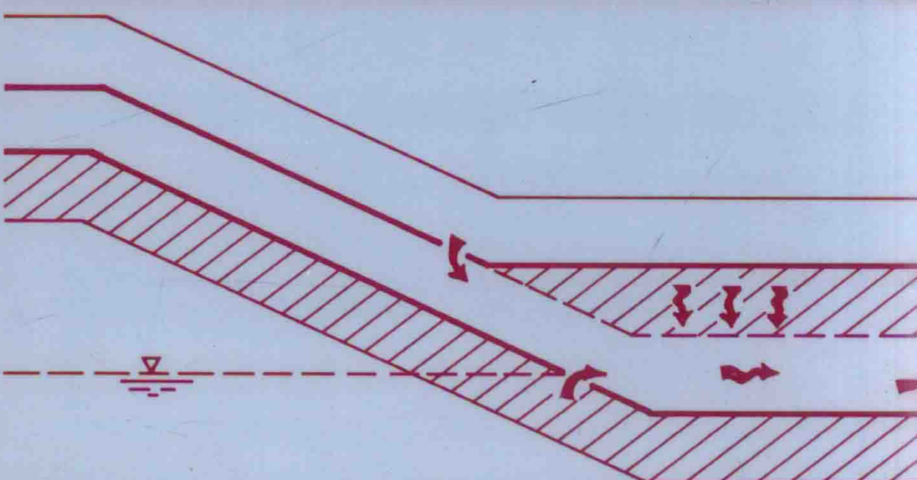
# WASTE CONTAINMENT SYSTEMS:



## Construction, Regulation, and Performance

Edited by Rudolph Bonaparte

GEOTECHNICAL SPECIAL PUBLICATION NO. 26

# WASTE CONTAINMENT SYSTEMS:

## Construction, Regulation, and Performance

Proceedings of a Symposium sponsored by the
Committee on Soil Improvement and Geosynthetics
and the Committee on Soil Properties of the
Geotechnical Engineering Division,
American Society of Civil Engineers
in conjunction with the
ASCE National Convention
San Francisco, California
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**GEOTECHNICAL SPECIAL PUBLICATION NO. 26**

**Edited by Rudolph Bonaparte**

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**ABSTRACT**

This proceedings consists of papers presented at a symposium on waste containment systems at the ASCE Convention in San Francisco, California on November 6th and 7th, 1990. Geotechnical engineers are increasingly involved in the design and construction of waste containment systems that utilize soil and geosynthetic liners and drainage layers. This book presents twelve papers on the construction, regulation, and performance of waste containment systems. The papers cover topics such as: 1) federal and state landfill containment regulations; 2) performance evaluations of earthen liners; 3) field behavior of double-liner systems; 4) long-term properties of earthen and geomembrane liners; and 5) detailed case studies of earthen liner performance. It also discusses construction quality control of earthen and geomembrane liners, field verification of earthen liner hydraulic conductivity, and the use of waste-attenuating soil materials, such as bentonites, zeolites, organically modified clays, and fly ash, in earthen liners.

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# PREFACE

Geotechnical engineers are increasingly involved in the design and construction of waste containment systems that utilize soil and geosynthetic liners and drainage layers. The role of geotechnical engineers in the field of waste containment has been recognized by the Geotechnical Engineering Division for some time. In 1977, the Division sponsored the conference on *Geotechnical Practice for Disposal of Solid Waste Materials* and in 1987 they sponsored the conference on *Geotechnical Practice for Waste Disposal '87*. Since 1987, the field has evolved significantly, due to the promulgation of ever more stringent federal and state regulations, and to a rapidly increasing understanding of the properties and capabilities of the materials used in construction. Accordingly, the Committee on Soil Improvement and Geosynthetics and the Committee on Soil Properties proposed a three-session symposium on recent developments in construction, regulation, and performance of waste containment systems. The November 1990 ASCE National Convention in San Francisco, California was selected as the venue for the symposium.

All of the papers presented in this symposium were invited by the sponsoring committees. The papers, although invited, were peer-reviewed for technical quality and content before being accepted. The standards of review were the same as for the ASCE *Journal of Geotechnical Engineering*. Each paper received two positive reviews before being accepted and was revised to conform to any mandatory revisions of the reviewers. It should be noted that all papers in this volume are eligible for discussion in the *Journal of Geotechnical Engineering* and for ASCE awards.

