WSRC-RP-2000-00425, Rev. 4

KEY WORDS: Stewardship
Waste Management
Environmental Protection

Closure Plan for the E-Area Low-Level Waste Facility

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Rev. 4

May 2004

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

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LIST OF ACRONYMS AND ABBREVIATIONS

ACRONYMS

ACI-Int	ACI International
AEMA	Asphalt Emulsion Manufacturer's Association
AI	Asphalt Institute
ASA	American Shotcrete Association
ASL	above mean sea level
ASTM	American Society of Testing and Materials
CB/TS	core barrels/thermal shields
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CIG	Component in grout
CLSM	Controlled Low-Strength Material
CSPE	chlorosulfonated polyethylene (hypalon)
DAS	Disposal Authorization Statement
DCG	derived concentration guide
ETF	Effluent Treatment Facility
F&HSB	F and H-Area Seepage Basins
FML	flexible membrane liner
GA	Georgia
GCL	geosynthetic clay liner
GSA	General Separations Area
GSE	GSE Lining Technology, Inc.
HD	hold down
HDPE	high density polyethylene
HELP	Hydrologic Evaluation of Landfill Performance
HLW	High-Level Waste
HMAC	hot-mix asphalt concrete
IL	Intermediate-Level
KAPL	Knolls Atomic Power Laboratory
LAW	Low-Activity Waste
LBI	LBI Technologies, Inc.
LDPE	low density polyethylene
LLRWDF	Low-Level Radioactive Waste Disposal Facility
LLW	Low-Level Waste
LLWF	Low-Level Waste Facility
MCL	maximum contaminant level
MMI	Modified Mercalli Intensity
MSB	M-Area Settling Basin
msl	mean sea level
MWMF	Mixed Waste Management Facility
NA	not available or none applicable
NCSU	North Carolina State University
ND	none detected
NPDES	National Pollutant Discharge Elimination System
NR	Naval Reactor
NRC	Nuclear Regulatory Commission
NWS	National Weather Service

ACRONYMS (continued)

PA	Performance Assessment
PCA	Portland Cement Association
PCI	Polidrid Coatings, Inc.
PVC	polyvinyl chloride
QA/QC	Quality Assurance / Quality Control
RCC	roller-compacted concrete
RCRA	Resource Conservation and Recovery Act
ROI	Region of Influence
SC	South Carolina
SCDHEC	South Carolina Department of Health and Environmental Control
SCF	Supercompactor Facility
SRS	Savannah River Site
SWDF	Solid Waste Disposal Facility
TPBARs	Tritium-producing burnable absorber rods
TSR	Technical Safety Requirement
U.S.	United States
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
WAC	Waste Acceptance Criteria
WEC	Westinghouse Electric Corporation
WQS	water quality standard
WSF	Waste Sort Facility
WSRC	Westinghouse Savannah River Company

LIST OF ACRONYMS AND ABBREVIATIONS

UNIT ABBREVIATIONS

c	cubic
c	centi
Ci	Curie
cm	centimeter
ft	foot, feet
^{0}F	degrees Fahrenheit
g	gram
gal	gallon
in	inch
k	kilo
km	kilometer
L	liter
lb	pound
m	meter
mg	milligram
mrem	millirem
n	nano
NTU	nephelometric turbidity unit
p	pico
R	rem
s	second
yr	year
µ	micro

1.0 EXECUTIVE SUMMARY

To comply with the applicable requirements of the U.S. Department of Energy (USDOE) Order 435.1 and its associated Manual and Implementation Guide (USDOE 1999, USDOE 1999a, USDOE 1999b), this closure plan has been developed for the E-Area Low-Level Waste Facility (LLWF). The plan is organized according to the specifications of the *Format and Content Guide for U.S. Department of Energy Low-Level Waste Disposal Facility Closure Plans* (USDOE 1999d).

Section 2 provides a brief overview of the general facility description, closure approach, closure schedule, related activities, and key assumptions. Sections 3 and 4 provide specific details of facility characteristics and the technical approach to closure, respectively, as well as supporting information. Additional schedule details are provided in Section 5. Section 6 provides a list of recommended items for consideration in association with future revisions to the E-Area LLWF Closure Plan and Performance Assessment (PA).

Operation of the E-Area LLWF began with placement of the first low-level waste box within the Low Activity Waste (LAW) Vault on September 28, 1994. It is anticipated that operations will continue for at least 25 years, and that a 100-year institutional control period will follow cessation of operations. It is further anticipated that closure will be conducted in the following three phases: operational closure, interim closure, and final closure. Operational closure will be conducted during the 25 year operational period as disposal units are filled, is specific to each type of disposal unit, and it is primarily intended to minimize infiltration, facilitate operations, promote worker safety, and prepare the facility for interim closure. Interim closure will be conducted after disposal operations have ceased, it is specific to each type of disposal unit, and it is primarily intended to minimize infiltration during the 100-year institutional control period and prepare the facility for final closure. Final closure of the entire E-Area LLWF will occur at the end of the 100-year institutional control period. Final closure will consist of site preparation and construction of an integrated closure system composed of one or more closure caps installed over all the disposal units and a drainage system. The final closure will thus be essentially the same for each disposal unit. Final closure is primarily intended to minimize infiltration during the post-institutional control period and provide an intruder deterrent.

The level of detail in this closure plan is consistent with the fact that the facility is in the first half of its operational history. As the facility evolves and operational features are modified, the closure plan will be updated to reflect the current status of the facility. This will ensure that the closure concept is consistent with the ultimate facility configuration and design parameters. Additionally, consistency will be maintained between the closure plan and the associated PA. As updates and revisions are made to either the closure plan or PA, the other document will be updated and revised as appropriate to maintain consistency between the documents. The closure plan will also be updated and revised as necessary to ensure compliance with applicable orders and regulations.

This revision of the closure plan has undergone a design check per Technical Report Design Check Guidelines, WSRC-IM-2002-00011 (WSRC 2002b), as documented within Appendix C.

2.0 INTRODUCTION

2.1 General Facility Description

The E-Area LLWF is the site for low-level radioactive waste disposal and storage at the Savannah River Site (SRS) and has been designed to manage all Low-Level Waste (LLW) resulting from SRS operations for an anticipated 25 years (Figure 2-1). The E-Area LLWF site is located on a 200-acre site immediately north of the former LLW disposal facility in an area of the SRS that is limited to industrial uses. Only 100 acres have been developed at this time; the additional 100 acres will allow for expansion of the LLW disposal capacity, as needed. The nearest SRS boundary to the E-Area LLWF is about 11 km to the west. The surrounding portions of the SRS are a mixture of industrial and administrative facilities as well as managed forestland. The general area adjacent to the SRS comprises forests, wetlands, water bodies, and unclassified predominantly rural lands. The current SRS Future Use Plan states that the entire SRS will never be released for unrestricted use. In particular, the plan states that the central portion of the SRS, which includes the E-Area LLWF, will only be used for industrial purposes (USDOE 1998).

The E-Area LLWF is a controlled release facility intended to maintain radionuclide migration from disposed LLW forms to below the Performance Objectives outlined within USDOE Order 435.1 and its associated Manual and Implementation Guide (USDOE 1999, USDOE 1999a, USDOE 1999b). Both containerized and uncontainerized LLW are disposed within the following types of disposal units at the E-Area LLWF: Low-Activity Waste (LAW) Vaults, Intermediate-Level (IL) Vaults, Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches), and Naval Reactor Component Disposal Pad (Figure 2-2). Waste Acceptance Criteria (WAC) have been developed for each disposal unit type that outlines the waste acceptable for disposal in each. Over the life of the E-Area LLWF, additional types of disposal units and additional disposal units will be constructed as needed.

The E-Area LLWF closure will consist of operational closure of individual disposal units as they are filled, interim closure of the entire E-Area LLWF at the end of the 25 year operational period, and final closure of the entire E-Area LLWF at the end of the 100 year institutional control period.

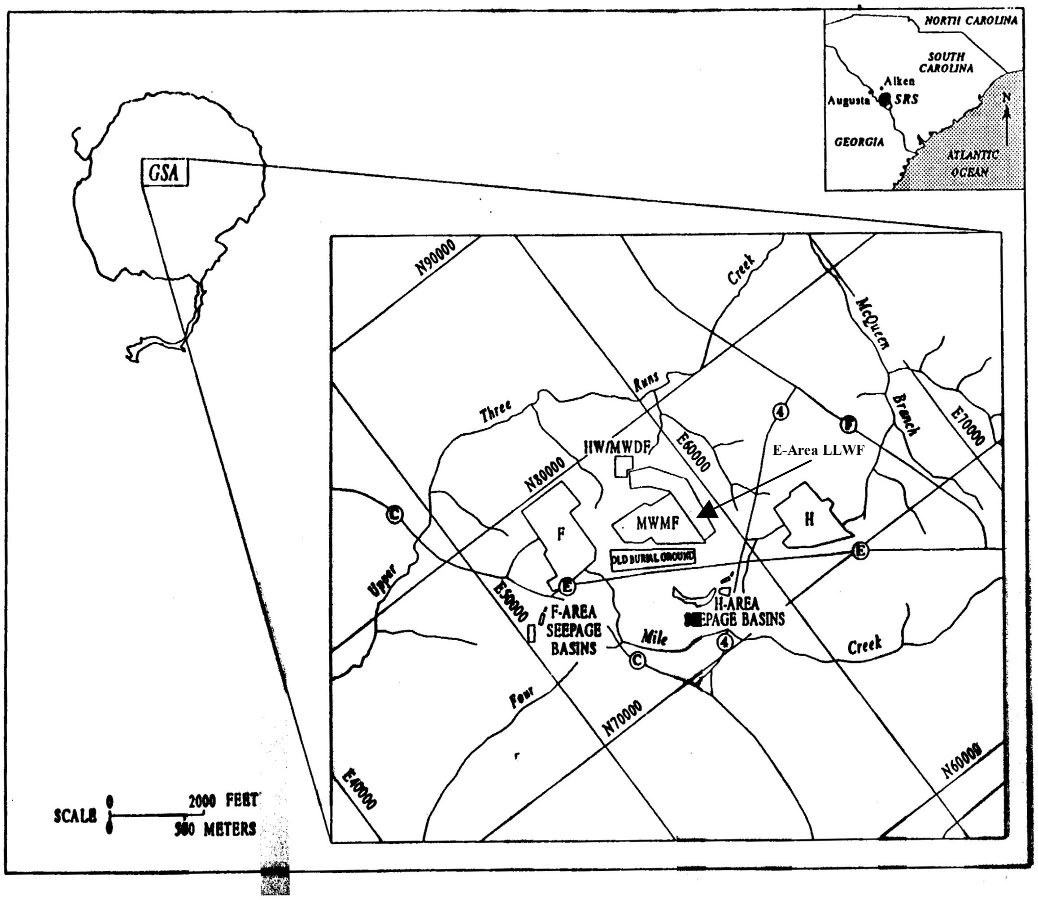
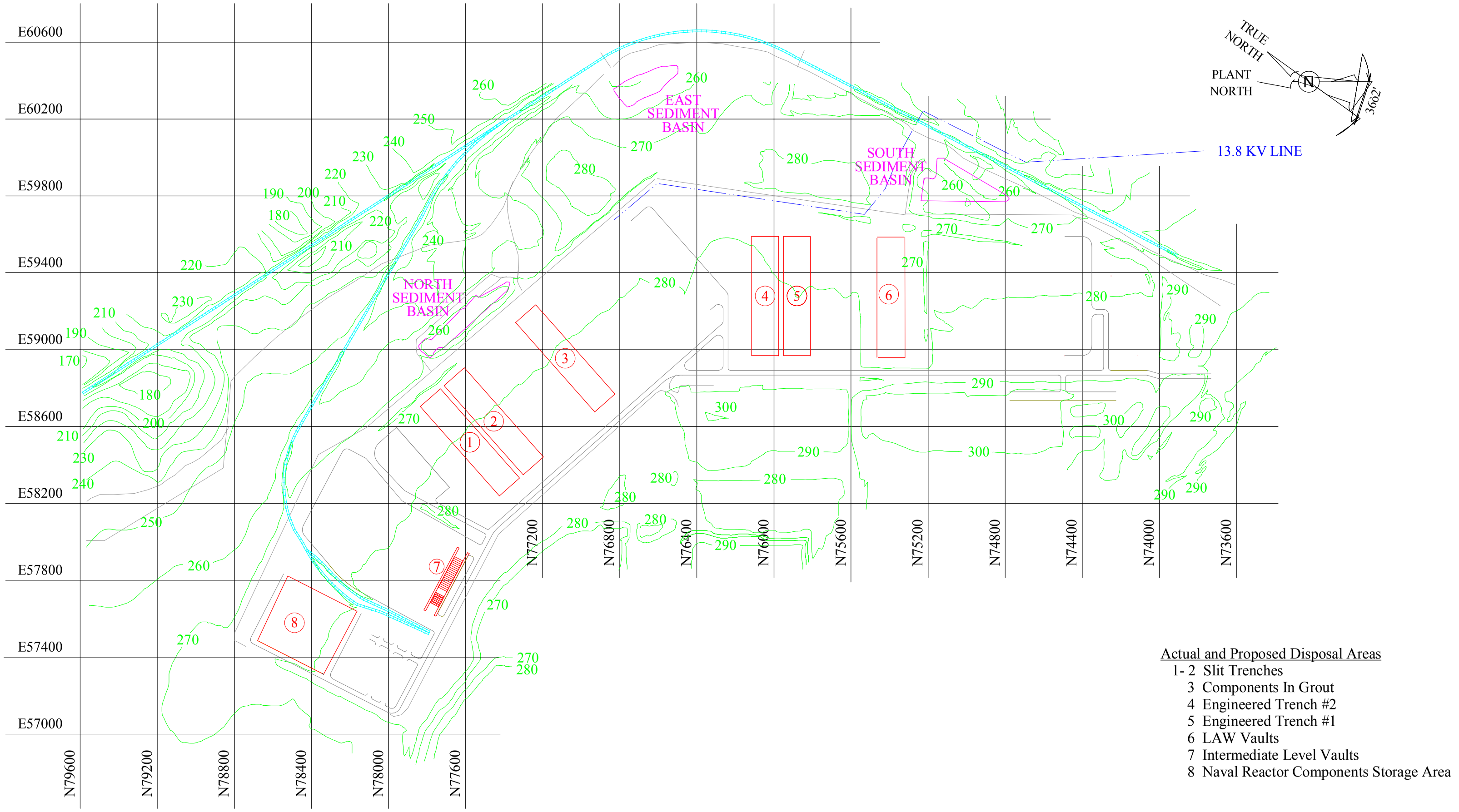


Figure 2-1 Location of the E-Area Low-Level Waste Facility



Actual and Proposed Disposal Areas

- 1-2 Slit Trenches
- 3 Components In Grout
- 4 Engineered Trench #2
- 5 Engineered Trench #1
- 6 LAW Vaults
- 7 Intermediate Level Vaults
- 8 Naval Reactor Components Storage Area

Date: October13, 2003
File: ELLWF.DGN
Drawn By: WEJ

E-Area Disposal
Facility Conceptual Layout
Figure 2-2

2.2 General Closure Approach

E-Area LLWF closure will be conducted in the following three phases: operational closure, interim closure, and final closure. Operational closure will be conducted during the 25 year operational period as disposal units are filled, is specific to each type of disposal unit, and it is primarily intended to minimize infiltration, facilitate operations, promote worker safety, and prepare the facility for interim closure. Interim closure will be conducted after disposal operations have ceased, it is specific to each type of disposal unit, and it is primarily intended to minimize infiltration during the 100-year institutional control period and prepare the facility for final closure. Final closure of the entire E-Area LLWF will occur at the end of the 100-year institutional control period. Final closure will consist of site preparation and construction of an integrated closure system composed of one or more closure caps installed over all the disposal units and a drainage system. The final closure will thus be essentially the same for each disposal unit. Final closure is primarily intended to minimize infiltration during the post-institutional control period and provide an intruder deterrent. Final closure will take into account the waste types and forms, unit location, disposition of non-disposal structures and utilities, site hydrogeology, potential exposure scenarios, and lessons learned implementing closure systems at other SRS facilities.

In general, the waste types and forms play a key role in disposal unit design. Each of the various types of disposal units at the E-Area LLWF has been designed to handle a range of specific waste types. The PA evaluates various exposure scenarios for the disposition of these various waste types and forms within the respective disposal units with the closure systems described in this plan in place. Using the PA as described, the design parameters of the E-Area LLWF operational closure, interim closure, and final closure are evaluated against the USDOE Order 435.1 Performance Objectives.

The closure system described in this closure plan has been revised from that assumed in previous revisions of the closure plan and in revision 1 of the PA (McDowell-Boyer et al. 2000) in three primary ways. First, compacted kaolin was previously utilized as the closure cap barrier layer, whereas the current barrier layer as described herein is a geosynthetic clay liner (GCL). A closure cap utilizing a GCL has been shown to be equivalent to or better than one, utilizing compacted kaolin, in term of minimizing infiltration. The change from kaolin to GCL has been reviewed and approved through the Unreviewed Disposal Question (UDQ) program (WSRC 2004) and the resulting UDQ Evaluation (WSRC 2002a; Jones and Phifer 2003). Second an erosion control barrier has been added to maintain a minimum 3 meters of clean material above the waste within Engineered Trenches, Slit Trenches, and CIG Trenches to prevent inadvertent excavation into the waste (Phifer 2004). Third the previous closure sequence included only operational closure and final closure, whereas the current closure sequence described herein includes operational closure, interim closure, and final closure. Interim closure during the 100-year institutional control period has been added to allow appropriate management of containerized subsidence potential within Engineered Trenches and Slit Trenches and to take advantage of the very low infiltration associated with the LAW Vaults, IL Vaults, and Naval Reactor Component Disposal Pad in their operationally closed configuration.

Other design features have been developed, based on the general design features included in the PA evaluation. Additional details have been added based on the current operational status of the facility. As operations continue, the closure plan will be updated to reflect the most current operational features that must be considered during closure.

This closure system will work in concert with the waste types and forms and the disposal units' features themselves, to the extent necessary, to minimize moisture contact with the waste, divert surface water, prevent unauthorized access, and minimize long-term maintenance in order that the USDOE Order 435.1 Performance Objectives are met. Specific details of the closure system features are provided in Section 4.0.

2.3 Closure Schedule

Operation of the E-Area LLWF began on September 28, 1994. It is anticipated that operations will continue for at least 25 years, and that a 100-year institutional control period will follow cessation of operations. During the 25-year operation period, operational closure of individual disposal units will occur as they are filled. At the end of the 25-year operation period, interim closure of the entire E-Area LLWF will occur. Final closure of the entire E-Area LLWF will occur at the end of the 100-year institutional control period.

The E-Area LLWF is in the first half of its anticipated operational life. This closure plan reflects the currently available information based on the facility's operational status. As operations continue, the closure plan will be updated to reflect the most current operational features that must be considered during closure. The schedule for final closure of the facility will be developed five years prior to completion of waste emplacement activities.

2.4 Related Activities

Operations at the E-Area LLWF will be managed to ensure that only waste meeting the criteria for classification as LLW will be disposed at the facility. There are currently no plans to handle any wastes that would invoke the requirements of the Resource Conservation and Recovery Act (RCRA). However, nearby/adjacent facilities are in various stages of compliance with RCRA and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) requirements, based on former or current operations at these facilities.

Eventual installation of the final integrated closure system for the E-Area LLWF will require coordination with these other facilities to ensure that the closure system does not interfere with activities underway nearby. A multidisciplinary team of individuals cognizant of the current and, to the extent possible, the planned future activities at these facilities participated in the development and review of this closure plan. Continued interaction with personnel from these adjacent and nearby facilities will be key to the success of the E-Area LLWF closure.

The closure system described in this closure plan has been revised from that assumed in previous revisions of the closure plan and in revision 1 of the PA (McDowell-Boyer et al. 2000) in three primary ways as discussed in Section 2.2. First, compacted kaolin has been replaced with a geosynthetic clay liner (GCL) as the barrier layer within the final closure cap. Second an erosion control barrier has been added to maintain a minimum 3 meters of clean material above the waste within Engineered Trenches, Slit Trenches, and CIG Trenches to prevent inadvertent excavation into the waste (Phifer 2004). Third an interim closure stage during the 100-year institutional control period has been added to appropriately manage containerized subsidence potential within trenches and to take advantage of the very low infiltration associated with the operational closure of some disposal units. The closure plan is designed to meet the Performance Objectives set forth in the PA and the Disposal Authorization Statement (DAS) [USDOE 1999c]. The PA Maintenance Program (WSRC 2000a) reviews the PA and associated documents, such as monitoring and closure plans, and ensures that the activities associated with each are coordinated and that ancillary tasks needed to support the work described in these documents is planned for and implemented. In addition, the PA Maintenance Program will review developments in closure system design, construction, performance in the field, and other developments relevant to closure at the E-Area LLWF and apply them to the closure as necessary. The PA Maintenance Program (WSRC 2000a) will address these major revisions to the previous closure plans.

