.

- Schlegel is disturbed that some companies still do installation during the winter. They refuse to do it except under the most controlled conditions. This includes covering the entire installation and maintaining adequate temperature ranges. They feel that welding cannot be done when the ambient temperature is below 45°F. If only the welding temperature is raised to compensate (as opposed to raising the sheet material temperature) the adjacent material can become crystallized and significantly weakened.

Incorporation of QA/QC Requirements in Regulations

- Schlegel would like to see QA/QC procedures written into the regulations. Because they put a lot of time and expense into QA/QC already, regulatory requirements would not adversely affect them, but would increase the expenses of others in the industry; this would help Schlegel to reduce the cost advantage others presently enjoy. A third party QA/QC audit should be made mandatory. Standards setting organizations (e.g., ASTM) may take too long to reach a consensus, and may be influenced by certain portions of the industry.

- Because there are still a number of fly-by-night lining manufacturers and installers, Schlegel feels that the licensing of installers has merit. However, they also feel that such a program would be an administrative nightmare, and impossible to carry out effectively.

- The industry does currently have adequate technology to test the integrity of a synthetic liner system but improvements could be made to improve the speed and accuracy of the testing procedures. Part of the problem is in personnel training, both for installers and QA inspectors.

- Regulations should put a ban on liner installation during adverse weather conditions.

Major Causes of Liner Failure

- Liners can fail for a variety of reasons, including the following:

  - Failures at welds or seams.
  - Punctures due to equipment or carelessness (e.g., workmen dropping hot welding tips onto the liner and heavy equipment digging through a soil cover into the liner).
  - Incompatibility. This can cause failures at the weakest point. Often times, the waste contains contaminants that were not specified (e.g., oil wastes in a brine pond).

- Penetrations. This is Schlegel's biggest problem. They try to have piping passing through the liner made of HDPE, so that they can make a direct bond. When pipes of other composition are used, they sleeve the pipe with HDPE and use a closed-cell neoprene gasket compressed by clamps. Stresses at penetrations may also induce mechanical failure of the liner sheeting unless proper design is incorporated into the system.

Warranties

- Schlegel gives a two-year warranty on material and workmanship; problems uncovered during the warranty will be repaired or replaced. Schlegel has had warranty repairs; where they have made mistakes, they have gone back and fixed the problems. They try to eliminate them, but human errors do occur.

- Schlegel has never had a waste/liner incompatibility failure. When the waste is identifiable and tested prior to installation, failures can be eliminated. After installation, problems can occur when different wastes are entered into the basin. Schlegel will not attempt to sell a liner where the waste is incompatible with the sheet material.

- There are many irresponsible warranties in the market. Many of the twenty year (or longer) extended warranties are full of loop-holes and worthless. Schlegel may offer an extended warranty if certain parameters such as controls over operating conditions, security, waste concentration, etc., can be achieved and maintained.

Materials Supplied to TRW

The following "non-confidential" materials were supplied to TRW by Schlegel during the interview:

- Schlegel Lining Technology, Inc. Evaluating Lining Materials. The Woodlands, Texas. 1982. 13 pp.

- Schlegel Lining Technology, Inc. Test Procedure for Determining Chemical Resistance of Flexible Membrane Liners. 2 December 1980. 3 pp.

- Schlegel Lining Technology, Inc., The Woodlands, Texas. (Company literature and related technical data on Schlegel liner applications, flexible membrane properties, and design and installation details.) Approximately 100 pp.

In addition, Schlegel has agreed to forward copies of certain proprietary technical data upon receipt of a confidentiality agreement signed by TRW. Because of the schedule constraints for the project, however, it was decided at this time to avoid the often lengthy process of drafting and signing a mutually agreeable secrecy agreement.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-2

Sta-Flex Corporation: Louis Peloquin
San Jose, CA 408-224-0604

TRW: Louis L. Scinto

14 December 1982

Summary

- The performance of a properly selected, designed, and installed FML will exceed that of a clay liner over the long term.
- Most liner failures can be traced back to improper design or inadequate design specifications.
- Each liner material has different installation requirements; therefore, any installation standards must be written to be material-specific.
- Installers should be responsible for quality control during liner installation. Inattention to recommended installation and quality control procedures by inexperienced installers (particularly general "dirt" contractors) can lead to serious deficiencies in the quality of the job and increases the probability of liner failure.
- Locational standards for hazardous waste facilities should be adopted to restrict siting of these facilities in environmentally sensitive areas.

Background

Sta-Flex Corporation is a well-known installer of flexible membrane liners (FML), headquartered in Greenland, NH; Mr. Peloquin is in charge of the West Coast Office in San Jose, CA. The company was founded in 1970. Mr. Peloquin joined the firm in 1977. Prior to that time, he had been with Burke Rubber Co. and was in charge of engineering, manufacturing, marketing, sales, and installation of Hypalon for the company. Sta-Flex employs four full-time superintendents and four foremen who travel between job sites supervising installation work. Local labor is employed at each project, but only to perform such manual labor as positioning sheets of liner material. Seams are all done by experienced Sta-Flex personnel. The company will install most liner materials, but the majority of their experience has been with Hypalon, and more recently HDPE.

The following are the perspectives of Sta-Flex Corporation (as conveyed by Mr. Peloquin to TRW) on: (a) long-term performances of clay vs. flexible membrane liners (FML); (b) design considerations; (c) FML installation practices; (d) quality control and testing requirements; (e) standards and regulatory reforms; and (f) miscellaneous considerations including contacts for additional data.

Performance of Clay vs. Synthetic Liners

- If properly selected to be compatible with the waste contained and designed and installed properly, FML will outperform clay in the long run. The Bureau of Reclamation has a lot of information on the compatibility of clays with wastes which basically shows clay is only good over the long term to contain fresh water.

Design Considerations for Flexible Membrane Liners

- Some failures of FML can be related to installation problems, e.g., inadequate seams. However, most of the failures can be related directly or indirectly to improper design and/or inadequate design specifications.

- Proper design, including siting, can prevent many potential problems such as chemical attack of the liner material by the waste, and generation of gas under the liner and subsequent formation of "bubbles" in the liner. One example of a failure which resulted from improper design was a lined pond constructed at a Scott Paper mill in Wisconsin in the early 1970's. The lined pond was built directly over an older unlined pond site which had contained organic sludges. The pond was designed and constructed with a flat bottom. Gas was generated under the liner from the residual organics in the subsoil, causing large gas bubbles in the liner. The design should have incorporated a slightly sloped bottom with vents on the slopes for gas.

- One aspect of a proper design is selecting a liner material that is compatible with the waste to be contained, and that will resist degradation due to weathering. Most membrane liners show good weatherability (with the exception of PVC which degrades when exposed to ultraviolet light and, therefore, must be covered with earth). Large differences between materials in terms of their weatherability do not usually exist. However, in designing a lined disposal facility, compatibility tests must be run to determine the suitability of the membrane for the specific application. Some weatherability and compatibility data can be extrapolated from the use of certain liner materials (e.g., PVC) in other applications such as piping. Data on specific materials and wastes are usually developed by liner manufacturers.

- Failures due to chemical attack are not widespread occurrences. Sometimes the introduction of an unexpected waste constituent or a large quantity of a normal trace constituent into a lined disposal facility can cause problems due to chemical interactions between the waste and the liner. Such a condition, however, may not necessarily lead to liner failure. For example, a Hypalon liner installed in a pond operated by Buckeye Cellulose in Perry, Florida, was subjected to higher than expected concentrations of oil which caused swelling and bubbling of the liner. After draining the pond, removing the oil, and drying the liner in the sun, the swelling subsided. No permanent damage to the liner was experienced. Thus, some potential damage to liners due to waste variations or incompatible wastes may be reversible.

- Structural design of the waste facility has a lot to do with the final success or failure of the liner. Slopes should not be too steep (2:1 is about the limit, 3:1 is preferred for most FML). Soil should be properly and uniformly compacted. Geotextiles should be considered if rocks are likely to be a problem in the finished subgrade. Penetrations of the liner, such as for inlet/outlet structures, should be minimized and care should be taken in specifying proper methods of installing liners around these penetrations.

- Designing a lined facility to use two or more different liner materials is a mistake. Seams between different materials are not as strong as between two pieces of the same type of material. Seams can be made where no other solution exists, but should be avoided if possible.

Installation Practices

- Subgrade preparation is important. It is hard to define an "acceptable" surface quantitatively. The decision whether or not to accept a prepared subgrade prior to placement of FML should be left to the installer to make, based on his experience.

- Each liner material installer has different techniques which are used for seaming. Even for the same material, different manufacturers may recommend slightly different seaming methods.

- Seams in HDPE are done exclusively by heat welding (as opposed to Hypalon for which bodied solvent adhesives are commonly used). Hot air, hot wedge, or hot melt (extrudate) systems are used. One type of seaming method uses a hot wedge to make a double seam in the liner with an air pocket between the seams. Testing of these seams is performed by injecting 60 psi compressed air into the space between the seams, waiting 10 minutes, and checking for leaks or drops in pressure. Such a technique can be used both during installation and later when the facility is in operation. Care must be taken in seaming HDPE to prevent crystallization in the seam. Crystallization weakens the seam by making it susceptible to flex cracking. Since HDPE expands and contracts quite a bit with changes in temperature, stress cracking at crystallized seams could be a problem, particularly on parts of the liner which are exposed to the elements.

Quality Control and Testing

- Quality control is an essential part of all installations. Tests with such devices as the air lance, vacuum box, spark testers (not applicable for some Hypalons), or ultrasonic testers should be done by the installer.

- A big concern of installation contractors such as Sta-Flex, which specialize in installation of FML, is that general contractors which have little or no experience installing FML will win contracts by bidding low and will

not be able to do an adequate job. This will give specific products and/or the entire industry a bad name. The opportunity for big profits has lured a number of general contractors into buying liner material off the shelf, and installing the material without consulting with the manufacturer on recommended installation and quality control practices, or obtaining test data on compatibility. This can lead to problems with or failure of the liner. Solutions to this problem might be to have all manufacturers approve fabricators and installation contractors before selling them materials or to better educate design engineers in the preparation of detailed specifications for installation contractors to follow.

- Properties of liner materials affect seam strength. For example, reinforced membranes with 6 x 6 scrim form stronger seams than the same material with 10 x 10 scrim. The 6 x 6 scrim provides greater strike through, allowing more surface area for bonding between the two materials, with only a slight reduction in tear resistance compared to 10 x 10. Peel strength of a seam is often as important as (and may be totally unrelated to) shear strength. Many seams turn out like adhesive bandages; they are very easy to peel apart but very difficult to shear. As for properties of the liner material itself, elongation and tear are better indicators of suitability than tensile strength, because the ability to elongate (e.g., due to local subsidence of the subgrade) is what makes flexible liners useful in pollution control applications.

Standards and Regulatory Reforms

- NSF's proposed standards may suffer because the range of inputs used to develop the standards was not broad enough. In order to set good standards input needs to be obtained from a variety of sources.

- The major problem with setting standards for FML is that it is difficult or impossible to imagine a standard generally applicable to all types of materials. Individual standards for each material, covering specifications and installation procedures, may be worth considering.

- There should be restrictions on location of hazardous waste disposal facilities to mitigate environmental damage in the event of liner failure because there can never be total assurance of 100 percent containment of wastes in man-made structures.

Miscellaneous, Including Additional Contacts

- A potentially popular new material for liners is linear low density polyethylene.

- The polyethylenes such as HDPE will be a dominant factor in the liner market.

- A leachate detection system purported to be capable of locating leaks is being used at a solar brine pond in Nevada. It is part of the State Public Works Board's Playa Project in Boulder City. Don Day is the Project Manager. Copper wires intersect in a grid pattern of 6 foot squares under the pond. Any leaks from the pond can be detected as short circuits in the grid. This technique is only applicable in a limited number of cases (e.g., where shallow groundwater would not trigger the short circuit).

- Research on compatibility of polyethylene resins with various materials is done by Clark Gunness in Canton, Massachusetts, for liner manufacturers like Sarnafil. Mr. Gunness can be reached at 617-828-5400.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-3

Burke Rubber Company: D. Kutnewsky
San Jose, CA Ralph Woodley
408-297-3500

TRW: Louis L. Scinto

16 December 1982

Summary

- The best way to assure the quality of a liner installation is to adopt a systems approach, where there is an unbroken chain of responsibility for quality assurance/quality control (QA/QC) from designer to manufacturer to fabricator to installer to operator.

- Pinholes can be present in any single ply membrane and the manufacturers of single ply materials are hard put to guarantee a pinhole-free product.

- The amount of weepage through pinholes would be orders of magnitude less than through a bad seam or a substantial tear. The puncture resistance of most materials is sufficient to prevent enlargement of pinholes under most circumstances.

- Both non-destructive in-place testing and testing of random samples cut from the finished liner should be performed to test the quality of field seams.

- It is difficult or impossible to define the quantitative effects that deviations from recommended installation practices have on liner performance.

- Liner warranties cover material quality, workmanship, and "normal weathering". Damage resulting from exposure of the liner to harmful chemicals is excluded from the warranty.

- Tensile strength alone is insufficient to characterize the performance of reinforced synthetic membrane liners. The relationship between tensile strength and elongation defines an important property of a liner material, its "tensile performance factor", or "work-to-break" as defined in ASTM D-885.

Background

Burke Rubber is a major manufacturer and fabricator of synthetic liner materials. The company has done some installation work through a subsidiary, Burkeline Construction Company; however, most installations of Burke material are done by independent, specialty contractors approved by the company. Burke will only sell material to approved contractors, or to firms which agree to allow a Burke supervisor on-site to oversee the installation and provide technical assistance.

Discussions with Burke personnel encompassed primarily the following areas: (a) general aspects of QA/QC requirements for flexible membranes; (b) QA/QC during liner installation; (c) sources, significance, and control of pinholes in flexible membranes; (d) construction/installation specifications; and (e) liner warranties. Outcomes of discussions of these topics are summarized below.

General Aspects of QA/QC Requirements for Flexible Membranes

- The best way to assure quality is to use a systems approach. Burke attempts to do this by requiring a continuity of control through all stages of the project: design, manufacturing, fabrication, and installation. By exerting direct control or providing technical assistance during all stages of the project, the manufacturer is the master link in an unbroken chain of responsibility for quality assurance. For the installation stage of the project, control is maintained through either direct supervision of the work by Burke personnel, or by use of contractors approved by Burke who have proven their qualifications by receiving on-site training by the manufacturer in the installation of at least 250,000 square feet of the material being used.

- Responsibilities for QA should be clearly delineated. The design engineer should be responsible for ensuring that waste/liner compatibility is considered and that the impoundment is properly designed and sited. The manufacturer should ensure that the material meets or exceeds its specifications. QA/QC for factory seams is the responsibility of the fabricator. The installation contractor has the job of ensuring that earthwork and field seaming are done properly and that the liner is not damaged during installation. The owner's responsibility for QA/QC during installation should be to define the overall QA/QC program, incorporating a level of detail that is consistent with the waste being contained and the location of the facility*.

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*For example, some facilities may require greater attention to QA/QC than others because they will contain a highly toxic and mobile constituents which, if the liner were to fail, could migrate from the facility and adversely affect human health or the environment.

- In reviewing bids for lining jobs, operators must realize the importance of QA/QC and that this necessary aspect of the job has costs associated with it. Price should not be the only consideration in selecting an installer.

QA/QC During Installation

- Some form of certification for liner installers is necessary. One means of certification would be for manufacturers to approve installation contractors (this is the approach taken by Burke). Licensing of installation contractors (e.g., by EPA using some type of standard) might not be sufficient to maintain the continuity of control which is so important in QA. Such an approach, in combination with requirements that the installer post a surety bond against installation-related failures, may provide more assurance that the job will be done properly, since there would be a financial incentive for the installer to perform adequate QA/QC.

- Quality control testing of field seams by the installation contractor should include both non-destructive testing of 100 percent of the field seams (e.g., using an air lance) and testing of samples of field seams cut from the finished liner at random for shear testing, per specifications. If non-specification seams are detected by either method, further testing of the same kind should be done in both directions to the point where the seam again meets specification requirements; and then a cap strip should be placed over the suspect seam between the tested acceptable points and seamed using standard seaming methods (applied with extra care). The same basic methods would apply to testing of factory seams by the fabricator.

- The air lance method of QC testing of field seams has fewer disadvantages than tests such as the vacuum box or ultrasonic measurements. The vacuum box method is not as reliable for thin, flexible materials as it is for thick, stiff materials. Temperature and humidity variations can affect the reliability of ultrasonic methods.

- It would be difficult, if not impossible, to develop a single QA/QC procedure applicable to all flexible membrane liner installations.

Sources, Significance, and Control of Pinholes in Flexible Liners

- Pinholes can be present in any single ply membrane. The largest of these may be visible to the naked eye or may be spotted by passing the liner over a light bar; the smallest may be a few microns in diameter. Pinholes in a single ply can originate during the calendering or extrusion process where air bubbles, raw material contaminants, or poorly dispersed granules (e.g., undispersed carbon black) in the mixed stock can pass through, or nearly through, the single ply.

Quality control during manufacturing may include fine screening of the mixed stock before calendering or extrusion. Post-manufacturing QC can consist of merely visual inspection of the finished liner on both sides (usually during fabrication) and patching of any holes that are found.

- Pinholes which penetrate the liner are less of a problem for multi-ply liners (such as most Hypalon) because the chances of a pinhole in one ply matching up with another pinhole in a second ply are very small. The only potential problem is if a pinhole exposes scrim such that contact with waste fluids could cause wicking along the scrim to a pinhole in the opposite ply, or build-up of fluid between plies and eventual delamination. The probability of this happening is greatest for tightly-woven scrims and thick yarns (e.g., 10 x 10 - 1000 denier), but in any case is small.

- Any single ply material is very difficult to manufacture completely free of pinholes. Most lining materials possess sufficient puncture resistance to minimize significant pinhole enlargement. In multiple-ply construction, the amount of weepage through pinholes would probably be orders of magnitude less than through a bad seam or a substantial tear or delamination.

- Burke multi-ply membrane materials are specified as "pinhole-free". Some manufacturers of thin single-ply liner membranes include a maximum allowable pinhole count. NSF did not include a pinhole count as a standard for thinner plies of single-ply membranes for liners used for waste containment.

Construction/Installation Specifications

- Burke provides detailed procedural instructions in its company literature for field seaming of Burke membrane lining materials. Bonded seam strength and shear must meet the specification requirements for both factory and field seams. These specification requirements for installation represent the best methods known to ensure that liners are installed properly, but a low bond seam may not significantly affect liner performance. If a failure occurs, the impoundment must be emptied and the point of leakage inspected to determine the cause of failure. The responsibility for repairs is usually indicated by the type of failure. A factory seam failure is the responsibility of the fabricator; a field seam failure is the responsibility of the installing contractor; and a mechanical failure due to damage following installation is the responsibility of the owner.

- Burke specifications recommend the use of optimum size factory seamed panels to minimize field seaming and time of installation. It is important to minimize installation time to decrease the probability of inclement weather adversely affecting the condition of the subgrade.

- Thermal expansion and contraction of some liner materials must be considered to avoid undue stress on the seams. Materials with high rates of thermal expansion and thick cross-section are sometimes seamed at night to minimize the effects of contraction. Sandbagging the edges of panels during field installation also prevents the tendency of some membranes to shrink in an unrestrained state. Some materials require excess wrinkles to allow for shrinkage caused by reduction in mass.

Warranties

- Burke generally provides a limited warranty for its Hypalon liners and covers. The warranty is only valid if installation is supervised by Burke or is done by an approved installer. The warranty guarantees: (a) that the material will be free from manufacturing defects in workmanship or materials for one year, and (b) that the membrane will not develop cracks/holes which penetrate the liner due to the effects of "normal weathering" for 20 years.

- Fitness for use (i.e., compatibility of the liner and waste) is not specifically covered by most limited warranties. Effluent immersion testing is often conducted by the manufacturer of the liner material to indicate the effects of a specific effluent on a specific lining material as a service to the end user.

- Requests are growing for manufacturers to extend current warranties for certain types of installation. One possible solution might be to increase the material cost per square foot for each incremental extension of the warranty beyond normal limits.

Miscellaneous

- Installation procedures for landfill closure covers is essentially the same as for liners.

- Leak detection systems are sometimes installed under liners to collect and identify leakage. As an impoundment is filled, the compression of the soil below the liner can squeeze liquid out of the compressed soil. This can show up as an apparent leak in the liner, and the "de-watering" may show up in the leakage monitoring system for a period of time. Care should be exercised to determine that the liquid appearing in the leak detection system comes from the impoundment rather than the compressed subgrade material.

- Burke has studied the effects of fabric reinforcement on tensile properties of its Hypalon products, and has developed a means of characterizing a material's ability to absorb deformation forces through

its strength and conformational properties. Data from measurements of tensile properties (ASTM D751-Grab Method) provide the basis for defining the "tensile performance factor" of a material. This factor is equal to the area under the Load/Elongation curve (referred to in ASTM D885 as "work-to-break") and gives a value (in inch-pounds) that relates the energy absorbed by the liner before it ruptures. Burke data for reinforced Hypalon of different scrim sizes show that while breaking strength increases with finer scrim weaves (e.g., 10 x 10 > 6 x 6), elongation at break decreases. The effect of reduced elongation is greater than the effect of increased breaking strength, such that the reduced elongation accompanying the more tightly woven high-strength fabric accounts for a lower overall tensile performance factor. Thus, tensile strength alone, as measured by breaking strength of the reinforcing fabric, does not represent the total tensile performance capability of a fabric-reinforced membrane liner. Since tensile performance (e.g., the ability to bridge gaps in the subsurface due to subsidence or sink holes) is such an important property of a liner, elongation to the point of rupture must also be tested to determine optimum performance. A carefully considered balance of properties should be considered by the design engineer in determining the choice of flexible membrane liners.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-4

Gundle Lining Systems, Inc: Dr. Richard K. Schmidt
Houston, TX 713-443-8564

TRW: Michael T. Haro
Michael D. Powers

17 December 1982

Summary

- The major problems/concerns with flexible membrane liner installation are as follows: (a) extremes of temperatures; (b) a wet job site; (c) high wind conditions; and (d) cross joint and T-joint seaming (seaming areas where 3 or 4 sheets come together).

- Quality assurance/quality control guidelines for both installing and manufacturing of flexible membrane liners should be added to the regulations, as well as QA auditor program for liner installation.

- Flexible membrane liner customers must be aware of all the factors which affect the quality of the final product, including liner material and compatibility, seam quality, and financial condition of the manufacturer.

- Forcing manufacturers to warranty flexible membrane liners for the life of the facility is not practical because: (a) warranties are only as good as the financial strength of the company that provides them; (b) in most cases, companies take exception to incidental and consequential damages which could occur as a result of failure; and (c) companies attempt to limit their liability to a dollar amount which does not exceed the selling price of a particular job. Warranties for synthetics should be comparable to those required for clay liners.

- It is important that qualified, experienced flexible membrane liner contractors be used to install liner material. This is a specialized business, and should not be left to a general contractor who has no liner installation experience. The best installation can be obtained when a qualified licensed contractor is used in conjunction with a quality control technician from the liner manufacturer.

Background

Gundle Lining Systems Inc. is a manufacturer of the following flexible membrane liners: high density polyethylene (HDPE), elastomeric polyolefin alloy based HDPE, ethylene vinyl acetate co-polymer, and co-polymer low density polyethylene. Over the past 20 years, the company has installed over

50 million square feet of liners and covers worldwide. Gundle produces a 22-1/2 foot wide, totally seamless roll of HDPE that ranges in thickness from 20 to 100 mils. The company subcontracts with about 6 licensed installers that are trained by Gundle. The company also subcontracts the earthwork construction and has a representative on site to ensure quality.

Presented below are the perspectives and recommendations of the company on the following: (a) specifications and quality assurance/quality control (QA/QC) of liner manufacturer; (b) warranties; and (c) installation and field QA/QC. The statements and assertions, which are largely qualitative, reflect the extensive experience of the company; quantitative technical data on HDPE physical properties and chemical resistance were provided.

Specifications and QA/QC of Manufacturer

- Liner manufacturers should be required to certify their products almost to the point of "finger printing". A common problem in the industry is when a company shows prospective customers high quality material, but actually delivers low-grade material. For example, in order to qualify for the Hypalon trade name, the liner material is only required to be 40 percent Dupont polymer. Other materials that are used in the liner vary from company to company and, therefore, the liner specifications will also vary.

- Flexible membrane liner customers need to take cognizance of the total quality of the product they are purchasing. Many customers emphasize the quality of the material, but ignore seam quality or the financial stability of the manufacturer. Overall, the industry needs a better educated customer.

- Quality control in all phases of the process is essential to a secure containment system. Quality control starts with the raw materials. Out of hundreds of polyethylene formulations tested, Gundle uses only 3 types of resins to make their 97.5 percent pure HDPE liner. The quality control procedure used is as follows:

  - Raw material received from each rail car is sampled top and bottom. A screening analysis is performed on each resin sample in the laboratory. The material is unloaded into the storage silos only if it passes the screening analysis tests.
  - Visual inspection of the liner material occurs as the liner rolls off the machine. Samples of each roll are taken twice a shift for laboratory analysis. Gundle will not ship out a roll of material that does not pass the laboratory tests.
  - Each roll is batch-coded, date-coded, and numbered before being shipped to the field.
  - A quality control certificate is provided to the customer documenting the approval of the liner material according to specifications.

- Immersion tests should be carried out at the design stage of the project in order to confirm waste-liner compatibility. Gundle uses a 90-day room temperature immersion test with the customer's wastes on both sheets and seams. Tests at higher temperatures are performed if the liner will be subject to higher temperatures in the disposal environment.

- Price is extremely important in the liner industry market. Municipalities are notorious for compromising on liner quality for lower prices.

Warranties

- The strength of an individual warranty is only as good as the financial strength of the company providing them. In general, most companies limit their warranty to the actual product that they are supplying and in most cases take exception to incidental and consequential damages which could occur as a result of failure. Further, they attempt to limit their liability to a dollar amount which does not exceed the selling price of a particular project. No company wishes to take on a warranty liability which can far exceed the revenue that would generate from a specific project. Warranties for synthetic liners should be comparable to those required for clay liners. In general, most responsible companies will readily live up to the terms of their warranty agreement.

- Because of the July 1982 regulations, customers will soon ask for 30-year warranties. Typically, there are companies that will give a 30-year warranty, but realistically, they are worthless because the companies that give them are small, under-capitalized firms. Most 30-year warranties will probably be around a lot longer than the companies that provided them.

- Gundle provides a 20-year weathering warranty for their liner. The company guarantees the liner will serve its intended purpose for 20 years. The warranty excludes physical or mechanical damage caused by the customer, acts of God, and chemical incompatibilities other than those which have been certified. Normally, the company limits the value of the warranty to the selling price of the project. (The licensed installers for Gundle also provide a 2-year workmanship warranty on liner installation.)

- Gundle has contacted many insurance companies. For 2 to 3 percent of Gundle's annual sales, these companies would be willing to provide Gundle with coverage, but they will not insure individual jobs.

Installation and Field QA/QC

- The major problems with flexible membrane liner installation are as follows: (a) extremes of temperatures; (b) a wet job site; (c) high wind weather; and (d) cross-joint and T-joint seams (seams of 3 or 4 liner sheets).

- EPA should provide quality assurance guidelines in the regulations for both the installer and manufacturer. Less than 5 percent of the hazardous waste facility operators check on the liner material used or workmanship of the installer once the liner has been placed in the field.

- EPA should also provide a third party QA auditor requirement in the regulations for liner installation. A third party auditor is not necessary for the manufacturer; instead, have the customer (operator) perform their own immersion and physical property tests on the prospective liner material to ensure quality.

- Gundle's field installation and quality control procedures are as follows:

  - To ensure an adequate containment system, the subgrade must be firm and void of debris or sharp angular rocks.
  - The installation begins in the morning with a test weld to ensure good seaming technique. The installer uses Gundle's patented fusion/extrusion welding process that mixes liner sheets with extrudate. Because proper welding temperature is very important, the installer double checks the weld temperature with a hand held pyrometer.
  - Preparation of the area to be welded is also important. The installer will double tape liner sheets together to avoid too much slack in the sheets (a condition that results in "fish mouths"). The sheet surfaces are cleaned by grinding; then the sheets are welded together.
  - Gundle's QC technician will visually inspect seams and questionable areas will be marked for repair. The final control checks on seams are performed with vacuum box tester and a field tensiometer. (More and more clients are requesting 100 percent vacuum testing of seams.)
  - Gundle's QC technician has unilateral authority to shut down the installer in bad weather. When day-time temperatures rise above 95°F, they will work at night. They will work in temperatures as low as 25°F as long as there is no wind.

- Gundle asserts that the benefits of subcontracting licensed installers are greater than those incurred by installing liners themselves. Gundle's installers have been in the business for 5 to 10 years and have relatively stable work forces and local geographical experience.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-5

Watersaver Company, Inc.: Bill Slifer
Denver, CO Jim Bryan
303-623-4111

TRW: Heather White

17 December 1982

Summary

- Quality assurance/quality control procedures must be followed throughout the manufacturing process as well as during installation of the flexible membrane liner or cover.
- The July 1982 regulations are reasonable because they recognize that clay has not proved effective in containing certain wastes.
- Quality assurance/quality control requirements and installation contractor requirements should be added to the regulations.
- Installation procedures should not be specified in the regulations because each facility is different and may require that unique installation methods be used.
- Liner designs that incorporate both clay and synthetic materials are particularly good because they provide the assurance of both.
- Solvent and dielectric seaming methods are preferable to hot air seaming methods (where applicable to the particular type of liner) for factory fabrication of liners.
- A solvent bodied adhesive (at least 10 parts solids) is a superior method to any other type of seaming system in the field, since changing weather and temperatures affect working conditions. Seam quality is more consistent no matter what material is used. Visual inspection can be used to spot field seaming problems.
- Destructive testing of solvent seams is unwarranted because visual inspection by experienced QA/QC personnel can ensure at least 99 percent seam integrity. Moreover, destructive tests are inappropriate because the cutting and seaming allows more chances for failure. Some destructive testing with representative samples seamed under the same installation (weather) conditions should be required.

Background

Watersaver Co. is a fabricator of synthetic membrane liners and covers. The company has been in business since 1953 and has sold over 300,000,000 square feet of liners worldwide. They do some installation work on occasion but prefer to concentrate on fabrication. Watersaver Co. is a proponent of a systems approach to liner and cover design, construction, and installation. They believe that ignorance in any area is the primary cause of liner failure and that the experience of the designer, manufacturer, fabricator, installer, and lab and quality control personnel is vital to the success of the liner system.

The following are perspectives of the company on: (a) various aspects of liner and cap design and installation; (b) quality assurance/quality control requirements; (c) standards and warranties; (d) adequacy of regulations and regulatory reform needs; and (e) research needs. Listing of additional suggested contacts and data sources are also provided. The statements and assertions, which are largely qualitative, reflect the extensive experience of the company; quantitative technical and engineering data to support the statements and assertions were not provided.

Design Considerations for Liners

- During the design phase, the long-term use of the site must be considered. The site owner/operator must be very specific regarding the types and quantities of wastes to be disposed in the facility so that the designer and manufacturer may recommend the best possible liner system.

- Designs that incorporate both clay and synthetic liners are particularly good because they provide the assurance of both materials. In addition, the clay serves to protect the primary synthetic liner.

- Solvent seaming systems (used with CPE, PVC, Hypalon, etc.) are more dependable than heat seaming systems (used with HDPE and similar type of materials) because the quality of the seam is more consistent and can easily be inspected visually. The temperature at which solvent seaming takes place influences the time it takes the solvent to take effect, not the ability of the seaming process to work at all as with heat seaming methods. Because of this solvent systems seam faster and are not as dependent on weather conditions as heat seaming methods.

Construction and Installation Considerations for Liners

- For large or complex facilities (e.g., facilities with many structures to which the liner must be sealed), it is best to work with an installer who specializes in flexible membrane liner installation. He should have installed many types of facilities in many geographical areas. Possible minimum qualifications might be fifty jobs in five years for a total of five to ten million square feet of liner material installed.

- For small, simple jobs (earthwork and some seaming), a general contractor may carry out the installation work. Someone with experience in field installation of flexible membrane liners should, however, be on hand to guide the contractor and to thoroughly inspect all aspects of the construction.

- Subgrade preparation is particularly important to liner performance. Smoothing the subgrade with a vibratory roller is preferable to simply spreading a layer of sand over the subgrade. The use of black liner material is preferable because the heat absorbed by the liner brings soil moisture to the surface. This softens the subgrade and reduces the chances of puncturing the liner with the subgrade material.

- The weight of a roll of liner material is a major factor in determining the size of the roll. 4000 pounds have been found to be the maximum convenient size for field equipment and personnel to work with.

- No equipment should be driven across any type of synthetic liner, no matter how thick. To provide a good safety margin, soil lifts should be at least twelve inches deep.

Caps vs. Liners Requirements

- The cap on a landfill is very important because it prevents liquid from accummulating and exerting pressure on the liner system. A minimum cap grade of 2% may prevent surface runoff from exerting pressure on the cap. "Hounding" may be an option to encourage drainage from larger areas.

- Waste resistance is not as important for cap selection because the cap will not be in direct contact with the waste. However, factors such as weatherability and strength may be more important for a cap than for a liner. The cap and liner must be designed as a system to ensure compatibility for field seaming, if required.

- Subgrade preparation is even more important for cap installation than for liner installation. Good compaction is necessary to prevent later subsidence and possible damage to the cap.

- Caps are much easier to repair in case of damage (e.g., due to subsidence) because they are above the waste.

Quality Assurance/Quality Control

- Quality control begins with the liner manufacturer. They must have performed research to back up their materials formulations. They should have their own government-approved laboratories capable of performing certified tests. They should have tested their products with a variety of effluents.

- It is advantageous to have the design engineer at the site during construction to ensure the design is followed. This is particularly valuable for large, complex facilities.

- Upon request by the customer, Watersaver will send a technical service representative (TSR) to the construction site. These TSRs are full-time Watersaver employees with good training and field experience. The TSR instructs the construction contractor in proper field techniques for the particular liner system and weather conditions, and performs QA/QC activities (e.g., seam inspection, etc.).

- Watersaver has had very few problems in working with general contractors on small jobs. In general, they are eager to do a good quality job and to cooperate with and learn from the TSR. For small jobs, having an experienced TSR who can teach the contractor exactly what to do is more important than the experience of the contractor with flexible membranes.

- Destructive testing of solvent seams is unwarranted because visual inpection by experienced QA/QC personnel can ensure at least 99 percent seam integrity. Moreover, destructive tests are inappropriate because the cutting and seaming allows more chances for failure. Some destructive testing with representative samples seamed under the same installation (weather) conditions should be required.

Standards and Warranties

- Mr. Slifer has been involved with NSF's standards committee for synthetic liners and on AWWA's committee for developing a manual of recommendations for liners and floating covers.

- A standard is not believed to be necessary because the liner industry is so small and specialized. There is no one liner that will work for all conditions, and giving any or all types of liners the NSF seal of approval will not change that fact. (A national standard cannot be written that excludes any company which wants to be included.) Each liner must be chosen specifically for the waste and environment that it will be subjected to.

- The materials standards under consideration by NSF's committee are only a half-way step toward assuring liner quality. The only control occurs at the manufacturer's and fabricator's plant with no assurance of performance. After that, there are still many opportunities for liner quality to be compromised (e.g., during installation).

- Standard warranties cover only normal weathering processes. They do not warranty against contact with harmful chemicals, acts of God, etc.

- A rider can be added to the standard warranty. It may ensure the liner against damages due to the specific chemicals and concentrations thereof that the liner is designed for. It may also specify that the warranty is only valid if the facility is capped within one year, etc.

- Watersaver's standard warranty states that their fabricated seams will last as long as the liner does. In other words, if the liner manufacturer guarantees the liner for five years, Watersaver's seams are guaranteed for five years.

Perspectives on Regulations and Regulatory Reform Needs

- The July 1982 regulations are reasonable because they address the fact that clay has not proved effective in combination with certain wastes.

- Other good aspects of the regulations are that they address the longevity of a site and how the site should be capped.

- Some types of liner systems that will be built because of the regulations will be expensive in the short term. However, these liner systems will be cost-effective in the long term, and will save clean-up costs that will be in the billions of dollars.

- QA/QC requirements should be added to the regulations. However, they should be written very carefully so that they are cost-effective and not too restrictive. For instance, Watersaver likes to have the design engineer on-site during construction and installation, but that is not necessary for many small jobs.

- Installing contractor qualifications could also be added to the regulations. As with QA/QC requirements, however, they should not be too restrictive.

- Installation procedures should not be specified in the regulations because each facility is unique and may require special installation methods.

Research Needs

- Research on combining the use of geotextiles and synthetic membranes would be useful. Watersaver has found that geotextiles are very useful when placed on the bottom of a site because they can protect the subsoil and provide an avenue for gas or liquid movement away from the site. However, they can cause installation problems on exposed side slopes because they alter the way the liner reacts to wind and other conditions.

- Research on the behavioral differences of liners in deep and shallow ponds would also be helpful in tailoring fabrication techniques to the specific conditions experienced by the liner.

Additional Suggested Contacts

The following companies/individuals can be contacted for further information:

- Gaston Containment Systems, Inc.; El Dorado, KS. Contact Larry Gaston, President. The firm is an excellent installing contractor.

- Dynamint Nobel of America (Harte); Rockleigh, NJ. Richard Dickenson is the contact here; he has extensive experience with adhesive systems and with CPE and PVC.

- J.P. Stevens; Arnold Peterson. The company is currently the top Hypalon manufacturer and has good data on chemical resistance. They have performed both accelerated laboratory tests and tests of liners which have been in place for several years.

- SCA; John DiNapoli, Project Engineer. They have used synthetic liners extensively in their facilities.

- Wehren Engineers; Middletown, NY; Dave Phillips. The company designs all types of liner systems.

- Carlisle Tire & Rubber has been manufacturing liner materials continuously since the 1960's and would be a good contact.

- Brookhaven, NY. Watersaver worked with them on a landfill liner system. Contact Jim Hile for data on the installation.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-6

E.I. DuPont De Nemours & Co.: Gerald E. Fisher
Hinsdale, IL 312-986-0990

18 January 1983
31 January 1983

TRW: Masood Ghassemi
Michael Haro
John Metzger
Michael Powers
Sandra Quinlivan
Louis Scinto
Heather White

Summary

- Liners for hazardous waste facilities can be designed, constructed, and operated so that they will not fail for 30 years or more. This, however, requires that the liner material suppliers, manufacturers, fabricators, design engineers, dirt work contractors, installers, and facility operators recognize their respective responsibilities and communicate effectively through all stages of material selection, manufacturing, etc. Inadequate communication and failure to recognize and discharge responsibilities are primary causes of liner failures. Education and communication are more effective in preventing such failures than regulation alone.

- DuPont has developed and promotes the use of a liner "material qualification form" which identifies the types of information required and factors which should be considered in assuring a successful lining job. The format is based on the premise that "the job dictates what liner material should be used". The information required includes: process/waste compatibility data (waste composition, equipment, etc.), site characteristics (temperature, wind velocity, soil type, etc.), and design requirements (unit size, dimensions and configurations, connections, etc.).

- Most cases of liner failure can be attributed to improper design due to a lack of communication which leads to a poor installation. It is possible to design around many of the potential problems if such problems are identified during the design state.

- There is no single liner material (including clay) which would be compatible with all waste types. Based on short term laboratory compatibility tests, however, the spectrum of waste types encountered in a commercial hazardous waste facility can be adequately handled with no more than 3 or perhaps even 2 types of synthetic liner material.

- Currently, there are no long term performance data for any liner material (clay included) in actual landfill service. Laboratory compatibility tests and limited short term field experience indicate that flexible membranes should withstand 30 years or more of service if field installations incorporate systems for collection and continuous removal of leachate and for waste segregation to keep out waste categories known to be incompatible with the liner material.

- It is very difficult to simulate actual field conditions in laboratory compatibility tests (e.g., fluid immersion tests) and this should be considered in the selection of liner material and estimation of performance based on laboratory results.

- Singly or in combination with flexible membranes, clay liners can be very suitable for certain applications and there should be no regulatory restrictions on the use of clay. In a multiple liner system arrangement, clay and synthetic liners can compensate for the inherent deficiencies of any single liner material.

- To date, there is not one set of specific criteria which is used throughout the industry to define liner material uniformity and waste/liner compatibility. For example, Hypalon liners must meet the requirements of containing at least 45 percent Hypalon 45 by weight as the sole elastomer and a minimum set of physical specifications. Consequently, as with all generic classes of liners (e.g., PVC, EPDM, HDPE, etc.), Hypalon liners available from different manufacturers may vary widely in properties. If verification of the physical properties is desired, it should be so stated in the specifications.

- The present manufacturing equipment and methods (including QA/QC procedures) allow the production of a virtually pinhole-free liner and the presence of pinholes in liners is no longer a matter of concern.

- To avoid damage to synthetic liners by construction equipment during backfilling, it is necessary to specify the maximum weight for the equipment which can be driven on the liner backfill. A QA technician must also be present at the site to watch the equipment operator.

- Any regulations on liners and caps should include/address the following concepts: (a) design flexibility to allow the use of clay and/or flexible membranes as appropriate and to take into account site-specific (location) factors; (b) minimum permeability (and not minimum liner thickness) consideration; and (c) requirement for submission of detailed analysis and documentation of the basis for design as part of the facility permit application.

- Areas in need of research and development include: (a) better definition of conditions and circumstances requiring the use of geotextiles

or reinforced membranes; (b) development of long-term data on use of backfills and leachate removal as measures to protect and extend the life of liners; (c) development and demonstration of better seaming methods; and (d) quantification of the credibility of liner materials.

Background

DuPont is a major supplier of raw elastomers (in the form of latex or chips) for the manufacture of flexible membrane liners. It supplies material to six manufacturers which market polyethylene, Neoprene, Hypalon, Nordel, and Hytrel. The company is not involved in the actual manufacture of liners and has no control over the selection of compounding ingredients (e.g., carbon black, pigments, fillers, plasticizers, accelerators, and antioxidants) used in the manufacturing to impart various properties to the finished product, but offers a suggested starting compound and sets required minimum physical specifications. The company is also not involved in design and installation of liners and covers, but it interfaces and offers guidance to the manufacturers, fabricators, and installers as well as to the design engineering contractors and facility operators. The company has an extensive research and development effort aimed at developing improved elastomers with a range of properties for different application needs.

The concept of "the job dictating what liner material should be used" is actively promoted by DuPont which has developed a liner "material qualification form" for addressing key information factors which should be considered in material selection, design, installation, and operation of liners and covers. This interview report summarizes a presentation by Mr. Gerald Fisher of DuPont to TRW, in which Mr. Fisher described various elements of DuPont's material qualification form and answered a number of questions relating to Hypalon manufacture and performance; membrane-waste compatibility; failure mechanisms; regulatory considerations; research and development needs; quality assurance and quality control considerations; and additional contacts and referrals.

On 31 January 1983, Mr. Fisher also arranged for TRW to visit: (a) its Elastomers Laboratory in the Chestnut Run area of Wilmington, Delaware, where the company conducts liner R&D work and compatibility tests, and (b) its landfill at the Chambers Works (Deepwater, New Jersey). Mr. Fisher was present during both visits. Additional information collected as a result of these visits to DuPont R&D and testing laboratory and to the disposal site is also included in this interview summary report. Many of the statements and assertions made are largely qualitative and reflect the extensive experience of Mr. Fisher; quantitative technical and engineering data to support some of the statements and assertions were not provided. A copy of DuPont's "Material Qualification Form", which is the basis for the following discussion relating to liner selection, installation, and operation, appears as an attachment to this interview report.

Liner Selection, Installation, and Operation

- The principal design criteria for flexible membrane liners are: waste (process) compatibility, sheet and seam strength, high and low temperature resistance, impermeability, longevity, and cost. The success of any liner installation is highly dependent upon whether or not many site-specific factors are met. DuPont has developed a "Liner Materials Qualification" questionnaire which addresses these site-specific factors and is intended to serve as an aid to the design engineer or purchasing agent. The form, which is presented as an attachment, addresses the following seven major topics or "factors" which bridge the communication gap between engineering and sales: user identification; compatibility of liner material with waste input; site correlation; dimensions and connections; landfill design; and bidding and follow-up considerations. The following paragraphs discuss some highlights and several major points associated with each of the seven factors.

Factor No. 1 - User Identification.

- This includes the general information on the prospective liner user. DuPont believes that good communication between the client and the manufacturer is essential for a successful project.

Factor No. 2 - Compatibility (Liner With Input Waste).

- Waste temperature is an important consideration in liner material selection, since temperature variations cause liner expansion and contraction and may result in seam rupture. Sometimes published liner temperature tolerances do not apply to seams, and this factor is overlooked in liner applications and may result in failures.

- Flow rate is another factor. Seams should be able to withstand high flow rates. However, direct impurgement should be compensated for.

- Perhaps the most significant factor on the subject of compatibility is waste composition. There is no single perfect liner for a combination of all wastes. If there were, there would be no need for waste neutralization and other pretreatment steps prior to disposal. Waste segregation is also very important, as evidenced by the fact that most landfills today practice waste segregation.

- With respect to waste height, care must be taken to control load, including vehicular traffic over the liner, which may cause puncturing in unsupported materials. Factors such as the loading of the tires then must be taken into account.

- Freeboard height for waste impoundments is an important but frequently overlooked design factor. In general, gas vents are recommended around

the freeboard area 12 inches down from the top of the berm, in order to release gas caused by decomposing organics and air sucked in under the liner by receding groundwater tables or other causes.

Factor No. 3 - Site Correlation.

- Site location is extremely relevant from the standpoint of liner selection and installation. For example, sites underlain with large deposits of natural, high-quality, process compatible clay do not require synthetic liners.

- There are a number of considerations involving site temperature. Field seaming operations are dependent upon pressure, dwell time, and temperature. Wind chill factors cannot be disregarded in assessing whether the seaming temperature lower limit can be met. It also determines the choice of solvent used for seaming. For example, FMLs can be seamed using trichloroethylene or toluene. If the ambient temperature is above 65°F, toluene should be used since it has a lower flash point. If the ambient temperature is below 55-65°F, seaming should be conducted using a hot air gun. FMLs can be seamed under a mini-greenhouse at subzero temperatures.

- The amount of rainfall is an important factor with respect to seaming scheduling. Although liner repair work can be performed under wet conditions, seaming cannot. In some cases, floating platforms have to be used during repair operations in order to provide dry working areas.

- The amount and size of hail is a critical factor. Liners are designed to elongate under field conditions. If a clay or sandy loam is used under the liner, it will elongate properly and the hail will not puncture the liner.

- Regarding side slopes, a steep (3:1) slope may mandate the use of special seaming techniques. To properly seam PVC using trichloroethylene/TFX blends on steep slopes, the solvents should be applied from a polyethylene bottle attached to a paint roller which prevents the solvents from flowing out of the weld area. This eliminates tack welds.

- Regarding flexible membrane liner backfill requirements, a backfill or a geotextile must be placed over Hypalon in order to reduce equipment damage.

- A geotextile and rip rap should be used on impoundment slopes because a soil backfill on a lined impoundment slope will eventually erode. This leads to high maintenance costs.

- Animals can severely damage liners, especially deer. Preventative measures include use of fences, geotextiles, or vertical slopes, or installation of intentional watering and feeding areas away from operational areas.

- Liner material selection is also dependent upon the degree of waste compaction. A thin, unsupported liner material requires good compaction to eliminate subsidence which would create stress, cause distortion, and result in liner fractures or seam failure.

Factor No. 4 - Dimensions and Connections.

- The best leak detection system is a French drain underlain with filter cloth or having a backwash (flushing) system. The electrical conductivity wire bridge system is not a long-term reliable leak detection system because there often is natural oxidation of the wire grids and the resultant resistance curves constantly vary.

- The types of foreign material (projections) the liner must be attached to should have compatible expansion/contraction characteristics. Stainless steel is a good choice. Concrete may also be used, but if poor quality material or irresponsible labor is used, there may be void spaces in the concrete. These voids can later be filled, however, if discovered during final inspections.

Factor No. 5 - Landfill Design and Operation.

- Rapid removal of leachate can help protect flexible membrane liners by reducing the contact time. This may eliminate the need for long-term compatibility testing. Leachate collection systems are easy to install in new facilities, but can be quite costly at older existing sites.

- Synthetic liners can be very effective as caps in preventing rainwater infiltration. The waste input should be well compacted to minimize subsidence. The site should be graded to be self-draining and should have a collection sump or runoff at the bottom, and the FML design should anticipate additional spot subsidence.

- Only reinforced and uv resistant flexible membranes should be used as capping material. Clay alone does not have any credibility as a capping material because of its tendency to fracture, erosion susceptibility, etc.

Factor No. 6 - Bidding.

- One should try to avoid giving bid specifications to anyone that does not fulfill prior performance, reference, warranty, or bonding requirements.

- Bidders can be chosen from a variety of firms that manufacture, fabricate, install, or perform a combination of all of the above; however, verification of persons performing the installation is important as to the degree of capability and past performance. Generally, firms specializing in installation would have the widest range of experience in difficult installation conditions.

- If an FML is to be stored for a duration prior to site mobilization, conditions and methods of storing should be predetermined and included in the bid specifications. Timing of seaming operations to meet weather conditions are also important.

- Labor rates and union considerations are noteworthy. At one site, installation operations were shut down for six months because of a strike. The weather became inclement over that period of time and caused many problems.

- Utility requirements must be ascertained. For example, if Lyster hot air guns are to be used, local codes must be identified and complied with.

Factor No. 7 - Follow-Up.

- Numerous safety factors must be considered at each facility. Flexible membrane liners can become very slippery when wet. Lagoons may need to be fenced off, and/or tie-off ropes installed to assist in pulling personnel from the lagoons. Adequate lighting is essential.

- QC measures must be taken to insure all systems remain intact over the life of the site and after closure.

- Waste input loads should be periodically tested to see if their contents match their reported values.

- There must be a good system of liner longevity backup testing. Samples of the liner should be placed in strategic positions so that samples can periodically be removed and sent back to the manufacturer in order to identify changes in physical characteristics.

Hypalon Manufacture and Performance

- Hypalon liners must, as a minimum specification, contain at least 45 percent by weight of Hypalon 45 as the sole elastomer and must meet minimum physical specifications. Consequently, as with all generic classes of liners (e.g., PVC, EPDM, HDPE, etc.), Hypalon liners available from different manufacturers may vary widely in properties.

- Hypalon leaves the plant uncured in order to make a film carrying bond at the site. All FMLs should be spot checked upon delivery for physical specifications compliance; but this practice is not an industry standard.

- Hypalon's properties will vary over time. For example, tensile strength will increase and elasticity will decrease. This change is altered by different types of compounding which suit different applications. Industrial grade (lead-based) Hypalon rather than "potable grade" Hypalon is specified for hazardous waste landfill applications.

- DuPont cannot refuse to sell its polymers to any liner manufacturer.

- Hypalon is a good landfill cover material because it is strong and uv resistant; it is far superior to clay covers in preventing rainfall penetration and infiltration.

Perspectives on Waste/Liner Compatibility

- Although waste inputs are complex and vary considerably, liner systems can be designed to work successfully. However, one cannot say how long the liner will work. The results of actual field performance are generally more reliable than laboratory testing results.

- All liners are incompatible with certain waste types. For example, solvents will dissolve most FMLs. Even clays are incompatible with certain waste types. The type of clay is also an important factor which should be taken into consideration.

- Compatibility tests provide important inputs in the process of selecting a liner, but much of the information is limited to indicating potential problem areas that need to be investigated. However, a good compatibility test result only means that the material meets the process requirements and not necessarily the physical and site conditions.

- Compatibility tests that reasonably simulate field conditions are very difficult to devise. Even where the exact characteristics of the corrosive fluid are known, a suitable test may not be possible. For example, in certain immersion tests, all the contaminant may be sorbed by the test material without any apparent change in its characteristics. However, the physical characteristics of the material may in fact not change until its sorptive capacity for the subject chemical is exhausted. In the field, this sorptive capacity of the material may be quickly overwhelmed.

- Compatibility tests should be done using fluids with contaminant levels simulating those anticipated in the field. No pure level should be used, as it is the combination that will be contained.

- All FMLs' physicals change when wet vs. dry, or with age.

- Immersion tests should expose the material on one side only to realistically simulate its field condition. The dominant mechanism responsible for mass transfer through a synthetic membrane is probably vapor transfer. There is probably no gross movement of material through the membrane and molecular diffusion probably involves a flux too small to be important. The driving force for vapor transfer is differential vapor pressure so that once the pressures on the two sides of the material equilibrate, flow stops.