This symposium was organized under an accelerated timeframe and would not have been possible without the significant support of Loren R. Anderson, Chairman of the Committee on Soil Improvement and Geosynthetics, Gary M. Norris, Chairman of the Committee on Soil Properties, and J. Michael Duncan, Chairman of the Committee on Sessions. The symposium organizers also owe their gratitude to the following individuals who peer-reviewed the symposium papers, also under an accelerated timeframe.

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Finally, the symposium organizers extend their thanks to Shiela Menaker and the staff at ASCE who managed the assembly and printing of this volume.

Rudolph Bonaparte
Proceedings Editor

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## Session 1: Regulation and Performance



## Session 2: Long-Term Performance



## Session 3: Construction, Quality Control, and Future Directions

# LANDFILL CONTAINMENT SYSTEMS REGULATIONS

Robert E. Landreth[1]

The Congress of the United States, through the Resource Conservation and Recovery Act of 1976 (RCRA) and its 1984 Hazardous and Solid Waste Amendments (HSWA), mandated the United States Environmental Protection Agency (EPA) to develop standards for the management of both hazardous and nonhazardous wastes in this country in a manner that would protect human health and the environment. In response, the EPA through its experience in field activities and research developed interim guidelines. Many of these guidelines have evolved into current EPA regulations, and the Agency continues to refine the control strategies. The regulations and guidance documents will continue to be updated as construction materials are improved and as design concepts are better understood and verified in the field.

The current status of hazardous waste regulations (Subtitle "C" of RCRA as amended by HSWA) and nonhazardous waste regulations (Subtitle "D") including proposed regulations are summarized below. The role of geosynthetics, including flexible membrane liners (FMLs), geonets, geotextiles, and plastic pipes, in meeting the regulatory requirements will be discussed. Cover systems and liner systems are discussed rather than the individual components.

## SUBTITLE "C" REGULATIONS

Under Section 3004 of RCRA, owners and operators of treatment, storage, and disposal facilities (TSDFs) are required to comply with standards "necessary to protect

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human health and the environment." Since enactment of RCRA, EPA has promulgated interim status standards (40 CFR Part 265) and permitting standards (Part 264) governing the design, operation, and maintenance of landfills, surface impoundments, and waste piles used to treat, store, or dispose of hazardous wastes (Federal Register, 1986a and 1987b).

In the fourteen years since the passage of RCRA, the standards have been modified to incorporate new information developed through research and field experience. Most recently the Agency has also proposed new performance and design standards for control of leaks, including leak detection, the establishment of an action leakage rate, and a permit requirement for inclusion of a response action plan (Hokanson, 1988). The current schedule for publishing these final regulation is the fall of 1990. Although existing facilities will not have to meet these regulations, existing double-liner facilities may be required to develop action leakage rate and response action plan criteria based on site-specific capabilities.

When the Hazardous and Solid Waste Amendments (HSWA) were passed in November 8, 1984 the liner containment requirement for landfills was for two or more liners with a leachate collection systems above and between the liners. To clarify the HSWA a rule issued on July 15, 1985 set top liner standards that could be met by a flexible membrane liner (FML) and a bottom liner that could be met by three feet of compacted soil or other natural materials with a hydraulic conductivity equal to or less than $1X10^{-7}$ cm/sec. The rule was reviewed and modeled in saturated and unsaturated hydraulic flow conditions. The result of these studies is the current Agency policy for hazardous waste landfills requiring a double liner which has a composite bottom liner and a top FML, Figure 1. The composite bottom liner is one that consists of a FML on a compacted, low-permeability, natural soil.

## LINER SYSTEMS

The liner system currently being proposed by most hazardous waste management facilities incorporate in descending order a filter layer, followed by a primary leachate collection and removal system (LCRS), a primary FML, a leak detection, collection and removal system (LCDRS), and a composite liner above the native soil foundation (EPA, 1987). The composite liner is defined as a FML an a compacted, low permeability ($k \leq 1X10^{-7}$ cm/sec) natural soil.