2.5 Summary of Key Assumptions

The following are the key assumptions in the closure approach for the E-Area LLWF:

- It is anticipated that closure will be conducted in the following three phases: operational closure, interim closure, and final closure. Operational closure will be conducted during the 25 year operational period as disposal units are filled, and it is primarily intended to minimize infiltration, facilitate operations, promote worker safety, and prepare the facility for interim closure. Interim closure will be conducted after disposal operations have ceased, and it is primarily intended to minimize infiltration during the 100-year institutional control period and prepare the facility for final closure. Final closure of the entire E-Area LLWF will occur at the end of the 100-year institutional control period, and it is primarily intended to minimize infiltration during the post-institutional control period and provide an intruder deterrent.
- Inadvertent intrusion into the E-Area LLWF is not considered feasible during the operational and institutional control periods, due to facility security during these periods.
- Estimated subsidence potential, estimated time of disposal unit structural failure, and assumed subsidence impact upon disposal unit cover integrity and water infiltration, are provided in section 3.2.
- It is assumed that active maintenance of the interim closure occurs during the 100-year institutional control period and that interim closure maintains a low infiltration similar to that of the intact final closure cap.
- Subsidence treatment conducted on Engineered Trenches and Slit Trenches at end of 100-year institutional control period is assumed to eliminate all subsidence potential for these disposal units.
- Specific values for the hydraulic properties of the final closure cap materials and the total thickness of the cap were utilized to demonstrate compliance with the Performance Objectives within revision 1 of the PA. It is assumed that the actual closure cap material properties will be equivalent to or better than those utilized within the PA.
- It has been shown within this closure plan that a closure cap utilizing a GCL is equivalent to or better than one, utilizing compacted kaolin, in term of minimizing infiltration. Therefore it is assumed that compliance with the Performance Objectives will be demonstrated when the PA is revised to account for this change in the closure cap.
- Though technological improvements are likely to make alternatives to the closure cap described herein more feasible, and perhaps, more cost effective, while still achieving the necessary hydraulic properties to meet the performance objectives, it is important to maintain the total cap thickness assumed in the PA (i.e. 2.9 m). This thickness is necessary for shielding in the inadvertent intruder scenario.
- After installation of the final closure cap, it is assumed that the closure cap is not maintained and that its hydraulic properties will immediately begin to degrade after construction due to the following (Phifer and Nelson 2003; Phifer 2004):
  - Formation of holes in the upper GCL by pine forest succession,
  - Reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers, and
  - Erosion of layers that provide water storage for the promotion of evapotranspiration.

- It is assumed that normal residential construction and well drilling equipment used in the vicinity of the SRS is not capable of penetrating structurally intact reinforced concrete or metal plate.
- It is assumed that the requirements within USDOE Order 435.1 and its associated Manual (USDOE 1999, USDOE 1999a), regarding long-term stability of the disposal units, minimization of subsidence, and minimization of the contact of the waste with water, are applied to the extent practicable and to ensure compliance with the USDOE Order 435.1 Performance Objectives.

Further details of the specific relationships between these key assumptions and closure system design are provided in Section 4.0 of this plan. Specific details of these assumptions and their role in the PA are provided in the PA.

3.0 DISPOSAL FACILITY CHARACTERISTICS

Per the guidance for preparation of LLW facility closure plans, this section summarizes information in the facility PA, which is referenced periodically throughout this section and listed in the reference section. For source references of specific data cited from the PA, refer to the PA (McDowell-Boyer et al. 2000).

3.1 Site Characteristics

Evaluation of radionuclide transport from the E-Area LLWF, and of human exposure resulting from release of radionuclides to the environment, requires careful consideration of factors affecting transport processes and exposure potential. Topographic features and hydrogeologic characteristics strongly affect the direction and flow of radionuclides potentially released from the disposal site. Projected land use and population distributions affect the estimation of human exposure. In this section, the relevant natural and demographic characteristics of the E-Area site and surrounding area are discussed.

3.1.1 Geography and Demography

3.1.1.1 Disposal Site Location

The SRS occupies about 780 km^2 in Aiken, Barnwell, and Allendale Counties on the Upper Atlantic Coastal Plain of southwestern South Carolina. The center of the SRS is approximately 36 km southeast of Augusta, GA; 32 km south of Aiken, SC; 160 km from the Atlantic Coast; and is bounded on the southwest by the Savannah River for about 28 km. The Fall Line, which separates the Atlantic Coastal Plain physiographic province from the Piedmont physiographic province, is approximately 50-km northwest of the central SRS (Figure 3-1).

Prominent geographic features within 80 km of the SRS are the Savannah River, Thurmond Lake, Par Pond, and L Lake. The Savannah River forms the southwest boundary of the SRS. Thurmond Lake is the largest nearby public recreational area. This reservoir is on the Savannah River and is about 64 km upstream of the center of the SRS. Par Pond is an 11 km^2 former reactor cooling water impoundment that lies in the eastern sector of the SRS. L Lake is a 4 km^2 former reactor cooling water impoundment that lies in the southern sector of the SRS.

The E-Area LLWF is located in the central region of the SRS known as the General Separations Area (GSA). The disposal site consists of approximately 0.8 km^2 (200 acres) and is situated immediately north of the former LLW burial grounds. Construction of the E-Area LLWF began in October 1989. Planned construction covers an elbow-shaped, cleared area of 0.4 km^2 (100 acres), curving to the northwest on an interfluvial plateau.

3.1.1.2 Disposal Site Description

The elevation of the SRS ranges from 24 m above msl (ASL) at the Savannah River to about 122 m ASL in the upper northwest portion of the site. The Pleistocene Coastal terraces and the Aiken Plateau form two distinct physiographic subregions at the SRS (McDowell-Boyer et al. 2000). The Pleistocene Coastal terraces are below 82 m in elevation, with the lowest terrace constituting the present flood plain of the Savannah River and the higher terraces characterized by gently rolling topography. The relatively flat Aiken Plateau occurs above 82 m.

Numerous streams dissect the Aiken Plateau. Because of the large number of tributaries to small streams on the SRS, no location on the site is far from a flowing stream, most of which drain to the Savannah River.

The E-Area site has low to moderate topographic relief and is drained by several perennial streams (Figure 2-1). It slopes from an elevation of about 88-m in the southernmost corner to an elevation of 76 m in the northernmost corner. The site is bordered by three streams with several intermittent streams present within the area boundary. Runoff is to the north toward Upper Three Runs, to the east toward Crouch Branch, and to the west toward an unnamed branch. Upper Three Runs is approximately 760 m north of the facility boundary. The nearest perennial stream is approximately 370-m northeast of the boundary.

The dominant vegetation on the SRS is forest, with types ranging from scrub oak communities on the driest areas to bald cypress and black gum in the swamps. Pine forests cover more area than any other forest type. Land utilization presently is about 56 percent in pine forests, 35 percent in hardwoods, 7 percent in SRS facilities and open fields, and 2 percent in water (McDowell-Boyer et al. 2000).

Except for three roadways and a railway that are near the edge of the SRS, public access to the SRS is restricted to guided tours, controlled deer hunts, and authorized environmental studies. The major production areas located at the site include: Raw Materials (M Area), Separations (F and H Areas), Waste Management Operations (E, F, and H Areas), and Defense Waste Processing (S and Z Areas). Administrative and support services, the Savannah River Technology Center, and the Savannah River Ecology Laboratory are located in A Area.

3.1.1.3 Population Distribution

Based on state and federal agency surveys and trends, the estimated 1994 population in the region of influence was 457,824. More than 89 percent lived in Aiken (28.8 percent), Columbia (17.5 percent), and Richmond (42.8 percent) counties (Table 3-1). The population in the region grew at an average annual growth rate of 1.2 percent during the 1980s and slowed to a less than 1-percent rate between 1990 and 1994. The positive net immigration that occurred in the region was consistent with population growth in Georgia and South Carolina. Columbia County experienced the greatest increase, 146 percent total net increase. Aiken County was second with a 53 percent total net increase. Over the same period, however, Bamberg, Barnwell, and Richmond counties experienced a net loss of population.

Population projections indicate that the overall population in the region should continue to grow until about 2040. Three counties—Allendale, Bamberg, and Barnwell—should experience little growth after 2000, while the others should increase consistently (Table 3-2). Columbia County will continue to show a significant upward growth pattern (McDowell-Boyer et al. 2000).

Table 3-1 Population Distribution and Percent of Region of Influence for Counties and Selected Communities

Jurisdiction	1994 Population	1994 %ROI
South Carolina	3,663,990	
Aiken County	132,060	28.8
Aiken	24,930	5.4
Jackson	1,880	0.4
New Ellenton	2,490	0.5
North Augusta	17,610	3.8
Allendale County	11,690	2.6
Bamberg County	16,700	3.6
Barnwell County	21,420	4.7
Barnwell	5,600	1.2
Georgia	7,055,340	
Columbia County	79,920	17.5
Augusta/Richmond County	196,030	42.8
Six-county total	457,820	
United States	260,341,000	

NOTES:
ROI - Region of Influence
SOURCE:
McDowell-Boyer et al. 2000

Table 3-2 Population Projections and Percent of Region of Influence

	2000		2010		2020		2030		2040	
Jurisdiction	Population	% ROI	Population	% ROI	Population	% ROI	Population	% ROI	Population	% ROI
South Carolina										
Aiken County	133,760	26.81	145,800	26.35	156,590	26.22	168,180	26.19	180,620	26.07
Allendale County	12,960	2.60	14,130	2.55	15,180	2.54	16,300	2.54	17,510	2.53
Bamberg County	18,690	3.75	20,380	3.68	21,880	3.66	23,500	3.66	25,240	3.64
Barnwell County	22,440	4.50	24,460	4.42	26,270	4.40	28,220	4.39	30,310	4.37
Georgia										
Columbia County	80,290	16.10	90,010	16.27	97,390	16.31	105,376	16.41	114,020	16.46
Richmond County	230,700	46.25	258,610	46.73	279,820	46.86	300,526	46.80	325,170	46.93
Six-county total	498,850	100	533,390	100	597,130	100	642,098	100	692,860	100

NOTES:
ROI - Region of Influence
SOURCE:
McDowell-Boyer et al. 2000

3.1.1.4 Uses of Adjacent Lands

In the area adjacent to the SRS, less than 8 percent of the existing land is devoted to urban and built-up uses. Most such uses are in and around the cities of Augusta and Aiken. Agriculture accounts for about 21 percent of total land use; forests, wetlands, water bodies, and unclassified, predominantly rural, lands account for about 70 percent.

The projected future land uses of the area adjacent to the SRS are similar to existing patterns. Developed urban land is projected to increase by 2 percent in the next 20 years. The largest percentage of this growth is expected to occur in Aiken and Columbia Counties as a result of the expansion of the Augusta metropolitan area (McDowell-Boyer et al. 2000).

3.1.2 Meteorology and Climatology

The southeastern United States has a humid, subtropical climate characterized by relatively short, mild winters and long, warm, and humid summers. Summer-like weather typically lasts from May through September, when the area is subject to the persistent presence of the Atlantic subtropical anticyclone (i.e., the “Bermuda” high). The humid conditions often result in scattered afternoon thunderstorms. Average seasonal rainfall is usually lowest during the fall.

The weather is changeable during the winter as mid-latitude low-pressure systems and fronts migrate through the region. Measurable snowfall is rare. Spring is characterized by a higher frequency of tornadoes and severe thunderstorms than the other seasons. During spring, temperatures are mild and the humidity is relatively low.

Sources of data used to characterize the climatology of the SRS consist of a standard instrument shelter in A Area (temperature, humidity, and rainfall for 1961 to 1994), the Central Climatology Meteorological Facility near N Area (temperature, humidity, and precipitation for 1995-1996), and the H-Area meteorological tower (winds and atmospheric stability).

The average annual temperature at the SRS is 64.7°F. July is the warmest month of the year with an average daily maximum of 92°F and an average daily minimum near 72°F. January is the coldest month with an average daily high around 56°F and an average daily low of 36°F. Temperature extremes recorded at the SRS since 1961 are 107°F in July 1986 and -3°F in January 1985.

Annual precipitation averages 49.5 inches. Summer is the wettest season of the year with an average monthly rainfall of 5.2 inches. Fall is the driest season with an average monthly rainfall of 3.3 inches. Relative humidity averages 70 percent annually with an average daily maximum of 91 percent and an average daily minimum of 45 percent.

Winds are most frequently from the northeast and southwest sectors. Measurements of turbulence are used to determine whether the atmosphere has relatively high, moderate, or low potential to disperse airborne pollutants (commonly identified as unstable, neutral, or stable atmospheric conditions, respectively). Generally, SRS atmospheric conditions were categorized as unstable 56 percent of the time (McDowell-Boyer et al. 2000).

Meteorological data are critical inputs to atmospheric transport and dose models that are used to estimate the effects of releases from SRS facilities. The atmospheric transport and dose modeling performed for this PA is based upon a 5-year average meteorological data set from the period 1987 to 1991. This quality-assured meteorological database is the most recent for the SRS.

An average of 54 thunderstorm days per year were observed at the National Weather Service (NWS) Augusta, GA, office during the period 1951-1995. About half of the thunderstorms occurred during the summer. Since operations began at the SRS, ten confirmed tornadoes have occurred on or in close proximity to the site. Several of these tornadoes were estimated to have winds up to 150 miles per hour and did considerable damage to forested areas of the SRS. None caused damage to structures. Tornado statistics indicate that the average frequency of a tornado striking any single point on the site is 7.11×10^{-5} per year or about once every 14,000 years (McDowell-Boyer et al. 2000).

The highest sustained wind recorded at the Augusta NWS Office is 82 miles per hour. The maximum 100-year straight-line wind speed for the SRS area has been estimated to be 107 miles per hour. Straight-line winds are produced by hurricanes, thunderstorms, and strong winter storms. Hurricanes struck South Carolina 36 times during the period 1700 to 1992, an average recurrence frequency of once every 8 years. A hurricane force wind of 75 miles per hour has been observed at SRS only once, during Hurricane Gracie in 1959.

3.1.3 Ecology

3.1.3.1 Aquatic Ecology

Flora in the Savannah River basin and in creeks on the SRS is diverse and seasonally variable. Several species of diatoms, green algae, yellow-green algae, and blue-green algae are present. In seasonally flooded areas, bald cypress and tupelo gum thrive. In less severely flooded areas, oak, maple, ash, sweet gum, ironwood, and other species less tolerant of flooding are found. In the river swamp formed by the Savannah River in the vicinity of the SRS, herbaceous growth is sparse. A number of macrophytes, such as cattail and milfoil, are found in areas receiving sufficient sunlight.

The fish communities in the Savannah River and in creeks on the SRS are very diverse. Redbreast sunfish, spotted sucker, channel catfish, and flat bullhead are the dominant species. Sunfish, crappies, darters, minnows, American shad, and striped bass are also abundant.

Macroinvertebrate communities are largely comprised of true flies, mayflies, caddisflies, stoneflies, and beetles. Leaf litter input is high but is rapidly broken down by macroinvertebrate shredders. The Asiatic clam is found in the Savannah River and its larger tributary streams.

3.1.3.2 Terrestrial Ecology

Prior to its acquisition by the United States (U.S.) Government in 1951, approximately one-third of the SRS was cropland, about half was forested, and the remainder was floodplain and swamp. Since that time, the U.S. Forest Service has reclaimed many previously disturbed areas through natural plant succession or by planting pine trees. As was noted in Section 3.1.1.2, 91 percent is now pine or hardwood forests, with the remaining 9 percent divided between SRS facilities and water bodies.

A variety of vascular plants exist on the site. Scrub oak communities cover the drier sandy areas, which include predominantly longleaf pine, turkey oak, bluejack oak, blackjack oak, dwarf post oak, three awn-grass, and huckleberry. On the more fertile, dry uplands, white oak, post oak, southern red oak, mockernut hickory, pignut hickory, and loblolly pine predominate, with an understory of sparkleberry, holly, greenbriar, and poison ivy. Pine trees cover more area than any other tree genus (McDowell-Boyer et al. 2000).

The heterogeneity of the vegetation on the SRS supports a diverse wildlife population. Several species of reptiles and amphibians are present due to the variety of aquatic and terrestrial habitats. These include snakes, frogs, toads, salamanders, turtles, lizards, and alligators. More than 213 species of birds have been identified on the SRS. Burrowing animals at the SRS include: Peromyscus polionotus, known commonly as the Old Field Mouse; Blarine brevicauda, known as the short tail shrew; Scalopus aquiticus, known as the eastern mole; Pogonomyrmex badius, known as the harvester ant; Dorymyrmex pyramicus, known as the pyramid ant; and earthworms (McDowell-Boyer et al. 2000).

3.1.4 Geology

3.1.4.1 Regional and Site-Specific Geology/Topography

The surface of the Upper Atlantic Coastal Plain on which the SRS is located slopes gently seaward. The province is underlain by a seaward dipping wedge of unconsolidated and semi-consolidated sediments that extends from the Fall Line to the seaward edge of the continental shelf. Sediment thickness increases from zero at the Fall Line, where the crystalline Piedmont province gives way to the Coastal Plain, to more than 1.2 km near the coast of South Carolina. The SRS is underlain by about 180 to 370 m of Coastal Plain sediments. These sediments vary in age from Late Cretaceous to Miocene and are divided into several groups based principally on age and lithology. A brief discussion of these groups follows. The presence and approximate thicknesses of the sediments in the vicinity of E Area are also provided. An in-depth treatment of the stratigraphy of the SRS is given in a recent report by the State of South Carolina's Department of Natural Resources (Aadland et al. 1995).

Late Cretaceous Sediments

The Late Cretaceous sediments include, from oldest to youngest, the Cape Fear Formation and the three formations of the Lumbee Group: the Middendorf, Black Creek, and Steel Creek Formations. These sediments are approximately 210 m thick at the center of the SRS, near E Area. The lowermost Cape Fear Formation rests on a thin veneer of saprolitic bedrock, which defines the surface of the crystalline and sedimentary basement rock. This formation is composed of poorly sorted silty-to-clayey quartz sands and interbedded clays. Bedding thicknesses range from 1.5 to 6 m, with sand beds being thicker than clay beds. The formation is about 9 m thick at the northwestern boundary of the SRS, and it increases to more than 55 m near the southeastern boundary. This formation has not been observed to outcrop in the vicinity of the SRS (McDowell-Boyer et al. 2000).

The thickness of the Lumbee Group, which overlies the Cape Fear Formation, varies across the SRS from 120 m in the northwest to more than 230 m near the southeastern boundary. The Middendorf Formation, which directly overlies the Cape Fear Formation, is composed mostly of medium and coarse quartz sand that is cleaner and less indurated than the underlying sediments. Clay casts and pebbly zones occur in several places in the Middendorf Formation. A clay zone up to 24 m thick forms the top of this formation over much of the SRS. In total, the Middendorf Formation ranges from approximately 40 to 55 m thick from the northwestern to southeastern boundary of the SRS. Outcrops of this formation have been identified northwest of the SRS (McDowell-Boyer et al. 2000).

The Black Creek Formation consists of quartz sands, silts, and clays. The lower section consists of fine- to coarse-grained sands with layers of pebbles and clay casts. The upper section changes in composition as it crosses the SRS from northwest to southeast, from massive clay to silty sand with interbeds of clay. Thickness of the Black Creek Formation under the SRS ranges from 34 m in the northwest to 76 m in the southeast. Outcropping in the vicinity of the SRS has not been confirmed (McDowell-Boyer et al. 2000).

The uppermost formation in the Lumbee Group is the Steel Creek Formation (previously referred to as the Peedee Formation), which consists of fine-grained sandstone and siltstone with marine fossils. This formation is comparable in age, but lithologically distinct, from the Peedee Formation in southwestern South Carolina. The lower portion of this formation consists of fine- to coarse-grained quartz sand and silty sand, with a pebble-rich zone at its base. Pebbly zones and clay casts are common throughout the lower portion of the Steel Creek Formation. The upper portion of this formation is a clay that varies from more than 15 m to less than 1 m in thickness at the SRS. The Steel Creek Formation is about 34 m thick at the northwestern SRS boundary and about 40 m thick at the southeastern boundary. No nearby outcropping has been identified (McDowell-Boyer et al. 2000).

Paleocene-Eocene Black Mingo Group

Paleocene-Early Eocene sediments make up the Black Mingo Group. In E Area, this group consists of the Early Paleocene Lang Syne/Sawdust Landing Formations, the Late Paleocene Snapp Formation, and the Early Eocene Fourmile Formation. This group is about 21 m thick at the northwestern SRS boundary, thickens to about 46 m near the southeastern boundary, and is about 210 m thick at the coast (McDowell-Boyer et al. 2000).

The Lang Syne/Sawdust Landing Formations together are equivalent to the lithologic unit previously referred to as the Ellenton Formation (McDowell-Boyer et al. 2000). These formations, treated as a single unit due to difficulty in mapping them separately (Aadland et al. 1995), consist mostly of gray, poorly sorted, micaceous, lignitic, silty and clayey quartz sand interbedded with gray clays. They are approximately 12 m thick at the northwestern boundary of the SRS and thicken to about 30 m near the southeastern boundary. These formations outcrop about four miles northwest of the SRS.

The deposits near the SRS that are time-equivalent to the Williamsburg Formation differ from the type Williamsburg and are designated as the Snapp Formation. The sediments are typically silty, medium- to coarse-grained quartz sand interbedded with clay. The Snapp Formation pinches out at the northwestern SRS boundary and thickens to about 15 m near the southeastern boundary. In E Area, the distribution of the Snapp Formation is sporadic, not continuous.

Sand immediately overlying the Snapp Formation is identified as the Fourmile Formation. The well-sorted sand of this formation is an average of 9 m in thickness. Clay beds near the middle and top of the formation are a few feet thick. In E Area, this formation may not be continuous.

Middle Eocene Orangeburg Group

The middle Eocene sediments make up the Orangeburg Group, which in E Area consists of the lower middle Eocene Congaree Formation, the upper middle Eocene Warley Hill Formation, and the late middle Eocene Tinker/Santee Limestone Formation. The sediments thicken from about 30 m at the northwestern SRS boundary to about 49 m near the southeastern boundary (Aadland et al. 1995). The dip of the upper surface of this formation is about .002 m/m to the southeast across the site. The Orangeburg Group is about 100 m thick at the coast. The group outcrops at lower elevations in many places near and on the SRS.

The Congaree Formation consists of fine to coarse, well-sorted and rounded quartz sands. Thin clay laminae occur throughout, as do small pebble zones. The sand is glauconitic in places. The formation is about 26 m thick at the center of the SRS (McDowell-Boyer et al. 2000).