- For facilities that accept a large variety of waste inputs, use of multiple liners is necessary to compensate for single liner deficiencies. For example, a commercial hazardous waste facility handling virtually all types of wastes could definitely operate successfully using three different liners, and could possibly get by with two. Waste segregation is very important in such a case.

- At the DuPont testing laboratories in Wilmington, DE, materials are tested both for customers who request the service and as part of the company's on-going research and development. Mixing facilities, small calenders, and all other equipment needed to fabricate sheets support the operations. All tests listed in the proposed NSF standards can be done, plus more complex ones such as complete material fingerprinting. The most routine physical tests made are tensile strength, stress-strain (Young's Modulus), and high/low temperature breakpoint.

- In selecting a specific liner material, the customer should follow a step-wise process of elimination approach. First, they should try to identify which process may contact the liner. Certain polymers will be eliminated from further consideration based on this analysis. Next, try to identify which acids and bases are involved, and eliminate other candidate materials. Finally, physical factors which require use of certain materials should be identified (e.g., use of a 2:1 slope ratio will eliminate unsupported PVC and CPE liners). Most customers rely heavily on the manufacturer's experience when selecting a liner and consider especially the material warranties that are available.

- DuPont strongly encourages customers who have made a materials selection to obtain a letter of certification from the liner manufacturer guaranteeing that the liner will be compatible with the input waste, both from the standpoint of waste composition and site design features.

- There currently is no one set of specific criteria which is used uniformly throughout the industry to define waste/liner compatibility and/or material uniformity (QA). However, there are a few standards in limited use. For example, one manufacturer considers a sample which deforms to greater than 10 percent of its original weight and tensile strength to be incompatible with the waste tested. DuPont has, for a long time, wanted one set of ASTM standards to be applicable to all FMLs. It has also wanted certain modifications to the existing ASTM standards, many of which originated within the pulp and paper industry.

- Since FML manufacturers will provide clients interested in the compatibility/performance of its liner materials with the names of past customers and/or with references to where, in general geographic terms, the material has been successfully used, so that waste input and climatic/topographic factors can be taken into consideration in liner selection.

- Many FML manufacturers believe that there are synthetic liners that can withstand up to 30 years contact with leachate. However, there is a paucity of long-term test data on the compatibility of both synthetic and clay liners and leachate.

Perspectives on Liner Failure

- Both improper installation and design contribute to liner failure; however, most problems are due to designs based on poor communication between the engineer and the FML industry.

- Although liners can be designed and installed so that they will not fail, whether or not they actually are well designed and installed is a separate issue. DuPont's approach is to work with the customer and use the Liner Material Qualification form to help assure the landfill operator and end user of a proper design.

- For flexible membranes, if there is to be a liner failure, it will generally occur within the first two years following installation. More rigid membranes can fail within five years of the installation, due to steam, thermal, and stress fatigue.

- There is very little published information available on installations and, for proprietary and business confidentiality reasons, manufacturers cannot provide site specific liner failure data.

Perspectives on Regulations and Regulatory Needs

- Regulations should define acceptable limits and conditions. Methods should be the sole prerogative of industry, engineering, and end users. However, proof of performance and compliance should be incorporated in said regulations.

- DuPont feels that education and communication are better approaches to preventing liner failures than regulation alone. "Regulation provides the need; education and communication provide the means." DuPont is currently educating engineering firms and facility operators to use the company's Liner Material Qualification form. DuPont has suggested that EPA consider this form or a similar one be submitted with facility permit applications.

- The July 1982 regulations have serious problems. They were probably written hastily and under pressure from numerous interested groups. The liner/locational study is worthwhile in that it may result in the incorporation of many needed compromises.

- The regulations should be made more site-specific. For example, facilities should not be located into a water table since synthetic

liner seams cannot be properly made in the presence of moisture. Also, sites located in areas of existing high groundwater contamination should not be told to exceed conditions that already exist.

- EPA should not disallow the use of clay. There are justifiable applications for all liner materials.

- Rather than have the EPA run a QA program during liner installation, it would be better to leave that task to existing qualified engineering firms. One of their tasks should be to inspect the liner on the job site and, if it was not up to specifications, order it returned to the manufacturer at his expense.

- In promulgating a synthetic liner thickness requirement, the regulations should require a minimum permeability specification, not a minimum thickness.

- EPA should not get too involved with compounding because this constitutes specifying a product for which the agency then becomes liable.

- In the area of foreign regulations, the Europeans are starting to follow the lead of the United States. France, Italy, and Spain are just starting to get interested. The more sophisticated countries of Germany, The Netherlands, England, Switzerland, and the Scandinavian countries do not have specific requirements regarding clay or synthetic liners as yet, but do require that facilities be well operated. In Australia, although there are currently no specific regulations, various environmentalists and public interest groups are exerting pressure on the larger firms to use liners.

Quality Assurance/Quality Control

- Whether or not bid specifications are actually followed during installation is not always verified. However, there are systems available to determine the credibility of the liner and its seams. These include seam peel and shear tests. The best test is the peel test; one can improve shear test results simply by increasing the width of the seam.

- Field seams should be tested for credibility and in the lab for strength. Useful seam testing techniques include the air lance test, conductivity test, vacuum test, and standing water or dye test. There are new testing concepts under development by the industry. One manufacturer asserts that 1 mm is the limit for the ultrasonic test, but this has not been verified. Seam voids are temperature dependent. Heat collapses voids. Thus, measurements are temperature dependent.

- Field seam integrity is a function of: (a) leachability/impermeability of the seam; (b) the physical strength of the seam; and (c) the degree of variation in the seam based on installation conditions.

- The more seams that can be done under controlled conditions at the fabricator's plant, the greater the integrity of the installation.

- The air lance test must be applied to every foot of seam in order to test for leaks. But to test for strength, only one sample from every 500 to 1,000 linear feet of seam needs to be tested.

- It is virtually impossible to backfill a disposal unit without tearing the flexible membrane unless a proper design and placement is specified and followed. One of the most critical areas is where the equipment is driven on and off the disposal unit. Having a QC technician constantly watch the equipment operator and specifying the maximum weight to be driven on the liner are two ways to alleviate this problem.

R&D Needs

The following areas would be good candidates for research and development activities:

- Seams. Better methods need to be developed.

- Quantification of the credibility (permeability limits) of liner materials.

- Use of geotextile versus reinforced materials. When does one stop using a reinforced material and convert to a geotextile? Some experts believe geotextiles should be used everywhere. DuPont feels its usage is more site-specific and based on experience. Specific criteria and guidelines need to be developed.

Site Visit to the Land Disposal Facility at Chambers Works, Deepwater, NJ

- The land disposal facility receives waste sludges from a wastewater treatment plant servicing the Chambers Works and drums containing tars (these are placed in the center of the facility). There are three five-acre fields. Field 1 is closed; Field 2 is being filled; and Field 3 has just been constructed. A double liner was constructed in Field 3, consisting of the following layers (extending from the upper surface downward): Typar (a geotextile), 12-inch gravel layer with leachate collection pipes, Typar, Hypalon, 4-inch sand layer, Typar, 8-inch gravel layer with leak detection pipes, Typar, Hypalon, and a 12-inch sand layer.

- Groundwater is at a depth of only 2 to 3 feet below the bottom of the facility. To provide additional safety, the site was built up with several feet of added soil, and French drains were installed to remove excess water.

- The following quality control measures were taken during the seaming operation. Seams in the bottom Hypalon liner were checked with an air lance. However, this method does not detect very small holes, and since the upper Hypalon liner was considered more sensitive to the project's success, seams in it were checked by vacuum testing. The overall integrity of the upper liner was also tested by a spark test. This test detects small holes in the entire sheet by a conductivity method. It requires a water layer below the material being tested, which was provided by moisture in the underlying sand layer.

- Field 2 has a liner system similar to that of Field 3. Shortly after opening, the leak detection system showed a large flow, but its source is believed to be water held by the sand layer. More water than normally expected may be squeezed out by the weight of the waste. Flows from the leak detection system also showed some of the same characteristics as leachate collected from that field. This, however, was not believed indicative of a leak in the upper Hypalon liner. With time, the strength of the leachate increased greatly while the strength of the fluid from the leak detection system increased only marginally. The leachate-like characteristics are believed to result from some waste from Field 1 that accidentally got between the Hypalon liners of Field 2 during its construction.

Miscellaneous

- DuPont can supply EPA/TRW with a rebuttal to Dr. Peter Montague's report on the liner failures in New Jersey, including the DuPont Chambers Works Hypalon failure.

- The DuPont's "Liner Materials Qualification" form is not perfect and many factors could be added. Also, only ranges of certain values are called for. However, it is a starting point toward responsible liner design, installation, and maintenance.

- Recent advances in manufacturing technologies now allow manufacturing of liners which are virtually free of pinholes and hence, presence of pinholes in liners (laminated or single layers) is no longer a matter of concern.

Additional Contacts/Referrals

The following individuals are additional contacts:

- John Pacey; Emcon Associates.

- Bill Way; Gulf Seal; Houston, TX. 713-359-2607.

- Bill Karns; Project Engineer; Watkins Engineers and Constructors; Route 3, Box 260; Perry, FL 32347. 904-584-0493.

Documents Provided

- E.I. DuPont de Nemours & Co., Wilmington, DE. (Company literature and related journal articles on liner properties, design, and installation specifications for Hypalon, Hytrel, Neoprene, and Nordel flexible membranes.) Approximately 100 pp.
- "Preparing a Bid Specification"; Dupont, 7 pp.
- "Expansive Clays"; excerpt from reference handbook, 3 pp.
- HDPE failure test described in letter from W. Halter, Resin Search, Inc. to Mr. B. Zolin, DuPont, dated March 2, 1981; 6 pp.
- "Installation Equipment and Methods", describing weld (joint) testing methods; 1 p.
- "American Vacuum Seal Tester" flyer; 1 p.
- "ASTM D34-05.01 Guidelines".

DuPont's Liner Materials Qualification Form

P R E F A C E

This material qualification form should not be misconstrued as a design standard. It is intended to be an aid to the designing engineer or purchasing agent. The format is based on the premise that "the job dictates what liner material should be used".

The majority of projects have in common, general qualifiers, based on requirements the liner must fulfill:

- Process compatibility
- Sheet and seam strength
- High and low temperature resistance
- Impermeability
- Longevity
- Cost

These six basic liner requirements are fundamental and sound but narrow in job scope. They acknowledge the basic liner needs, but offer little understanding of the sites contributing factors that determine the installation's success.

A lining membrane is meant to be an impermeable container. It is not compounded to be a structural entity. This is a function of the design engineer, based on the following variables:

- Lining material
- Labor
- Site
- Service

This design versus use concept is intended as a bridge to cross the communication gap between engineering and sales. Each knows his own service requirements and abilities but only through communication can individual job stresses be compensated for by engineering, and the total cost of in line service life be determined.

Liner Materials Qualification
Based on Design Vs. Use

Factor #1 - Identification:

End User _____ Engr. Firm _____

Location _____ Location _____

Contact _____ Contact _____

Telephone _____ Telephone _____

Factor #2 - Compatibility:

Process Composition _____

Temp. _____ °C PH _____ Flow Rate _____ %Solids _____ Service Size _____

Aeration _____ Type _____ No. _____ Evaporation Rate _____

Freeboard Height _____ Process Height _____

Product Reclamation _____ Method _____ Freq. _____

Factor #3 - Site Correlation:

Site Location _____

Ambient Temp High _____ Low _____ Wind Velocity _____

100 yr. elev. of Ground Water Table _____ Reservoir Base Elev. _____

Average Rainfall _____ Amount & Size of Hail _____

Liner Backfill Requirements _____ Type _____ Application Method

Type of Soil _____ No. of Core Samples _____

Type of Clay _____ % Sand _____ % Limestone _____

% Organics _____ % Gypsum _____

Type of Traffic _____ Type of Animals _____

Types of Vegetation _____ Degree of Compaction _____

Moisture control-Method & Degree _____

Cut & Fill Requirements _____

Factor #4 - Dimensions & Connections:

Reservoir Size. Length_____Width_____Depth_____Slope Ratio_____

Monitor System Method_____

No. of Process Inlets_____Outlets_____Pipe Size_____Type_____

No. of projections through liner _____Type_____Location_____

Type of process impingement on Liner_____

Type of foreigh material Liner must be attached to_____

Factor #5 - Landfill:

Composition_____

Fill Depth_____Age_____Volume_____(800lbs/cy for sanitary fills)

Type of protective fill cover_____

Type of Leachate Collection System_____

Type of Recirculation System_____

Temp. & Location of Fill Hot Spots_____

Ratio of Carbon Dioxide to Methane_____

Gas Vent & Flashback Design_____

Existing Type of Liner_____

Describe the Site Location & Surrounding Area_____

_____

Factor #6 - Bidding:

Approximate Bid Date_____Has Specification Been Written_____

Type of Installer Preferred_____

Time Allotted for Installation_____

Mobilization Date_____

Type of Labor: Union_____ Non-Union_____ Plant_____

Labor Rate & Type of Trade Required_____

Utility Services Required_____

Safety Requirements_____

Terms of Contract & Delivery_____

Factor #7 - Follow-Up:

Safety_____

Quality Control_____

Abuse Protection_____

Longevity Back-Up_____

Communication_____

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-7

M. Putterman & Co.: Jack Moreland
Chicago, IL 312-927-4121

TRW: Masood Ghassemi
John F. Metzger

24 January 1983

Summary

- Good quality control at the fabrication stage alone is not sufficient to ensure adequate liner performance. Quality control should be in place throughout all stages of manufacturing, fabrication, transportation, site preparation, and installation. To this end, a turn key approach which assigns the "chain of custody" for QA/QC to a single contractor has substantial merits.

- Through regulations, education or other means, the user community should be made to recognize the value of quality products, and to consider more than merely costs in awarding bids.

- Because of the current lack of a QA/QC chain of custody, M. Putterman & Co. (MPC) takes upon itself to "police" material suppliers by requiring them to certify their products based on certain tests. The material is also inspected at least at three points: when received from the manufacturers, at the seaming machine, and when folded for shipment. The capability of installers is also taken into account in designing/specifying field seams (e.g., simple overlap vs. tongue-and-groove).

- MPC's QA/QC program for factory heat-weld seams includes the use of "peel test" on test seams to establish optimum seaming conditions (temperature, pressure, speed), use of experienced operators/technicians, visual inspection of seams for extrusion of material at the interface of the welded sheets, stress and creep testing of seam samples, and use of tick marks to ensure proper lining of sheets prior to feeding into the seaming machine.

- Spread coating method of liner manufacture is superior to calendering as it provides little potential for formation of pinholes and allows the use of higher scrim density, and thus development of higher strength material and seams.

- R&D effort should emphasize development of new methods for joining liner sheets and generation of "real world" data via tests in prototype applications.

Background

M. Putterman and Company (MPC) is a fabricator of liner materials. They seam sheets of the material received from the manufacturer into large panels deliverable to the use site. MPC considers itself a leading fabricator with a reputation for high fabricating standards. The firm specializes in liner fabrication for heavy duty uses and estimates that it now commands a 45 percent share of the market for reinforced membrane liners used in waste disposal applications. MPC has pioneered certain modifications to standard seaming equipment which allow better quality control and more efficient operation. MPC's asserted good reputation stems from the thorough familiarity of several of MPC's technical managers (in particular Mr. J. Moreland) with all aspects of liner material formulation, fabrication, and installation. Thus, on major jobs, MPC's personnel interface with material suppliers, sheet manufacturers, design engineers, and installers, advising them on liner selection, required seam strength, chemical compatibility, etc. This total involvement, which MPC considers not typical of the fabricating industry as a whole, is based on the premise that fabrication is only one of the elements of a chain which will lead to high liner performance in actual field application.

The objective of this interview, which included a first-hand observation of a factory seaming operation, was to determine aspects of the fabricating operation which influences eventual performance of a liner in a waste disposal site application, and to obtain the perspectives of a fabricator on liner installation problems, QA/QC issues, applicable regulations, and research and development needs.

Fabricating Operation at MPC

- Many of the reported problems with synthetic membranes in land disposal applications can be traced to faulty seams. The fabricator can greatly reduce these problems by making high quality factory seams and providing guidance for field seams. High quality factory seams require a good understanding of the factors affecting seam properties, and this may necessitate a careful structural analysis of the seam, something that is not done by most fabricators.

- Temperature and pressure are the critical variables that must be controlled carefully during seaming.

- Factory seams are developed by several techniques, the choice being dependent on the liner material. In the dielectric bar seaming method used with certain materials, a current is passed through a bar implanted between the overlapped materials. The heat thereby generated in combination with applied pressure welds the material. This method is limited by the pressure which can be applied to a material to effect seaming without causing excessive thinning of the heat-softened material at the seam.

- MPC usually fabricates seams for materials having a high melting point. A specially-developed machine, modified from a standard design is used. The surfaces to be joined are heated to about 1000°F (by a 1000°F blast of air) and are pressed together at about 80 psi. The two sheets are fed both by hand and by the machine advancing on a track. The sheets overlap varies with the intended application of the liner, but 2" is typical.

- MPC's method of seaming liner sheets results in a weld with a strength 12 to 15 percent greater than by other systems. Where the material is a reinforced thermoplastic and the overlap is 2 inches, the strength of the material can be duplicated in the seam. The same seam strength can sometimes be developed with certain unsupported copolymeric liners.

- Liner panels can be constructed to a maximum area of about 20,000 square feet. Smaller sizes, however, are more commonly handled as better control can be maintained with smaller total areas. An average sized panel of copolymer material is about 10,000 to 12,000 square feet.

MPC's Quality Control for Factory Seams and for Sheeting Materials Used in Fabrication

- At the start of the seaming operation, test sections of the material are welded to obtain proper application temperature and pressure. The correct combination, which is determined via "peel" test, corresponds to conditions resulting in peeling off the liner material (top "coat") from the scrim reinforcement rather than separation of the sheets directly at the interface of the two surfaces.

- The main technique of quality control during seaming is visual inspection. An extrusion of material at the interface of the welded sheets is a strong indication of a homogeneous bond, and the seal of the edges of the material thereby formed encapsulates the scrin reinforcement and, hence, prevents possible wicking of leachate in actual field installations (wicking involves a slow flow/leak of leachate drawn through the fiber reinforcement by capillary flow). These extrusions, however, do not occur with Hypalon or butyl rubber.

- Every 400 feet, a sample of the seam is taken and tested in MPC's laboratories. Two of the tests are done to simulate creep of a stressed liner in an unsupported condition, such as where it is pushed into a sink hole. The material is loaded to 50 percent of its normal tensile strength for 4 hours at room temperature. A similar test is made at 25 percent of its tensile strength for 4 hours at 160°F. Both tests are evaluated on a pass or fail basis.

- Seams of highly elastic materials are sometimes also tested by an air lance.

- Tick marks are made at equal distances from the end of each of the two liner sections being joined. As the panels feed into the machine, adjustments are made to keep the marks aligned. If the panels are not aligned, one panel is elongated more than the other, building a stress directly into the seam.

- MPC's equipment and operations are often inspected by the customer before bids are awarded and during the job. This practice is encouraged by MPC, especially for jobs requiring high liner performance (e.g., for a hazardous waste facility).

- MPC frequently interfaces with its sheeting material suppliers to ensure use of high quality material in its fabrication operation. This is done by requiring manufacturers to certify the material on the basis of a series of tensile, tear, adhesion, and total weight tests. The material is also inspected visually at three points: when received from the manufacturer, at the seaming machine, and when folded.

Interaction With Field Operations

- The most important liner characteristics for good performance are chemical compatibility, puncture resistance, and factory and field seam integrity. The integrity of field seams is most difficult to ensure. MPC generally specifies to the installing contractors the required conditions for field seaming and the inspection procedures needed to guarantee quality seams. Similar guidelines are generally not given for Hypalon liners since there generally exists a much broader experience with this material.

- In specifying a particular seaming method to installers, MPC pays careful attention to the qualifications of the installer. In MPC's judgement, there are only one or two contractors with a high enough level of expertise to produce high quality seams via simple overlapping methods. For most others, a tongue and groove seam is specified because tongue and groove can be fabricated in the factory, and there is little opportunity for mistakes during field seaming.

- The liner can be damaged during transportation from the fabricator to the job site. One of two methods of transportation is written into the bid specifications: "FOB plant" and "FOB site". FOB plant should generally be avoided because the site owner will be responsible for transportation to the job site, including writing of all specifications (e.g., crate specs) and handling all damage claims, and this is often not conducive to assuring actual installation of a high quality product. With FOB site, the fabricator assumes responsibility for delivery of the product to the job site and, hence, checks the delivered material, and records and repairs minor damages. If damage is too extensive, the shipment is rejected and the fabricator's insurance company takes up the subject.

Other QA/QC and Performance and Cost-Related Considerations

- Some competitors repeatedly underbid legitimate fabricators by offering inferior products for which there has been little or no quality control. When the cost of QA/QC is deducted from the total price, nearly all fabricators are competitive. (Because of its more elaborate QA/QC program, MPC's prices are usually 12 to 15 percent higher than the competitors'. This problem, however, has been a manageable one since a large part of MPC's liner business is for complex jobs for which there are no competitors or for which owners write specifications so that potential competitors are discouraged from bidding.)

- Although more costly, a turn key approach to project management would have a substantial potential for ensuring good liner performance. Assigning the total responsibility to a single contractor is more conducive to ensuring adequate quality control at all levels of the project.

- Liner manufacturers most willing to stand behind their products generally favor reinforced materials. A 36-mil reinforced membrane of the type manufactured by MPC can perform equal or better than a clay or a clay-reinforced synthetic membrane combination system.

- There are two fundamentally different methods of manufacturing a synthetic liner: by calendering and by spread coating. The spread coating method generally results in a higher quality product.

  - For the calendered product, the pulp layers (sheets) are made separately, then laminated. The density of the reinforcing scrim is limited (generally to 10 per inch) because there is limited opportunity for the two laminated sheets to flow across the voids in the scrim to make a positive seal.
  - In spread coating, the liner is built up from layers of the material applied as a liquid "coat", and cured in an oven. The scrim reinforcement is therefore completely encapsulated, permitting a very high density scrim to be used. Since the strength of seams is partly a function of scrim density, liners manufactured by the spread coating method can be joined by very high strength seams.
  - With the calendered product, pinholes are a possibility. However, if the liner is constructed of several sheets, the pinholes of adjacent layers are unlikely to line up. The pinholes, though, may provide a point of liquid entry and hence leaking due to the wicking action of certain scrims. Liners constructed by the spread coating method should have no pinholes.

- A general misconception exists that the thickness of a liner is the principal factor determining its performance (i.e., "thicker is always better"). However, in an MPC-sponsored test, MPC's 30-mil reinforced

liner developed fewer punctures than an unspecified 80-mil liner when both were sandwiched between a base of 1-1/2 inch stone and a cover of 8 inch diameter, angular stones.

Perspectives on Regulations

- Regulations (perhaps in the form of performance standards) can be effective if they result in forcing the owners/operators of disposal sites to consider more than merely cost when evaluating bids. Through regulations, education or other means, the customer should be made to recognize the value and the long-term benefits of good quality control programs, and to require such programs throughout manufacturing, fabrication, transportation, and installation of liners.

Research and Development Needs

- R&D effort should emphasize development of new approaches to joining liner sheets. For example, the engineering and cost aspects of a mechanical seam (a "zipper"), which has been designed and tested by Mr. Moreland of MPC in a grain storage facility application, should be evaluated for possible use in landfill lining.

- R&D effort should also emphasize generation of "real world" data, perhaps through studies involving testing of new designs and installation methods in prototype disposal sites.

Miscellaneous

- Synthetic liner materials manufactured in Europe are largely inferior to U.S. products. Some European liners require a geotextile to provide additional strength.

- Polyethylene is a better material than PVC for piping of leachate. PVC embrittles.

- The principal suppliers of scrim to synthetic membrane manufacturers are Burlington and J.P. Stevens. These companies can be contacted for information on scrim properties and their importance in liner performance.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-8

American Colloid: Christopher Jepsen
Skokie, IL Robert J. Masini
312-966-5720

TRW: Masood Ghassemi
John F. Metzger

26 January 1983

Summary

- When treated with certain proprietary formulations to improve expandability and contaminant resistance, sodium montmorillonite can be mixed with other soils to produce a material of low permeability (10^{-8} cm/sec) suitable for use as liners. In mixed-blanket applications, the liner permeability and self-healing properties are claimed to be superior to those of native and recompacted clay.

- American Colloid has made many laboratory permeability determinations on its products over the years, using a low head test that passes two pore volumes of permeate. Excellent correlation has been found between these tests and the field condition, and the results have been confirmed by the later performance of large-scale facilities.

- Based on extended laboratory permeability tests, chemically conditioned bentonite is compatible with most leachate constituents with possible exception of acetone and alcohols in concentrations exceeding 10 percent. Possible effect of acetone and alcohols at concentrations exceeding 10 percent is currently under investigation. In a parallel application as a liner material to contain tank farm spills, the bentonite was compatible, at least on a short term basis, with concentrated chemicals.

- As with other liner types, quality control during installation is essential to developing an adequate bentonite admix liner.

Background

American Colloid is the largest producer of sodium montmorillonite (bentonite). It mines and processes bentonite at its facilities in Wyoming and South Dakota. The largest current uses of bentonite, in the order of use quantities, are in oil well drilling muds, iron ore pelletizing (taconite), and foundry sand binding. These three uses account for 80 percent of the tonnage used. Bentonite has characteristics largely unlike other clays. It has the lowest permeability of all clays, is extremely expansive, and has very high liquid and plastic limits. In liner applications, bentonite is

used as an admixture. When mixed with another soil and hydrated, the bentonite swells and expands into voids, making a highly impermeable material that is suitable as a liner. American Colloid asserts that for regulatory purposes, its product should not be considered a "clay" material, but rather as an admixture which has liner properties superior to both native and recompacted clay. American Colloid does about 200 admixture lining jobs per year; only about one to three of these jobs are landfills, the remainder are lagoons and tank farm spill containment systems. Several bentonite liners have been installed for DuPont for storage of chemicals and radioactive wastes.

The purpose of the interview with American Colloid was to obtain technical information on the properties and installation of the bentonite admixtures.

Characteristics of Sodium Montmorillonite (Bentonite)

- For certain landfill applications, bentonite is treated to increase its expandability and its resistance to various chemicals. It is generally compatible with many chemicals likely to be present in hazardous waste, with the exception of acetone and alcohols which are so polar that they easily displace the bound water. Results of laboratory tests assessing the long-term impact of various chemicals on the permeability of bentonite products are presented in Table 1. As noted in the table, there is no notable increase in permeability for the specific solutions tested over extended contact periods. In applications where bentonite is used for soil containment at tank farms, short-term contact between the bentonite and concentrated chemicals has shown no evidence of incompatibility.

- During the past 10 years, American Colloid has run upwards of 1,300 permeability columns. These tests have represented field conditions very well, with no performance of any completed facility being contrary to the permeability test predictions.

- When conducting permeability tests, American Colloid does not accelerate the time factor by using a high head, such as was done in some of the testing by Dr. Kirk Brown (Texas A&M University; College Station, TX). Instead, two pore volumes of fluid are collected under a maximum head of 2.5 to 5 feet. This volume has been suggested in the literature as producing results that correlate well with field conditions.

- American Colloid specifies the amount of bentonite to be mixed with a particular soil by applying empirically developed relationships to in-house laboratory analyses of soil samples from the site. Soils exceeding 40 percent gravel cannot be combined with bentonite because the structure is not fine enough for the clay to seal.

- Soils contaminated with oils or organics can affect the swell characteristics of bentonite. Potential problems due to high concentrations of ionizable species are indicated by a conductivity exceeding 250 μmho/cm of a 200 gm sample added to 400 ml DI water. A free swell test is then made to determine exactly how the swell properties are affected. Sometimes the clay particles flocculate rather than swell. The two conditions are dissimilar in appearance, and the seal and long-term stability of the flocculated state is considerably less. The usual remedial action for contaminated soil is to use clean soil from another source for mixing with bentonite. There has never been a need to excavate the material or later add gas vents where organics are involved.

- American Colloid has not developed data on contaminant attenuation capacity of its products and has not carried out any side-by-side comparison test with natural clay.

Liner Installation

- Several methods can be used to mix the bentonite with the soil, the most expensive of which is use of a pugmill. An approximately 6-inch layer of local soil is excavated (or, more likely, some other soil such as sand is hauled in) and mixed with bentonite and water on a batch or continuous basis. The water used for hydration is always high quality, usually drinking water quality. After pugmilling, the admixed soil is piled and bladed into place (or is laid with an asphalt paver). As an alternative to pugmilling, the bentonite can be mixed into the in-situ soil using a rotary tiller. Earlier methods substituted a discing or raking device.

- Widths of the admixed soil are rolled for compaction. The edge of each width is not rolled until the next width is applied and the edges are overlapped. These successive widths bond together well and appear as a continuous material.

- When bentonite is mixed into the local soil using a rotary tiller, attaining the proper moisture content for compaction can be a problem. If the local soil is too wet, the contractor may have to wait for it to dry, whereupon any additional rain may resoak the soil, hence requiring further delays.

- Bentonite holds water very well, but dessication can occur if the material is not covered quickly enough after hydration. A cover of at least 6 inches is always used, although much less is actually required (just a thin film of plastic or even a layer of gravel) to protect the moisture. In an arid, southwest facility, dessication has not been a problem.

- The bentonite admixed soil has been placed in a 4-inch thick layer until recently. A thicker layer of approximately 6 to 12 inches is now considered more satisfactory and is usually used.

- The main requirement needed to ensure a successful facility is on-site supervision. American Colloid usually maintains contact with the field engineer to ensure that quality control is adequate and when requested, will have a company representative on-site during actual installation.

- The failure rate of American Colloid lined sites is less than 1 percent per year, and nearly all are attributed to the recommendations for installation not being followed, especially mixing specifications. Surface impoundments that fail at all usually do so shortly after being filled.

Perspectives on Caps

- Differential settling is responsible for many cap failures. Bentonite, however, is more plastic and therefore better able to follow deformations than native clays.

- Clay caps of any kind adhere poorly to an underlying synthetic membrane.

Quality Control Considerations

- Bentonite is an effective liner material, but it, like others, requires adequate quality control during installation. This, however, increases costs so that underbidding by less consciencious competitors is a problem. In many cases, the bid specifications can be written sufficiently restrictive to eliminate less competent companies. However, even many design engineers do not fully appreciate the quality control needed when applying a liner. Therefore, contractors should be required to have quality control supervisors on-site at all times.

Miscellaneous

- Bentonite is more expensive than thin synthetic liners of about 20 mil thickness. Depending on the hauling distance (the product has to be shipped from mining/processing sites in the Northwest), it can be competitive with the higher performance liner systems such as Hypalon.

- Some competitors have recently entered the landfill lining market because their principal market of drilling muds has declined. Unfortunately, the material being sold as a liner admixture is essentially the same as a drilling mud and has not received the special treatment that American Colloid's products receive to make them suitable for liner application.

- The following facilities are examples of American Colloid's jobs:

  - A site near Queensbury, New York, owned by the Ciba Geigy Company. This landfill is one of the documented cases of a contaminant resis-

tant bentonite being used successfully. American Colloid is required to maintain a column simulation of the field (a clay liner overlaid by a sludge from the manufacture of dye with DI water added) conditions throughout the entire active life of the facility. A second facility is to be installed soon. Contact: Basil Burns.

- General Electric Corp.; Gainsville, FL. Contact: J. Mary Phillips; Environmental Engineering, Building 36/120; Schenectady, New York 12345. 518-385-5161.
- Olin Chemical, Tenn. This facility contains a calcium hypochlorite sludge. The liner system consists of the following layers from the top surface working downward: 8-inch gravel, 7-inch concrete sand, 1-foot native clay compacted, two 6-inch lifts of bentonite, 3-feet compacted clay, 4-inch gravel, 4-inch concrete sand, and 4-inch gravel. The following layers are on the sideslopes: 1-foot gravel, 3-feet native clay, two 3-inch bentonite soil mixtures. Contact: Charles Hawk, 615-336-2251*.

- Art Clem is a good source of experience with bentonite. He was previously with American Colloid for 40 years and has developed numerous products for the company. His address: Clem International; Des Plains, Illinois. 312-296-3834.

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*TRW later contacted Charles Hawk and was told that the waste is a mercury-contaminated sandy sludge. A calcium hypochlorite sludge is also somehow involved, but it was not certain how. TRW was referred to Dave Vaughn, 615-336-4555.

LONG-TERM LABORATORY PERMEABILITY DATA FOR BENTONITE WITH VARIOUS SOLUTIONS AND LEACHATE

Col. No.	Leachate	Product	Thickness (inches)	Apl Rate ppsf	Dates Run	# of Days Run	m/s Passed Through	PVD	Head	Permeability
R81-65	10% $CaCl_2$ (L)	SS-100	4	3 30	2/17/81 - 9/4/81	197	126	0.5	2.5	2.8×10^{-8}
760	1% $CaCl_2$	SLS-71	2	1.65	6/13/77 - 1/3/80	934	11210	91.1	2.5	4.4×10^{-6}
729	10% $CaCl_2$ (B)	SS-100	2	3 30	8/23/76 - 1/13/77	141	136	1.1	2.5	3.5×10^{-7}
8061/1636A	10% $Ca(OCl)_2$	SLS-70	4	2 50	7/27/79 - 8/15/79	19	58	0.2	2.5	1.0×10^{-6}
	PCB Soln.	SLS-71	2	1 65	3/31/76 - 8/4/76	126	2.8	0.02	2.5	1.0×10^{-10}
712	Gasoline	SS-100	2	1 32	7/30/76 - 10/6/76	68	61.2	0.6	2.5	4.7×10^{-7}
	Kerosene	SS-100	4	3 90	1/4/81 - 4/8/81	85	40 2	0.16	2.5	4.7×10^{-8}
457	Lime sludge	SS-100	2	3.30	5/11/76 - 6/1/76	20	---	---	2.5	NLD
818	Ether	TFS-81	4	3.30	10/17/79- 1/4/80	79	41.9	0.17	2.5	1.5×10^{-7}
756	10% KCl	SS-100	2	3.30	5/23/77 - 3/14/78	326	232.5	1.89	2.5	3.4×10^{-7}
825-D	Acid waste	SS-100	4	9.00	3/14/80 - 6/4/80	82	194.5	0.79	5.0	5.9×10^{-8}
737	3% NH_4Cl	SS-100	2	3.30	1/31/77 - 7/22/77	173	172.8	1.40	2.5	2.8×10^{-7}
715	10% NH_4Cl	SS-100	2	3.30	3/8/77 - 1/3/80	1090	3625.5	29.4	2.5	2.7×10^{-6}
804	10% NH_4Cl	Improved SS-100	2	1.65	11/2/78 - 1/3/80	481	1615 8	13.1	2.5	1.5×10^{-7}
801	10% NH_4Cl	SS-100	2	1.65	10/30/78- 6/21/82	1330	18665	152.0	2.5	8.3×10^{-7}
799A	10% NH_4Cl	SS-100	2	2 00	1/29/79 - 6/21/82	1266	15983	130.0	2.5	7.6×10^{-7}
2506A	Acid waste sludge	SS-100	4	3.30	2/18/81 -11/20/82	375	235 4	0.95	2.5	9.5×10^{-8}
R81-62	Sludge from paper mill	SS-100	4	3 30	2/18/81 - 3/29/82	414	784.6	2.97	2.5	$2 0 \times 10^{-7}$
	Oil w/low level PCB	SS-100	4	3.30	2/17/81 - 9/14/81	210	125.6	0.51	2.5	2.8×10^{-8}
R81-1678	Paper mill w.w	SS-100	6	3 70	7/13/81 - 4/2/82	264	1048	2.84	5.0	2.2×10^{-8}

2" volume = 411.3 cc @ 30 PV = 123 m/s.
4" volume = 822.6 cc @ 30 PV = 247 m/s
NLD = No loss detected.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-9

Woodward-Clyde Consultants: Jean-Pierre Giroud
Chicago, IL 312-939-1000

TRW: Masood Ghassemi
John F. Metzger

27 January 1983

Summary

- With the proper approach and supporting investigations, liner systems can be designed so that they will not fail. Most failures result from poor design or the use of low quality materials due to owners considering cost as the overriding decision variable. Education to upgrade the profession is needed and can perhaps be best accomplished by EPA through technology transfer seminars and training courses with emphasis on increasing the understanding of the personnel at regulatory permitting agencies so that they can require proper design and installation procedures from permit applicants.

- The argument that clay is a natural product that has been around for millions of years and, hence, has a better track record and can, therefore, be trusted more than synthetic materials for lining hazardous waste sites is too simplistic. It can be countered with an equally simplistic argument that, in its natural environment, clay has not been in contact with waste products of a modern industrial society and that man-made liners can perhaps provide a better answer to man-made problems than natural liners. Many designers feel more comfortable with clay because they are more familiar with clay properties and there is more experience with design of clay structures.

- In some respect, a synthetic liner is probably superior to a clay liner although a clay underlying a synthetic liner has merit. In all cases, leachate should be removed from the facility and attenuation properties of clay liners should not be relied upon as the sole means to prevent migration of pollutants.

- Pinholes in synthetic liners, if they exist, do not pose a major problem. No known failures have been promoted by pinholes.

- Research and development effort to date has not been sufficient regarding practical design concerns. Areas requiring emphasis include development of: (a) design/construction criteria for making connections between geomembrane and concrete structures; (b) better sump systems for leachate collection in landfills; and (c) development of seaming specifications.

- Overall, the liner manufacturing, fabrication, and installation technologies in the U.S. are superior to those used overseas.

Background

Woodward-Clyde Consultants provides consulting services in the field of geomembranes and geotextiles out of their Chicago office. Dr. Jean-Pierre Giroud, Director of the Geotextiles and Geomembranes group, is an internationally-recognized expert on the subject and has authored numerous technical papers on the design of geomembranes and geotextiles. He has indeed coined the terms "geomembrane" and "geotextile" and has extensive experience in both academic and consulting practice. The purpose of the interview was to obtain Dr. Giroud's perspectives on liner installation problems and related matters.

General Design Considerations

- Identification of conditions which may lead to failure is an important design element. For example, a small leak might not be a problem unless it can trigger a larger problem. A case in point is an incidence where a small hole in a surface impoundment holding acidic waste (pH $\sim$ 1.0) resulted in a major failure within 11 months of installation. The slow but continuous leakage into the underlying carbonate-containing stratum resulted in a very large sink hole.

- With the conditions of failure established, all potential mechanisms of failure must be identified and addressed during design. With current technology, most failure mechanisms can be mitigated. The analyses generally require an extensive geotechnical investigation, but such an investigation is seldom undertaken and this can lead to poor design and hence possible liner failure. Thus, liners can be designed and installed so that they will not fail.

- A leaking liner does not fit the definition of a failure per se since all liners leak to a certain extent. Instead, the amount of leakage that can be tolerated and is expected must be identified and worked into the design.

- All land disposal systems should provide leachate removal. The concept of using only attenuation by leachate flowing through a clay liner to control pollution is a poor one. Deliberate movement of leachate into the ground is always a highly uncertain and potentially dangerous proposition. However, clay layers as an attenuating backup to a synthetic membrane have plenty of merit. Leachate should be removed from the landfill in all cases, although this may often be difficult with a commonly used bottom slope of 2 percent which promotes ponding.

- Leachate removal essentially provides for the transfer of the leachate from a difficult-to-control environment (i.e., the landfill) to a more

controllable one (i.e., surface treatment and/or direct discharge to public wastewater treatment plants). This approach is preferable to leachate recirculation schemes. One scheme involves circulation of leachate through the gravel liner cover layer thereby promoting dilution of any highly corrosive leachate and hence drastic impact on the liner. This system, however, may not be feasible due to shallow bottom slopes which may not sustain adequate flow.

Relative Merits of Clay and Synthetic Liners

- Many opportunities exist for problems to develop with a synthetic membrane liner, but these generally result from a lack of knowledge. The body of knowledge and level of experience of all concerned parties is more highly developed for clay liners than for synthetic liners.

- Arguments asserting that clay is a good liner material because it is highly stable as evidenced by its being around for millions of years are not valid. More importantly, the material has not been in contact with a leachate environment for the same or even a much shorter period.

- Precautions must be taken with clay liners to prevent cracking as the result of dessication. One method of preventing this loss of moisture is to place an extra foot of clay, then scrape it off at the last opportunity. Alternatively, a temporary cover can be placed.

- The method of clay compaction and, hence, the degree of compaction achieved has often been the same as that practiced for large embankments or dams; this degree of compaction, however, may not be appropriate for liners. A highly compacted clay can be more sensitive to changes in density resulting from loss of moisture. Slightly less compaction than is generally used may, therefore, be optimal. (Dr. J. Mitchell, of the University of California at Berkeley, can be consulted for additional details on the effect of compaction on clay properties.)

- The current regulations suggest that a synthetic membrane placed directly on top of clay can provide a good liner system. This assessment would probably be true if leachate passing through the synthetic liner would be absorbed by the clay liner at the close vicinity of the leak. In actual practice, however, there will seldom be perfect contact between the synthetic and clay liners, and channels will be present through which leachate will flow and accumulate at low points in the interface. The condition of perfect and continuous contact between the two layers may only be approached when the facility is full and, hence, large pressures are exerted on the liner. Also, better contact occurs if the clay is soft, compacted at less than its maximum. Including a layer of permeable material, such as a geotextile, between the two liners can increase the potential for flow between the two liners.

- Contrary to the generally held view, pinholes are not much of a problem in liner design and performance (consult H. Haxo for data). While there seems to be no evidence indicting pinholes in a liner failure, they could conceivably present a problem with a reinforced liner due to wicking action of the reinforcing scrim.

- Pinholes are much less of a problem than it has been generally asserted and there seems to be no evidence indicting pinholes in liner failures.

- The assertion that pinholes would not be of consequence with laminated liners due to a very low probability that pinholes in different layers would "line up" at exactly the same spots may not always be true because of the possible wicking action of certain scrims.

- In general, because of their characteristics, geomembranes would perform better on slopes than on bottoms. A reasonable solution would perhaps be to use clay as the bottom liner and to use geomembrane on the side slopes.

- Pinholes can be defined to have a maximum diameter of approximately 0.1 mm. The larger ones can be detected visually if there is sufficient light behind the material. The results of one study with a water containment system suggested that 2000 pinholes are equivalent to one hole of 10 mm diameter or 10 holes of 3 mm diameter. (More information on pinholes can be obtained from Dr. Henry Haxo of Matrecon, Oakland, CA.)

- Recycling of scrap material to the polymer melting pot can result in pinhole formation during calendering. This is especially true with reinforced liners when scrim material is present in the recycled scraps. The liner product quality standards which are being developed by the National Sanitation Foundation (NSF) are expected to address the scrim recycling problem.

- There is no clear way to establish compatibility of a synthetic liner with leachate. In selecting and designing liners, Woodward-Clyde follows the following steps:

  a) Identify chemicals in waste.

  b) Screen available geomembranes for chemical compatibility using data in manufacturers' literature.

  c) Discuss anticipated chemical composition of waste with manufacturers of prospective liners.

  d) Select liner candidate(s) based on steps b) and c) above.

  e) After a liner material has been selected, conduct compatibility tests (which usually take upwards of four months) to identify incompatible wastes so that restrictions can be placed on their acceptance to the proposed site.

- Animals can be a potential problem. Any rodent so inclined can chew through the liner; however, this does not seem to be much of a problem.

Perspectives on Caps

- Clay will not slip on a synthetic membrane if it is underlaid by a properly designed geotextile.

- Synthetic materials can better handle subsidence than clays and are therefore preferred as a cap. Unreinforced membranes can elongate upwards of 300 percent (maximum elongation for reinforced liners is usually about 20 percent). The ability of liners to elongate decreases somewhat with time, but the decrease is not large if the liner has been protected by a cover.

Quality Control Considerations

- Quality control requirements are specific to each project, but special attention should always be given to seaming and connections between liners and structures.

- All seams should be inspected visually and with at least one piece of equipment such as an air lance, an ultrasonic detector, or a vacuum detector. Factory seams are not necessarily always better than field seams and it is good practice to test factory seams in both the factory and the field.

- Criticism of the ultrasonic test is largely unfounded. In one job, one mile of seams was checked and the ultrasonic test was in error on only four inches.

- Manufacturing limitations involving the scrim make it difficult to follow seam specifications. A minimum scrim to scrim overlap is generally required with no loose, upper flap. The width of the seam is, therefore, measured from the upper edge backward, but the width of selvage is highly variable, even on one roll, resulting in a variable scrim overlap if a constant seam width is constructed. Further complicating field operations, seam specifications are sometimes poorly written with requirements that, when considered together, are contradictory.

- Connections between the liner and structures are often poorly designed. Certain geometries (e.g., sharp corners) are not easily handled and should be avoided in the design of structures. Quality control of connections is also very important since the liner is usually heavily stressed in these areas. Stresses include those resulting from differential settlement, gravity pull on slopes, and differential contraction.

- The quality of connections has, in the past, been poor because they were made last. At that point, the contractor is usually anxious to move his crews to another job. Either the work is done in a hurry or an inexperienced crew is sent to finish the project.

Institutional Barriers to Development of Adequate Facilities

- There are numerous problems within the industry that result from a poor understanding of liner and land disposal technology. Two problems in particular are design of facilities by inexperienced engineers, and the proliferation of low bids that subvert the efforts of quality contractors and suppliers. If, for example, a material supplier does not compromise quality or quality control, he will probably be underbid (a good turn key liner project which would have reasonable assurance of good performance may cost 25 percent or more than an average job). Unfortunately, the principal decision variable considered by owners is often cost. Generally, two types of clients can be identified: those who are willing to accept marginal designs and materials and those who want superior designs and materials with no costs spared. The latter is characteristic of private companies and commercial waste disposal firms. But the purchasing departments of these firms also apply pressure, at times, to cut costs.

- In the past, there has been little incentive to develop an adequate land disposal facility. But with increasing public attention and liability problems, the incentive may now exists to develop a facility that works rather than one that is within budget. Education is an ongoing process and should naturally upgrade the profession within 10 to 20 years to a point where adequate facilities are developed. However, such a lengthy period cannot be afforded, and something is needed to speed up the process. EPA can be very instrumental in speeding up the educational process by promoting transfer of information on latest technologies to the user community, in particular to the personnel at regulatory agencies responsible for permit review and approval. This education process should be very specific, should address facts as well as philosophy, and should be aimed at increasing the awareness of all parties involved. This awareness can be promoted by requiring each facility to meet a checklist of general procedures for design and quality control. Specific requirements (most importantly, quality control) can be written directly into the permit application.

- A checklist of design procedures and quality control providing detailed instructions for installation of synthetic liners for land disposal facilities has been developed by Woodward-Clyde under a subcontract to TRW in connection with present effort. The detailed instructions, which address the following topics, follow this interview summary:

  - Selection of suppliers (manufacturers, fabricators, and installers).
  - Installation procedures, including ground preparation and general recommendations regarding seaming procedures with specific examples for three liner types: high density polyethylene (HDPE), Hypalon, and polyvinyl chloride (PVC).
  - Quality control to be requested from suppliers.
  - Quality assurance to be requested from site engineers.

- Sometimes even respectable firms send inexperienced field crews to a site. Some structure may therefore be needed to guarantee minimum qualifications of individuals within firms actually involved in the installation, particularly seaming. On some projects, Woodward-Clyde requires passage of a practical examination. On another project (in Africa), local people were trained to do the seaming; practice seams were made and tested, and the most accomplished "seamers" were selected for the job. Quality control of seams has also been improved by numbering the seams (on design drawing) and recording the individual assigned to specific seams.

- Performance standards are not an appropriate approach to ensuring quality installation, mainly because it is difficult to both define and determine a failure. Also, such a system could, in some instances, be subverted. For example, facilities having a double synthetic membrane might intentionally be constructed with the lower membrane being less than adequate so that any leachate passing the first liner would pass through the second liner, thus escaping detection by any leachate collection detection system placed in between the two liners. Since monitoring wells are also not required for double-lined facilities, the escaping leachate would move unnoticed into the ground.

U.S. Vs. Foreign Technologies

- Possibly more mistakes are made at foreign installations than in U.S. installations and, in this respect, foreign experience can provide valuable lessons.

- A foreign method of welding elastomerics is superior but is not usable in the U.S., apparently because of differences in materials. Foreign fabricators seem to work with EPDM and butyl rubber that is less fully cured. In general, field techniques and quality control are better in the U.S. than in Europe.

- In general, fabrication is better in the United States than overseas.

- Insurance companies are involved in European facilities but do not play the prominant role that they could. Requirements are set forth for issuing insurance, but these requirements, especially for quality control, are minimal.

Research and Development Needs

- More important than technical improvements is organization of the profession so that information on current technologies is fully disseminated and properly applied. A large gap exists here. For example, quality control guidance could be included in permit requirements.

- While research to date has been very fruitful, practical concerns of designs have not been addressed. For example, the recommended seam width values which are presumably based on capabilities of existing equipment have not been supported by data from systematic engineering and scientific research.

- The following can be cited as technical research needs:

  - For liquid impoundments: improvement of connections between the geomembrane and concrete structures (development of design/construction criteria).
  - For landfills: development of a good sump system. Sumps are the most delicate part of the entire landfill system because there are many connections to it and the largest concentration of leachate exists in its vicinity. A standard, prefabricated sump might be appropriate.
  - Development of a good set of specifications for seaming, particularly the practical aspects that have largely not been addressed to date. The specifications should be compatible with seaming equipment, existing or proposed.

GUIDE SPECIFICATIONS FOR CONSTRUCTION OF FLEXIBLE MEMBRANE LINERS FOR HAZARDOUS WASTE DISPOSAL FACILITIES

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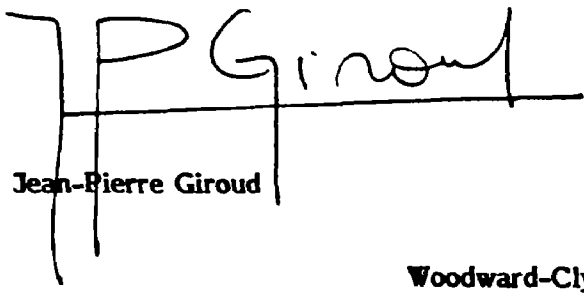
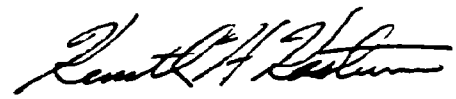


Jean-Pierre Giroud



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83C005-2
15 February 1983

GUIDE
SPECIFICATIONS
FOR
CONSTRUCTION
OF
FLEXIBLE MEMBRANE LINERS
FOR
HAZARDOUS WASTE DISPOSAL FACILITIES

FOREWORD

The following Guide Specifications represent an effort to establish a comprehensive framework to verify and document the construction of a flexible membrane liner (FML) system for hazardous waste disposal facilities. Some of the technical requirements may have significant impact upon the FML industry and review and comments should be solicited from industry representatives.

WOODWARD-CLYDE CONSULTANTS

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INTRODUCTION

The Guide Specifications which follow are intended to be used by persons writing specifications for the construction of a flexible membrane liner (FML) for land disposal of hazardous wastes.

The specifications do not relate to design of the FML system but rather provide guidelines for control and verification of construction of the designed FML system. The guidelines are not all inclusive to the needs of each site but form a framework into which site specific requirements can be inserted. Where appropriate, choices are provided, with examples for high density polyethylene (HDPE), reinforced chlorosulfonated polyethylene (CSPER, known as "Hypalon") and polyvinyl chloride (PVC).

These specifications have recognized the need to verify that the installed FML must provide total containment of hazardous waste fluids. This recognition resulted in requirements for thorough quality control during FML fabrication and installation, and systematic documentation. Further, the recognition of the parties involved in FML installation and the need for these parties of agree on individual responsibilities have been highlighted.

Parties who may be involved with FML installation include: Designer, Earthwork Constructor, FML Fabricator, FML Installer, FML Manufacturer, Inspector, Monitor, Owner, Regulatory Authority, and Specifier. These terms are defined in the Appendix. Each of these parties may be involved in FML installation, or responsibilities defined for one party may be assumed by another party (ie, the FML Manufacturer may also be the FML Fabricator).

Reference is made in the text to the test procedures of the American Society for Testing and Materials (ASTM) and the Proposed Standards for Flexible Membrane Liners of the National Sanitation Foundation (NSF).

1 FML CONSTRUCTORS

1.1 FML Manufacturer

To demonstrate an ability to manufacture the FML rolls, the FML Manufacturer shall provide the Monitor with a list of at least ___ projects totaling a minimum of ___ hundreds of thousands m^2 (millions sq. ft), for which the FML Manufacturer supplied the same generic type of FML. For each project, the following information shall be provided: name and purpose of project, location, date, name of owner, designer, fabricator, and installer, type of FML, thickness, surface area, and available written information on the performance of the project.