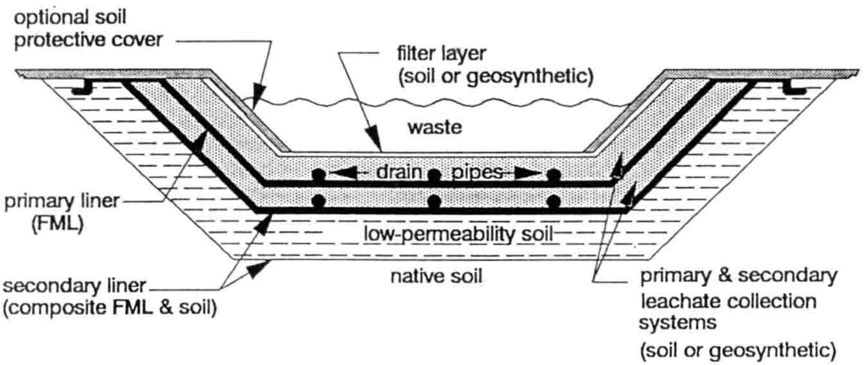


Figure 1. Schematic of Double Liner System.

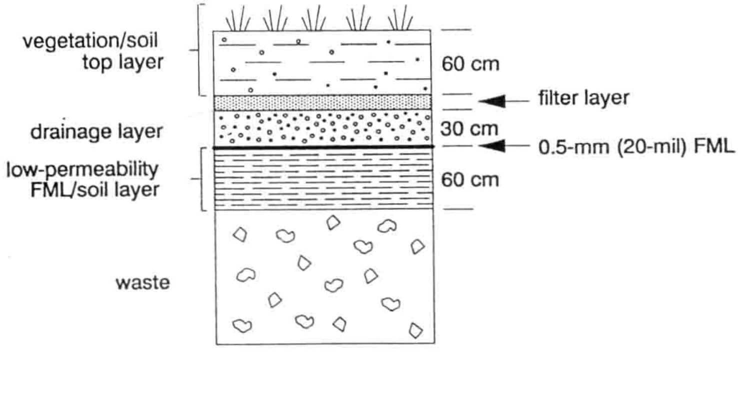


Figure 2. Schematic of Cover System.

In bottom liner systems, regulations require the FML to be at least 30 mils thick or 45 mils thick if left exposed to the elements for more than 30 days. These thicknesses may not be suitable for all FML materials. The required FML thickness will depend on the site-specific design, installation/construction concerns, seamability, and long-term durability. Taking these factors into account, the EPA recommends the following minimum thicknesses: polyvinylchloride (PVC) - 30 mil, chlorinated polyethylene (CPE) - 30 mil, reinforced chlorosulfonated polyethylene (CSPE-R) - 36 mil and semi-crystalline polyethylene (PE) - 60 mil.

Chemical Resistance

Chemical compatibility or chemical resistance to the waste or leachate to be contained has been and continues to be a major factor in selecting the FML for a waste containment facility. The increased use of other types of geosynthetics has raised similar issues. The Agency has a long standing policy (EPA, 1966; Matrecon, 1988) that all materials coming in contact with leachate must be chemically resistant to that leachate. The Agency uses the EPA Method 9090 as the immersion procedure to expose the candidate materials to the leachate for various periods of time. The procedure requires that samples of the geosynthetic be immersed in the representative sample of leachate from the waste management unit for a periods of 30, 60, 90 and 120 days at temperatures of 23°C and 50°C. After each exposure period, various physical property tests are performed to determine changes in these properties. The containing vessel should not be of the same material as that being tested and should not compete with the geosynthetics being evaluated for potentially aggressive leachate constituents. The leachate vessel should be sealed with no free air space in order to prevent the loss of volatile constituents from the leachate.

An alternative immersion procedure is being developed by the American Society for Testing and Materials (ASTM) Committee D-35 Committee on Geosynthetics. This ASTM procedure closely follows the procedure of EPA Method 9090 but adds details regarding test conditions and the immersion vessel. This procedure is under review by the EPA for potential acceptance in lieu of portions of Method 9090.

As a part of the Method 9090 test, procedures are identified for evaluating the physical properties of FML, but other types of geosynthetics were being used in waste management facilities and a consistent set of physical property evaluation tests were needed. Therefore, Agency in consultation with several research and testing firms developed initial recommendations (Landreth, 1990) for evaluating the chemical resistance of geosynthetics. This paper identifies ASTM standard tests for geotextiles, geonets, geogrids and plastic pipe.