The Warley Hill Formation, made up of glauconitic sand and green clay beds and thus previously referred to as the "green clay," overlies the Congaree Formation. This formation is generally 3 to 6 m in thickness. However, northwest of E Area, the Warley Hill Formation is missing or very thin, such that the overlying Tinker/Santee Formation rests unconformably on the Congaree Formation.

The Tinker/Santee Formation consists of calcilutite, calcarenite, shelly limestone, calcareous sands and clays, and micritic limestone. The sands are glauconitic in places and fine- to medium-grained. The sediments comprising this formation have been referred to in the past as the Santee Limestone, McBean, and Lisbon Formations and indicate deposition in shallow marine environments. The Tinker/Santee Formation is about 12 to 15 m thick in the center of E Area (McDowell-Boyer et al. 2000). In places where the Warley Hill Formation is absent, the Tinker/Santee Formation rests directly on the Congaree Formation.

Late Eocene Barnwell Group

The Late Eocene sediments make up the Barnwell Group, which consists of the Clinchfield, Dry Branch, and Tobacco Road Sand. The Clinchfield Formation, the oldest of the three, is made up of quartz sand, limestone, calcareous sand, and clay. It is generally identified only when the contrasting carbonates of the overlying Dry Branch and underlying Tinker/Santee Formations are present, with the sand of the Clinchfield Formation sandwiched between them. It has been identified at several areas within the SRS, where it is up to 8 m thick, but is indistinguishable in the central regions of the SRS, near E Area.

The Dry Branch Formation consists of three distinguishable members: the Twiggs Clay Member, the Griffins Landing Member, and the Irwinton Sand Member. The Twiggs Clay Member is not mapable as a continuous unit within the SRS, but lithologically similar clay is present at various levels within this formation. The tan, light gray, and brown clay of the Twiggs Clay Member has previously been referred to as the "tan clay" at the SRS. The Griffins Landing Member is up to 15 m thick in the southeastern part of the SRS. This member consists mostly of calcilutite and calcarenite, calcareous quartz sand, and slightly calcareous clay. It occurs sporadically and pinches out in the center of the SRS. The remainder of the Dry Branch Formation within the SRS is made up of the Irwinton Sand Member, which is composed of moderately sorted quartz sand, with interlaminated clays abundant in places. Clay beds of this member have also been referred to as the "tan clay" at the SRS. The Irwinton Sand is about 12 m thick at the northwestern SRS boundary and thickens to 21 m near the southeastern boundary. It outcrops in many places around and within the SRS.

The Tobacco Road Sand overlies the Dry Branch Formation. This formation consists of moderately to poorly sorted quartz sands, interspersed with pebble layers and clay laminae. The sediments have the characteristics of a shallow marine deposit. The upper surface of this formation is irregular due to an incision that accompanied deposition of the overlying "Upland Unit" and later erosion. The thickness is variable as a result of erosive processes, but it is at least 15 m in places (McDowell-Boyer et al. 2000).

"Upland Unit"

The "Upland Unit" is an informal stratigraphic term applied to terrestrial deposits that occur at higher elevations in some places in the southwestern South Carolina Coastal Plain. This unit overlies the Barnwell Group in the Upper Coastal Plain of western South Carolina, on which the SRS is located. This unit occurs at the surface at higher elevations in many places around and within the SRS, but it is not present at all higher elevations. The sediments are poorly sorted, clayey-to-silty sands, with lenses and layers of conglomerates, pebbly sands, and clays. Clay casts are abundant. The "Upland Unit" is up to 21 m thick in parts of the SRS. Much of this unit corresponds to the Hawthorne Formation and the Tertiary alluvial gravels identified in previous documents (McDowell-Boyer et al. 2000).

Soils

Most of the soils at the SRS are sandy over a loamy or clayey subsoil. The distribution of soil types is very much influenced by the creeks on the site, with colluvial deposits on hilltops and hillsides giving way to alluvium in valley bottoms (McDowell-Boyer et al. 2000). Road cuts and excavations on interstream areas near the SRS commonly expose a deeply developed soil profile. Two horizons are apparent. The A horizon may be up to 3 m thick and typically consists of structureless fine- to medium-grained quartz sand, and the lower B horizon, which may be from 0.6 to 3 m in thickness, contains iron and aluminum compounds leached from the overlying material.

Weathering effects are evident. In some areas, intense weathering has produced tensional soil fractures as a result of volume reduction. These fractures are dominant features in shallow exposures such as drainage ditches or roadside embankments. Average soil erosion rates for the area surrounding the SRS, much of which is cropland, range from 1.5 to 2.0 $kg/m^2/yr$. The PA provides an estimate predicting that the presence of natural successional forests would reduce erosion by a factor of 400 to 500 over cropland erosion.

Seismology

The susceptibility of the SRS, and particularly E Area, to seismic motion is of interest to establish if E Area is suitable for waste disposal. Seismic events could result in cracking of the encapsulating material. Cracking could be fairly severe if liquefaction of supporting soils were to take place. However, liquefaction of supporting soils is not considered to be a potential problem at the SRS based on a review of previous studies at the SRS. Following is a discussion of seismic zones that are known to exist in the vicinity of the SRS and the expected intensity associated with seismic activity in these zones at the SRS.

Location of Nearby Seismic Zones

The SRS is located in the interior of the North American plate. In the past 200 years, the nearest zones of concentrated seismic activity in the region have been centered in the Charleston-Summerville area of South Carolina and near Bowman, SC, which is 60 km northwest of Summerville, SC. Recent seismic activity in the Charleston area, probably including the earthquake of 1886, has originated largely or entirely in the basement beneath the Coastal Plain sediments. The seismicity in the Charleston area is believed to occur at the intersection of the Ashley River fault and the Woodstock fault, at minimum depths of 4 km and 8 km, respectively.

Seismicity associated with the Bowman seismic zone occurs along a border fault of a buried Triassic basin, extending to a depth of about 6-km (McDowell-Boyer et al. 2000).

Underlying the Coastal Plain sediments of the central and southern portions of the SRS is a Triassic-Jurassic rift basin within the crystalline basement. This basin, called the Dunbarton Triassic basin, is located in the Aiken Plateau, about 50-km southeast of the Fall Line. Associated with this basin on the SRS are at least two faults; the northern border fault and a parallel fault, the Pen Branch fault, which may coincide with the border fault. These faults do not extend upward into post-Oligocene sediments at the SRS.

Faulting has also been recognized in sediments as young as Oligocene in the Atlantic Coastal Plain sediments of South Carolina. Faulting has been postulated to occur in these sediments based on structure-contour mapping of the Eocene-Oligocene unconformity, which lies between 30 and 61 m below the surface, in the vicinity of Charleston, and about 100 km from the SRS. A shallow fault, associated with a 16-km wide graben of Oligocene and Miocene rocks which crosses beneath the Savannah River from Georgia into South Carolina, is postulated about 56 km southeast of the SRS. It is not currently possible to relate these shallow faults to modern earthquakes that occur at depths greater than about 2 km.

Intensities of Historical Earthquakes

The largest known earthquake to affect the site region was the Charleston earthquake of 1886. This Modified Mercalli Intensity (MMI) X earthquake struck Charleston SC, on August 31, 1886. The greatest intensity felt at the SRS has been estimated at MMI VI-VII (felt by all; everyone runs outdoors; damage negligible in buildings of good structure, but considerable in poorly built structures) as a result of the Charleston earthquake. Minor tremors from aftershocks of the 1886 Charleston event were also felt in the area where the SRS is now located. Intensities of these tremors were estimated to be equal to or less than MMI IV.

Seismic activity producing earthquakes of estimated MMI up to V to VII has been present in the Bowman area (about 95-km northeast of the SRS) over the last 200 years. These earthquakes produced acceleration at the SRS of less than 0.1 times the earth’s gravitational acceleration. An earthquake (MMI VIII) that struck Union County, SC, about 160-km north-northeast of the SRS in 1913 was felt at Aiken (6-km north-northwest of the SRS) with an MMI of II-III (vibration indoors like a passing truck).

Two earthquakes of MMI III or less have occurred with epicentral locations within the boundaries of the SRS. An MMI III earthquake occurred in June 1985 at the SRS, as did an MMI I-II earthquake in August 1988. Neither of the earthquakes triggered the seismic alarms at the SRS facilities, which are triggered when ground accelerations equal or exceed 0.002 times the earth’s gravitational acceleration. The epicenters of these earthquakes appear to be located within about six miles of the intersection of a northwest-trending fault and the northeast-trending border fault at the northern edge of the Dunbarton Triassic basin and are relatively shallow (1 to 3 km below the earth's surface).

Projected Recurrence of Earthquakes

The recurrence interval for a Charleston-size shock (MMI X) for the Charleston area and for the Coastal Plain is on the order of 1,000 years, at the 95 percent confidence level. A recurrence of the 1886 Charleston earthquake would result in an intensity of MMI VII at the SRS. Recurrence of earthquakes associated with other known seismic zones in the region are not expected to be of greater intensity nor cause greater shaking at the SRS (McDowell-Boyer et al. 2000).

3.1.5 Hydrology

3.1.5.1 Surface Water

The Savannah River cuts a broad valley approximately 76 m deep through the Aiken Plateau, on which most of the SRS sits. The Savannah River Swamp lies in the floodplain along the Savannah River and averages about 2.4 km wide. Upper Three Runs, Fourmile Branch, Tinker Creek, Pen Branch, Steel Creek, and Lower Three Runs are the major tributaries of the Savannah River that occur on the SRS. Three breaches of the natural levee occur at the confluences of the Savannah River with Beaver Dam Creek, Fourmile Branch, and Steel Creek, allowing discharge of these streams to the river. During swamp flooding, water from Beaver Dam Creek and Fourmile Branch flows through the swamp that parallels the river and combines with the Pen Branch flow. Pen Branch joins Steel Creek about 0.8 km above its mouth.

Surface water is held in artificial impoundments and natural wetlands on the Aiken Plateau. Par Pond, the largest impoundment on the SRS, is located in the eastern part of the SRS, covering about 11 km^2. A second impoundment, L Lake, lies in the southern portion of SRS and covers approximately 4 km^2. The waters drain from Par Pond and L Lake to the south via Lower Three Runs and Steel Creek, respectively, into the Savannah River. Lowland and upland marshes and natural and man-made basins on the SRS retain water intermittently.

Near the SRS, the flow of the Savannah River has been stabilized by the construction of upstream reservoirs. The yearly average flow is approximately 300 m^3/s (10,400 cubic feet per second [cfs]) at the point where Highway 301 crosses the river (approximately 20 km downstream of the site). Based on data collected from 1954 to 1988, the minimum, average annual flow rate at this location was 150 m^3/s (5,200 cfs) in 1988. From the SRS, river water usually reaches the coast in five to six days but may take as few as three days. At the Beaufort-Jasper water treatment plant, approximately 160-km downstream of the site, the average annual flow rate is estimated to be approximately 450 m^3/s (15,800 cfs).

The watershed of Upper Three Runs drains about 500 km^2 of the Upper Coastal Plain northeast of the Savannah River. Significant tributaries to this creek are Tinker Creek, which is a headwaters branch that comes in northeast of E Area, and Tims Branch, which connects up west of E Area. There are no lakes or flow control structures on Upper Three Runs or its tributaries. The stream channel has a low gradient and is meandering. Its floodplain ranges in width from 0.4 to 1.6 km and is heavily forested with hardwoods.

Upper Three Runs is gauged by the U. S. Geological Survey about 14 km above the confluence with the Savannah River, just above Road C. This location is of interest in this analysis because it is just west of E Area and thus is a point through which radionuclides potentially discharged to Upper Three Runs and tributaries in E Area would pass. The average annual flow at this location, as measured by the U.S. Geological Survey between 1989 and 1992, was approximately 6.2 m^3/s (220 cfs). During the driest of the four years of measurement, the average flow was 4.8 m^3/s (170 cfs). These flow rates reflect contributions of upstream tributaries, including McQueen Branch and others that receive groundwater discharges from E Area. All of the major streams at SRS, including Upper Three Runs and Fourmile Branch, receive groundwater discharge and are gaining streams.

Fourmile Branch has been gauged in the vicinity of E Area, approximately 10 km from its confluence with the Savannah River. Data were collected at this gauging station for approximately four years (1985 through 1988). These data indicate an average annual flow of 0.40 m^3/s (14 cfs) at this location. A minimum annual flow rate during the gauging period of approximately 0.34 m^3/s (12 cfs) was measured in 1988 (McDowell-Boyer et al. 2000).

3.1.5.2 Groundwater

A discussion of groundwater hydrology must consider all the aquifers and confining units that affect the subsurface distribution of contaminants potentially released from the E-Area LLWF. In this report, the discussion of groundwater hydrology is restricted to hydrostratigraphic units above the Meyers Branch confining system because units below that system are considered protected from contamination. Justification for this assumption is given in the subsection entitled "Meyers Branch Confining System" below.

The nomenclature used in this report to identify hydrostratigraphic units is consistent with Aadland et al. (1995). Two different alphanumeric systems of hydrostratigraphic nomenclature were utilized in the Z- and original E-Area Performance Assessments. These systems are listed in Table 3-3, along with the present nomenclature. The "common" names listed in this table are names that have historically been used for the hydrostratigraphic units and that are utilized in many older documents on this subject. These units, and their hydrologic properties, are defined and described below.

Potentiometric surfaces and particle tracking data provided in the discussion of flow modeling in Section 4.3.3 of the PA support this interpretation of E-Area hydrology (McDowell-Boyer et al. 2000).

Table 3-3 Hydrostratigraphic Nomenclature

Nomenclature of Aadland et al. 1995	E-Area Nomenclature	Z-Area Nomenclature	Common Nomenclature
Floridan Aquifer System	Aquifer System II		
Upper Three Runs aquifer			
"upper" zone	Aquifer unit IIB, zone 2	Zone 7c/8	Water table unit
"tan clay" zone	Confining unit IIB_1-IIB_2	Zone 7b	Tan clay
"lower" zone	Aquifer unit IIB, zone 1	Zone 6/7a	Barnwell/McBean
Gordon confining unit	Confining unit IIA-IIB	Zone 5b	Green clay
Gordon aquifer	Aquifer unit IIA	Zone 5a	Congaree
Meyers Branch Confining System	Confining System I-II	Zone 4	Ellenton clays

SOURCE:
McDowell-Boyer et al. 2000

Meyers Branch Confining System

The Meyers Branch confining system overlies the Dublin and Dublin-Midville aquifer systems. Sediments of this Late Cretaceous-Paleocene system correspond to the lignitic clays and interbedded sands of the upper Steel Creek Formation and the laminated clays and shale of the Lang Syne/Sawdust Landing and Snapp Formations. At the SRS, the Meyers Branch system consists of a single hydrostratigraphic unit, the Crouch Branch confining unit, which includes several thick and relatively continuous (over several miles) clay beds. East of E Area, the Meyers Branch confining system is 41-m thick, 21 m of which are clay beds. The Crouch Branch confining unit constitutes the Meyers Branch confining system over much of the SRS, ranging in thickness from 17 m to 56 m. The updip limit of the Meyers Branch confining system, where the system is no longer a regional confining system, occurs north of the intersection of McQueen Branch and Upper Three Runs streams and runs approximately east to west. North of the updip limit, the Crouch Branch confining unit continues and is considered part of the Floridan-Midville aquifer system (in which all aquifer units above and including the McQueen Branch aquifer are considered layered parts of one aquifer system).

Areas of the SRS which are adjacent to the Savannah River flood plain and the Upper Three Runs drainage systems, including E-Area, exhibit an “upward” gradient across the Crouch Branch confining unit. Hydraulic heads in the underlying Crouch Branch aquifer are higher than those in the overlying Gordon aquifer in these areas, due to the incisement of the overlying aquifer by these two river systems. This area of upward gradient encompasses all of E Area. The magnitude of the upward gradient is about 5 meters in the vicinity of E Area, but the low transmissivity of the Meyers Branch Confining System results in a low water flux into the Gordon Aquifer. Thus, in E Area, the confining nature of the Crouch Branch confining unit along with the head-reversal phenomenon, provides a natural protection of aquifers beneath the Floridan aquifer system from contamination.

Floridan Aquifer System

Because of relative hydrologic isolation due to the Meyers Branch confining system, only the Floridan aquifer system is of interest in the performance assessment and special analysis of potential groundwater contamination from operations at E Area. The Floridan aquifer system is comprised of the lowermost Gordon aquifer unit, the Gordon confining unit, and the uppermost Upper Three Runs aquifer unit, which contains the water table.

Gordon Aquifer Unit The Gordon aquifer unit overlies the Crouch Branch confining system and is approximately 23 m thick at E Area. The aquifer consists of sandy parts of the Late Paleocene-Early Eocene Snapp, Fourmile, and Congaree Formations. Sands and clayey sands of the Gordon aquifer unit are largely yellow to orange in color and consist of fine- to coarse-grained, subangular to subrounded quartz. The sands range from well to poorly sorted. Locally confining clay beds are present, as are pebbly zones. The unit dips at 1.5 to 1.7 m/km to the south and southeast and thickens in the western portion of E Area and to a minor extent to the southeast (McDowell-Boyer et al. 2000).

The hydraulic gradient in the Gordon aquifer across the SRS is generally from northeast to southwest, averaging 0.9 m/km, towards the Savannah River. However, the potentiometric surface (Aadland et al. 1995) indicates considerable deflection of the contours due to incisement of aquifer sediments by Upper Three Runs, such that flow from E Area is westerly. Potentiometric surfaces demonstrating this trend are provided in Section 4.3.3 of the PA

(McDowell-Boyer et al. 2000). Based on measurements and modeling (Aadland et al. 1995), an average horizontal hydraulic conductivity of 1×10^{-2} m/s is reported for this unit.

Gordon Confining Unit The Gordon confining unit separates the underlying Gordon aquifer unit from the Upper Three Runs aquifer unit. This confining unit is informally known as the "green clay." It is comprised of the fine-grained glauconitic sand and clay beds of the Middle Eocene Warley Hill Formation and the micritic limestone of the Tinker/Santee Formation. Thickness of the Gordon confining unit in the vicinity of the SRS varies from 1.5 to 25 m. In the vicinity of E Area, it is from 0.6 to 9 m thick. Recent studies indicate the unit is composed of several lenses of green and gray clay that thicken, thin, and pinch out abruptly. Extensive carbonate sediments associated with areas of thin or truncated clay beds are present in E Area.

Leakance coefficients, estimated from modeling and pump tests, indicate an updip limit of the Gordon confining unit at the SRS that runs southwest to northeast along Upper Three Runs and Tinker Creek. Southeast of this limit, leakances are relatively low except in areas associated with extensive faulting. Laboratory- and model-derived vertical hydraulic conductivities in E Area are on the order of 5×10^{-10} m/s (Aadland et al. 1995), suggesting that the Gordon confining unit is an effective aquitard in this region. Horizontal hydraulic conductivities ranging from 1.4×10^{-10} to 1.6×10^{-9} m/s have been determined from laboratory tests. A map of hydraulic head differences across the Gordon confining unit (Aadland et al. 1995) shows a downward gradient in the vicinity of Upper Three Runs and the Savannah River.

Upper Three Runs Aquifer Unit The Upper Three Runs aquifer unit overlies the Gordon confining unit and is the water table unit. This unit includes the sandy sediments of the Tinker/Santee Formation and all the heterogeneous sediments in the Late Eocene Barnwell Group. In the center of the SRS, the aquifer unit is 40 m thick. In E Area, the aquifer unit is divided into three hydrostratigraphic zones with respect to hydraulic properties (Aadland et al. 1995): a "lower" zone, a "tan clay" locally-confining zone, and an "upper" aquifer zone (the water table zone).

In E Area, the "lower" aquifer zone occurs between the overlying "tan clay" confining zone and the Gordon confining unit. It consists of sand, clayey sand, and calcareous sand of the Tinker/Santee Formation and of the lower part of the Dry Branch Formation. Groundwater that leaks across the "tan clay" confining zone recharges this zone. Most of the recharge water moves laterally toward the bounding streams that incise this zone; the remainder flows vertically downward across the Gordon confining unit. Hydraulic conductivity of the "lower" zone has been estimated for the E-Area vicinity by several methods: slug tests, pumping tests, minipermeameter test, and sieve analyses. Average values for the various methods range from 3×10^{-6} m/s to 6×10^{-4} m/s. The lower values are based on pumping tests, and the higher values are based on sieve analyses. The large discrepancy between the two methods suggests that large-scale heterogeneities, not sample-in-sieve-analysis techniques, are important in determining conductivity.

The "tan clay" confining zone is a leaky confining zone, ranging in thickness from 0 to 10 m throughout the E-Area vicinity. The average thickness is about 3 m. The clay beds of this confining zone, when present, generally support a head difference (up to 5 m) in E Area between the "upper" and "lower" aquifer zones of the Upper Three Runs aquifer unit and thus retard the movement of water downward across this zone. Laboratory analyses of undisturbed samples of the "tan clay" confining zone yielded a range of hydraulic conductivities from 6×10^{-11} to 5×10^{-7} m/s in the horizontal direction and 1×10^{-11} to 4×10^{-7} m/s in the vertical direction (Aadland et al. 1995).

In E Area, the “upper” aquifer zone consists of the silty sands of the Irwinton Sand Member of the Dry Branch Formation overlain by the clayey sands of the Tobacco Road Formation. The water table occurs in the “upper” zone. This zone overlies the “tan clay” confining zone, when present, or the “lower” aquifer zone when the confining zone is absent. Units below the “upper” aquifer zone are always saturated, so the “upper” aquifer is not a perched system. Slug tests, minipermeameter tests, pumping tests, and sieve analyses have been used to estimate hydraulic conductivity of the “upper” zone in the vicinity of E Area (Aadland et al. 1995). The average hydraulic conductivity estimates for the “upper” aquifer zone ranged from 2×10^{-6} to 5×10^{-4} m/s for the various methods.

