

ExxonMobil DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	1 of 58
		December 2004	

CONTENTS

Section	Page
1 SCOPE	5
2 REFERENCES.....	5
GENERAL	5
SLURRY WALLS	5
JET GROUTING	6
DEEP SOIL MIXING	6
GEOMEMBRANE AND COMPOSITE WALLS	6
SEALABLE STEEL SHEET PILING.....	6
SOIL FREEZING.....	6
PORE-PLUGGING METHODS	6
COVERS.....	7
LINERS	8
LEACHATE COLLECTION	8
HYDRAULIC CONTROL.....	8
GAS COLLECTION	8
SUPPORT GRIDS	8
QUALITY ASSURANCE/QUALITY CONTROL.....	9
MONITORING.....	9
3 DEFINITIONS	9
4 BACKGROUND.....	11
5 SITE CHARACTERIZATION REQUIREMENTS	11
6 TECHNOLOGY SELECTION AND DESIGN CONSIDERATIONS.....	12
6.1 CONTAINMENT PROJECT AT THE BAYWAY REFINERY	13
7 VERTICAL BARRIERS	13
7.1 DESCRIPTION.....	13
7.2 ESTABLISHED TECHNOLOGY.....	13
7.2.1 Slurry Wall	13
7.2.2 Jet Grouting.....	18
7.2.3 Soil Mixing	23
7.2.4 Geomembrane Walls and Composite Walls	26
7.2.5 Sealable Steel Sheet Piling	29
7.3 INNOVATIVE TECHNOLOGY	31
7.3.1 Soil Freezing	31
7.3.2 Microbial Grouts	31
8 COVERS AND LINERS	32
8.1 DESCRIPTION.....	32
8.2 COVERS	32
8.2.1 Infiltration Control	32
8.2.2 Climate	34

ExxonMobil DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	2 of 58
		December 2004	

8.2.3	Traditional Cover Designs	35
8.2.4	Alternative Cover Designs	38
8.2.5	LINERS	43
8.2.6	Developed Technology	43
8.3	ROBERSTON BARRIER	45
8.3.1	Geosynthetic Clay Liners	46
8.3.2	Multi-Layer Mineral Liner	47
8.3.3	Stabilized Fly Ash Liner	49
9	OPTIONAL FEATURES	50
9.1	BIOTIC BARRIER LAYER	50
9.2	FILTER LAYERS	50
9.3	LEACHATE CONTROL	51
9.4	HYDRAULIC CONTROL	51
9.5	GAS CONTROL	51
9.6	SOLIDIFICATION AND STABILIZATION	52
9.7	GEOGRIDS	52
10	QUALITY ASSURANCE/QUALITY CONTROL	53
10.1	SOIL COVERS	53
10.2	GEOMEMBRANES	53
10.3	GEOSYNTHETIC CLAY LINERS	54
10.4	SLURRY WALLS	54
10.5	GROUTING	55
11	MONITORING AND MAINTENANCE	55
11.1	GROUND WATER	55
11.2	HYDRAULIC HEAD	55
11.3	LEACHATE	55
11.4	AIR QUALITY	55
11.5	SUBSIDENCE	55
11.6	SURFACE EROSION AND GENRAL COVER MAINTENANCE	56
11.7	OTHER CONSIDERATIONS	56
12	TECHNOLOGY SUMMARY TABLES	56

ExxonMobil DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	3 of 58
		December 2004	

TABLES

Table 1 - Cement-Bentonite vs. Soil-Bentonite slurry Walls	14
Table 2 - Slurry Wall	17
Table 3 - Key Properties of Chemical Grouts	19
Table 4 - Jet Grouting	22
Table 5 - Soil Mixing	25
Table 6 - Installation Methods for Vertical Geomembrane Walls	28
Table 7 - Geomembrane and Composite Walls	28
Table 8 - Sealable Steel Sheet Piling	30
Table 9 - Traditional Multi-Layered Cover	36
Table 10 - Traditional Soil Covers	37
Table 11 - Geosynthetic Clay Liner Covers	39
Table 12 - Capillary and Anisotropic Barriers	40
Table 13 - Evapotranspiration Covers (Vegetative Covers)	41
Table 14 - Bioengineered Covers	42
Table 15 - Asphalt and Concrete Covers	42
Table 16 - Conventional Liners	44
Table 17 - Robertson Barrier Liner System™	45
Table 18 - Geosynthetic Clay Liners	46
Table 19 - Multi-Layer Mineral Liner	47
Table 20 - Stabilized Fly Ash Liner	49
Table 21 - QA / QC Criterion for Soil-Bentonite Slurry Wall	54
Table 22 - Vertical Containment Technology Summary Sheet	57
Table 23 - Cover Technology Summary Sheet	58

FIGURES

Figure 1 - Slurry Wall Excavation	15
Figure 2 - Grain Size Distribution for Soil Used in Soil-Bentonite Backfill	16
Figure 3 - Jet Grouting Configurations	18
Figure 4 - Various Jet Grouting Installation Geometries	20
Figure 5 - SoilSaw™ Barrier System	21
Figure 6 - Soil Mixing Technology	24
Figure 7 - Rolled Geomembrane Wall Installation	26
Figure 8 - Vibrating Insertion Plate Method for Geomembrane Panel	27
Figure 9 - Slurry Supported Geomembrane Panels	27
Figure 10 - Waterloo Barrier™ Sealable Steel Sheet Piling	29

