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Standard Guide for Design of a Liner System for Containment of Wastes[1]

This standard is issued under the fixed designation D 1973; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers information which will aid in the design of liner systems to minimize the migration of wastes to the environment. Basic information is provided on facility requirements and site characteristics. Information on various liner materials including test methods and suggestions for determination of liner characteristics and compatibility with wastes are also presented.

2. Referenced Documents

2.1 *ASTM Standards:*

C 33 Specification for Concrete Aggregates[2]

C 109 Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or 50-mm Cube Specimens)[3]

C 150 Specification for Portland Cement[3]

C 226 Specification for Air-Entraining Additions for Use in the Manufacture of Air-Entraining Portland Cement[3]

C 260 Specification for Air-Entraining Admixtures for Concrete[2]

C 311 Method for Sampling and Testing Fly Ash or Natural Pozzolans for Use as a Mineral Admixture in Portland Cement Concrete[2]

C 494 Specification for Chemical Admixtures for Concrete[2]

C 573 Method for Chemical Analysis of Fireclay and High-Alumina Refractories[4]

C 593 Specification for Fly Ash and Other Pozzolans for Use with Lime[3]

C 595 Specification for Blended Hydraulic Cements[3]

C 618 Specification for Fly Ash and Raw or Calcined Natural Pozzolan for Use as a Mineral Admixture in Portland Cement Concrete[2]

C 821 Specification for Lime for Use with Pozzolans[3]

C 845 Specification for Expansive Hydraulic Cement[3]

D 412 Test Methods for Rubber Properties in Tension[5]

D 413 Test Methods for Rubber Property—Adhesion to Flexible Substrate[5]

D 421 Practices for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants[6]

D 422 Method for Particle Size Analysis of Soils[6]

D 427 Test Method for Shrinkage Factors of Soils[6]

D 471 Test Method for Rubber Property—Effect of Liquids[5]

D 558 Test Methods for Moisture-Density Relations of Soil-Cement Mixtures[6]

D 559 Method for Wetting-and-Drying Tests of Compacted Soil-Cement Mixtures[6]

D 560 Methods for Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures[6]

D 624 Test Method for Rubber Property—Tear Resistance[5]

D 638 Test Method for Tensile Properties of Plastics[7]

D 698 Test Methods for Moisture-Density Relations of Soils and Soil Aggregate Mixtures, Using 5.5-lb (2.5-kg) Rammer and 12-in. (305-mm) Drop[6]

D 746 Test Method for Brittleness Temperature of Plastics and Elastomers by Impact[7]

D 751 Method of Testing Coated Fabrics[8]

D 792 Test Methods for Specific Gravity (Relative Density) and Density of Plastics by Displacement[7]

D 806 Test Method for Cement Content of Soil-Cement Mixtures[6]

D 882 Test Methods for Tensile Properties of Thin Plastic Sheeting[7]

D 1004 Test Method for Initial Tear Resistance of Plastic Film and Sheeting[7]

D 1149 Test Method for Rubber Deterioration—Surface Ozone Cracking in a Chamber[5]

D 1203 Test Methods for Volatile Loss from Plastics Using Activated Carbon Methods[7]

D 1204 Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature[7]

D 1239 Test Method for Resistance of Plastic Films to Extraction by Chemicals[7]

D 1556 Test Method for Density of Soil In-Place by the Sand-Cone Method[6]

D 1557 Test Method for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54 kg) Rammer and 18-in. (457-mm) Drop[6]

D 1558 Test Method for Moisture Content Penetration Resistance Relationships of Fine-Grained Soils[6]

D 1586 Method for Penetration Test and Split-Barrel Sampling of Soils[6]

D 1593 Specification for Nonrigid Vinyl Chloride Plastic Sheeting[7]

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[1] This guide is under the jurisdiction of ASTM Committee D-34 on Waste Disposal and is the direct responsibility of Subcommittee D34.05 on Evaluation of Liner Materials.

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[2] *Annual Book of ASTM Standards*, Vol 04.02.

[3] *Annual Book of ASTM Standards*, Vol 04.01.

[4] *Annual Book of ASTM Standards*, Vol 03.06.