Three streams on site, Upper Three Runs to the north of E Area, McQueen Branch (a tributary of Upper Three Runs) to the northeast, and Fourmile Branch to the south, are natural boundaries to groundwater flow in the Upper Three Runs aquifer unit. All creeks cut into this, and thus groundwater is either intercepted by the creeks or recharges the underlying Gordon aquifer unit. A groundwater divide occurs in this water table unit due to the influence of these streams.

Hydrologic Characteristics of the Vadose Zone

The vadose zone extends from the ground surface downward to the water table. Core Laboratories, Inc., in Carollton, Texas (McDowell-Boyer et al. 2000) most recently investigated hydraulic characteristics of unsaturated soil in E Area. Capillary pressure vs. water saturation relationships and relative permeability vs. water saturation relationships were developed for field samples of topsoil, gravel, two clays, sand, and backfill to provide a range of analyses for various vadose zone materials found, or planned for use, in the E-Area LLWF. Saturated hydraulic conductivity of topsoils was measured to be on the order of 10^{-5} m/s, with porosity on the order of 0.40. Saturated hydraulic conductivity of gravels and clays were measured to be on the order of 10^{-1} and 10^{-8} m/s, respectively, with respective porosities of 0.38 and 0.56.

3.1.6 Geochemistry

Geochemical aspects of the disposal site are not evaluated nor used directly in assessing radionuclide migration. Rather, site-specific sorption coefficients, which are affected by pH and other geochemical conditions, are used when available. Geochemical modeling conducted for the E-Area PA (McDowell-Boyer et al. 2000) was restricted to the vault environment and thus is not pertinent to the present discussion of disposal site characteristics.

3.1.7 Natural Resources

3.1.7.1 Geologic Resources

The only material of significance as a geologic resource in the vicinity of the SRS is kaolin clay. About 90 percent of the U. S. production of kaolin at one time came from a district in Georgia and South Carolina that includes Aiken County. Commercial deposits occur as lenses in the Lang Syne Formation along the Fall Line bordering the northwestern edge of the Coastal Plain (McDowell-Boyer et al. 2000).

At E Area, the Lang Syne Formation is at a depth greater than 100 m from the ground surface, making commercial exploration unlikely due to the large amount of overburden that would have to be removed to exploit a deposit.

3.1.7.2 Water Resources

The South Carolina Department of Health and Environmental Control (SCDHEC) has been delegated authority by the United States Environmental Protection Agency (USEPA) to implement and enforce the requirements of the Clean Water Act for the State of South Carolina. SCDHEC therefore is responsible for maintaining the chemical and biological integrity of all state waters, including those on federal reservations such as SRS. It does this by enforcing a system of water quality standards and by regulating all point-source discharges through the National Pollutant Discharge Elimination System (NPDES) program. SCDHEC is the principal regulatory authority for water quality issues on the SRS.

Surface Water

The Savannah River is the principal surface water system associated with the SRS. Five of its major tributaries (Upper Three Runs, Fourmile Branch, Pen Branch, Steel Creek, and Lower Three Runs) flow through and drain the SRS. Mean annual flow at river mile 187.4, approximately 12 miles south of Augusta, GA, during the period 1984 to 1996 was 16,580 cfs. The Savannah River serves as a domestic and industrial water source for the SRS and several downstream communities (the cities of Port Wentworth and Savannah in Georgia and Beaufort and Jasper counties in South Carolina). The intakes for these downstream water systems are located at river miles 29 and 39.2, respectively. In addition, the Vogtle Electric Generating Plant, located across the river from the SRS, uses the Savannah River for cooling water, withdrawing an average of 46 cfs. Table 3-4 characterizes Savannah River water quality both up- and downstream of the SRS. Table 3-5 characterizes water quality in SRS streams (McDowell-Boyer et al. 2000).

Groundwater

Within 20 miles of the SRS, there are more than 56 major municipal, industrial, or agricultural groundwater users that consume approximately 36 million gallons of water per day. Total SRS groundwater (domestic and process water) use ranges from 9 to 12 million gallons per day. At the SRS, only the deeper aquifers (Crouch Branch and McQueen Branch) are used as groundwater sources.

Under most of the SRS, the quality of groundwater is considered to be good. The pH for SRS groundwater ranges from 4.9 to 7.7 and the water is generally soft. Concentrations of dissolved and suspended solids are low, but iron concentrations are elevated in some of the aquifers. At the SRS, approximately 5 to 10 percent of the shallow aquifer system has been contaminated with tritium, industrial solvents, metals, and other chemicals (McDowell-Boyer et al. 2000).

Table 3-4 Water Quality in the Savannah River Upstream and Downstream from SRS (Calendar Year 1996)[a,b]

Parameter	Unit of measure[c]	MCL[d,e] or DCG[f]	Upstream Minimum	Upstream Maximum[g]	Downstream Minimum	Downstream Maximum
Aluminum	mg/L	0.05-0.2[h]	0.15	0.71	0.16	79
Ammonia	mg/L	NA[i,j]	ND	0.27	ND	0.33
Cadmium	mg/L	0.005[d]	ND[k]	ND	ND	ND
Chemical oxygen demand	mg/L	NA	ND	22	ND	20
Chloride	mg/L	250[h]	4	9	4	9
Chromium	mg/L	0.1[d]	ND	ND	ND	0.011
Copper	mg/L	1.3[l]	ND	ND	ND	ND
Dissolved oxygen	mg/L	>5.0[m]	6.4	11.5	6.2	13
Fecal coliform	colonies/.1L	1,000[m]	Nr[n]	300	Nr[n]	1,100
Gross alpha radioactivity	pCi/L	15[d]	<0.62[o]	0.7	<0.62[o]	0.97
Lead	mg/L	0.015[l]	ND	ND	ND	ND
Mercury	mg/L	0.002[d,e]	ND	0.0005	ND	0.0003
Nickel	mg/L	0.1[d]	ND	ND	ND	ND
Nitrite/nitrate (as N)	mg/L	10[d]	0.24	0.47	0.24	0.51
Nonvolatile (dissolved) beta radioactivity	pCi/L	50[d]	<1.6	3.	<1.6	2.8
pH	pH units	6.5-8.5[h]	5.8	6.8	5.5	7
Phosphate	mg/L	NA	ND	ND	ND	ND
Sulfate	mg/L	250[h]	4	9	5	10
Suspended solids	mg/L	NA	6	36	8	23
Temperature	°F	90[p]	44	76	42	78
Total dissolved solids	mg/L	500[h]	51	72	58	76
Tritium	pCi/L	20,000[d,e]	<410	450	520	2,200
Zinc	mg/L	5[h]	ND	0.029	ND	0.046

NOTES:

a. Source: McDowell-Boyer et al. 2000.
b. Parameters are those USDOE routinely measures as a regulatory requirement or as part of ongoing monitoring programs.
c. mg/L = milligrams per liter; a measure of concentration equivalent to the weight/volume ratio.
d. Maximum Contaminant Level (MCL), USEPA National Primary Drinking Water Standards (40 CFR Part 141).
e. Maximum Contaminant Level (MCL), SCDHEC (1976).
f. USDOE Derived Concentration Guides (DCGs) for water (USDOE Order 5400.5, "Radiation Protection for the Public and the Environment"). DCG values are based on committed effective dose of 100 millirem per year for consistency with drinking water MCL of 4 millirem per year.
g. Minimum concentrations of samples. The maximum listed concentration is the highest single result found during one sampling event.
h. Secondary Maximum Contaminant Level (SMCL), USEPA National Secondary Drinking Water Regulations (40 CFR Part 143).
i. NA = none applicable.
j. Dependent upon pH and temperature.
k. ND = none detected.
l. Action level for lead and copper.
m. WQS = water quality standard.
n. Only fecal coliform bacteria exceedances are reported.
o. Less than (<) indicates concentration below lower limit of detection (LLD).
p. Shall not exceed weekly average of 32.2°C (90°F) after mixing nor rise more than 2.8°C (5°F) in 1 week unless appropriate temperature criterion mixing zone has been established.

pCi/L = picocuries per liter; a picocurie is a unit of radioactivity; one trillionth of a curie.

Table 3-5 Water Quality in Selected SRS Streams

Sampling location		Temperature (°F)	pH	Dissolved oxygen (mg/L)	Specific conductance (µS/cm)	Turbidity (NTU)	Total suspended solids (mg/L)
Upper Three Runs at Road A (1996)	Mean	63	6.35	8.21	24.3	13.55	13.33
	Range	45.3-74.3	6-7	6.5-12.7	21-29	3.2-65	3-51
Upper Three Runs at Road A (1987-1991)	Mean	66.7	6.08	8.36	24.5	5.24	10
	Range	NA	NA	4.9 - 12	3.0 - 41	1.0 - 22	2- 97
Upper Three Runs at Road 8-1 (1996)	Mean	61.5	6.03	8.29	48.2	5.60	9
	Range	49.6-71.2	5.3-6.8	5.2-10.2	3-140	1.6-11	2-15
Crouch Branch at Road 4 (1996)	Mean	64.9	6.06	7.13	37.9	26.23	16
	Range	46.4-76.6	5.4-6.4	5.2-8.5	22-50	3.4-130	4-76
Lower Three Runs at Patterson Mill (1996)	Mean	64	6.29	7.49	84.5	4.28	9
	Range	49.3-80.6	6-7	5.8-10.6	60-120	1.2-9.8	2-24
Lower Three Runs at Patterson Mill (1987-1991)	Mean	64.4	NA	8.0	75	2.8	5
	Range	45.9-84.2	5.9 - 7.4	5.8 - 11	13 - 140	0.94 - 38	1 - 34

NOTES:
NA = Not available
SOURCE:
McDowell-Boyer et al. 2000

3.2 Facility Characteristics

The E-Area LLWF contains the following types of disposal units: Low-Activity Waste (LAW) Vaults, Intermediate-Level (IL) Vaults, Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches), and Naval Reactor Component Disposal Pads (Figure 2-2). The following three time periods are anticipated for the E-Area LLWF: 25-year operational period, 100-year institutional control period, and post-institutional control period. It is further anticipated that closure will be will be conducted in the following three phases: operational closure as units are filled, interim closure at the end of the 25 year operational period, and final closure at the end of the 100 year institutional control period (Phifer 2004). Table 3-6 provides a summary of each disposal unit's characteristics and closure phases. The functionality of each disposal unit type is discussed for each time period and closure phase in relation to structural stability, disposal unit cover integrity, water infiltration, and inadvertent intruder barrier within the following sections. The closure sequence described herein has been revised from that of previous closure plan revisions. Table 3-7 provides a comparison of the previous closure sequence to the revised closure sequence described herein. Table 3-7 also provides the reasons for the change in the closure sequence.

Table 3-6 Disposal Unit Characteristics and Closure Phases

Disposal Unit	Disposal Unit Design	Waste Packaging	Operational Closure (During 25 year Operational Period)	Estimated Subsidence Potential (After Operational Closure)	Interim Closure (At end of 25 year Operational Period)	Subsidence Treatment (At end of 100-year Institutional Control Period)	Final Closure (At end of 100-year Institutional Control Period)	Estimated Time Frame of Unit Structural Failure [5]
LAW Vaults	Above grade concrete vaults	Stacked containerized waste (predominately in B-25 or B-12 boxes; may have concrete containers)	Seal openings with reinforced concrete and cover roof slab with waterproof membrane	10 ft [2]	None anticipated beyond that of Operational Closure	None anticipated	Construction of integrated closure system consisting of one or more final closure caps and a drainage system	3,100 years after final closure [2]
IL Vaults	Below grade concrete vaults and silos	• Vaults: equipment, containers, and containerized waste (predominately in drums, B-12 boxes, B-25 boxes, and concrete containers) • Silos: tritium crucibles	• Vaults: grout encapsulation of containers • Silos: concrete silo plug • Both: construction of reinforced concrete roof slab with waterproof membrane cover	Not currently estimated; however it should be substantially less than that of the LAW Vault (will be variable)	None anticipated beyond that of Operational Closure	None anticipated	Construction of integrated closure system consisting of one or more final closure caps and a drainage system	1,050 years after final closure [2]
Engineered Trenches	Below grade drive-in earthen trench with gravel base and a sump	Stacked containerized waste (predominately in B-25 boxes, B-12 boxes, drums, and SeaLands)	Cover with a minimum 4 ft clean soil cover graded to provide positive drainage off the trench	13.5 ft [3]	Installation of interim runoff cover to be maintained during 100-year institutional control period	Static surcharging and/or dynamic compaction	Construction of integrated closure system consisting of one or more final closure caps and a drainage system	Subsidence treatment at end of 100-year institutional control period assumed to eliminate all subsidence potential [6]
Slit Trenches	Below grade earthen trench	Bulk waste (soil, rubble, concrete, metal, wood, etc.), containerized waste (predominately in B-25 boxes, B-12 boxes, drums, and SeaLands), and large equipment and containers	Cover with a minimum 4 ft clean soil cover graded to provide positive drainage off the trench	Not currently estimated (will be variable up to 13.5 ft) [4]	Installation of interim runoff cover to be maintained during 100-year institutional control period	Static surcharging and/or dynamic compaction	Construction of integrated closure system consisting of one or more final closure caps and a drainage system	Subsidence treatment at end of 100-year institutional control period assumed to eliminate all subsidence potential [7]
Components-In-Grout Trenches	Below grade earthen trench with grout encapsulation of waste	Large equipment and containers	Encapsulation of components with grout and cover with a minimum 4 ft clean soil cover graded to provide positive drainage off the trench [1]	Not currently estimated (will be variable)	Installation of interim runoff cover to be maintained during 100-year institutional control period	None anticipated; dynamic compaction will not be performed	Construction of integrated closure system consisting of one or more final closure caps and a drainage system	300 years after operational closure [2]
Naval Reactor Component Disposal Pad	Above grade gravel pad	Naval reactor component in heavily shielded shipping/disposal casks (assumed to be watertight for 750 years)	Placement of casks on gravel pad	Not currently estimated	None anticipated beyond that of Operational Closure	Fill space around, between, and over the casks with a structurally suitable material	Construction of integrated closure system consisting of one or more final closure caps and a drainage system	8,000 years after placement on the pad [8]

Dynamic compaction will not be performed over any portion of a disposal unit containing ETF Carbon Columns

[1] Steel reinforced concrete mats will be constructed over trench portions, which contain components that will not maintain 300 years of structural stability

[2] McDowell-Boyer et al. (2000)

[3] Phifer and Wilhite (2001)

[4] Phifer (2004)

[5] Unit structural failure could result in subsidence if the unit's waste has significant subsidence potential. Unit structural failure and potential subsidence could result in increased infiltration

[6] Without the subsidence treatment at the end of the 100-year institutional control period, it has been estimated that structural failure would occur between 200 to 300 years after burial (Phifer and Wilhite 2001; Jones and Phifer 2002)

[7] Without the subsidence treatment, it has been estimated that structural failure would occur within the 100-year institutional control period for bulk waste and between 200 to 300 years after burial for containerized waste (Phifer and Wilhite 2001; Jones and Phifer 2002; Phifer 2004)

[8] McDowell-Boyer et al. (2000) (The casks are assumed to have an initial thickness of 35 cm, corrode at a rate of 4E-03 cm/yr, and structurally fail after corrosion has reduced the wall thickness to 3 cm)

Table 3-7 Closure Sequence Comparison

Comparison Item	Previous Closure Sequence	Revised Closure Sequence [4]	Comments
Closure Sequence	Operational Closure during 25-year Operational Period Final Closure at end of 25-year Operational Period 100-year Institutional Control Period Post-Institutional Control Period	Operational Closure during 25-year Operational Period Interim Closure at end of 25-year Operational Period Final Closure at end of 100-year Institutional Control Period Post-Institutional Control Period	The Revised Closure Sequence adds an Interim Closure at the end of the 25-year Operational Period and delays Final Closure until the end of 100-year Institutional Control Period
25-year Operational Period	Disposal units will be operationally closed as they are filled	Disposal units will be operationally closed as they are filled	The 25-year Operational Period is the same for both Closure Sequences
100-year Institutional Control Period	Subsidence treatment of the Engineered and Slit Trenches consisting of static surcharging and/or dynamic compaction will be performed as part of Final Closure Final Closure consisting of one or more closure caps installed over all disposal units and a drainage system will be installed at the beginning of this period and maintained during this period	LAW Vaults, IL Vaults, and NR Component Disposal Pads will remain in their operationally closed state (i.e. no additional actions required during this period) Engineered, Slit, and CIG Trenches will be covered with an interim runoff cover at the beginning of this period and maintained during this period	The Revised Closure Sequence adds an Interim Closure that takes advantage of the very low infiltration through the LAW Vaults, IL Vaults, and NR casks in their operationally closed state and it will allow appropriate management of containerized subsidence potential within Engineered Trenches and Slit Trenches
Post- Institutional Control Period	The Institutional Control Period will be extended beyond 100 years in order to manage containerized subsidence within Engineered Trenches and Slit Trenches and maintain the Final Closure Cap until such subsidence has ceased The entire Final Closure Cap will degrade due to pine forest succession, colloidal clay migration, and erosion [1] Portions of the Final Closure Cap over the LAW Vaults, IL Vaults, CIG Trenches, and NR Component Disposal Pads may degrade due to subsidence in year 3,100, 1,050, 300, and 8,000, respectively	Subsidence treatment of the Engineered and Slit Trenches consisting of static surcharging and/or dynamic compaction will be performed as part of Final Closure Final Closure consisting of one or more closure caps installed over all disposal units and a drainage system will be installed at the beginning of this period and it will not be maintained beyond the construction period The entire Final Closure Cap will degrade due to pine forest succession, colloidal clay migration, and erosion [1] Portions of the Final Closure Cap over the LAW Vaults, IL Vaults, CIG Trenches, and NR Component Disposal Pads may degrade due to subsidence in year 3,100, 1,050, 300, and 8,000, respectively	Under the Previous Closure Sequence subsidence treatment of Engineered and Slit Trenches would be conducted at the end of the 25-year Operational Period. However, it has been estimated that dynamic compaction of the Engineered Trenches and those portions of the Slit Trenches containing containerized waste, at this time, will at best reduce the subsidence potential by 50 percent. It has also been estimated that this remaining subsidence potential will result in subsidence from 100 to 150 years after burial. Therefore the Institutional Control Period for the Previous Closure Sequence would have to be extended beyond 100 years in order to manage subsidence and maintain the Final Closure Cap until such subsidence has ceased. [2]
Management of subsidence potential due to containers in Engineered and Slit Trenches	Subsidence treatment of the Engineered and Slit Trenches consisting of static surcharging and/or dynamic compaction will be performed at the beginning of the 100-year Institutional Control Period This subsidence treatment will at best reduce the subsidence potential by 50 percent [2] The remaining subsidence potential will be handled by extending the Institutional Control Period beyond 100 years and repairing the Final Closure Cap until such subsidence has ceased	Subsidence treatment of the Engineered and Slit Trenches will be delayed until the end of the 100-year Institutional Control Period, when its efficiency will be greater. With performance of the subsidence treatment at the end of the 100-year institutional control period, it is assumed that essentially all subsidence potential will be eliminated and that the Engineered and Slit Trenches will be stable thereafter.	The Revised Closure Sequence delays Engineered and Slit Trench subsidence treatment until it will be more efficient at the end of the 100-year Institutional Control Period. It also avoids the need to extend the Institutional Control Period and repair the Final Closure Cap due to subsidence. [4]
Infiltration through LAW Vaults, IL Vaults, and NR Casks during the 100-year Institutional Control Period	Infiltration through the LAW Vaults, IL Vaults, and NR Casks during the 100-year Institutional Control Period will increase over that in their operationally closed state due to the presence of the Final Closure Cap which will allow a head of water to development on top of the vaults and casks	Infiltration through the LAW Vaults, IL Vaults, and NR Casks during the 100-year Institutional Control Period will be essentially zero, since they will remain in their operationally closed state during this period [5]	The Revised Closure Sequence maintains the LAW Vaults, IL Vaults, and NR Casks in their operationally closed state during the 100-year Institutional Control Period which results in an infiltration through the vaults and casks of essentially zero, which is less than will occur under the Previous Closure Sequence [5]
Technological Advances	15 years of technological advances are available for incorporation into subsidence treatment and final closure	115 years of technological advances are available for incorporation into subsidence treatment and final closure	The Revised Closure Sequence can take advantage of 115 years of technological advances, whereas the Previous Closure Sequence can only take advantage of 15 years for incorporation into subsidence treatment and final closure
Total Relative Cost	The total relative cost associated with a 3.85 acre Engineered Trench from start of operations to the Post-Institutional Control Period has been estimated at $102,000,000 [3]	The total relative cost associated with a 3.85 acre Engineered Trench from start of operations to the Post-Institutional Control Period has been estimated at $22,400,000 [6]	The Revised Closure Sequence results in a total relative cost saving of $79,600,000 in association with a 3.85 acre Engineered Trench from start of operations to the Post-Institutional Control Period relative to the Previous Closure Sequence

[1] Phifer and Nelson (2003)
[2] Phifer and Wilhite (2001); Phifer (2004)
[3] Phifer and Wilhite (2001)
[4] Phifer (2004)
[5] WSRC (2002)
[6] See Appendix B

3.2.1 Low-Activity Waste Vaults

The current LAW Vault is an above grade, reinforced concrete vault. It is 643 feet long, 145 feet wide, and 27 feet high, is divided into 12 cells, and is designed to contain more than 12,000 B-25 boxes of waste. There is currently one LAW Vault in the E-Area LLWF and it is anticipated that two will be required. (McDowell-Boyer et al. 2000) The LAW Vault consists of the following (McDowell-Boyer et al. 2000):

- Controlled compacted backfill base,
- Crushed stone acts as both a base and a sub-drainage system to collect water from under and around the vault and route it to manhole drains,
- 30-inch continuous footer under all interior and exterior walls,
- 1-foot thick, cast-in-place, reinforced concrete floor slab sloped to a collection trench, which drains to a sump,
- 2-foot thick, cast-in-place, reinforced concrete walls that are structurally mated to the footer,
- Exterior and interior personnel openings with doors and exterior forklift access openings with rollup doors,
- 16-inch thick, cast-in-place, reinforced concrete, roof slab, supported on pre-cast concrete beams,
- A bonded-in-place layer of fiberboard insulation and a layer of waterproof membrane roofing on top of the roof slab, and
- A gutter/downspout system to drain the roof.