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ExxonMobil DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	4 of 58
		December 2004	

Figure 11 - Processes that Prevent Precipitation from entering the waste unit.....	33
Figure 12 - Climate Determination Chart	34
Figure 13 - Traditional Multi-Layered Cover	35
Figure 14 - Traditional Soil Covers	37
Figure 15 - GeoSynthetic Clay Liner Cover	38
Figure 16 - Capillary Barrier Cover	39
Figure 17 - Bioengineered Cover.....	41
Figure 18 - Double Liner System for Landfill Cell	43
Figure 19 - Cross Section of Multi-Layer Mineral Liner.....	48
Figure 20 - Multi-layered Cover with Optional Layers	50
Figure 21 - Geogrid Material Placed on Top of a Containment Unit	53

Revision Memo

12/04 Update technology and costs. General editing.

 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	5 of 58
		December 2004	

1 SCOPE

This Design Practice provides guidance on the selection and design of containment systems at contaminated sites. Horizontal barriers, vertical barriers, and technologies that enable the use of such barriers in a containment system are discussed. Horizontal barriers include conventional liner systems and covers. Vertical barrier systems include slurry walls (both soil-bentonite and cement-bentonite), jet grouting, soil mixing, geomembrane walls, composite walls, and sealable steel sheet piling. Enabling technologies include leachate control, hydraulic control, gas control, solidification/stabilization, support grids, quality assurance/quality control, and monitoring. Emerging technologies and refinements to existing techniques are discussed.

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 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	6 of 58
		December 2004	

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 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	7 of 58
		December 2004	

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 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	8 of 58
		December 2004	

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 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	9 of 58
		December 2004	

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3 DEFINITIONS

Adsorption - The attraction and adhesion of aqueous particles to solid surfaces.

Attapulgite - A colloidal, viscosity-building clay.

Atterberg limits - Quick, economical soil tests for characterizing the consistency of soil. The Liquid Limit of a soil is the moisture content above which the soil behaves as a liquid and below which it behaves as a plastic. The Plastic Limit is the lower moisture content limit of plastic behavior. Below that level, the soil behaves as a solid.

Barrier underflow - Ground water flowing in or out of the containment unit beneath the key.

Bentonite - Colloidal clay, composed of the mineral montmorillonite, that is used for sealing applications. It has a low hydraulic conductivity and exhibits a very high level of swelling when hydrated.

Cover - A landfill protection system, often consisting of various layers of different materials. The Cover is placed on top of the contaminated soil to prevent direct contact and minimize infiltration.

Composite liner - A liner composed of a combination of materials, commonly a geomembrane sheet within a slurry wall.

Clamshell excavation - A method of trench excavation using a clam-shaped bucket.

Contaminant plume - An area of contamination spreading downgradient from the source.

Contaminant transport - The movement of contaminants by ground water or surface water flow.

Cutoff wall - Vertical barrier wall.

Darcy's Law - The rate of fluid flow through a unit area of a permeable substance is directly proportional to the pressure drop per unit length divided by the fluid viscosity. The proportionality constant is the substance's permeability.

Drainage layer - The portion of a landfill cover that promotes the movement of liquids away from the impermeable layer by way of high hydraulic conductivity (at least 0.004 to 0.4 in/sec [0.01 to 1 cm/sec]).

Ex situ - Refers to a technology in which the contaminated soil or ground water is removed from its original location for treatment or containment.

Flexible membrane liner - Geomembrane.

Flyash - Particulate matter removed from the flue gas of combustion processes.

Geogrids - High-strength geotextiles with a mesh arrangement and composed of heavy polyester or polypropylene yarns used for structural stability or support.

Geomembrane - Sheets of polymeric materials like high-density polyethylene, typically 20 to 100 mils thick, used for many applications involving isolation and containment. The sheets can be thermally or chemically welded to allow lining large areas.

Geosynthetic Materials - Synthetic material used in geotechnical engineering applications.

Geotextile - A woven or non-woven man-made fabric used in earth engineering applications for purposes of drainage, filter layers, pavement support, septic systems, landscaping, erosion control, etc.

Gradation - The particle distribution of grain size in a soil.

Grouting - Introduction of cementitious materials into the pore spaces of soil or fractured rock.

Hanging wall - A vertical barrier that does not reach a low permeability layer.

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 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	10 of 58
		December 2004	

Higher hydraulic conductivity windows - Zones of increased hydraulic conductivity within a low hydraulic conductivity barrier wall.

HDPE - High-density polyethylene, the most common synthetic liner or cover material.

Hydraulic conductivity - The capacity of a porous medium to transmit water. Commonly expressed in units of cm/sec, it is the volumetric flow rate of water (under laminar conditions) through a given cross-section of a material under a unit hydraulic gradient. .

Hydraulic gradient - The change in total hydraulic head over a measured distance in a specific direction.

Hydrofracture - A fracture in a barrier caused by hydraulic stresses.

Illite - A clay mineral that develops from the weathering of sediments in temperate conditions.

In situ - Literally "in place." Refers to treatment or containment technology in which the contaminated soil and/or ground water is left in place.

Infiltration - The downward movement of rain water through the subsurface soil.