1.2 FML Fabricator

The FML Fabricator shall be trained and qualified to fabricate the type of FML to be used for the project. The FML Fabricator shall be an approved and/or licensed Fabricator of the FML Manufacturer. A copy of the approval letter or license shall be submitted to the Monitor.

To demonstrate an ability to fabricate FML, the FML Fabricator shall provide the Monitor with a list of at least ____ previous fabrications, totaling a minimum of __ hundreds of thousands m^2 (millions sq. ft), completed with the same generic type of FML. For each fabrication, the following information shall be provided: name and purpose of project, location, date, name of owner, designer, manufacturer, and installer, type of FML, thickness, total amount of FML fabricated, type of seaming, and available written information on the performance of the project. Also, the FML Fabricator shall provide information on the factory size and equipment, and daily production quantity available.

1.3 FML Installer

The FML Installer shall be trained and qualified to install the type of FML to be used for the project. The FML Installer shall be an approved and/or licensed Installer of the FML Manufacturer and/or FML Fabricator. A copy of the approval letter or license shall be submitted to the Monitor.

To demonstrate an ability to install FML, the FML Installer shall provide the Monitor with a list of at least ____ previous installations, totaling a minimum of __

hundreds of thousands m^2 (millions sq. ft). For each installation, the following information shall be provided: name and purpose of project, location, date, name of owner, designer, manufacturer, fabricator and leader of the installer's crew, type of FML, thickness, surface area, type of seaming, duration of installation, and available written information on the performance of the project.

2 FLEXIBLE MEMBRANE LINER

2.1 Raw Materials

The FML shall be manufactured of first quality newly produced raw materials. The use of reclaimed polymers and other materials shall not be permitted. Recycling of materials containing reinforcing scrim shall not be permitted. Recycling scrap that does not contain scrim may be permitted.

The FML Manufacturer shall: (i) indicate the origin of raw materials; (ii) provide a copy of quality control certificates issued by the producer of raw materials; and (iii) provide reports on the tests conducted to verify the quality of the raw materials. These tests should include at least:

- Density (ASTM D792-66) and melt index (ASTM D 1238-79), for HDPE.
- Analysis of the chemical composition of the plasticizers, for PVC.

2.2 Rolls

The FML rolls shall be designed and manufactured specifically for the purpose of fluid containment. The FML shall be free of holes, blisters, undispersed raw materials, and any sign of contamination by foreign matter.

The FML to be used for this project shall be ___ mm (__ mil) thick ___ (mention here the type of FML, such as HDPE; Hypalon; PVC). The FML shall meet the specifications listed in Table 1. (Note 1)

The following information shall be provided by the FML Manufacturer as an indication of the quality of the material supplied:

- Material properties sheet, pertaining to the FML to be used for the project, (including data regarding chemical compatibility of the FML with contacting fluids) shall be provided. The sheet should at least include all properties listed in Table 1. The allowable range in values of properties listed in the sheet must meet the specifications given in Table 1. The sheet shall provide minimum properties guaranteed by the FML Manufacturer and indicate test methods used. Unless otherwise specified, test methods shall be in accordance with NSF Proposed Standards.

- Quality control certificates pertaining to the rolls of material delivered to the site shall accompany the rolls. Each roll shall be identified by a unique manufacturing number. The quality control certificate shall include results of at least the following tests: thickness, tensile characteristics, and tear resistance (also, coefficient of thermal expansion-contraction for HDPE) (also: hydrostatic burst resistance, and ply adhesion, in the case of Hypalon). Unless otherwise necessary, test methods shall be in accordance with NSF Proposed Standards. The quality control certificates shall be signed by a responsible party employed by the FML Manufacturer, such as production manager, and shall be notarized.

2.2 (Continued for Hypalon)

The FML Manufacturer shall indicate the composition of roll material. The polymeric compound shall contain at least 45% by weight of "Hypalon type 45" as the sole elastomer. The reinforcing scrim shall be defined by the number of yarns per unit width (eg. per meter or per inch) in each direction and by the linear density (in kg/m, tex, or deniers) of the yarns. The type of polymer used for the reinforcing scrim shall also be indicated.

2.2 (Continued for unreinforced PVC)

The FML Manufacturer shall indicate the proportion by weight of plasticizers, and the amount of volatile loss measured using ASTM D 1203, method A. The maximum value of the volatile loss shall be ___. (Note: the NSF Proposed Standards recommend 0.7% for a 0.75 mm (30 mil) thick FML and 0.5% for a 1.15 mm (45 mil) thick FML; values for other FML thicknesses may be interpolated or extrapolated beyond the 1.15 mm (45 mil) value).

2.3 Blanket Fabrication

(Note: The entire section 2.3 shall be deleted if the rolls are not fabricated into blankets in a plant. This is usually the case for HDPE FML.)

2.3.1 Blanket Geometry

The FML shall be fabricated into blankets. Blanket sizes shall be: (i) proposed by the FML Fabricator; (ii) consistent with the instructions (if any) given by the Designer; and (iii) approved by the Monitor and the FML Installer.

2.3.2 Factory Seaming

The rolls shall be fabricated into the designed blanket sizes using one of the following seaming techniques: adhesive, heat seaming, or dielectric seaming.

The overlap shall provide the minimum required seam width (as indicated below). The seam shall extend to the edge of the sheet, so that no loose flap is present on the top side of the blanket. A loose flap is permissible on the bottom side of the fabricated blanket.

The rolls shall be laid out without tension and seamed without wrinkles or fish-mouths. If wrinkles occur within the sheet due to the seaming process, the wrinkle shall not extend into the seamed width. Wrinkles which extend into the seamed width shall be treated as specified in Section 3.5.7.

The overlap area to be seamed shall be free from moisture, dust, dirt, debris of any kind, and foreign material. The fabrication area shall be in a clean, enclosed, temperature controlled facility.

The dielectric and heat seaming devices shall be accurately monitored and controlled at all times to effect a consistently acceptable seamed width. Dielectric bars or wheels with ribs shall effect the full specified seam width. Space between the bar ribs shall not be counted in the seam width.

2.3.2 (Continued for Hypalon)

To effect a clean, bondable surface, the seam interfaces shall be cleaned with trichlorethylene or perchlorethylene solvent before the Hypalon adhesive is applied. The Hypalon based adhesive product for seaming the rolls together shall be as recommended by the Hypalon FML Manufacturer. The adhesive product shall be applied as specified by the Hypalon FML Manufacturer with special attention to the ambient temperature and rolling pressure.

The minimum scrim-to-scrim seam widths shall be:

Hypalon based adhesive	50 mm (2 in.)
Heat seaming	25 mm (1 in.)
Dielectric seaming	25 mm (1 in.)

The minimum seam width shall be the scrim-to-scrim seam width, plus the selvage width.

2.3.2 (Continued for PVC)

The PVC adhesive used for seaming the rolls together shall be as recommended by the PVC FML Manufacturer and shall not be deleterious to the PVC FML material in any way after seaming. The adhesive product shall be applied as specified by the PVC FML Manufacturer with special attention to the ambient temperature and rolling pressure. The adhesive shall have been tested for longevity in contact with the PVC FML material and its application shall result in no appreciable stiffening of the FML. Prepared adhesive tapes shall not be used.

The minimum seam widths shall be:

	Unreinforced	Reinforced
PVC adhesive seaming	25 mm (1 in.)	50 mm (2 in.)
Heat seaming	25 mm (1 in.)	25 mm (1 in.)
Dielectric seaming	20 mm (3/4 in.)	25 mm (1 in.)

3 INSTALLATION

3.1 Definition of Responsibilities

All parties involved with FML installation shall attend a meeting held prior to installation of any FML. The purpose of this meeting is to: (i) define the responsibilities of each party; (ii) establish lines of authority and lines of communication; (iii) establish site specific quality control and monitoring procedures; and (iv) define the method of acceptance of the completed liner. The meeting shall be documented and minutes transmitted to all parties.

3.2 Surface Preparation

The upper 0.1 m (4 in.) of the supporting soil shall not contain stones larger than 25 mm (1 in.). The surface to be lined shall be rolled with a smooth drum steel or pneumatic roller so as to be free of irregularities, loose earth, and abrupt changes in grade. The surface preparation shall be done by the Earthwork Constructor. The FML Installer shall certify in writing that the surface on which the FML is to be installed is acceptable. Thereafter, the FML Installer shall provide the necessary equipment and personnel to maintain an acceptable soil surface during liner installation.

No FML shall be placed in an area which has become softened by precipitation (ie, unconfined compressive strength less than 50 kPa (0.5 tsf)).

3.2 (Specific to surface preparation when the FML is supported on a soil liner)

Special care must be taken to maintain the prepared soil surface in areas where the soil functions as an impermeable soil liner. The soil surface shall be observed daily by the Monitor and FML Installer to evaluate desiccation cracking. The daily observations shall also ascertain the effects of surface desiccation cracking upon the integrity of the soil liner. Prior to installation of any FML, the Designer and Monitor shall define in writing the maximum allowable crack depth and width which will not significantly affect the soil liner design intent. The Monitor shall inform the FML Installer of the requirements regarding crack depth and width. Precautions for reducing desiccation potential (ie, temporary FML cover) and crack repairs shall also be defined by the Designer and approved by the Monitor. (Note 2)

3.3 Handling of FML

3.3.1 Packaging

FML rolls or blankets shall be packaged and labeled prior to shipment to the site. The label shall indicate the FML Manufacturer, FML Fabricator, type of FML, thickness, and roll or blanket number.

3.3.2 Transportation

When transported to the site, FML rolls or blankets shall be handled by appropriate means so that no damage is caused. Wooden cases shall be strong enough to withstand impacts and rough handling without breaking or splintering.

Transportation shall be the responsibility of the FML Manufacturer (if fabrication is not required, which is usually the case of HDPE), or of the FML Fabricator (if fabrication is required, which is usually the case of Hypalon and PVC).

3.3.3 On-site Storage

Once on-site, storage of the FML is the responsibility of the FML Installer. The FML shall be protected from direct sunlight and heat to prevent degradation of the FML material and adhesion of individual whorls of a roll or layers of a blanket.

Adequate measures shall be taken to keep FML materials away from possible deteriorating sources (ie, vandalism, theft).

3.3.4 On-site Handling

On-site handling of the FML is the responsibility of the FML Installer. Appropriate handling equipment shall be used when moving rolled or folded FML from one place to another. Instructions for moving the FML shall be given by the FML Installer to the workers and shall be approved by the Monitor.

3.3.5 Panel Placement

Each roll or blanket shall be redesignated with a panel number. A panel is the unit area of in-place membrane which is to be seamed (ie, one roll may be cut into

several panels). The FML shall be positioned on the site as shown in the layout drawings. Instructions on the boxes or wrapping containing the FML materials shall be followed to assure the panels are unrolled or unfolded in the proper direction for seaming. Only the panels which are to be anchored or seamed together in one day shall be unrolled or unfolded. Care shall be exercised to not damage the FML during this operation. All workers shall wear shoes which will not damage the FML.

Pulling FML panels shall be minimized to reduce permanent tension.

The following precautions should be taken to minimize the risk of damage by wind during panel placement:

- No more than one panel should be unrolled prior to seaming (unless authorized by the Monitor);
- Work shall be oriented according to the direction of prevailing winds if possible, unless otherwise specified;
- Adequate loading on FML panels to prevent uplift by wind shall be provided by sand bags, tires or any other means which will not damage the FML. Along the edges, loading shall be continuous, to avoid possible wind flow under the panels.

Any panels, which, in the judgement of the Monitor, become seriously damaged (torn or twisted permanently), shall be replaced. Less serious damage should be repaired according to Section 4.4.

FML placement shall not proceed at an ambient temperature below 5°C (41°F) or above 35°C (95°F), unless otherwise specified.

FML placement shall not be done when raining nor in an area of ponded water.

3.3.4 (Specific to HDPE)

The HDPE roll shall be installed so that there will be neither tension nor wrinkles at the average expected temperature of the final use condition.

3.3.4 (Specific to PVC)

Unless otherwise specified, the PVC panels shall be installed in a slack untensioned condition allowing for a 5% excess in each direction (unless otherwise specified).

3.4 Considerations of Site Geometry

3.4.1 Layout Drawings

The FML Installer shall produce layout drawings of the proposed FML placement pattern and seams prior to FML placement. The drawings shall indicate the panel configuration and location of seams. Field seams should be differentiated from factory seams (if any). (Note 3)

3.4.2 Anchor Trench

The anchor trench (if required) shall be constructed to the lines and width shown on the design drawings prior to FML placement. If clay soils, susceptible to desiccation, will be encountered in the anchor trench, no more than one days trench length shall be excavated in advance of the FML placement. Backfilling shall proceed rapidly, unless otherwise specified, to minimize desiccation potential of the anchor trench clay soils.

3.4.3 Installation Around Appurtenances

The FML shall be installed around any pipes, piers, concrete pits (or other appurtenance protruding through the FML) as detailed on the design drawings. Unless otherwise specified, a FML sleeve or shield shall initially be installed around each appurtenance, prior to the areal FML installation. After the FML has been placed and seamed, the final field seam connection between the appurtenance sleeve or shield and the FML shall be completed. A sufficient initial overlap of the appurtenance sleeve shall be maintained so that shifts in location of the FML can be accomodated.

Installation on rough surfaces such as concrete shall be carefully performed to minimize FML damage. Additional, loosely placed FML or geotextile sections may be used by the FML Installer as protection for the FML if approved by the Monitor. (Note 4)

All clamps, clips, bolts, nuts or other fasteners used to secure the FML around each appurtenance shall have a life-span equal to or exceeding the FML.

3.5 Field Seaming

3.5.1 Requirements of Personnel

All personnel performing seaming operations shall be qualified by experience or by successfully passing seaming tests.

At least one seamer shall have experience seaming at least one hundred thousand m^2 (1 million sq. ft.) of a FML of the same generic type as the FML used for the project using the same type of seaming method. This master seamer shall provide direct supervision over apprentice seamers.

Apprentice seamers shall be qualified by attending training sessions taught by the master seamer and performing at least two successful seaming tests under similar weather conditions using the seaming method used for production seaming.

3.5.2 Overlapping

3.5.2 (Specific to HDPE)

The panels shall be overlapped a minimum of 75 mm (3 in.)

3.5.2 (Specific to Hypalon and PVC, Heat Seaming)

The panels shall be overlapped a minimum of 100 mm (4 in.)

3.5.3 (Specific to Hypalon and PVC, Adhesive Seaming)

The panels shall be overlapped a minimum of 150 mm (6 in.).

3.5.3 Preparation

Prior to seaming, the seam area shall be clean and free of moisture, dust, dirt, debris of any kind, and foreign material.

3.5.3 (Specific to HDPE)

The seam overlaps shall be ground according to the FML Manufacturer's instructions.

3.5.3 (Specific to Hypalon)

The seam overlaps shall be cleaned with thrichlorethylene or perchlorethylene in accordance with the FML Manufacturer's instructions.

3.5.4 Seaming Equipment and Products

3.5.4 (Specific to HDPE)

Each seaming unit must include thermometers giving the temperature of the extrudate in the machine and at the nozzle.

3.5.4 (Specific to Hypalon and PVC, Heat Seaming)

The heat seaming device (hot air or hot wedge) shall include a thermometer allowing the temperature to be monitored.

3.5.4 (Specific to Hypalon and PVC, Adhesive Seaming)

The adhesive (bodied solvent compound or cement) shall be formulated in accordance with the FML Manufacturer's specifications.

3.5.5 Weather Conditions for Seaming

Weather conditions required for seaming are as follows: (i) no weld shall be done below 1°C (34°F); (ii) between 1°C (34°F) and 10°C (50°F), seaming is possible if the FML is preheated by either sun or hot air device, and if there is not excessive cooling resulting from wind (as determined by the Monitor); and (iii) above 10°C (50°F), no preheating is required. In all cases, the FML shall be dry.

3.5.6 Seaming Procedure

Seaming on horizontal surfaces shall commence at the center of a panel side and proceed to either end of a side (if possible) in an effort to reduce wrinkles and subsequent fishmouths at the seam interface. The direction of seaming on slopes shall be the most expedient direction for the type of seaming used. Seaming shall extend to the outside edge of panels to be placed in the anchor trench.

If the supporting soil is soft, a firm substrate shall be provided by using a homogeneous board, a conveyor belt, or similar hard surface directly under the seam overlap to effect proper rolling pressure.

3.5.6 (Specific to Hypalon and Reinforced PVC, Heat Seaming)

The width of the seam shall be 25 mm (1 in.) scrim to scrim. Then, the loose upper flap shall be bonded using either a hot air gun or an adhesive (bodied solvent or cement).

3.5.6 (Specific to Hypalon and PVC, Adhesive Seaming)

The width of the seam shall be 100 mm (4 in.) starting from the edge of the FML placed on top (so there is no loose flap).

3.5.6 (Specific to Unreinforced PVC, Heat Seaming)

The width of the seam shall be 25 mm (1 in.) starting, if possible, from the edge of the FML placed on top. Any loose flap shall be bonded using either a hot air gun or an adhesive.

3.5.7 Procedure for Seaming Wrinkles

Fishmouths or wrinkles at the seam overlaps shall be cut along the ridge of the wrinkle back into the panel so as to effect a flat overlap. The cut fishmouths or wrinkles shall be seamed as well as possible, and shall then be patched with an oval or round patch of the same generic FML extending a minimum of 150 mm (6 in.) beyond the cut in all directions.

3.5.7 (Specific to Hypalon and PVC)

The patch shall be bonded over its entire area, using either a hot air gun or an adhesive (bodied solvent or cement).

3.5.8 Cap-strips

Cap-strips shall be at least 75 mm (3 in.) wide and shall be centered over the completed seam edge. Cap-strips shall be of the same generic FML material as the liner but without reinforcing scrim. The thickness of cap-strip shall be ___ mm (__ mils) (at least 0.75 mm (30 mils)).

Cap-strips shall shall be placed on all field seams. They shall be placed only after quality control of the original seam has been performed.

3.5.8 (Specific to HDPE)

Cap-strips shall not be longer than 3 m (10 ft) long if they are not bonded over their entire surface.

3.5.8 (Specific to Hypalon and PVC)

Cap-strips shall not be placed on a loose flap (loose flaps shall be bonded as explained in Section 3.5.6). Cap-strips shall be bonded over their entire surface, using hot air gun or adhesives (either bodied solvent or cement).

3.5.8 (Specific to Hypalon and Reinforced PVC)

Cap-strips shall be placed on all seams where the reinforcing scrim daylights: (i) ends of rolls; (ii) tapered rolls in corners and other special locations of cells or ponds; and (iii) places where the unreinforced selvage is too narrow (smaller than 3 mm (1/8 in.)) or has been damaged.

3.6 Installation of Materials in Contact with the FML

3.6.1 Granular Materials

Granular materials (ie, for FML protection or as a leachate collection system) shall be placed by the FML Installer or Earthwork Constructor at the direct supervision of the FML Installer in a manner so as not to damage the FML.

Placement of a granular material layer shall commence after the FML anchor trench (if any) has been completely backfilled and compacted and the leachate collection sump structures (if any) have been installed.

Unless otherwise specified, initial granular material placement shall be done by placing the material at the toe of the lined slope and pushing the material up the side slope with a light dozer (eg. D-6) or other equipment approved by the Monitor. The full design thickness of the granular material layer shall be maintained when spreading the material. The granular layer shall be placed over the FML before any construction traffic is allowed. If necessary, an access ramp comprised of granular material shall be gradually advanced over the geomembrane to the bottom of the disposal cell. The access ramp and other highly trafficked areas shall be a minimum of 0.9 m (3 ft) thick. Rubber tired vehicles shall not be allowed where the granular layer is less than 0.9 m (3 ft) thick.

The layer of material shall be compacted using the dozer. The Monitor shall obtain direct layer thickness measurements to verify conformance with design drawing requirements.

3.6.2 Concrete

If concrete is to be placed on the FML, care should be taken to avoid all damage to the FML. Additional layers of FML or geotextiles should be considered as protection layers for the FML.

3.6.3 Geotextiles

Geotextiles shall be overlapped 0.3 m (1 ft) unless otherwise specified (Note 5). If necessary because of the wind, the overlaps can be glued together with spots of glue (one to three per meter) (at a distance of one to three feet). In general, overlaps shall be oriented parallel to the lines of maximum slope.

During the placement of the geotextile, care should be taken not to entrap stones in the geotextile.

Unless specially selected for their ultraviolet light resistance, geotextiles shall not be exposed more than seven days.

4 QUALITY CONTROL AND INSPECTION

4.1 Materials

The test reports, material properties sheets, and quality control certificates required in Sections 2.1 and 2.2 shall be supplied to the Monitor by the FML Manufacturer prior to fabrication (or installation if there is no fabrication).

The quality control certificates shall be reviewed by the Monitor to verify that a certificate has been received for all rolls.

4.2 Factory Seams

(Note: The entire Section 4.3 shall be deleted if the rolls are not fabricated into blankets in a plant. This is usually the case for HDPE FML.)

4.2.1 Inspection

The Monitor shall visit the FML Fabricator's plant and verify that:

- The plant is clean.
- Ambient temperature in the plant is adequate (higher than 10°C (50°C)).
- The specified rolls are used.

- The unreinforced selvage is wide enough (at least 3 mm (1/8 in.)).
- Seaming procedures recommended by the FML Manufacturer are followed.
- Appropriate seaming equipment and adhesive products are used.
- The specified overlaps are used.
- The factory seams have no upper loose flap.
- Non-destructive and destructive testing equipment is available in the plant.

The Monitor shall also:

- Observe non-destructive testing.
- Collect samples for destructive laboratory testing.
- Obtain, from the FML Fabricator, reports on quality control tests performed on factory seams.
- Obtain, from the FML Fabricator, daily reports on the plant's production, including number and identification of blankets, and number and identification of rolls used to fabricate each blanket.

4.2.2 Non-Destructive Testing

Non-destructive testing of factory seams shall be performed by the FML Fabricator. All factory seams shall be checked for loose flaps using an air nozzle directed on the upper seam edge and surface to detect unbonded overlaps within the seam. In addition, random vacuum seam testing shall be performed if required by the Monitor. All required repairs shall be made by the FML Fabricator before the FML blanket is packed for shipment.

4.2.3 Destructive Testing

Destructive testing of specimens of factory seams shall be done by the FML Fabricator and by an independant laboratory designated by the Monitor.

One 0.45 m (18 in.) square sample, with a seam in the middle, shall be cut-off from each fabricated blanket. This sample can be cut-off at the edge of a blanket, or from an extra length of seam, in order not to make a hole. All holes, if any, remaining in the FML from destructive seam testing shall be immediately repaired in accordance with repair procedures described in Section 4.5.3.

Each sample for destructive seam test shall be numbered. The number and the location where the sample was taken from the blanket shall be recorded by the Monitor. One half of the sample shall be retained by the FML Fabricator, the other half by the Monitor.

Tests to be performed in a laboratory designated by the Monitor include "Bonded Shear Strength" (ie, tensile shear) and "Peel Adhesion", as recommended in the NSF Proposed Standards for FML. The specified values to be obtained in these tests are the values recommended in the NSF Proposed Standards for FML for the particular type of FML tested.

4.3 Transportation, Handling and Placement

Upon arrival at the site, the FML Installer and Monitor shall inspect all materials for defects in the manufacturing process and for damage during transportation. Materials judged by the Monitor to be severly damaged shall be rejected and removed from the site. Minor damages and other defects shall be repaired.

The Monitor shall inspect each panel, after placement and prior to seaming, for damage caused by placement operations or by wind. Damaged panels or portions of damaged panels which have been rejected, as judged by the Monitor, shall be marked and their removal from the work area recorded.

The Monitor shall also verify that the weather conditions (air temperature, non-excessive wind, and lack of precipitation) are acceptable for panel placement, in accordance with Section 3.3.5.

4.4 Field Seams

4.4.1 Field Seaming Operations

The Monitor shall verify that:

- The seaming personnel have the qualifications required in Section 3.5.1.
- The overlaps meet the requirements presented in Section 3.5.2.
- The seaming area is clean, as described in Section 3.5.3.
- A hard substrate such as a board or a piece of conveyor belt is used if the supporting soil is soft.
- Seaming equipment and adhesive products are available on the site and meet the requirements presented in Section 3.5.4.
- Weather conditions for seaming are acceptable, as required in Section 3.5.5.
- Seaming procedures described in Section 3.5.6 are followed.
- The panels are properly positioned to minimize wrinkling and wrinkled areas are seamed according to the procedures presented in Section 3.5.7.
- All cap-strips required in Section 3.5.8 are placed.
- Equipment for testing seams is available on site.

4.4.2 Test Seams

Test seams shall be performed to verify that seaming conditions are adequate. Test seams shall be conducted at the Monitor's discretion and at least two times each day (at the beginning of the morning and the beginning of the afternoon), for each seaming equipment or adhesive product used that day. Also, each seamer shall perform at least one test seam each day. Test seaming shall be performed under the same conditions as production seams. The test seam shall be at least 0.6 m (2 ft) long.

Specimens shall be cut from the test seam. These specimens shall be ___ mm (__ in.) wide (eg, 10 mm (0.5 in.) in the case of HDPE or 50 mm (2 in.) in the case of Hypalon or PVC). Specimens shall be tested by hand in shear and peel, and shall not fail in the joint. If a test seam fails, an additional test seam shall be immediately conducted. If the additional test seam fails, the seaming equipment or product shall be rejected and not used for production seaming until the deficiencies are corrected and a successful full test seam is produced.

The Monitor shall observe all test seams. A sample from each test seam shall be retained and labeled with the date, ambient temperature, number of seaming unit, seamer, and pass or fail description. One half of the sample shall be given to the FML Installer for subsequent laboratory testing and the other half retained by the Monitor.

4.4.3 Non-Destructive Seam Testing

All field seams shall be non-destructively tested over their full length. Each seam shall be numbered or otherwise designated. The location, date, test unit, name of tester, and outcome of all non-destructive testing shall be recorded by the Monitor.

The Monitor shall observe all testing. Testing shall be done as the seaming work progresses, not at the completion of all field seaming. All defects found during testing shall be numbered and marked immediately after detection. All defects found shall be repaired, retested and remarked to indicate completion of the repair and acceptability.

4.4.3 (Continued for HDPE)

The test unit shall be a vacuum test unit or an ultrasonic test unit.

4.4.3 (Continued for Hypalon and PVC)

The test unit shall be air lance or vacuum test unit.

4.4.4 Destructive Seam Testing

Destructive seam testing involves cutting out a sample of an existing seam for the purpose of verifying seam conditions through laboratory testing. Unless otherwise noted, destructive seam testing shall not be performed except as directed in Section 5.4.

The destructive testing specimen shall be a 0.45 m (18 in.) square sample with the seam in the middle.

Each destructive seam test sample shall be numbered. The sample number, seam number, location of sample along the seam, and reason for the destructive seam test shall be recorded on the test sample by the Monitor. One half of the test sample shall be retained by the FML Installer, the other half by the Monitor.

All holes remaining in the FML from taking destructive seam sample shall be immediately repaired in accordance with repair procedures described in Section 4.5.3. The new seams in the repaired area shall be tested according to Section 4.4.3.

Destructive seam test samples shall be stored and shipped in a manner which will not damage the test sample.

Tests to be performed in a laboratory designated by the Monitor include "Bonded Shear Strength" (ie, tensile shear) and "Peel Adhesion", as recommended in the NSF Proposed Standards for FML. The specified values to be obtained in these tests are the values recommended in the NSF Proposed Standards for FML for the particular type of FML tested.

4.4.5 Verification of Seams in Special Locations

All seams in special locations shall be non-destructively tested if the seam is accessible to testing equipment. If the seam cannot be tested in-place, but is accessible to testing equipment prior to final installation, the seam shall be non-destructively tested prior to final installation (eg, seams around pipes and appurtenances). The Monitor shall observe all seam testing operations. If the seam cannot be tested in-place, nor prior to final installation, it shall be observed by the Monitor and FML Installer, for uniformity and completeness.

The seam number, date of observation, name of tester, and outcome of the test or observation shall be recorded by the Monitor.

All defective seams shall be promptly repaired, retested and remarked to indicate completion of the repair.

4.5 Defects and Repairs

4.5.1 Identification

All seams and non-seam areas of the FML shall be inspected for identification of defects, holes, blisters, undispersed raw materials and any sign of contamination by foreign matter.

The surface of the FML shall be clean at the time of inspection. Brooming and/or washing of the FML surface shall be required if the amount of surface dust or mud inhibits inspection.

4.5.2 Evaluation

Each suspect location both in seam and non-seam areas shall be non-destructively tested using the methods described in Section 4.4.3. Each location which fails the non-destructive testing shall be marked and repaired.

4.5.3 Repair Procedures

Defective seams shall be repaired by reseaming or applying a cap-strip. Tears or pinholes shall be repaired by seaming or patching. Blisters, larger holes, undispersed raw materials, and contamination by foreign matter shall be repaired by patches. Each patch shall be numbered. Patches shall be round or oval in shape, made of the same generic FML, and extend a minimum of 150 mm (6 in.) beyond the edge of defects.

4.5.4 Verification of Repairs

Each repair shall be non-destructively tested using the methods described in Section 4.4.3. Tests which pass the non-destructive test shall be taken as an indication of an adequate repair. Failed tests shall be reseamed and retested until a passing test results. The Monitor shall observe all non-destructive testing of repairs and shall record the number of each patch, date, location, patcher and test outcome.

4.6 Documentation

4.6.1 Material Quality Control Certificates

The quality control certificates pertaining to raw materials and manufactured FML rolls required in Sections 2.1 and 2.2 shall be provided by the FML Manufacturer to the Monitor prior to installation. The Monitor shall review the test results for completeness and for compliance with the required minimum properties for both the raw materials and manufactured FML rolls. Materials and rolls which are in non-compliance with the minimum required properties shall be rejected.

4.6.2 Surface Preparation Certificate

The FML Installer shall provide the certification of acceptance of surface preparation to the Monitor prior to any FML installation. Thereafter the FML Installer shall provide the Monitor written acceptance daily for the surface to be covered by FML in that days operations.

4.6.3 Daily Fabrication Reports

The FML Fabricator shall provide the Monitor with daily reports addressing: (i) the total amount of FML seamed; (ii) identifiers of rolls and fabricated blankets; (iii) quality control tests of materials used during the day; (iv) seaming equipment and products used; (v) names of seamers; and (vi) seam testing performed. The Monitor shall visit the FML Fabricator's plant and independently record observations of daily fabrication activities, including all testing performed.

4.6.4 Daily Field Installation Reports

The FML Installer shall provide the Monitor with daily reports of: (i) the total amount and location of FML placed; (ii) total amount and location of seams completed and seamer and units used; (iii) changes in layout drawings; (iv) results of test seams; (v) location and results of non-destructive testing; (vi) location and results of repairs and; (vii) location of destructive test samples.

The Monitor shall record daily all activities of the FML installation, which shall include but not be limited to:

- receipt of the written daily acceptance of surface preparation from the FML Installer;

- observations of all FML placement activities and record of defects caused during transportation and handling;

- observations of test seams, including seaming unit number or identification of adhesive products, names of seamers, weather conditions and results;

- observations of anchor trench excavation, backfilling and compaction;

- observations of field seaming operations, including weather conditions, cleaning, overlaps, rate of seaming, names of seamers and units used;

- observations of seams around appurtenances, and connection to appurtenances;

- observations of non-destructive seam testing, including testing location, location of defects and testing unit used;

- observations of repairs and retesting, including locations, name of repairer and seaming equipment or product used.

5. PERFORMANCE REQUIREMENTS AND ACCEPTANCE OF INSTALLATION

5.1 Guarantees

The FML Manufacturer shall guarantee the FML materials to be free of defects for a period of __ years after manufacture.

The FML Fabricator shall guarantee the factory seams to be free of defects for a period of __ years after fabrication.

The FML Installer shall guarantee the installed FML and field seams to be free of defects for a period of __ years after installation.

5.2 Performance Expectations

It is expected that the FML installation will perform satisfactorily for a period of not less than __ years. The intent of the FML is to minimize the migration of fluids to the adjacent subsurface soils and to ground water and surface water. Performance of the FML will be partially evaluated by observations and testing of the long term monitoring system.

5.3 Long Term Monitoring

5.3.1 Exterior Monitoring System

It shall be the responsibility of the Owner or Owner's representative to observe and test monitor wells exterior to the cell or impoundment area for compliance with the permitted monitoring program. The presence of significant levels of contaminants in these exterior monitoring wells may be judged to indicate non-performance of the FML installation.

5.3.2 Leak Detection System

If the cell or impoundment design incorporates a leak detection system below or outside of the FML, it shall be the responsibility of the Owner or Owner's representative to monitor the leak detection system at regular intervals. Detection of leaks by the leak detection system may be judged to indicate non-performance of the FML installation.

5.3.3 Leachate Collection System (Specific to Land Disposal Cells and Waste Piles)

If a leachate collection system is incorporated into the design, it shall be the responsibility of the Owner or Owner's representative to monitor the leachate collection system and remove leachate at design levels or designated intervals. Failure to maintain design levels or pumping intervals may negate FML performance guarantees.

5.3.4 Coupon Monitoring Program

A coupon monitoring program shall be a part of the long term monitoring of durability of the FML and FML seams. Coupons (small samples of the FML with and

without seam) shall be buried at the disposal site under the same construction conditions and shall be placed for ready retrieval at construction intervals to be determined by the Monitor.

5.4 FML Liner Acceptance

The FML liner shall be accepted by the Monitor when: (i) the installation is finished; (ii) all documentation of installation is completed; and (iii) verification of the adequacy of all field seams and repairs, and associated testing is complete.

A passing test seam shall be an indicator of the adequacy of the seaming unit and seamer working under prevailing site conditions, but not necessarily an indicator of seam adequacy. A passing non-destructive test of seams and repairs shall be taken to indicate the adequacy of field seams and repairs. If the laboratory tests of the field test seams fail, they shall be taken as an indicator of the possible inadequacy of the entire seamed length corresponding to the test seam. Destructive test portions shall then be taken by the FML Installer at locations suggested by the Monitor and the same laboratory tests required of test seams shall be performed. Passing tests shall be taken as an indicator of adequate seams. Failing tests shall be an indicator of non-adequate seams and all seams represented by the destructive test location shall be repaired with a cap-strip. The cap-strip shall be non-destructively tested and repaired, as required, until adequacy of the seams is achieved.

NOTES

Note 1 Table 1 should list the required properties of the FML, as determined by the Designer. Table 1 can be presented in a way similar to the tables of material properties presented in the NSF proposed standards.

Note 2 FML, such as 10 mil polyethylene, or other available FML may be used for temporary protection. A temporary FML should be overlapped 0.3 m (1 ft) and does not need to be seamed. The temporary FML may remain in place under the design FML. Crack repairs may consist of re-wetting, if a sufficient time is available for crack healing, or brooming dry powdered bentonite onto the soil surface to fill the cracks.

Note 3 In general, seams should be oriented parallel to line of the maximum slope. In corners and odd shaped geometric locations, the total length of field seams should be minimized. No seams should be placed at the toe but should be a minimum of 1.5 m (5 ft) away from the toe toward the inside of the cell or impoundment.

Note 4 Additional, loosely placed FML or geotextile sections may create a potential path for liquids between the FML and the supporting soil, which may be detrimental, especially if the supporting soil is a liner.

Note 5 Specifications regarding geotextiles (including plastic nets) used as drains should be prepared by the Designer.

APPENDIX

DEFINITION OF TERMS

Designer	- The organization or person who generated the design drawings and plans of the FML system including the supporting soil.
Earthwork Constructor	- The organization who is responsible for the preparation of the surface on which the FML is to be installed; also the party responsible for placing the granular materials over the installed FML.
FML Fabricator	- The organization responsible for production of FML blankets from FML rolls.
FML Installer	- The organization responsible for field unrolling, placing, seaming and other site aspects of the FML construction.
FML Manufacturer	- The organization responsible for production of FML rolls from raw materials.
Inspector	- A person who observes the FML construction but is not responsible for the monitoring, testing or documentation.
Monitor	- The organization or person independent of the FML Manufacturer, Fabricator and Installer that is responsible for observing and documenting most activities and testing and approving certain other activities relating to FML construction.
Owner	- The organization or person that owns the hazardous waste disposal facility.
Regulatory Authority	- The organization responsible for issuing a permit for the completed waste disposal facility.
Specifier	- The organization or person who generated the specifications for the FML construction.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-10

Weston Designers, Consultants: Amir A. Metry TRW: John F. Metzger
West Chester, PA 215-692-3030

January 31, 1983

Summary

- There is often a conflict between developing a "real world" solution and meeting a regulatory requirement. The most suitable approach is to use the best possible design without regard to artificially set performance standards.

- No guarantee can be made that an engineered system will perform adequately over a very long design life in excess of perhaps 20 years. Even where every conceivable precaution is taken, including extensive overdesign, there is an inherent statistical risk that cannot be overcome completely.

- Liner compatibility tests may not correlate well with field conditions. The tests are, however, useful for comparative ranking of candidate liners for specific applications.

Background

Weston has a number of facilities in the design and construction phase for disposal of hazardous wastes or low level nuclear wastes. Dr. Metry has worked directly with many of these and other facilities, and has considerable field experience on liner design. Because of a time constraint, the discussion with Dr. Metry was very brief and primarily centered on the most relevant and controversial issues pertaining to liner installation.

Liner Installation

- There is a certain statistical risk associated with every liner system such that a facility cannot be developed that will succeed under all circumstances. However, catastrophic failures can be largely eliminated.

- Most obvious failures occur within the first several years after a facility is constructed, and many of these result directly from inadequate design and inadequate quality control during installation. However, while any initial absence of failure provides no measure of the probability of failure over a future period, this can provide some assurance that there are no gross inadequacies in the system.

- While compatibility test results rarely correlate well with field conditions, these tests are a useful tool to establish general, comparative rankings between candidate liner materials. Better results can be had by lengthening the period of the test, but cost considerations nearly always constrain the time period to something much less than desired.

- A geotextile can be used where the liner requires additional structural support. This approach also permits better analysis of the adequacy of the various materials of the liner system to carry out the functions assigned to or expected from them.

- The preferred method of field seaming is by application of heat to the overlapped panels with an extrudate sandwiched in between. Adhesive seams using solvents are less desirable because of possible excessive solvent on the sheets which are being joined.

Liner Caps

- A typical cap system might involve the following successive layers on top of the waste pile: soil, geotextile, more soil, clay or geomembrane barrier, a thick geotextile drain, gravel (possibly 18 inches), and topsoil to support vegetation.

- Subsidence normally cannot be eliminated, only reduced by good practices of placing and compacting wastes into the facility.

- It is probably not possible, nor is it always desirable, to construct a cap requiring no maintenance. A more economical approach might be to construct the cap to last a short period and replace it repeatedly as needed.

- There can be some conflict between developing a "real world" solution and meeting a regulatory requirement. Construction of caps provides a suitable example. At a nuclear waste disposal facility, a cap was required to last 1000 years. No such performance guarantee is possible under any circumstances, but in this case, the cap could be developed to have an extraordinary, though not fully known, service life. This was possible because the contained material was nearly homogeneous and could be stabilized to greatly minimize subsidence.

- A larger market demand is expected for cover systems than for bottom liners because of Superfund-related remedial work being done at old dump sites.

Perspectives on Regulations

- The preamble to EPA's interim final land disposal regulations establishes the appropriate philosophy. It correctly asserts industry's respon-

sibility to dispose of their waste materials in an environmentally acceptable manner, but equally important, places a time limit on that responsibility.

- Performance standards are a good approach to regulating facilities because failures can be reasonably defined. Most of the requirements of performance standards would be site-specific, but some reasonable, general requirements might include:

  - Dye testing of the facility before it begins operation (or by use of some other tracer).
  - A structure paralleling the NPDES system for surface waters except that, in this case, compliance would be determined by a system of monitoring wells (although it is important to note that leachate can unexpectedly bypass monitoring wells).

- All parties involved in developing a land disposal facility are partially liable for its performance. However, court interpretation of liability has most often been by the "deep pockets" philosophy - the party having the most money is assigned the principal burden of payment.

- EPA sometimes sets goals that are unattainable. The only option for design engineers then is to develop the best possible system regardless of how it compares with some ideal or otherwise artificially set goals.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-11

Slurry Systems: Frank Zlamal
Gary, IN 219-949-0561

TRW: Masood Ghassemi

2 February 1983

Summary

- Laboratory test results indicate that even the so-called contaminant-resistant bentonite is an inadequate liner material for hazardous wastes. Prolonged contact with leachate results in gradual increase in permeability and hence, ultimate failure.

- Provided that it is designed and constructed properly, bentonite is an excellent material for lining potable water impoundments (where the harsh leachate conditions are absent).

- Asphalt emulsion slurry walls have proven very effective in containing lateral escape of pollutants from hazardous waste disposal sites. Several large-scale systems handling chlorinated hydrocarbon, pesticide manufacturing and other hazardous wastes are in successful operation.

- R&D effort at the company has resulted in the development of a soon-to-be marketed asphalt emulsion spray-on liner system which, based on laboratory tests, is believed to be superior to most currently available flexible membrane liners. The spray-on system will consist of two 1/16-inch polyurethane layers which are sprayed onto a fiberglass mesh support reinforcement. The two liner layers are separated with a layer of porous material for the purpose of leachate collection and removal. The elimination of the field seams is considered the single big advantage of the spray-on system.

- Educating customers to use competent designers and engineers and to demand quality work is a better approach to ensuring liner performance than regulations which cannot be made specific enough to cover the spectrum of field conditions requiring site-specific solutions. In the past, many of the EPA regulations have been written by individuals who have lacked the necessary technical background and who generally do not stay on an assignment long enough to gain experience and to become fully familiar with a specific subject matter.

- R&D effort should emphasize development of a better understanding of the mechanism of interactions between bentonite and heavy metals and organics in the leachate.

Background

Slurry Systems, a division of Thatcher Engineering, provides design and construction/installation services for bentonite liners for potable water impoundments and asphalt emulsion slurry walls for hazardous waste disposal sites. Slurry Systems had sales of about $3 million last year and expects higher sales this year. The annual sales for the parent company, Thatcher Engineering, are about $20 million. Slurry Systems has branch offices/licensees at five different locations in the U.S., and in two locations in Canada. The company has been in business since 1974 and has considerable on-going R&D effort aimed at developing new formulations and equipment for slurry wall and liner applications. It has developed a special urethane spray-on liner formulation which it expects to actively market in the future and which it believes will prove superior to the present-day factory-fabricated, field-installed flexible membrane liners. The company prefers to be responsible for both design and installation as a means of providing better assurance for the good performance of the final product and, hence, reducing its potential liability.

The objective of this interview, which was carried out via telephone, was to expand the data base on clay and admix liners. The following topics were discussed: bentonite liners, slurry walls, asphalt emulsion spray-on liners, perspectives on regulations, and R&D needs.

Bentonite As a Liner Material

- Based on laboratory tests conducted by Slurry Systems, bentonite is not considered a suitable liner material for hazardous waste disposal facilities. Regardless of pretreatment to impart contaminant resistance properties, the treated bentonite will not withstand, over the long term, the harsh leachate conditions. Laboratory tests in which bentonite treated with carboxy methyl cellulose was kept in contact with actual leachate having a pH of 5.2 indicated a gradual loss of permeability after 3 to 4 years. These and similar tests in which bentonites from major commercial suppliers have been used indicate that the increase in permeability is "just a matter of time". Slurry Systems thus questions the statements and data presented by certain bentonite suppliers indicating that bentonite treated with polymeric (e.g., methyl, ethyl, or higher polymers) and other proprietary formulations will withstand extended contacts with actual or simulated leachates without loss of impermeability. Even though Slurry Systems would stand to benefit from any large-scale use of bentonite as a liner material, it will not recommend or use bentonite for lining hazardous waste disposal sites.

- Based on laboratory tests, it is postulated that the carbonic and organic acids present in the leachate cause the release of adsorbed water, and hence, collapse of the bentonite platelets and increase in

permeability. The test results also indicate that chlorinated hydrocarbons and aromatic compounds such as benzene and its derivatives are most destructive to the bentonite structure. Higher valency compounds such as sulfate and sulfite also promote degradation of bentonite (but not of kaolonite or illite which do not expand to the same extent as sodium montmorillonite).

- Bentonite can provide an effective liner material for potable water impoundments where harsh leachate conditions of disposal sites are non-existent. Slurry Systems has extensive experience in the use of bentonite for this purpose, and has developed and patented special machines for installing such bentonite liners.

- Bentonite liners for potable water impoundments should be designed for the most permeable conditions existing in the support soil at the site. Typically, 2.7 lb of bentonite per square foot is mixed with the topsoil of $K = 1 \times 10^{-4} \leq$ cm/sec, and compacted to a depth of 6 inches. If the topsoil is not suitable (e.g., due to high organic content), clean soil (or preferably sand) brought in from off-site can be used in preparing the bentonite admixture. Using special machines, fresh water is metered in to establish proper moisture level (14-16 percent) during mixing. Compaction is very critical to liner performance and achievement of a 90 percent Proctor density is considered desirable.

Asphalt Emulsion Slurry Walls

- When natural geological substrata provide an effective barrier against downward (but not lateral) movement of pollutants at a disposal site, the lateral pollutant migration can be arrested via slurry walls constructed around a disposal site. Slurry Systems has successfully used asphalt emulsion slurry walls for such a purpose in several large-scale applications. The formulation consists of a minimum of 30 percent asphalt emulsion, minus 60 mesh graded material, anionic surfactants and other proprietary additives. This slurry, which sets in 4 to 6 hours, has been found to exhibit excellent chemical compatibility properties both in laboratory tests and in full-scale applications. In a laboratory test, a 4-inch thick column of asphalt emulsion slurry was placed under a 40-inch column of free-standing gasoline for more than one year with no gasoline detected as having passed through the test section.

- To be effective, the slurry wall should extend down to and make contact with the bottom liner (the natural clay). The slurry wall thus may be as much as 100 feet deep, although 40 to 50 feet have been more common in cases designed by Slurry Systems. The construction of the asphalt emulsion slurry wall does not require digging (a substantial advantage), and the soil is merely displaced in-situ using special

machines which deliver the slurry behind a beam operated under 25 tons of force. The width of the slurry wall is usually between 3 to 6 inches.

- The following three large-scale asphalt emulsion slurry walls, which have been constructed by Slurry Systems, have performed very successfully:

  - A site in suburban Detroit handling chlorinated hydrocarbon waste. This site is owned and operated by Chemical Recovery Company.
  - A "Class-II" hazardous waste disposal site in Pasadena, Texas. This site is owned and operated by Western Refuse of Texas.
  - A liquid waste containment site in Richmond, California, for Chevron Chemical Company's Ortho Division. This site, which consists of 5 lagoons receiving pesticide manufacturing wastes, has been surrounded by a single slurry wall. To date, the data from monitoring wells have indicated very satisfactory performance. (For further information on this site, contact Mr. Heino Jogis of Chevron at 415-231-4453.)

Asphalt Emulsion Spray-on Liners

- Although not yet a marketed technology/product of Slurry Systems, the company has carried out R&D effort, including extensive testing, and has developed an asphalt emulsion spray-on liner which it considers superior to most currently available flexible membrane liners. The special formulation has, as its ingredients, elastomers, dilutors, fillers, urethane, polybutylene, and a number of other proprietary additives which have been developed.

- The following installation procedures are recommended for the asphalt emulsion spray-on liner:

  - Excavate supporting soil as necessary and compact to about 80 percent proctor density.
  - Spread a fiberglass mesh on the top of the prepared surface.
  - Spray on a liner layer of about 1/16-inch thick onto the fiberglass reinforcement.
  - Place 18 inches to 2 feet of graded material (e.g., sand with permeability of about 10^{-3} cm/sec) which will also constitute the leachate collection system and will contain the necessary piping.
  - Place a second layer of fiberglass mesh on top of the graded material and spray on a second coat (1/16-inch thick) of liner onto the fiberglass reinforcement.
  - Cover the top liner with about 6 inches of soil.

- Among the advantages claimed for the spray-on system are the following:
  - Elimination of field seaming which has been a major installation problem and the cause of most failures with other flexible membrane liners (in the spray-on system, the fiberglass mesh widths are overlapped by 6 inches).
  - Quick setting properties; the spray-on material sets in about 1/2 hour.
  - Resistance to degradation by sunlight and chemical action. In a laboratory test, a 1-inch thick specimen has been kept submerged in a gasoline/naphtha mixture for over one year with no noticeable change in color to indicate degradation.
  - Excellent puncture resistance property. In small scale tests, operation of the equipment on the liner has caused no apparent damage. Tests have also indicated a puncture resistancy of about 250 lb per square inch.

Perspectives on Regulations

- Educating customers to use competent designers and installers and to demand quality work is a far better approach to ensuring adequate liner performance than issuing more bureaucratic regulations. No regulations can be responsive to the wide range of site-specific conditions which are encountered in practice.

- A major problem with the EPA regulations in the past has been that they were written by administrative personnel who lacked experience and were not fully familiar with the "real world" problems and the available approaches for addressing such problems. There is also a very high staff turn-over at regulatory agencies, and this prevents the individuals drafting regulations to accumulate and apply experience in connection with a specific subject matter.

Research and Development Needs

- Reflecting the interest of Slurry Systems, R&D efforts are suggested for assessing the impact of heavy metals and aromatics on properties of bentonite, including the elucidation of the mechanism and chemistry involved.

Miscellaneous

- Mr. Zlamal indicated that he will forward to TRW, for use in the subject study, laboratory test results and technical data to support the claims and assertions discussed in this interview report. (Some research materials have been mailed to TRW.)

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-12

B.F. Goodrich, : T.R. Ward TRW: John F. Metzger
Fabricated Polymers Division 614-373-6611
Marietta, OH

February 4, 1983

Summary

- Most installation contractors use unskilled workers for field operations, including constructing seams. Few problems result though because while the work must be done exactly, it is not difficult and can be quickly learned using skilled supervision.

- No method of checking field seams is completely adequate. Nondestructive tests such as by the vacuum method or air lance give good results, but these only indicate the seal and not the seam strength. To test for seam strength, a sample of the material must be taken, but this then requires a patch whose integrity is never fully certain.

- Due to potential liability, the manufacturer of synthetic membranes has an interest in ensuring adequate use of his product. However, this can be frustrated by the general lack of information that is often available for a particular site and the lack of design expertise often represented on the manufacturer's staff. Probably the best approach is to deal with reputable firms as much as possible.

Background

B.F. Goodrich manufactures, fabricates, and installs reinforced CPE and Hypalon; and manufactures, subcontracts fabrication, and installs PVC and non-reinforced CPE. There are a number of advantages for a single company to handle the full range of liner operations; however, the overall industry is highly competitive, requiring Goodrich to supply fabricators or installation contractors other than their own.

The purpose of the interview was to determine the company's perspectives on installation problems associated with synthetic membrane liners, including technical and non-technical problems.

Perspectives on Liner Installation Problems

- Each land disposal project can develop its own unique installation problems, many of which cannot be anticipated. Therefore, individuals

with installation expertise are needed on-site to address problems as they develop. The attitude of workers involved in the installation is likewise important.

- A few firms that both fabricate and install liners use the same personnel for both operations. However, most firms install liners using unskilled workers that are locally available. Due to high transportation costs and the fluctuating availability of installation jobs, no other approach to doing business is cost competitive.

- Unskilled workers must be closely attended to initially. But the field operations are not difficult, and once trained, the laborers generally do a good job. The capability of the foreman to communicate with his workers is particularly important for ensuring an adequate job.

- Most field seams are made by an adhesive method, except HDPE which is made by applying heat to the overlapped sheets with an extrudate of the liner material sandwiched in between. Weather conditions must always be considered during seaming operations. Some adhesives will blush when the humidity is high, and temperature can cause the solvent to volatilize at a less than optimal rate. If the ambient temperature is too cold, the seam may set too slowly; if too hot, the solvent may evaporate too quickly, resulting in too little residence time for the seam to "bite" deep enough into the two materials.

- While factory seams are generally one inch in width, field seams are made wider, usually 4 to 6 inches, to increase the opportunity for a continuous connection to be made.

- Several methods should be used to check field seams. An air lance only establishes whether there is a leak across the interface. Structural weaknesses are not detected. Cut samples tested for peel and shear strength can more fully evaluate the seams, but only on a limited spot basis since this is a destructive test method, and the integrity of a patch is as uncertain as the integrity of the seam. To minimize the number of patches, cut samples are sometimes taken at the end of the sheet. If the seaming crews know where the sample will be taken, they may do an especially careful job in that section. A sampling program should be developed to provide a representative sampling.

- All methods of testing field seams provide some assurance of their integrity, but none is fool-proof. Simple visual inspection can provide an excellent check on more sophisticated test methods.