During the operational period low-activity waste contained within B-25 boxes, B-12 boxes, drums and/or concrete containers are stacked by forklift within the vault. B-25 and B-12 boxes are stacked four high. Operational closure of the LAW Vault will be conducted in stages. Individual cells will be closed as they are filled with stacks of containerized waste (metal and/or concrete containers) and the entire vault will be closed after it is filled. Such operational closure includes filling the interior collection trench and sump with grout and sealing cell and/or vault openings with reinforced concrete. The reinforcing steel will be tied into the reinforcing steel of the cell and/or vault itself, forming a unified structure with continuous walls. No additional closure actions are anticipated beyond that of operational closure for the LAW Vault during the 100-year institutional control period (i.e. interim closure). Final closure of the LAW Vaults will take place at final closure of the entire E-Area LLWF, at the end of the 100-year institutional control period. Final closure will consist of the installation of an integrated closure system designed to minimize moisture contact with the waste and to provide an intruder deterrent. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. (McDowell-Boyer et al. 2000)

Structural Stability

The LAW Vault is designed to withstand Design Basis Accident loads (as specified in Project S2889) that ensures continued structural stability during its anticipated life. It has been estimated that through slab cracking of the roof slab will occur from 1,400 to 3,100 years and that structural failure of the roof slab and pre-cast beams will occur around 3,100 years after final closure (McDowell-Boyer et al. 2000). It has also been estimated that a full LAW Vault has a void volume of approximately 50 percent and a subsidence potential of 10 feet with the use of supercompaction of the waste within the B-25 boxes (McDowell-Boyer et al. 2000). This void volume/subsidence potential does not impact the structural stability of the LAW Vaults until the time of anticipated, roof structural failure (i.e. 3,100 years). At the time of roof structural failure, it is assumed that the LAW Vault roof will collapse into the vault itself and that subsidence of the overlying closure cap will occur.

Disposal Unit Cover Integrity

The final E-Area LLWF closure cap will be installed at the end of the 100-year institutional control period (Phifer 2004). After installation it is assumed that no closure cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore it is assumed that the hydraulic properties of the closure cap will immediately begin to degrade after construction due to the following (Phifer and Nelson 2003; Phifer 2004):

- Formation of holes in the upper GCL by pine forest succession,
- Reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers, and
- Erosion of layers that provide water storage for the promotion of evapotranspiration.

As outlined above it has been estimated the LAW Vault roof will structurally fail about 3,100 years after final closure. At that point it is assumed that the LAW Vault roof will collapse into the vault itself and that subsidence of the overlying closure cap will occur. This will lead to further degradation of the hydraulic properties of that portion of the closure cap overlying the LAW Vault.

Water Infiltration

During the operational period water entrance into the LAW Vault is minimized through the crushed stone sub-drainage system, doors on external personnel and forklift openings, the waterproof membrane roofing, and the gutter/downspout system. Any water that does enter the LAW Vault during operations is collected in a sump, which is appropriately monitored and pumped out as necessary. During the 100-year institutional control period after the LAW Vault has been operationally closed, water infiltration into the vault is minimized through the crushed stone sub-drainage system, continuous concrete walls in all openings have been sealed, the waterproof membrane roofing, and the gutter/downspout system. During the post-institutional control period prior to vault structural failure, the final closure cap along with the structurally intact concrete vault structure minimize infiltration into the vault. During this period the hydraulic properties of the closure cap are assumed to degrade resulting in increased infiltration through the closure cap over time. Additionally through slab cracking of the roof slab is assumed to occur from 1,400 to 3,100 years, resulting in increased infiltration through the roof over time. At structural failure of the LAW Vault roof (i.e. 3,100) it is assumed that the roof will collapse into the vault itself, that subsidence of the overlying closure cap will occur, and that increased infiltration will occur through that portion of the closure cap overlying the collapsed LAW Vault. The potential for increased infiltration due to subsidence at the time of roof collapse is addressed in the PA in Section 5.4 (McDowell-Boyer et al. 2000). This PA evaluation shows that increasing infiltration by a factor of three causes an increase in amount of a radionuclide released ranging from 0 to 2.6 times.

Inadvertent Intruder Barrier

Inadvertent intrusion into the LAW Vault waste is not considered feasible during the operational and institutional control periods, due to facility security during these periods. However it is assumed that inadvertent intrusion could occur during the post-institutional control period. The roof slab and pre-cast beams ensure structural stability for about 3,100 years after final closure.

They also provide a barrier to intrusion for this time period because normal residential construction and well drilling equipment used in the vicinity of the SRS is not capable of penetrating the roof structure (McDowell-Boyer et al. 2000).

3.2.2 Intermediate-Level Vaults

The current IL Vault is a below grade, reinforced concrete vault. It is 279 feet long, 48 feet wide, and 29 to 31 feet deep. It contains eight 25-foot by 48-foot by 29-foot deep bulk cells and one 25-foot by 48-foot by 31-foot deep silo area containing 142 20-inch diameter by 20-foot long vertical silos. There is currently one IL Vault in the E-Area LLWF and it is anticipated that two will be required. (McDowell-Boyer et al. 2000) The IL Vault consists of the following (McDowell-Boyer et al. 2000):

- Controlled compacted backfill base,
- Crushed stone acts as both a base and a sub-drainage system to collect and drain any water under the vault to a dry well,
- 30-inch thick, reinforced concrete, base slab, which extends 2 feet beyond the exterior walls,
- The floor of each cell slopes to a drain which runs to a sump in the base slab of each cell,
- 30-inch thick, reinforced concrete, exterior walls coated with tar-based waterproofing, and 18-inch thick, reinforced concrete, interior walls, all of which are structurally mated to the base slab and have no horizontal joints,
- Continuous waterstop seals at all concrete joints,
- 1.5-foot, reinforced concrete, shielding tees for radiation shielding over all cells except for the silo cell which utilizes individual shielding plugs for each silo, and
- Sloped rain covers, consisting of a roofing membrane on metal deck on steel framing installed over each cell, to direct rainwater onto the ground for runoff.

During the operational period intermediate-activity waste is placed in a bulk cell as follows (McDowell-Boyer et al. 2000):

- The cell rain cover and any necessary shielding tees are removed by crane,
- Equipment, containers, and containerized waste (predominately in drums, B-12 boxes, B-25 boxes, and concrete containers) are placed in the cell in layers,
- Each layer of waste is encapsulated in grout which forms the surface for the placement of the next layer of waste, and
- The cell rain cover and any necessary shielding tees are replaced by crane after waste placement and grouting.

During the operational period tritium crucibles are placed in silos as follows (McDowell-Boyer et al. 2000):

- The cell rain cover is removed by crane,
- Tritium crucibles are placed in individual silos by crane,
- A shielding plug is place over each silo containing a tritium crucible, and
- The cell rain cover is replaced by crane.

Operational closure of the IL Vault will be conducted in stages. Individual cells and the silo area will be closed as they are filled with waste by placing a final layer of grout level with the top of the vault walls. Installed silo shielding plugs will remain in place within the final grout layer, and unused shielding plugs will no longer be required. After the entire vault has been filled, it will be operationally closed, by installing a 2-foot 3-inch to 3-foot 2 inch permanent reinforced concrete roof slab and overlying bonded-in-place fiberboard insulation and waterproof membrane roofing over the entire vault. The rain covers, shielding tees, and shielding plugs will no longer be required after installation of the permanent roof slab. No additional closure actions are anticipated beyond that of operational closure for the IL Vault during the 100-year institutional control period (i.e. interim closure). Final closure of the IL Vaults will take place at final closure of the entire E-Area LLWF, at the end of the 100-year institutional control period. Final closure will consist of the installation of an integrated closure system designed to minimize moisture contact with the waste and to provide an intruder deterrent. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. (McDowell-Boyer et al. 2000)

Structural Stability

The IL Vault is designed to withstand Design Basis Accident loads (as specified in Project S2889) that ensures continued structural stability during its anticipated life. It has been estimated that through slab cracking of the roof slab will occur from 575 to 1,050 years and that structural failure of the roof slab will occur around 1,050 years after final closure (McDowell-Boyer et al. 2000). The void volume or subsidence potential of the IL Vault has not been estimated. It is anticipated that some level of subsidence potential exists within the IL Vault, since it contains compressible waste within metal containers. However the subsidence potential of the IL Vault should be substantially less than that of the LAW Vault, since the space between waste containers and containers and the IL Vault itself has been filled with grout. This subsidence potential will not impact the structural stability of the IL Vaults until after both the time of anticipated, roof structural failure (i.e. 1,050 years) and the time of waste container collapse (not currently estimated). To be conservative it is assumed that the IL Vault roof will collapse into the vault itself and that subsidence of the overlying closure cap will occur at the time of roof structural failure.

Disposal Unit Cover Integrity

The final E-Area LLWF closure cap will be installed at the end of the 100-year institutional control period (Phifer 2004). After installation it is assumed that no closure cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore it is assumed that the hydraulic properties of the closure cap will immediately begin to degrade after construction due to the following (Phifer and Nelson 2003; Phifer 2004):

- Formation of holes in the upper GCL by pine forest succession,
- Reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers, and
- Erosion of layers that provide water storage for the promotion of evapotranspiration.

As outlined above it has been estimated the IL Vault roof will structurally fail about 1,050 years after final closure. At that point it is conservatively assumed that the IL Vault roof will collapse into the vault itself and that subsidence of the overlying closure cap will occur. This will lead to further degradation of the hydraulic properties of that portion of the closure cap overlying the IL Vault.

Water Infiltration

During the operational period water entrance into the IL Vault is minimized through the crushed stone sub-drainage system, the 30-inch thick waterproofed concrete walls, and the cell rain covers. Any water that does enter the IL Vault during operations or results from the grout is collected in a sump, which is appropriately monitored and pumped out as necessary. During the 100-year institutional control period after the IL Vault has been operationally closed, water infiltration into the vault is minimized through the crushed stone sub-drainage system, the 30-inch thick waterproofed concrete walls, and permanent reinforced concrete roof slab and overlying bonded-in-place fiberboard insulation and waterproof membrane roofing. During the post-institutional control period prior to vault structural failure, the final closure cap along with the structurally intact concrete vault structure minimize infiltration into the vault. During this period the hydraulic properties of the closure cap are assumed to degrade resulting in increased infiltration through the closure cap over time. Additionally through slab cracking of the roof slab is assumed to occur from 575 to 1,050 years, resulting in increased infiltration through the roof over time. At structural failure of the IL Vault roof (i.e. 1,050) it is conservatively assumed that the roof will collapse into the vault itself, that subsidence of the overlying closure cap will occur, and that increased infiltration will occur through that portion of the closure cap overlying the collapsed IL Vault.

Inadvertent Intruder Barrier

Inadvertent intrusion into the IL Vault waste is not considered feasible during the operational and institutional control periods, due to facility security during these periods. However it is assumed that inadvertent intrusion could occur during the post-institutional control period. The roof slab ensures structural stability for about 1,050 years after final closure. It also provides a barrier to intrusion for this time period because normal residential construction and well drilling equipment used in the vicinity of the SRS is not capable of penetrating the roof structure (McDowell-Boyer et al. 2000).

3.2.3 Engineered Trenches

The current Engineered Trench is a below grade earthen disposal unit. The excavated soil is stockpiled for later placement over disposed waste. It is approximately 650 feet long by 150 feet wide (bottom dimensions) and varies in depth from 16 to 25 feet and is designed to contain approximately 12,000 B-25 boxes of waste. (Phifer and Wilhite 2001) There is currently one Engineered Trench in the E-Area LLWF and it is anticipated that two Engineered Trenches will be required. The Engineered Trench consists of the following:

- A berm around the top on the sides where the local terrain slopes toward the trench,
- Side slopes on 1 to 1 or 1.25 to 1 slopes, covered with an erosion control, matting, and seeded,
- A vehicle access ramp to the bottom,
- A bottom consisting of compacted soil, a geotextile filter fabric, and approximately 6 inches of granite crusher run (from bottom to top) sloped to a sump, and
- A sump with 1 to 1 side slopes and a geotextile fabric and a polyethylene geoweb slope cover, infilled with 4,000-psi concrete covering the sump side slopes and sump bottom.

During the operational period low-level waste contained within B-25 boxes, B-12 boxes, 55-gallon drums, Sealand containers, and/or other metal containers are stacked by forklift or placed by crane within the Engineered Trench. B-25 boxes are the predominant disposal containers utilized. The B-25 boxes are stacked in rows four high (approximately 17 feet high) with a forklift, beginning at the end of the trench opposite the access ramp. The stacks of B-25 boxes are generally placed immediately adjacent to one another with as little void space as possible between the stacks. (Phifer and Wilhite 2001)

Operational closure of the Engineered Trenches will be conducted in stages. As a sufficient number of B-25 rows are placed, the stockpiled clean soil is bulldozed in a single lift over some of the completed rows to produce a minimum 4-foot thick clean soil layer over them (i.e. operational soil cover). This operational soil cover is only applied to that portion of the completed rows that still allows maintenance of a safe distance from the working face (i.e. where new boxes are placed in the stack) within the trench. The operational soil cover is graded to provide positive drainage off the trench and away from the working face. Placement of the B-25 boxes continues until the trench is filled with boxes. At that point the minimum 4 feet operational soil cover is placed over the remaining portion of the trench, the entire area is graded to provide positive drainage off the trench, a vegetative cover of shallow rooted grass is established, and it is considered operationally closed. The operational soil cover also provides shielding for operations personnel. (Phifer and Wilhite 2001) At the end of the operational period, an interim runoff cover will be installed and maintained during the 100-year institutional control period as detailed in section 4.0 (i.e. interim closure). Final closure of the Engineered Trenches will take place at final closure of the entire E-Area LLWF, at the end of the 100-year institutional control period. Static surcharging and/or dynamic compaction of the Engineered Trenches will be conducted at the end of the 100-year institutional control period, when the efficiency of the subsidence treatment will be greater due to container corrosion and subsequent strength loss. (Phifer 2004) Final closure will consist of the installation of an integrated closure system designed to minimize moisture contact with the waste and to provide an intruder deterrent. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. (McDowell-Boyer et al. 2000)

Structural Stability

During the operational period, B-25 boxes are stacked one on top of another and the stacks are generally placed immediately adjacent to one another with very little void space between the stacks. During placement of the operational soil cover, the lid of the top B-25 box in a stack is assumed to collapse into the box and the lower three boxes in the stack are assumed to remain undamaged. At that point the matrix of B-25 boxes provides significant structural stability to support the operational soil cover.

It has been estimated that an Engineered Trench, containing B-25 boxes of waste stacked four high, has a subsidence potential of approximately 13.5 feet (Phifer and Wilhite 2001; Phifer 2004). It has also been estimated that B-25 boxes that have not been dynamically compacted will structurally collapse 200 to 300 years after burial due to corrosion resulting in the failure of any cover or cap over the Engineered Trench. (Phifer and Wilhite 2001) It has been further estimated that dynamic compaction of an Engineered Trench containing B-25 boxes at the end of the operational period would at best reduce the subsidence potential by 50 percent. However the efficiency of subsidence treatment increases with time due to B-25 box corrosion and subsequent loss of strength. Therefore rather than performing subsidence treatment (i.e. static surcharging and/or dynamic compaction) of the Engineered Trenches at the end of the operational period it will be performed at the end of the 100-year institutional control period, when its efficiency will be greater. With performance of the subsidence treatment at the end of the 100-year institutional control period, it is assumed that essentially all subsidence potential will be eliminated and that the Engineered Trenches will be stable thereafter. (Phifer 2004)

Prior to performance of the subsidence treatment at the end of the 100-year institutional control period, both the operational cover and the interim runoff cover will be maintained and any subsidence induced damage to the covers will be appropriately repaired. However significant subsidence induced damage to the covers is not anticipated due to the inherent structural integrity of the stacked B-25 boxes until significant corrosion has occurred. (Phifer 2004)

Additional work is currently in progress to better estimate the anticipated time period of B-25 box structural collapse following burial. Additionally the timing of the use of static surcharging and/or dynamic compaction on the Engineered Trenches to achieve more efficient results is also currently in progress. While B-25 containers stacked four-high is the typical configuration currently placed in the Engineered Trenches, other containers are also placed there. These containers include 55-gallon drums, B-12 containers (of similar construction, but with about half the capacity of B-25s), and a few other types of steel containers. Recently, 20 ft- and 40 ft-long shipping containers commonly referred to as Sealand containers have been used (J. L. Kukreja to B. T. Butcher, email pers. com. October 15, 2003; S. R. Reed to W. E. Jones, pers. Com. October 28, 2003). These containers are commercially used to ship goods by sea, then transfer directly to a trailer for overland shipment by truck. To date, only the long-term structural stability of B-25s has been evaluated.

Disposal Unit Cover Integrity

Both the operational cover and the interim runoff cover will be maintained and any subsidence-induced damage to the covers will be appropriately repaired. However significant subsidence induced damage to the covers is not anticipated due to the inherent structural integrity of the stacked B-25 boxes until significant corrosion has occurred.

The final E-Area LLWF closure cap will be installed at the end of the 100-year institutional control period (Phifer 2004). As outlined above subsidence treatment of the Engineered Trenches will be performed immediately prior to installation of the final closure cap. At that time the subsidence treatment will be more effective, and it is assumed that such treatment will essentially eliminate all subsidence potential. Therefore no degradation due to subsidence of the final closure cap over the Engineered Trenches will be assumed to occur. However after installation it is assumed that no closure cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore it is assumed that the hydraulic properties of the closure cap will immediately begin to degrade after construction due to the following (Phifer and Nelson 2003; Phifer 2004):

- Formation of holes in the upper GCL by pine forest succession,
- Reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers, and
- Erosion of layers that provide water storage for the promotion of evapotranspiration.

Water Infiltration

During the operational period, water infiltration through the waste, is minimized by the following:

- Berms surrounding the Engineered Trench, which prevent run on,
- Metal containers, which divert water,
- The trench bottom, which is sloped to a sump from which water can be pumped, and
- The operational soil cover, which is graded to provide positive drainage off the trench and away from the working face.

The interim runoff cover and the metal containers minimize water infiltration through the waste during the 100-year institutional control period. The interim runoff cover, which is maintained during institutional control, minimizes infiltration into the soil column overlying the waste and the metal containers divert water around the waste while they remain intact. The final closure cap minimizes infiltration through the waste during the post-institutional control period. However after installation it is assumed that no cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore the hydraulic properties of the cap are assumed to degrade resulting in increased infiltration through the cap over time.

Inadvertent Intruder Barrier

Inadvertent intrusion into the Engineered Trench waste is not considered feasible during the operational and institutional control periods, due to facility security during these periods. However it is assumed that inadvertent intrusion could occur during the post-institutional control period. The closure cap (see Section 4.0) includes an erosion barrier designed to maintain a minimum of 3 meters of clean material above the waste. This provides a barrier to excavation into the waste, since is assumed that excavations for residential construction do not exceed 3 meters (McDowell-Boyer et al. 2000), it however is not assumed to provide a barrier to drilling into the waste.

3.2.4 Very-Low-Activity Waste Disposal Trenches (Slit Trenches)

Slit Trenches are below grade earthen disposal units. The excavated soil is stockpiled for later placement over disposed waste. Slit Trenches are generally 20 feet deep, 20 feet wide, and 650 feet long with essentially vertical side slopes. Ten feet of undisturbed soil separates each trench. (McDowell-Boyer et al. 2000; Phifer 2004) A set of five, 20-foot wide Slit Trenches, are grouped together within a 150-foot wide by 650-foot long footprint. Seven such Slit Trench groupings designated Slit 1 through 7 are anticipated. Currently waste has been placed within Slit 1 through 4. Slit Trenches up to 40 feet wide are under consideration.