Kaolinite - A non-expanding clay mineral of the kaolin subgroup.

Key - A naturally occurring horizontal strata with a low hydraulic conductivity used to restrict the movement of ground water when intersected by a vertical barrier wall.

Leachate - Water that seeps through a containment unit and takes on a portion of the contaminants of the waste material.

Marsh funnel - A measuring device used to determine the viscosity of bentonite slurry.

Monitoring well - A ground water well used to measure the quality and level of ground water.

Permeability - The property of a porous substance, defined by Darcy's Law, that determines its capacity to transmit fluids. (See hydraulic conductivity.)

Piezometer - A monitoring point to measure static ground water levels.

Pore space - The volume between the solid grains of soil containing liquid or gas.

Quality assurance (QA) - A system of planned activities to confirm that a facility is constructed as was planned in the design. QA also refers to measures taken to assess whether or not contractors comply with the project plans and specifications. QA measures include inspection, audits, and evaluations.

Quality control (QC) - A system of inspections to monitor and control the quality of a project to ensure that it complies with the design specifications.

Sheet pile - A steel sheet used to construct a vertical subsurface barrier.

Slump - A measurement of the settling that a fill material will exhibit when it is not confined vertically.

Slurry - A suspension of bentonite clay in water.

Slurry wall - A vertical subsurface barrier constructed by a trench backfilled with bentonite slurry or other low permeability material.

Soil cover - The layer of a cover comprised of soil that can support vegetation.

Soil mixing - A method of constructing a vertical barrier in which augers are used to mix grout with the soil to create a column of low-permeability material.

Stratigraphy - The layering or sequencing of soil and rock.

Subsidence - Settlement caused by the compression of soil.

Vertical barrier - An engineered barrier designed to limit the lateral flow of ground water and contaminants.

Vibrating beam method - A vertical barrier construction method consisting of an I-beam that is vibrated into the soil and dispenses grout.

Well graded - A geological term referring to soil with a good distribution of size fractions, rather than a high percentage of particles in a narrow size range.

 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	11 of 58
		December 2004	

4 BACKGROUND

Containment is an alternative to soil and ground water remediation that can avoid potentially high treatment costs. The objective of containment is to isolate rather than treat the contaminated media. This is done by eliminating contaminant transport pathways and thereby reducing risk to health, safety, and the environment.

Health risk is a function of a compound's toxicity, concentration, and exposure. Containment limits exposure by removing contaminant transport pathways. Exposure routes include inhalation, ingestion, and dermal adsorption. Contaminant transport pathways include gas vapors, ground or surface water, and direct contact. Containment mechanisms to limit gas migration include liners with a low hydraulic conductivity and vapor removal. Containment mechanisms to limit ground water migration include soil hydraulic conductivity reduction, limiting infiltration of water into the containment unit, and removal of water from within the containment unit (hydraulic control). Containment mechanisms for limiting direct contact include physical barriers such as covers, and engineered controls such as property fences and land use restrictions.

Containment can be a desirable alternative to treatment, depending on economic practicality and technical feasibility. In some cases, it may not be feasible to remove the contamination or to achieve the desired treatment objectives. Examples of cases where it may not be practical to treat the contamination include:

- Deeply buried contamination that is hazardous to excavate or difficult to treat in situ
- Mixed waste types and certain compounds that limit treatment options
- Large volumes of contaminated soil, ground water, or sludge
- Contaminants that are dangerous to come in contact with

Containment has not always been accepted by regulators because of their preference for remediation technologies. However, containment technology is improving, and interest in containment has increased since regulations began moving towards utilizing risk assessment and long-term risk management. Containment may be the most cost effective environmental management option at certain sites.

Containment technology consists of covers or liners and vertical barriers. Technology for covers and liners is often similar. Liners are generally used below the contamination to prevent downward migration, whereas covers are above the contamination to prevent direct contact or infiltration. Cover technology includes vegetative layers, soil covers, clay layers, and geomembranes. Liner technology includes geomembrane liners, clay liners, and impermeable geologic strata. Vertical barrier technology usually consists of constructing or installing a barrier with a low hydraulic conductivity in the soil to stop lateral movement of the contaminants. Vertical barriers include slurry walls, soil mixing, and jet grouting which use a mix with low hydraulic conductivity to fill the pore spaces of the soil, as well as sealable sheet piling and geomembrane walls, which form an impermeable wall.

Containment can be in situ, always consisting of a cap and usually a vertical barrier, or ex situ, which involves excavation and placement of contaminated soil into a landfill vault or cell. Containment can be used in conjunction with in situ remediation technologies such as natural attenuation or permeable reactive barriers that degrade the contaminants. Containment can also be combined with a ground water remediation system, to capture and direct flow to the recovery or treatment component. (For more information on ground water treatment, refer to [DP XX-B3 - Ground Water Remediation](#).) Finally, containment technology is used in the construction of waste disposal areas such as sludge lagoons and as secondary containment around storage tanks.

In almost all cases, application of a containment technology will necessitate long-term management, including periodic perimeter monitoring to test the integrity of the containment system. Costs for this maintenance effort must be considered in comparisons to other technologies. In addition, Quality Assurance/Quality Control programs are an important consideration for containment technology.