- Puckers, wrinkles, and all questionable areas within a seam should be patched. It is common practice, however, to leave wrinkles in the liner to allow for contraction and compaction.

- Precautions should be taken where nutgrass is indigenuous to the region. This plant can grow through most liners and must be eliminated by sterilizing the ground below the facility.

- Geotextiles can be useful in areas where there are problem soils.

- Some failures blamed on inadequate installation are actually the result of operating practices that were not designed for. A common example is emergency discharge of chemicals during a plant upset.

Installation Problems Related to Institutional Relationships Between Involved Parties

- Manufacturers of synthetic membranes can be somewhat vulnerable to claims of liability because often the manufacturer is the only involved party that has large assets worth suing for. Therefore, the manufacturer's best interests are served by monitoring his product to ensure no abuses occur. If there is a high enough potential for misuse, the manufacturer may choose to not bid the job. However, there is a delicate balance between the competing interests of maximizing profits by increased sales and taking reasonable precautions to avoid liability or other problems at a future time.

- Goodrich benefits by its vertical organization of manufacturer/fabricator/installer in several ways. Most importantly, the company is less susceptible to legal claims and can better defend itself against these because tighter control can be maintained on operations that are normally beyond the company's influence. Each of the separate operating sections communicates well, and information concerning the problems at a particular job site are therefore available first-hand.

- Goodrich fabricates only reinforced CPE and reinforced Hypalon. The following quality control checks are made:

  - Sections of joined panels are tested at the start of the seaming operation because this is the time when the process is most likely to not be adjusted properly.
  - Three tests are made on seam samples. The fabric to fabric overlap of the joined sheets is inspected, checking that there is a minimum of one-inch scrim overlap. Shear and peel strength are tested.
  - A final check of all seams is made by air lancing.

- Goodrich also subcontracts fabrication of its liners to other companies. Samples of the seams are submitted for testing. The frequency depends upon the fabricators' experience, equipment, and the use of the liner.

- While Goodrich manufactures, fabricates or subcontracts fabrication, and installs liners, roll goods are also sold to fabricator/installers

and fabricated blankets are also sold to installers. Goodrich often encourages its larger volume roll goods customers to become approved fabrication subcontractors. Goodrich can then work more closely to insure adequate quality control. When fabricated blankets are sold directly to an installation contractor, there is generally less opportunity to influence the use. Most installation contractors, however, are receptive to manufacturers input.

- Goodrich may request the owner of a proposed facility to make design changes if a high probability of failure is suspected. These judgements, however, can be difficult to make. Site-specific information, for example geological data, is often not readily available. Unless a site is grossly inadequate, a judgement has to be based on less precise information. Also, Goodrich often has only limited design expertise in comparison with consulting engineers making Goodrich's position difficult to argue. But not all consultants are aware of all design factors. For example, it is not unusual to request a liner having characteristics that do not exist. Therefore, if the design is judged seriously inadequate and if changes are not agreed to, Goodrich may choose not to bid it.

- On large installations, the liner installation is generally done under subcontract to a general contractor who has been awarded the entire project (including earthwork). In some cases, the general contractor may elect to handle the installation. Goodrich will provide technical support including supervision if requested. In rarer cases, liner material has been supplied to a general contractor with no support other than written instructions. Such an arrangement has not always worked well.

Miscellaneous

- Calendered products cannot be guaranteed to be free of pinholes. The number depends on the manufacturing process used and the materials. However, the materials that are most susceptible to pinholes are the same materials most commonly laminated. It is unlikely that pinholes of adjacent plies will align to form a continuous path for leachate or other fluids to cross.

- While no hard data can be cited, it is believed that loss of leachate or other fluids through pinholes is insignificant, and that the pinhole issue itself is therefore not significant as well.

- Caps are always subject to pressures of subsidence. However, the main purpose of a cap is usually to keep moisture out of the waste pile to minimize leachate generation. Caps usually perform well if the subsidence is not dramatic.

- Compatibility testing is done by Goodrich as part of its research and development and in support of customers. Most tests involve exposing liner materials to varying concentrations of standard chemical solutions such as acids, bases, and selected organic solvents. Immersion tests using a sample of the customer's synthesized or actual wastes are also done. An actual waste sample is preferred and is sometimes the only reliable approach when the composition of the waste is not known. Unknown waste compositions are often encountered, and this creates problem in assessing compatibility.

- Most companies have similar programs for bringing new products onto the market. However, while extensive testing is involved, every field condition cannot be anticipated nor simulated.

- The only warranty issued by Goodrich is for weathering of Hypalon. No other guarantee is practical since the end use service conditions can never be completely guaranteed.

- The overall regulation of hazardous wastes is appropriate but there is a tendency to adopt unreasonable standards (as was the parallel case for wastewater where zero discharge was made a goal). A more realistic determination is needed of goals that are both attainable and represent an appropriate balance between risk and cost efficiency.

- Performance standards for hazardous waste facilities is probably an unworkable approach. The boundaries of a properly functioning system would have to be defined arbitrarily. An unreasonable financial risk would then be presented to a contractor trying to construct a system because many of the factors contributing to failure, including operation, are outside his control. Bids would be made strictly on the basis of risk management, and the average bid price would increase dramatically. Many reputable firms would likely withdraw from the liner business.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-13

Pantasote, Inc.: Larry Kamp
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TRW: John F. Metzger

February 2, 1983

Summary

- A manufacturer of flexible membrane liners (FMLs) has a clear interest to involve himself fully with the customer and all other parties using his product. Warranties and court decisions have largely placed responsibility for liner failures on the manufacturer, requiring him to protect himself.

- Pinholes can form by several mechanisms during calendering of a liner material. Recycling scrap material is one mechanism, but this practice is not widespread and may even be acceptable in very limited applications (nonhazardous waste facilities) if the scrim is ground finely enough. There are many check points during manufacturing and subsequent fabrication and installation to patch the major pinholes.

- General (dirt) contractors should not be permitted to handle the installation of a liner. Where this has been permitted, very inadequate jobs have often resulted, including wholesale substitution of materials.

Background

Pantasote manufactures several types of flexible membrane liners (FML) for lining land disposal facilities and surface impoundments. Their principal products are PVC, reinforced Hypalon, CPE, and CPR, which are the same materials constituting approximately 80 to 90 percent of the synthetic liner market. These products are sold directly to a fabricator or to the general contractor for a facility. The purpose of the interview was to determine Pantasote's perspectives on the problems responsible for inadequate installation of a liner system.

Perspectives on the Manufacturer's Role in the Land Disposal Project

- Successful installation of an FML requires proper handling of the material by all parties. Some of these responsibilities are established by warranties. The following are typical:

  - A weathering warranty is issued by the manufacturer generally for a period of 20 years on a pro rata basis. It addresses the resistance of the exposed material, such as on berms, to ambient conditions.

- A construction warranty is issued by the fabricator and/or installer. It is for workmanship, usually for a period of 3 years.
- A soil burial warranty has been more recently included to guarantee that the material will not degrade while buried. This is especially important for PVC liners because the plasticizer is biodegradable.

Depending on the job, the manufacturer's warranties are issued to either the fabricator/installer or to the job site directly.

- The fabricator's and installation contractor's liability are often limited by even more than the typical workmanship warranty. Failure of land disposal sites and the cause-effect connections are so poorly understood that assignment of liability can become an arbitrary exercise. Fabricators and installation contractors are usually small businesses having a small net worth. Manufacturers, however, typically have the largest financial resources by which to make restitution, and they are therefore largely blamed in any cases of failure. The once prevailing philosophy that the manufacturer is no longer responsible for his product once it is delivered to another party no longer applies.

- To avoid later problems, manufacturers such as Pantasote work closely with fabricators, installation contractors, and end users, but in reality the manufacturer has only limited control of his product once the fabricator and/or installer takes delivery. Installers are, therefore, largely relied upon on the basis of their past performance. If a relatively new installer is involved, the manufacturer may have a representative on-site at all times. Also, Pantasote always has the opportunity to comment on the fabricator's or installer's specifications. The ultimate form of control is not selling the product, and while this is always an option, it is rarely exercised due to the competing interest of maximizing company profits. (It is fully legal to withhold a product from a customer, so long as the same price is charged to all who are permitted to purchase it.)

- Another form of control available to a manufacturer is to develop close ties with reputable installation contractors, including exchanging information on business leads.

- Before bidding on a job, issuing a warranty for a product, or delivering it for sale, complete information is needed on the material's end use. In some instances, a potential customer may choose to divulge process information only to the company awarded the job. Then a bid is made on the condition that all needed information will be supplied before delivery of the material.

- As support to customers, Pantasote has one full man doing immersion studies. For landfill applications, the leachate characteristics for compatibility study are based on the reasonably well established values

in the literature. For impoundments, the waste characteristics are supplied directly by the customer. This information is usually available since EPA normally forces industries to characterize their waste streams. If not available, Pantasote may work with the customer to develop the needed information from consideration of the contributing industrial processes.

- Industrial waste streams intended for impoundment are often characterized inadequately by an inventory of ions. This provides no indication of the predominant form of the various chemical species.

- Most of Pantasote's laboratory compatibility testing is done at room temperature and 158°F. The factor of time is accelerated so that tests can be completed in a reasonable period, but this may well worsen the already sensitive correlation with field conditions. As a consequence, some liner materials that are actually suitable for the application may be eliminated from further consideration.

Perspectives on Pinholes in Synthetic Liner Sheets

- Recycling scrap during the manufacture of a reinforced liner can cause pinholes. These often develop by small pieces of scrim penetrating the surface of the material. Then, if the liquid being contained is corrosive enough, the protruding scrim will dissolve, creating a small hole in its place. The practice of recycling scrap should probably be of concern only for hazardous waste applications. Only then might the public health be at risk. Also, if the recycled scrim is ground fine enough, no problem may exist for any application. Only one manufacturer is known to actively recycle scrap, but others are likely to be tempted due to the significant cost savings involved. To control the practice, a size limitation can be placed on the ground scrim that can be passed through a calender, and NSF has banned the practice altogether in their proposed standards.

- Other sources of pinholes are collapsed blisters during calendering (e.g., cold flow of material) and contamination of the product, including by dust. However, pinholes are not much of a problem. For laminated products, the pinholes in separate plies would have to align to provide a path for leachate to pass through. Also, currently used manufacturing equipment nearly eliminates all but the smallest pinholes. For example, with the extrusion method, contaminants that could form pinholes are removed from the molten polymer mix by a #100 screen.

- "Fly-by-night" firms utilizing poor quality control may be the principal source of materials having pinholes.

- There are many check points to detect pinholes or even more serious problems. A light station over the calendering equipment checks the

sheet as it is produced. Rolls are sampled and likewise put over lights to detect discontinuities. Finally, the fabricator and installing contractors inspect the materials they receive.

Installation Practices Crucial to Developing an Adequate Facility

- Development of an adequate lined installation involves many factors, but probably most important of these is the integrity of field seams and their technique of construction.

- Field seams must be made in agreement with the manufacturer's specifications; few changes are tolerable. Heat welds or adhesives are the most common method of seaming. Adhesives usually consist of the resin of the material to be bonded dissolved in a solvent. When the solvent evaporates, the seam becomes a continuous material.

- Contractors must not be permitted to substitute adhesives. In an extreme case, wall paper paste was used. In addition to their questionable bond strength, substituted adhesives are potentially incompatible with the waste.

- To ensure a good bond, the surfaces of the material to be seamed must be clean.

- A full program for testing all seams must be included for each job. It is good practice to test a cut sample at the end or elsewhere, but this is not sufficient in itself. Every foot of seam must also be checked by some method such as air lancing.

- There is often little distinction between an installation and a design problem. One such design problem may be an inadequate cover over the liner to protect it from heavy construction equipment. A layer approximately 2 feet thick is needed but even this may not be enough to protect the liner from dead standing turns by construction equipment. A study addressing heavy equipment on liners was made by the Army Corps of Engineers and presented at an EPA conference. Contact R. Landreth, EPA.

- Connections between the liner and concrete structures are another part of a land disposal facility that may be poorly designed so that adequate installation is effectively precluded. Here also, the distinction between an installation problem and a design problem may be slight; because even if the connections are well designed, the contractor may cut corners to lower costs. Properly made connections use a steel strap followed by caulking to ensure a seal. The thickness of the liner in contact with the concrete structure should be doubled to better resist the abrasion, but this is commonly omitted to reduce costs.

- The integrity and experience of the installation contractor are important for ensuring an adequate installation. But even reputable contractors may cut corners, and these are often selected in the worst possible place. It would generally be better to use a lower quality liner material (assuming it is compatible with the waste) than to compromise the design.

- No installation contractor has a staff of laborers, only field supervisors. All companies use local laborers, sometimes of the lowest quality, such as prisoners. The foreman's ability to motivate and instruct his crews can, therefore, be of key importance to ensuring an adequate installation job. The owner and other interested parties should, therefore, have inspectors on the job at all times.

- Dirt contractors sometimes try to double as installation contractors claiming suitable experience in this area. The result has on occasion been blatant substitution of materials and other disregard for proper procedures. An installation contractor should therefore always be used.

- Large installation contractors are generally preferred to the small firms. The availability of liner installation jobs fluctuates through wide cycles which large companies are better able to handle. However, there are enough small facilities being installed by small companies that this segment of the market cannot be overlooked by a manufacturer.

Perspectives on Regulations

- EPA personnel can be as knowledgeable about liners as anyone in the business, and are usually appreciative of the state-of-the-art. However, some local or state level input would also be helpful to ensure that the highly site-specific elements of a facility receive adequate consideration. A design checklist for local regulators to judge a project by might correct deficiencies in a project before it reaches a higher review level. Even having a city engineer approve a design before it is considered by EPA might improve designs.

- The end user is generally responsible to demonstrate that his proposed facility will not create an environmental or public health hazard. It is usually sufficient to cite a parallel facility as precedent. Otherwise, the owner must develop his own data base to secure the permits.

- A final "check off" of a constructed facility by a professional engineer is needed. All specifications should be checked a final time with special attention given to change-orders to ensure that none of these has resulted in compromised quality.

Miscellaneous

- Many sanitary landfills to date have been lined with PVC and have suffered some problems because of the biodegradable plasticizer in the material. Microbial attack on the surface facing the waste pile can be largely eliminated by placing a layer of sterilized sand over the liner. However, attack from the underside, especially if organic soils are present, is possible. Toxics, usually arsenic, should therefore be formulated directly into the PVC. A different additive is needed for exposed and unexposed liners. The appropriate test is ASTM G-21.

- Mechanisms of failure are poorly understood and should be studied with the support of EPA R&D money.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-14

Gulf Seal, Liquid Containment Specialists
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TRW: John F. Metzger

February 7, 1983

Summary

- Many installation problems result from poorly written job specifications. If written correctly, most bids would come in at about the same level. Use of the phrase "or equal" in material or procedural specifications in particular causes problems since it, in effect, opens the door to many substitutions.

- Quality control is imperative to an adequate installation job. However, owners do not show the same interest in construction quality of land disposal facilities as is generally expressed by owners of other facilities such as industrial plants. Quality control inspectors are often inept, getting in the way more than anything else.

- While local sources of labor are relied on for installation, some continuity is possible by using "camp followers". These are laborers who are willing to move from job to job, providing their own transportation and subsistence. Prevailing wage clauses in project specifications often provide enough incentive for "camp followers" to go long distances to a job site.

- A number of quality control checks is needed on the seaming operation, but one in particular that can be effective is to require the crews to make a test seam on scraps of material using the exact technique and equipment just used on the main liner. Cut samples of the seams should also be taken and laboratory tested.

Background

Gulf Seal is an installation contractor which handles many types of flexible membrane liner (FML) materials. The company represents a wealth of experience in dealing with field conditions and the various arrangements between involved parties at an installation job. The purpose of the interview was to obtain the company's perspectives on problems associated with installing FMLs.

General Perspectives on FML Installation Problems

- The attitude of owners creates many problems. Quality is claimed to be the factor of greatest importance, but cost nearly always controls the major decisions. Many owners are so cost-motivated that they would permit an obviously unqualified source to handle an installation if they came in with a lower bid.

- If the owner lacks technical expertise, he must be certain that his consultant is providing it. Many engineers do not have sufficient background to design an adequate facility; so, where lacking, they often solicit input from salesmen whose arguments are persuasive but not necessarily correct. Engineers should instead pay for technical input they need; however, they are very reluctant to dispense part of their fee when the information is seemingly available at no cost.

- Engineering drawings can also be deficient. Anchor trenches, for example, are often either overdesigned or underdesigned. This results sometimes from standard drawings and specifications being recycled from earlier projects and being included with no further consideration. The trenches, however, must be designed specific to the site, especially from the standpoint of climatic conditions such as wind expected at the site.

- Possibly no engineering business is as sloppy as that of FMLs and associated facilities. Owners should force liability for the design on the engineers. Rarely are engineering firms, however, held responsible.

- One major cause of inadequate installations is poorly written specifications. Many deficiencies could be cited. If written too oppressive, irresponsible firms are heavily favored because they are willing to guarantee anything, no matter how distant from reality. But most specifications are written too loose. Possibly the single feature causing the most trouble is the phrase "or equal" attached to material or installation specifications. This phrase ineffectuates any meaningful bid specifications and opens the door to every conceivable substitution of materials or techniques that can be rationalized by salesmen. Often the phrase is well intentioned to refer to the quality of a specific material, but owners usually permit a very broad interpretation to mean "equal materials". The phrase should be eliminated, and this does not constitute a restriction of trade.

- If a project were properly specified, most bids would come in about the same. The "or equal" phrase is largely responsible for the wide spread that often occurs.

- Several examples illustrate specific shortcomings that result directly from inadequately written design specifications:

- Connections between the liner and concrete structures are often specified as being according to the contractor's (or manufacturer's) recommendations. Gulf Seal does the following: galvanized iron and aluminum are never used in a water environment; all bolts and straps are oversized, of stainless steel construction, and closely spaced. However, this conservative (but appropriate) approach puts Gulf Seal at a competitive disadvantage to companies that utilize a far inferior approach.
- The liner connection requirements are typically no more than a sidestepping of specific requirements. Another example is soil sterilization. This is a primitive state-of-the-art as there is no truly effective way to kill all weeds permanently. However, this is not reflected in specifications. A guarantee may be required for a period of about 20 years that no weeds grow. This greatly exceeds the state-of-the-art, but plenty of irresponsible firms are willing to advance such a guarantee. Furthermore, while sterilization may be required, no minimum standard is given to indicate how it must be accomplished. Once again, the reputable firms may be underbid by others using inferior products and procedures.

- Despite the many opportunities for a reputable firm to be underbid by others using inferior approaches, good firms still sometimes qualify for jobs based on costs alone.

Installation Problems Related to Inadequate Quality Control

- Even when adequate specifications are written, they are often poorly followed. When bidding a project, many firms will ignore quality control specifications completely, knowing that they will not be strictly enforced. Some inspectors are willing to certify anything. It therefore becomes the job of the quality control program to force compliance.

- A surface impoundment constructed in the Southwest is a good example of a facility where good specifications were written but virtually ignored. For example, some of the field seams on the side slopes were constructed horizontally. Also, "fish mouths" in the liner were repaired by folding the material over and sealing rather than by cutting the section out and patching.

- Where guarantees are involved, the financial position of the firm must be considered. Long warranties are legitimate only if they can be backed.

- Quality control should include inspection of the manufacturer's and fabricator's operations.

- The quality control measures taken during installation are often fully inadequate. Inspectors representing the owner can be so incompetent

that they only get in the way: they fault good work and overlook bad. Any other craft endeavor would be inspected by a qualified individual. With land disposal facilities, however, a "shoe salesman" may be hired.

- The system has become so accustomed to shoddy practices that when an owner does provide high quality inspection personnel, many installers will increase the price believing that additional costs will be involved. Gulf Seal generally discounts their price when good inspection is available, since the presence of good knowledgeable inspectors makes the installation job much easier for Gulf Seal. Good inspectors are welcomed.

- Quality control applied to seaming operations is particularly important since this is an area especially prone to failure. Seams that may be strong in shear may be weak in peel, and peel tests should therefore be preferred as a quality control test. A peel test should be conducted several times daily at the leading edge of seaming operations.

- Two methods of seam testing are suggested. Random cut samples should be taken and laboratory tested. The resulting holes are easily patched. The other method is to "surprise" the seaming crews and require them to construct a seam on scrap material using the exact technique that was just being used on the liner. For example, if the weather is cool and the crew was not using a heat gun, no heat gun is permitted on the test strip. If the work was being done with a shadow cast on the seam or if dirty rags were being used, the same are to be used for the test seams. This test method gives a fairly representative indication of how well the seams are being constructed, and while the crew is constructing the test seam, a peel test can also be made on the main liner seal just completed.

- The labor used for many field operations is from local sources of generally unskilled workers. Close supervision is needed, especially on small jobs where there is not enough time for the learning curve to plateau. In all cases, turnover during the first few days can be high as some workers quit and others are run off the job. Training normally consists of practice on scrap materials. It is not difficult to differentiate between those workers interested in doing a good job and those who have no pride in their work.

- Many of the same laborers have been involved in several Gulf Seal projects in California. These "camp followers" follow the firm from job to job at their own transportation expense. This practice has worked well, mainly because by having some continuity in labor, complete retraining is not needed at every job. On several occasions these laborers have been transported to other states for critical jobs, in which case their transportation and living expenses are paid.

- Many projects involving federal monies have a prevailing wage clause; that is, a wage comparable to that paid unionized labor must be made no matter what the source of labor is. In these cases, local labor is still used, or preferably "camp followers" who have come from an earlier job. There are many advantages of using local sources of labor, including the following:

  - The liner installation industry is subject to widely fluctuating business cycles. By using local laborers, off-season periods are easily handled since workers are automatically laid off at the completion of a job. For the case of "camp followers", word of a new job can be easily spread.
  - Not all laborers used to date have been hard workers. Many problems associated with unions can, therefore, be avoided, including restrictive job descriptions. More pay does not necessarily correlate with harder or higher quality work.

Responsibility of Parties Other Than the Installer in Ensuring an Adequate Facility

- The manufacturer, fabricator, and end user play important roles in determining whether a facility performs as designed.

- The more reputable manufacturers exercise some control over the fabrication of their product and monitor its use downstream. Many others, however, sell roll stock with no regard for how it will be handled or used.

- The larger fabricators generally do quality work, but "fly-by-night" firms can be a problem.

- Once adequately constructed, the facility must be operated by the owner in accordance with its design. No changes in inputs to the facility or operating practices should be made without consultation with the design engineer.

- Inexperienced manufacturers should not be permitted to bid large projects or ones having otherwise sensitive conditions. Unfortunately, experience requirements given in project specifications can be easily circumvented.

- To reduce costs, some manufacturers have adjusted the formulation of their product, resulting sometimes in a material that is very similar to the original but differing, perhaps, in a few critical characteristics. One such change can be in blocking, which is the degree to which the material sticks to itself when folded. In extreme cases, blocking can result in failure by delamination. To minimize unauthorized changes in materials, mill specifications similar to those required in other industries might be effective. This program would consist mainly of a

guarantee that the product is identical to one produced on some earlier run. A sample of material would be submitted to the Design Engineer, and while its exact composition cannot be determined, it can be compared with a similar sample submitted from the earlier reference run.

Research and Development Needs

- There is no completely effective method of soil sterilization. Even where the best products are used, only a 90 percent effectiveness may result. While sterilization is not always required, this is still a suitable area for research.

- Probably more liners are destroyed by trapped gas than by any other single mechanism. Facilities underlaid by soils having high clay contents seem particularly susceptible. The interviewee has constructed two test ponds to study the many factors involved in gas venting, but this subject is too large to be handled by a single company. Research or support by EPA is needed. The following factors should be included:

  - The difference in response to gas build-up by reinforced and non-reinforced membranes.
  - The influence of conditions specific to a site, particularly climatic conditions.
  - The optimum bottom slope to permit gas transfer out of the facility.
  - The role of geotextile in gas venting. To what extent is it effective, particularly when it becomes saturated by water. Also, does the use of a geotextile permit more shallow bottom slopes.

Perspectives on Regulations

- The industry has been largely unsuccessful at setting its own standards, so EPA will have to fill the void. The result may well be standards that are unattainable; then industry will be forced to lobby heavily for a more realistic stance.

- While many issues related to liners are site-specific, some can still be addressed by EPA regulation, including the following:

  - Standardization of mixes and materials so that minimum compositions are stipulated for all products referred to by a particular trade name.
  - Test requirements for each liner material.
  - All aspects of earth covers.
  - Chemical compatibility testing.

- Performance standards on completed facilities may be worth considering for regulation, but this would require a definition of failure. Also, this approach would apply pressure on the owner when, in fact, pressure

applied on the Design Engineer might be much more effective since he has the major control of a facility. Realistic leak-rate standards for various lining systems are badly needed.

Miscellaneous

- Double-lined facilities provide the best liner design. On critical impoundments, the use of clay should be considered only for the lower lining where it can be shielded from the full hydrostatic head.

- HDPE is one of the most inert materials available. A form of it is commonly used in the container industry to hold pure chemicals, including organic solvents. However, HDPE is difficult to seam. Adhesive seams are poor, at best. Recently, welded seams have made this a viable FML.

- There are pinholes in every calendered product, although the effect of these is probably not serious. Part of the development of liner products has been in response to pinholes. Originally, a continuous material about 30 mil thick was produced, but to help minimize the effect of pinholes, a laminated product was manufactured of two plies of 15 mil thick material. When reinforced sheets were later fabricated, wicking was found to provide a hydraulic connection between pinholes in opposite sheets. Much of this was reduced by changing from a nylon scrim to the hydrophobic polyester scrim.

- CPE and CPER liner materials often present seaming and delamination problems. Perhaps the most useful role served by these materials is as competition to Hypalon.

- HDPE is probably the best synthetic material for a landfill FML since it is nearly chemically inert and can elongate up to 700% and, therefore, conform well with subsidence.

- Earth covers will stay on synthetic liners if the side slopes are constructed shallow enough, but such shallow slopes seldom occur.

- Some projects have specified different materials on the side slopes and bottom. However, many dissimilar synthetic materials cannot be seamed. On some projects, a combination of Hypalon and PVC is specified, with a buffer strip of CPE included between the two materials. However, this greatly complicates seaming operations since there can be five possible material combinations to seam.

- The following book was cited as a good reference, but in some need of update:

  - William B. Kays. Construction of Linings for Reservoirs, Tanks and Pollution Control Facilities. Wiley, 1977.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. A-15

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February 8, 1983

Summary

- A distinct advantage of asphaltic rubber over most other liner materials is that it can be formulated to have the exact characteristics needed by a specific job site. As a result, installation is preceded by an exhaustive program of testing mix formulations.

- Asphaltic rubber is applied by spraying. Since compaction is not required, steep side slopes can be accommodated so long as the material is applied in a stiff condition to prevent it from flowing before setting.

- Quality control is an important element of installation, but it is perhaps more easily handled than similar requirements for other liner materials since there are no seams. Separate layers or widths bond together to form a continuous material, completely free of seams. This characteristic also facilitates direct testing of the material since a sample can be taken and the hole patched with no evidence of repair.

Background

Arizona Refining Company is a wholly-owned subsidiary of the Union Oil Company and has been in business since 1938. Arizone Refining manufactures and installs liners made of asphaltic rubber, a mixture of asphalt, rubber, and extender compounds. This material has characteristics unlike other asphaltic products. Highway paving applications since the late 1960's and liner applications since about 1975 have all demonstrated this material's unusual strength and durability. The purpose of the interview was to obtain the company's perspectives on installation techniques and problems associated with asphaltic rubber in liner applications.

Characteristics of Asphaltic Rubber

- Asphaltic rubber is a combination of asphalt, rubber, and extender compounds. The rubber is usually from ground tires and is largely responsible for the material's tensile strength and deformation character-

istics, particularly rebound. The extenders are a by-product of lube oil manufacturing and are used to replace aromatics that the rubber sorbs out of the asphalt.

- Both the rubber and the extenders give asphaltic rubber unusual resistance to ultra violet (UV) radiation. Any asphalt exposed on the surface is largely degraded, but further decay is prevented by the rubber that shields lower layers. At a facility in Arizona, the Palo Verde Nuclear Generating Station, an asphaltic rubber liner has shown neither degradation nor cracks in direct exposure to the very high UV flux associated with the desert Southwest. Ozone resistance is also good. Some checking may occur on the surface but extends no deeper.

- Wind is not a problem during either installation of the liner or during later operation of the facility.

- Asphaltic rubber cannot be compared directly with other liner materials because no suitable tests have been devised to evaluate its characteristics. All current tests have been borrowed from those used on plastics, asphalts, or rubbers, but asphaltic rubber is unlike any of these materials. The key companies in the asphaltic rubber industry have agreed to some generic tests, but more precise standardization is not yet practiced.

- A major advantage of asphaltic rubber is that it can be formulated to accommodate the conditions at each site. The mix is designed using the following general approach. The conditions and stresses the liner will be exposed to are evaluated, such as the type of equipment that will operate over the liner, the stability of the base, and the exposure to chemicals and ambient conditions. These factors establish, approximately, the needed characteristics of the liner, such as cold temperature bend, softening, and elasticity; and from these, a suitable first combination of asphalt, rubber, and extenders can be made. From this starting point, trial formulations are laboratory tested to develop a mix with the exact characteristics needed. For a surface impoundment installed at the Palo Verde Nuclear Generating Station, 90 formulations were tested before the final mix was selected.

- While the exact mix of materials is different for each application, most are represented approximately by the following combination of materials:

  - 18 to 22 percent ground tires (the tires must have a minimum natural rubber content of 30 percent).
  - 10 percent extender.
  - 68 to 72 percent asphalt.

- Locally available sources of asphalt are always investigated initially when testing mix formulations, but if this material does not have the

necessary characteristics, asphalts may be shipped in for use or blending with local sources. A minimum of two rubber sources is also generally used to take advantage of the various characteristics of this material, particularly those of additives compounded in the tires. However, it is also important to use as few ingredients as possible to keep field operations simple. The logistics of transporting large volumes of materials and scheduling their timely arrival is greatly complicated by increasing the number of different materials involved.

- Long term performance can only be speculated. There is no long track record, but neither is there one for other liner materials. However, plenty of evidence supports an expected long term durability. For example, asphalt remains from certain applications in early Egyptian civilization. The Bureau of Reclamation has some asphaltic liners for canals and other potable water-related uses that have been buried for 50 years and are performing satisfactorily. While none of these applications simulate the corrosive environment possible in a landfill or surface impoundment, no evidence of incompatibility nor lack of durability has yet been found.

Installation

- The following layers are usually constructed in an asphaltic rubber-based liner system. If the base is irregular, it is built up with sand. In-situ soils are compacted to 95 percent of actual, maximum compaction (not theoretical), and no protrusions greater than 3/8 inch are permitted. The asphaltic rubber can be placed directly on any stable soil after a herbicide is added if needed for weed control. A cover layer 12 to 18 inches thick is placed over the liner to protect it from puncture by truck traffic.

- The asphaltic rubber is sprayed at 400 to 425^{o}F by a truck with an arm extending out the side. Two passes are made to build the necessary thickness. Adjacent widths of the material are overlapped 10 inches to ensure a good, continuous surface.

- Side slopes as steep as 1:1 have been lined, but slopes are generally restricted to 3:1 or less due to application problems. For steep slopes, a method of installing the liner has been developed utilizing a geotextile to provide additional strength to the material. The asphaltic rubber is applied to the geotextile and the slope by hand spraying the material in a highly viscous condition. However, this tends to increase the minimum application thickness, resulting in a thicker liner than needed and consequently increasing costs. The usual thickness on level surfaces of 150 to 200 mm must sometimes be increased to as thick as 350 mm on the slopes.

- Asphaltic rubber does not penetrate the subgrade when applied but does adhere to it. A tack coat of a cutback asphalt may be applied on side slopes to increase the bond.

- Asphaltic rubber liners have no seams. When properly applied, adjacent layers or widths form a continuous material. As additional insurance, a spread of cutback asphalt may be applied to the interface of adjacent layers.

- Inadequate design can lead to failure of any liner. No liner should be designed nor otherwise forced to perform as a structural member.

Quality Control During Installation

- Quality control is an important factor needed to ensure adequate installation of the material. This begins with compatibility testing. Arizona Refining tests asphaltic rubber on a long term basis with the material exposed to a wide variety of pure chemical solutions at various strengths. Before each project, the customer's waste stream is likewise tested. If deterioration is going to occur at all, it will generally be within the first 30 days of the test.

- Quality control tests during the actual installation are carried out in a mobile laboratory stationed at the job site.

- Sections of the liner are cut periodically, measured for thickness, and analyzed by laboratory tests such as cold temperature test and ring-and-ball softening test. The holes are easily patched by a specially compounded solution that, when applied, forms a continuous material.

- Quality control measures are the responsibility of several superintendents that are on-site at all times. One monitors the mixing operation and the application temperature. The rate of application is determined by measuring the tank volume before and after each pass with the truck. The taps on the spray bars are also checked to prevent plugging that would result in uneven application.

- A superintendent walks the liner daily to inspect it for irregularities. At one site, the subgrade was not properly prepared, and there were a number of protrusions through the liner. Repair crews cut the liner at all protrusions, repaired the subgrade, and filled the hole with a patching compound.

- All personnel involved in critical installation operations are staff of Arizona Refining. Most superintendents have experience at 15 to 50 sites.

- Novices in the industry can be a problem since they may construct an inadequate site that generates bad publicity the reputable firms must answer to. Overall, though, the specifications on most projects have clauses limiting the work to adequately experienced contractors.

Research Needs

- Carl Monismith of the University of California, Berkeley, Department of Transportation, has done two studies with asphaltic rubber in highway-related applications. There is no one in academia who is experienced with the material in liner applications.

- Tests are needed to adequately characterize asphaltic rubber. EPA, Cincinnati, has excellent laboratories and staff to handle such a project, but some direction should be given by a company such as Arizona Refining since there is so little experience with the material. This can help avoid, for example, improper handling of the material that could essentially invalidate any tests developed.

Perspectives on Regulations

- EPA regulations are appropriate to require the use of liners and associated procedures needed to ensure an adequate facility.

- A common problem with guarantees is that these are often required by the project specifications for the liner, but not for the subgrade. Since the subgrade has everything to do with the integrity of the liner, it too should be tightly specified, having requirements such as 90 percent compaction. However, there is a general reluctance by engineers to increase the requirements on a construction project for fear of increased cost.

Miscellaneous

- An emulsified asphaltic rubber is being researched by Arizona Refining, but no application as a liner is foreseen.

- Asphaltic rubber has a distinct cost advantage over synthetic membrane liners that has actually forced the price of synthetics down somewhat. Asphaltic rubber is not in more widespread use mainly because it is a relatively new material that, typical of such, is accepted slowly.

- Asphaltic rubber is a good cover material because it can conform somewhat with subsidence. The elongation of this material is not known exactly, but a minimum of 300 percent has been demonstrated. Further tests are in progress. A typical cover system would consist of a 200 mil asphaltic rubber liner, overlaid by a layer of cover material having side slopes no steeper than 10:1.

Perspectives on Asphaltic Concrete

- Arizona Refining does not construct any liner systems of asphaltic concrete, although they may supply the needed materials to contractors.

Asphaltic rubber is so superior that there are few situations where the latter should be preferred.

- The main problem with asphaltic concrete is its permeability. The material is often laid by standard highway contractors, few or any of which can do a hydraulic-grade job. An asphaltic concrete of low permeability requires all voids to be filled by using a higher fraction of asphalt, smaller aggregate, and greater compaction than used in highway or parking lot jobs. This also involves an increased cost. Therefore, asphaltic concrete should probably be limited to situations where it is used in conjunction with another liner material.

4.2 INTERVIEW REPORTS WITH OWNERS/OPERATORS OF HAZARDOUS WASTE MANAGEMENT FACILITIES

B-1. CECOS International, Inc.

B-2. Gulf Coast Waste Disposal Authority

B-3. Browning-Ferris Industries

B-4. Waste Management, Inc.

B-5. Lanchester Corporation

B-6. Monsanto Polymer Product Co.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. B-1

CECOS International, Inc.: Frank Nero
Kenmore, NY Robert Stadelmaier
Kenneth Malinowski
Peter Tarnawskyj
Ernest Gedeon
Anne E. Burke
716-873-4200

TRW: John Metzger
Sandra Quinlivan

14 December 1982

Summary

- A composite liner system consisting of remolded clay and a flexible membrane is crucial to realize satisfactory performance of a land disposal facility. In-situ clay should never be relied upon. It frequently has discontinuities that are difficult to detect, but which provide potential paths for transport of contaminants toward groundwater.

- All of CECOS' exhausted facilities are capped with a system of materials that includes a membrane that is welded to the bottom liner to isolate the contents of the facility from the environment. Leachate results only from water accumulated by the facility during its operating (uncapped) phase. The volume of leachate generated decreases yearly. At about five years following closure, only a low, background level of leachate flow usually remains.

- Certain regulations are a concern. Some of the problems may result from the regulations being directed primarily toward facilities that are quite unlike those that CECOS operates.

- By combining careful design with strict operating practices, CECOS handles with minimal problems a wide variety of industrial wastes in the Buffalo disposal facility. Each waste is handled separately, with many receiving some processing prior to emplacement in the landfill. Liquid wastes are transferred to a solid form by a liquid treatment facility, and semi-liquids are sorbed by a suitable sorbent. When finally placed in the facility, careful consideration is given to the waste's compatibility with previously placed materials.

Background and Objectives

CECOS International owns and operates a secure landfill near Niagara Falls, NY, for the disposal of industrial and municipal wastes generated in the Erie-Niagara County area. The firm considers itself a leader in the use of innovative waste treatment, recovery, and detoxification procedures prior to waste

emplacement in the landfill. The objectives of the interview were to obtain information on: (a) the design, construction, operation, and performance of the secured landfill and its HDPE liner; (b) CECOS' perspectives on liner regulations and R&D needs; and (c) additional references and data sources. The perspectives and data presented herein are largely based on CECOS' experience with the Niagara Falls facility, but also reflect CECOS' broader experience that includes operation of a secure landfill in Ohio, facilities for industrial pretreatment/processing of liquid wastes, and special environmental services such as emergency response. CECOS presented their practices by an introductory movie and slides, supplemented by a lengthy round-table discussion and presentations by the various participants present. The meeting concluded with a tour of the landfill.

Summary of CECOS Operating Procedures

Successful handling of waste material in a secure landfill is determined equally by the facility's design and by operating practices. Even the best of designed, secured landfills can be subverted by improper operations. Therefore, operating practices are fully relevant to any consideration of liner performance, and certain of these followed at CECOS' Buffalo facility are summarized below:

- The principal hazardous wastes accepted originate from various chemical, electro-metallurgical, and metal fabricating industries within an approximately 250-mile radius of the facility. CECOS also has a program for treatment and disposal of non-incinerable PCBs and PCB-contaminated wastes.

- CECOS exercises control over all steps leading to disposal of a material. This includes regulation of transporters, for example, by reviewing driving records and providing instructional programs.

- Individual wastes are carefully placed, never dumped, into individual cells in the secured facility. Five subcells are designated to handle the following waste types:

  - General waste material;
  - Pseudometals (soluble at both high and low pH);
  - Heavy metals;
  - Flammables (e.g., entrained solvents that may have a low flash point);
  - Toxics (e.g., PCBs).

- All wastes handled are catalogued into a computer library that records waste characteristics, the waste's exact location in the landfill, and appropriate supporting documentation. Physicochemical characteristics of each waste are supplied by the customer and verified by CECOS laboraties.

- All previous and future additions surrounding a newly placed waste are considered to ensure that they are chemically compatible or that, if

reactions do occur, they are in the direction of increased stabilization. The objective is to immobilize all waste material to minimize the generation of leachate, and a number of other measures can be taken to ensure this. These additional steps include separation of waste within the individual cells and case-by-case selection of cover material for each waste addition.

- All liquid materials are immobilized or otherwise handled prior to placement in the facility. "Lab packs" also receive special handling, but not the individual vials. Semi-liquids are immobilized by addition of sorbents, frequently an expanded silicate material. Development of new sorbents is a part of CECOS' on-going R&D program.

- Aqueous wastes are treated by CECOS on-site to transfer the contaminating constituents to a solid form that is suitable for landfilling. Following treatment, the aqueous stream is discharged to a municipal wastewater treatment plant (POTW). The level of treatment is determined by negotiations with the responsible authority of the POTW.

- The liquid treatment plant is a batch operation. Each waste handled can be input to the plant at a different point in the sequence of unit operations, according to that waste's characteristics and treatment requirements. Leachate from the land disposal facility is also treated in the liquid treatment plant, but this results in part of the plant's capacity being utilized in an essentially non-productive function. Less of the total capacity is thereby available to handle liquid wastes from customers for which the service can be assessed. This is strong motivation to operate the landfill in such a manner to minimize leachate generation (i.e., by careful waste emplacement to minimize void spaces, by use of good intermediate cover practices, etc.).

- There is a leachate collection system consisting of two concrete standpipes in each of the subcells, which are hydraulically connected to 4-inch perforated vitrified drainage clay pipe overlaid with No. 3 stone. The system operates automatically in "Unit 4". By the end of June 1983, there will be similarly operating systems in units 1, 2, and 3. While leachate does not freeze within the facility itself, freezing is a problem in transfer pipes. All pipes are heat traced, but even a single, localized malfunction can create a problem.

- There is no system designed to detect leakage of leachate at the CECOS facility, although the groundwater is monitored extensively. The following zones are monitored:

  - Perched water table - This is due primarily to previous site owners having deposited non-hazardous industrial waste on the site. This material sits on top of the naturally occurring clay soils found at the site. The "perched water table" results at this interface due to the lower permeability of the clay soils.

  - Top of the bedrock - This zone is most heavily monitored since it is usually first affected by any problems.
  - A zone just into the bedrock.

- There is no provision to withdraw samples of the liner from within the fill to make periodic inspection.

Construction, Liner Installation, and QA/QC

- The base layer of the Buffalo facility consists of a constructed 10-foot layer of clay compacted to 95 percent Proctor and permeability between 10^{-7} and 10^{-8} cm/sec. This layer is topped by an HDPE liner and covered by a 2-foot thickness of clay. External sideslopes are 3:1; slopes internal to the facility are 1:1. HDPE can support such severe internal sideslopes; few other liner materials can do so. However, clay and other soils do not adhere to HDPE, and the cover over the liner must therefore be fully self-supporting on the sideslopes.

- Considerable construction skill is required to compact 1:1 sideslopes. Only contractors having proper skills can be considered. However, to date, all work on CECOS' facilities has been done by a construction company that is a subsidiary of CECOS.

- Extensive quality control and other measures are taken during construction. No heavy equipment is permitted over the liner. The amount of seaming done in the field is kept to a minimum.

- Seaming was done by a Lyster Seaming Machine, a device that essentially heats the material and presses it together. The seams are tested by several methods, including visual observation, and use of screw driver and ultrasonic tests. The screw driver test involves using such an instrument to attempt to wedge the weld apart. The field installer/seamer conducts all tests, but they are certified by others, including state people that are otherwise present to witness operations.

- Additional QC functions are summarized in "Appendix A and B" supplied by CECOS. Wehran Engineering was responsible for the QA/QC at the CECOS site.

- The following considerations are most crucial to ensuring that a satisfactory facility is constructed:

  - Placement of the clay - In-situ geology cannot be relied on.
  - Quality control during all construction operations.
  - Restrictions on certain construction activities during periods of cold weather (seaming of the liner, for example).

Liner Material Selection

- CECOS works closely with the liner manufacturer, especially during selection of the polymeric resin.
- No compatibility testing has been done by CECOS since this is considered the responsibility of the manufacturer.
- CECOS feels that the characteristics of the liner must be carefully considered. Generally, the more dense the material, the less permeable it is, but also the less elastic (and therefore subject to rupture) it is. A suitable liner, therefore, represents a compromise between these two factors.
- HDPE is considered by CECOS to have characteristics of superior resistivity and good tensile strength.

Closure of CECOS' Facilities

- The objective of closure is to fully isolate the contents of the landfill from the environment. The principal concerns are to prevent or minimize infiltration of water into the facility and to prevent lateral migration of leachate.
- All CECOS' facilities are capped by a system of materials that includes the following: a clay cap adjacent to the uppermost layer of waste material, a 20-mil HDPE membrane, soils to support vegetation, and topsoil. The membrane is seamed to the bottom liner so that the contents of the facility are encapsulated.
- Each facility is mounded to facilitate run-off of precipitation and to better control subsidence*. None of the closed facilities have experienced subsidence. (The longest period of closure is about four years).
- After closure, each facility is fully managed, including control of leachate and provision of contingencies (such as fire protection). A full maintenance program is operated and includes one full man to operate the leachate collection system (for those facilities not having automatic leachate collection).
- Nearly all leachate generated is believed to be from water entering the facility before closure of both individual cells and of the entire facility, and from water held by the waste that was not fully removed prior to addition. Very little leachate is generated five years following closure.

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*How mounding can control subsidence was not elaborated on.

Perspectives on Regulations and Regulatory Reform Needs

- In concurrence with current Part 264 regulations, a synthetic liner is considered essential for all land disposal facilities. However, the combination of clay and synthetic liners provides the best assurance of performance. An important role played by clay is to attenuate any leachate that might escape the liner. All such clay that is directly a part of the liner system should be fully remolded. No in-situ geological formations can be relied upon due to the possible presence of secondary permeabilities (cracks, sand lenses, etc.) that readily escape detection.

- CECOS' concerns about permitting standards (interim final) for land disposal facilities are summarized in a letter (dated 18 November 1982) to US EPA (Docket Clerk, Office of Solid Waste). Following are some of the concerns.

  - There are several concerns with a requirement limiting the depth of leachate over the liner to a maximum of 30 cm. This requirement is especially difficult to comply with during the operating period of a facility preceeding closure. No direction is given concerning what constitutes the bottom of the liner. The floor of the facility is sloped to aid in collecting leachate, resulting in large differences in elevation where large areas are considered. The depth of leachate above the bottom liner will, therefore, vary considerably with the position considered in the facility. Additionally, when the facility is open during its service life, some siltation occurs in the leachate collection reservoirs. The depth of this material has not been considered in specifying the 30 cm limit.

  - Certain situations are possible under the framework of the interim final standards whereby neither a liner nor a leachate collection system is required. CECOS' position is that no conditions are suitable to eliminate the need for a liner. For nearly every case, a composite system combining a synthetic membrane with remolded clay is the only appropriate approach. A similar concern is the possibility of liquids being handled by a facility with two membrane liners. Such a system would be exempt from leak detection; however, CECOS does not consider this to be acceptable practice.

  - There are requirements for run-on and run-off control systems. This requirement has, perhaps, been developed by assuming typical conditions at a "standard" facility. Such a requirement, however, does not apply to the CECOS facilities as each is constructed well above the elevation of the 25-year storm.

  - There is a requirement that the leachate collection and detection system be operated until leachate is no longer detected. Any possibility of this requirement interfering with transfer of a site to the authority of the Post-Closure Liability Fund (per Section 107(k)(3) of the Comprehensive Environmental Response, Compensation and Liability Act of 1980) should be eliminated. In particular, better definition of the term "no leachate detected" is needed. Most leachate is

generated within a five year term following closure of a site. However, a very low level of leachate continues to be generated over the longer term. This level should be specified as "no leachate detected".

- There is concern that lab-packs will require individual handling of the containers to fulfill requirements that no liquids be introduced into the facility. CECOS has successfully immobilized the contents of lab-packs without handling individual containers.

Miscellaneous Considerations

- CECOS conducts extensive R&D oriented toward detoxification and recovery of materials. The proper emphasis in disposal of solid wastes is in the area of improving the characteristics of the materials that must be landfilled rather than in addressing the landfill itself, such as liner compatibility.

- The volume of industrial wastes received from individual customers has generally decreased due to volume reduction, modification of industrial processes, substitution of materials, detoxification, and resource recovery.

- Vestalin liners produced by Schlegel Mfr. (West Germany) are excellent liners and are preferred at many European sites.

Reference Documents Provided

- "Executive Summary: Ten Year Technology Plan", CECOS International.

- "Appendix A: Quality Control Program, SCMF No. 4 - Liner Installation", October 6, 1981.

- "Appendix B: Oxford Liners, Inc., Ultrasonic Test Instrumentation, Theory of Operation".

- Letter from E.J. Norman, Corporate Counsel, to U.S. EPA/OSW dated November 18, 1982, regarding Docket 3004, Permitting Standards for Land Disposal Facilities.

- Eight miscellaneous brochures and pamphlets describing CECOS' operations.

Additional Suggested Contacts

- Mr. Franc Grabar; NY State Department of Environmental Conservation, Buffalo, NY; for computerized waste input and leachate monitoring data, and additional background/performance data.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. B-2

Gulf Coast Waste Disposal Authority; LaMarque, TX: Robert Dyer, 713-935-4783

TRW: Michael D. Powers, Michael T. Haro

15 December 1982

Summary

- GCWDA is a commercial facility that accepts wastes from two refineries and two chemical plants in the Texas City area.
- The facility uses recompacted clay liners because at the time of permit application:
  - The state required clay;
  - The facility manager does not trust synthetics;
  - Suitable low permeability clay is available on site.
- The operator of a hazardous waste facility should choose the liner that is most appropriate for his site.
- Compatibility between liner and waste is a theoretical concept with little practical application. Rather than conduct extensive testing, operators of a facility should rely on the experience gained from disposing the same or similar wastes.

Background

Gulf Coast Waste Disposal Authority (GCWDA) is a commercial facility accepting wastes from only four participants in the Texas City area: Marathon Oil, Texas City Refining, Monsanto, and Union Carbide. GCWDA's Texas City facility began construction in July 1979, was put into operation in March of 1980, and had new disposal trenches added in 1981 and 1982. They currently operate five active landfill trenches for different types of wastes, and one land treatment unit; none of these units has been closed.

The following are perspectives of GCWDA on: (a) various aspects of liner design and installation; (b) operation; (c) quality assurance/quality control requirements; and (d) adequacy of regulations and regulatory reform needs. The statements and assertions, which are largely qualitative, reflect the experience of GCWDA; quantitative technical and engineering data to support the statements and assertions were not provided.

Design and Installation of Liners

- Clay liners only are used at the site. The land treatment unit (landfarm) has an in-place natural clay liner; liners for the landfills consist of recompacted clay derived from excavation of the trenches.

- GCWDA uses clay liners for two main reasons:

  - Texas Department of Water Resources refuses to allow any material other than clay for liners; GCWDA does not particularly like synthetics either. State regulations require clay with a permeability less than 10^{-7} cm sec^{-1}.
  - GCWDA has ample clay available on site; water-well drilling logs indicate that the facility is underlain by at least 260 feet of low-permeability soil assigned to the Beaumont Clay and Lake Charles Clay formations.

- State regulations contain guidelines for design parameters such as thickness of liner and side slopes. In addition, permits from TDWR contain specific construction requirements.

- Geotechnical studies of the site were conducted by Southwestern Labs and Law Engineering; GCWDA prefers to have two geotechnical consultants because "soils are less than an exact science".

- Compatibility testing of the disposed wastes with the clay liners is not conducted; instead, GCWDA assumes compatibility, relying on the many years of experience Union Carbide and Monsanto have had in disposing similar wastes into the same clay; the state has allowed this.

- Liners are constructed by excavating trenches, scarifying the bottom, removal of side walls; this technique is necessary to seal silty and then recompacting lenses. Excavation and liner compaction work are done by a dirt-work contractor. There have been no real problems during construction, although some soil slumps occurred later that had to be repaired.

- Construction QA/QC is done by soils engineers on-site during dirt work; liner is certified as meeting specifications by a Registered Engineer. Tests include:

  - Visual check for proper construction;
  - Compaction by means of nuclear density measurements;
  - Permeability using falling head permeameters.

Leachate Collection System

- Leachate is defined at GCWDA as "that which we collect from our leachate collection system". They haven't generated too much leachate except after periods of heavy rainfall.

- Each landfill trench has its own leachate collection system. This system consists of coarse sand and/or gravel with slotted pipe placed in the bottom of the trench above the liner. This pipe leads to a manhole from which collected leachates can be pumped off at weekly intervals or as needed.

- TDWR allows three methods for disposing of leachate:

  - Incorporate it into soil;
  - Send it to another site;
  - Other method as authorized by TDWR Executive Director.

  GCWDA uses the first method listed.

- Analytical results from recently collected leachate are being forwarded to TRW.

Operation

- The facility currently operates one landfarm unit and five landfill trenches, none of which is closed. The landfarm handles refinery wastes such as slop oil, tank bottoms, and API separator sludges, with the landfill handling refinery process wastes, cooling tower sludge (the sludge does not contain Cr^{+6}), insulation and metal catalysts. Guidelines in the state regulations require segregation of certain reactive wastes into separate landfill cells; acrylonitrile sludges, neutralized "acid" wastes (pH is around 12-1/2), and metal catalysts are kept separate from a general waste trench.