During the operational period low-level waste consisting of soil, debris, rubble, wood, concrete, equipment, and job control waste is disposed within the Slit Trenches. The waste may be disposed as bulk waste or contained within B-25 boxes, B-12 boxes, 55-gallon drums, Sealand containers, and other metal containers. Trench excavation begins at one end of the trench and only proceeds as needed toward the other end of the trench in order to minimize the area of open trench. Waste placement in turn begins at one end of the trench and proceeds toward the other end. Bulk waste is pushed into the trench from one end. Containerized waste and large equipment are typically placed in one end of the trench with a crane. Eventually containerized waste areas of the trench are filled in with either bulk waste or clean soil to fill the voids between adjacent containers and the trench wall. Slit trenches are typically filled to within four feet below the top of the trench with waste and daily cover. (McDowell-Boyer et al. 2000; Phifer 2004)

Operational closure of the Slit Trenches will be conducted in stages. Once a section of the slit trench is filled, the stockpiled clean soil is bulldozed in a single lift over that section of trench to produce a minimum 4-foot thick clean soil layer over the waste (i.e. operational soil cover). The operational soil cover is graded to provide positive drainage off and away from the disposal operation. Subsequent trench sections are filled with waste, covered with an operational soil cover, and graded to promote positive drainage until the entire trench is filled and covered. The only mechanical compaction that the soil and waste in the trench receive is from the bulldozer and other heavy equipment moving over the top of a completely backfilled trench. No operational equipment or personnel are allowed in the trench. Once a trench is filled, completely covered with the 4-foot soil cover, and a vegetative cover of shallow rooted grass is established, it is considered operationally closed. The operational soil cover also provides shielding for operations personnel. (McDowell-Boyer et al. 2000; Phifer 2004) At the end of the operational period, an interim runoff cover will be installed and maintained during the 100-year institutional control period as detailed in section 4.0 (i.e. interim closure). Final closure of the Slit Trenches will take place at final closure of the entire E-Area LLWF, at the end of the 100-year institutional control period. Static surcharging and/or dynamic compaction of the Slit Trenches will be conducted at the end of the 100-year institutional control period, when the efficiency of the subsidence treatment will be greater due to container corrosion and subsequent strength loss. (Phifer 2004) Final closure will consist of the installation of an integrated closure system designed to minimize moisture contact with the waste and to provide an intruder deterrent. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. (McDowell-Boyer et al. 2000)

Structural Stability

The subsidence potential of Slit Trenches has not been estimated to the extent performed for Engineered Trenches. However, the subsidence potential and estimated time of subsidence for those portions of Slit Trenches that receive containerized waste should be similar to that of Engineered Trenches. That is these portions of Slit Trenches should have a maximum subsidence potential of 13.5 feet and subsidence is expected to occur within 200 to 300 years after burial due to container corrosion (based upon B-25 box corrosion). Portions of Slit Trenches that receive bulk waste should have substantially less subsidence potential than this and it is anticipated that such subsidence would occur within the 100-year institutional control period. (Phifer and Wilhite 2001; Phifer 2004)

As with Engineered Trenches, subsidence treatment of Slit Trenches is currently planned at the end of the 100-year institutional control period. At this time greater treatment efficiency is anticipated for those portions of the trenches, which contain metal containers, due to container corrosion. Prior to performance of the subsidence treatment at the end of the 100-year institutional control period, both the operational cover and the interim runoff cover will be maintained and any subsidence induced damage to the covers will be appropriately repaired. Significant subsidence induced damage to those areas of the covers overlying trench portions containing containerized waste is not anticipated due to the inherent structural integrity of the containers until significant corrosion has occurred. However some subsidence induced damage is anticipated to those areas of the covers overlying trench portions containing bulk waste is anticipated. With performance of the subsidence treatment at the end of the 100-year institutional control period, it is assumed that essentially all subsidence potential will be eliminated and that the Slit Trenches will be stable thereafter. (Phifer 2004)

Disposal Unit Cover Integrity

Both the operational cover and the interim runoff cover will be maintained and any subsidence-induced damage to the covers will be appropriately repaired. Significant subsidence induced damage to those areas of the covers overlying trench portions containing containerized waste is not anticipated due to the inherent structural integrity of the containers until significant corrosion has occurred. However some subsidence induced damage is anticipated to those areas of the covers overlying trench portions containing bulk waste is anticipated.

The final E-Area LLWF closure cap will be installed at the end of the 100-year institutional control period (Phifer 2004). As outlined above subsidence treatment of the Slit Trenches will be performed immediately prior to installation of the final closure cap. At that time the subsidence treatment will be more effective for the containerized waste, and it is assumed that such treatment will essentially eliminate all subsidence potential. Therefore no degradation due to subsidence of the final closure cap over the Slit Trenches will be assumed to occur. However after installation it is assumed that no closure cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore it is assumed that the hydraulic properties of the closure cap will immediately begin to degrade after construction due to the following (Phifer and Nelson 2003; Phifer 2004):

- Formation of holes in the upper GCL by pine forest succession,
- Reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers, and
- Erosion of layers that provide water storage for the promotion of evapotranspiration.

Water Infiltration

During the operational period, water infiltration through the waste, is minimized by minimizing the area of open trench and the operational soil cover, which is graded to provide positive drainage off the trench and away from the working face. The interim runoff cover minimizes water infiltration through the waste during the 100-year institutional control period. The interim runoff cover, which is maintained during institutional control, minimizes infiltration into the soil column overlying the waste. The final closure cap minimizes infiltration through the waste during the post-institutional control period. However after installation it is assumed that no cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore the hydraulic properties of the cap are assumed to degrade resulting in increased infiltration through the cap over time.

Inadvertent Intruder Barrier

Inadvertent intrusion into Slit Trench waste is not considered feasible during the operational and institutional control periods, due to facility security during these periods. However it is assumed that inadvertent intrusion could occur during the post-institutional control period. The closure cap (see Section 4.0) includes an erosion barrier designed to maintain a minimum of 3 meters of clean material above the waste. This provides a barrier to excavation into the waste, since is assumed that excavations for residential construction do not exceed 3 meters (McDowell-Boyer et al. 2000), it however is not assumed to provide a barrier to drilling into the waste.

3.2.5 Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches)

Components-In-Grout (CIG) Trenches are below grade earthen disposal units. The excavated soil is stockpiled for later placement over the grouted components. CIG Trenches are generally 20 feet deep, 20 feet wide, and 650 feet long with essentially vertical side slopes. Ten feet of undisturbed soil separates each trench. (McDowell-Boyer et al. 2000; Jones et al. 2004) The depth and width can vary greatly depending upon the size of the components being disposed. A set of five, 20-foot wide CIG Trenches, are grouped together within a 150-foot wide by 650-foot long footprint. Two such CIG Trench groupings, designated CIG 1 through 2, are anticipated. Currently waste has been placed within CIG 1.

Components to be disposed within the CIG Trenches consist of large radioactively contaminated equipment. In order to ensure structural integrity for 300 years after disposal, components are filled with grout or structural foam, determined to be in and of themselves structurally sound for 300 years after burial, or overlaid with a reinforced concrete mat (Jones et al. 2004). During the operational period, trench excavation is conducted on an as needed basis and only that length of trench required for disposal of a particular component(s) is excavated in order to minimize the area of open trench and the time the trench section is open. The bottom of the trench section is filled with 2,000-psi grout to a minimum one-foot, and the grout is allowed to cure. The component(s) are then placed on the one-foot base grout layer with a crane and 2,000 psi grout is poured around, between, and over the component(s) in order to encapsulate the component(s). Additional layers of component(s) and grout may be placed on top of previous layers until approximately 16 feet of trench is filled up with component(s) and grout. The operation is conducted so that a minimum one-foot of grout is between the component(s) and the trench bottom and side and so that a minimum one-foot of grout is over the top of the upper most component(s). After the grout has cured, the stockpiled clean soil is bulldozed in a single lift over that section of trench to produce a minimum 4-foot thick clean soil layer over the encapsulated components (i.e. operational soil cover). The operational soil cover is graded to provide positive drainage off and away from the CIG Trench. This process continues until the entire trench is filled, completely covered with the 4-foot soil cover, and a vegetative cover of shallow rooted grass is established, at which point the trench is considered operationally closed. The operational soil cover also provides shielding for operations personnel. (McDowell-Boyer et al. 2000) At the end of the operational period, an interim runoff cover will be installed and maintained during the 100-year institutional control period as detailed in section 4.0 (i.e. interim closure). Final closure of the CIG Trenches will take place at final closure of the entire E-Area LLWF, at the end of the 100-year institutional control period. Final closure will consist of the installation of an integrated closure system designed to minimize moisture contact with the waste and to provide an intruder deterrent. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. (McDowell-Boyer et al. 2000; Phifer 2004)

Structural Stability

The cement-stabilized encapsulated waste form is likely to maintain its structural stability for 300 years after burial (McDowell-Boyer et al. 2000). The subsidence potential of the components disposed within the CIG Trenches has not yet been evaluated and therefore the structural stability of the CIG Trenches after 300 years has also not been evaluated.

Disposal Unit Cover Integrity

Since it is anticipated that the cement-stabilized encapsulated waste form will maintain its structural stability for 300 years after burial, it is not anticipated that the integrity of the operational cover and the interim runoff cover will be impacted by subsidence.

The final E-Area LLWF closure cap will be installed at the end of the 100-year institutional control period (Phifer 2004). After installation it is assumed that no closure cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore it is assumed that the hydraulic properties of the closure cap will immediately begin to degrade after construction due to the following (Phifer and Nelson 2003; Phifer 2004):

- Formation of holes in the upper GCL by pine forest succession,
- Reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers, and
- Erosion of layers that provide water storage for the promotion of evapotranspiration.

As outlined above it has been estimated that the cement-stabilized encapsulated waste form will maintain its structural stability for 300 years after burial. At that point it has not yet been determined whether or not the trench will collapse. Collapse at that point will be primarily based upon the subsidence potential of the disposed components. Therefore it is not known whether further degradation of the hydraulic properties of that portion of the closure cap overlying the CIG Trenches will occur or not due to the loss of waste form structural stability.

Water Infiltration

During the operational period, water infiltration through the waste, is minimized by minimizing the area of open trench, minimizing the time a trench section is open, encapsulating the components in grout, and the operational soil cover. The operational soil cover is graded to provide positive drainage off the trench. The interim runoff cover and grout encapsulation minimize water infiltration through the waste during the 100-year institutional control period. The interim runoff cover, which is maintained during institutional control, minimizes infiltration into the soil column overlying the waste while the grout encapsulation diverts water around the waste. The final closure cap minimizes infiltration through the waste during the post-institutional control period. However after installation it is assumed that no cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore the hydraulic properties of the cap are assumed to degrade resulting in increased infiltration through the cap over time. Additionally as outlined above it is currently not know whether loss of waste form structural stability results in increased infiltration or not.

Inadvertent Intruder Barrier

Inadvertent intrusion into CIG Trench waste is not considered feasible during the operational and institutional control periods, due to facility security during these periods. However it is assumed that inadvertent intrusion could occur during the post-institutional control period. During the 300 years period of waste form structural stability, the grout encapsulation is assumed to provide a barrier to since normal residential construction and well drilling equipment used in the vicinity of the SRS is not capable of penetrating the grout (McDowell-Boyer et al. 2000). Additionally the closure cap (see Section 4.0) includes an erosion barrier designed to maintain a minimum of 3 meters of clean material above the waste. This provides a barrier to excavation into the waste, since it is assumed that excavations for residential construction do not exceed 3 meters (McDowell-Boyer et al. 2000), it however is not assumed to provide a barrier to drilling into the waste.

3.2.6 Naval Reactor Component Disposal Pad

The Naval Reactor Component Disposal Pad is an above grade gravel pad. It is approximately 150 feet by 150 feet, and is designed to contain 100 Naval Reactor Waste Shipping/Disposal Casks.

During the operational period naval reactor components contained within the Naval Reactor Waste Shipping/Disposal Casks are placed on the Naval Reactor Component Disposal Pad. The steel casks have thick walls, are closed with a gasket or welds, and are considered watertight. No additional operational closure or interim closure beyond simply placing the casks on the pad is anticipated due to the watertight nature of the casks. Final closure of the Naval Reactor Component Disposal Pad will take place at final closure of the entire E-Area LLWF, at the end of the 100-year institutional control period. The space around, between, and over the casks will have to be filled with a structurally suitable material at the end of the 100-year institutional control period as outlined within Section 4.4.2.1. Final closure will consist of installation of an integrated closure system designed to minimize moisture contact with the waste and to provide an intruder deterrent. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system as detailed in section 4.0. An old Naval Reactor Component Disposal Pad (643-7E), located adjacent to the E-Area LLWF, will be closed in a manner similar to that described herein.

Structural Stability

The typical cask is assumed to have a wall thickness of 35-cm (McDowell-Boyer et al. 2000) and it is assumed that the casks will remain structurally stable until the wall thickness has been reduced to 3 cm due to corrosion. A corrosion rate of 4E-03 cm/yr has been assumed for the typical steel cask (McDowell-Boyer et al. 2000). Based upon these assumptions, it has been estimated that the casks will remain structurally stable for 8,000 years. The subsidence potential of the casks has not yet been estimated, therefore it has not yet been determined whether the loss of cask structural stability will result in a subsequent collapse or not.

Disposal Unit Cover Integrity

The final E-Area LLWF closure cap will be installed at the end of the 100-year institutional control period (Phifer 2004). After installation it is assumed that no closure cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore it is assumed that the hydraulic properties of the closure cap will immediately begin to degrade after construction due to the following (Phifer and Nelson 2003; Phifer 2004):

- Formation of holes in the upper GCL by pine forest succession,
- Reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers, and
- Erosion of layers that provide water storage for the promotion of evapotranspiration.

Since it is anticipated that the casks will maintain structural stability for 8,000 years after placement on the pad, it is not anticipated that the integrity of the final closure cap could be impacted by subsidence until that time. At that point it has not yet been determined whether or not the casks will collapse. Collapse at that point will be primarily based upon the subsidence potential of the waste within the casks, which has not yet been evaluated. Therefore it is not known whether further degradation of the hydraulic properties of that portion of the closure cap overlying the Naval Reactor Component Disposal Pad will occur or not due to the loss of cask structural stability.

Water Infiltration

As noted above the steel casks have thick walls, are closed with a gasket or welds, and are considered watertight (McDowell-Boyer et al. 2000). Additionally it has been estimated that the casks will remain watertight for 750 years after placement on the pads. Therefore no water infiltration through the contained waste is anticipated during the operational period, the 100-year institutional control period, and during the post-institutional control period prior to cask hydraulic failure at 750 years. The final closure cap, in addition, will minimize infiltration to the casks. However after installation it is assumed that no cap maintenance will be performed other than that required for establishment of the vegetative cover. Therefore the hydraulic properties of the cap are assumed to degrade resulting in increased infiltration through the cap over time. Finally as outlined above it is currently not known whether loss of cask structural stability results in increased infiltration or not.

Inadvertent Intruder Barrier

Inadvertent intrusion into the Naval Reactor Component Disposal Pad waste is not considered feasible during the operational and institutional control periods, due to facility security during these periods. However it is assumed that inadvertent intrusion could occur during the post-institutional control period. The casks are assumed to be structurally stable for 8,000 years after placement on the pads. They also provide a barrier to intrusion for this time period because normal residential construction and well drilling equipment used in the vicinity of the SRS is not capable of penetrating a structurally intact cask (McDowell-Boyer et al. 2000).

3.3 Waste Characteristics

Low-level radioactive solid waste may be characterized and segregated into three categories. The disposition of waste in the E-Area LLWF will be based on these categories. The waste categories are as follows:

1) Low-activity waste

2) Intermediate-level waste

3) Naval Reactor components.

Low-activity waste will be disposed in the LAW Vaults, Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), and Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches). Intermediate-level waste will be disposed in the Intermediate-Level Vaults. Naval Reactor components will be disposed in the Naval Reactor Components Disposal Pads.

All of the following forecasted radionuclide inventories are from Table 2 of “FY2002 Annual Review E-Area Low-Level Waste Facility Performance Assessment and Composite Analysis” (WSRC 2003). Except for the Engineered Trench, estimated disposal unit radionuclide inventories are also provided in the PA.

3.3.1 Low-Activity Waste Vaults

3.3.1.1 Waste Type/ Chemical and Physical Form

The LAW will include job control waste, scrap metal, and contaminated soil and rubble. Job control waste will consist of potentially contaminated protective clothing including plastic suits, shoe covers, lab coats, and plastic sheeting. Scrap metal will be contaminated tools, process equipment, and laboratory equipment. Soil and rubble will be generated from demolition and cleanup activities. Historically, the majority of this waste has been generated by the High-Level Waste (HLW) tank farms.

The radioactive content of LAW is primarily fission products from the tank farms and Separations. Waste will also be received from offsite facilities, which will have a variety of radionuclides.

3.3.1.2 Radionuclide Inventory

The radiation dose rate measured at 5 cm from the surface of an unshielded container is less than 200 mR/hr for containers destined for the E-Area LLWF (LAW Vault). The transuranic activity concentration for the LAW Vault is less than 100 nCi/g of alpha activity.

The total forecasted radionuclide inventory at facility closure for each of the LAW Vault planned for the E-Area LLWF is 2.298+05 Curies. (WSRC 2003).

3.3.1.3 Waste Volume

The LAW Vault provides approximately 4.8×10^4 m^3 of LAW capacity. Provided that curie inventory limits are not exceeded, waste volumes may approach that capacity for the LAW Vault during the period of operation.

3.3.1.4 Packaging Criteria

All LLW is subject to the packaging requirements of the 1S Manual. Most of the LAW will be received in standard 1.2 m × 1.2 m × 1.8 m metal containers (B-25 boxes), but some waste will also be received in standard 0.6 m × 1.2 m × 1.8 m containers (B-12 boxes). The LAW may also receive waste in non-standard engineered concrete or metal containers. These containers shall be pre-approved by Solid Waste Management prior to their receipt at the E-Area LLWF.

Many different containers will be received at the E-Area LLWF. However, all containers are required by the Technical Safety Requirements (TSRs) to be engineered concrete or metal containers that have been approved by Solid Waste. A procedure has been written that defines this approval process and requires Solid Waste Management Engineering, Solid Waste Management Operations, and Solid Waste Management Maintenance to concur that the container can be safely handled, will not impair vault space utilization, and will satisfactorily contain the waste contents.

The B-25 and B-12 containers are carbon steel boxes that have been used in the past for waste disposal in the Solid Waste Disposal Facility (SWDF). The boxes are similar in construction with the exception of size. The B-25 is a 2.5 m^3 container that is approximately 1.2 m high, 1.2 m wide, and 1.8 m long. It is typically constructed of 14-gauge carbon steel (1.9 mm) but some B-25s are constructed of 12-gauge carbon steel (2.6 mm) to allow use in the compactor. The B-12 is a 1.3 m^3 container that is approximately 0.6 m high, 1.2 m wide, and 1.8 m long and is constructed of either 12-gauge or 14-gauge carbon steel.

The B-12 and B-25 containers are constructed with a rubber-gasket seal between the lid and the container with a gasket compression of 20 to 30 percent. The interior and exterior of each container is coated with a zinc chromate primer. The exteriors are given an additional coating of alkyd enamel as a finish coat of paint.

A variety of drums, corresponding to international drum specifications, will also be received as standard containers. Use of these containers is restricted to situations where use of a B-25 is not practical. Drums will be banded together and banded to a fire-resistant pallet prior to shipment to the E-Area LLWF.

For waste that cannot be placed in a standard container, specific size and weight limits have been specified. Maximum dimensions for containers in the LAW Vaults are 4.3 m high × 7.3 m wide × 15.2 m long. The maximum uniform load on the vault floor cannot exceed 2.8×10^6 kg/m^2 for the LAW Vaults.

3.3.1.5 Pre-Disposal Treatment Methods

Prior to fiscal year 2003, many B-25 containers were opened and the contents sorted at the Waste Sort Facility (WSF). The compactible fraction was compressed with a super-compactor in the Supercompactor Facility (SCF) prior to disposal in the Engineered Trench or LAW vault. Pretreatment for low-level waste destined for trench disposal was determined to not be cost effective. WSF/SCF operations were shut down after fiscal year 2002.

3.3.1.6 Waste Acceptance Restrictions

Waste acceptance for disposal in the LAW Vaults must conform to criteria put forth in the SRS Waste Acceptance Criteria (WAC) [WSRC 1999].

3.3.2 Intermediate-Level Vaults

3.3.2.1 Waste Type/ Chemical and Physical Form

The IL Vault consists of eight bulk cells and a silo area containing 142 vertical silos. The IL Vault bulk cells will be used for disposal of bulk Intermediate-level (IL) waste. Bulk IL waste consists of job control waste, scrap hardware, and contaminated soil and rubble. Job control waste is primarily highly contaminated lab coats, plastic suits, shoe covers, plastic sheeting, etc. This material is assumed to be combustible and is contaminated primarily with fission products. Scrap hardware consists of reactor hardware, reactor fuel fittings and target fittings, jumpers, and used canyon and tank farm equipment contaminated with fission products and/or induced activity. Depending on the origin of this waste, it can contain either fission products or induced activity contamination. The induced activity waste will be mostly metal reactor hardware and fittings that have been exposed to a high neutron field. This waste generates a high radiation field but the activity is fairly immobile due to the metal matrix. Job control waste and process piping from Separations and High Level Waste Management will be contaminated with fission products. These fission products will be both loose and fixed surface contamination.

Bulk tritiated waste, is also disposed within the IL Vault bulk cells. Bulk tritiated waste consists of job control waste, used process equipment, and tritium-producing burnable absorber rods (TPBARs) that are contaminated with tritium. The DOE is developing a means of producing tritium by irradiating TPBARs in a commercial light water reactor, and extracting the tritium in a tritium extraction facility at the SRS. Following the tritium extraction, the TPBARs will be placed in an overpack container for disposal in the IL Vault bulk cells. In the future it is anticipated that the TPBARs will be disposed in Slit Trenches. IL waste disposed within the bulk cells will be packaged in engineered metal or concrete containers that have been approved by Solid Waste Management. The containers will be remotely placed into the cells in layers. IL waste containers will be grouted in place to provide better waste isolation, reduce dose to operators, and improve stacking of additional containers.

SRS tritium extraction crucibles will be placed within silos and shielding plugs will cap the silo.

3.3.2.2 Radionuclide Inventory

Waste is categorized as IL if the radiation dose rate measured at 5 cm from the surface of the unshielded container is greater than 200 mR/hr. Also, the transuranium element alpha activity concentration is less than 100 nCi/g.

The total forecasted radionuclide inventory at facility closure for the IL Vault planned for the E-Area LLWF is 1.013E+06 Curies (WSRC 2003).

3.3.2.3 Waste Volume

The IL Vault provides approximately 7.3×10^3 m^3 of waste capacity for Intermediate-Level (IL) waste. Provided that curie inventory limits are not exceeded, waste volumes may approach that capacity during the period of operation.

3.3.2.4 Packaging Criteria

The bulk of the waste received by the E-Area LLWF is containerized by the waste generator in B-25 or B-12 engineered metal boxes, or in 55-gallon drums. TPBARs will be overpacked in a disposable, seal-welded carbon steel shipping cask.

The maximum dimensions for containers in the IL Vaults are 7.3-m high ×10.7-m long × 6.1 m wide. The maximum uniform load on the vault floor cannot exceed 4.9×10^6 kg/m^2 for the IL Vaults.