5 SITE CHARACTERIZATION REQUIREMENTS

The physical characteristics of the site are particularly important in selecting and designing a containment system. These physical site characteristics include topography, stratigraphy, geotechnical properties, hydrogeology, and the extent of contamination.

Typically, soil borings are taken to characterize of the site stratigraphy. If the soil is heterogeneous, then borings should be taken at a small interval. If conditions are homogeneous, borings can be spaced further apart. Guidance for soil sampling can be found in the Exxon Site Characterization Manual (TMEE 072) and [DP XX-B - Guidelines and Considerations for Site Remediation](#). In addition to obtaining soil samples for testing, soil borings also serve to determine the location and extent of any low permeability layer that could be used to "key-in" vertical barriers, as discussed later. However, caution should be taken to ensure that any confining layer used as a "key" for vertical barriers is continuous and thick enough to prevent contaminants from seeping through. The existence of a clay segment in a few widely spaced soil borings does not necessarily imply the existence of a continuous confining layer beneath the entire site. Enough soil borings should be taken so that accurate interpolation of the strata between

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 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	12 of 58
		December 2004	

them is possible. As an alternative or supplement to soil borings, geophysical exploration techniques such as Ground Penetrating Radar or Electromagnetic Induction may be used to characterize the site stratigraphy and locate obstructions.

Site geotechnical data can be provided by tests such as grain size distribution, Atterberg limits (liquid and plastic limits), natural moisture content, and bulk unit weight. These tests are important for consideration of appropriate remediation or containment technology. If samples are obtained during environmental field investigations, these tests can be done at minimal additional cost. Grain size distribution tests will determine whether the native soil is suitable for use as backfill or if non-native soil will have to be brought on-site at additional cost. As discussed later, soil is suitable for backfill material if it is well graded, which limits compressibility and decreases hydraulic conductivity. In addition, soil boring and hydraulic conductivity tests of the soil from the key-in layer should be performed in order to verify the adequacy of the strata to act as a horizontal barrier. Other important site details include the type and location of above-grade and underground structures, utility corridors, or other potential obstructions.

Site hydrogeology is important because installation of underground barriers can alter natural ground water flow. Additional ground water fate and transport modeling may assist in evaluating the effects of installing a particular containment system.

The degree and extent of contamination must be determined, including characteristics of each contaminant of concern (COC), and its distribution in the soil and ground water. Contaminant concentrations and the presence of non-aqueous phase liquids will impact the effectiveness and cost of both containment and remediation technologies. Containment may be most applicable when the costs and/or the logistics of remediation are prohibitive.

Knowledge of the regulations affecting the site investigation and required cleanup levels is important. However, understanding the regulatory environment itself and the acceptability of containment technologies can be even more vital. Some issues to consider include whether containment systems have been approved in this jurisdiction before, and whether the regulatory authorities are supportive of risk-management-based strategies and/or are willing to consider innovative solutions to contamination problems. To the regulator, an essential component of the containment plan is the long-term monitoring and sampling program, since this will provide the proof that the technology is working. A contingency plan should also be in place in the event that samples indicate that the COCs are above regulatory limits. An example of a contingency plan might include supplementing or repairing the original barrier.

6 TECHNOLOGY SELECTION AND DESIGN CONSIDERATIONS

Some of the considerations that determine the choice of containment technology include:

- Dimensions of the containment required
- Hydraulic conductivity required
- Depth of the contaminants
- Type and hardness of the soil to be drilled into or excavated
- Bottom barrier conditions
- Existence of natural or man-made obstructions
- Depth to the water table
- Available construction equipment
- Prior experience of the contractors to perform the work with the technology
- Cost of the technologies.

Complete cost estimates of the containment technologies should include the costs for mobilization and demobilization of equipment, materials, waste and soil disposal, equipment, labor, health and safety protection, contingencies, QA/QC, maintenance and repair, and a long term monitoring plan.

The materials chosen for the containment will depend on such factors as site geologic and hydrogeologic conditions, type of contaminants and properties, performance specifications, and construction methods. Requirements for an in situ barrier material include low hydraulic conductivity, adequate strength, low shrinkage, and long-term durability.

A treatability study should be performed to aid in selecting the appropriate containment technology. Soil properties to consider include hydraulic conductivity, leachability, wet-dry and freeze-thaw durability, unconfined compressive strength, and bulking factor. In addition, shear and compressive strength are also needed for jet grouting design. Compatibility testing of the subsurface barrier material with the contaminants is important to ensure that they will not degrade the barrier over time. In addition to a normal soil investigation, split-spoon soil samples may be necessary to assess the driveability of steel sheet piling, and soil strength tests may be required to estimate allowable loads.

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 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	13 of 58
		December 2004	

Joint considerations include walls being keyed into a floor (naturally occurring or artificial), covers sealed to walls, and, if a panelized construction technique is used, a joint sealing system must be employed.

As discussed later, periodic monitoring and soil and ground water sampling will often be required to verify the effectiveness and long-term durability of the containment system. In most cases, the long-term costs of the monitoring program will be a significant component of a containment system cost estimate.

For all containment technologies, quality control is an important aspect of achieving project objectives. Regulators often require a very low hydraulic conductivity (maximum 4×10^{-8} in/sec [10^{-7} cm/sec]) for most containment barriers, such as slurry walls, and jet grouting. For interconnected geomembrane cells, quality control in welding the sheets together, testing the completed seams, as well as providing proper protection against traffic damage are critical.