The paper also discusses the need for finger-printing geosynthetics. Fingerprinting characterize the material in general terms such as polymer type and amount that is used; the amount of extractables; and the carbon black and ash contents. Fingerprinting, is performed to help the Agency determine that the geosynthetic material evaluated for chemical resistance in laboratory testing is essentially identical to the geosynthetic material installed in the waste management unit.

Chemical resistance must be achieved if the geosynthetic material is to survive. The Agency has long recognized that no single material is resistant to all wastes and has never granted blanket approval to any generic type of geosynthetic. Recognizing the importance of chemical resistance the Agency initiated several modifications to the type of waste that could be disposed of in landfills. The EPA has banned the placement of certain classes of chemicals and liquids in landfills has improved the potential "quality" of any leachate that may be generated. These modifications should increase the number of FML compositions available for use. The increased number of FML compositions should now allow the designer to develop innovative designs. We believe innovative designs will be more economical, technically viable, and be more reliable.

## DESIGN ELEMENTS

The actual design of the landfill lining system considers not only the chemical resistance of the geosynthetic but the minimum technology guidance (EPA, 1987), material stress considerations, structural details, and panel fabrication. The development of a comprehensive Quality Assurance/Quality Control program will help ensure that the landfill design is constructed to specifications and with specified materials.

Technology Guidance: To achieve EPA guidelines for minimum leakage, the liner should not leak at a rate greater than the action leakage rate stated in the site's response action plan as determined by the owner/operator and the permit writer. The minimum thickness of FML is set at 0.75mm (30 mils) or 1.2mm (45 mils) if it will be exposed for more than 30 days. State requirements may be more stringent than EPA guidelines; the more stringent requirements must be followed in design. It should be noted increasing the liner thickness can greatly increase the cost. Increasing the liner thickness of the same material from 0.75mm to 1.52mm (30 to 60 mils) can double the per acre cost of the FML, the actual increase will depend on the polymer type.

Stress Considerations: Stress conditions must be considered for both the bottom and the side slopes of a landfill. For side slopes, the weight of the FML itself and the weight of the waste must be reckoned with. Because the geosynthetic must be able to support its own weight on the side slopes, the specific gravity, thickness, and yield stress of the material and the friction angle must be known to calculate self-weight. For exposed FMLs, uplift forces caused by wind is another critical loading condition. For FMLs covered with a layer of soil, the tendency of the soil to slide down the slope is a critical leading conditions and should be evaluated. For the bottom two different mechanisms by which loads can be applied to the FML should be evaluated. The first mechanism is due to compression of consolidation of the foundation soil supporting the landfill. The second mechanism is due to compression or consolidation of the waste.

Structural Details: Anchorage, access ramps, collection standpipes, and penetrations are all structural details that warrant attention, especially in double liner systems.

In anchorage trenches, the geosynthetic can be ripped or pulled out. The pullout capacity for various anchorage configurations (e.g., trenches with box or V-shape) can be calculated (Koerner, 1990). Research is currently being conducted at Drexel University's Geosynthetic Research Institute to evaluate this design approach.

Most facilities have access ramps to bring waste into the landfill. With double liner systems, the continuity of both liners must be maintained over the entire surface. Construction activities such as traffic induced damage and site drainage must be addressed in the design. Vertical collection standpipes are used to access the primary leachate collection sumps. As waste settles the standpipe can be affected by downdrag and the primary FML beneath can be punctured. ASTM-D-2435 is a one dimensional consolidation test that could be used to measure the consolidation properties of the waste. From these properties, the settlement of the waste can be calculated. This calculated settlement is used to calculate the downdrag forces acting on the stand pipe. The settlement of the standpipe due to the downdrag forces can them be calculated to determine the impact on the FML. Remedies could include coating the standpipe with a viscous or low-friction coating or encapsulating it with multiple layers of low friction resistance material. A flexible foundations or spread footer design could provide a more gradual transition and spread the distribution of contact pressures over a larger portion of the FML than would a rigid foundation design.

The leak detection, collection and removal system should be designed with side slope risers to avoid penetration of the primary FML.