- No leak tests as such are conducted in the liners; instead, GCWDA relies on their leachate collection system and groundwater monitoring. The groundwater monitoring system consists of 12 wells; of these wells, one is located up slope and three down slope from the disposal area; GCWDA considers these their "EPA wells". Three more wells are located in the actual disposal area, and the rest are scattered around the facility. There is a brackish aquifer occupying an old buried stream channel approximately 15-30 feet below the surface in the northerly portion of the site; no disposal is allowed in this area.

General Comments and Perspectives

- The facility manager would not choose a synthetic liner unless forced to do so by EPA. The use of plastic liners is governed by "Murphy's Law"; there are too many things that can go wrong with them. Also, there is no way to adequately test these liners. Although not a happy prospect, the current EPA synthetic liner requirements are expected to stand.

- It is not possible to install liners within the current regulations so that they will not leak; as the regulations currently stand, the time frame specified is unrealistic.

- The operator of a hazardous waste disposal facility should use the liner that is most appropriate for the site. The specific characteristics of a site can overcome inherent problems of a liner system. For example, clay can dry out and become badly cracked, but because GCWDA is located right on the Gulf Coast, the clay is almost constantly saturated. Shallow cracks can form, but will not affect performance of the liner.

- Compaction of clay liners is very important. Because soil is a natural material, it contains inhomogeneities such as sand lenses that can have much higher permeability than the surrounding clay. Over-excavation and recompaction result in a much more homogeneous liner material.

- Compatibility between waste and liner is a nice theoretical concept which is primarily of academic interest but of little practical utility. Waste has no specifications. Material that meets specifications would be considered a by-product and either reused or sold. Wastes contain varying concentrations of contaminants that cannot be removed economically; these contaminants, in an otherwise benign waste stream, can affect the liner. Based on K. W. Brown's work, aromatics and other organics can become soluble in water; these chemicals can deteriorate synthetic liners and can make clays more permeable. For these reasons, the facility does not conduct compatibility testing, but prefers to rely on the experience of Monsanto and Union Carbide with the same wastes in nearby facilities.

- From a technical standpoint, QA/QC guidelines in the regulations covering both facility operators and installation contractors are desirable. Such requirements are likely to slow down operations and increase costs, but the amount of increase is uncertain due to widely varying bid rates. From a political standpoint, QA/QC guidelines may not mean a great deal; if the public does not want a landfill in its neighborhood, it is unlikely to accept data or be reassured by a QA program.

- The facility manager is concerned that EPA might require a double synthetic liner. For this particular site, GCWDA would however prefer the addition of a single synthetic liner to the existing clay liner.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
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FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. B-3

Browning-Ferris Industries:	Robert Johnson	TRW:	Michael T. Haro
Houston, TX	Jerry Duggan		Michael D. Powers
	713-870-7913		

17 December 1983

Summary

- BFI has considerable experience with the design, installation, and performance of both clay and flexible membrane liner systems. Based on experience from four BFI sites, little confidence can be placed on synthetic liners and in-place clay. Five feet of recompacted clay can prove effective if the clay is installed according to site specific design and under a comprehensive quality assurance program, and the facility is operated in the absence of any liquid wastes and designed so that the cell will only be open for part of the year to minimize erosion.

- The three greatest problems/concerns with flexible membrane liner systems are as follows:

  - The technology is probably unavailable currently to properly install such liners.
  - It is not possible to completely control trace contaminants in wastes received at hazardous waste facilities.
  - Heavy equipment and miscellaneous tools can puncture all types of flexible membrane liners.

- A 5-foot compacted clay liner is more resistant to mechanical and chemical damage than any flexible membrane liner.

- QA/QC procedures and third party audit should be added to the regulations. EPA should not develop only one set of QA specifications because liners are custom-designed by location. The third party auditor should be an engineering firm that assumes responsibility for their certification of each secure cell.

Background

Browning-Ferris Industries (BFI) is the operator of a number of hazardous waste treatment, storage, and disposal facilities throughout the country. Because of poor contractor performance in the past, the company now designs and constructs their own hazardous waste disposal facilities. BFI is a proponent of an approach to hazardous waste facility design, construction, and

installation that incorporates the use of compacted clay liners. The liners are installed according to site-specific design details and stringent quality control/quality assurance measures, as demonstrated in their Livingston, Louisiana, secure landfill site. This approach is based on years of company experience with both clay and flexible membrane liner systems.

The following are perspectives of the company on: (a) site-specific experience with hazardous waste facility liner systems; (b) liner and cover design and performance considerations; (c) installation procedures; and (d) quality assurance programs and regulatory reform needs. The statements and assertions, which are in part qualitative, reflect the extensive experience of the company; quantitative specifications and some permeability test results for the construction of secure cells at the Livingston site were provided.

Site-specific Experience

- Baltimore, Maryland, site: This site consists of a sanitary landfill with an in-place clay liner that will close in January 1983, and a treatment system for the leachate from the landfill. The leachate is treated in neutralization and settling lagoons. The company hired a contractor to install a compacted clay liner in the lagoon. BFI conducted tests on the contractor's work and discovered that the liner had been installed improperly. Due to time constraints, BFI decided to install a flexible membrane liner. A high density polyethylene (HDPE) liner, which BFI considered the best flexible membrane liner available, was installed exactly according to the manufacturer's specifications. After installation, the facility received 7-1/2 inches of rain and water seeped under the liner. When BFI began placing clay over the HDPE, they noticed "water geysers" emanating from the liner. The geysers were caused by flaws (pinholes) in the liner material. This convinced BFI that flexible membrane liners will not perform adequately.

- Ohio site: Construction began in 1973 on two surface impoundments with Hypalon liners designed to fixate pickling liquor wastes. Because there were other less costly methods of treating these wastes in the area, the company never operated the facility as designed. However, the impoundments were used to temporarily store the wastes and when the wastes were finally removed, they discovered that the liner had leaked.

- Houston, Texas, site: The company operates two large surface impoundments lined with Hypalon at this location. There is evidence of physical deterioration of the liner as well as soil movement behind the liner. The company discovered that metal ears on the hoses of trucks used to place waste in the ponds had been puncturing the liner. BFI replaced the Hypalon with polyethylene liners; these liners also failed. The company subsequently closed the facility.

- Lake Charles, Louisiana, site: BFI purchased this 40-acre site containing pits, ponds, and lagoons that were used to store brines, refinery wastes, and treated solidified wastes. The impoundments were lined with in-place clay soil. These ponds had also been leaking.

Liner Design and Performance

- The Louisiana State regulations require a minimum 3-foot clay liner for hazardous waste facilities. The use of in-place clays is unacceptable to the state. Because of these stringent regulations, BFI developed a high performance secure cell design for the Livingston Secure Landfill Facility*. The design consists of a 5-foot cell base layer of compacted clay underlain by a 1-foot layer of sand followed by a 2-foot bottom layer of compacted clay. A leachate collection system, consisting of a sump and gravel drainage trenches with perforated PVC pipe, is installed above the 5-foot clay base prior to placement of waste in the cell. A leachate detection system between the clay layers is also incorporated into the cell design. Side slopes are constructed in vertical lifts. All lifts are 6 to 8 inches, and each lift is tested for compaction and permeability, and certified by a consulting geotechnical engineering firm. A secure hazardous waste cell will produce the most satisfactory results when the system is designed in this manner.

- The Louisiana facility is designed so that the cells will only be open for approximately six months in order to minimize erosion.

- BFI does not dispose of any liquids in its landfills. Liquids are solidified first, using fly ash or kiln dust. The liquids react with the ash or dust instead of the clay liner.

- With the use of 5 feet of compacted clay, the concern over heavy equipment (or other sources of mechanical damage) does not exist as it does with flexible membrane liners.

- When constructing secure cells with 5 feet of compacted clay, 60,000 to 160,000 cubic yards of clay are used. In contrast, flexible membrane liners are very thin. A 5-foot thick compacted clay liner is more chemically resistant to a given volume of any hazardous waste compound than flexible membrane liners.

- At the Louisiana site, groundwater will penetrate the clay liner system throughout the operation and closure of the facility, a time period of about 50 to 60 years. With time, an equilibrium will be reached between the groundwater and the water inside the cell. Then the water (and waste) inside the cell will move slowly in the direction of groundwater flow. It may be hundreds to thousands of years before the waste front passes through the liner.

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*Complete design details for the Livingston facility are presented in a report entitled "Specifications for Construction of Secure Cell at BFI Livingston Site". Evaluation and analysis of these design specifications is not presented here, but is reserved for the final report.

- Kirk Brown performed a study on the effects of concentrated organic solvents on the permeability of clay soils. The ratio of the volume of chemicals to that of the clay, and the fact that the chemicals are in the liquid state, are critical to interpreting the results.

- In anticipation of the July 1982 regulations, BFI has developed a landfill design that will incorporate the use of a flexible membrane liner. The company will simply use their state-of-the-art clay liner system (i.e., the Louisiana site design) and place a flexible membrane liner on top of the clay system.

- A major problem with using flexible membrane liners is waste-liner compatibility. It is difficult to completely control trace contaminants in the types of wastes received. For example, there may be enough trace organics in an inorganic waste to damage an otherwise inert synthetic liner.

Liner/Cover Installation

- Liner installation is extremely important to the overall performance of the liner system. It is questionable whether the technology is available to properly install flexible membrane liners at this time.

- There also can be difficulties with the installation of clay liners. Due to problems with contractors in the past, BFI now constructs and installs their own clay liner systems.

- BFI caps their secure cells with 3 feet of clay and 1 foot of topsoil. The waste in the cell is 75 to 80 percent compacted during the regular operation of the cell, and BFI does not recommend the waste to be compacted further before capping. BFI has had no problems with subsidence (problems will occur if containerized liquid wastes were placed in the cell).

- Since cell covers are only preventing water infiltration and are exposed to limited heavy equipment trafficking, flexible membrane liners may be suitable capping materials in conjunction with clay and top soil.

Quality Control/Quality Assurance

- Quality assurance is enhanced by having a third party auditor during design and construction of a secure cell. The third party should be an engineering firm that reports to the operator on the witnessing, testing, and certification of each aspect of cell construction (e.g., subgrade preparation, liner installation, etc.). The operator should be able to sue the engineering firm if the liner does not perform as certified. This measure ensures the competence of the third party.

- BFI would welcome QA requirements in the regulations since BFI already has an established and comprehensive QA program, while many of their competitors do not. Many state regulations require the applicant to document construction specifications and EPA should not devise a single set of specifications because liner systems must be custom-designed by location.

- Requiring a QA program in the regulations will increase costs, but should not slow down schedules. By design, operators should account for QA in their facility construction schedules.

References

- Browning-Ferris Industries Specifications for Construction of Secure Cell at BFI Livingston Site. Approved by Robert Johnson and James Jones. June 1982.

- BFI-Livingston District Permitting Study (various permeability and hydraulic gradient test results). Investigated by Soil Testing Engineers, Inc., and Jones, Walker, Waechter, Poitevent, Carrere & Denegre. 1982.

- For complete details and to obtain copies of permit files on the Livingston, Louisiana, site, Mr. Johnson suggested that TRW contact Jim Porter with the Department of Natural Resources, Baton Rouge, Louisiana.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. B-4

Waste Management, Inc.: John Rohr
Oak Brook, IL Steven Menoff
Don Walgreen
312-654-8800

TRW: Masood Ghassemi
John F. Metzger

January 27, 1983

Summary

- Synthetic liner material has better permeability characteristics than clay, but clay liners are less susceptible to failure due to installation errors. A clay-FML combination system, whereby clay offers back-up capabilities, can probably provide the most protection.

- Identification and removal of discontinuities such as sand and silt lenses from clay during installation is essential to developing an adequate clay liner. The task, however, requires trained personnel due to the difficulty in distinguishing some discontinuities from the background clay.

- Unless proper supervision is provided by a capable foreman, the common practice of using unskilled labor in installing FML liners is conducive to poor quality of the installed liner.

- Maintaining a properly functioning cap is probably the most expensive part of post closure care. Subsidence and erosion are two critical factors which should be addressed in design.

- Materials other than clay and FML are generally less suitable for lining hazardous waste facilities.

- Research and development efforts should include programs to assemble design vs. performance data for various liners under actual use conditions.

Background

Waste Management, Inc., has extensive experience in collection, transportation, and disposal of solid wastes. It owns and operates a number of land disposal facilities having various liner systems including in-situ and reformed clays, flexible membrane liner (FML) of various types, and clay-FML combination systems.

The purpose of the interview was to determine the company's perspectives on engineering and installation aspects of FML and clay liner installation.

Relative Merits of Clay and FML, and Compatibility Testing

- On the basis of the relative permeability of the liner material and the usual liner thicknesses used in practice, an FML should theoretically be more suitable than clay for lining hazardous waste land disposal sites. Neither type, however, can be relied upon entirely and an approach using an FML-clay combination system is probably more desirable. If only a single liner material must be used, clay would probably be better because it is more forgiving.

- Standard laboratory compatibility tests do not adequately simulate field conditions. The difficulties primarily relate to the short duration of these tests and the general inability to establish, with certainty, the composition of the leachate from a particular facility (the composition is also subject to a wide variation).

- Waste Management, Inc., has obtained some data on leachate characteristics for three of its clay-lined facilities. The data have been used in conjunction with liner manufacturers' information on liner material properties to assess liner compatibility at other company sites using FML.

- Compatibility problems can be at least partially reduced by providing the facility with a system for the collection and removal of leachate. Per corporate policy, all new company sites where annual precipitation is 20" or more incorporate leachate collection (usually via sand or gravel drains). The leachate may be recycled to landfill, discharged to a POTW, treated on site, or solidified and returned to the facility.

Installation Problems

- Most cases of liner failures can be attributed to poor design and inadequate quality control during installation.

- Tests for quality control during clay liner installation include determinations of moisture content, degree of compaction, and permeability. Identification and removal of discontinuities in clay (e.g., silt and sand lenses) are important and require trained personnel due to the similarity in color and texture between such discontinuities (especially silt lenses) and the background clay. The presence of silt lenses has been identified as the cause of failure for some water reservoirs. No such determination is possible for landfills due to the inaccessibility of the liner for inspection.

- Unless proper supervision is provided by a capable foreman, the use of unskilled labor for installation of FML (a common practice) can lead to

poor work quality. A capable foreman can provide the necessary training and leadership to the unskilled laborers who, at least on some occasions, have been hired directly from the local unemployment lines. Some installation jobs in Florida have used off-duty police and fire protection personnel with considerable success.

- Proper design would not allow the use of horizontal seams on the side slopes as gravity-related stresses can lead to failure of such seams.

- From the standpoint of reducing field seaming requirements, HDPE has an advantage over some other FMLs in that it can be manufactured and delivered to the site in larger sections.

- Waste Management, Inc., is currently developing an overall QA/QC policy applicable to all new installations. Certain elements of the policy, which have been followed by the company in the past, include:

  - Inspection of the operation of the prospective liner manufacturer and fabricator.
  - Use of reputable manufacturers and fabricators, preferably those with which the company has worked in the past.
  - Presence of a company representative at the site during installation to ensure strict compliance with specifications (field seaming should be under continuous surveillance; the company has, on several occasions, shut down a construction site due to the contractor not adhering to specifications).
  - Inspection to ensure base compaction according to specifications and complete removal of all projections.

Perspectives on Caps

- FML can be an excellent material for caps. Generally, placement of a 1-foot clay on top of the membrane and keeping flatter than usual side slopes will prevent the clay cover from sliding off.

- Facilities having a clay bottom liner usually also use clay for the cap. Secured facilities are usually capped with a 2 to 4 foot thick clay layer with 6 to 7 percent top slopes to control erosion and minimize subsidence. Erosion is probably the most destructive force affecting the longevity of clay caps.

- Bentonite caps may be susceptible to desiccation cracking, even when there is a soil with vegetation cover.

- Maintaining a properly functioning cap is probably the most expensive part of post-closure care. While subsidence cannot be totally eliminated, it can be minimized significantly by use of proper operating practices during waste emplacement.

- Landfill gas moving through the cap can kill the vegetation on the cover. The problem can be eliminated by proper design which would allow venting.

- Cap design can influence the movement of leachate across the bottom liner. In one facility in Delaware, capping resulted in the leachate plume retreating.

Perspectives on Liners Other Than Clay and FML

- In general, liners other than clay and FML would probably be less suitable for lining hazardous waste sites. For example, asphaltic liners cannot be fully relied upon where there is a possibility of ground movement. (Waste Management has acquired a site which uses an asphaltic liner.)

- If properly applied, soil cements can provide an adequate liner. Quality control requirements, however, are even more important than for FML or clay.

Research and Development Needs

- A data base assembled on design vs. actual performance of liners and other "real world" studies involving full installations would be most helpful and will advance the state-of-the-art.

- Suitable methods should be developed to assess liner performance under actual use conditions. One study proposed previously, which involved taking core samples from liners, was received less than enthusiastically by owners/operators due to the potential for permanent damage to the liners and hence consequent liability.

Regulatory Perspectives and Miscellaneous Considerations

- Licensing of liner installers below the foreman level is probably unnecessary and impractical.

- A checklist of key factors leading to a successful installation can be helpful to regulatory agencies charged with permitting land disposal sites. The checklist should be general, as specific requirements would be site-specific.

- The State of Texas and several others requires certification of land disposal facilities construction by a professional engineer.

- There is a general trend for municipalities to turn over the responsibility for operation of land disposal sites to the private sector. In this connection, Waste Management, Inc., has contracts with several municipalities.

Documents Received from Waste Management, Inc.

The following documents have been provided to TRW by Waste Management, Inc.:

- Two documents on leachate characterization test results for two hazardous waste sites.
- "Technical Specification No. 5-2, Construction of New Solid Waste Disposal Cell: Bottom Liner Phase II - Geomembrane Liner and Leachate Collection System" (this document provides FML installation specifications used at the Waste Management's Furley, Kansas facility).

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EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. B-5

Lanchester Corporation: Morris W. Holman, Jr. TRW: John F. Metzger
Honeybrook, PA 717-354-4351

February 1, 1983

Summary

- An asphaltic concrete liner can be installed by standard asphalt contractors since the job is no different than a highway paving project. These contractors have considerable experience handling the material. No equivalent level of experience exists for other liner materials.

- The asphaltic concrete liner at the Lanchester facility is sufficiently impermeable to protect the environment. However, permeability is not a big issue because of the unusually steep side slopes within the facility and the provision for collection and removal of the leachate.

- Caps constructed of carefully selected native soils perform well although some maintenance is required Subsidence that can potentially destroy the cap cannot be eliminated completely, but can be minimized by careful operating practices. This must include prohibiting liquids in the waste pile since a void forms when the liquid leaks out of its containing vessel.

- Most EPA requirements are legitimate but facilities should not be required to supply exhaustive characterizations of leachate and other waste streams. These requirements in effect force the facilities to support EPA research resulting in higher charge to customers that ultimately make the facility a less attractive disposal option.

Background

At its Honeybrook location, the Lanchester Corporation owns and operates a sanitary landfill, a hazardous waste facility, a wastewater treatment plant for the leachate from the sanitary landfill, and a hazardous waste stabilization facility. The sanitary and hazardous waste facilities are each lined with asphaltic concrete. The purpose of the interview was to obtain perspectives on installation and general performance of an asphaltic concrete liner.

Design of the Lanchester Land Disposal Facility

- The major operation of the Lanchester Corporation is the sanitary landfill. Soil beneath it was excavated to a very stable "plate rock"

formation, and a one-foot layer of natural soils was placed and compacted. French underdrains were included to provide dewatering as necessary and leak detection. A liner of 4-inch thick asphaltic concrete was constructed on the compacted soil and topped with an 18-inch soil layer having leachate collection pipes. Flows from both the underdrains and the leachate collection network can be monitored.

- The facility is situated in a valley having steep slopes (generally not less than 5 percent). The permeability of the liner is therefore less of a concern than in many land disposal facilities since the residence time of leachate over most of its extent is very short.

- When the facility was designed and constructed around 1974, the technology for synthetic membranes was not well developed. This and the relatively low cost of asphaltic concrete were principal reasons for its selection as the liner material.

- No compatibility testing was done because information published in the open literature established that asphaltic concrete is compatible with leachate from sanitary landfills, having an overall resistance not much different than PVC. Only solvents, oils, and grease readily pass through the liner and, therefore, cannot be handled in the facility. The same, however, is largely true of synthetic membrane liners.

Perspectives on Installation of an Asphaltic Liner

- All operations associated with installing an asphaltic liner are identical to those used in highway construction. Standard asphalt contractors can therefore be used, and their considerable expertise developed from roadway jobs can be applied to real advantage in constructing the liner. No other liner material has a comparable advantage.

- The asphaltic liner derives its support from the subbase; under no conditions should it be relied on for strength. At the Lanchester facility, a solid base constructed of native soils is possible largely because of the area's very stable geology. In locations were ground movements are likely, however, asphaltic concrete is not a suitable liner material.

- The asphaltic mix used in the Lanchester facility was a standard State of Pennsylvania mix of materials with a 1/2-inch aggregate base. The characteristics of the mix were not considered in detail, but generally, if the aggregate is too small, the concrete will not have enough strength; if the aggregate is too large, the concrete will be too permeable for a liner application.

- The temperature of the asphaltic mix during application must be maintained within narrow limits, although this is easily done by construction crews experienced in highway work. Side slopes as steep as 3:1 can be handled, but on the more severe slopes, compaction by rolling equipment becomes difficult.

- After placement, the asphaltic concrete is sealed with a spray applicant. If rain or moisture accumulates on the surface between these steps, the sealant does not penetrate the asphalt as well as it otherwise would.

- The interface between adjacent widths of the asphaltic concrete bonds well to form a tight seal.

- Poor construction quality is a potential problem common to all engineered projects. Other areas of potential compromise include switching materials or cheating on the concrete mix. None of these problems, however, are worse than at other construction sites.

- The Lanchester Corporation's landfill is somewhat unique among medium sized facilities because no outside consultants were used in its design or inspection. The owner is very familiar with construction practices (he can operate any piece of heavy equipment) and he was, therefore, uniquely qualified to monitor the site's design and to personally head all quality control during construction. Thus, no opportunity existed for the objectives of the owner to become diluted by being implemented by another party.

Miscellaneous Factors Contributing to the General Success of a Facility

- While subsidence cannot be eliminated entirely, it can be minimized greatly by proper operating procedures, mainly compaction of the daily lifts of wastes. At the Lanchester facility, the individual cells are deeper than at most comparable facilities (about 15 to 20 feet versus about 8 feet).

- Leachate recycling to the waste pile is not considered a desirable action, and at the Lanchester facility, all leachate is collected and treated on site by a wastewater treatment plant. Prior to construction of the treatment facility on site, the leachate was delivered to DuPont Corporation for handling.

- Waste held in the facility is far from its field moisture capacity, and leachate flows are low, particularly in the summer. To further minimize leachate production, liquids are not permitted into the facility. However, leachate flows are expected to increase, especially once the field capacity of the waste is exceeded. Water generated as a product of biological degradation will also contribute to the leachate flow.

- Water can move predominantly upward through the waste pile if evaporation and capillary transport are great enough.

- The asphaltic concrete liner is not susceptible to damage by frost. Once only partially full, the frost line does not even reach the liner. Newly lined sections are not threatened either because there is usually little water entrained in the subbase.

Perspectives on Caps

- There are no completely closed fields at the Lanchester facility, although one has a temporary cap constructed of carefully selected native soils. A large variety of soils are locally available and one suitable for nearly any purpose can be found.

- One of the principal reasons for eliminating disposal of liquids in a land disposal facility is to minimize subsidence. For example, when drums are disposed, they eventually corrode and empty their liquid contents. The resulting large void formed is a point where subsidence will occur.

- The effectiveness of caps in general, and particularly of those constructed of soils native to the Lanchester site, is demonstrated by the capping of an abandoned dump site. This site existed long before the Lanchester Corporation purchased the property, and leachate flowed uncontrolled over a nearby public road, staining it brown. A cap consisting of a 3- to 4-foot thickness of carefully selected native soils was constructed and mounded for subsidence control. A cutoff trench was provided to intercept any continuing leachate flow and transport it for treatment. Since the cap was constructed, leachate has not continued to escape the waste pile, although on occasions, holes requiring repair have developed. All such caps require periodic inspection and repair. The distinct color of the leachate from this particular facility simplified detection of any problems.

Perspectives on Regulations

- Most EPA regulations are appropriate, but some create unnecessary hardships on landfill owners. The following are examples:

  - There is no need to document every step taken during design and construction of a land disposal facility. Most matters should be left to the discretion of a professional engineer.
  - Some requirements have no bearing on the performance of a land disposal facility. Paperwork especially seems to have become an obsession, assuming even greater importance than the facility itself.
  - Groundwater monitoring is a legitimate need, but its characterization should be limited to a few variables such as TOC, COD, and volatile solids. If these parameters indicate a larger problem, more detailed analyses including metals are justified. Detailed analyses made on a routine basis is effectively forcing the facilities to support EPA research, which is not an appropriate role for the facilities. This increases costs, thereby potentially driving customers to use alternative and clearly less desirable disposal methods.

- Regulatory officials, particularly those who work directly with the land disposal facilities, should be required to have some minimum practical experience as this will enable them to better appreciate "real world" problems.

- Performance standards may have some merit as a mechanism to encourage owners to construct better facilities since when a poorly constructed facility fails, remedial action may not be adequate to completely restore the site.

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EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. B-6

Monsanto Polymer Product Co.: Jerry N. McGuire TRW: Masood Ghassemi
St. Louis, MO 314-694-5262

2 February 1983

Summary

- Based on the company's poor experience with the installation and performance of synthetic liners in a wastewater lagoon lining application, clay was selected as the choice liner material in a subsequent landfill lining job at another company site.

- Experience indicates that the present practice and technology will not guarantee installation of synthetic liners that will not fail.

Background

On 20 December 1982, TRW informed Dr. Janet Matey of Chemical Manufacturers Association (CMA) of the subject study which TRW had just initiated for EPA. CMA was requested to bring the study to the attention of its member companies so that interested members could provide input to the program, if they so desired. A copy of the work plan was subsequently sent to CMA.

On 2 February 1983, Mr. Jerry N. McGuire of Monsanto telephoned TRW and provided the information presented in this interview summary report. To date, Monsanto has been the only company responding to the TRW-CMA request for input to the subject study.

Although Monsanto provides sheet materials for miscellaneous uses, it does not market FMLs. Mr. McGuire has designed both clay and synthetic membrane liners for several of the company's waste disposal facilities, and the data provided here reflect his personal experience with the two types of liners.

Description of Two Lined Waste Disposal Sites and Performance Results

- A wastewater treatment lagoon was originally lined with 30-40 mil butyl rubber. The mastic material used on joints did not hold up and exhibited only a 5-lb tear strength. The failed liner was later replaced by a 20-mil DuPont 3010 liner. Heat welding was used for seaming in the field. The experience with the second liner was also unfavorable.

- One landfill/land mound site which receives chemical sludges has a double clay liner. The selection of clay over synthetic liner, which was

primarily influenced by the above-mentioned bad experience with synthetic membranes, had to be justified to the state which initially favored synthetic liners. The top and bottom clay liners are 18" and 12" deep, respectively, and are separated by a 1-foot layer of sand containing the leachate collection system. The 5-acre site consists of two operating cells: a "wet" cell which receives the liquid sludge and is used as a drying bed, and a "dry" cell which is used for dry solids. The top clay layer in the wet and dry cells are overlaid by a layer of sand and a layer of gravel, respectively. Approximately one year after the operation, leachate was detected in the intermediate sand layer. In the five years of operation, the leachate generation rate has varied from 0 to 200 gallons per day. The quantity of water collected between the two liners is directly related to rainfall. Constituent concentration levels in the collected leachate from between the liners is 20 to 50 times lower than the levels in the leachate samples collected from above the top liner, and these concentrations have been dropping. Although the collected leachate is of a quality which can be directly discharged to the river, the leachate is treated on-site in a secondary wastewater treatment plant before it is discharged to the river.

Perspectives on Synthetic vs. Clay Liners

- Experience indicates that it is very difficult to install synthetic liners which are free from pinholes or other faults (e.g., due to bad seams).
- On liner installation jobs, the foreman usually hires local help with no liner installation experience and this can lead to poor quality work and hence failure.
- Heat welding may produce good results under office or laboratory conditions, but not necessarily under actual field conditions. Field test methods for confirming seam tightness have not been completely successful.
- Overall, clay liners would be superior to synthetic liners, assuming compatibility with the material they are meant to contain. Clay can be installed in the field without encountering installation problems associated with synthetic liners.
- Clay is definitely more suitable for use with heavy earth moving equipment.
- Quality assurance in the manufacturing of synthetic liners has been a problem. Monsanto has experienced difficulties with thickness, reinforcing scrim, material uniformity, etc.

4.3 INTERVIEW REPORTS WITH STATE REGULATORY AGENCIES

C-1. New York State Department of Environmental Conservation

C-2. Pennsylvania Department of Environmental Resources, Bureau of Solid Waste Management; and Lycoming County Planning Commission

C-3. Pennsylvania Department of Environmental Resources, Bureau of Solid Waste Management

C-4. Pennsylvania Department of Environmental Resources, Bureau of Water Quality Management

C-5. New Jersey Department of Environmental Protection: Division of Water Resources, Solid Waste Administration, and Bureau of Hazardous Waste

C-6. Maryland Department of Health and Mental Hygiene, Office of Environmental Programs

C-7. Wisconsin Department of Natural Resources, Bureau of Solid Waste Management

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EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. C-1

New York State Dept. of Environmental Conservation
Buffalo, NY
: Mark Hans
716-847-4585

TRW: John Metzger
Sandra Quinlivan

13 December 1982

Summary

- Most facilities in the region utilize a liner system consisting of three layers: a base of clay; a synthetic, flexible membrane; and an upper layer of clay.
- The following two requirements are essential to ensuring that a land disposal facility performs satisfactorily: adequate quality control during placement of the liner and a leachate collection system. The importance of the leachate collection has been identified only recently.
- The regulations, as written, are sufficient to ensure an adequate facility but not so rigid to prevent innovations where appropriate.
- Direct experience is most important in advancing the state-of-the-art. Most research is of lesser utility.

Background and Objective

The Division of Solid Waste Management of the State of New York, Department of Environmental Conservation, is divided into nine regional offices. Each retains design, operational and monitoring data of hazardous waste sites within its region. In the Region 9 office (Buffalo), Mr. Hans is in charge of permitting and, in some cases, inspecting various land disposal facilities. Much of the experience represented by professionals in this office has been acquired by working with either of two facilities that have national significance: SCA Chemical Services, Model City, NY; and CECOS International, Niagara Falls, NY.

The objective of the interview was to obtain perspectives of this state office on use of liners in land disposal facilities. The following subject areas were considered: (a) characteristics of typical facilities in the region; (b) construction requirements of new facilities and the state's involvement; (c) assessment of liner performance and of the current regulations; and (d) other references and data sources. Information presented in the following sections represent opinions and, therefore, is not necessarily substantiated.

Design Considerations and Acceptable Standards of Practice

- The following summarizes liner systems typical of land disposal facilities in Region 9, NY. Most details are nowhere stated explicitely in regulations, but a system conforming approximately to the following is the norm understood by parties seeking a landfill permit. Landfills are constructed with the following layers:

  - First, a 2-foot thick layer of compacted clay overlying a synthetic liner.
  - Next, a synthetic, flexible membrane. Most older facilities use Hypalon. Newer facilities use high density polyethylene (HDPE), largely in response to it being promoted by consulting engineers as a material that is easier to handle and install. Most HDPE liners are 60 to 80 mils thick.
  - Last, a 10-foot base layer of clay having permeability less than 10^{-7} cm/sec.

- Compatibility testing of the liner with leachate is not required in the region, nor is there any known requirement elsewhere in this part of the country. However, it was emphasized that the liner is protected by the clay cover.

- There are many factors requiring consideration when siting or designing a landfill. These include the following:

  - The factor of potentially greatest influence is public opposition to a new disposal site. Political problems can usually be minimized by expanding an old facility or constructing a new site adjacent to an old one.
  - Areas where clay occurs naturally are preferred. Some deposits in the region approach a thickness of 20 feet.
  - Generally, a vertical distance of 10 feet is required between the groundwater and the waste deposit. Some facilities, such as the CECOS International landfill near Buffalo, are located almost on bedrock and up to 10 feet of clay must be trucked into the site prior to placement of the synthetic liner. Certain recent designs referred to as "intragradient" are exceptions. For these, the groundwater elevation exceeds that of the base of the landfill, thereby exerting a hydraulic gradient inward on the facility. If leakage occurs, it is in the direction of groundwater migrating into the landfill.

Construction Requirements - State Involvement

- Three persons from the state office are on-site at all times during construction to oversee operations. An engineer from the state is present on a less frequent basis.

- There is no requirement that contractors installing liners be licensed. However, each contractor is required to certify that the system complies fully with design specifications.

- A soils engineer, responsible to the owner, supervises quality control activities. One important duty is supervision of compaction/recompaction of clay. Clay lifts are limited to 6 to 9 inches, and a compaction test is made at 50-feet intervals using a nuclear densitometer to verify 90 percent compaction.

- HDPE liners are seamed by heat welds. The material is overlapped and a weld is made along the edge on both sides. All welds are tested by applying air under pressure to the natural gap created by the two welds and measuring the leakage. Alternatively, the welds are tested by a sonic method which measures the thickness of the seam and correlates this to seam integrity. Hypalon is usually seamed by solvent welding. Testing is done manually by simply attempting to pull the sections apart.

Perspectives on Liner Performance

- Substantive regulation of landfills in the region began in about 1976. Few leachate problems generally occur due to the following measures: use of a liner and a leachate collection system and elimination of landfilling liquids.

- No landfill in the region has an elaborate leak detection system. With the intragradient designs, leakage is indicated by excessive generation of leachate. For other systems, leakage is indicated only by overwhelming evidence.

- Placement of the liner and quality control are the most important activities during construction to guarantee satisfactory performance in the future. The most important design feature to likewise ensure performance is the leachate collection system. By minimizing contact between the leachate and the liner, there is less opportunity for the liner to be degraded or for leachate to escape the facility if a hole has already developed in the liner. The important role played by leachate collection has been identified only recently as evidenced by it being required over only the past 1-1/2 years.

- Mechanisms of failure are not usually well understood. Few problems have occurred in the region. One exception is failure of a cell (Cell 7) at the SCA facility. There, a portion of the sidewall collapsed, creating a tear in the Hypalon liner.

Perspectives on Regulations

- The current regulations as well as construction and installation practices are judged adequate. The regulations are also sufficiently flexible to permit an equivalent system to be substituted for the current typical design. The state office is receptive to innovations so long as performance can be assured.

Research Needs

- No suitable areas of research could be identified, and much of the current research was considered of questionable value. An example is provided by water balances around the disposal site. Such balances are made in this region, if at all, upon closure of the facility. However, too many variables are involved or are very difficult to quantify to permit formulation of a reasonable model describing landfill performance.

- The most important advances in the state-of-the-art result from compiling direct experience. There is no suitable substitute.

- Land disposal is an evolving technology with innovations occurring regularly. Owners are probably in the best position to push innovations as they are most directly influenced by, and therefore most responsive to, economic and political pressures.

- An example of a recent innovation is provided by a new SCA facility incorporating a "continuous design". The facility will cover approximately 25 acres, but only 4 or so will be opened as needed. Leachate collection systems will operate independently in each section of the facility.

Additional Suggested Contacts

The following individuals were identified as having extensive experience in the indicated areas:

- John Beecher. Mark Hans' supervisor, who was characterized as having extensive field experience.

- Paul Counterman (518-457-3273). He is in the Albany state office and has experience writing hazardous waste disposal regulations. (Note: Paul Counterman was contacted by telephone and can provide TRW with additional data on liner performance at the following sites: (a) Town of North Hempstead, NY, which has a 20-mil PVC liner and has had liner problems; (b) Rotterdam landfill which has a silty clay liner; and (c) Colony landfill which also has a silty clay liner.)

- Jim Woods, Wheran Engineering, Inc. He should be contacted for details of liner design and construction, and regarding compatibility studies, and for details of recent slope failure in Cell 7 of SCA's landfill.

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INTERVIEW NO. C-2

PA Dept. of Environmental Resources, Bureau of Solid Waste Management
Williamsport, PA
: Richard L. Bittle
717-327-3653

TRW: John Metzger
Sandra Quinlivan

Lycoming County Planning Commission
Williamsport, PA
: Jerry S. Walls
717-327-2230

15 December 1982

Summary

- The Lycoming County facility is a sanitary landfill which utilizes a liner system consisting of the following layers constructed atop in-situ clay: two 12-inch sand layers separated by a PVC membrane and an overlying layer of 12-inch compacted clay. PVC has been selected due to its proven performance and relatively low cost.

- The PVC liner was not tested for compatibility with leachate, largely because leachate characteristics were poorly understood initially. Recovery and testing of a section of the liner after four years of operation showed liner characteristics almost identical to the new material.

- Favorable experience with the PVC liner is attributed to good design, not accepting certain potentially incompatible wastes, and removal of the leachate from the landfill.

- Not all factors contributing to an adequate landfill facility are technical. Carefully structured legal arrangements, including assigning of liability, can be invaluable for ensuring quality construction and promoting effective quality control during all aspects of liner design, fabrication, and installation.

Background and Objectives

The Lycoming landfill is a sanitary landfill operated since 1977 under the supervision of the Pennsylvania Department of Environmental Resources and the Lycoming County Commissioners. It is a major landfill in the region and is located on land which is part of a minimum security state prison. There are three fields: Field 1 is at capacity and closed, Field 2 is being filled, and Field 3 is under construction. The site uses a PVC liner which is reported to perform very satisfactorily. The objectives of the interview were to obtain information on: (a) the design, operation, construction, and performance of PVC liner at the Lycoming facility; (b) perspectives of the state

and county commissioners/site operators on liner performance and current liner regulations; and (c) additional references and data sources to be contacted. Part of the data is specific to the Lycoming facility, while the rest represents the broader experience of both Mr. Bittle and Mr. Walls who were interviewed.

Design and Operation of the Lycoming County Sanitary Landfill

- The Lycoming sanitary landfill has a liner system consisting of the following layers of materials:
  - A base of limestone overlain with in-situ "glacial" clay. The site has an abundance of natural clay.
  - A 12-inch layer of sand. This layer is included as part of a monitoring and leak detection system. Underdrains are laid in trenches excavated into the in-situ clay. Any leachate escaping the overlying liner can migrate laterally through the sand layer to an underdrain.
  - A flexible membrane. The synthetic liner is 20-mil PVC except in the vicinity of gas vents where it is 50-mil thick. PVC was selected because it was economically superior to all other liner materials considered. For the first project at Lycoming, the fabricator was Watersaver Company (Denver, CO), and Staff Industries (Montclair, NJ) was used for the second.
  - A 12-inch layer of sand. Earlier projects used a 6-inch layer, but 12 inches was found to be superior, strictly from a construction standpoint.
  - A 12-inch layer of compacted clay.
- A liner system must receive close attention during construction if it is to perform adequately. A number of measures were taken at the Lycoming facility to ensure the quality of construction, including the following two arrangements:
  - The contractor was required by the project specifications to post a construction guarantee, and the contract was structured so that the contractor was designated liable at every step of his involvement in the project. For example, the contractor was required to ensure that all materials received from the fabricator met specifications. Such a system of liability could be arranged only by eliminating the project from its tax-exempt status normally given a government project. However, this structure was considered necessary to ensure tighter definition of responsibilities and, therefore, an increased likelihood of the project being completed satisfactorily.
  - A warranty was required for the flexible membrane, and a draft had to be presented up-front with all bids. The warranty was a replacement warranty, meaning that if failure occurs prior to the end of the service life of approximately 20 years, adjustments would be pro-rated

over the period of successful service. In reality, such a warranty is of limited usefulness, mainly because of the difficult task of proving failure and assigning responsibility. However, it serves another very important purpose: should major problems occur requiring litigation, the matter is one for contract law, a legal area having extensive precedent, rather than "landfill law" or some other equally unchartered legal area.

- Approximately 700 tons of input waste are handled each day, with all wastes screened to protect the liner. Rejected materials include aromatic solvents and cutting oils which must be handled by a hazardous waste facility. Even entire truck-loads of undesirable deliveries have been turned away on occasion. Acidic industrial sludges are neutralized with lime prior to emplacement in the landfill, but sludges having less than 20 percent solids content are not accepted. Inert fillers, such as sawdust or "stay-dry" or auto repair shop oil spill adsorbent materials, are occasionally added to increase the solids content of waste materials.

- Runoff is routed around the landfill by means of diversion trenches.

- Operating units within the landfill are closed using a cap of clay only.

- Removal of leachate from the facility helps to ensure the long-term integrity of the liner. Leachate is collected (about 40 gpd) by a network of lateral pipes and routed to a holding basin lined with 30-mil PVC. There it is mechanically aerated via two aeration pumps and, in the past, was sprayed onto the surface of the landfill. In the future, the leachate will be hauled in 5,000 gallon loads via vacuum trucks to a WWT plant in Williamsport (the possibility of building a new leachate impoundment lagoon complete with settling and flocculation capabilities was studied, but the costs were found prohibitive for a county-run landfill). Fluorine has recently been approved for use as a tracer element to indicate leakage.

- At the time of the first landfill project at the Lycoming site, there were no regulations requiring compatibility testing of the liner. Additionally, the state-of-the-art was in its infancy; there was little or no information on leachate characteristics. Research by Henry Haxo of Matrecon was only beginning. A. Tungaroli's work on leachate characteristics was being done at Drexel Industries, but these were laboratory-scale, not field tests. Such laboratory-scale studies were considered to be of debatable value since they rarely represent field conditions. However, in an attempt to ensure some minimal guarantee of compatibility between the liner and leachate, leachate characteristics based on the best available information were included in the bid specifications.

- Characteristics of the leachate have been monitored since start-up, and no evidence of incompatibility between it and the liner has been found. For the most recent field, now under construction, some compatibility tests were available to assist in selecting the liner. However, the

eventual choice of PVC was based more upon successful field experience with this material than on compatibility or other testing.

- A section of the PVC liner from Field 2 was dug up after approximately four years of service in response to pressure exerted by the "Organization for Ecology", a local citizens' group. The section met all specifications of the new material with exception of the low temperature (-20°F) test. However, this test is considered somewhat irrelevant since the site only gets a 36-inch frost (0°F), and the liner is under at least 12 inches of clay and 12 inches of sand, except on the slopes.

- Problems have occurred with leachate breaking out the side of the landfill mound at a point above the reach of the bottom liner. This movement is believed to result from the daily cover material of clay restricting downward flow. Instead, channels of lower permeability develop laterally, resulting in a like movement of leachate and eventual break-out at the side.

- Water initially collected from the incompleted underdrain system at the Lycoming facility had shown increasing conductivity (up to 3-4,000 mg/l), but this was less than the conductivity of the leachate. Some of this increase may have resulted from lime that had been used on service roads for dust control. There had also been construction activities at the site which may have stirred up soils containing naturally high levels of iron and magnesium. Finally, animals are known to crawl into certain drains at the facility since dead ones have been flushed out on occasion. Decay products may have contributed to the increased conductivity. Recent monitoring of the completed, vented underdrain system showed decreases in the conductivity measurements (1,600 mg/l).

- No adverse impacts to aquatic life were detected in a recent aquatic survey of a stream downgradient of the landfill. Also, deep groundwater monitoring wells have shown no evidence of contamination to date.

Perspectives on Liner Installation and Performance

- Clay liners are used very little in the region. No such facilities could be cited.

- For liner systems having sand layers constructed adjacent to the flexible membrane for cushioning, such as at the Lycoming facility, the characteristics of the sand must be controlled carefully to eliminate any material that might puncture the membrane. The sand should have a gradation within the following approximate limits:

  - 90 percent passing #4 sieve;
  - 0-30 percent maximum, passing #200 sieve;
  - 0-15 percent maximum, passing #2000 sieve.

The sand grains should be well weathered to minimize abrasive contact with the flexible membrane, and all sand lifts should be spot-checked to ensure conformance with the specified gradation. Pockets of off-spec material sometimes occur in the original deposit from which the material was taken.

- Liner installation is particularly difficult during conditions of high wind. The sheets are large (approximately 100 feet by 270 feet) and are easily lifted by a strong wind.

- Manufacturers have been known to make unauthorized substitution of materials to use up inventories. This problem is not common but can usually be avoided entirely by monitoring purchase orders at all levels.

- PVC is seamed by solvent bonding, and all seams are tested by a portable air compressor and wand. The contractor is required to furnish this equipment, but frequently not enough is available on-site to allow testing of seams to keep pace with placement of the liner. The permit specifications should, therefore, be modified so that the owner can designate the number of pieces of equipment for leak checking that must be on site.

- The inspector is the owner's direct representative responsible for QA/QC, and the contractor should fully interface his operations with the inspector while seams are being checked. Repairs can then be made quickly as leaks are located, thereby minimizing greatly the chance of repairs being overlooked entirely.

- All factory welds should be checked for leaks in the field after the liner is in place. This, typically, is not done.

- Creases in the installed liner should be patched or filled with a caulking compound of polyurethane. After it has set, no difference should be discernable between the caulking and the surrounding PVC.

- The first lift of waste into a newly-constructed facility (that is, the material contacting the exposed surface of the bottom liner) should be screened carefully to eliminate materials that might puncture the flexible membrane.

- Operating errors are sometimes also responsible for tears in the liner, a typical incident being improper handling of heavy equipment. PVC repairs more easily in the field than most liner materials. Hypalon repair is notably difficult and effectively impossible under conditions of high moisture.

Perspectives on Regulations

- No improvements to current regulations could be suggested with exception of better definition of the sand when such a layer is constructed facing the flexible membrane. The sand characteristics (depth, type, gradation) need to be carefully specified to eliminate any possibility of the layer puncturing the liner.

- Some problems have occurred with installers, but none have been serious enough to warrant a licensing program.

Perspectives on Research and Development Needs

- New product development is suggested to concoct a caulking compound for field repairs of PVC (especially for covering creases) that has characteristics more closely resembling the liner material.

- The permeability of various liner materials needs to be determined better than the typical specification of a range of values with a lower limit. Such information would be more useful for needed calculations projecting movement of materials.

- It is difficult to correlate the characteristics of leachate with material contained in the facility. With the Lycoming County facility, for example, it is very uncertain exactly what has gone into the facility. With the exception of a number of industrial accounts, most of the material can be classified no better than as garbage, and the exact composition of this material is undeterminable. But even with the industrial accounts, the wastes received are only classified generically, the intent being mainly to ensure compatibility of the material received with others already held in the facility.

Miscellaneous

- Some of the current workers at the landfill are working off light sentences imposed under the state criminal justice system for crimes such as shoplifting, or are under various CETA-funded programs. Such workers are occasionally careless with heavy operating equipment, which sometimes results in liner damage.

Additional Suggested Contacts

Dr. Richard Dickenson; Dynamit Nobel-Harte, Inc.; Auburn, NY; 315-253-4433; for additional data on PVC liners.

Dr. Charles Staff; Staff Industries; Monte Claire, NJ; for liner fabrication information.

Bill Slifer; Watersaver Company, Inc.; Denver, CO.

Reference Documents

Copies of the following reference documents were provided to TRW:

- "Controlled Sanitary Landfill, Allenwood Site, Lycoming County, PA"; Contract Documents for Field III Construction, June 1982, and Section B Bid Forms.
- Addendum No. 1 to Contract Documents.
- Section 26. Sealing Existing Borings.
- Copies of Contractor's Financial Statement, Plan and Equipment Questionnaire and Experience Questionnaire.
- Target Schedule for Preconstruction Events.
- Transcript of Environmental Hearing Board Adjudication for Brary Township, Gregg Township and Elizabeth Steward vs. Commonwealth of Pennsylvania, Dept. of Environmental Resources and Lycoming County Commissioners, Docket No. 74-246-W, August 7, 1975.
- Lycoming County Landfill "General Plan" (Blueprint).
- Letter from R.H. Dickinson, Marketing Manager, Dynamit Noble-Hart, Inc., to Mr. Jerry S. Walls, Lycoming County Planning Commission, regarding specification testing of 4-year old sample taken from the landfill PVC liner.
- Sample "Module 1" waste input form.
- Listing of Waste Generators disposing of wastes at the Lycoming landfill.
- Sample leachate analytical data for May 1978 to October 1979.
- Sample groundwater monitoring well analytical data, quarterly analysis, dated 4 December 1981.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. C-3

PA Dept. of Environmental Resources, Bureau of Solid Waste Management, Norristown, PA : Dennis C. Orenshaw 215-631-2420

TRW: John Metzger
Sandra Quinlivan

16 December 1982

Summary

- In installing asphaltic liners, fluid application temperatures should be maintained above a minimum temperature in order to maintain low viscosity. Since asphalt adheres to rollers during the rolling operation, better results are obtained when two applications are made at half rate rather than one application at full rate, by having the spray nozzles on the spray truck mounted on the sides of the truck rather than on the back.

- Incoming residual wastes should be screened for oil content, and a maximum concentration level should be established.

- In installing synthetic liners, seams should have one-foot overlap to ensure adequate bonding. On sloping sides, overlaps should allow drainage away from the seam rather than into the seam.

- Most landfill facilities in the region have liners that are constructed of several layers. The installation of the primary liner, whether it be PVC, asphalt or other material, and the clay base which supports it, are the most crucial elements in the development of an adequate facility.

- The state's involvement during construction varies. In some cases, responsibility for QA/QC has not been independent of the contractor. The only independent check remaining then is the landfill owner, and his technical expertise or interest in the project may be somewhat lacking.

- Exhausted facilities are capped with permeable soil to encourage water to flow into the pile. Contact between the held waste material and the water is believed to promote stabilization. The majority of the total leachate production therefore occurs within a short period after the facility is capped, which corresponds with a period during which the liner is probably more resistant to corrosive conditions.

- Subsidence at older landfills is more the result of poor compaction practices than the construction of caps.

Background and Objectives

The Pennsylvania Department of Environmental Resources is divided into six regions. The Norristown regional office, which was visited, has jurisdiction over all state Region 1 landfills, including the following 10 facilities:

- Grows Landfill; Bocks County, PA
- Boyertown Landfill; Montgomery County, PA
- Western Berks Landfill; Berks County, PA
- Montgomery County Landfill; PA
- Pottstown Landfill; Montgomery County, PA
- Strasburg Landfill; Chester County, PA
- Knickerbocker Landfill; Chester County, PA
- Cloverdale Landfill; Berks County, PA
- Grand Central Sanitation; PA
- Brooks Landfill; PA

Of these sites, the most complete information is available for the Grows, Boyertown, and Stroudsburg landfills*. The Grows and Boyertown landfills have interim hazardous waste permit status. The Strasburg facility is primarily a sanitary landfill. The remaining landfills are municipal landfills for which little detailed data are available. The Grows landfill has a PVC liner which is underlain by 10 feet of clay. The Boyertown landfill has an asphaltic liner. The Strasburg site is also PVC-lined. Each facility has leachate collection by clay pipes draining to sumps.

The objective of this interview was to obtain an overview of the liner design and installation problems from a state regulatory perspective. The statements and assertions made reflect the experience with design, construction, and operation of the landfills under jurisdiction of the State Region 1 office.

Landfill Design and Operation

- Most landfills in the region utilize a liner consisting of a system of layers. The following cross-section is typical (layers in order of increasing elevation):

  - Clay base.

*The very voluminous and extensive state data files on these landfills, which include design information, were made available to TRW for review and/or photocopying during the visit. Because of schedule constraints, however, detailed review or obtaining photocopies had to be postponed to some future occasion.

- Layer of MC 30. This is a thin oil having the consistency of dirty motor oil. Its purpose is to provide a break in permeability between layers.
- Sand/gravel layer. This zone contains pipes and related appurtenances of a leachate detection system.
- Liner. A synthetic membrane.
- Flow layer. This layer contains a network of leachate collection pipes. Permeability is about 10^{-4} cm/s.

- The clay base is an essential part of a successful facility. An added margin of safety is provided by the synthetic membrane. The installation of the primary liner, whether PVC, asphalt or other material, and the clay base which supports it, are the most important elements in landfill design.

- Most landfill facilities in the region collect leachate and recirculate it to the top of the pile (applied by spraying) during the operational life of the facility. Once capped, the leachate is either held in a suitably constructed holding pond or, preferably, is routed to a POTW. At the Grows landfill, there is an on-site wastewater treatment plant with a complete aeration system; treated wastewater is discharged to the Delaware River. Leachate from the Boyertown and Strasburg sites is hauled off-site to hazardous waste treatment facilities. Very little leachate is generated at the Strasburg landfill because it is a new site.