6.1 CONTAINMENT PROJECT AT THE BAYWAY REFINERY

A good example of containment technology that was applied at an ExxonMobil site is the remediation project for the Bayway Sludge Lagoon Operable Unit (SLOU) in Linden, New Jersey. (See references 6-11.) Initiated in 1999, this project involves the containment of a 42-acre waste management area within the Bayway Refinery, formerly owned by Exxon Company, USA. The project included nearly all of the types of containment technology described in this Design Practice. Specifically, it included a perimeter vertical barrier wall, solidification of sludges and sediments, a surface barrier cap, groundwater extraction and treatment, stormwater discharge facilities, and a groundwater monitoring program. In addition, during the planning stages for the project, containment was justified to the New Jersey regulators by demonstrating that the cost of alternative remediation technologies would have been prohibitive. The wealth of information included in the references forms a good basis for planning and executing projects of this type anywhere in the world.

The following sections provide information that will be helpful in selecting a containment technology. Technology descriptions include a table containing a technology overview, applicability, costs, advantages, and disadvantages.

7 VERTICAL BARRIERS

7.1 DESCRIPTION

Vertical barriers are containment systems designed to prevent the lateral migration of contaminants through the subsurface. There are generally two approaches used for vertical barriers. The first approach uses low-permeability material to fill the pore spaces of the soil and reduce the hydraulic conductivity. Examples of such methods would be slurry walls, grouting, and soil mixing. The second approach involves inserting a physical barrier, such as sheet piling or geomembrane walls. Certain vertical barriers, such as jet grouting, can also be used as bottom horizontal barriers or can be installed on an incline around the perimeter to create a conical encasement.

Together, horizontal and vertical barriers are used to completely encapsulate the contaminated media. Sometimes, the horizontal barrier is a naturally occurring layer of shale, bedrock, or other low permeability strata. When the vertical barrier connects with this horizontal layer, it is said to be "keyed-in." Fully penetrating walls typically are keyed in 2 to 3 ft (0.6 to 0.9 m) into the low hydraulic conductivity layer. If the vertical barrier does not reach an impermeable layer, it is a "hanging wall." Hanging walls may be applicable when water table fluctuations are well below the base of the waste unit.

7.2 ESTABLISHED TECHNOLOGY

Proven vertical containment technologies include slurry walls, jet grouting, soil mixing, geomembrane walls, composite walls, and sealable steel sheet piling. Each of these technologies are described below.

7.2.1 Slurry Wall

Technology Description – A trench is excavated around the perimeter of the area to be isolated. As the trench is excavated, a slurry of water and bentonite, which has a specific gravity greater than 1.0, is used to support the walls of the trench. The bentonite slurry permeates the soil pores, and creates a zone of reduced hydraulic conductivity at the walls of the trench. As the excavation progresses, the trench is backfilled with an engineered material consisting of water, bentonite, soil, and occasionally cement. If cement is used, the slurry wall is called a cement-bentonite (CB) wall; if only soil is used, it is called a soil-bentonite (SB) wall. The trench and backfilled material creates a flow barrier called a cutoff wall. If a CB wall is used, the slurry hardens as the cement hydrates and cures. [Table 1](#) compares the two most common types of slurry walls. A more detailed summary of slurry wall characteristics is given in [Table 2](#).

The SB wall is constructed by displacing the slurry in the trench with a mixture of soil and bentonite, which is bulldozed down a slope from one end of the trench. This is shown schematically in [Figure 1](#). The backfill soil can be mixed using either a pugmill, or

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 DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	14 of 58
		December 2004	

by tracking and blading the bentonite slurry into the soil with a bulldozer adjacent to the trench. Both approaches require a considerable amount of on-site space. Because of the construction method, it is not uncommon for soil to fall from the sides of the trench causing zones of higher hydraulic conductivity known as "windows" in the SB wall. This reduces its effectiveness as a cutoff.

Another way to install a slurry wall in shallow soils is the vibrating beam method. A vibrating beam is a modified H-pile driven into the ground by a vibratory pile driver. Grout (usually bentonite slurry) is injected through nozzles along the bottom end of the pile, which fills the void space left by the withdrawal of the pile. This process is repeated, overlapping each subsequent insertion to create a continuous wall. The hydraulic conductivity achieved depends on the continuity of the wall and the grout used. Usually, CB grouts are used and the resulting average hydraulic conductivity is about 4×10^{-6} to 4×10^{-7} in/sec (10^{-5} to 10^{-6} cm/sec). Maintaining accurate alignment is critical to ensure that there are no gaps.