[5] *Annual Book of ASTM Standards*, Vol 09.01.

[6] *Annual Book of ASTM Standards*, Vol 04.08.

[7] *Annual Book of ASTM Standards*, Vol 08.01.

[8] *Annual Book of ASTM Standards*, Vol 09.02.

D 1633 Test Method for Compressive Strength of Molded Soil-Cement Cylinders[6]
D 1634 Test Method for Compressive Strength of Soil-Cement Using Portions of Beams Broken in Flexure (Modified Cube Method)[6]
D 1635 Test Method for Flexural Strength of Soil-Cement Using Simple Beam With Third-Point Loading[6]
D 1693 Test Method for Environmental Stress-Cracking of Ethylene Plastics[9]
D 1790 Test Method for Brittleness Temperature of Plastic Film by Impact[9]
D 2136 Methods of Testing Coated Fabrics—Low-Temperature Bend Test[5]
D 2166 Test Methods for Unconfined Compressive Strength of Cohesive Soil[6]
D 2167 Test Method for Density and Unit Weight of Soil in Place by the Rubber-Balloon Method[6]
D 2216 Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures[6]
D 2240 Test Method for Rubber Property—Durometer Hardness[4]
D 2434 Test Method for Permeability of Granular Soils (Constant Head)[6]
D 2435 Test Method for One-Dimensional Consolidation Properties of Soils[6]
D 2552 Test Method for Environmental Stress Rupture of Type III Polyethylenes Under Constant Tensile Load[9]
D 2850 Test Method for Unconsolidated, Undrained Compressive Strength of Cohesive Soils in Triaxial Compression[6]
D 2901 Test Method for Cement Content of Freshly Mixed Soil-Cement[6]
D 2922 Test Methods for Density of Soil and Soil Aggregate in Place by Nuclear Methods (Shallow Depth)[6]
D 2937 Test Method for Density of Soil in Place by the Drive-Cylinder Method[6]
D 3080 Method for Direct Shear Test of Soils Under Consolidated Drained Conditions[6]
D 3083 Specification for Flexible Poly(Vinyl Chloride) Plastic Sheeting for Pond, Canal, and Reservoir Lining[6]
D 3385 Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometers[6]
D 3441 Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Tests of Soil[6]
D 3987 Test Method for Shake Extraction of Solid Waste with Water[10]
D 4253 Test Methods for Maximum Index Density of Soils Using a Vibratory Table[6]
D 4254 Test Methods for Minimum Index Density of Soils and Calculation of Relative Density[6]
D 4318 Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils[6]
D 4437 Practice for Determining the Integrity of Field Seams Used in Joining Flexible Polymeric Sheet Geomembranes[6]
D 4545 Practice for Determining the Integrity of Factory Seams Used in Joining Manufactured Flexible Sheet Geomembranes[6]
D 4833 Test Method for Index Puncture Resistance of Geotextiles, Geomembranes and Related Products[6]
D 4885 Test Method for Determining Performance Tensile Strength of Geomembranes Using Wide Strip Testing[6]
G 51 Test Method for pH of Soil for Use in Corrosion Testing[11]

2.2 *AASHTO Standards:*
M-85 Standard Specification for Portland Cement[12]
T134 Moisture-Density Relations of Soil-Cement Mixtures Standard Specification for Transportation, Materials, and Methods Sampling Testing, Part II[12]
T135 Wetting and Drying Test of Compacted Soil-Cement Mixtures[12]
T136 Freezing-and-Thawing Tests of Compacted Soil-Cement Mixtures[12]
M-240 Standard Specifications for Blended Hydraulic Cements[12]

2.3 *ACI Standards:*
Committee 211.1 Standard Procedures for Selecting Proportions for Normal, Heavy Weight and Mass Concrete[13]
Committee 212 A Guide for Use of Admixtures in Concrete[13]
Committee 350 Concrete Sanitary Engineering Structures[13]
Committee 515 A Guide to Use of Waterproofing, Dampproofing, Protective and Decorative Barrier Systems for Concrete[13]

2.4 *NSF Standard:*
54 Standard for Flexible Membrane Liners[14]

2.5 *Code of Federal Regulations:*
40 CFR Resource Conservation and Recovery Act[15]