3.3.2.5 Pre-Disposal Treatment Methods

No pre-disposal treatment methods are currently planned for IL waste.

3.3.2.6 Waste Acceptance Restrictions

Waste acceptance for disposal in the IL Vaults must conform to criteria put forth in the SRS WAC (WSRC 1999).

3.3.3 Engineered Trenches

3.3.3.1 Waste Type/ Chemical and Physical Form

The waste disposed in the Engineered Trenches is similar to that disposed in the LAW Vault (see section 3.3.1.1).

3.3.3.2 Radionuclide Inventory

The total forecasted radionuclide inventory at facility closure for the Engineered Trenches is 2.000+E3 Curies (WSRC 2003).

3.3.3.3 Waste Volume

The projected disposal volume for the Engineered Trench is approximately 46,000 cubic meters.

3.3.3.4 Packaging Criteria

The Engineered Trench packaging criteria is similar to that for the LAW Vault (see section 3.3.1.4).

3.3.3.5 Pre-Disposal Treatment Methods

No pre-disposal treatment methods are currently planned for Engineered Trench waste.

3.3.3.6 Waste Acceptance Restrictions

Waste acceptance for disposal in the Engineered Trenches must conform to criteria put forth in the SRS Waste Acceptance Criteria (WAC).

3.3.4 Very-Low-Activity Waste Disposal Trenches (Slit Trenches)

3.3.4.1 Waste Type/Chemical and Physical Form

Waste destined for trench disposal can generally be described as contaminated soil, debris, rubble, concrete, wood, equipment, job control waste, and various containerized wastes and large equipment components. In addition M Area glass waste contaminated with uranium has been received. Levels of radioactivity are lower than for waste destined for vault disposal.

3.3.4.2 Radionuclide Inventory

The total forecasted radionuclide inventory for the ten trenches planned for the E-Area LLWF is 5.000E+1 Curies (WSRC 2003).

3.3.4.3 Waste Volume

The volume capacity of each trench is 5760 m^3. Therefore the capacity of ten trenches is 5.7×10^4 m^3.

3.3.4.4 Packaging Criteria

No packaging criteria apply to the waste destined for very-low activity trench disposal.

3.3.4.5 Pre-Disposal Treatment Methods

Pretreatment for low-level waste destined for trench disposal was determined to not be cost effective. WSF/SCF operations were shut down after fiscal year 2002.

3.3.4.6 Waste Acceptance Restrictions

Waste acceptance for disposal in trenches must conform to criteria put forth in the SRS WAC (WSRC 1999).

3.3.5 Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches)

3.3.5.1 Waste Type/Chemical and Physical Form

In general, large equipment contaminated with radioactive materials will constitute the type of waste destined for disposal in these trenches. Any solid wasteform, however, that meets the WAC, which is based on the results of the PA, will be suitable for disposal as an encapsulated wasteform.

3.3.5.2 Radionuclide Inventory

The total forecasted radionuclide inventory for the Components-In-Grout is 9.409E+04 Curies (WSRC 2003).

3.3.5.3 Waste Volume

The volume capacity of each trench is 5760 m^3. Therefore the capacity of ten trenches is 5.7×10^4 m^3.

3.3.5.4 Packaging Criteria

Wasteforms encapsulated in grout will be placed directly in the designated trenches. No packaging criteria apply to waste destined for these trenches.

3.3.5.5 Pre-Disposal Treatment Methods

Waste destined for these trenches will be encapsulated by grout or other cementitious backfill as an alternative to vault disposal.

3.3.5.6 Waste Acceptance Restrictions

Waste acceptance for disposal in the trenches designated to receive cement-stabilized encapsulated waste must conform to criteria put forth in the SRS WAC.

3.3.6 Naval Reactor Components Disposal Pad

Heavily shielded shipping/disposal casks containing naval reactor waste components are planned to be disposed of at the Naval Reactor Components Disposal Pad, within the fenced 100-acre boundary of the E-Area LLWF, at the SRS. Large quantities of activation products are associated with the metal matrix of the waste forms within the disposal containers. Lesser amounts of radioactive contaminants are present in “crud” corrosion products.

3.3.6.1 Waste Type/ Chemical and Physical Form

Within the E-Area LLWF, disposal of up to 100 steel casks with carbon steel or low-alloy steel shipping containers containing Naval Reactor (NR) components is proposed. The NR component waste is composed of activated metals and can include control rods, control rod drive mechanisms, resin vessels, adapter flanges, core barrels/thermal shields (CB/TS), closure heads, holddown (HD) barrels, pumps and other similar equipment. Certain components are also covered with a thin layer of adherent corrosion products, referred to as “crud,” which contains lesser amounts of radioactive contamination. These waste components include Bettis CB/TS, HD barrels, Bettis heads, Bettis adapter flanges, Bettis shrouds, Bettis pumps, Knolls Atomic Power Laboratory (KAPL) CB/TS, and KAPL Heads. Volumes of the metal waste components range between 1.05 and 7.05 m^3 for each component. Most waste components also contain some water, with the maximum amount being about 9.5×10^{-3} m^3 (2.5 gal). The high shielding shipping/disposal containers reduce the safety risks involved in the disposal of NR component wastes. More detailed configurational descriptions of the NR waste components are not available because of the classified nature of this information.

3.3.6.2 Radionuclide Inventory

The total forecasted radionuclide inventory for the NR Pad is 5.000E+05 Curies (WSRC 2003).

3.3.6.3 Waste Volume

Naval reactor core barrels and reactor components are to be disposed of on gravel pads in the E-Area LLWF. The gravel pads have a total storage capacity of 2,090 square meters (22,500 square feet). Up to 100 containers may be disposed at the E-Area LLWF per the PA evaluation. The metal volume of the waste is approximately 3.5 m^3 per container.

3.3.6.4 Packaging Criteria

There is no standard Naval Reactor Component waste disposal container due to the variety of waste components. The actual container configuration, thickness, material of construction and closure method may be tailored to the characteristics of the Naval Reactor waste component at the time of disposal. The planned or proposed containers for Naval Reactor waste disposal are mostly composed of carbon steel or low-alloy steel and closed by a gasket or a weld. The assumed thickness of the container is based on estimated shielding requirements (by Bettis) for a bounding KAPL CB/TS radionuclide inventory. The overall containerized waste volume is about 43 m^3.

The life expectancy and shielding capacity of the shipping/disposal casks are determined by the specifications of the containers.

3.3.6.5 Pre-Disposal Treatment Methods

The offsite generator is responsible for any pre-disposal treatment methods prior to shipment to SRS.

3.3.6.6 Waste Acceptance Restrictions

Waste acceptance for disposal on the Naval Reactor Waste pad must conform to criteria put forth in the SRS WAC.

4.0 TECHNICAL APPROACH TO CLOSURE

The E-Area LLWF is a controlled release facility; i.e., a facility intended to control radionuclide migration within acceptable levels. A controlled release facility is not intended to eliminate all radionuclide migration. Rather, a controlled release facility is intended to maintain radionuclide migration from disposed LLW forms to below the Performance Objectives outlined within USDOE Order 435.1 and its associated Manual and Implementation Guide (USDOE 1999, USDOE 1999a, USDOE 1999b). The following design objectives are applicable to the E-Area LLWF closure to the extent practicable and to ensure compliance with the USDOE Order 435.1 Performance Objectives:

- Maintain waste confinement to the extent necessary to meet the Performance Objectives
- Provide long-term stability to the extent necessary to meet the Performance Objectives:
  - Minimize settling and subsidence
  - Minimize erosion
  - Minimize slope failure
- Minimize the contact of the waste with water to the extent necessary to meet the Performance Objectives:
  - Promote drainage
  - Minimize infiltration
  - Minimize run on
- Minimize the need for active maintenance during the institutional control period

One of the primary design objectives to ensure compliance with the Performance Objectives is to minimize infiltration (i.e. limit moisture flux through the waste). Therefore this design objective will be an integral part of the long-term strategy for E-Area LLWF closure as previously outlined in sections 3.2.1 to 3.2.6.

E-Area LLWF closure will be conducted in the following three phases: operational closure, interim closure, and final closure. Operational closure will be conducted during the 25 year operational period as disposal units are filled, is specific to each type of disposal unit, and it is primarily intended to minimize infiltration, facilitate operations, promote worker safety, and prepare the facility for interim closure (see Section 4.2). Interim closure will be conducted after disposal operations have ceased, it is specific to each type of disposal unit, and it is primarily intended to minimize infiltration during the 100-year institutional control period and prepare the facility for final closure (see Section 4.3). Final closure of the entire E-Area LLWF will occur at the end of the 100-year institutional control period. Final closure will consist of site preparation and construction of an integrated closure system composed of one or more closure caps installed over all the disposal units and a drainage system (see Section 4.4). The final closure will thus be essentially the same for each disposal unit. Final closure is primarily intended to minimize infiltration during the post-institutional control period and provide an intruder deterrent. Table 3-6 provides an overview of disposal unit characteristics and closure phases.

Because final closure of the E-Area LLWF will not occur for approximately 125 years, a detailed closure design has not been fully developed for the E-Area LLWF. However a closure concept has been developed as described herein, and this proposed closure concept will subsequently be tested in models that simulate its performance as an integral part of the E-Area LLWF PA.

The closure system described in this closure plan has been revised from that assumed in previous revisions of the closure plan and in revision 1 of the PA (McDowell-Boyer et al. 2000) in three primary ways. First, compacted kaolin was previously utilized as the closure cap barrier layer, whereas the current barrier layer as described herein is a geosynthetic clay liner (GCL) (Jones and Phifer 2003). Second an erosion control barrier has been added as an intruder deterrent (Phifer 2004). Third the previous closure sequence included only operational closure and final closure, whereas the current closure sequence described herein includes operational closure, interim closure, and final closure (Phifer 2004).

4.1 Compliance with Performance Objectives and Other Requirements

Each disposal unit at the E-Area LLWF has been designed, is operated and will be closed in accordance with the Performance Objectives set forth in USDOE Order 435.1 (USDOE 1999). The Performance Objectives require that: 1) Dose to representative members of the public shall not exceed 25 mrem in a year total effective dose equivalent from all exposure pathways, excluding the dose from radon and its progeny in air; 2) Dose to representative members of the public via the air pathway shall not exceed 10 mrem in a year total effective dose equivalent, excluding the dose from radon and its progeny; and, 3) Release of radon shall be less than an average flux of 20 pCi/m2/s at the surface of the disposal facility; alternately, a limit of 0.5 pCi/L of air may be applied at the facility boundary. The Order also requires, for purposes of establishing limits on radionuclides that may be disposed near-surface, assessments of impacts to water resources and to hypothetical inadvertent intruders. Closure activities are an important part of the overall waste management system at SRS, and designed to ensure compliance with the Performance Objectives.

4.1.1 All Pathways Dose

As shown in the PA (McDowell-Boyer et al. 2000), the calculated dose from the All Pathways scenario is totally due to contaminant transport by the groundwater pathway. Therefore, the limitation of moisture flux through the waste is necessary to achieve compliance with the All Pathways Dose Performance Objective. The primary aspect of closure that is significant to limiting the moisture flux through the waste is the overall hydraulic properties of the closure systems (i.e. operational closure, interim closure, and final closure). For the final closure cap the hydraulic conductivity and thickness of the barrier layer (i.e. GCL), the hydraulic effectiveness of the lateral drainage layer, and hydraulic effectiveness of the overall E-Area LLWF drainage system are the most significant hydraulic considerations to limiting the moisture flux through the waste. Other factors that will be considered during closure design include:

- the amount of cap overhang
- the durability of the system
- the configuration of the system
- the size of the drains
- the thickness of each layer
- filter design
- anticipated subsidence and necessary methods to minimize
- erosion control

4.1.2 Air Pathway Dose

The only feature of the closure systems that is a factor in the calculation of the air pathway dose is the total thickness of the closure cap. Greater cap thickness results in greater diffusion path length and reduction in air pathway dose.

4.1.3 Radon Flux

The major feature of the closure systems that is a factor in the calculation of the radon flux is the total thickness of the closure cap. Greater cap thickness results in greater diffusion path length and reduction in radon flux.

4.1.4 Other Requirements

4.1.4.1 Groundwater Resource Protection

The closure system features that are significant to the Groundwater Resource Protection requirement are those that help to limit moisture flux through the waste. For the final closure cap the hydraulic conductivity and thickness of the barrier layer (i.e. GCL), the hydraulic effectiveness of the lateral drainage layer, and hydraulic effectiveness of the overall E-Area LLWF drainage system are the most significant hydraulic considerations to limiting the moisture flux through the waste.

4.1.4.2 Intruder Protection

In the case of the LAW Vaults, IL Vaults, and Naval Reactor Component Disposal Pad the vaults themselves and the NR casks provide intruder protection over the time period that they remain structurally stable. They provide a barrier to intrusion for this time period because normal residential construction and well drilling equipment used in the vicinity of the SRS is not capable of penetrating a structurally intact vault or cask (McDowell-Boyer et al. 2000). It is anticipated that the LAW Vaults, IL Vaults, and NR casks will remain structurally stable for 3,100, 1,050, and 8,000 years, respectively.

The Engineered Trenches, Slit Trenches, and CIG Trenches do not have characteristics, which in and of themselves provide a barrier to residential construction and well drilling for an extended time frame. Therefore the closure cap(s) over these disposal units includes an erosion barrier, which maintains a minimum of 3 meters of clean material above the waste. This provides a barrier to excavation into the waste, since is assumed that excavations for residential construction do not exceed 3 meters (McDowell-Boyer et al. 2000), it however is not assumed to provide a barrier to drilling into the waste. While the closure cap(s) over the LAW Vaults, IL Vaults, and Naval Reactor Component Disposal Pad includes the erosion barrier, a minimum 3 meters of clean material above the waste is not necessarily provided due to the extended structural stability of these disposal units. The clean material above the waste can not only provide an intruder deterrent but it also provides shielding from gamma radiation.

4.2 Operational Closure

Operational closure will be conducted during the 25 year operational period as disposal units are filled, is specific to each type of disposal unit, and it is primarily intended to minimize infiltration, facilitate operations, promote worker safety, and prepare the facility for interim closure.

4.2.1 Low-Activity Waste Vault Units

Operational closure of the LAW Vault will be conducted in stages. Individual cells will be closed as they are filled with stacks of containerized waste (metal and/or concrete containers) and the entire vault will be closed after it is filled. Such operational closure includes filling the interior collection trench and sump with grout and sealing cell and/or vault openings with reinforced concrete. The reinforcing steel will be tied into the reinforcing steel of the cell and/or vault itself, forming a unified structure to provide continuous, structurally sound walls to isolate the waste from the environment. Additionally the roof slab is covered with a bonded-in-place layer of fiberboard insulation and a layer of waterproof membrane roofing. (McDowell-Boyer et al. 2000)

4.2.2 Intermediate-Level Vault Units

Operational closure of the IL Vault will be conducted in stages. Equipment, containers, and containerized waste (predominately in drums, B-12 boxes, B-25 boxes, and concrete containers) are placed in the cell in layers in each cell within the reinforced concrete vault. After a layer of waste is placed in a cell, grout will be poured to encapsulate the waste and form a surface for emplacement of the next layer of containers. One cell is used to dispose of tritium crucibles in silos. The tritium crucibles are place in vertical silos and concrete shielding plugs are placed above the filled silos. Individual cells and the silo area will be closed as they are filled with waste by placing a final layer of grout level with the top of the vault walls. After the entire vault has been filled, it will be operationally closed, by installing a 2-foot 3-inch to 3-foot 2 inch permanent reinforced concrete roof slab and overlying bonded-in-place fiberboard insulation and waterproof membrane roofing over the entire vault. The rain covers, shielding tees, and shielding plugs will not longer be required after installation of the permanent roof slab. (McDowell-Boyer et al. 2000)

4.2.3 Engineered Trenches

Operational closure of the Engineered Trenches will be conducted in stages. Metal containers of waste (typically B-25 boxes) are stacked in rows four high (approximately 17 feet high) within the gravel lined Engineered Trench. As a sufficient number of B-25 rows are placed, the stockpiled clean soil is bulldozed in a single lift over some of the completed rows to produce a minimum 4-foot thick clean soil layer over them (i.e. operational soil cover). This operational soil cover is only applied to that portion of the completed rows that still allows maintenance of a safe distance from the working face (i.e. where new boxes are placed in the stack) within the trench. The operational soil cover is graded to provide positive drainage off the trench and away from the working face. Placement of the B-25 boxes continues until the trench is filled with boxes. At that point the minimum 4 feet operational soil cover is placed over the remaining portion of the trench, the entire area is graded to provide positive drainage off the trench, a vegetative cover of shallow rooted grass is established, and it is considered operationally closed. The operational soil cover also provides shielding for operations personnel. (Phifer and Wilhite 2001)

4.2.4 Very-Low-Activity Waste Disposal Trenches (Slit Trenches)

Operational closure of the Slit Trenches will be conducted in stages. Waste placement typically begins at one end of the trench and proceeds toward the other end. Bulk waste is pushed into the trench from one end. Containerized waste and large equipment are typically placed in one end of the trench with a crane. Eventually containerized waste areas of the trench are filled in with either bulk waste or clean soil to fill the voids between adjacent containers and the trench wall. Slit trenches are typically filled to within four feet below the top of the trench with waste and daily cover. Once a section of the slit trench is filled, the stockpiled clean soil is bulldozed in a single lift over that section of trench to produce a minimum 4-foot thick clean soil layer over the waste (i.e. operational soil cover). The operational soil cover is graded to provide positive drainage off and away from the disposal operation. Subsequent trench sections are filled with waste, covered with an operational soil cover, and graded to promote positive drainage until the entire trench is filled and covered. The only mechanical compaction that the soil and waste in the trench receive is from the bulldozer and other heavy equipment moving over the top of a completely backfilled trench. No operational equipment or personnel are allowed in the trench. Once a trench is filled, completely covered with the 4-foot soil cover, and a vegetative cover of shallow rooted grass is established, it is considered operationally closed. The operational soil cover also provides shielding for operations personnel. (McDowell-Boyer et al. 2000; Phifer 2004)

4.2.5 Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches)

Components to be disposed within the CIG Trenches consist of large radioactively contaminated equipment. In order to ensure structural integrity for 300 years after disposal, components are filled with grout or structural foam, determined to be in and of themselves structurally sound for 300 years after burial, or overlaid with a reinforced concrete mat (Jones et al. 2004). During the operational period, trench excavation is conducted on an as needed basis and only that length of trench required for disposal of a particular component(s) is excavated in order to minimize the area of open trench and the time the trench section is open. The bottom of the trench section is filled with 2,000-psi grout to a minimum one-foot, and the grout is allowed to harden sufficiently to support the component(s). The component(s) are then placed on the one-foot base grout layer with a crane and 2,000 psi grout is poured around, between, and over the component(s) in order to encapsulate the component(s). Additional layers of component(s) and grout may be placed on top of previous layers until approximately 16 feet of trench is filled up with component(s) and grout. The operation is conducted so that a minimum one-foot of grout is between the component(s) and the trench bottom and side and so that a minimum one-foot of grout is over the top of the upper most component(s). After the grout has harden sufficiently to support the overburden, the stockpiled clean soil is bulldozed in a single lift over that section of trench to produce a minimum 4-foot thick clean soil layer over the encapsulated components (i.e. operational soil cover). The operational soil cover is graded to provide positive drainage off and away from the CIG Trench. This process continues until the entire trench is filled, completely covered with the 4-foot soil cover, and a vegetative cover of shallow rooted grass is established, at which point the trench is considered operationally closed. The operational soil cover also provides shielding for operations personnel. (McDowell-Boyer et al. 2000)

4.2.6 Naval Reactor Component Disposal Pads

During the operational period naval reactor components contained within the Naval Reactor Waste Shipping/Disposal Casks are placed on the Naval Reactor Component Disposal Pad. The steel casks have thick walls, are closed with a gasket or welds, and are considered watertight. No additional operational closure beyond simply placing the casks on the pad is anticipated due to the watertight nature of the casks. (McDowell-Boyer et al. 2000) However, if radiation shielding is required for personnel protection during the operational or institutional control period, the casks may be surrounded with a structurally suitable material as outlined within Section 4.4.2.1.

4.3 Interim Closure

Interim closure will be conducted after disposal operations have ceased, it is specific to each type of disposal unit, and it is primarily intended to minimize infiltration during the 100-year institutional control period and prepare the facility for final closure. Inadvertent intrusion is not considered feasible during the 100-year institutional control period, due to facility security, therefore provision of a separate intruder deterrent for the interim closure is not required.

No interim closure actions are anticipated beyond that of operational closure during the 100-year institutional control period for the Low-Activity Waste Vaults, Intermediate-Level Vaults, and Naval Reactor Component Disposal Pad other than monitoring and maintenance activities (see Section 4.2). Operational closure for each of these facilities is such that infiltration through the waste is already minimized to the maximum extent practicable.

Subsidence treatment will be performed at the end of the 100-year institutional control period on Engineered Trenches and Very-Low-Activity Waste Disposal Trenches (Slit Trenches), due to the inability of static surcharge and/or dynamic compaction, performed at the end of the operational period, to eliminate the bulk of containerized waste subsidence potential. It will be more effective at that time. At the end of the institutional control period, substantial corrosion of the typical carbon steel containers would have occurred, resulting in a substantial reduction in structural integrity and a subsequent increase in static surcharge and/or dynamic compaction effectiveness. In order to perform static surcharge and/or dynamic compaction at the end of the institutional control period, while at the same time minimizing infiltration, an interim runoff cover will be installed at the end of the operational period. It is not necessary for this cover to be designed in consideration of intruders, since it will be assumed that unauthorized intrusion will be prevented by the institutional control measures. The interim runoff cover will be installed over the Engineered Trenches and Slit Trenches and it will be maintained during the 100-year institutional control period. (Phifer 2004) Additionally the interim runoff cover will also be installed over the Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches), since they are located in close proximity to the Engineered and Slit Trenches, and since the CIG Trenches are not designed in and of themselves to minimize infiltration to the extent practicable. (Phifer 2004) The interim runoff cover will consist of the following:

- Soil added above the operational soil cover and graded to a maximum one percent slope to promote runoff off and away from the disposal units,
- A surface treatment that can be installed at a low cost, has a low installed permeability (<1E-07 cm/s), maximizes runoff (i.e. minimizes infiltration into the disposal units), and can be easily repaired at a low cost, and
- The existing E-Area LLWF drainage system may be improved, as necessary, to accommodate anticipated increases in runoff from the interim runoff cover.