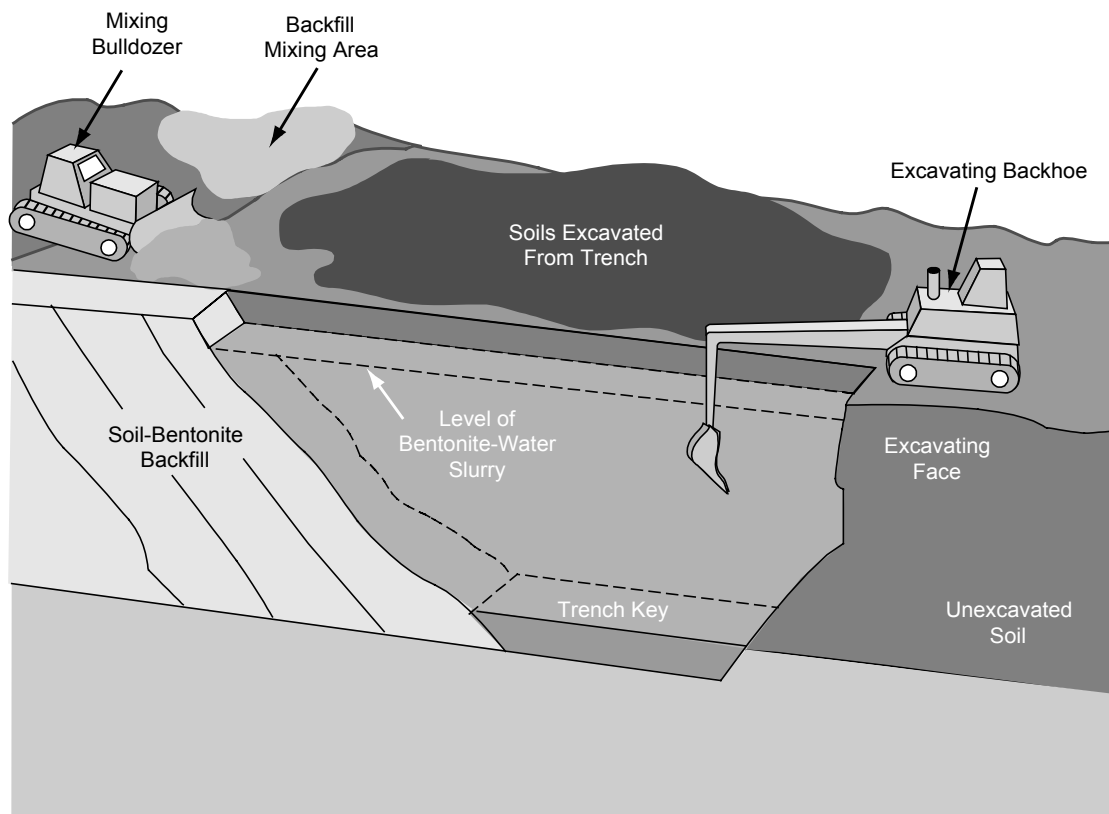
There are two advantages to the vibrating beam method. First, there is no excavated material to handle; and second, the vibrating beam can be inserted in confined areas. A disadvantage of this method is that at greater depths, the H-piles may deflect from vertical alignment, which could compromise the continuity of the barrier. Another disadvantage is that the bottom of the vibrating beam barrier cannot be inspected to confirm that it is keyed-in properly. In addition, pre-auguring may be needed to assist insertion of the beam into tight soil.

Table 1 - Cement-Bentonite vs. Soil-Bentonite slurry Walls

SLURRY WALL TYPE	ADVANTAGES	DISADVANTAGES
Cement-Bentonite	- Less effort to construct than SB wall - Less likely to have material with higher hydraulic conductivity, such as trench-wall soil, than SB wall - Higher strength than SB wall	- Higher hydraulic conductivity than SB wall, typically about 4×10^{-7} in/sec (10^{-6} cm/sec); - Higher cost than SB wall - Excavated material requires disposal - More brittle and prone to cracking under deformation (which can occur due to settlement or other cause) than SB wall
Soil-Bentonite	- Can achieve lower hydraulic conductivity than for CB wall, ranging from 4×10^{-7} to 4×10^{-10} in/sec (10^{-6} to 10^{-9} cm/sec) - May be able to use excavated soil in backfill material - Lower cost than CB wall	Method subject to windows of higher hydraulic conductivity since soil backfill does not perfectly displace slurry

ExxonMobil DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	15 of 58
		December 2004	