2.6 *EPA Standards:*
SW-846 Test Methods for the Evaluation of Solid Waste, Physical/Chemical Methods[15]
SW-867 Evaluating Cover Systems in Solid and Hazardous Waste[15]
SW-868 Hydrologic Simulation on Solid Waste Disposal Sites[15]
SW-869 Landfill and Surface Impoundment Performance Evaluation[15]
SW-870 Lining of Waste Impoundments and Disposal Facilities[15]
SW-873 Closure of Hazardous Waste Surface Impoundments[15]

2.7 *Corps of Engineers' Manual:*

[9] *Annual Book of ASTM Standards*, Vol 08.02.
[10] *Annual Book of ASTM Standards*, Vol 11.04.
[11] *Annual Book of ASTM Standards*, Vol 03.02.
[12] Available from the American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol, Washington, DC 20001.
[13] Available from the American Concrete Institute (ACI), P.O. Box 19150, Detroit, MI 48219.
[14] Available from National Sanitation Foundation (NSF), 3475 Plymouth Rd., P.O. Box 1468, Ann Arbor, MI 48106.
[15] Available from Standardization Documents, Order Desk, Bldg. 4, Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, ATTN: NPODS.

EM 1110-2-1906 Laboratory Soils Testing[16]

2.8 *ASA Standards:*

Method 46 Petrographic Microscope Techniques[17]

Method 46-2 Grains[17]

Method 46-3 Thin Sections[17]

Method 47 Electron Microscope Techniques[17]

Method 48 X-Ray Diffraction Techniques for Mineral Identification[17]

Method 49 X-Ray Diffraction Techniques for Mineral Identification and Mineralogical Composition[17]

Method 50 Thermal Analysis Techniques for Mineral Identification and Mineralogical Composition[17]

Method 51 Infrared Spectrometry[17]

3. Significance and Use

3.1 This guide has been prepared as a reference in the planning and design of liner systems for containment of wastes. It is intended for use by owners, operators, and designers of waste disposal sites requiring liner systems. These organizations may also benefit from the information pertaining to facility considerations.

3.2 Not all of the methods and procedures outlined will be applicable to each facility. It is anticipated that the user will select from this guide the most appropriate information for his/her use. Specific investigations and evaluations are required on most projects due to variability of both waste and site conditions. Because of these variations, design considerations other than those described in this guide may also be required.

4. General Considerations

4.1 A flow diagram of landfill and impoundment liner development is presented in Fig. 1.

4.2 In selecting a liner system, the primary objective is to contain the waste and waste constituents. The general environmental conditions around the facility need to be adequately considered. Potential adverse affects of any seepage from the facility and any external factors should be addressed. These factors should be considered in determining the criticality of a failure of the liner system. This evaluation may lead to a liner design that is either more or less stringent than standard practices.

4.2.1 Current and future uses of groundwater are of major importance. This should be a consideration in determining the level of redundancy in design.

4.2.2 The potential for waste constituents to migrate from the facility after they have entered the environment (because of liner failure or seepage) should be considered. Some chemicals are more mobile in the subsurface environment than others.

4.2.3 The waste constituents should be evaluated in terms of their potential for causing health effects in humans or damage to wildlife and vegetation.

4.3 Any liner design document should contain a Quality Assurance/Quality Control program for implementation during construction.

4.4 Thickness and configuration of the liner system and components should be determined by the engineer responsible for the design on a site specific basis.

5. Regulatory Requirements

5.1 An early step in liner development is to identify the relevant regulatory agency or agencies to determine permitting status. The appropriate regulations should be reviewed and closely examined to aid in compliance with the applicable laws. Early contact with the agencies will address the areas of concern so the required permits may be successfully and expeditiously processed.

5.2 The number and types of permits required will depend on the specific situation and regulatory agencies. It is not feasible to list all the permits which must be obtained, nor the regulatory agencies, because they vary widely across the country. The following sections provide a general list of regulatory agencies and the focus of their concerns and authorizations.

5.2.1 The local environmental authorities may not have technical regulations regarding containment facilities or liner design criteria. It is recommended, however, that all local public health departments, zoning boards and conservation districts be researched.