- Caps are constructed of permeable soil only. Precipitation is thereby intentionally encouraged to enter the facility. This helps to stabilize the waste material and results in the largest volume of leachate being generated when the liner is new and probably better able to resist the corrosive characteristics of the leachate. Accelerating the rate of waste stabilization is considered appropriate since the long-term integrity of flexible membranes is highly uncertain.

- At most of the newer facilities, caps have been constructed carefully and little subsidence has occurred. At older facilities in the region, however, marked subsidence has often occurred. In an extreme case, slumping occurred at the Grows site. In general, the subsidence at older landfills is more the result of poor compaction of input wastes than the construction of caps.

Liner Installation and QA/QC

- Asphaltics are difficult to install as liner materials. During application, the material must be maintained above a minimum temperature to maintain low viscosity. Transfer from transport truck to application

truck is difficult when the material is cold, and the spray bars on the applicator tend to freeze up. Cold and inclement weather therefore can play a prominent role during installation. Asphalt also tends to adhere to the rollers during rolling operations. In addition, truck tires have a tendency to kick the material up and create small holes and bubbles in the surface. One cannot make two passes over the same area with the spray bar mounted on the back side of the truck. Two applications at half rate (possibly when the spray bar extends from the side of the truck) produce a better liner than one application at full rate. This side-spray technique was put into practice at the Boyertown site. Asphalt is not necessarily difficult to install, and rolled asphalt is not used. All materials (such as ACP-1 or AC-20) are sprayed and then harden into a thin layer of approximately one-half inch in thickness.

- The state's involvement during construction varies. A representative of the state is usually on-site on a daily basis, although during liner installation, additional inspections may be performed. In some cases, an inspection of the site is made by a special technical representative upon completion of each layer of the base.

- In some cases, no QA/QC has occurred independent of the contractor's internal program. Only the landfill manager can then ensure compliance with specifications, but he does not necessarily have the technical expertise needed to do an adequate job.

- Two specific field tests were noted as part of QA/QC:

  - Falling head/standing head permeability test.
  - Inspection of seams, visually only, for adequacy of gluing and to ensure that there is a one-foot overlap of PVC layers at the seams which slope downward.

- The Strasburg landfill currently has an application for a huge expansion under consideration by the state. As a supplement to their file, county personnel have put in recommendations for better inspection procedures and schedules during site construction and liner installation.

Siting Considerations

- One of the more significant siting considerations is the availability of cover material. Prior to being permitted, there should be an exact accounting of cover material, not merely an assurance that all needed material will be shipped in.

- Nearly all other criteria typically considered when siting a new facility are of marginal value. So long as regulations are complied with, a facility can probably be sited at any location.

- Political problems accompanying siting of a new facility usually far outweigh technical problems.

Compatibility Testing Requirements

- New regulations for hazardous waste landfills require compatibility testing. However, there seems to be no "clear-cut" policy on compatibility testing requirements at either the state or federal levels. The state has developed certain general guidelines. One example is that waste oils are not allowed at sites (e.g., Boyertown) with asphaltic liners, since the oil may dissolve the asphaltic material. Microphotographs of Boyertown leachate in contact with the asphaltic liner have recently been submitted to the Harrisburg regional office for analysis; no results or comments have been received to date by the Norristown office.

Perspectives on Regulations and Miscellaneous

- In general, current landfill regulations are considered adequate.

- Maximum concentration levels of oil in incoming wastes should be established for landfills with different types of liner systems.

- The concept of failure is nebulous and needs better definition. (What constitutes failure?)

Additional Suggested Contacts

- It was suggested that the following individuals be contacted for additional information on liners and compatibility testing:

  - Dwight Worby/Douglas Lorenzen
    PA Dept. of Environmental Resources, Bureau of Solid Waste Management
    Harrisburg, PA. Telephone: 717-787-7383

- For blueprints and mylars of the Strasburg landfill:

  - Martin and Martin, Inc.
    149 E. Queen Street, Chambersburg, PA 17201

Available Documents

The following documents can be obtained from the state office:

- For the Grows landfill

  - Module 1 waste input forms
  - Analytical data on influent to on-site wastewater treatment plant
  - Analytical data on effluent from WWT plant
  - Report on recommended 30-day compatibility test for Grows landfill
  - General background documents on site design, construction, and operation

- For the Boyertown landfill

  - Module 1 waste input forms
  - Leachate discharge reports
  - Background documents on leachate collection system
  - General background reports on site design, construction, and operation

- For the Strasburg landfill

  - Module 1 waste input forms
  - Leachate incident reports
  - Background documents on site design, construction, and operation
  - Letters and memoranda describing various landfill and leachate incidents (e.g., waste spill mop-up operations with straw bales)

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. C-4

PA Dept. of Environmental : Resources, Bureau of Water Quality Management Pittsburgh, PA	Michael Hospodar Andrew Kondis Scott McDougall Vince Luci 412-565-5091	TRW: Sandra Quinlivan John Metzger

17 December 1982

Summary

- Clay liners, particularly those of montmorillite clay, are preferred to synthetics. Many of the wastes handled in the region are a by-product of mining operations, and synthetic liners seem generally incapable of resisting the highly acidic characteristics of these wastes. Clay is also a locally abundant material.

- Some liner failures in the region occur as a result of subsidence. Many landfills are located over areas of extensive deep mines, resulting in highly unstable ground conditions.

- Regulations should be flexible to allow locational considerations such as use of deep and surface mines for waste disposal and use of clay as liner material.

Background and Objectives

The PA Department of Environmental Resources, Region 5, Pittsburgh Office, has jurisdiction over several hazardous waste landfills which are sited in abandoned strip mines or over deep mines. Although many of these landfills are unlined, several of the larger and more recently active sites are clay-lined. Three of these major sites - for which background reports, design data, liner and/or leachate data are available - are the Mill Services, Inc. landfills near Bulger, PA and near Yukon, PA, and the Municipal and Industrial Waste Disposal landfill near Elizabeth, PA. The objectives of this interview were to obtain: (a) the design, installation, and performance of the clay liners at the sites; (b) the perspectives of the regional office on liners and associated problems unique to their geological terrain; and (c) additional references and data sources. Much of the perspectives provided appears to reflect field experience and are qualitative in nature.

Principal Landfill Facilities Considered

- The Mill Services, Inc., Bulger, PA, landfill consists of two pits located over deep mines. The first pit is older and unlined and is almost totally covered with soil and bentonite; the second adjacent pit is only one year

old and is lined with clay. Leachate (seepage) is diverted to a collection lagoon at the old pit; the new pit has a downslope French underdrain system which leads to a settlement pond before treatment at a local WWT plant and discharge to local streams. There are 10 monitoring wells to different depths and aquifers around the site. Input waste is primarily neutralized pickle liquor. The raw waste is neutralized with lime, flocculated with a polymer and aerated prior to emplacement.

- The Mill Services, Inc., Yukon, PA, landfill consists of five landfill "lagoons", all located over a deep mine. One of the lagoons (No. 4) is lined with PVC. Another lagoon (No. 5A) is reportedly lined with bentonite clay. The remaining three lagoons are presently inactive. None of the lagoons has a real system of leachate collection or treatment onsite. Liquid supernatant from lagoon No. 4 is occasionally pumped to wastewater treatment system. A few minor surface seeps of leachate have been observed near the lagoons. Input waste is primarily neutralized pickle liquor and some organic wastes. There are no monitoring wells at the site.

- The Municipal and Industrial Disposal Co. landfill near Elizabeth, PA, occupies an abandoned strip mine. The site is bentonite clay-lined and has an extensive underdrain leachate collection system which leads to a holding lagoon. Leachate is removed periodically by vacuum truck and taken to a local WWT plant.

Perspectives on Liners

- As evidenced by their performance at the major landfills in the area, clay liners are preferred over synthetic liners because of the local availability of clay soils and because some synthetic liners (e.g., Hypalon) are incompatible with acid mine drainage and acidic wastes.

- Montmorillite clay is preferred because of its ion exchange capacities. Vince Luci of the regional office, who is considered an expert on clay liners, has studied various properties of this material and thinks very highly of it. It should be utilized with a copolymer organic (e.g., an acrylamide) which forms an organic linkage with the montmorillite clay and retards its shrinkage or expansion.

- There are problems with liners in general in the region because of the tendency for subsidence of the sites, many of which are located over deep mines.

- Each waste type must be evaluated individually against the clay liner. The permeability and interlattice structure of the clay are the most important factors affecting its performance. Synthetic liners are superior to clay liners from the standpoint of permeability.

- QA/QC is a most important consideration in any liner installation. Efforts should be made to recheck measurements, to verify the integrity

of seams, etc. Unless the clay liner is properly installed, it is essentially worthless.

Siting Factors

- The region is fortunate to have an abundance of surface and deep mines for use in waste disposal. Attempts are made to use the in-situ conditions and geology to maximum advantage.

Perspectives on Regulations and R&D Needs

- Current liner and landfill regulations are adequate and flexible, both at the state and federal levels.
- EPA should not ban clay for use in liners.
- Additional compatibility testing needs to be performed between various liner types and waste/leachate types.
- There is a need for the development of a synthetic liner which is highly resistant to acidic wastes (e.g., acid mine drainage, pickle liquors, etc.) which are commonly encountered in the region.

Additional Suggested Contacts

The following organizations/individuals can be contacted for further information:

- Mr. Gary Berman, Vice-President; Mill Services, Inc.; Pittsburgh, PA. Telephone: 413-343-4906.
- Mr. Vince Luci; Pennsylvania Department of Environmental Resources; Pittsburgh, PA, for details of liner performance.
- EPA/FIT team files at Ecology and Environment, Inc.; Rosslyn, VA.

Reference Documents

The following documents were provided to TRW:

- Selected hazardous waste monitoring (groundwater) reports.
- Excerpts from several geotechnical reports describing site layouts.
- Selected waste input reporting forms.
- Selected seepage analytical reports.
- List of hazardous waste generators.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. C-5

NJ Dept. of Env. Protection Division of Water Resources:	Merry L. Morris David Kaplan William Brown 609-292-0424	TRW: Sandra Quinlivan John Metzger
Solid Waste Administration :	John Castner 609-292-7744	
Bureau of Hazardous Waste :	Ernest Kuhlwein David Scott 609-984-4061	

20 December 1982

Summary

- More confidence can be placed in clay liners than in synthetics. The long term integrity of synthetic liners in contact with leachate is highly uncertain, and the effectiveness of such a liner is also very sensitive to careful control of construction practices.
- All liners leak; various quantities of leachate have been collected in the leak detection system underneath the primary liner at several NJ sites using Hypalon, Polyester BIDIM, PVC, DuPont 3110 primary liner and in-situ clay.
- Lack of adequate quality control during installation is a key source of subsequent problem with all liners. Accepting wastes which are incompatible with the liner material is another potential cause of liner failure.
- Liner failures result most commonly from build-up of leachate. Many landfill problems can, therefore, be avoided by providing a system to quickly remove leachate from the facility.
- In assessing liner compatibility, data from carefully designed laboratory tests must be supplemented with field data from operating sites, including data on leachate generation rates and characteristics; such field data currently do not exist and must be compiled.
- A large number of landfill facilities exist in the state, and for most, there are problems. Even most controlled landfills in the state show some organics in the surrounding groundwater.

Background and Objectives

The New Jersey Department of Environmental Protection, Trenton, NJ, has jurisdiction over approximately 160 operating landfills located throughout the state. Some of these have clay or synthetic liners; most are small, unlined municipal sites situated on old sand and gravel pits. Of the 160 total sites, approximately 20 are considered "problem" or "selected" sites. The most complete information is available for the following six relatively large and/or relatively new sites:

- DuPont; Carneys Point, NJ
- Monsanto Industrial Chemical Corp.; Bridgeport, NJ
- J.T. Baker Chemical Co.; Phillipsburg, NJ
- Toms River Chemical Corp. (now Ciba-Geigy); Dover, NJ
- N.L. Metals; Pedrickstown, NJ
- LiPari Landfill; Gloucester County, NJ

The first five of the sites are operating, secure hazardous waste landfills. The LiPari site is a closed municipal and industrial landfill. The objectives of this interview were to obtain information on: (a) the design, installation, and performance of various liners associated with the six sites; (b) the perspectives of the various state offices on liner performance and current landfill regulations; and (c) additional references and data sources to be contacted. The perspectives presented largely reflect the experience with operating landfills in NJ, in particular the six lined landfills for which brief descriptions follow.

Principal Landfill Facilities Considered

- The DuPont landfill began operations in January 1979. It is a 15-acre double-lined secure landfill consisting of three five-acre cells constructed with two liners of 0.03-inch nylon-reinforced Hypalon and a leak detection system between the two liners. Over 50 gallons of fluid per day have been collected in the leak detector. The principal waste inputs are dewatered primary WWT sludges and drummed and bulk solids from various DuPont facilities.

- The Monsanto site was established in 1978 and consists of a 3-acre landfill, double-lined with 12-inch compacted clay and having a 0.9-inch polyester BIDIM liner beneath the clay liners, and a leak detection system; and a 3.5-acre, 33,000 cy capacity clay double-lined surface impoundment. Within a month of start of operation, between 26 and 48 gallons of fluid were collected in the leak detection system.

- The J.T. Baker landfill is a 2.5-acre, 60,000 cy capacity site which began operating in 1979 and has two liners of 0.05-inch PVC film separated by a leak detector, which accumulates leachate at a rate of one to three gallons per day. The principal waste input is liquid WWT sludges.

- The Toms River landfill was established in 1979 and was constructed with a lower liner of 0.02-inch PVC and an upper liner of 0.03-inch PVC, which are separated by a leak detection system. The leakage rate has averaged between 60 to 131 gallons per day.

- The N.L. Metals landfill is a 5.7-acre, 145,000 cy capacity landfill having a 20-mil thick DuPont 3110 primary liner and a 2-inch AC-20-coated asphalt secondary liner. The site has a series of leak detector pipes and leachate collection sumps. Collected leachate is hauled via vacuum truck to an off-site wastewater treatment facility. The major input waste is bulk kiln slag from secondary lead smelting operations.

- The LiPari landfill operated between 1958 and 1971, and is underlain with natural clay. As part of closure, a bentonite slurry wall was constructed at the site, and an impermeable cap will be installed in the future. Passive gas venting systems will also be installed. There is extensive leachate generation and there have been incidents of leachate contamination of surface waters (e.g., Chestnut Branch and Rabbit Run) and groundwater.

Liner Construction, Performance, and QA/QC

- State personnel generally prefer clay liners to synthetics. The long term integrity of synthetics is a big unknown factor. Many sites (e.g., the Parklands municipal and industrial landfill) try to take advantage of natural clay liners, cut-off walls, or other natural features at the site.

- One of the principal problems with all liner systems is quality control during installation. Technical problems of quality control are sometimes compounded by landfill operators who are not fully aware of the problems involved. Many operators are not patient with, do not fully appreciate, or otherwise indirectly and unintentionally subvert quality control. Some liners that are intact before installation can turn into "swiss cheese" during installation. Moreover, seaming methods that work well under controlled laboratory conditions may not work well in the field. Even small gaps/cracks in seams can cause big problems later.

- There are permit requirements for QA/QC testing, but the specific tests utilized are fully at the discretion of the engineer on-site. In some cases, the party responsible for QA/QC has not been independent of the contractor/installer. On a continuing basis following construction, a quarterly or annual certification is required of each facility by a professional engineer.

- The principal problem causing failure of liners is build-up of hydraulic head. It is, therefore, imperative that the leachate be collected, and that such a system be properly maintained. Many of the sites in New Jersey either have no drains or malfunctioning ones.

- Another feature helping to ensure a successful facility is careful control over the materials that are placed in it. Despite legislation, some smaller facilities continue to accept liquid waste materials. Especially troublesome are septic tank pumpouts. These are notorious for their content of noxious materials and can, therefore, be highly corrosive to a liner. However, disposal of this material by landfilling has been practiced for many years and is not easily stopped.

- Subsidence varies greatly from site to site and is largely a function of operating and placement practices, especially compaction to minimize void spaces within the landfill.

- A public relations agent for DuPont was quoted saying that failures occurring in the liners are a result of installation practices, not of the material.

- The 0.1-inch thick Vestalin liner manufactured by Schlegel has been reportedly used effectively in European landfills. The material is available in 0.5-acre sheets and seams are spot-welded.

Liner Compatibility

- Long-term compatibility of the liner with leachate needs to be better understood. Under the current system, an escrow account is established to maintain each landfill for a period of 30 years. However, neither the period of leachate generation nor the resistance of the liner to it are known. Currently, the liner manufacturer is relied upon to provide compatibility data and guidance.

- Laboratory scale compatibility testing can be useful if carefully conceived. However, the most useful research would consist simply of compiling more data from existing sites.

Siting Factors

- The majority of the existing landfills are situated on old gravel pits. In siting new facilities, geological and hydrological factors are of primary importance; socio-political factors are secondary but are also of great importance. The least amount of opposition is incurred when existing landfills are simply expanded.

Perspectives on Regulations and R&D Needs

- All current landfills in New Jersey are required to have a liner and a leachate collection system. The liner can be either synthetic or natural material, but permeability through it must be less than 10^{-7} cm/sec. The DuPont, Monsanto, J.T. Baker, and Toms River landfills, as well as most new facilities, pretreat their collected leachate then discharge it to a POTW.

- The regulations should provide expanded monitoring requirements since even most controlled landfills are showing some organics in the groundwater. The present requirements are usually inadequate to interpret conditions or events at a site.

- One area of particular interest for R&D is characteristics of the leachate and especially its time variance. This is a difficult area because numerous factors influence the generation and composition of leachate (e.g., waste pretreatment, amount of rainfall, etc.), and little is currently known about how and how long leachate is actually generated. Leachate data for the Park Mills landfill may be useful in this type of study.

Additional Suggested Contacts

- Because of the large number of landfills under their jurisdiction, it was recommended that a large amount of additional detailed liner and leachate information on selected sites could be obtained if TRW would prepare a pseudo-questionnaire and circulate it among the 20-30 key state office personnel who handle the various individual site files. This effort would be performed with the assistance and under the direction of Dr. Merry Morris, and with the concurrence of Ed Londres, Assistant Director of Engineering and Permits Bureau.

- For additional information on the DuPont, Monsanto, J.T. Baker, and Toms River Chemical sites, contact Mr. Angel Chang, Senior Environmental Engineer, NJ State Department of Environmental Protection, Bureau of Hazardous Waste, 32 E. Hanover Street, Trenton, NJ, (609-984-4062).

- For information on a Rutgers University study on leachate plume formation, contact Jeff Hoffman or Kay Kassaback of the NJ DER, Division of Water Resources, Trenton.

- For data on pretreatment and discharge to sewers, contact Kenneth Goldstein of the NJ DER, Division of Water Resources, Trenton.

- For information on liner performance at several major NJ landfills, contact Jim Bell of the NJ DER, Bureau of Hazardous Waste, Trenton.

- For data on various synthetic liners used in the area, contact Mr. Douglas Fish, E.I. DuPont de Nemours, Kirk Mill Building, Wilmington, Delaware.

- Dr. Peter Montague, Center for Energy and Environmental Studies, Princeton University, Princeton, NJ, has additional reports on the DuPont, Monsanto, J.T. Baker, and Toms River Chemical sites.

Reference Documents

Copies of the following documents were provided to TRW:

- List of selected New Jersey "problem" landfills.
- Sample leachate analytical data and waste input data for the DuPont, Monsanto, J.T. Baker, and Toms River Chemical sites.
- Background memo describing the design, construction, operation, and proposed modifications to the LiParı landfill.
- Waste Identification and Definition document used in landfill permitting activities.
- Copies of the latest state regulations governing sanitary landfill closure and post-closure and pollutant discharge elimination system regulations.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. C-6

MD Dept. of Health and Mental Hygiene, Office of Env. Programs
Baltimore, MD

Robert M. Byer
Reid J. Rosnick
301-383-5736

TRW: Sandra Quinlivan
John Metzger

21 December 1982

Summary

- Most landfill facilities in the State of Maryland have clay liners consisting of either reformed or in-situ clay. Good performance requires minimizing emplacement of liquid wastes, removal of leachate, and proper site selection to avoid contiguous sand lenses and to take advantage of in-situ geology.

- QA/QC is important to ensure adequate performance of the liner. Comprehensive requirements of a QA/QC program should be specified to the contractor covering every conceivable problem. The requirements actually implemented might then be lessened according to the conditions that develop during construction.

- Areas of research needs include evaluation of alternatives to landfills and long-term permeability of clay liners, including leachate constituent transport.

Background and Objectives

In 1982, the State of Maryland had only one operational hazardous waste landfill, the BFI Solley Road facility in Glen Burnie, MD. This site, which has a clay liner, was closed on 31 December 1982. A second nearby site at Hawkins Point, near Baltimore City, will be expanded to include a new facility which will be lined with a 30-mil PVC liner. The liner is to be installed in January 1983.

The objectives of this interview were to obtain information on: (a) the design, installation and/or performance of the liners at the existing and new sites; (b) the general perspectives of the state on liner performance and current liner regulations; and (c) additional references and data sources. The perspectives expressed are based on the experience from the Solley Road and Hawkins Point sites, as well as other facilities in the State of Maryland.

Principal Landfill Facilities Considered

- The Solley Road facility, which operated from the early 1960's to 31 December 1982, was originally an uncontrolled landfill handling what was thought to be solely municipal wastes. The landfill is located on a

total of 50 acres; however, the active portion permitted to accept hazardous wastes contained approximately 8 acres. The in-situ clay in which the facility is located ranges in thickness from approximately 20 feet in the northwestern portion of the landfill to 100 feet in the eastern portion. This clay may be part of the Patapsco formation or the silt-clay facies of the upper Potomac group. Not all sand lenses encountered in the eastern portion of the landfill are water bearing. The lenses that do contain water do not appear to be hydraulically connected to the sands of the Patapsco formation. More study, however, is needed in describing this aspect of the site geology. The landfill was permitted to accept hazardous wastes in 1978 by means of an amendment to its Refuse Disposal Permit. Input hazardous wastes are primarily heavy metals-containing organic wastes from electroplating and iron and steel industries, and various organic wastes. A leachate monitoring well was installed in 1980; all collected leachate was removed via vacuum truck to local Chem Clear, Inc., for treatment and disposal.

- The EPA became involved with the Solley Road Landfill as part of their FIT (Field Investigation Team) program in the spring of 1981. Leachate seeps were noted at that time; however, BFI pumped and packed those seeps as they occurred. The FIT reported groundwater contamination based only on one round of samples. Due to the minute quantities of certain compounds encountered (ppb range), further study was in order. At that time, the amount of data collected was insufficient to draw a conclusion.

- BFI discovered construction problems with the original 6-well groundwater monitoring system in the spring of 1982 which may have caused improper sampling of the groundwater environment. A new 10-well system was developed by the State and BFI and installed by the company in the summer of 1982, capable of assessing site specific groundwater quality. At this time, insufficient data has been collected from the new well system to comment on groundwater quality.

- Closure of the landfill started on January 1, 1983, and will continue for approximately 6 months. When the site is completely closed, a clay cap will be emplaced with a soil cover to establish a proper vegetative growth. Leachate seeps continue to be identified and analyzed.

- The Hawkins Point landfill is an 8-acre site having three cells. This site is and has for sometime been very close to capacity, and a second nearby site is being planned. One cell of the existing site is a monofill of chrome ore tailings. The Hawkins Point landfill, including the chrome ore refuse monofill, is lined with reformed in-situ clay, as well as an 80 mil. high density polyethylene liner. No sand lenses are within at least three feet from the waste boundary. Leachate is collected via a drainage pipe network and is pumped to a PVC-lined lagoon, then is transported to Chem Clear, Inc., for disposal. Several leaks which have been observed have been attributed to the holding lagoon, which has been

in place for about two years. The new site will be small at first (approximately 30,000 cubic yard capacity) and will be operated by the Maryland Environmental Services, which is an agency of the State.

Specific Experience and Perspectives on Liner Installation, Performance, and QA/QC

- All permitted Controlled Hazardous Substances (CHS) disposal facilities within the State of Maryland are sited in naturally occurring or recompacted clay. Combinations of synthetic liners or recompacted clay supplement in-situ clay when deemed necessary. No liquid wastes are permitted to be disposed of in Maryland CHS disposal facilities. Leachate is removed as it accumulates from approved leachate collection systems. Where synthetic liners were used, no compatibility testing was performed. The liner manufacturer is relied upon to provide guidance in the area of compatibility.

- The liner proposed for the new Hawkins Point site is reformed in-situ clay and 80 mil. high density polyethylene. Welds will be made by overlapping the material and applying heat. Since welds should not be made when the ambient temperature is less than 40°F, the January-February weather can cause delays in installation. Because the subject Hawkins Point facility is small, an alternative approach might involve constructing a "mini-greenhouse" over the welding site to eliminate interruptions due to cold weather.

- The state usually requests the manufacturer to be on-site to certify proper seaming technique.

- QA/QC responsibilities are usually handled by a consultant hired by the contractor. Any compromise of QA/QC integrity is minimized by proof of performance of the contractor by the consultant whose records are maintained at the individual facility.

- All QA/QC requirements must be specified carefully in the construction permit for a facility. Unless every conceivable contingency is addressed, a less than satisfactory job is likely. Minor modifications lessening the QA/QC requirements can later be made as appropriate during construction.

- The performance of clay liners is related to several factors: (a) emplacement of liquid wastes - this should be minimized; direct disposal of liquids is no longer permitted in Maryland; (b) leachate build-up - this should also be kept to a minimum via collection and removal of leachate; (c) occurrence of sand lenses among the clay deposits - these may not be too troublesome unless they are hydraulically connected.

Siting Factors

- All in-situ geology should be taken advantage of as much as possible. This provides an additional margin of safety since the long-term integrity of the liner is questionable.

- There exists a siting board in Maryland, and all new sites as well as changes to existing ones must be considered by this group. In many cases, the only likely approach to minimize both locational and political problems is to expand an existing facility. The political barriers can be formidable.

Perspectives on Regulations and R&D Needs

- In certain areas of the regulations, it would be helpful to see specific number requirements (e.g., "A site having hydrogeological conditions X and Y must utilize 7 feet of clay and a 20-mil thick liner"). However, this too can cause problems if the established values are indefensible or not applicable to the particular site under consideration. Overall, regulations cannot effectively communicate policy. Problems are highly site-specific and should be treated as such to the extent possible. For example, with monofils, monitoring is simplified since the type of waste input to the fill is known. Not all requirements are therefore appropriate.

- Specific areas of R&D needs include the following:

  - Alternatives to landfills. There seems to be an underlying, but incorrect, assumption that many waste materials can be handled only by land disposal.
  - Mechanisms of transport of leachate constituents.
  - Long-term permeability of clay liners, including for inorganic wastes.
  - Standardization/regulation of monitoring well construction and especially of sampling procedures. One sampling problem in particular has been debated concerning sampling from wells, that is whether such samples should be field filtered, lab filtered, or not filtered at all prior to analysis. There is uncertainty concerning both the amount of constituents of the groundwater that sorb to silt and clay (particularly metals in the ppb range), and the public health and broader environmental significance of this. Proponents of field or lab filtering generally assume that the water's suitability as a potable source should be of principal interest, and that no water of high turbidity would thereby be used without filtration.

- Regulations can and do communicate policy. They are/should be based on best available technology. Site specific problems can be treated to a large extent within the framework of the regulations. Some general questions are suitable as research topics, and the results of research can be effectively applied. An example is identification of materials that degrade the liner.

Additional Suggested Contacts

The following organizations/individuals should be contacted for further information:

- Catherine Hodgkins; EPA/Philadelphia; for leachate seep analytical data for the BFI Solley Road landfill.
- Law Engineering, Inc.; Baltimore, MD; for additional hydrological and geological data for the BFI Solley Road landfill.
- Mr. Craig Fadam; Chem Clear, Inc.; for leachate analytical data for the BFI Solley Road and Hawkins Point sites.
- EPA/FIT damage case files on the BFI Solley Road facility.

Reference Documents

The following documents were provided to TRW:

- Selected excerpts from "Field Investigations of Uncontrolled Hazardous Waste Sites", FIT Project, TDD No. F3-8007-48, EPA No. MD-6, 1981.
- Report by Hardin-Knight Associates, Inc., Pasadena, MD, on results of permeability testing of Hawkins Point chrome ore leachate with clay soils.
- Copies of State of Maryland Title 10, Subtitle 51, hazardous waste regulations (12 December 1980), and addendum (8 January 1982), and proposed regulations (effective 30 January 1983).
- Extensive waste input data, leachate, and groundwater analytical data available.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. C-7

WI Department of Natural Resources, Bureau of Solid Waste Management
Madison, WI

: Peter Kmet
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TRW: Sandra Quinlivan

14 January 1983

Summary

- Most facilities in the State of Wisconsin use a liner system consisting of four to five feet of recompacted local clay, covered with 12 inches of sand and/or gravel, and containing the leachate collection system.
- A thickness of 4 to 5 feet reduces the chances for liner damage during installation.
- The state is extremely pleased with the performance of clay as a liner material, as evidenced by results of groundwater monitoring at many sites. Its concepts of liner and landfill design, construction, and operation have been proven effective and are currently being documented and disseminated.
- In addition to proven performance of clay liners, the preference for clay stems from its natural abundance and ready accessibility for landfill lining in Wisconsin.
- The type and thickness of clay are the most important factors affecting the performance of a clay liner.
- The existing state regulations require more emphasis on use of clay (as opposed to synthetic liners) and on siting factors for new facilities.
- There is a great need for R&D in areas of leachate prediction, compatibility testing, and landfill stabilization. In the realm of leachate prediction, exchange of information among those having "real world" leachate data for use in model testing is needed.

Background and Objective

The Bureau of Solid Waste Management, Land Disposal and Residuals Management Section, has responsibility for permitting and inspecting municipal and industrial landfills in the State of Wisconsin. There are approximately 1100 landfills in the state. Most of these sites consist of small unengineered

town dumps. However, it is estimated some 250 sites operate in accordance with engineering plans of varying detail and complexity. One design concept employed at 7 of the larger municipal solid waste landfills consists of the use of a recompacted clay liner and full leachate collection system. Several new sites are also currently being proposed utilizing this concept. The objective of this telephone interview was to obtain information on the perspectives of the state on the use of clay and synthetic liners. Specific topics discussed included: (a) considerations in design, construction, and installation of liners in typical facilities; (b) assessment of liner performance; (c) perspectives on current regulations and research needs; and (d) other references and data sources.

Landfill Design and Operation Considerations

- A summary of the design and operating characteristics of seven major, recently constructed landfills is presented in Table 1. As indicated in the table, all of the sites are clay-lined.

- Clay is highly preferred over synthetic liners in Wisconsin because of its availability throughout the state and its excellent overall performance. Most of the state's clay-lined landfills have clay deposits on the same or nearby properties. The Brown County Landfill, the City of Janesville Landfill, and the Waste Management, Inc. Landfill are situated in old gravel pits having clay overburden which was stripped off and later recompacted for use as the liner material. For the remaining sites listed in Table 1, the furthest that clay had to be hauled was 20 miles (for the Portage County Landfill).

- All sites have a sand and/or gravel blanket over the clay liner to facilitate drainage of leachate. Leachate is removed via a series of perforated pipes and directed to an external storage tank where it can be periodically removed for treatment. The goal of this system is to minimize the build-up of a leachate head on the liner.

- Although the state has a high degree of confidence in the use of clay liners, each site is carefully evaluated to insure there is minimal risk of groundwater impacts. Factors considered include the site's geology (soils, bedrock) and hydrogeology (depth to gel H_2O and direction of flow, existing water quality, location of site in flow system (recharge vs. discharge zone)), potential impacts on surface water bodies and existing or potential groundwater users. Each site must also identify a suitable clay source and method of leachate treatment.

- All of the landfills practice co-disposal of various industrial wastes such as boiler ash, manufacturing wastes, pulp and paper sludges, foundry wastes, and household chemical wastes with municipal trash.

TABLE 1. DESIGN AND OPERATING CHARACTERISTICS OF SEVEN MAJOR WISCONSIN LANDFILLS

Landfill	Start-Up Date	Capacity (in cubic yards)	Liner System	Leachate Collection System	Miscellaneous
Brown County, Green Bay, WI	1976	6,000,000	4 ft of recompacted clay, with 5 ft under the leachate collection lines, plus 12 inches of sand and gravel on top of the clay.	System of perforated ABS pipes (SDR 13, 6" ID) leading to holding tank; ∿1,000 gallons/day of leachate sent to local wastewater treatment plant via vacuum truck.	Site is currently at 20% of capacity, the following quantities of leachate were collected from 1977 to 1982. 29,900 gal/5 acres (1977), 224,550 gal/10.5 acres (1978); 505,950 gal/17.0 acres (1979), 257,225 gal/17.0 acres (1980), 376,801 gal/21.0 acres (1981); 325,986 gal/24.0 acres (Jan.-June 1982). Cost - $7.35/ton.
Seven Mile Landfill, Eau Claire, WI	1979	1,200,000	Same as for Brown County landfill, except 12 inch sand blanket	PVC pipes (Schedule 40, 4 & 6" ID) leading to holding tank; leachate sent to local wastewater treatment plant via vacuum truck.	Site has better overall design than Brown County site in terms of sloping of the base and certain other features. There are several leak detection suction lysimeters underneath the liner at this site. Cost - $18.75/ton.
City of Janesville Landfill, Janesville, WI	1979	700,000	5 ft of recompacted clay under entire site, plus 6 inches of sand and gravel on top of the clay.	PVC pipes (SDR 35, 4 & 8" ID) leading to holding tank. Leachate currently taken to wastewater treatment plant via vacuum truck, but a direct hook-up to the plant is being considered.	Site has experienced some suspected plugging of leachate collection lines by silt. Recent cleanout of the lines appears to have resolved this problem. The following quantities of leachate were collected: 0 gal/5.5 acres (1979); 555 gal/10.0 acres (1980), 29,200 gal/14.0 acres (1981); 13,000 gal/14.0 acres (Jan -May 1982). Cost - $12.00/ton. Cost - $12.00/ton.

(Continued)

TABLE 1. (Continued)

Landfill	Start-Up Date	Capacity (in cubic yards)	Liner System	Leachate Collection System	Miscellaneous
Waste Management Inc. Landfill, Muskega, WI	1980	1,300,000	Same as for Brown County landfill.	Same as for Seven Mile landfill, except Schedule 40 & 80 PVC, 4" ID.	No cost data available.
Marathon County Landfill, near Wausau, WI	1980	1,500,000	Same as for Brown County landfill, except 12 inch sand blanket.	Leachate directed to a clay-lined storage basin via SDR 35, 8" ID PVC pipes In addition, a layer of 20-mil PVC sheets connected to a riser was installed underneath a small portion of the clay layer to monitor liner leakage.	The following quantities of leachate were collected: 267,224 gal/4.5 acres (1981); 186,415 gal/7.0 acres (Jan.-June 1982). Cost - $14.00/ton.
Portage County Landfill, near Portage, WI	1982	---	Same as for Brown County landfill.	Same as for Seven Mile landfill, except 6" ID, Schedule 80 PVC pipes. In addition, a 30-mil PVC liner and riser system similar to that at the Marathon County site was recently installed.	Cost - $15.90/ton.
Sauk County Landfill, near Madison, WI	1982	1,200,000	Same as for Brown County landfill, except 6 inch select gravel plus 6 inch sand blanket on clay.	Same as for Portage County landfill.	Cost (estimated) - $14.81/ton.

- At the Marathon County, Portage County, and Sauk County landfills, a 30-mil PVC sheet connected to a riser has been or is currently being installed under a small portion of the clay liner at each site to monitor leakage from the clay liner. There are no results as yet from these monitoring systems.

Liner Construction, Installation, and Performance

- Construction activities typically involve preparation of subgrade, extensive staking and surveying to insure proper thickness and slope of liner, compaction of clay in thin lifts, testing of clay as it is placed, installation of leachate collection system, sand blanket placement, construction of drainage structures and site access, and installation of monitoring devices.

- On-site inspections are the responsibility of the consulting firm, which must provide the state with "as-builts" which certify that the site was constructed according to state-approved plans and which document any deviations from these plans. State personnel will periodically go out and do quick visual inspections of the landfill grades and general construction procedures. The state would be much more likely to become more heavily involved in the inspections if only a one-foot thick clay liner were being installed instead of a four- or five-foot thick liner. Since they are convinced that their four- to five-foot design requirement is adequate, as evidenced by the fact that all monitored sites are working effectively (i.e., that no changes in groundwater quality have been observed at any of the sites), there are less stringent state inspection requirements.

- Prior to construction of the liner, a sample of clay from the clay source is subjected to an extensive laboratory physical testing which includes the following measurements:

  - Proctor and/or modified Proctor density (a minimum compaction spec of 90 percent mod. Proctor is usually specified).
  - Permeability at different densities (a maximum permeability of 1 x 10^{-7} cm/sec is required).
  - Grain size. The clay and silt fraction of the sample must be greater than 50 percent passing a #200 sieve without excessive stones or gravel.
  - Atterburg limits. A liquid limit of 30 and a plasticity index of 15 or better, to insure high quality, readily compacted clay.
  - Attenuation characteristics. The candidate clay must be at least 25 percent clay.

- Cation exchange tests are felt to be desirable but are not yet mandated (see later comment on costs).

- High-shrinkage bentonite clays are considered inferior to other types of naturally occurring Wisconsin clays.

- No compatibility testing between leachate and clay is currently required by the state, but they are seriously considering it. Up until now, there wasn't thought to be any problem, based on the waste input types accepted. However, recent research sponsored by EPA has raised this as a concern. Hence, it likely will be required at some of the newer sites, or expansions of existing facilities.

- The state is extremely pleased with the performance of the four- to five-foot thick clay liners, based on no changes in groundwater quality which have been observed in any of the sites listed in Table 1. All sites have extensive groundwater monitoring systems for which samples are routinely analyzed for pH, conductivity, alkalinity, COD, total hardness, iron, and chloride. There had been a strong trend toward the use of clay in the state as far back as the late 1960's and early 1970's. The Brown County landfill, which was constructed in 1976, was the first site that actually was constructed utilizing a well documented recompacted clay liner. The state is also quite pleased with its overall leachate collection and general landfill design concepts, and is at the point of documenting these and disseminating them to other agencies/organizations in other parts of the country.

- The most important factors affecting the performance of the clay liner are the type and thickness of the clay itself. (A good quality clay will facilitate construction and provide an effective barrier to leachate migration.) Other factors which may affect performance (e.g., subgrade preparation, recompaction techniques, equipment handling, etc.) are also important but are really secondary. For example, at one of the landfills, a careless driver crossed the liner and rutted it up; However, because the layer of clay was so thick, it would not have affected the liner's effectiveness if left uncorrected.

- Other considerations in proper site operation are adequate design and installation of leachate collection lines with respect to the liner, and of other equipment. There have been a few incidents in Wisconsin landfills involving collection system failures. For example, at the Seven Mile landfill near Eau Claire, a leachate collection line was crushed during filling. Department staff feel this could have been avoided if the line had been installed in a trench in the liner rather than directly on top of the liner (providing little lateral support). This has been required at other sites with no reported failures to date. At this same site, a leachate holding tank broke due to improper design.

- Regarding closure requirements, clay-lined landfills are also required to be clay-capped to minimize leachate generation. Closure is generally performed in phases; that is, the landfill is built, filled, and abandoned in a phased manner in modules. The specifications for the clay

cap are less stringent than those for the liner. The Seven Mile landfill is currently experimenting with use of a paper mill sludge cap for closure of filled cells. All sites are required by state statute to set aside monies for the closure and long term care for at least 20 years. LTC includes land surface care, monitoring and leachate removal and treatment. A special state fund has been established to care for sites after the 20 year owner responsibility.

Perspectives on Regulations

- The current federal regulations emphasize synthetic liners rather than clay liners. Wisconsin doesn't have a great deal of experience with synthetic liners as yet, but in general they would like to see more extensive use made of clay systems which are performing adequately there.

- The federal regulations currently do not adequately consider siting factors, especially the hydrological, geological, and other physical characteristics of new sites. There should be more concern for the risk to aquifers in the event of liner failures.

- Approval for new facilities have been handled in Wisconsin on a case-by-case basis. However, now that the state is becoming more confident of the performance of clay liners and of their landfill design criteria in general, they are beginning to document their design criteria and are considering making them mandatory throughout the state.

Research Needs

R&D efforts would be worthwhile in the following areas:

- Liner compatibility testing. Studies should be conducted either by the applicants or by research institutions on various liner materials.

- Materials (e.g., piping filter fabrics, tanks) compatibility testing. Research is needed to determine the compatibility of PVC, ABS, and other materials used in leachate collection lines. There have been a few incidents at Wisconsin sites involving failures of collection lines and holding tanks. Although these incidents were thought to be due to mechanical problems, the area of compatibility still needs to be explored. Also, methods for detecting leaks below liners need to be developed.

- Leachate prediction, both qualitative and quantitative. Several models have been used in Wisconsin for leachate plume prediction and landfill design. The state relies primarily on the U.S. EPA water balance method (1975) for predicting the quantity and timing of leachate generation (see internal staff memorandum). To determine liner efficiency and

evaluate design options, Department staff use a variation of a model developed by Dr. Wong (Water Resources Research, Vol. 13, No. 2, April 1977). The model is discussed in a paper presented by Kmet, Quinn, and Slavik (see References section). For industrial wastes, various laboratory leaching tests have been used in an attempt to predict leachate quality. These models and methods need to be verified using "real world" data. There is also a need for a better mechanism of exchange of information among various agencies having real leachate generation data.

- Landfill stabilization. The actual length of time required for stabilization needs to be determined as a function of waste types and fill configurations. Laboratory studies using lysimeters need to be confirmed by "real world" conditions.

Additional Suggested Contacts

The following individuals have extensive experience/data in the indicated areas:

- Mr. Dan Kolberg; Warzyn Engineering Co.; Madison, WI; (608-257-4848); for details of landfill and liner design and installation. (Firm has experience with several sites.)

- Mr. Clarence Stoffel; Owen-Airs & Associates; Eau Claire, WI; (715-834-3161); for information on synthetic liners. (Also design firm for Eau Claire Site.)

- Dr. Robert Ham; University of Wisconsin; Madison, WI; for landfill and liner design and performance.

References Provided

- P. Kmet and P.M. McGinley. "Chemical Characteristics of Leachate from Municipal Solid Waste Landfills in Wisconsin", presented at Fifth Annual Madison Conference of Applied Research and Practice on Municipal and Industrial Waste, Sept. 22-24, 1982, University of Wisconsin Extension, Madison, WI.

- P. Kmet, K. Quinn, and C. Slavik. "Analysis of Design Parameters Affecting the Collection Efficiency of Clay Lined Landfills", 1981.

- P. Kmet. "EPA's 1975 Water Balance Method - Its Use & Limitations", Internal Staff Memorandum, 1982.

4.4 INTERVIEW REPORTS WITH RESEARCHERS IN ACADEMIC AND RESEARCH ORGANIZATIONS

D-1. Southwest Research Institute

D-2. University of Texas

D-3. Texas A&M University

D-4. Matrecon, Inc.

D-5. Denver Research Institute

D-6. U.S. Army Corps of Engineers, Waterways Experiment Station

D-7. U.S. Bureau of Reclamation

D-8. Illinois State Geological Survey

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. D-1

Southwest Research Institute: David Shultz
San Antonio, TX 512-684-5111

TRW: Michael D. Powers
Michael T. Haro

13 December 1982

Summary

- A non-destructive method to detect and locate leaks in synthetic liners is being tested. The method can be applied to existing as well as new surface impoundments or landfills, and can be used for monitoring or liner QA/QC.

- There is no way to 100 percent guarantee that a liner will not fail; there are too many things that can go wrong.

- All possible sources of problems should be explored during the design and/or construction phases, and contingency plans made for correcting problems as they occur. Landfills and surface impoundments should be designed so that the liner can be reached for repairs.

Background and Objectives

Shultz's research has centered on problems of liner installation and performance. His most recent work has focused on an electrical resistivity method that will allow the detection and location of leaks from synthetic liners. Objectives of this interview were to obtain information on: (a) background, results, conclusions, and recommendations from studies to date; (b) Dr. Shultz's perspectives on liner installation and performance; (c) planned research efforts; and (d) additional references and data sources to be contacted.

Prior and Current Research

- Shultz has completed an EPA-funded study, "Case Studies for Lined Impoundments" (Grant No. R806645010); a draft report has been submitted and is currently undergoing review. A project to conduct follow-up studies of the sites visited has not been funded.

- Shultz and his colleagues at SWRI are currently testing an electrical resistivity method designed to detect and locate leaks in synthetic liners. Preliminary computer and small-scale physical modelling are complete; SWRI is now in the process of building a small (one acre) surface impoundment for field-testing the method.

- Dr. Shultz expects the method to be applicable for both surface impoundments and landfills, and can be used at existing sites as well as being built-in at new facilities. It is expected that the method will enable leaks to be discovered before groundwater contamination occurs; the only other methods available at present (i.e., groundwater monitoring) will not detect leakage until after a contaminant plume has travelled to the nearest down-gradient monitoring well at a concentration that can be detected. The method can be used as a QA/QC leak test; it is more sensitive than water balance testing because no estimates of evaporation need to be made, and even very small flows will be detectable. The method may also be applicable to detecting gas leaks in landfill caps. The method requires a conducting medium such as water or soil in the impoundment that is separated from the underlying soil by a high resistance liner material such as synthetics; the resistance of clay is too low for the method to work. Current is injected by means of electrodes located inside the impoundment, and at a distance well outside. The resulting electrical field is analyzed by measuring the voltage at various points across closely spaced electrodes. In the absence of a leak, current flows only through soil at the buried edge of the liner. Current flows through the liner only where a leak is present; the resulting current produces an anomaly in the field which can be located with fairly high accuracy.

- Other projects, either in progress or forthcoming, include:

  - A study of ways to retrofit existing leaky fluid impoundments without taking them out of service. One of the proposed methods involves pulling a flexible membrane across the surface, then pumping the fluid onto the top of the membrane: a "pump-over" technique. The other involves pulling a membrane along the bottom contour of the impoundment: a "pull-through" technique. Both techniques are seen as temporary "quick-fixes" of leaking facilities that are to be drained and retired within a short period of time.
  - Additional remedial action studies involve repairs to existing facilities, using grout or patching with synthetic sheeting.
  - A monitoring system will be tested using electrical resistivity readings made from boreholes spaced around the perimeter of the small test impoundment being installed at SWRI. Anomalies in the electrical field caused by fluids flowing through leaks can be detected and then located by triangulation.
  - One corner of the SWRI test impoundment will be used by EarthTech to demonstrate the feasibility of using acoustic emission and time-domain reflectrometry techniques for leak detection.
  - An RFP has been sent out by EPA for a study on the success or failure of liners. Unfortunately, the major source of such data lies in the files of the installers and manufacturers; such data are generally not available, but could be pried loose by tying permits to the release of the data. Even with such data, we may never be able to determine for sure the cause of a liner failure.

Perspectives on Liner Installation and Performance

- There is no way to 100 percent guarantee that a liner will not fail; there are too many things that can go wrong (i.e., ground shifting, poor installation, heavy equipment damage, damage from wildlife). Synthetic liner sheeting has the potential to contain fluids, but most realize the limitations; it is not possible to just install a liner and then forget it. However, if a facility has been properly designed, installed, operated, and maintained, if it is properly monitored, and if the operation has adequate contingency plans for handling problems as they occur, it is possible to be reasonably confident about the overall performance of the liner. Several possible ways to alleviate problems are:

  - Design landfills and surface impoundments so that the liner can be reached, if necessary, for repair. Multi-cell facilities, spread over larger areas so that they are not as deep, would help in this regard; landfills 150 feet deep or surface impoundments 80 feet deep would not be amenable to liner repair.
  - All possible sources of problems should be explored during the design and construction phases, when potential leaks can be sealed easily.
  - Better QA/QC during construction and installation.
  - Performance monitoring of the liner system.

- Installation QA/QC requirements should be developed by EPA with industry participation. Regulations should contain guidelines for the content of the QA/QC effort; third party installation QA should be required, in much the same way as required by the NRC.

- Dr. Shultz says that the owners of facilities are ultimately responsible for leachate damages, not the liner installers; the owners "should be willing to take the ball and run with it", since they are the ones likely to be sued in the event of a failure. Part of the problem is deciding what an owner should be required to do. Many times, owners are ignorant of what is actually happening, relying instead on the consulting engineer; often, the best techniques for construction, installation, and operation are not being communicated by EPA, consultants, or contractors. Another part of the problem is the chain of responsibility; in many cases, this is long and complicated, with the owner far removed from the actual liner installation contractor. In such instances, an owner may hire the design engineer who subcontracts to the general construction contractor, who in turn hires the dirt-work contractor, who finally hires the installation contractor, with the type and manufacturer of the liner possibly being chosen at any of these levels.

- "If the [electrical resistivity] method does what we want it to, it should be put into the regulations". However, the method should not be required by regulations without a qualification regarding its applicability. Instead, a performance standard is probably more appropriate.

- Where phased expansion of a landfill is planned, an area along the edge of the liner in the existing disposal area should be protected from contact with the wastes. This will prevent the deterioration of the surface of the sheet, and will facilitate bonding of the old and new liner sheets.

Documents Cited

The following documents were cited by Shultz; no new documents were provided.

- Shultz, David W. Case Studies for Lined Impoundments (Draft). U.S. Environmental Protection Agency, Cincinnati, Ohio. 58 pp.

- Shultz, D.W. and M.P. Milkas, Jr. Procedures for Installing Liner Systems. In: Land Disposal of Hazardous Waste, Proceedings of the Eighth Annual Symposium. EPA-600/9-82-002, pp. 224-238.

- Shultz, D.W. and M.P. Milkas, Jr. Installation Practices for Liners. In: Land Disposal, Hazardous Waste Proceedings of the Seventh Annual Research Symposium. EPA-600/9-81-002b, pp. 157-166.

- Shultz, D.W. and M.P. Milkas, Jr. Assessment of Liner Installation Procedures. In: Disposal of Hazardous Waste, Proceedings of 6th Annual Research Symposium. EPA-600/9-80-010, pp. 135-146.

- Peters, W.R.; D.W. Shultz; and B.M. Duff. Electrical Resistivity Techniques for Locating Liner Leaks. In: Land Disposal of Hazardous Waste, Proceedings of the Eighth Annual Symposium. EPA-600/9-82-002, pp. 250-260.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. D-2

University of Texas: Dr. David E. Daniel
Austin, TX 512-471-1555

TRW: Michael D. Powers
Michael T. Haro

13 December 1982

Summary

- Actual permeability of an installed clay liner may be as much as 2 or 3 orders of magnitude greater than that predicted by laboratory testing due to:
  - Differences in field and lab permeability tests
    - -- differences in compactive effort;
    - -- small laboratory sample size not representative of the overall liner;
    - -- lab samples are uniformly moistened prior to compaction whereas soil in the field is not.
  - Desiccation of the clay liner between the end of construction and the beginning of operation.
- All liners leak; even under the best of conditions, the requirement for an impermeable liner cannot be satisfied.
- Field testing of clay liner permeability and construction techniques aimed at improving the quality of finished products are recommended.

Background and Objectives

Dr. Daniel's main area of research centers around the flow of fluids through fine grained soils such as clay. Recent work has focused on the problems of fluid leakage through compacted clay liners. The objectives of this interview were to obtain information on: (a) background, results, conclusions, and recommendations of Dr. Daniel's studies to date; (b) Dr. Daniel's perspectives on liner installation and performance; (c) Dr. Daniel's current and planned research effort; and (d) additional references and data sources to be contacted.

Background and Recommendations Based on Case Studies

Dr. Daniel has analyzed data for several leaking clay liners in Texas. The work has resulted in the development of specific conclusions and recommendations for soil permeability testing and clay liner construction. The case studies include work with two leaking reflecting pools in San Marcos, TX,

in which Dr. Daniel was involved as a consultant as well as in analysis of data obtained from the Texas Department of Water Resources and from other sources on a number of leaking ponds in Texas.

- Case Studies:

1) Reflecting pools in San Marcos, TX. In 1980, Dr. Daniel was contacted by a consulting engineer to assist in resolving problems with two reflecting pools in San Marcos, TX. The natural soil at the site consisted of 5 ft. of clay overlying gravel deposits. However, in order to achieve the desired 5-foot depth, the ponds had to be excavated through the clay into the underlying gravel; the excavated clay was to be stockpiled and then recompacted to form a liner. Laboratory tests of the clay compacted indicated permeabilities in the 10^{-7} to 10^{-10} cm sec^{-1} range, with 10^{-8} being a typical value. Field density tests of the as-built liners indicated compaction to about "optimum", but with a moisture content about 2% below optimum. When an attempt was made to fill the ponds, it was found that the ponds would not hold the design depth of 4 ft. of water; leakage exceeded pumped in-flow at a depth of 12 inches. The ponds were subsequently allowed to drain; using the fall rate, evaporation rate, and prior pump rate, permeability was estimated to be 2×10^{-5} cm sec^{-1}. An actual field permeability test was run with similar results. The liner was removed, recompacted wet of optimum, with filling commencing immediately upon completion, so that no desiccation of the clay was allowed. Field permeability tests had marginally lower results (about 10^{-6}), which did allow the ponds to be filled to their design depth. Laboratory permeability tests of clay compacted much drier than optimum still had results close to 10^{-7} cm sec^{-1}, as did tests of an "undisturbed" sample.