Figure 1 - Slurry Wall Excavation



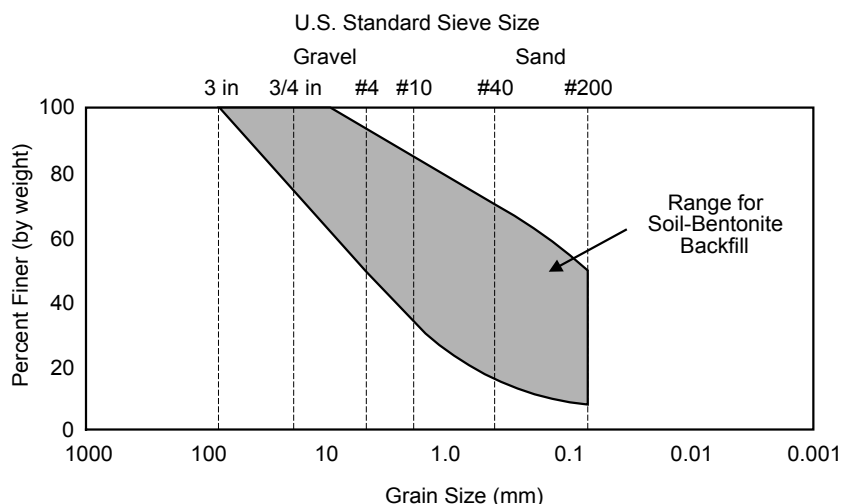
Source: R.R. Rumer and M.E. Ryan, 1995

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For a soil bentonite slurry wall, it is necessary to have adequate backfill. If in situ soils are adequate, they can be used for the soil component, although it is often necessary to purchase suitable soils for trench backfill. If the native soil is not adequate for backfilling, soil removed from the trench must be properly handled and disposed of, as for the CB wall. The important characteristics of the backfill include chemical compatibility, low hydraulic conductivity, low compressibility, and moderate strength. The most important soil parameters that influence these backfill characteristics are grain size distribution and water content. The containment objectives of long-term durability and low hydraulic conductivity can be achieved by using a well-graded soil that includes a wide range of particle sizes. A recommended particle size range for the soil used in the backfill is given in Figure 2 (Ref. 2). The advantages of using a well-graded soil include low compressibility due to larger particles, low inherent hydraulic conductivity of the soil due to fines filling the pore spaces, and minimal changes in long-term hydraulic conductivity. Further, since a well-graded soil inherently has a low hydraulic conductivity, the need to add additional bentonite to achieve this is minimized. By minimizing additional bentonite, the potential for swelling is reduced.

ExxonMobil DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	16 of 58
		December 2004	

Figure 2 - Grain Size Distribution for Soil Used in Soil-Bentonite Backfill



Source: R.R. Rumer and M.E. Ryan, 1995

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Enhancements & Refinements – One enhancement to slurry walls is the composite barrier, discussed below, under "Geomembrane and Composite Liners," where a geomembrane (e.g., HDPE) is inserted into a slurry wall to produce a redundant barrier design. Other improvements focus on the mix design, striving for better chemical resistance, improved slurry rheological properties, and lower (or more stable) hydraulic conductivity characteristics. For example, polypropylene fibers can add toughness and strength to cement or grout by limiting the growth of cracks.

Calcium bentonite has some benefits over sodium bentonite in terms of chemical resistance, but it requires considerably more material (three to four times as much) to achieve an equivalent low hydraulic conductivity mix. Research indicates favorable results when used in combination with fly ash and slag cement (Ref. 45).

Slurry walls are designed for impermeability, but consideration is now being given to the immobilization (adsorption) potential of slurry wall mix components for both organic and inorganic contaminants. This concept is similar to that of reaction walls in [DP XX-B3](#), except that the purpose of slurry wall additives is not to degrade or treat the contaminants, but rather to retard their migration through the wall. Because the main mechanism of contaminant transport at low hydraulic conductivity is diffusion, decreasing hydraulic conductivity below 4×10^{-8} in/sec (10^{-7} cm/sec) shows little benefit. However, adding adsorbent minerals such as attapulgite, calcium chabazite, or additional bentonite to a soil-bentonite slurry wall can improve containment by trapping contaminants within the wall. Shredded tires have also been added to slurry walls as a method of decreasing the mobility of VOCs. Tests show that scrap tire pieces in the range of 0.5-1.0 in (1.3- 2.5 cm) readily adsorb chemicals such as toluene, methylene chloride, TCE, and m-xylene from aqueous solution.

Of course, some adsorbent additives can be expensive, and their treatment effectiveness is limited, so a careful cost/benefit analysis would be required to justify their use.

ExxonMobil DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	17 of 58
		December 2004	