5.2.2 States which have Federal authorization to administer the hazardous waste program can be dealt with exclusively, whether the wastes are hazardous or nonhazardous. The state's hazardous waste regulations will comply with all Federal guidelines and be no less stringent than those guidelines. The state regulations regarding nonhazardous waste disposal and subsequent regulations pertaining to liner installations may be quite variable from state to state. In any event, it is recommended that all applicable state laws pertaining to liner requirements be reviewed early in the containment facility and liner design stages. In-depth discussion with the appropriate environmental regulatory authorities, as well as health departments and disposal agencies, regarding all phases of the containment facility and the intended liner installation, is recommended. Contact with the United States Army Corps of Engineers may also be appropriate. Investigating the applicability of stream encroachment and wetlands regulations is also recommended.

5.2.3 The U.S. EPA administers regulatory programs in the areas of water pollution control and solid waste management, as authorized by the Resource Conservation Recovery Act (RCRA). The regulations, promulgated under RCRA, should be reviewed in detail in regard to management of waste materials. In the event the waste is classified as hazardous, the appropriate federal regulations promulgated under the RCRA will likely apply and the containment facility design will be largely governed by such regulations. This includes those requirements relative to liner design, construction, operation, monitoring and maintenance, and quality control.

6. Identifying Site Characteristics

6.1 Prior to undertaking time consuming and expensive investigations, a determination should be made as to whether the proposed facility site will impact the selection of a liner. Typical factors to consider include whether the site is located in an area having high ground water, a floodplain, wetland,

[16] Available from Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, MS.

[17] Available from the American Society of Agronomy (ASA), Methods of Soil Analysis, Parts 1 and 2, 677 S. Segoe Rd., Madison, WI 53711.