Panel Layout: The layout of FMLs in the landfill should be planned so that seams run up and down the slope and that the length of field seams is minimized whenever possible.

## LEACHATE COLLECTION SYSTEMS

During the active life of a waste management unit and, to a lesser extent, after closure, some of the rainfall falling on the unit percolates into and through the waste. This liquid, called leachate, contains chemical constituents leached from the waste. Leachate is both site-specific and waste-specific with regard to its quantity and quality. To prevent the accumulation of leachate in the bottom of landfill facilities, collection and removal systems are constructed as shown in Figure 1, to facilitate the removal of liquids for treatment. There are at least two leachate collection systems, the primary leachate collection and removal system (LCRS) and the leak detection, collection, and removal system (LDCRS), in a modern waste management facility.

The leachate will first contact the LCRS located directly below the waste and above the top liner. The design and construction of this system is based on site-specific conditions. LDCRS is between the top and composite liners. Ideally, the LDCRS system should see only small amounts, if any, of leachate, but it is usually designed to accommodate total failure of the primary liner and collection system.

### Materials of Construction

Until recently, collection systems were constructed exclusively of natural materials, i.e., sands and gravels. However, the substitution of geosynthetics for the natural materials has given engineers greater freedom in developing innovative designs to efficiently collect and remove excess liquids. Geosynthetics used in collection systems include geotextiles, for filtration and for separation of structural components; geonets for in-plane liquid movement; and plastic pipes for collection and removal. Natural materials may still be used either independently or in combination with geosynthetics.

Geotextile filters are designed (Carroll, 1987; FHWA, 1987; Giroud, 1982; Koerner, 1990) to prevent fine soil particles from entering and fouling the drainage media. Although filter designs using sands and gravels have been commonly used, they take up valuable space and may move under loading conditions, especially on slopes. The open spaces in a geotextile are designed to allow liquid flow perpendicular to the surface without becoming plugged with soil. Geotextiles have the advantage of requiring less vertical space than granular soil filters, resulting in more space for waste containment. Geotextiles are also easy to install and to anchor against slope instability. They have the disadvantage of clogging with soil if not properly designed. An ongoing study (Koerner, 1989) indicates that geotextiles can also become biologically clogged very quickly in municipal solid waste landfill leachate collection systems. This study is also investigating methods, including the use of biocides, to prevent biological clogging.

To meet high in-plane flow rate (transmissivity) criteria, a geonet may be used. Geonets require less space than granular soil for equivalent flow capacity, thus promoting rapid transmission of liquids. Because of larger apertures, they are less likely to clog than soils or geotextiles. Depending on the overall design, they may require geotextile filters on one or both sides to prevent the entrance of soil or waste that would reduce their efficiency. Potential disadvantages over long periods of time and under high compressive loads are creep (a tendency to flatten) and intrusion (material working its way into the openings). Again proper design should minimize the potential for these problems.

Geocomposites, which may combine the features of geotextiles and geonets, have generally not been used in leachate collection systems due to their relatively low crush strength (Koerner, 1990). They may, however, be useful in surface water collector systems, where the applied normal stresses are low.

Plastic pipes are used to collect the leachate and rapidly remove the liquid. Plastic pipes are designed to perform with both natural and geosynthetic drainage media.

Design Considerations

The design of leachate collection systems is based on hydraulic flow in the media, the chemical resistance of the media and the strength of the media in resisting overburden pressures. Since collection system designs are a function of the amount of the liquid they may have to transport, it is necessary to determine the maximum removal rate that may be required at a given site.

The Hydrologic Evaluation Landfill Performance (HELP) computer model can be used to estimate the amount of leachate that may travel through the system (EPA, 1984) HELP was developed to assist in estimating the magnitude of water-balance components and the height of water-saturated soil above the barrier layer. The program has historical data for 184 cities throughout the United States and other soil and vegetation data that can be used in a default mode in the event local data are unavailable. A simple water balance method may also be used to calculate leachate volumes.

Once the rate of leachate generation has been determined, the hydraulic flow capacity, for a granular drainage layer needed to handle that generation rate, must be calculated. The flow capacity is dependent on certain physical soil characteristics of the drainage layer. EPA's Minimum Technology Guidance recommends that granular drainage layers have the following minimum characteristics:

- be 30 cm (12 in) thick
- 1.00 cm/sec (2.0 ft/min) minimum hydraulic conductivity
- a slope$\geq$ 2%
- a perforated pipe and a layer of filter soil, and
- cover the bottom and side wall of the facility.