Table 2 - Slurry Wall

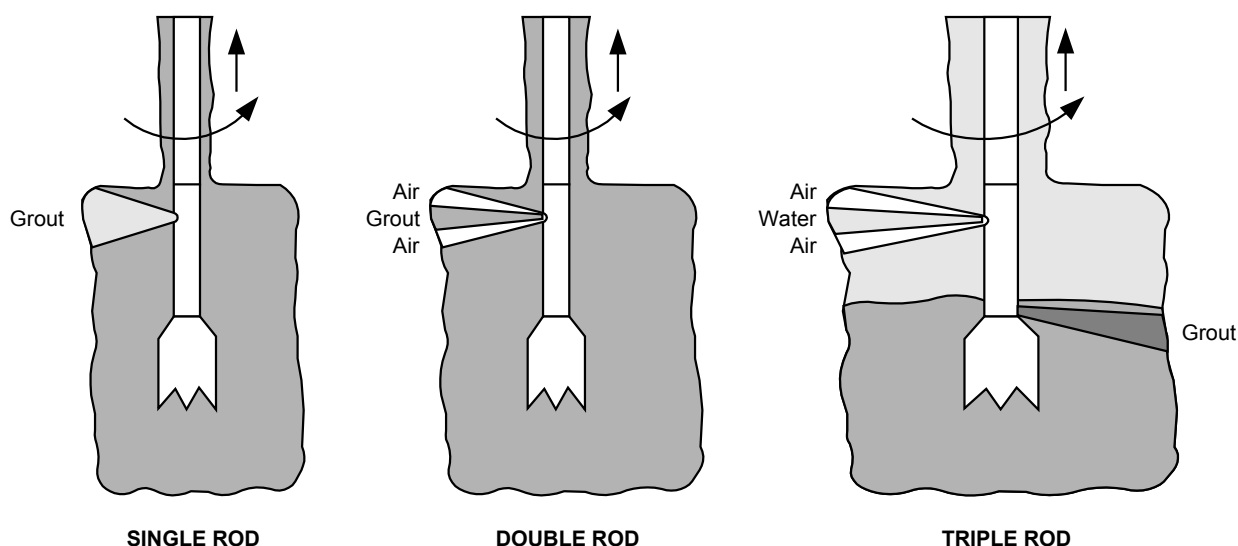
APPLICABILITY	- Hydraulic conductivities typically range from 4×10^{-6} to 4×10^{-8} in/sec (10^{-5} to 10^{-7} cm/sec). If slag or fly ash is added to the mix, the hydraulic conductivity is around 10^{-7} cm/sec, and if superplasticizers are used, hydraulic conductivities of 4×10^{-11} in/sec (10^{-10} cm/sec) are possible. - Shallow to moderate depth - Surface grade no greater than 1% for SB walls since the slurry will flow downslope - Adequate on-site space for mixing, hydrating, and storing slurry as well as mixing the backfill - Sites where ground water movement is slow and the base of the wall is below the ground water table, which limits underflow of floating products - Site capable of supporting trenching equipment
APPROXIMATE COSTS	\$45-90/sq yd (\$54 to 108/sq m) for a SB wall 2-3 ft (0.6 to 0.9 m) thick assuming in situ soil is used as backfill - Higher costs for purchased backfill soil \$63-126/sq yd (\$75 to 151/sq m) for a CB wall - Excludes disposal and treatment of excavated soil, or excavation in extremely difficult conditions such as boulders or rubble - Cost increases with depth
TIME	- SB construction rate: 300-1778 yd²/10 hr (250-1500 m²/10 hr) - CB construction rate: 120-956 yd²/10 hr (100-800 m²/10 hr) - Depends on soil conditions and obstructions
DESIGN DETAILS	- Conventional excavation equipment such as backhoes used for shallow depths (20 to 60 ft [6 to 18 m]) - Specialized equipment, such as clamshells or hydromills, are needed for the maximum depth (up to 200 ft [60 m]) - Typical slurry wall thickness is 2-3 ft (0.6 to 0.9 m), but deep walls can be up to 5 ft (1.5 m) thick. - For the CB wall, the construction slurry consists of 2-4% bentonite, 15-20% cement, 5-10% soils, and 60-70% water; for an SB wall, the slurry consists of 1-3% bentonite, 60-75% soil (typically 70-90% gravel to sand), and 25-40% water - Well-graded sand and gravel with low-plasticity fines is optimum backfill soil for an SB wall; The soil should have a 4 to 6 in. (10 to 15 cm) slump. - The slurry wall can be "keyed" into a low permeability geologic layer, such as clay or soft rock if it exists at a reasonable depth. - Perimeter monitoring wells are typically required - Design and contaminant compatibility tests should be performed by an experienced consulting engineer - If the slurry wall must pass near existing structures, design and construction monitoring must ensure that the structures are not jeopardized
ADVANTAGES	- Well understood, practiced, and accepted - Can be used in conjunction with other technologies, including in situ treatment methods - Excavation of the contamination is not required (except the material removed during trench construction) - Can be installed to shallow depths using a normal backhoe - Greater chemical resistance can sometimes be achieved by the use of lime, fly ash, kiln dust, or other clay types such as attapulgite
DISADVANTAGES	- Trench stability may be a concern in coarse-grained soils - Presence of boulders, rubble, and construction debris can substantially increase costs and difficulty - If the soil is not reused as backfill, it must be removed and/or properly disposed (often used as subgrade material for the cover) - SB walls may have compatibility problems with strong acids, bases, salt solutions, and some organic chemicals, which require additives or additional bentonite quantities. Where slurry walls intersect NAPL plumes, the potential for barrier degradation is high. - Potential for slurry walls to degrade over time, especially under wet/dry, freeze/thaw cycles - Potential for defects in the slurry walls causing high conductivity "windows"

ExxonMobil DESIGN PRACTICES	WASTE MANAGEMENT CONTAINMENT	Section	Page
		XX-B2	18 of 58
		December 2004	

7.2.2 Jet Grouting

Technology Description – Jet grouting involves permeating the soil matrix with a grout material. The grout is injected into a borehole by means of high-pressure jets that cut, replace, and/or mix the soil with the injected grout slurry. This produces columns of grout, which harden and cure to form what one vendor terms "Soilcrete." Three different systems are available, using grout pressure alone, grout plus air, and grout plus air and water. These are shown schematically in Figure 3.

Figure 3 - Jet Grouting Configurations



JET GROUTING SYSTEM

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The injected grout typically consists of a mixture of Portland cement and water, silicates, or various chemical grouts. However, Polymer grouts and coagulants have also been used. Polymer grouts that are candidates for barrier materials include polyester styrenes, vinylester styrenes, high-molecular weight acrylics called methacrylate monomers, sulfur polymer cement, bitumen, and furan polymer. Polymer concrete forms when aggregate mixed with liquid monomer or resin (binder), undergoes a chemical reaction. Polymer concretes and sulfur polymer cement concretes exhibit low hydraulic conductivity, high strength, and long-term durability. Hydraulic conductivity of 10^{-10} cm/sec can be achieved with polymers. Additional advantages of polymers include low viscosity, low flammability, and cost effectiveness. However, some polymers are not suitable for pH extremes. The physical and chemical properties vary for each polymer as shown in Table 3. An overall summary of jet grouting technology is given in Table 4.