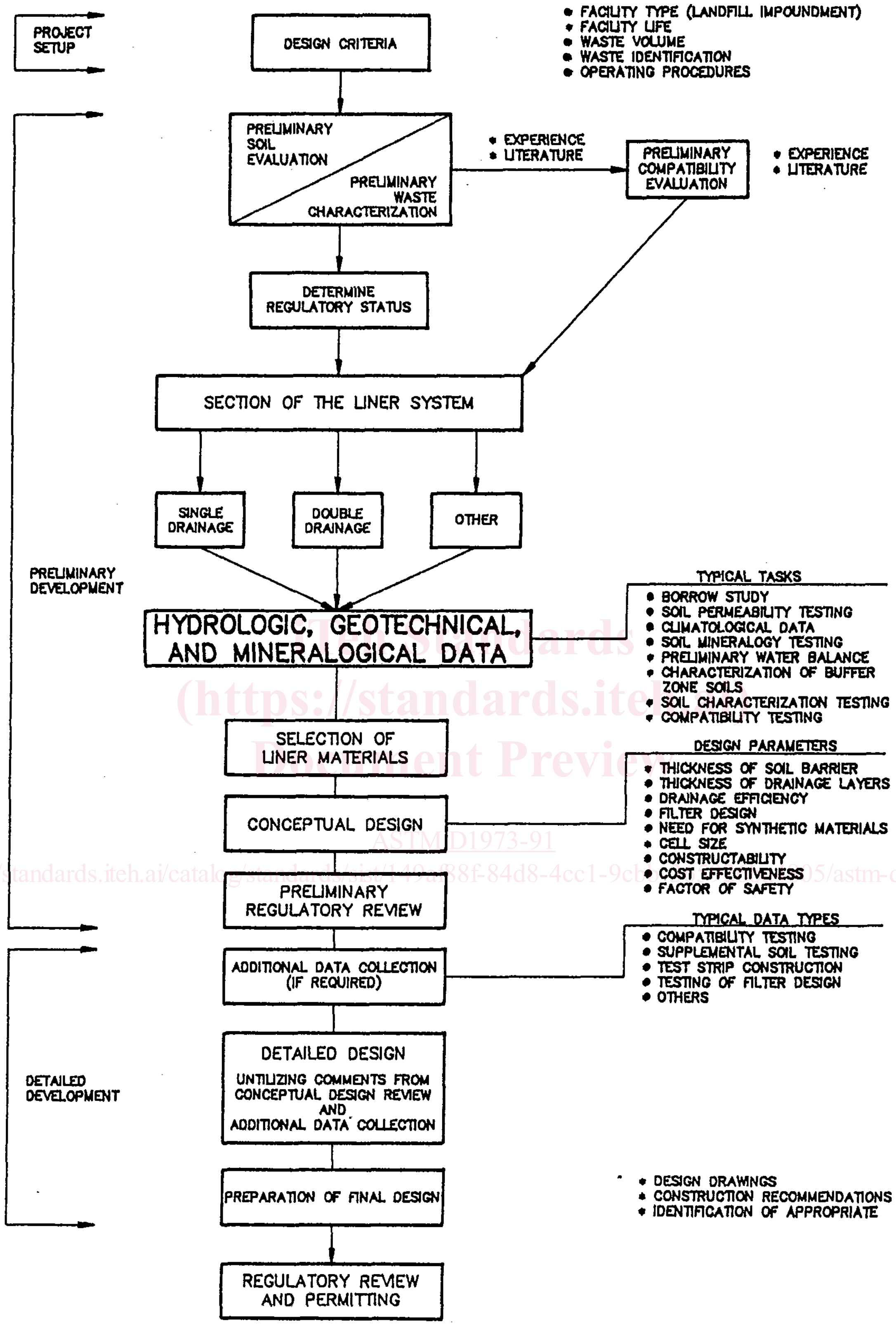


FIG. 1 Flow Diagram for Landfill and Impoundment Liner Development

area of seismic risk, or utilities that would preclude use of a significant portion of the prospective site. Any one, or a combination, of these constraints may be enough to eliminate consideration of a given waste disposal site, or eliminate a particular liner system, or both.

6.1.1 The elevation of groundwater is a factor that must be considered. Some regulations require a buffer zone of unsaturated soil between the liner and the groundwater while other regulations allow the design of intra-gradient waste containment facilities.

6.1.2 Waste containment facilities located in floodplains can cause significant difficulties with respect to the stability of containment systems during high water conditions due to erosion, flooding, and embankment strength reduction. In some cases, waste containment facilities in floodplains may be prohibited by regulation or statute.

6.1.3 A waste containment facility should not be placed on or around any underground utilities that may require a breaching of the liner containment system in order to allow for the continued use of the utilities.

6.1.4 Wetlands generally will preclude the use of any in-ground containment system.

6.1.5 Waste containment facilities located in areas of high seismic activity should be evaluated with regard to potential risk of ground movements. In addition, nonseismic faults may be a restraint.

6.1.6 Evaluation of bearing capacity, settlement, and slope stability for the design life of the waste containment facility should be performed.

6.2 Meteorological data are extremely helpful to describe the climatic extremes to be experienced by the liner system during placement or during operation of the facility, to determine the opportunity for infiltration into the waste disposal site, and to design stormwater control facilities. Available data can be obtained from the National Oceanic and Atmospheric Administration (NOAA) or local and regional agencies that may have more localized data. The following kinds of information will be most useful:

6.2.1 The prevailing wind velocity and direction can be analyzed to determine the frequency of occurrence of winds by season and by direction. These data may be graphically presented as a rose diagram.

6.2.2 Temperature extremes may be critical to a liner installation and to its performance. It is recommended that maximum, minimum, and average temperatures be determined for the period of record. Dates of first and last killing frost, depth of frost penetration, length of frost-free period and temperature extremes (highest and lowest on record) are additional information that is readily available.

6.2.3 In order to manage the surface runoff during the liner placement, or during operation of the facility, the anticipated rainfall from various frequency storm events will have to be determined. Data on the intensity, duration, frequency, and form of precipitation (rain versus snow) can be used to describe rainfall. Extremes of record shall be noted. Average annual and average maximum precipitation, and minimum and maximum monthly precipitation can be obtained for the period of record. This information is useful as data input in determining the hydrologic budget for a surface impoundment or for a land disposal facility.