   Data and experience with the reflecting pools case study thus indicated that a larger sample size resulted in much higher measured permeabilities. Testing of large undisturbed samples resulted in permeabilities in the 2×10^{-5} to 2×10^{-6} range, whereas recompaction of smaller samples of the same clay has results two to three orders of magnitude lower. This effect may be due to the presence of large, surface-wet clods of clay; moisture does not have adequate time to penetrate to the dry and cracked interior portions of the clod.

2) Power plant cooling pond in Texas. At a Texas power plant cooling pond with a bentonite-soil admixture, monitoring wells indicated a groundwater mound beneath the site. Using very conservative assumptions (e.g., using the volume of water currently in the mound as the total discharge), effective permeability was estimated to be about 10^{-6} cm sec^{-1}. Double-ring field permeameter tests had similar results. Laboratory studies by the power company's geotechnical consultant showed much lower permeability.

3) Brine pond near Corpus Christi. This pond leaked badly. Using conservative assumptions similar to those above, permeability was estimated to be in the 10^{-5} to 10^{-6} cm/sec^{-1} range.

4) Cooling pond in Northern Mexico. Estimates of effective field permeability for this pond, which was also leaking, were more than 10 times the results of field tests when the pond opened, and laboratory values.

- Conclusions from the case studies:

1) Desiccation of the clay liner between the completion of construction and the commencement of operation allows the clay to become severely cracked, resulting in much higher effective permeabilities.

2) A non-uniform moisture distribution in the soil results in clods with wet surfaces, but dry, cracked interiors that allow rapid leachate migration. This problem is in part due to: (a) inadequate break-up of large clods during compation; (b) large water trucks do not distribute water evenly; and (c) inadequate time is allowed for the water to penetrate the soil.

3) Allowing compaction dry of optimum to less than 95% of Proctor density results in a high permeability clay liner. This is caused in part by the optimum water content shifting a few percent "wetter" when less energy is used in compacting soil; soil compacted "dry" of optimum can be several orders of magnitude more permeable than soil compacted at or greater than optimum.

4) Small roots and other homogeneities in the clay adversely affect permeability.

- Recommendations based on results from case studies:

1) Clay liners should usually be compacted wet of optimum, with final density at or greater than the Proctor maximum measured in the laboratory.

2) Dirt-work construction specifications should specify smaller clods; a 3-inch maximum size would be ideal, but 6 inches may be all that can be achieved using current equipment and techniques.

3) Achieve uniform moisture distribution, for example, by premoistening clay so that it is thoroughly hydrated.

4) Protect the clay liner from desiccation from the completion of dirt-work to the start of operation. Examples of ways to do this are: (a) spray on a thin coating of asphalt; (b) use of thin membrane of polyethylene (or other synthetic); (c) use of 1 to 2 feet of soil; and (d) put water on the liner immediately.

Perspectives on Liner Installation and Performance

- All liners leak, even under the best of conditions. Based on the results from the case studies presented above, it is not possible to make an impermeable liner; requiring prevention of seepage through liner for 30

years may be very difficult. Actual seepage velocity through liner is very much faster than that predicted by Darcy's law, based on total porosity:

$$v = ki/n$$

where v = velocity
k = permeability
i = hydraulic gradient, $\Delta H/\Delta l$
n = porosity

In clays, part of the void space is filled by cations and water molecules adsorbed along the clay layer surfaces. In addition, many pores have no outlets; they are, in effect, "dead ends". These two factors result in an "effective" porosity much lower than the total void space expected. Dr. Keros Cartwright of the Illinois State Geological Survey has found that effective porosity of clay is about 1 to 3% (as opposed to 30-40% total porosity). Thus, actual velocity of a fluid through the clay is much faster than might be expected based on apparent porosity.

- EPA should include installation QA/QC requirements in new regulations. These requirements should include:
  - Measurements of dry unit weight and moisture content of the compacted soil.
  - Field permeability tests; laboratory tests are often useless. Possible ways of field testing the liners are: (a) during the design phase, build a test liner and test over a relatively large area for 2-4 weeks; and (b) test the first lift of fill over a relatively large area.
  - A QA/QC inspector should be on-site (most dirt-work contractors are used to having inspectors on-site).
  - Desiccation of the clay should be minimized.
  - EPA should also require data on seepage after operation begins, to allow an estimation on "back-calculation" of actual permeability.
  - The current lack of a standard method for determining permeability in the field must be addressed. Dr. Daniel is currently working with ASTM Committee D-18.20 on the development of such a test, but expects that it will be some time before a consensus is reached.
- Licensing of installers will not ensure quality work. Almost anyone can be an installer now, and would be able to continue after a licensing requirement took effect. Requirement for a QA/QC inspection by a third party is preferable to licensing of installers. It may be difficult to get really qualified QA inspectors, but a training system or manual would help.
- We know almost nothing about the long-term performance of liners. The best source of data regarding performance of clay liners is earth dams; they have been around a long time, and with a few notable exceptions, they have performed relatively well.

On-going and Planned Research

Research work currently being carried out or planned by Dr. Daniel includes the following:

- EPA-sponsored project. This research centers on the permeability of clay liners and includes:
  - Comparison of results from field and laboratory permeability tests.
  - Testing of a flexible wall permeameter apparatus. This design should correct a problem seen in fixed wall permeameters wherein the clay "liner" can separate from the solid walls, allowing a seepage path around the clay.
  - Compatibility of compacted clay liners with wastes using concentrated organic chemicals and hydraulic gradients of 2, 10, 50, 300, and 1000.
- CMA-sponsored study. This study will expand upon K.W. Brown's basic clay permeability work by changing some variables including use of several concentrations of the organic chemicals, and real leachates (to be supplied by CMA).
- NSF study. A two-year project for NSF will evaluate clay liners for hazardous waste sites. The study will seek to address the following: (a) why is the permeability of clay so hard to predict; (b) is desiccation a critical factor; and (c) is clay clod size a critical factor?
- Use of drilling mud to produce sand-bentonite liner. A waste disposal study for Texas Petroleum Resources Commission to determine if bentonite from liquid drilling mud can migrate into sand, forming a sand-bentonite liner.

Reference Documents

- Copies of the following reference documents were provided to TRW by Dr. Daniel:
  - Daniel, D.E. Predicting Hydraulic Conductivity of Clay Liners. Undated preprint.
  - Daniel, D.E. Problems in Predicting the Permeability of Compacted Clay Liners. In: Symposium on Uranium Mill Tailings Management; Fort Collins, CO; October 26-27, 1981; Colorado State University.
- In addition, Kirk Brown of Texas A&M referred TRW to the following papers by Dr. Daniel and his colleagues at UT, in Permeability and Groundwater Contaminant Transport, ASTM Publication STP 746, 1981:
  - Olson, R.E. and D.E. Daniel. Measurement of the Hydraulic Conductivity of Fine-grained Soils.
  - Hamilton, J.M.; D.E. Daniel; and R.E. Olson. Measurement of Hydraulic Conductivity of Partially Saturated Soils.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. D-3

Texas A&M University: Dr. Kirk W. Brown
College Station, TX 713-845-5286

TRW: Michael T. Haro
Michael D. Powers

14 December 1982

Summary

- Clay may be acceptable as a liner if: (a) the leachate does not adversely impact the permeability of the liner (as would be expected with dilute inorganic, and possibly even dilute organic materials), and (b) a properly designed and managed leachate removal/disposal system is provided or the site is in certain geological settings where a small leak rate is acceptable.

- Organic fluids can substantially increase the permeability of compacted clay soils; the permeability of prospective clay liners should be tested using the leachate to which they will be exposed.

- Possible detrimental effects of differential settlement of waste on clay caps are unknown. Long-term usefulness of caps for hazardous waste landfills is not known.

- There are no comprehensive data on successes and failures of flexible membrane liners, nor is there long-term experience with liners in landfill situations. The data base for exposure of liners to hazardous waste covers only a few waste streams.

- The technology does not now exist that would allow the proper installation of flexible membrane liners. Also, the degree of quality control in flexible membrane manufacturing plants is not acceptable; some new techniques have been researched but are not yet in widespread use (e.g., spark-gap or vacuum technology for pinhole detection).

- No liner presently on the market can stand up to the full range of chemicals which might be found in a hazardous waste landfill.

- The use of alternative disposal techniques (e.g., incineration and land treatment) and waste recycling should be encouraged, while the use of "classical" landfills should be discouraged. The smaller volume of wastes not disposable by these alternative techniques should be placed in aboveground landfills where it is much easier to maintain, monitor, and clean up the facility in the event of failure.

Background

Dr. Kirk W. Brown is a soil scientist with the Soil and Crop Sciences Department of Texas A&M University in College Station, Texas. Dr. Brown's major interest is with installation and testing of clay liners. He is the author of several reports on the subject of the effects of organic fluids on the permeability of clay soil liners. Dr. Brown has also published a technical resource document for EPA on hazardous waste land treatment. Dr. Brown is well respected in his field and has testified before Congress concerning his studies and other hazardous waste disposal matters.

Current Research

- Laboratory investigations showed that organic fluids can substantially increase the permeability of compacted clay liners. These findings in part were regrettably responsible for the newly instituted regulations that require flexible membrane liners. As soon as data were developed with concentrated organic liquids, only one end of the spectrum, EPA abandoned clay liners in favor of flexible membrane liners for lining disposal facilities. There are several situations in which clay liners may be acceptable, such as those facilities that would generate inorganic leachate or possibly even dilute organic leachate.

- In the field study, 28 cells were constructed using reinforced concrete and lined with a 100 mil thick high density polyethylene (HDPE) liner to facilitate leachate collection. The field cells (with 1.8 cubic meter volumes) were fitted with clay liners compacted to at least 90 percent Proctor density. Perforated barrels containing a xylene paint solvent waste or an acetone waste were placed in the cells. The cells were then backfilled with sand and capped with a plastic cover and top soil. Permeability was calculated from the leachate volume using Darcy's Law.

- Preliminary results of both laboratory and field cell tests indicate that concentrated organic liquid-bearing wastes may alter the structure of clay soils, resulting in permeabilities 100 to 1000 times greater than the values measured with water. Visual observations of dyes and chemical analyses of soil samples indicated that the wastes moved through preferential channels in the soil mass and not along the edges of the permeameters or test cells. The following should be considered in evaluating this research effort:

  - Dr. David Daniel (see Interview Report for University of Texas) showed that the ratio of laboratory to field permeability test results can range from 0.5 to 4,000 with laboratory test results most often indicating permeabilities 100 times lower than field tests indicate.
  - Control cells with water alone were not used in the study.

- A number of scientific studies (Macey, 1942; Schram, 1981; Buchanan, 1964) supports the findings that organic liquids can greatly increase the permeability of clay soils, while no studies have been found that refute these results.

- Preliminary results of the field cell tests also indicated that 11 out of 12 HDPE cell liners have leaked. These liners were installed according to the manufacturer's specifications under optimal conditions by the manufacturer, using the same seaming techniques as prescribed in the field.

Referenced Flexible Membrane Liner Research

- The only actual study on flexible membrane liners (Montague, 1981) indicated that 3 out of 3 landfills double-lined with various synthetic liners were leaking contaminated liquid shortly after installation.

- Puncture resistance tests of flexible membrane liners covered with a protective layer of soil indicated that all the materials tested suffered puncture wounds (Gunkel, 1981).

- The many laboratory studies on flexible membrane liners conducted by Haxo indicate deterioration of the physical properties of many of the synthetic liners subjected to municipal waste leachate, including swelling and loss of seam strength. None of the materials tested held up to the range of hazardous wastes used (Fong and Haxo, 1981; Haxo, 1980; Haxo, 1981; Haxo, 1982).

- Haxo's tests were of relatively short duration and were conducted without replicate sampling. Also, despite these laboratory tests, field tests are still needed to develop data which allow extrapolation of laboratory data to the field.

Extensions of Current Research

- The field and laboratory study on clay liner permeability using the concentrated xylene and acetone wastes will continue for another 1 and 1-1/2 years. Fourteen of the field cells remain to be excavated, photographed, and sampled. Laboratory studies on the influence of dilutions of water soluble organics are presently being conducted. It is anticipated that further laboratory evaluations will include mixtures of organic wastes and testing of polymer-treated clays. Morphological studies are also under way, and efforts are being made to quantify the changes in pore soil distribution which may occur as a result of organic liquid interactions with soil.

Research Needs

- There is a need to investigate various techniques that would make landfills chemically and biologically stable. For example, constructing

a drainage layer out of material that will attenuate pollutants in the leachate, such as crushed limestone or activated charcoal. (Stabilization is most easily accomplished with monofills.)

- There is a need to research the bonding energies of clays with organics versus water. Bulk studies show a correlation with the dielectric constant of the solvent.

- There is a need to obtain liner performance data in the field (i.e., observing the performance of hazardous waste landfill liner systems).

- While clay caps are generally well designed, there is only very limited field experience under conditions that would allow measurement of increased infiltration (indicative of leaks), no information on the potential effects of subsidence, and no long-term performance data on the subject of clay caps at hazardous waste facilities.

Perspectives on Design of Liners/Covers

- The requirement set down in 264.301 (EPA, 1982) that the waste be prevented from passing into the liner during the active life of a facility could obviously not be met for clay liners, and the requirement is going to be difficult if not impossible to meet for flexible membrane liners. Data on 12 liner materials tested with 8 different wastes indicated that the wastes were absorbed in 89 out of 96 test specimens (Haxo, 1981).

- In conjunction with above-ground landfills, EPA should discourage the use of the classical landfills and encourage the use of techniques that either destroy (incineration), degrade (land treatment), or recycle hazardous wastes. The small volume of wastes untreatable by these alternate techniques would be disposed in above-ground storage units. Generally, with landfills on the surface, it would be much easier to detect problems, monitor leachate, maintain the integrity of the system, and clean up leaks. Two objections to this approach are: (1) poor aesthetics and (2) erosion of caps. However, these can be mitigated by placing a vegetative cover over closed cells and using proper landscaping techniques. It is difficult, however, to get engineers and regulators to consider innovative systems when the Agency continues to encourage the use of below-ground landfills, even though a large portion of these facilities will likely require massive clean up operations in the future.

- Liners should be selected which will provide the best long-term stability and which will suffer minimum degradation by the leachates. These liners will most likely be made of natural materials such as recompacted or treated clays and will thus allow some slow movement of liquid. Drainage systems must be required which will allow the continuous removal of leachate for a period equal to the expected life of the hazardous materials disposed of in the facility. This can only be achieved by building land disposal systems on compacted clay liners

above the surface of the soil. Such facilities could be equipped with free gravity drains which would prevent the build-up of a head of free liquid on the liner. Provisions must be made to collect and treat the leachate as long as it is produced, or until the leachate is demonstrated to be free of toxic constituents.

- Clay liners may be acceptable if the leachate is of such characteristics that it does not adversely impact the permeability of the liner as would be expected with dilute inorganic, and possibly even dilute organic chemicals. Clay liners may also be a viable liner material where a properly designed and managed leachate removal system is provided and assurances can be provided that it will be maintained and the leachate will be removed and disposed of until it reaches acceptable quality. If a small leak rate is acceptable as may be possible for facilities in certain geological settings, then clay liners may also be the best long-term option. Careful laboratory and field testing are, however, needed to determine if properly selected and compacted clays provide sufficient protection of the environment for the particular leachate to be retained.

- Design of a clay liner system in locations with large natural clay deposits should consider that they are not uniformly permeable due to sand lenses, roots, debris, and natural cracks and fissures.

Perspectives on Performance of Liners/Covers

- The main factors that affect liner performance are poor installation techniques and disposal of concentrated liquid wastes.

- About 80 to 90 percent of the performance problems are related to installation. Factors such as changes in ambient temperature, wind-blown dust, and changes in humidity, which all occur during installation, cause problems with seaming. Thermal expansion of liner sheets (especially black ones) is a definite problem.

- Despite horror stories of leaking flexible membrane liners circulating among those in the field, there is yet no compilation of either the successes or failures of this technology. One study (Montague, 1981), however, indicated that all three flexible membrane lined hazardous waste landfills in New Jersey were leaking. In Dr. Brown's study, 11 out of 12 field cells lined with one type of flexible membrane liner have leaked. Unfortunately, there is no long-term experience with these liners in landfill situations.

- Flexible membrane liners have successfully been used for lining water reservoirs. They have been used successfully for retaining hazardous waste in open ponds, where only a set of specified chemicals will come in contact with a carefully selected material, and where constant surveillance and monitoring is possible. Facilities which have functioned

well for years have been known to fail quickly if suddenly exposed to other chemicals which they were never intended to retain. Haxo (1980, 1982), after testing 12 flexible membrane liners with a series of hazardous industrial wastes, concluded that "there does not appear to be any single lining material now commercially available which is suitable for long-term impoundment of all wastes".

- Flexible membrane or clay liners cannot be installed under the current regulations so that they do not leak. The very limited data available on exposed membranes (Haxo, 1982) indicate degeneration of the materials exposed to landfill conditions for 4-9 years. Pacey (1980) suggested that even if flexible membrane liners were properly installed so that they did not leak immediately, they would deteriorate 20, 30, or 40 years later. Pertusa (1980) suggested that seven flexible membrane liners had useful lives of between 5 and 20 years for water impoundments and that the useful lives would likely be reduced when exposed to wastes. Nonetheless, the Agency is now asking us to rely upon flexible membrane liners to prevent discharge of dangerous chemicals which may retain their toxicity for centuries (EPA, 1982).

- Kays (1977) reports that flexible membrane liner failures can be categorized into those resulting from physical, chemical, and biological failures. Physical failure mechanisms include punctures which may result from traffic pressure even when the liners are covered (Gunkel, 1981), tears, creep, freeze-thaw cracking, wet-dry cracking, differential settling, thermal stress, differential hydrostatic pressure, abrasion, and failure of seams (Haxo, 1982). Chemical failure results from deterioration resulting from ultraviolet light, ozone, hydrolysis, ionic species attack, extraction, ion species incompatibility, and solvent attack which may dissolve either the plastic or the plasticizer. Biological degradation includes microbial attack, attack by burrowing animals, or as a result of animals trying to escape from inside the facility.

- Many failures have been attributed to installation difficulties, including seaming difficulties in the field and tears and rips occurring during or shortly after installation. Furthermore, no liner presently on the market can stand up to the full range of chemicals which might be found in a hazardous waste landfill. If the membrane is resistant to acids, it may be destroyed by oils; if it resists polar organics, it may be destroyed by nonpolar organics.

- To obtain true performance data, one would have to examine the files of the liner installers and manufacturers (e.g., to determine how many times an installer had to repair a liner after installation, and why).

Perspectives on Construction and Installation

- The technology does not now exist that would allow the proper installation of flexible membrane liners.

- A major problem with clay liner installation is dessication of the liner. Installers are not preventing dessication cracks during installation or after installation, but before operation commences. In just one day, dessication cracks can become 6 to 8 inches deep.

- An Australian firm, called Nylex, manufactured and installed a flexible membrane liner; however, because of many pending law suits, they stopped installing them.

Perspectives on QA/QC

- There are material problems associated with flexible membrane liners as well as seaming and installation problems. The degree of quality control in flexible membrane manufacturing plants is not acceptable; some new techniques have been researched (e.g., using spark-gap or vacuum technology to detect pinholes in the material), but they are not yet in widespread use.

- Strategies such as writing QA/QC procedures into the regulations or licensing installers will not significantly change the current situation. These strategies are simply additional attempts ("band-aid" policy) to retrofitting an unsolvable problem.

Miscellaneous

- Solidification of liquid wastes (264.314) will work for certain aqueous solutions or suspensions of inorganic materials and very low concentrations of organic liquids. Thus, the technique should not be utilized for organic liquids unless it can be fully demonstrated to be effective. Otherwise, the liquids adsorbed on the solids used for stabilization will only drain through capillaries from the solids when they are stacked in the landfill, thus putting a direct head of liquid on the leachate collection system and the liner. Consequently, the EPA's regulations should reduce but will not eliminate free liquids in landfills.

- Disposal of bulk liquids in landfills that require the use of synthetic membranes is not adequate to protect the environment and should be banned. They should be recycled (where feasible), treated, and dewatered before disposal.

- A final concern centers around the lack of control over small quantity generators which can continue to legally dispose of free liquids into landfills. A few barrels of organic liquids may drastically alter the permeability of a landfill liner, essentially pulling the plug from a bath tube and thus allowing contaminated leachate to leak rapidly from the facility. Dr. Brown recognizes that steps are being taken to regulate these policies; however, during the two years alloted to tighten standards, thousands of barrels of liquid waste will be disposed of in facilities which were not designed as hazardous waste landfills.

References Cited By Brown

- Buchanan, P.N. 1964. Effect of Temperature and Adsorbed Water on Permeability and Consolidation Characteristics of Sodium and Calcium Montmorllonite. Ph.D. Thesis, Texas A&M University.

- EPA. 1982. Hazardous Waste Management System; Permitting Requirements for Land Disposal Facilities. Federal Register 47(143): 32274-32388.

- Fong, M.A. and H.E. Haxo, Jr. 1981. Assessment of Liner Materials for Municipal Solid Waste Landfills. p. 138-162. In: D. W. Shultz (ed.). Land Disposal: Municipal Solid Waste. Proceed. Seventh Annual Res. Symp. EPA 600/9-81-002a. U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

- Gunkel, R.C. 1981. Membrane Liner Systems for Hazardous Waste Landfills. p. 131-139. In: D. W. Shultz (ed.). Land Disposal: Hazardous Waste. Proceed. Seventh Annual Res. Symp. EPA-600/9-81-002b. U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

- Haxo, Jr., H.E. 1980. Interaction of Selected Lining Materials With Various Hazardous Wastes. II. p. 160-180. In: D. W. Shultz (ed.). Disposal of Hazardous Waste. Proceed. Sixth Annual Res. Symp. EPA-600/9-80-010. U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

- Haxo, Jr., H.E. 1981. Durability of Liner Materials for Hazardous Waste Disposal Facilities. p. 140-156. In: D. W. Shultz (ed.). Land Disposal: Hazardous Waste. Proceed. Seventh Annual Res. Symp. EPA-600/9-81-002b. U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

- Haxo, Jr., H.E. 1982. Effects on Liner Materials of Long-term Exposure in Waste Environments. p. 191-211. In: D. W. Shultz (ed.). Land Disposal of Hazardous Waste. Proceed. Eight Annual Res. Symp. EPA-600/9-82-002. U.S. Environmental Protection Agency, Cincinnati, Ohio 45268.

- Kays, W.B. 1977. Construction of Linings for Reservoirs, Tanks and Pollution Control Facilities. Wiley Interscience, John Wiley and Sons, Inc., New York. 379 pp.

- Macey, H.H. 1942. Clay-water Relationships and the Internal Mechanism of Drying. Trans. Brit. Cer. Soc. 41: 73-121.

- Montague, P. 1981. Four Secure Landfills in New Jersey -- A Study of the State of the Art in Shallow Burial Waste Disposal Technology. Draft. Department of Chemical Engineering and Center for Energy and Environmental Studies. School of Engineering/Applied Science. Princeton University, Princeton, NJ 08544.

- Pacey, J. and G. Karpinski. 1980. Selecting a Landfill Liner. Waste Age. 11(7): 26-28, 104.

- Pertusa, M. 1980. Materials to Line or to Cap Disposal Pits for Low-level Radioactive Wastes. Geotechnical Engineering Report GE80-1. Dept. of Civil Engineering, University of Texas, Austin, Texas 78712.

- Schram, M. 1981. Permeability of Soils to Four Organic Solvents and Water. M.S. Thesis, University of Arizona, Tucson, Arizona. 60 p.

- Seymour, R.B. Plastics Versus Corrosives. John Wiley and Sons. 1982.

References Supplied to TRW

- Brown, K.W.; J.W. Green; and J.C. Thomas. The Influence of Selected Organic Liquids on the Permeability of Clay Liners. Draft Report. 1982.

- Anderson, D.; K. Brown; and J. Green. Effect of Organic Fluids on the Permeability of Clay Soil Liners. In: Proceedings of the Eighth Annual Research Symposium; March 8-10, 1982. EPA-600/9-82-002. p. 179-190.

- Anderson, D.; K. Brown; and J. Green. Organic Leachate Effects on the Permeability of Clay Liners. In: National Conference on Management of Uncontrolled Hazardous Waste Sites. October 28-30, 1981.

- Brown, K. Testimony Before the House Subcommittee on Natural Resources, Agricultural Research and Environment of the Committee on Science and Technology. 30 November 1982.

- Brown, K. Landfills of the Future (a seven-page description of Brown's above-ground land storage concept). 15 December 1982.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. D-4

Matrecon, Inc.: Dr. Henry Haxo
Oakland, CA 415-451-2757

TRW: Louis L. Scinto

15 December 1982

Summary

- Quality assurance/quality control (QA/QC) during liner installation is not given enough priority.
- Testing needs to be done on liner materials during installation to ensure quality and uniformity, and to assure that the quality of the material placed in the field is the same as that which was selected in the design.
- Inspection and testing of clay liners during installation should focus on soil properties, roller characteristics, and characteristics of the compaction operation.
- Inspection and testing of flexible membrane liners during installation should focus on subgrade preparation, seam integrity, and sealings between the liner and penetrations.
- Correlations have not been established between results obtained during QC testing and actual performance, i.e., performance cannot accurately be predicted from results of field tests performed during installation.

Background

Dr. Haxo's main area of research centers on testing of materials used as liners in waste disposal facilities. He has performed and published the results of extensive research into the compatibility of various wastes and leachates with liner materials (primarily flexible membranes) and has developed a body of test methods needed to guide the selection and design of liners for specific applications, ensure the quality of the designed liner is as installed, and monitor the condition of the liner during service. Dr. Haxo maintains an up-to-date library of related research papers and reports on liner technology, including both domestic and foreign sources. He is the principal author of SW-870, EPA's Technical Resource Document (TRD) on Lining of Waste Impoundment and Disposal Facilities.

Highlights of the interview and of Dr. Haxo's published work related to liner installation are presented below under the following headings: (a) general QA/QC and testing requirements; (b) QC testing during installation of clay liners; (c) QC testing during installation of flexible membrane liners (FML); and (d) relationship of test results to liner performance. Specific

conclusions based on detailed review of documents published by and/or obtained from Dr. Haxo will be included in TRW's final report on this work assignment.

General QA/QC and Testing Requirements

- Generally, QA/QC during liner installation is not given enough priority. This aspect of the job is of utmost importance in ensuring that liners installed in the field meet all design specifications.

- Much of the research into general methods of inspection and testing has been and is being done by the Bureau of Reclamation (largely for FML) and by the Army Waterways Experiment Station (for clays). Specific test methods have been devised by ASTM and preliminary work to define physical requirements for FML based on these tests has been done by the National Sanitation Foundation and other standard-setting organizations. This body of work formed the basis for many of the guidelines presented in SW-870.

- An adequate QA/QC program for installation should include at a minimum: (a) a checklist to ensure all facility requirements are met; (b) a specific plan which addresses procedural inspections and sampling, testing, and record keeping requirements; and (c) continuous monitoring and review of all important activities.

- Testing requirements for the evaluation and assessment of liner materials for waste impoundments fall into three general areas:

  - Tests for the selection of liner materials and in the design of impoundments incorporating liners.
  - Tests to ensure quality and uniformity of liners placed in the field, and to assure that the quality of the material placed in the field is that which was selected in the design.
  - Tests for assessing performance and condition of liners in service.

  The second of these areas has application to this work assignment. General aspects of this type of testing is discussed below for clay and synthetic liners.

QC Inspection and Testing During Installation of Clay Liners

- The inspection/testing program for clay liners should assure that the following aspects of the installation meet design specifications:

  - Soil characteristics such as:
    -- moisture content
    -- density
    -- permeability
    -- infilterability
    -- uniformity

- Roller characteristics such as:
  - -- size, arrangement, and safety features of drums
  - -- number, location, length, and cross-section area of tamping feet
  - -- weight of loaded roller
- Characteristics of the compaction operation such as:
  - -- number of passes
  - -- thickness of lifts and variations in lift height
  - -- lift thickness in relation to length of tamping feet

QC Inspection and Testing During Installation of Synthetic Liners

- The important aspects of FML installation which need QC inspection and testing are:
  - Subgrade preparation
  - Liner and seam properties
  - Liner penetrations (e.g., for inlet/outlet structures or gas vents)
- QC procedures for subgrade preparation are similar to those for clay liners.
- The integrity of the liner material particularly at factory and field seams should be tested. Both non-destructive, in-place tests (such as the air lance) and tests on random seams cut out of the liner should be performed. Seam samples should be tested to determine their strength (in shear and peel configurations), ply adhesion (where applicable), and sensitivity to variations in ambient conditions (particularly temperature).
- Operations involving sealing between the liner and penetrations should undergo careful visual inspection, and in-place testing of the integrity of the connection should be performed.

Relationship of Test Results to Liner Performance

- Correlations of test results (which characterize specific properties of installed liners) with actual field performance of the liner have not been established. Field test results can only serve to indicate the quality of the specific material under test and the degree to which the quality of the installed liner is the same as the pre-installation quality observed in the compatibility tests.

Miscellaneous Comments

- One problem with installing bentonite clay liners occurs when water is added to the clay prior to compaction. Some of the water is not quickly absorbed and, especially on slopes, can flow downhill to form puddles at low spots. This produces a non-uniform distribution of moisture in the liner, which can affect compaction.

- In applying asphaltic liners, problems can occur if the material is too hot. When applied to slopes, the material can flow downhill before hardening, creating a liner of non-uniform thickness.

- Some states (for example, Pennsylvania) prefer man-made liners over clay.

- Waste/liner compatibility tests should be run for as long as possible. Manufacturers generally run one week to one month tests. Dr. Haxo believes at least four months are needed to identify potential compatibility problems.

- Cohesive energy density (CED) comparisons between liners and wastes (or the most aggressive waste constituent) can potentially determine whether a particular liner will be suitable to contain a specific waste. Small differences in CED indicate that the waste may tend to dissolve the liner.

- The firm of Hovater-Way Engineers in Laguna Hills, CA, has experience with QA/QC programs for FML installation.

- The long-term integrity of asphaltic liners in general is hard to assess because different grades have different properties (e.g., for water absorption). Asphalts are not pure chemicals and their properties vary widely depending on their source and method of manufacture.

- Cool, dark, anaerobic service environments are generally conducive to long life for flexible membranes.

- Some clays may be unacceptable as liners for long-term confinement of some inorganic wastes. For example, if a soil has a low flocculation value with the particular waste liquid that is permeating through the soil liner, it is likely that the flux-density will be larger than the one anticipated on the basis of the designed K-value with water.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. D-5

Denver Research Institute: William Culbertson
Denver, CO Charles Habenicht
303-753-2911

TRW: Heather R. White

16 December 1982

Summary

- The purpose of DRI's research program is to develop materials suitable for lining embankments of spent oil shales from the spent oil shales. The program is in its preliminary stages and results are not currently available.
- Major concerns of the program are minimizing brittleness and maximizing impermeability and creepability of the liner material. The effects of consolidation pressures on the liner must also be considered, since in an actual installation 300 feet of spent oil shale may be placed atop the liner.
- There are several possible ways to install liners of spent oil shale. Four sample fabrication methods will be used to simulate these options and determine which options will prevent cementation and brittleness. The steps in the fabrication methods will be conducted at various temperatures and pressures.
- The possibility of adding clays, silts, or sands to the spent oil shales to confer the desired properties on the liner will be explored by testing combinations of materials as well as spent shale alone.
- The possibility of using spent shale for covers will not be specifically addressed by this project because different properties are expected to be important for cover materials.
- Permeabilities of consolidated samples are expected to be on the order of 10^{-7} cm/sec.
- The compatibility of the highly alkaline liner material with other materials must be determined before its use with other wastes is considered.
- The potential effects of groundwater on these liner materials will not be addressed in this study but must be determined before the materials are used in the field.

Background

EPA/IERL in Cincinnati, OH, has contracted the Denver Research Institute (DRI) of Denver to conduct a study of the possibility of developing liner materials from spent oil shales. Under the direction of Dr. William Culbertson, DRI is conducting a number of tests on spent oil shales from various processes to determine what properties are obtained under various conditions and what properties are desirable for a liner beneath an "embankment" of spent shale (this embankment would consist of a 300-foot pile of spent oil shale). DRI is now beginning to test the materials and will continue the program through 1984, so results of the study will not be available for some time. TRW's purpose in visiting DRI was, therefore, to determine the nature, not the results, of DRI's work. Copies of DRI's third and fourth progress reports were obtained.

The following sections describe DRI's current research program, possible applications of this work to the subject EPA hazardous waste program, DRI's research concerns, and similar research by other organizations.

Current DRI Research

- The purpose of this research program is to develop liner materials from spent oil shales. The materials will line embankments of spent shale much as clay might line a land disposal facility.

- The tests to be conducted for this program are designed to determine how to maximize the production of materials with clay-like properties such as impermeability and creepability. At the same time, it is desired to minimize the production of cementitious reactions and resultant cement-like properties such as brittleness.

- Both the combinations of raw materials used and the processes they undergo in becoming liner materials will be varied in the attempts to maximize impermeability and creepability and minimize brittleness. The contribution of different minerals to the development of clay- or cement-like properties and the chemical reactions that occur will be studied.

- Raw materials to be tested in this program include bentonite, Portland cement, and several types of silts, sands, and spent shales. The clays, cements, silts, and sands will be used as additives to the spent shales. Silts and sands to be used include siliceous and calcareous fly ash and fine silica sand. Spent shale types include unburned and burned shale from the Tosco II process, ground unburned and burned shale from the Union B process, and well-burned and mildly-burned shale from the Lurgi process.

- Spent oil shales will be tested alone or in combination with the other materials listed above. Fine-grained materials (clays and spent shales) appear to have the greatest potential in this research. However, coarser (silty) material may be added to reduce brittleness and to reduce the

plasticity index to 10-20. Clays may be added to alleviate quick-clay tendencies. Shales that have been subjected to high temperatures in an autoclave to spend their cementing powers may be tested alone or blended with other materials to obtain a less brittle liner material.

- The effects of consolidation pressures will be examined by the program. In practice, the spent shale liners are to be placed in thicknesses of up to twenty feet, depending on the potential for subsidence. Up to 300 feet of spent shale are to be placed atop the liner, and a cover will be placed over this structure. This will subject the liner to high consolidation pressures.

- Installation of liners made from spent oil shales must be done in a way that minimizes cementation and brittleness. Placing and compacting these liner materials in the same way natural clays are placed may cause the material to cement. To avoid this, several alternative placement methods are being considered. One option is to "knead" it as it is placed to break up the cementation reaction. Another is to place it and let it consolidate under its own weight or with a small amount of embankment material placed atop it. A third option is to place all the embankment material on the liner at once immediately after the liner is placed; this might break up the cementation reaction. All three of these options will be explored through the testing program.

- Four basic methods will be used to prepare and fabricate liner materials from combinations of the raw materials listed above:

  - Sparse moisturization, immediate simple compaction, consolidation, and secondary consolidation with aging. This simulates the embankment construction methods usually proposed by developers.
  - Ample moisturization, heap mellowing for approximately 14 days, delayed compaction and consolidation with the final material nearly saturated. It is thought that the moisture and mellowing period will spend much of the cementing potential of the materials before they are placed.
  - Slurry mellowing, slow cooling, and partial air drying or flash cooling and drying, vacuum extrusion or compaction, consolidation, and secondary consolidation with aging.
  - Blending of solids into slurry-mellowed product, followed by heap secondary mellowing.

  The above methods will be conducted at several different cure temperatures, cure times, and consolidation pressure combinations.

- This research program will not consider the use of spent oil shales for cover material. The program is designed to examine the "self-healing" properties of the material and the effects of consolidation pressure on the material. Neither of these factors is of great concern for a cover, which can be reached more easily for repair than a liner can, and which is not subjected to the high consolidation pressures a liner is subjected to.

- Initial spent shales will be analyzed using the following methods:
  - Elemental analysis.
  - Mineral carbon (carbonate) analysis.
  - Total carbon analysis.
  - X-ray diffraction analysis.
  - Sieve analysis.
  - Hydrometer size analysis.
  - Mineral grain specific gravity.
  - BET surface area.
- Fabricated liner materials will be tested for chemical composition and aggregative mechanical properties. In addition to the analyses listed above, moisture content, material balance, liquid limit, plastic limit, void ratio, compressibility, permeability, shear strength, tensile strength, and brittleness index will be determined. Scanning electron microscope pictures will also be taken.
- Permeabilities of consolidated samples are expected to be on the order of 10^{-7} cm/sec. Permeabilities as low as 10^{-8} cm/sec have been measured during preliminary tests of unconsolidated samples.

Applicability to Hazardous Waste Facilities

- The compatibility of the liner material with other materials must be determined before its use with other wastes is considered. Burned shale tends to be highly alkaline. The alkalinity may assist in immobilizing some materials (e.g., metals), but it may cause adverse reactions with other materials (e.g., acids).
- The primary purpose for liner materials made from spent oil shales is envisioned to be on-site containment of spent shale. However, it has been suggested that spent catalysts could possibly be disposed with the spent shale. These catalysts may contain hazardous metals, which might be partially immobilized by the alkaline spent shale material.
- Spent oil shale is not currently listed as a hazardous waste. It is possible that some organic materials may remain in the spent shale, but since most retorting processes attempt complete burning, there should be little or no remaining organics*. Spent shale can, however, contain certain metals (e.g., arsenic) which are considered hazardous. The embankments of spent shale could, therefore, be considered hazardous waste facilities in the future.

*However, these organics could be hazardous.

Research Concerns

- DRI is concerned about the effects of groundwater on liners made of spent oil shale. Groundwater high in carbonates and sulfates could "attack" the liner in the same way it attacks Portland cement.

- The embankment is to be so thick and will be so dehydrated that any water coming through the cover would probably be soaked up by the embankment and would not reach the liner. If the embankment was cracked, however, water could reach the liner from above. If a large amount of water leaked through a large crack in the embankment, erosion of the liner might be a problem. However, the chances of this occurring are quite small.

- DRI is collecting references dealing with the nature of clays for their work. They are particularly interested in data regarding the shear strength and creepability of clays and on the evaporation of water from clays.

Research by Other Organizations

- Monsanto has been involved in similar work but is presently waiting to see the results of DRI's work before proceeding.

- Several oil shale developers have examined the properties of spent oil shale. Much of their research has been focused on determining the relationships between moisture content and cementation and compactibility. These are several of the organizations involved:

  - Occidental has studied spent oil shales from the Lurgi process.
  - Tosco has studied their own spent oil shales.
  - Paraho has studied properties of embankments of spent oil shale. Mr. Holtz of Woodward-Clyde has been involved.

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FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. D-6

U.S. Army Corps of Engineers: Capt. Michael Kelley
Waterways Experiment Station 601-634-3378
Vicksburg, MS

TRW: Michael D. Powers
Michael T. Haro

16 December 1982

Summary

- Research for EPA on covers has resulted in two reports: "Design and Construction of Covers for Solid Waste Landfills" and "Evaluating Cover Systems for Solid and Hazardous Waste". Causes of failure and remedial measures have also been studied.
- In NRC-sponsored work, parameters necessary for site characterization and design of disposal trenches for low level waste facilities were evaluated.
- A draft QA/QC program for construction of disposal facilities has been submitted to EPA for review.
- There is not enough actual field data currently available to adequately evaluate the performance of liners. Clay generally performs fairly well as a liner material due to its low permeability and filtering effects on leachate.
- Operators of disposal facilities must be able to put confidence in their liner systems; however, the lack of adequate standardized testing procedures and data on proven performance results in very little confidence on the part of the operators.
- If a facility has been properly designed, and an appropriate liner material chosen, the most important factor in ensuring a successful liner is installation.
- Care must be taken by men and equipment working on top of a liner to prevent damage.
- Site-specific QA/QC requirements in the facility permit allows flexibility and the development of programs to meet site-specific needs.
- Subsidence of the fill can result in rupture of the cover; while this can occur with any cover material, the problem is worse for relatively inflexible liner materials.

Background

The Waterways Experiment Station (WES) of the U.S. Army Corps of Engineers at Vicksburg, MS, has been conducting research into various aspects of design, construction, and operation of land disposal facilities for EPA, NRC, and other agencies for a number of years. Current activities center on liners and covers for hazardous waste facilities.

As part of the data acquisition effort for this project, several key technical staff at WES were interviewed. The objectives of these interviews were to obtain information on the following: (a) background, results, conclusions, and recommendations from research to date; (b) recommendations for future research; (c) perspectives on liner and cover performance, design, and installation, and on QA/QC requirements; and (d) additional references and data sources to be contacted. The interviews consisted of a joint discussion meeting attended by several WES technical staff, separate interviews with a number of specific individuals, and a follow-on call to one individual who was not available during TRW's visit to WES. This report integrates results from all of the individual interviews.

The following persons at WES attended the large joint discussion meeting which was arranged by Capt. Michael Kelley:

- From the Soil Mechanics Division, Geotechnical Laboratory

  - Capt. Michael Kelley, Engineer, 601-634-3378
  - Patrick G. Tucker, Engineer, 601-634-2710
  - Paul Miller, Civil Engineer; 601-634-3247

- From the Engineering Geology and Rock Mechanics Division, Geotechnical Laboratory

  - Colin C. McAneny, Geologist, 601-634-3954

- From the Pavement Systems Division, Geotechnical Laboratory

  - George Regan, Engineer, 601-634-2728

- From the Environmental Engineering Division, Environmental Laboratory

  - Dr. Phil Malone, Geologist, 601-634-3960
  - Robert J. Larson, Geologist, 601-634-3959

The separate interviews were with:

- Dr. Joseph Spigolon, Civil Engineer, 901-454-2746. Dr. Spigolon is from Memphis State University, but has worked the past summer with Capt. Kelley.

- Dr. Richard J. Lutton, Geologist, 601-634-3393; Engineering Geology and Rock Mechanics Division, Geotechnical Laboratory.

- William Murphy, Geologist, 601-634-3322; Engineering Geology and Rock Mechanics Division.

- Paul Gilbert, Soils Engineer; Soils Engineering Division, Geotechnical Laboratory.

The telephone interview, which was carried out on 13 January 1983, was with:

- Gordon Carr, Engineer, 601-634-3387; Pavement Systems Division, Geotechnical Laboratory.

Current Research

- Dr. Lutton has managed an EPA study of covers for solid and hazardous waste landfills. The project has produced two reports: "Design and Construction of Covers for Solid Waste Landfills" and "Evaluating Cover Systems for Solid and Hazardous Waste".

- As part of Dr. Lutton's work for EPA on hazardous waste landfill covers, he is evaluating the efficacy of cover designs at various disposal facilities. Problems being investigated include those that occur after facility closure and their repair. One of the case studies investigated was at a municipal landfill at Windham, CT. At that site, a cover system consisting of a PVC membrane covered by local glacial soil and aged sewage sludge to support vegetation was completed in 1980. After only a few months, erosion had occurred at several places, exposing the PVC membrane. The erosion was directly attributable to run-off after the vegetative cover had failed to grow. The damage was successfully repaired by placing coarse gravel, rock tailings, and a geotextile in the eroded areas. Based on this investigation, in designing covers, considerable attention should be given to:

  - Cover surface topography, including configuration, slope, and texture of drainage pathways.
  - Condition of soil cover and/or age of sewage sludge, where used to support vegetation, in order to ensure successful growth.
  - Time of seeding, to ensure adequate time for vegetation growth before heavy rains.
  - Adequate post-closure inspection.

- In an NRC-sponsored study, Dr. Lutton is evaluating geological, hydrological, and engineering parameters critical for characterizing sites for

disposal of low level radioactive wastes. NRC regulations require disposal facilities to control migration of radionuclides for at least 100 to 500 years following facility closure. The NRC prefers to minimize leachate generation and to choose sites that will allow fluids to drain slowly, rather than containing them in the disposal unit, thus avoiding a "bathtub" effect.

- Mike Kelley and Joseph Spigolon have completed work and co-authored a report on Geotechnical Quality Assurance of Construction of Disposal Facilities; a draft has been submitted to EPA for review. Objectives of the work were to: (a) identify geotechnical parameters that should be tested in a QA/QC program; (b) recommend test methods; and (c) develop a QA/QC program. The QA program development became the main part of the project. A similar project by Spigolon, Kelley, and Herb Johnson was underway at the same time for NRC. In general, the recommendations in the two reports are similar, with differences reflecting the respective points of view of and types of wastes being regulated by the two agencies. Major differences between the two agencies are that NRC mandates a QA program to the licensee, while EPA expects the permittee to check himself. The EPA report requires documentation of QA/QC tests. A "watchdog agency", responsible only to EPA, will make sure the documentation is done properly; acceptance testing will be performed by the permittee, and checked by the "watchdog". Facility operators will have a design group, an operation group, and an inspection group. The inspection group will maintain documentation that cannot be falsified, and a test plan, to be monitored by the watchdog. The design group will review the inspection reports and make any indicated changes.

- Effects of subsidence on liners and covers at RCRA hazardous waste landfills are being studied by William Murphy and Paul Gilbert using a finite element model. Input to the modified CLOUGH finite element model program includes "real world" values for physical properties, such as density and shear strength of the liner, waste, fill, and cover, as well as loading. They are starting with a simple model of a compressible solid with no large voids, and vertical strain only. The model will account for layering of waste and fill. The model should indicate whether subsidence results in ponding or rupture of the cover material. In addition, Murphy and Gilbert will be reviewing the existing data base and make site visits to determine design characteristics that have affected the occurrence or non-occurrence of settlement.

- Additional research areas include:

  - Work is currently underway on an NRC study on Trench Design and Construction Techniques for Low Level Radioactive Waste, by Pat Tucker.

- Colin McAneny, Pat Tucker, Mike Kelley, and Paul Miller are working on the preparation of a Technical Handbook on Cover Design and Construction at Uncontrolled Hazardous Waste Sites for EPA (Bob Landreth, EPA Project Officer).
- Using scaled-down loads and pressures, Gordon Carr has developed a laboratory method of measuring puncture resistance and wear of flexible membrane liners that duplicates the results of small-scale field tests performed by Robert Gunkel. The field tests were designed to measure the effects of heavy construction equipment on flexible membrane liners.
- Treatment and solidification of hazardous waste for co-disposal with municipal wastes.
- Grout sealing beneath existing disposal facilities.
- Developing standards for geotextiles.

Recommendations for Future Research

- Puncture resistance and wear of synthetic liners (including field seams) need to be studied on a large scale in the field to supplement current WES laboratory investigations. (Additional laboratory puncture resistance tests still need to be conducted for a number of FMLs before field tests can begin.)

- Because of disposal unit conditions that may result in contact between waste constituents and the cover material (e.g., volatilization of organics, "bathtub" effects, etc.), there is a need to investigate the probability and magnitude of waste/cover compatibility problems.

- Acceptance test methods that lend themselves to a QA/QC program need to be developed to give the permittee adequate confidence that his installed liner will perform to design specifications.

- Research should be conducted into the relative effectiveness of various types of seaming techniques for synthetic liners.

- Long-term performance of cover systems will be investigated in the near future by Dr. Lutton.

Perspectives on Liner and Cover Performance and Installation

1. Performance

- There is currently an inadequate data base to evaluate whether liners can be installed under the present regulations without leaking. More field experience with liners of all types will be necessary before the question of liner performance is settled. It appears that quality assurance, operation, and maintenance practices have been performed adequately in many instances. The weak link may be in the beginning -

can the material (clay or synthetic) perform as designed? If the material is adequate, how can the permittee be assured that the material as installed will meet design specifications.

- Choosing the correct liner material for a particular facility can be a big problem and is critical for successful facility operation. When choosing a liner material, it is important to specify not only the waste types, but also the environment and setting. There are applications where the environment itself may cause deterioration of the liner; as an example, expansion and contraction in high temperature environments make HDPE difficult to seam. Also, after seams are made, the stresses generated by the expansion and contraction of exposed seam pieces might cause the seam to fail. There are drawbacks found in both Schlegel's and Gungle's products. There may be facilities where a material that is unsatisfactory for many other applications is the best that can be chosen to match a site-specific situation. Where differential settlement is possible, brittle materials (e.g., soil cement) should be avoided.

- There have been a number of problems with seams in synthetic liners. This has been especially true for reinforced materials; leachate seeps into the exposed scrim at the edges, resulting in a failure between the laminations.

- The objective of engineers is to solve problems; some solutions may not be perfect, but some approach that goal. A good solution to the problem of liner performance is the use of a double liner with a compartmented leachate collection system. Such a liner system would approach the ideal of 100 percent containment; it would also be very expensive.

- In general, clay is a good liner material. It acts as a filter, adsorbing many contaminants from the leachate.

- Disposal facility operators must have confidence in the liner material used. Because of the possibility of litigation if the liner fails, operators cannot take chances. However, there are currently insufficient standard methods of testing, and insufficient data base on proven performance for most liner materials; operators use liner materials at their own risk. For this reason, operators tend to be very conservative in their approach, using only materials that have a reputation for effectiveness.

2. Liner and Cover Installation

- The most important factor in ensuring a successful liner is installation and soil cover placement, if the facility has been properly designed, and the appropriate material has been chosen. A facility in Sheffield, IL, is an example of where installation problems can result in difficulties in meeting specifications for clay liners.

- Subgrade preparation is important. The subgrade should be well-compacted; some materials are very susceptible to damage from differential settlement. The surface should be free of sharp stones that can puncture synthetic liner material.

- Damage to synthetic liners can occur during storage and handling prior to installation. Potential sources of damage include:

  - Folding and unfolding - Crimps in the material will result in weak spots that can fail readily.
  - Wind damage - Relatively gentle breezes (as little as 10 mph) can easily lift and tear liner sheeting.
  - Sun - The ultraviolet component in sunlight damages a number of synthetic materials, especially PVC.
  - Mechanical - Machinery can tear or stress material.

- During seaming with extrusion welding systems, such as those used for HDPE, if the ribbon of extrudate is interrupted, there is no seam.

- It is important that a liner be protected from damage due to the operation of construction equipment. Buffer layers, both over and under the liner, must be thick enough to keep objects from puncturing it. For example, a landfill compactor with 6-inch cleats running over a 4-inch layer of soil is a sure way of perforating the material.

3. Problems Unique to Covers

- The major sources of problems during installation of synthetic membrane covers are:

  - Holding the material in place during placement and seaming to prevent wind damage.
  - Seaming, both factory and field; failure of seams can allow moisture to seep into the fill.
  - Equipment operation during placement of soil over the membrane; improper operation can puncture the membrane.
  - The insufficiency of QA/QC tests and/or observations detracts from the permittee's confidence in the performance of his installed liner.

- Inadequate compaction of waste and fill can cause excessive subsidence, which can result in rupture of the cover. Rupture will occur with any material, those with low tensile strength, or those with little elongation

prior to rupture. Differential subsidence can also result in ponding, which in turn will allow increased percolation, and will also disrupt leachate collection systems.

- Erosion of material from the cover can result in exposure of the wastes. This occurred at Sheffield, IL, where low level radioactive wastes were covered with a collapsible loess. Factors that can promote erosion, or directly expose the wastes, include:

  - Vehicle traffic over covered trenches before or after final grading and vegetation. Traffic can consist of trucks working on other trenches as well as the covered one. Tire ruts are conducive to erosion.
  - Selection of a cover soil susceptible to erosion such as loess, or that is not conducive to vegetative growth.
  - Surface disturbances such as a farmer plowing.
  - Burrowing animals.
  - Frost heave.

- Gas generated in a landfill should be collected and vented through the cover. When gas or vapors from volatile chemicals are not removed, expansion and contraction of gases in the fill with variations in atmospheric pressure will result in rupture of the cover.

- Contrasts in permeability between a fine-grained (e.g., clay) cover and coarser-grained fill can produce a "wick" effect. Because of the high capillary attraction in fine soils, moisture will not flow across the interface to the high permeability material until the low permeability soil is saturated. This effect will act as a barrier to unsaturated flow into the fill material.

- After closure, landfills should be monitored for water ponding in closed depressions caused by subsidence.

- It is possible, but not inexpensive, to install cover systems under the present regulations so that they will not leak. Good installation techniques, inspection, and maintenance are very important in establishing the integrity of the cover.