Collection pipe hydraulic designs are usually taken directly from nomographs developed for the specific pipe used. The overburden pressure on the pipe during the active life will cause the pipe to deform. A normal limiting deflection value of twenty percent of the pipe diameter is often used for plastic pipe. This is compared with the trench geometry to determine if the deflection value is acceptable.

Geosynthetic drainage materials or geonets are produced by a variety of manufacturers. Their physical and hydraulic characteristics are published. The ASTM D-4716 test method is generally used to determine the flow rate/transmissivity of the geosynthetic drainage material for a design. The proposed cross section of the design should be modeled as closely as possible, i.e., same profile layer combination. The Agency recommends applying 2 to 3 times maximum overburden pressure during the test to try to account for long-term creep and intrusion of the profile. The planar flow, at a constant hydraulic head, is applied and the flow rate as a function of time through the geonet is measured.

A very important part of a leachate collection system is the removal component. Low-volume submersible pumps can present problems e.g., burn out from constantly running, if the EPA recommended 1-foot head maximum is maintained. Consideration must also be given to whether the system's exit will be vertical, up the side wall, or out through the side. In all cases the design should address the need for periodic clean-out of the system.

COVER SYSTEMS

After a landfill or impoundment has been filled, the regulations require that a multi-layered cover system figure 2, be designed to isolate the waste from the environment, minimize infiltration of surface water, and thus, minimize liquid migration and leachate formation. The cover system must function with minimum maintenance, promote drainage, accommodate settling and subsidence, and have a permeability no greater than that of the liner system.

Generally a vegetated upper layer prevents erosion and promotes evapotranspiration; an underlying drainage layer conveys percolation out of this cover; and a moisture barrier (e.g., FML) prevents infiltration to the waste.

Because site conditions differ so greatly, no one universal design should be used. Rather, a state-registered, qualified design engineer must perform a technical analysis of the overall design to ensure that the performance standards have been achieved for that particular geological setting.

The waste and its placement must be characterized because the cover settlement primarily depends on how the waste mass consolidates, compresses, and collapses. Will the waste settle unevenly? Models have been developed to help estimate the effects of settlement, and covers can be designed to compensate for anticipated settlement (EPA, 1987). The designer must also analyze for slope stability and determine and allow for possible soil erosion.

EPA guidance document (EPA, 1989) recommends that a cover system include first a foundation layer between the waste and the cover, followed, in turn, by a low-permeable soil layer, a geomembrane (min 20 mil thick), a drainage layer, a graduated granular soil or geotextile layer, and finally a vegetated top soil layer, with special attention given to the outer edges of the cover system.

For each of these layers comprising the cover, the materials must be suitable to their task, and a Quality Assurance/Quality Control program for the materials, the construction, the layer thickness, the final grades, etc., must be developed, followed, and documented. The earthwork for cover construction is similar to that used for roadways, although the contact pressure of the equipment must be within an allowable load-bearing range. Preventive maintenance work should be done during the post-closure period to prevent loss of vegetation and gully development.

## SUMMARY

The RCRA hazardous waste containment regulations prescribe performance standards rather than design standards or recommendations. The EPA has compiled source documents to aid the designer, permit reviewer, and owner/operator with each element of the design, construction, and what is needed for the approval process. Geosynthetic materials are being increasingly used in the design and construction of containment systems. Geomembranes are required as the mainstay of the low-permeability barriers in liners and covers. Geonets may be substituted for high-permeability soil in drainage layers in the cover and between the liners in a double-liner system. Geotextiles are frequently used to separate layers to prevent material encroachment from one layer into another or to prevent abrasion damage. Plastic pipes are used to quickly carry off liquid from drainage layers. Geosynthetic materials must be carefully selected, tested, and installed to assure that they will carry out their intended functions indefinitely. Otherwise, they are subject to a variety of deterioration mechanisms, such as chemical dissolution, creep under pressure, or rupture under physical stresses. All of these can be prevented by materials testing and careful attention to detail in design, construction, and construction quality assurance.