7. Determination of Facility Life

7.1 The intended life of the proposed facility should be considered during the liner selection process.

7.1.1 That landfills should be considered long-term facilities should be taken into account in the liner selection process. The liner system will not be very accessible after landfill operations have commenced. As operations progress through site closure, the liner will become progressively less accessible. That is, liner system repairs should be considered extremely expensive and liner design should be such that the risk of liner failure is minimal. Greater care should go into the selection of liner material for long-term facilities, particularly the consideration of the long-term effects of the physical and chemical characteristics of the waste materials on the liner system.

7.1.2 Impoundments may be considered temporary facilities, inasmuch as they are likely to be cleaned or emptied, or both, as part of the operation of such facilities. Because of this, the liner system is more accessible in a surface impoundment than in a permanent facility and repairs to such a system are comparatively more feasible, should problems develop. This does not imply that less care should go into the selection of liner materials for ponds and lagoons. Environmental degradation as a result of liner failure in either a temporary or permanent facility is to be avoided. However, the available remedies for repair of a failed liner system in a temporary facility are less costly than those for a permanent facility. This may influence liner selection and design criteria.

7.2 The effects of exposure of liner materials to the ambient environment should be considered in the liner selection process. Potential liner resistance, or lack thereof, to ambient conditions such as wind, sunlight, freezing, thawing, and so forth, should be considered in the liner selection process.

8. Waste and Leachate Characteristics

8.1 The liner system for a containment facility should be properly designed to prevent environmental degradation. The physical and chemical properties of the waste should be reviewed. This knowledge will assist in the liner system design.

8.1.1 Chemical and physical analyses of the waste should be obtained to evaluate its compatibility with various liner alternatives.

8.2 The origin, process, chemical analysis, and physical analysis of the waste are valuable resources in determining the type of facility required to contain the waste. This knowledge can be used to guide physical and chemical characterization. Knowledge of the source and any pretreatment to the waste is a valuable guide for further characterization.

8.3 The physical properties of the waste materials should be identified in order to establish disposal techniques. These properties will determine the physical condition of the waste, information that is needed to design liner systems.

8.3.1 If the waste stream exists in a liquid state, analysis should typically include temperature, viscosity, specific gravity, solid content, water content, and vapor pressure.

8.3.2 If the waste stream exists in a solid state, analysis might typically include moisture content, density, permeability, shear strength, compressibility, and leachability.

8.3.3 Every containment facility is unique, and while certain physical tests are applicable for most sites, additional information may be required. The knowledge obtained pertaining to the physical waste characteristics determines the level of engineering judgment required for overall design of the facility.

8.4 *Chemical Properties:*

8.4.1 The chemical properties of wastes and waste leachate must be known to determine their effects on the liner and may be more critical than the physical properties, with respect to the potential environmental impact of the waste stream. The chemical properties will dictate the level of design necessary for the containment facility and the associated liner.

8.4.2 The chemical characteristics of wastes are determined by several classifications. The United States Environmental Protection Agency (U.S. EPA) has established regulations directed at classifying wastes based on their chemical properties. The Code of Federal Regulations (40 CFR Part 261) should be reviewed for the regulatory testing requirements for hazardous wastes. These regulations are divided into parts for specific waste streams which are classified by their specific chemical properties.

8.5 *Leachate:*

8.5.1 A major problem in designing a liner system is determining the character of the leachate that will actually be in contact with the liner material(s).

8.5.2 The Extraction Procedure (EP) Toxicity Test Method (EPA SW-846, Method 1310) is designed for waste classification but may not be a true estimate of the leachate characteristics for a single source waste. Test Method D 3987 designates a water extraction procedure and may be utilized with appropriately selected parameters to assist in waste characterization. EPA and ASTM committees are developing further alternative extraction and analytical procedures for the chemical characterization of waste as well as waste/liner compatibility.