- When considering a soil liner for caps, clay is not the only material choice. Depending on site characteristics, other types of soils are acceptable. For example, in dry climates a soil that will not crack may be more effective than clay.

4. QA/QC Requirements

- EPA should mandate specific QA/QC requirements in permits, rather than in the regulations. This will allow more flexibility in specifying a QA/QC test program appropriate for the site and liner being installed.

- Installation quality would be improved by having guidelines for QA/QC programs in the regulations, and by certification of installers. EPA training and certification of installers would help to ensure that only qualified people were doing such work, in much the same way that training and certification programs ensure that only qualified people perform blasting. Training and certification programs could be funded by a "user fee" included in the facility permits.

- The concept of third parties conducting installation QA/QC programs has merit. One possibility would entail an EPA "watchdog" agency to monitor installer QA/QC programs; the installer QA/QC group would submit documentation that could not be falsified to the "watchdog".

- Manufacturers of synthetic liner materials should be required to submit their products to an outside testing agency such as the National Sanitation Foundation for testing and approval. They should then be required to affix the NSF seal of approval to the material produced.

- QA/QC procedures should be added to the regulations on the condition that they are carefully prepared and properly qualified. The most important aspect of QA is monitoring the installer's work via visual inspection and appropriate field tests. A third party QA program should be added to the regulations only if it will not involve additional costs as would be the case when the third party is already on-site or close to the site (e.g., state inspectors).

References Cited

The following documents were cited by interviewees at WES. A copy of the first was supplied to us by Dr. Lutton; the second was supplied by EPA, and a copy of the third was supplied by Dr. David Daniel of the University of Texas at Austin. TRW has copies of all but the last two in its possession; the last two will be acquired for use in the preparation of the final report.

- Lutton, R.J. Characterization of Sites for Low-Level Waste Disposal Facilities. 1982 Nuclear Science Symposium, IEEE, 3 pp.

- Kelley, M. and S.J. Spigolon. Geotechnical Quality Assurance of Construction of Disposal Facilities.

- Pertusa, M. Materials to Line or to Cap Disposal Pits for Low-Level Radioactive Wastes. Geotechnical Engineering report GR 80-1, Dept. of Civil Engineering, University of Texas, Austin, 1980.

- Lutton, R.J., G.L. Regan, and L.W. Jones. Design and Construction of Covers for Solid Waste Landfills. EPA-600/2-79-165. August 1979.

- Lutton, R.J. Evaluating Cover Systems for Solid and Hazardous Waste. SW-867. September 1980.

- Gunkel, R.C. Membrane Liner Systems for Hazardous Waste Landfills. In: Land Disposal; Hazardous Waste Proceedings of the Seventh Annual Research Symposium, March 16-18, 1981. EPA-600/9-81-002b. pp. 131-139.

- Lutton, R.J., V.H. Torrey, and J. Fowler. Case Study of Repairing Landfill Cover. In: Land Disposal of Hazardous Waste, Proceedings of the Eighth Annual Research Symposium. EPA-600/9-82-002. pp. 486-494.

- Tucker, P.G., et al. Trench Design and Construction Techniques for Low-Level Radioactive Waste.

- McAneny, C.C., et al. Technical Handbook on Cover Design and Construction at Uncontrolled Hazardous Waste Sites.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. D-7

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303-234-7044

TRW: Heather R. White

16 December 1982

Summary

- The U.S. Bureau of Reclamation (USBR) has many years of experience with a variety of liner materials. USBR has used liners primarily for water supply systems where the goal of the liner project was to reduce seepage, not to prevent it.

- Clay and synthetic materials each have a proper role as liners, depending on material quality, availability, and cost, site considerations, and the required level of seepage control.

- Good quality assurance (QA) is important both in soil and flexible membrane liner construction. In the case of flexible membranes, a good QA program is essential to good performance. USBR has had better success with flexible membranes than others have with flexible liners, primarily because of its comprehensive QA program.

- For soil liners, laboratory tests on proposed soils, conducting soil density tests for construction control, compacting soil within two percent of optimum moisture content, and compacting soil to 95 or 98 percent of Proctor test density are important elements of a good QA program.

- For flexible membrane liners, a good QA program begins with inspection of manufacturing, fabrication, and laboratory facilities. Test methods must be coordinated among those responsible in order to assure compatible test results. All parties involved must be experienced in the work to be done.

- Thorough field inspections include peel tests of cut-out seam samples. Peel tests proved more effective than shear tests, and cut-out samples were more representative of actual seam quality than mock seam samples.

- Coupon programs should be conducted after installation to monitor liner quality.

- EPA should have some regulations regarding QA procedures because they are the key to liner longevity.

Background

The U.S. Bureau of Reclamation (USBR) has responsibility for federal water and power resource projects of the Department of the Interior. Its Engineering and Research Center designs water and power supply facilities, and conducts research that will benefit the design and construction of these facilities. One area of long-standing interest has been materials which can be used to line earthen structures such as canals and reservoirs. Materials used and studied have included compacted earth, asphalt, flexible membranes, and concrete.

The USBR began using and studying compacted earth linings in the 1940's and investigated many aspects of soil use, including permeability, lift thicknesses, moisture content vs. density, costs, frost action, and soil additives. Although they stopped using asphalt in the 1970's, the USBR used many hot-applied and catalytically blown buried asphalt liners. In the 1950's, they began to use polymer linings. Most of their experience has been with polyvinyl chloride (PVC), but they have also used polyethylene (PE), CSPE, CPE, butyl, and various copolymers. The USBR has not used many of the rubber products because their main virtues are as exposed membranes, for which the USBR has less need since most of its membranes serve as buried liners in canals or reservoirs.

The USBR has used liners primarily for water supply systems where the goal of the liner project has been to reduce seepage to a reasonable level, not to prevent it entirely which is not practicable. For earth-lined structures, the design seepage rate used by USBR engineers is less than 0.1 ft^3/ft^2-day. In some flexible membrane-lined facilities, liner sections were overlapped but not seamed since the goal was not prevention of seepage and any reduction in water losses was considered an improvement. Some of the USBR's data, therefore, may not be comparable to data from installations where prevention of seepage is desired. However, their liner degradation studies and more recent installation projects should be of general interest.

When the USBR began lining its water supply facilities in the 1940's, the use of a liner had to be justified economically. The value of water has risen so that now they must justify not lining a facility. The issue today is one of choosing a liner system that will provide the desired seepage rate at the least cost.

The following describes USBR's projects and research, their perspectives on quality assurance and regulations, related research, and research needs. Additional contacts and references are also provided.

Bureau of Reclamation Projects and Research Results

1. Compacted Earth Linings

- An example of the USBR's use of compacted earth linings concerns a brine evaporation pond in New Mexico that was part of a salinity alleviation

experiment to reduce brine seepage from an aquifer which was polluting the Pecos River. A liner was constructed in a 52-acre natural depression by scarifying the top 18 inches of in-place soil, moistening this soil with brine, and recompacting the soil with a vibratory roller. This pond was operated from 1963 to 1976, when the pond had filled with brine.

- Samples of this soil lining were taken in March 1982. Results of chemical and physical tests showed that the density of the soil lining had increased by approximately ten percent and that its seepage rate was reduced to 0.2 mm/day, about one-tenth the seepage rate calculated during the first year of pond operation.

- The increased density and decreased permeability of the liner may have resulted from the deposition of salt in the soil voids (as observed in electron microscope photographs). The chemical properties of the soil were not observed to have changed much. However, osmosis and chemical reactions between the salt and clay in the soil may have caused some of the observed physical changes. The possible causes of these phenomena are still being studied. The results of this and related studies will be useful in designing linings for brine evaporation ponds and salt gradient solar energy ponds, an on-going USBR project.

- Although the use of a scarified and compacted soil liner was successful in the above case, this is not the USBR's usual procedure nor do they recommend its use. The usual procedure is to build up linings in 6-inch thickness to design depth.

- The USBR's engineers use a seepage rate of less than 0.1 ft^3/ft^2-day to design earth-lined facilities. In two large-scale tests of concrete and soil in California, both attained seepage rates of 0.05 ft^3/ft^2-day.

2. Admixed Lining Materials and Soil Additives and Sealants

- Asphalt may be a desirable liner material in some situations because of its flexibility. However, it has become expensive in the U.S. U.S. contractors are not as knowledgeable or experienced with asphalt as their European counterparts. Asphalt is more widely used in Europe than here even though more of it must be imported there. Start-up costs for asphalt are higher here than in Europe.

- The USBR has studied the use of bentonite, sodium carbonate, soil cement, and fly ash as soil sealants and additives. Attempts to add bentonite and chemicals to canal liners by adding them to the flowing canal water were not very successful as the additives failed to penetrate significantly below the canal surfaces. A 22 percent sodium carbonate solution sprayed on two canals initially reduced seepage from 120 to 50 mm/day in one canal and from 600 to 290 mm/day in the other. However, the seepage reduction was only temporary; after one season the beneficial effects of

the sodium carbonate had diminished considerably due to erosion and other factors. It is possible that the sodium carbonate might have been more effective if it had been mixed with the soil instead of sprayed onto it.

- The USBR has experimented with both compacted and plastic types of soil cements. Cracking and shrinking are potential problems when working with soil cements. Good installation practices and the proper amount of cement are vital to the success of a liner incorporating soil cement.

- Soil cement is particularly valuable for protection against erosion. In Nebraska, silty loessial soil stabilized with 4-1/2 percent cement was able to resist the erosion forces.

3. Flexible Polymeric Membranes

- During the summer of 1980, the USBR installed 290 acres of 45-mil reinforced chlorinated polyethylene (CPER) in the Mt. Elbert Forebay Reservoir in Colorado. CPER was selected because: (a) a consistently good quality seam can be produced with the material; (b) a reinforced material suitable for placement on the side slopes of the forebay was desired; (c) manufacturing problems they had identified in the past (e.g., too much creep in the material) had been solved; and (d) the low bidder selected CPER over the other two materials included in the specifications, 80-mil high-density polyethylene (HDPE) and 45-mil reinforced chlorosulfonated polyethylene (RCSPE).

- Alternative linings such as Portland cement concrete and asphaltic concrete were considered for use at Mt. Elbert but were rejected due to the large amounts of aggregate necessary and the schedule, which required that the liner be installed in one construction season. Asphaltic concrete would not have provided the desired level of seepage control.

- Rubber sheeting such as butyl and EPDM were not considered for this project because USBR personnel were not confident in the manufacturer's ability to produce a good quality seam in the material. USBR believes that the rubber sheeting manufacturers have lagged behind the fabricators in developing seaming methods for their products.

- PVC was not considered for the project because of the potential for plasticizer migration and loss and subsequent liner deterioration.

4. Miscellaneous

- Clay and synthetic liners each have a proper role. In locations where the water table is high and freezing occurs, a soil liner may not be appropriate because it may be damaged by frost action. There are cases where an earthen liner is not an option because a suitable soil is not available. There are also sites where a local soil is suitable and provides the best seepage control for the price.

- Granular covers are recommended for both flexible membrane and cohesionless soil liners for protection against erosion (e.g., wave action).

- The USBR has published the results of related studies on the performance of granular soil covers on canals and the effects of freezing on soil structures and linings.

Quality Assurance/Quality Control

- Good quality assurance (QA) is important in soil liner construction. Some important elements of a good QA program are laboratory tests on proposed soils, conducting soil density tests for construction control, compacting soil within two percent of optimum moisture content, and compacting soil to 95 or 98 percent of Proctor test density. The USBR usually does not perform permeability tests on its installed liners.

- QA is the most important factor in obtaining a good flexible membrane liner. USBR has had better success than others have with flexible liners because it has had better factory and installation inspection programs.

- For the Mt. Elbert project, QA was an integral part of each step. USBR personnel inspected the manufacturer's and fabricator's facilities and operations as well as those of the independent laboratories they hired. They discussed testing procedures with the manufacturer before testing began to ensure more compatible test results. The experience and qualifications of the laboratories and the installers were carefully considered. A minimum of five million square feet of installation experience was required of the installing contractor.

- Every tenth factory blanket of material for Mt. Elbert was thoroughly tested along an 18-inch width containing all seams and sections from each panel. Inspectors checked the entire length of each seam in the field for problems such as delamination, which were marked for subsequent repair by the installation contractor.

- Adhesive field seams were considered the most critical step in the installation procedure at Mt. Elbert. These field seams were inspected by monitoring the temperature at which they were seamed, testing them with a 50 psi air lance, and applying a cap strip of 30-mil CPE.

- The results of the Mt. Elbert testing program show that the seam peel test is a better test than the shear test. This is because it shows how homogeneous the material is and where and when interface failure occurs. Manufacturers prefer shear tests because the results are more favorable to the manufacturer.

- Cutout seam samples are more representative of actual seam quality than are mock seams constructed especially for QA tests and should be included

in QA programs. There is no reason why the patches installed to fill in where the cutout samples were taken should create a lower quality liner.

- Coupon programs should be conducted after installation so that liner performance can be monitored over time. At Mt. Elbert, eleven 4-foot by 20-foot coupons were buried within the fluctuating water level of the reservoir. During the first year of operation, two coupons were removed and tested. During the next four years one coupon will be removed and tested each year. If gross failure occurs in the coupons within the first five years, the manufacturer must replace the liner (the warranty covers materials and seams for five years; it does not cover installation). If the coupons do not deteriorate significantly during the first five years, the interval between testing the remaining coupons may be lengthened.

- Liner materials should be tested for compatibility with the waste or liquid in question prior to liner installation. A coupon program should then be used to monitor performance.

Perspectives on Regulations and Regulatory Reform Needs

- EPA should have some regulations regarding QA procedures because they are the key to liner longevity.

- Licensing can help in a general way but it does not ensure quality. The client must develop confidence in his consultants before hiring them by taking the time to thoroughly inspect their facilities and their experience record.

- USBR might use a third party for QA/QC activities if they identified a good consultant. However, they feel that their own personnel have the expertise to conduct in-house QA/QC programs.

Related Research

- Soviet Union has considerable experience with PE as a buried plastic lining for use in canals. L.O. Timblin of USBR may be contacted for information (see reference list).

- Private French companies have been progressive in their use of new materials such as geotextiles to protect membranes, facilitate installation, or provide leachate or gas flow channels.

- Earthtech Research Corporation is developing sophisticated seepage detection methods using such tools as sonar and resistivity grids.

- Some research on soil liners for brine disposal and solar ponds is being performed in Israel.

Research Needs

USBR perceives a need for additional research in the following areas:

- The combination of geotextiles with unreinforced membranes.
- The durability of seams under various conditions.
- The development of methods to evaluate soil liners after placement without violating liner integrity.
- The development of soil liners specifically for brine disposal.
- The use of dispersants to compact soils to higher densities.

Additional Contacts

- Mr. L. Timblin and Mr. W. Morrison of USBR were unavailable at the time of the meeting and could provide additional information and data on the joint U.S./U.S.S.R. program on polymers for canal construction and on USBR synthetic liner degradation studies, respectively.

References

- L.O. Timblin, Jr. U.S./U.S.S.R. Studies on Polymers for Canal Construction. Preprint for ASCE Convention, April 1977, Dallas, TX.
- W.R. Morrison, R.K. Frobel, et al. Installation of Flexible Membrane Lining in Mt. Elbert Forebay Reservoir. U.S. Dept. of Interior, Bureau of Reclamation, Denver, CO. September 1981. 46 pp.
- C.W. Jones. Summary of Presentation at SERI Workshop on Pond Linings, Snowmass, CO, Bureau of Reclamation, Denver, CO. August 1981. 11 pp.
- C.W. Jones. What Happened to the Soil Lining in the Salt Pond" In Research News, January 1983, Bureau of Reclamation, Denver, CO. 9 pp. (Preprint draft).
- C.W. Jones. Soil Linings for Seepage Control. In Parks and Recreation, February 1968. 3 pp.
- R.K. Frobel. Quality Assurance Program for the Mt. Elbert Forebay Flexible Membrane Lining Installation. Bureau of Reclamation, Denver, CO. Proceedings of Water Conference, Paris, 1983. 6 pp.
- R.K. Frobel. A Microcomputer-Based Test Facility for Hydrostatic Stress Testing of Flexible Membrane Linings. R.K. Frobel, Bureau of Reclamation, Denver, CO. Proceedings of Water Conference, Paris, 1983. 6 pp.

- Ground Water Manual. Bureau of Reclamation, Denver, CO, 1981. 480 pp.
- Earth Manual. Bureau of Reclamation, Denver, CO, 1980. 810 pp.
- W.G. Smoak and M.J. Stodolski. Polymer Impregnation and Collection of Undisturbed Soil and Rock Samples. Bureau of Reclamation, Denver, CO, March 1979. 41 pp.
- J.T. Dikeou. Fly Ash Increases Resistance of Concrete to Sulfate Attack. Bureau of Reclamation, Denver, CO, 1981. 17 pp.
- M.E. Hickey. Investigations of Plastic Films for Canal Linings. Bureau of Reclamation, Denver, CO, 1969. 35 pp.
- W.G. Holtz. Soil as an Engineering Material. Bureau of Reclamation, Denver, CO, 1974. 45 pp.
- R.E. Glover. Ground-Water Movement. Bureau of Reclamation, Denver, CO. 76 pp.
- W. R. Morrison. Bureau of Reclamation Experiences With Flexible Membrane Linings for Seepage Control in Canals, Reservoirs, and Ponds. Summary of Presentation at SERI Workshop on Pond Linings, Snowmass, CO, August 1981. 10 pp.
- Interim Report, U.S./U.S.S.R. Joint Studies on Plastic Films and Soil Stabilizers, Volume III. Laboratory and Field Studies on Plastic Films for Hydrotechnical Construction. December 1982.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. D-8

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TRW: Masood Ghassemi, John F. Metzger

25 January 1983

Summary

- While clay and synthetic membrane liners both have certain merits, clay should be preferred for hazardous waste land disposal applications because: (a) much greater confidence can be placed in the long-term stability of clay which has been around for millions of years; (b) uncertainty as to the integrity of synthetic liners in long-term service; (c) established performance of clay liners (largely in-situ clay) in sanitary landfill applications; and (d) ability of clay to attenuate pollutant movement.

- Some wastes discharged to landfills can be significantly more hazardous and present greater long-term threat to the environment than low-level radioactive wastes. Synthetic liners are not considered viable in radioactive waste management applications and, hence, should also not be relied upon for hazardous waste disposal sites which present a much more difficult case of long-term care and monitoring of pollutants escaping the disposal site.

- Cases of clay liner failure can be attributed to poor design which has failed to recognize differences in clay properties under various level of moisture saturation and to poor installation allowing extremes in swelling and inappropriate compaction.

- In clay lined systems, the cap should be of a lower permeability than the bottom liner and the leachate should be allowed to percolate into the bottom liner. Leachate collection and above-ground treatment for hazardous waste sites necessitate perpetual care which is impractical.

- A cap consisting of two layers of clay with a gravel layer sandwiched in between offers good long-term performance. The gravel layer perches the water in the upper clay layer where it is removed by evapotranspiration during dry weather conditions. During wet weather conditions, when the storage capacity of the top layer is exceeded, some of the water is transmitted to the gravel layer and is drained out and away from the site.

- Areas requiring research and development attention include: (a) identification and listing of wastes which should be banned from landfills; (b) soil attenuation studies on specific organic wastes; (c) contaminant transport in fine grain sediments; and (d) assessment of the validity of Dorcy's law at low permeabilities (10^{-7}-10^{-8} cm/sec).

Background

Dr. Cartwright is a nationally recognized expert on the subject of clay permeability and has worked on this subject matter for the past 20 years. Most of Dr. Cartwright's recent work relates to the design of clay covers for landfills. The purpose of this interview was to obtain technical information and perspectives on the design, adequacy, and performance of clay liners and caps, and related regulatory considerations and research and development needs.

Clay Versus Synthetic Liners

- Except in cases where dramatic failure occurs, it is generally not certain how well either synthetic or clay liners perform. Neither is completely adequate.

- EPA's preference for synthetic membranes (as expressed in the interim final regulations) probably stems from misinterpretation of Kirk Brown's research on clay compatibility with organic solvents. Where a distinction must be drawn, clay liners which are recompacted to minimize discontinuities are probably better. However, the best system is most likely one using a combination of synthetic and clay liners.

- The following advantages of clay can be cited:

  - Materials not indigenous to an area would generally be expected to have limited long-term durability. Local clays have proven their stability over a period of millions of years and, therefore, should be suitable as liner materials (particularly for the cap).
  - There is an established record of performance for clay liners, particularly for in-situ clays underlying sanitary landfills (somewhat less experience exists in impoundment applications involving inorganic waste liquids).
  - Moisture entering a land disposal facility must be removed by allowing it to percolate into the bottom liner and hence to prevent its build-up and possibly overflow into surface waters. Clay liners permit leachate to flow out of the facility while attenuating the noxious constituents of the leachate.

- Inadequate installation practices are responsible for most problems which have been cited for clay liners. Extremes in swelling, for example, must be prevented because shrinkage can cause the clay to crack. Also, clay liners are typically designed by engineers or hydrogeologists who are familiar primarily with saturated flow when the clay is, in fact, placed in an unsaturated condition.

- While clay lifts are compacted wet of optimum, somewhat different moisture conditions may exist at a later time. This depends, in part, on the water content of the waste material and the level of the water table.

Reliance on Attenuation Capacity of Clay

- Removal of leachate from a landfill is not appropriate since this requires perpetual care of the facility and connotates storage of waste rather than disposal. There are also serious problems concerning what can be done with collected leachate. Waste stabilization which results in improving leachate quality occurs at a very slow rate where materials resistant to degradation are involved. Thus, leachate may have to be collected for years. The appropriate approach, then, is to eliminate collection of leachate and design an appropriate clay liner which will allow leachate percolation and has adequate capacity to absorb and attenuate leachate constituents.

- The landfill cap should be less permeable than the bottom liner to prevent build-up of leachate in the system. Although the needed permeability of the bottom liner is site specific, it typically ranges 10^{-7} to 10^{-8} cm/s. Clay caps having permeability less than this range, however, probably cannot be constructed.

- The extent of the zone of attenuation is specific to the site but must be considered in the design of the facility. For one site located in an arid western location, the zone of attenuation extended approximately one mile below the facility. An extension of 30 to 50 feet is more typical. The attenuation capacity of clay for individual leachate constituents can be established in the laboratory by chromatographic or equivalent methods. Certain species such as chloride or calcium/magnesium (hardness) may be suitable indicator species. Generally, however, the attenuation of organics, especially in a matrix of many species, is poorly known. Solubility in water can provide some insights, but the complexity of interactions involved is usually so high that no prediction is adequate. For example, PCBs become mobile not by the water but by trace amounts of organic solvents in which they are soluble. Once dissolved, the PCBs may move farther than the main leachate front.

- To lessen the strength of leachate, disposal of liquids into land disposal facilities should, with only a few exceptions, be eliminated. One approach is to solidify all liquids and sludges before disposal in landfills. The potential of various materials to generate leachate varies (and is often unknown). Thus, waste segregation (according to some common characteristics) and disposal in separate cells may provide for better leachate management.

Caps for Land Disposal Facilities

- Caps are difficult to maintain because of constant exposure to stressful conditions.

  - Erosion is a principal stress causing failure of poorly constructed caps, especially those having clay placed directly on a synthetic membrane.

- Subsidence occurs in every case although it can be greatly minimized if moisture is prevented from entering the facility. Where there is significant consolidation and hence differential settling, precipitation can pond on the cap, thus increasing infiltration. In Northern Illinois, for example, where there is 30 to 34 inches of rainfall per year, only 2 percent of this normally reaches the groundwater. By comparison, infiltration into a poorly designed/constructed cap can exceed 60 percent.
- An "EPA standard" of a two-foot compacted clay cover is not sufficient in Northern Illinois to protect it against annual freeze/thaw cycles. In the winter, the frost line may extend 30 to 40 inches deep. Another recommendation has been to plant grass on the soil cover for the cap. This practice minimizes erosion, but by holding water, it increases infiltration. Compared with a row crop such as corn, infiltration with a grass cover may be four to five times higher.

- An appropriate cap system might be a one-foot layer of compacted clay covered by gravel and/or sand (to protect it against freeze/thaw cycles and root penetration) and a layer of cover soil. A synthetic liner combined with clay might also be appropriate, as long as the synthetic is everywhere covered to protect it from decay.

- A wick-effect cap has been proposed and built in four cases to compare its performance with modeling studies and to prove that a natural cover can be built to greatly restrict inflow. The system, which is currently under evaluation, consists of a permeable gravel layer sandwiched between two clay layers. The dramatic change in permeability between the upper two layers results in some water being perched in the upper layer. During warm months, evapotranspiration removes much of this water. During wet months when the storage capacity of the upper layer is exceeded, it drains into the gravel layer and is routed out of the facility. This, of course, assumes that any liquid reaching the lower gravel-clay interface will flow over the top of the bottom liner and not into it as has been hypothesized by other researchers who consider liquid film formation necessary for free lateral flow at the interface and question whether such a film will indeed be formed, given the greater potential for slow liquid penetration into the bottom clay. The wick-effect cap is considered a potential long-term solution. It would be installed after the period of most active subsidence, and when constructed at least seven feet thick and with a well-developed grass cover, it should last for 300 to 400 years in the Northern Illinois area.

- Other cap studies are being done (among others) under NRC and EPA funding at the University of Kentucky, University of Arizona, Los Alamos Laboratory, USGS, and U.S. Corps of Engineers.

- Land disposal sites can be developed into parkland, including with some buildings, almost immediately upon closure. This use provides an excellent mechanism by which to ensure continued institutional interest in maintaining the site (including cover).

Perspectives on Regulations

- Many of the regulations/goals proposed for disposal of radioactive wastes, while more stringent, are appropriate for hazardous wastes as well (Federal Register, Vol. 47, No. 248, 27 December 1982: Licensing Requirements for Land Disposal of Radioactive Waste - Final Rule). Some hazardous wastes, particularly organics, are more persistent than low level radioactive wastes. Additionally, these materials are often very elusive in the environment, being very difficult to monitor or detect. By comparison, radioactive wastes are easily detected.

- Some organic materials (such as volatile solvents) are probably unsuitable for landfilling and should be banned. Some of these are easily incinerated.

- Materials that are toxic near their detection limits should be disposed of by a method other than landfilling.

- The review process for land disposal facilities needs to be upgraded. Regulators should pressure owners, perhaps via establishing performance standards, to eliminate cost from being the overriding decision-making variable. Performance standards are practical because movement of leachate can be predicted and later verified by monitoring wells.

- Other requirements set by regulators could be improved. Data for each facility should be as complete as practical. In many cases, consultation with a geological expert may be appropriate and should be required. Finally, consultants should be forced to write adequate reports. The entire process of upgrading the design, construction, and operation of facilities is probably a process that may require an excess of 12 years. There should also be much better segregation of materials in the landfill and some should be banned altogether.

- Although perhaps impractical and contrary to the present trend, construction of more smaller landfills should be promoted over construction of fewer but very large landfills. With smaller landfills, the chances that the attenuation capacity of the underlying strata would be exceeded is less and also damages resulting from a failure would not be as dramatic and perhaps could be more readily corrected.

Research and Development Needs

- There is a pressing need to transfer R&D information to field personnel. Some screening of this information is also needed, since not all developments are of immediate practical utility and not all information can be agreed on by key experts.

- Additional R&D needs are suggested as follows:
  - Listing of materials that should be banned from landfilling.
  - More clay/natural soils attenuation studies with organic chemicals.
  - Assessment of contaminant transport in fine grain sediments, including in fracture networks (fracture networks are sometimes believed responsible for unexpected movement).
  - Studies of the validity of Darcy Law at permeabilities of 10^{-7} to 10^{-8} cm/s; also, an investigation of the effective porosity term used in this relationship.
  - Some standardization and survey of methods used to measure design parameters. These practices may be reasonably good, but the information has never been assembled in one location.

Key Contacts

- The following individuals/companies have good field experience with clay liners and waste disposal site design and operation:
  - Warzen Engineering; Madison, WI. Contact: Dan Vista, 608-257-4848.
  - Todd Giddings; State College, PA. Has own business installing synthetic liners, but possibly clay as well.
  - Environment Resource Management, Inc.; Westchester, PA. Contact: Ronald Landen, 215-696-9110.
- For access to a well operating clay-lined facility:
  - George Hughs; Ontario Ministry of the Environment.
- NRC: David Seifken; Silver Springs, MD. 301-427-4434 or 301-427-4663.

4.5 INTERVIEW REPORTS WITH TRADE/PROFESSIONAL AND STANDARDS SETTING ORGANIZATIONS

E-1. American Water Works Association

E-2. Electric Power Research Institute

E-3. National Sanitation Foundation

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. E-1

American Water Works Association: John Capito
Denver, CO George Craft
303-794-7711

TRW: Heather White

15 December 1982

Summary

- AWWA Standards Committee recently completed a draft manual on flexible tanks, covers, and linings. This Manual will be presented to the Standards Council for review and approval. The Standards Committee will now prepare standards on that subject.
- The manual and the standards are to be specifically directed towards potable water uses, and all sections of them may not be directly applicable to hazardous waste facilities.
- The manual is strictly advisory in nature. It is intended to serve as a guide for engineers and water utility managers in the design, installation, operation, and maintenance of facilities utilizing flexible linings and covers.
- The standards will emphasize materials specifications. Design, installation, and/or QA/QC could also be addressed in the standards, or could be addressed in separate standards at a later date.

Background

The American Water Works Association (AWWA) is concerned with various aspects of potable water supply and quality. Their Committee on Flexible Tanks, Covers and Linings for Potable Water Reservoirs was formed seven years ago to develop a manual containing guidelines and recommendations for consideration in the design, installation, operation, and maintenance of facilities utilizing flexible linings and covers. The ten-member committee recently completed the draft manual, and has received authorization from the AWWA Standards Countil to commence work on a standard which will emphasize potable water contact requirements for liners and covers. TRW originally contacted the committee chairman, Mr. Robert Nichols, who recommended that for the purpose of the subject EPA task TRW speak with John Capito, the committee's coordinator.

Flexible linings and covers might be used in the potable water industry in the following situations:

- In an earthen reservoir used to store untreated or raw water to minimize water losses due to seepage and evaporation.
- In an earthen reservoir used to store potable water, both to reduce water losses and to protect the water from contamination.
- In an existing storage facility (made of steel or concrete or lined with asphalt) which has developed excessive leakage.
- In an existing open-top facility requiring protection from contamination.

The following is a description of the status and nature of the manual and standards, and of the process by which AWWA manuals and standards are developed. Research needs perceived by AWWA and suggested contacts are also provided.

Status of the Manual and Standards

- The manual has been completed by the committee and will now be reviewed for approval by the Standards Council*.
- The committee recently received authorization to prepare standards for the use of flexible membrane covers and linings. The committee will be expanded for this effort, which may take four to five years.

Nature of the Manual and Standards

- The manual is intended to serve as a guide for engineers and water utility managers in the design, installation, operation, and maintenance of facilities utilizing flexible linings and covers.
- The manual is strictly advisory in nature. It is not intended to be a design handbook or a set of materials specifications. It includes recommendations regarding design, installation, operation, and maintenance of both flexible linings and floating covers. An engineer may choose whether or not to follow the manual's recommendations.

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*TRW has obtained a copy of the draft manual. The draft covers such aspects of liner and cover design and installation as climatic considerations, life expectancy, seaming procedures, leakage, traffic on installed liners, certifications of manufacturers and/or fabricators as to background experience, disinfection of the reservoirs, etc. Although many of the topics covered can apply (or be extrapolated) to hazardous waste facilities, some will clearly not apply (e.g., certification of the membrane for potable water use). The manual will be studied by TRW in some detail and the information from it that is applicable to hazardous waste facilities will be used in the subject work assignment for EPA.

- The standards will emphasize materials specifications, although it could include design, installation, and/or QA/QC procedures as well. These other considerations could be addressed in separate standards at a later date instead of in the standards presently under development.

- No effort is made to cross-check AWWA standards with those of other organizations. However, AWWA standards do refer to American Society of Testing and Materials (ASTM), National Sanitation Foundation (NSF), and other standards as appropriate. They attempt not to duplicate other organizations' standards and to make them specific to potable water uses only.

- NSF standards coordinator Gary Sherlaw has attended the last few meetings of this AWWA Committee. An AWWA representative is a member of the NSF Committee and has participated in NSF standards activities. He felt that NSF's standard was too broad for the AWWA's purposes and that a separate, more narrowly defined standard specifically directed to potable water uses was appropriate and justified.

- AWWA has no plans to address clay or asphalt lined reservoirs because there is no need for specific recommendations or standards for potable water applications. The most closely related item is a relatively old manual on spillways.

- Both the manual and the standards are oriented towards potable water applications. They are not intended to address the special concerns of hazardous waste applications (e.g., waste/liner compatibility). Because of this, even though portions of the manual and standards could apply to hazardous waste facilities, it is up to the engineer to decide whether or not a specific article in the manual or standards applies to the facility in question.

Development of AWWA Manuals and Standards

- A standard is only developed when there is a recognized need for one, as pertains to potable water uses. There must be at least two manufacturers of the product. Often the manufacturers will request standardization. The Standards Council must authorize the project and assign it to a committee.

- All AWWA committees are composed of volunteers with expertise in the subject under consideration by the committee. The committee members need not be members of AWWA. Manufacturers, consumers (water utility personnel), and people with general interest in the subject (e.g., consultants) may all be on a committee, although manufacturers may not comprise more than one-third of the committee.

- The personal knowledge and practical experience of the committee members, as well as appropriate reference materials and case studies, are used in developing and supporting a standard or manual. The committee must meet the product quality needs of the water works industry while limiting standard requirements to those which are technically justified and do not unreasonably limit product competition.

- Each committee meets at least once each year at the annual AWWA convention. Mid-year meetings may be conducted (and were in the case of this committee). Much of a committee's work is conducted via correspondence.

- Decisions are made by consensus of the committee. This applies to the contents of a manual as well as the specifications of a standard.

- A standard is approved only after it has passed six review levels:

  - The committee votes on the standard.
  - The AWWA Standards Council votes on it by letter ballot. The twenty council members are all consumers or those with a general interest in the subject matter; no manufacturers are on the council. Many council members have experts on their staff review the standard.
  - A notice of Standard Council action is published in AWWA's newsletter, Mainstream, to begin a 30 day public comment period. If an appeal is received during the 30 day comment period, then Standard Council action is suspended until the appeal is resolved.
  - The AWWA Board of Directors votes on the standard.

- The American National Standards Institute (ANSI) conducts a 60 day public review of the standard prior to their adoption of the standard as an American National Standard. This 60 day review may be concurrent with AWWA's 30 day public comment period.

- A manual undergoes only the first two of the above review levels. After it has been approved by the committee and the Standards Council, it is published and offered for sale.

Research Needs

- In keeping with their concern for potable water, AWWA is interested in seeing more research in the following areas:

  - The interactions of liners and water and the possibility of decreases in water quality (due to toxic substances entering the water, etc.).
  - The potential for groundwater contamination due to waste or leachate seepage from land disposal facilities, which could result from adverse reactions between wastes and liners.

- Environmental effects (e.g., sunlight, smog, acid rain, rodents) on floating covers.

Suggested Contacts

Robert L. Nichols, Partner, Freese & Nichols, Fort Worth, TX, is chairman of the Standards Committee on flexible reservoir covers and linings for potable water storage and may be able to suggest additional contacts or provide reference material.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND
INSTALLING COVER AND BOTTOM LINER SYSTEMS
FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. E-2

Electric Power Research Institute: Dean Golden
Palo Alto, CA 415-855-2516

TRW: Louis L. Scinto

17 December 1982

Summary

- Clay liners have their place in utility waste disposal applications since in the long term, they provide waste attenuation rather than "interim" containment.
- EPRI has simple hydrologic models for predicting leachate migration from landfills, but it will take 3-5 years to incorporate into the models laboratory data on soil attenuation of specific constituents.
- Although not directly affected by the July 1982 hazardous waste regulations (because utility coal combustion wastes are not hazardous wastes), the electric power industry is finding that states tend to apply many of the provisions of EPA's hazardous waste regulations to non-hazardous waste disposal facilities.
- EPA or the states should provide on-site inspectors during liner installations to ensure the quality of the work.
- Completed, on-going, and planned EPRI activities relevant to the subject program are identified.

Background

Mr. Golden is Manager of Solids By-Products and Hazardous Waste Disposal in the Coal Combustion Systems Division of the Electric Power Research Institute (EPRI). The objectives of this interview were to obtain information on: (a) completed, on-going, and future work by (or for) EPRI which might have bearing on the subject effort for EPA; and (b) Mr. Golden's views on the regulation of waste disposal facilities. A number of reports and project summaries were received during the interview which have not yet been reviewed by TRW. Results of these reviews will be incorporated into TRW's final report.

Relevant EPRI Activities

- RP1457-1: Liner Evaluation (Matrecon, Inc.). This on-going project is primarily an experimental program in which selected liner materials are exposed to actual wastes from coal-fired power plants for extended periods under conditions which simulate some of those that exist in actual facilities. The objectives are to determine liner/waste compatibility,

durability, and cost-effectiveness, and to estimate effective lives of various liner materials in specific applications. Also as part of the project, surveys were conducted of the open literature, of synthetic liner manufacturers, and of selected users to determine the state-of-the-art in liner use and groundwater monitoring at utility disposal sites.

- RP1406-1: Groundwater Mathematical Model, Battelle Northwest. A model was developed for predicting the quality and quantity of leachate and its migration path from a sludge/fly ash disposal site. A model data base and results of laboratory studies were used to implement, calibrate, and verify a two-dimensional, finite difference hydrologic flow model for the study area. The saturated flow model was developed in 1980 and in 1981 a new model incorporating unsaturated flow conditions was developed and linked with the original model. Beginning in 1983, laboratory studies will begin (under RP 2198 of Environmental Assessment Department) to determine soil attenuation properties which could be incorporated into the model in 3-5 years.

- RP1685: By-Product Disposal Manuals - Manual for Upgrading Existing Disposal Facilities, SCS Engineers. This manual, published in August 1982 as CS-2557, provides a description of current disposal systems and where they may be deficient compared to EPA criteria, and what remedial measures can be taken when necessary to bring existing systems up to standard. A discussion of liner and leachate collection system installation is included in the document.

- RP1260-9: Evaluation of Levels for Solid Waste Disposal Areas, Hydrocomp, Inc. During this study, 551 coal-fired power plants were located relative to floodplains. Of these sites, only 109 were definitely outside the 100-year floodplain. The report also assesses the Federal Insurance Administration (FIA) methods of flood mapping, which may be used to enforce potential EPA regulations concerning facility locations. Major issues and concerns regarding use of FIA maps/methods for enforcement of regulations are pointed out. This report was published in October 1979 as FP-1205.

Views on Regulations and Relevant Activities

- One of the concerns of the electric utility industry is that states will adopt regulations for non-hazardous waste facilities that are as stringent as EPA's new regulations for hazardous waste sites. In fact, three states have already adopted regulations that are more stringent than EPA's rules. The industry believes clay liners are suitable for some wastes produced by coal-fired power plants; however, some low volume waste streams may require disposal as hazardous wastes, for example, because of their toxicity. Radian Corp. is studying management options for these low volume wastes as part of RP2215.

- Michael Baker, Jr. Inc. has prepared for EPRI engineering and economic assessments of how EPA regulations may affect the electric utility industry. Their assessment of the impact of the July 26 regulations is due to be published in May 1983.

ASSESSMENT OF TECHNOLOGY FOR CONSTRUCTING AND INSTALLING COVER AND BOTTOM LINER SYSTEMS FOR HAZARDOUS WASTE FACILITIES

EPA Contract No. 68-02-3174; Work Assignment No. 109

INTERVIEW NO. E-3

National Sanitation Foundation: Gary Sherlaw
Ann Arbor, MI 313-769-8010

TRW: Masood Ghassemi
John F. Metzger

28 January 1983

Summary

- Voluntary standards being developed by NSF from the combined input of liner manufacturers/fabricators, regulators, and users can assure the quality of materials used to line land disposal facilities.
- NSF efforts to develop liner standards have been on-going since January 1978. The work is nearing completion as another set of objections has been addressed and another ballot is currently circulating. The standards could conceivably be in place by mid-year.
- Accreditation of field installers at the foreman level could be an effective means of ensuring better quality control during field installation.
- Research and development should emphasize development of "accelerated" performance tests which can simulate 25 or more years of service within a short time frame of a laboratory or field test.

Background

National Sanitation Foundation (NSF) is a nonprofit corporation that develops voluntary standards in selected public health and environmental areas. There are three formal service areas: listing, certification, and assessment. Listing services include standards development and list products meeting the standards developed by NSF. Certification services are similar to listing services but the standard against which a product is tested has been developed by someone other than NSF. Assessment services encompass special studies and service, including research, demonstration, and protocol development.

The objectives of the NSF standards development program is to assure that standards are developed based on facts, not curbstone opinion. To meet this objective, existing knowledge, both published and unpublished, is consulted; and new research is conducted when necessary. During this process NSF works to develop a mutual understanding between manufacturers of the products involved, the users of those products, regulatory officials

concerned with the products' performance and the general public. The ultimate purpose of these efforts is to provide a mechanism for cooperative action by these groups which will lead to uniform national voluntary consensus standards in the area of concern. NSF standards development program is entirely voluntary and involves the active cooperation of the manufacturer, the user and the regulatory officials charged with rendering decisions concerning the products involved. The NSF's staff function is entirely that of coordination and liaison between these groups in an effort to promote mutual understanding to obtain improvement in the public and environmental health of the nation.

NSF is in the process of developing a standard for the flexible membrane liner industry. The purpose of the interview was to determine the status and significance of this standard and the process by which it is developed.

Impetus For and General Procedures For Developing Standards at NSF

- The impetus for developing standards can come from industry, from public health agencies or from the consumer. The Foundation determines the need for the development of new standards by meeting with industry and professional public and environmental health groups. The need can also be determined through discussions held at clinics and at public health and environmental congresses. Once the need has been established, the necessary committee framework for the specific standards area is put in place. Basically, it involves a joint committee which has overall jurisdiction during the development phase of the project and, if indicated, a task committee to assist in writing the standard.

- Participation on a joint committee is by invitation. Each organization, public or private, involved in the standard under consideration appoints its own representative. Representation from the manufacturing sector is broad and unrestricted in attendance. Military and civilian U.S. government agencies send professional representatives. The consumer may be represented by individuals or by special consumer groups, if available, or by government or military personnel.

- The NSF professional staff coordinates the activity, provides secretarial services and acts as liaison between the joint committee and the task committees. Meetings are structured to allow the maximum flexibility for free and wide ranging discussion. The joint committee is chaired by an individual selected from the current, or past, membership of the NSF Council of Public Health Consultants. Usually, the person selected is one having experience or expertise in the standards area involved.

- Once hearings have been held and necessary research conducted, the NSF staff brings together the reports and recommendations from the joint committee and the task committees, and the draft of a proposed standard is prepared. The joint committee then meets to consider the preliminary

draft of the proposed standards. At this point, the joint committee may approve the proposed standard or criteria, so that it can be submitted to the NSF Council of Public Health Consultants. On the other hand, it may refer specific items back to the task committee for further study. It may ask the task committee to clarify points, revise or otherwise modify the draft. In some cases the joint committee may call in special advisory groups or consultants. The joint committee may also reject the draft. Should this occur, the entire subject is reworked by the appropriate task committee and resubmitted to the joint committee for reconsideration.

- Once approval is obtained, the final draft of the proposed standard is endorsed by the joint committee before being sent to the NSF Council of Public Health Consultants. The Council of Public Health Consultants determines if the standard is adequate to the protection of the environment and public's health. If so, the Council will recommend its adoption by the NSF Board of Trustees. If this is not the case, the Council will refer it back to the joint committee for further work. Once objections, if any, are clarified, the NSF Board of Trustees adopts the standard, at which point the standard is published and distributed to public health agencies, manufacturers and users.

- A copy of an NSF publication describing NSF policies relating to the use of NSF seals by manufacturers on the products covered by a published NSF standard is attached.

- Industry supports the standards development effort with a one-time fee which is currently $1,260 per company. This money is used primarily to cover the cost of travel of regulatory people, for whom out of state travel is usually not paid for in their work. In the future, the fee structure may be modified somewhat to better reflect the incurred costs. NSF's overall operations are financed by test program fees and annual inspection fees, and government grants and contracts.

- A membership list of the NSF Joint Committee for flexible membrane liners, industry representatives inputting the NSF standards development effort, and individuals/organizations receiving courtesy copies of various drafts is attached to this summary.

Status of the Synthetic Liner Standards and Perspectives on Their Development

- NSF work on the development of synthetic liner standards has been ongoing since January 1978.

- A consensus of 90 percent is needed to move the draft standards out of the joint committee; currently there is 77 percent approval. To get the remaining votes needed, objections must be reviewed along with supporting data to determine if changes are warranted. If all pieces fall together soon, the standards could be in place by mid-year.

- Although NSF standards will only address the liner quality, it will include, as attachments to the standards, recommendations on practices in related areas (e.g., liner installation). These recommendations are included in the standard to provide useful information to concerned regulatory officials and users.

- NSF standards require a mandatory review every five years. Due to the rapid development occurring in the synthetic liner industry, more frequent reviews may be necessary. Some standards that have been developed by NSF in other areas were reviewed annually after issue.

Importance of Liner Standards

- The standards under development apply only to manufacturers and fabricators of synthetic liners; however, input is given by material suppliers, installers, and regulators (see listings attached) to ensure their full acceptance.

- The main value of standards is the acceptance of procedures and materials by an independent third party by criteria that has been agreed to by all parties in the industry. This probably results in an improved functioning and higher level of product quality by the entire industry.

- The standards program is fully voluntary, but most of the major manufacturers and fabricators are probably participating along with a smaller representation of installers. Once the standards are in place, those who do not subscribe to the program will not necessarily be pushed out of the market. This will depend on how the standards are applied by concerned regulatory officials and users/consumers.

- NSF has no enforcement power. Its relationship to listed companies is largely contractual. The main leverage that can be applied to companies who will be in the program but not abiding by the NSF policies is to drop that company or its product from the listing.

QA/QC for Liner Installation

- Once the standards are in place, the feasibility of a program to accredidate installers will be investigated by NSF, particularly with regard to construction of field seams. Such a program should extend only to the level of field foremen as it is impractical to require accreditation of individual field workers. Implementation of such an accreditation program would provide for significant improvements in quality control during installation.

- It is not feasible to develop standards for clay liners because the quality of material is almost completely dependent on the specific application and site. Even with synthetic liners, no attempt is made in the standards to ensure adequate installation; only the material quality is addressed.

Research and Development Needs

- Research is needed to develop performance tests that can be made in the laboratory and that correlate well with field experience. All areas of liner performance need to be addressed in this way, but especially accelerated tests that compact 25 years or more of service into a short period of laboratory tests.

Additional Contacts

The list of individuals/organizations in the lining industry which TRW has interviewed or plans to interview should be expanded to include at least the following industry experts (which also include representation of the practices in the Northeastern part of the U.S.):

- Charles E. Staff; Staff Industries; Upper Montclair, NJ.
- Richard Ward; B.F. Goodrich Company; Marietta, OH.
- Richard Dickinson; Dynamit Nobel of America; Rockleigh, NJ.
- Larry Kamp; The Pantasote Company of New York, Inc.; Passaic, NJ.
- Arnold Peterson; Stevens Elastomeric and Plastic Products; East Hampton, MA.

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NATIONAL SANITATION FOUNDATION

POLICIES RELATING TO THE USE OF NSF SEALS

AS REVISED NOVEMBER, 1977

As a public service, the National Sanitation Foundation offers to any reputable manufacturer the use of the NSF seal upon formally listed products subject to the following conditions and stipulations

1 Any company, after it has determined that its products are covered by a published NSF standard or criteria may apply for evaluation and listing by National Sanitation Foundation (NSF)

2 Each manufacturer who desires the use of the NSF seal must file with NSF an "Application for Evaluation, Testing and Listing Services." This application shall contain an affidavit, signed by the manufacturer, certifying that if said company is authorized the use of the NSF seal, the seal will be placed only on new products fully complying with the NSF standards or criteria, only at the authorized point of production, and that said company will abide by the "Policies Relating to the Use of NSF Seals."

3 Evaluation and/or testing of any product which a company desires to have listed shall be made by NSF Authorization to use the NSF seal upon such products shall not be granted until evidence has been furnished the Senior Vice President of NSF that the product meets the standards or criteria

4 Evaluation of products may be made in the applicant's manufacturing plant, at a site acceptable to NSF or at NSF

5 By authority of the Board of Directors, the Senior Vice President or other Corporate Officer, of NSF may authorize the listing of products as eligible for the NSF seal The manufacturer will be advised of such listing in writing, and the listing will be made public Equipment listed by model number shall bear a permanent type plate or label stating said model designation.

6 The observance of the requirements of the standard by a manufacturer is one of the conditions of the continued listing of the manufacturer's product NSF, however, assumes no responsibility for the effect of such observance or nonobservance by the manufacturer upon the relations between the manufacturer and any other party or parties arising out of the sale or use of the product or otherwise

7 Evaluation and/or testing by NSF of all items or products produced during any listing period is impractical It is therefore the responsibility of each manufacturer who is granted authorization to use the NSF seal to place the NSF seal only on new equipment or products fully complying with NSF standards or criteria A manufacturer may not use the same model number on NSF listed and "non" NSF listed products Further it is understood that only products bearing the seal shall be considered as listed

8 By authority of the Board of Directors, the Senior Vice President or other Corporate Officer, of NSF reserves the right to withdraw the listing of any item at any time for failure to comply with the standard and attendant policies Upon notice of the removal of a product from NSF listing, the manufacturer shall immediately stop applying the NSF seal to such products.

9 Variations or alternates in material design, construction or operation requirements of established NSF standards or criteria shall be approved by NSF prior to adoption and use by the manufacturer Such variations or alternates shall be approved only when they have been evaluated and found to be fully equal to or better than, the material, design, construction or operation requirements of the applicable NSF standards or criteria and conform to the minimum requirements thereof.

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10. It is fully understood that NSF will conduct unannounced visits to production facilities for the evaluation of listed products. Such product evaluations shall be made as determined necessary by the Senior Vice President of NSF.

11 Whenever a product which is listed by model number or which bears the NSF seal is found by NSF to be in noncompliance with the requirements of the applicable NSF standard or criteria, the manufacturer thereof shall immediately effect correction of all future production in said regard, and shall effect correction of said violations on the specific product found in noncompliance. Corrective action(s) shall be carried out within such reasonable time as is established by NSF.

12 When after receipt of satisfactory evidence of correction of reported violations, subsequent evaluations of the products (future production or the specific product in question) indicate that the corrective measures have not been, or are not being effected, the authorization to use the NSF seal on said model or equipment or by the manufacturer, whichever is deemed appropriate by NSF, shall be withdrawn. When authorization to use the NSF seal has been withdrawn from a manufacturer under the above provisions, NSF may advise such health agencies, manufacturers and other interested parties as deemed appropriate.

13 Reinstatement following withdrawal of listing and authorization to use the NSF seal by the manufacturer, or on specific products, shall be effected only after re-evaluation of the product in question by NSF. The cost of re-evaluation shall be subject to such charges as are established by NSF.

14 Minimum charges will be made for services These service charges cover cost of standards development, inspection at the company's facilities, printing and distribution of listing, and administrative processing. Service charges will start at the date of execution of application for evaluation and listing service by the company Services of NSF will be available to the company; it will be the company's responsibility to avail itself of these services within the period specified in the application. In the case of a company who does not avail itself of services, the monies paid upon the application will be considered expended during the period specified in the application Additional service charges may be rendered for special field evaluations and investigations of listed products found not to be in compliance with the applicable NSF standards or criteria Any deletion in evaluation/listing services or testing must be communicated to NSF within 30 days of the date of the annual invoice or the charges shall be due and payable as stated Further, all costs incurred by NSF in collection thereof shall be charged to and paid by the firm invoiced.

15 The cost of evaluation and testing of products sent to NSF as well as any required special testing at the plant shall be subject to charges to be agreed upon between the applicant and NSF

16. The NSF seals in the established form used by the company shall be purchased from the approved source on orders forwarded through NSF for approval.

17. The manufacturer hereby holds NSF harmless and agrees to indemnify it against any and all claims, causes of action or lawsuits arising from the use of the seal, including but not limited to costs and attorney's fees attendant thereto

18 NSF will use every legal means available to prevent unauthorized use of the seal on unlisted items or on listed items found to be substandard. The manufacturer agrees to be sued in either the State of his principal place of business or the State of Michigan for failure to comply with any of the terms of this contract including, but not limited to, payment of fees due to National Sanitation Foundation or National Sanitation Foundation Testing Laboratory.

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FOR

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