9. Liner System Concepts

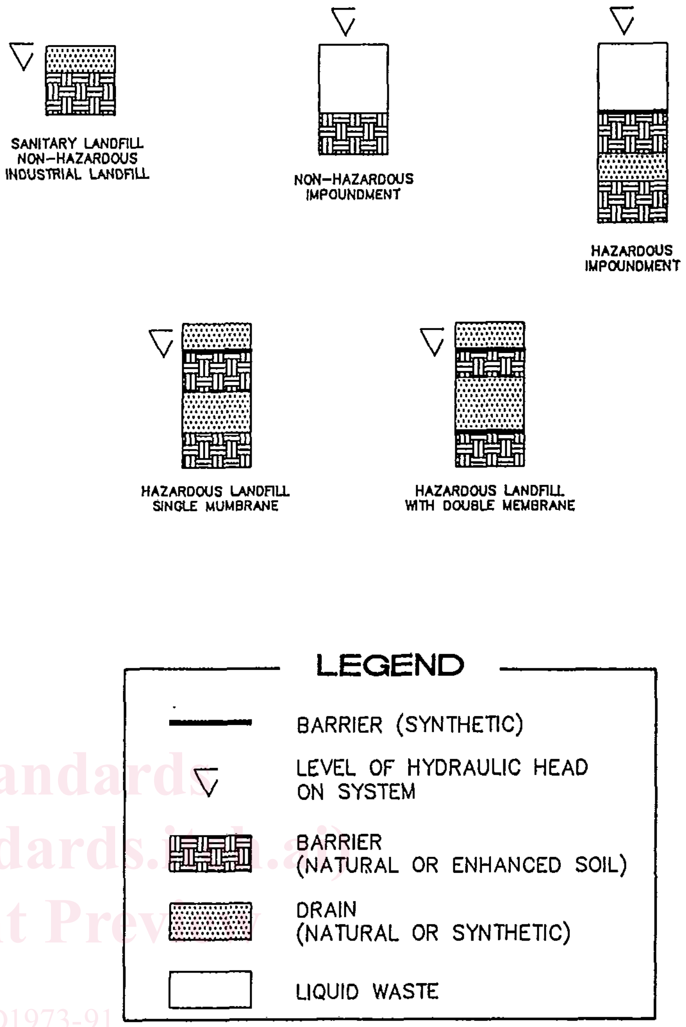
9.1 Liner systems are a primary mechanism for managing leachate once waste has been placed in an in-ground disposal or storage facility. Liner systems are designed to utilize a combination of barrier and drainage materials. The barrier(s) are necessary to contain leachate within the designed system. The drainage paths provide the mechanism for detection, collection, and removal of contained (or collected) leachate. In combination, the barrier(s) and drain(s) are designed to meet the specific leachate management criteria for each site.

9.2 Examples of five liner systems for typical facilities are presented in Fig. 2. These samples do not reflect the specific material selection or thickness requirements which may be appropriate for a particular situation. Further, site, waste, or regulatory specifics may dictate and should be closely reviewed for each case.

9.3 The use of leak detection systems in double liner systems may affect selection of some types of liners. Asphaltic, cementitious, and pozzolanic materials may contribute contaminants or affect pH of groundwater that penetrates the secondary liner, or both. Such conditions may be mistaken for a leaking primary liner.

10. Natural Soil Liners

10.1 Certain soil types (especially those that contain a high clay fraction) are relatively impermeable to the passage of liquids, are capable of sorbing or retaining contaminants,



NOTE—The above diagrams are conceptual approaches to typical configurations. Site specific and waste specific criteria may require other considerations.

FIG. 2 Typical Liner Systems for Waste Containment Facilities

have sufficient buffer capacity to attenuate leachate pH, and are reasonably resistant to chemical deterioration.

10.1.1 Utilization of soils as the primary containment system for landfills and impoundments is effective only if the liquids (leachates) resulting from the waste do not penetrate the soil for significant distances, or if the soils have the ability to allow the fluids to move while retaining the contaminants (attenuation). This condition must exist for the design life of the facility or, considering wastes that degrade with time, the time interval over which the wastes are an environmental hazard. As a result, short and long-term compatibility of wastes (and their leachates) and the soils lining the waste containment facility should be considered in the design. Test procedures should be selected that can be used to evaluate changes in liner properties. However, standard practice in this area is liner material specific and should be dealt with cautiously.

10.1.2 Soil liners can be designed for permeability control, to retard the movement of contaminants but allow some water to pass through the liner, or to rely on attenuation of contaminants but allow some water to pass through the liner, or to rely on attenuation of contaminants only and not