Soil will be added above the operational soil cover and it will be graded to a maximum one percent slope to promote runoff off and away from the disposal units. The thickness of this added soil will vary. The thickness will depend upon the aerial geometry of the disposal unit groupings and the drainage paths. This layer is not intended to act as an infiltration barrier, but it is intended to provide a suitable base for installation of the surface treatment. The surface treatment shall be one that can be installed at a low cost, has a low installed permeability (<1E-07 cm/s), maximizes runoff (i.e. minimizes infiltration into the disposal units), and can be easily repaired at a low cost. Table 4-1 provides a list of potential surface treatments and associated general information relative to permeability, thickness, traffic loads, application, degradation, and repair. An evaluation will be conducted to determine which surface treatment will perform adequately and have the lowest installation and repair costs. The existing E-Area LLWF drainage system may be improved, as necessary, to accommodate anticipated increases in runoff from the interim runoff cover. Improvements may include additional drainage ditches, channels, culverts, and sedimentation basins as necessary. This information on the interim runoff cover provides sufficient information for planning purposes and to evaluate its implementability, but it is not intended to constitute final specifications.

Table 4-1 Potential Interim Runoff Cover Surface Treatments

Material	General Information
Spray-on asphalt material: • Cutback asphalt • Emulsified asphalt • Polymer-modified asphalt (e.g. styrene-butadiene)	• Low permeability (<1.0E-07 cm/s) • 10s to 100s mils thick surface treatment • Does not support traffic loads • Spray on application • Degradation by asphalt aging and shrinkage • Spray on repair
Shotcrete (spray-on concrete): • Polypropylene fiber reinforced • Silica-fume • Polymer-modified (e.g. styrene-butadiene, acrylic polymer latexes, epoxy resins) • Combination	• Low permeability (<1.0E-07 cm/s) • Approximately inch thick surface treatment • Might support moderate traffic loads • Pneumatic spray-on application • Shrinkage cracking • Pneumatic spray-on repair
Spray-on elastomeric/polymer material: • Furan • Polysiloxane • Polyurea * • Polyurethane * • Resins (epoxy and polyester) * • Vinylester Styrene * These are thought to be the most promising spray-on elastomeric/polymer materials	• Low permeability (<1.0E-07 cm/s) • 10s to 100s mils thick surface treatment • Does not support traffic loads • Spray on application • Potential ozone and ultraviolet light (UV) degradation • Spray on repair
Geotextile impregnated with spray-on asphalt material: • Cutback asphalt • Emulsified asphalt • Polymer-modified asphalt (e.g. styrene-butadiene)	• Low permeability (<1.0E-07 cm/s) • 10s to 100s mils thick surface treatment • Does not support traffic loads (higher tensile strength than spray-on asphalt material alone) • Spray on application • Degradation by asphalt aging and shrinkage (less susceptible to shrinkage than spray-on asphalt material alone) • Repair by replacing geotextile and spraying on asphalt material
Geotextile impregnated with sprayed-on elastomeric/polymer material: • Furan • Polysiloxane • Polyurea * • Polyurethane * • Resins (epoxy and polyester) * • Vinylester Styrene * These are thought to be the most promising spray-on elastomeric/polymer materials	• Low permeability (<1.0E-07 cm/s) • 10s to 100s mils thick surface treatment • Does not support traffic loads • Spray on application • Potential ozone and ultraviolet light (UV) degradation • Spray on repair

Table 4-1 Potential Interim Runoff Cover Surface Treatments (continued)

Material	General Information
Geomembranes: • PVC (polyvinyl chloride) • HDPE (high density polyethylene) • LDPE (low density polyethylene) • Hypalon (chlorosulfonated polyethylene (CSPE))	• Low permeability (essentially only vapor permeability except through installation defects) • 10s to 100s mils thick sheeting • Does not support traffic loads • Installation by unrolling, anchoring, and seaming • Potential ozone and ultraviolet light (UV) degradation • Repair by replacing failed sections and seaming to existing
Mixed-In-Place (road mix) with Fog Seal (asphalt based)	• Low permeability (<1.0E-07 cm/s) • Inches thick surface treatment • Supports low traffic loads • Conventional paving equipment installation • Degradation by asphalt aging and shrinkage • Spray on repair for minor repairs and conventional paving repair for major repairs
Slurry Seal (asphalt based)	• Low permeability (<1.0E-07 cm/s) • Inches thick surface treatment • Supports low traffic loads • Conventional paving equipment installation • Degradation by asphalt aging and shrinkage • Spray on repair for minor repairs and conventional paving repair for major repairs
Asphalt pavement: • Low air void, high-asphalt-content, hot-mix asphalt concrete (HMAC) • MatCON^{TM} (Modifed Asphalt Technology for Waste Containment)	• Low permeability (<1.0E-07 cm/s) • Inches thick surface treatment • Supports traffic loads • Conventional paving equipment installation • Degradation by asphalt aging and shrinkage • Conventional paving repair
Roller-compacted concrete (RCC)	• Low permeability (<1.0E-07 cm/s) • Inches thick surface treatment • Supports moderate traffic loads • Conventional paving equipment and roller compaction • Construction joints / shrinkage cracking • Conventional paving with roller compaction repair
Lime/fly ash	• Low permeability (<1.0E-07 cm/s) • Approximately inch thick surface treatment • Might support moderate traffic loads • Conventional paving equipment installation • Shrinkage cracking (less so than with concrete) • Conventional paving repair

Table 4-1 Potential Interim Runoff Cover Surface Treatments (continued)

Material	General Information
Poured in placed reinforced concrete	• Low permeability (<1.0E-07 cm/s) • Inches thick surface treatment • Supports traffic loads • Conventional reinforced concrete construction (i.e. form, rebar/wire fabric, pour, construction joints) • Construction joints / shrinkage cracking • Conventional reinforce concrete repair
Grout	• Low permeability (<1.0E-07 cm/s) • Inches thick surface treatment • Might support moderate traffic loads • Pour and level (joints could be a concern) • Shrinkage cracking • Repour in area of repair
Flowable fill or Controlled Low Strength Material (CLSM)	• Moderate permeability • Inches thick surface treatment • Might support moderate traffic loads • Pour and level (joints could be a concern) • Shrinkage cracking (not as great a concern as for concrete) • Repour in area of repair

NOTES:
The following materials were deemed to be unsuitable for use as a temporary runoff cover due to erosive potential, potential desiccation damage, high hydraulic conductivity, etc.: acrylate gel, acrylic, colloidal silica gel, controlled compacted clay, geosynthetic clay layer, lignin gel, montan wax, paper mill sludge, sodium silicate gel, soil cement, and sulfur polymer cement.

References:
ACI-Int 2004; ASA 2004; AEMA 2004; AI 2004; ASTM 2001; ASTM 2002; Daniel and Estornell 1990; Frye-O'Bryant et al. 1993; Freeman et al. 1994; ISSA 2004; Koerner 1990; LBI 2004; PCI 2004; PCA 2004 ; Rumer and Ryan 1995; Rumer and Mitchell 1995; USACE 1993; USACE 1994; USACE 1995; USACE 2000; USEPA 2003; USDOE, DuPont, and USEPA 1997; WEC 1985

4.4 Final Closure

Final closure of the entire E-Area LLWF will occur at the end of the 100-year institutional control period. Final closure will consist of site preparation and construction of an integrated closure system composed of one or more closure caps installed over all the disposal units and a drainage system. The final closure will thus be essentially the same for each disposal unit. Final closure is primarily intended to minimize infiltration during the post-institutional control period and provide an intruder deterrent. Final closure will take into account the waste types and forms, unit location, disposition of non-disposal structures and utilities, site hydrogeology, potential exposure scenarios, and lessons learned implementing closure systems at other SRS facilities. An Independent Professional Engineer will be retained by SRS to certify that the E-Area LLWF final closure system has been constructed in accordance with the approved closure plan and the final plans and specifications at the time of final closure. A disposal facility layout is provided in Figure 2-2.

4.4.1 Final Closure System Conceptual Design

The E-Area LLWF final closure, integrated closure system will be constructed over the entire facility at the end of its operational life. The integrated closure system will consist of one or more closure caps installed over all the disposal units and a drainage system. The final closure cap described in this closure plan has been revised from that assumed in revision 1 of the closure plan and in revision 1 of the PA (McDowell-Boyer et al. 2000) in the following ways:

- Compacted kaolin was previously utilized as the closure cap barrier layer, whereas the current barrier layer as described herein is a geosynthetic clay liner (GCL) (Jones and Phifer 2003).
- An erosion control barrier has been added to maintain a minimum 3 meters of clean material above the waste within Engineered Trenches, Slit Trenches, and CIG Trenches to prevent inadvertent excavation into the waste (Phifer 2004).

The type of GCL outlined within this closure plan is one that consists of “bentonite sandwiched between two geotextiles” (USEPA 2001). The following is the definition of a Geotextile GCL as defined by the Environmental Protection Agency (USEPA 2001):

> A Geotextile GCL “is a relatively thin layer of processed” bentonite … “fixed between two sheets of geotextile. … A geotextile is a woven or nonwoven sheet material … resistant to penetration.” … “Adhesives, stitchbonding, needlepunching, or a combination of the three” are used to affix the bentonite to the geotextile. “Although stitchbonding and needlepunching create small holes in the geotextile, these holes are sealed when the installed GCL’s clay layer hydrates.”

The following are some of the typical advantages of a Geotextile GCL over compacted clay layers, which led to the replacement of the compacted kaolin with a GCL:

Faster and easier to install (USEPA 2001), the GCL is installed dry (unrolled like a carpet), whereas compacted kaolin must be installed wet of optimum in multiple lifts.

- Lower hydraulic conductivity (i.e. $< 5.0\times10^{-9}$ for a GCL versus $< 1.0\times10^{-7}$ for a compacted clay layer) (USEPA 2001)
- Ability to self-heal rips or holes (USEPA 2001)
- Cost-effective (USEPA 2001)
- Not as thick (USEPA 2001)
- Less negative impact “due to differential settlement, freezing-thawing cycles, and wetting-drying cycles” (Rumer and Mitchell, 1995)
- The bulk of the required Quality Assurance / Quality Control (QA/QC) associated with a GCL is factory based whereas that of compacted kaolin is entirely field based. Factory based QA/QC generally provides a higher degree of QA/QC, and it is included in the cost of the material. (Phifer 1991; GSE 2002).

Within revision 2 of the closure plan the previous closure cap, kaolin hydraulic barrier layer was replaced with a GCL. The equivalence, in term of minimizing infiltration, of an equivalent GCL closure cap to the previous kaolin closure cap has been evaluated utilizing the Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994; USEPA 1994a). To demonstrate equivalence, the two and a half foot thick kaolin layer (Figure A-1) was replaced with a 0.2 inch thick GCL and backfill was added to make up the difference in thickness. No other changes were made in order to have a direct comparison between the kaolin and GCL. The HELP model estimate for the average annual percolation out the bottom of the previous kaolin closure cap was 0.0177 m/year (i.e. amount of water reaching the top of the operationally/interimly closed disposal unit). Whereas the HELP model estimate for the average annual percolation out the bottom of an equivalent GCL closure cap was 0.006 m/year. The percolation out an equivalent GCL closure cap was estimated to be approximately a third of that estimated for the previous kaolin closure cap, thus demonstrating that an equivalent GCL closure cap is equivalent to or better than the previous kaolin closure cap.

The erosion barrier will consist of a one foot thick layer of 2-inch to 6-inch granite stone that has been filled with a Controlled Low Strength Material (CLSM) or Flowable Fill. This erosion barrier has been designed to handle the maximum precipitation event for a 10,000-year return period. (Phifer and Nelson 2003)

These changes to the E-Area final closure cap result in the revised E-Area LLWF final closure cap configuration shown in Figure 4-1.

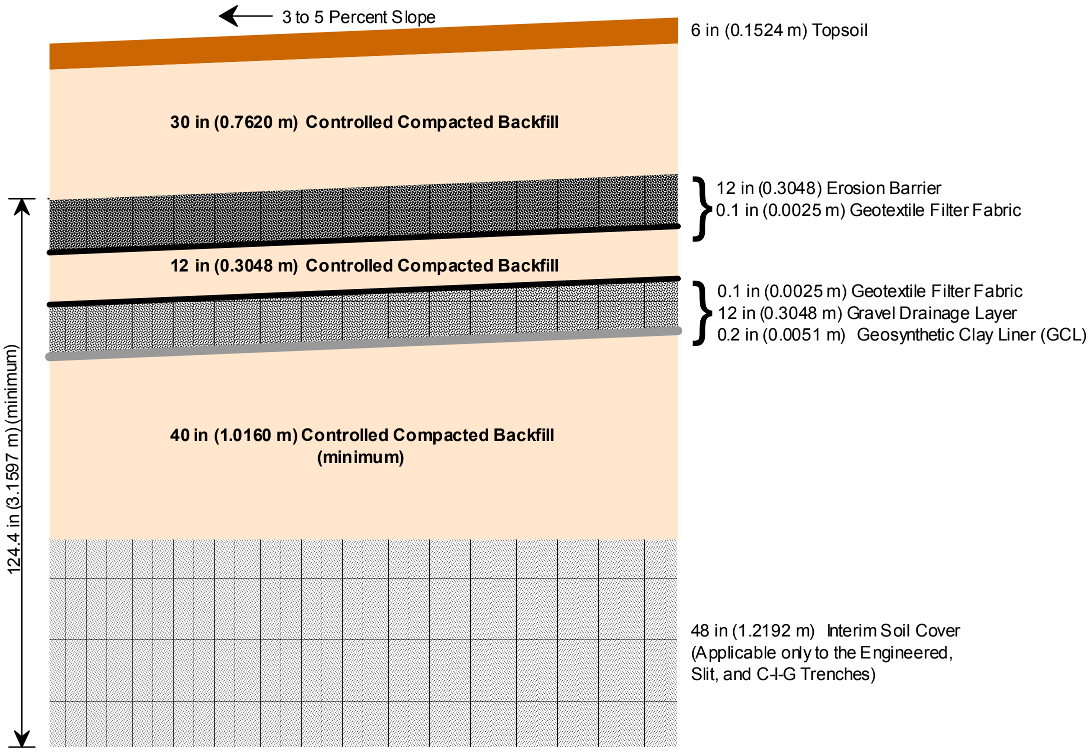


Figure 4-1 Revised E-Area LLWF Final Closure Cap Configuration (Phifer 2004)

4.4.2 Final Closure System Installation

4.4.2.1 Site Preparation

Final closure will consist of site preparation of the operationally/interim closed disposal units and construction of an integrated closure system composed of one or more closure caps installed over all the disposal units and a drainage system (see Figure 2-2).

Discussions of the estimated subsidence potential and estimated subsidence time frames for each type of disposal unit were included in Sections 3.2.1 through 3.2.6, and Table 3-6, which provided an overview of disposal unit characteristics and closure phases, also included subsidence information. A summary of this information specific to subsidence is provided in Table 4-1 along with the potential subsidence treatments that will be considered. As indicated in Table 4-1, there are no subsidence treatments that are currently anticipated for the LAW Vaults, IL Vaults, and Components-In-Grout Trenches. In particular dynamic compaction will not be conducted over these three types of disposal units.

Table 4-2 Potential Subsidence Treatments

Disposal Unit	Estimated Subsidence Potential	Estimated Subsidence Time Frame	Potential Subsidence Treatment Beyond that of Interim/Operational Closure
LAW Vaults	10 ft [1]	3,100 years after final closure [1]	None anticipated
IL Vaults	Not estimated (less than that of LAW Vaults)	1,050 years after final closure [1]	None anticipated
Engineered Trenches	13.5 ft [2]	Subsidence treatment assumed to eliminate subsidence potential [4]	Static surcharging and/or dynamic compaction
Slit Trenches	Not estimated (variable up to 13.5 ft [3])	Subsidence treatment assumed to eliminate subsidence potential [5]	Static surcharging and/or dynamic compaction
Components-In-Grout Trenches	Not estimated (variable)	300 years after operational closure [1]	None anticipated; dynamic compaction will not be performed
Naval Reactor Component Disposal Pads	Not estimated	8,000 years after placement on pad [6]	Fill space around, between, and over the casks with structurally suitable material

NOTES:

[1] McDowell-Boyer et al. 2000

[2] Phifer and Wilhite 2001

[3] Phifer 2004

[4] Without subsidence treatment, it has been estimated that subsidence will occur 200 to 300 years after burial for the Engineered Trench containerized waste (Phifer and Wilhite 2001; Jones and Phifer 2002)

[5] Without subsidence treatment, it has been estimated that subsidence will occur 200 to 300 years after burial for the Slit Trench containerized waste and within the 100-year institutional control period for Slit Trench bulk wastes (Phifer and Wilhite 2001; Jones and Phifer 2002; Phifer 2004)

[6] McDowell-Boyer et al. 2000 (The casks are assumed to have an initial thickness of 35 cm, corrode at a rate of 4E-03 cm/yr, and structurally fail after corrosion has reduced the wall thickness to 3 cm)

Dynamic compaction will not be performed over any portion of a disposal unit containing ETF Carbon Columns.

It has been estimated that an Engineered Trench, containing B-25 boxes of waste stacked four high, has a subsidence potential of approximately 13.5 feet (Phifer and Wilhite 2001; Phifer 2004). It has also been estimated that B-25 boxes that have not been dynamically compacted will structurally collapse 200 to 300 years after burial due to corrosion resulting in the failure of any cover or cap over the Engineered Trench. (Phifer and Wilhite 2001; Jones and Phifer 2002) It has been further estimated that dynamic compaction of an Engineered Trench containing B-25 boxes at the end of the operational period would at best reduce the subsidence potential by 50 percent. However the efficiency of subsidence treatment increases with time due to B-25 box corrosion and subsequent loss of strength. Therefore rather than performing subsidence treatment (i.e. static surcharging and/or dynamic compaction) of the Engineered Trenches at the end of the operational period it will be performed at the end of the 100-year institutional control period, when its efficiency will be greater. With performance of the subsidence treatment at the end of the 100-year institutional control period, it is assumed that essentially all subsidence potential will be eliminated and that the Engineered Trenches will be stable thereafter. (Phifer 2004) Additional work is currently in progress to better estimate the anticipated time period of B-25 box structural collapse following burial and the optimal time to perform subsidence treatment to achieve the greatest efficiency and minimize institutional control maintenance costs. The use of static surcharging, prior to installation of the interim runoff cover over Engineered Trenches, may be considered in order to minimize closure cap maintenance during the 100-year institutional control period. Such static surcharging may eliminate voids between containers, which could potentially cause subsidence during the institutional control period.

The subsidence potential of Slit Trenches has not been estimated to the extent performed for Engineered Trenches. However, the subsidence potential and estimated time of subsidence for those portions of Slit Trenches that receive containerized waste should be similar to that of Engineered Trenches. That is these portions of Slit Trenches should have a maximum subsidence potential of 13.5 feet and subsidence is expected to occur within 200 to 300 years after burial due to container corrosion (based upon B-25 box corrosion). Portions of Slit Trenches that receive bulk waste should have substantially less subsidence potential than this and it is anticipated that such subsidence would occur within the 100-year institutional control period. As with Engineered Trenches, subsidence treatment of Slit Trenches is currently planned at the end of the 100-year institutional control period. At this time greater treatment efficiency is anticipated for those portions of the trenches, which contain metal containers, due to container corrosion. (Phifer and Wilhite 2001; Jones and Phifer 2002; Phifer 2004) There is probably little difference in subsidence treatment efficiency for those portions of Slit Trenches containing bulk waste regardless of whether the treatment is performed at the end of the operational period or at the end of the 100-year institutional control period. Therefore if some benefit is derived from performing subsidence treatment on those portions of Slit Trenches containing bulk waste at the end of the operational period, it could be performed at that time. However it is currently assumed that subsidence treatment is performed on all of the Slit Trenches or at the end of the 100-year institutional control period.

Static surcharging is the placement of a thick soil cover (tens of feet) to consolidate the underlying materials over a long period of time (months). A 25-foot thick soil cover with a wet bulk density of 100 lbs/ft^3 would result in a static load of 2,500 lbs/ft^2.

Dynamic compaction is the controlled application of dynamic stresses to the ground surface and/or waste layers by the systematic dropping of heavy weights in a predetermined grid pattern in order to improve the structural stability of the soil and/or waste layers. Weights up to 35 tons and 8 feet in diameter are dropped from a height of up to 100 feet with specially built compactors that have single-line hoists to minimize friction losses (i.e. up to 90 percent of free fall energy). This produces impact energies of up to 60 ton-ft/ft^2. The weight is dropped repetitively in each location of a predetermined grid pattern, resulting in 50 to 100 percent of the area being impacted typically. Typically compaction in each location continues until a predetermined number of drops, crater depth, or displacement between drops is achieved. Dynamic compaction depth of influence and overall compaction effectiveness increases with greater applied energy, greater area of impact, and a reduction in the displacement between drops. That is dropping a larger weight from a greater height on more of the area until a minimum displacement (a fraction of a foot) between drops is achieved results in the greatest compaction effectiveness. Dynamic compaction of the Engineered Trenches and Slit Trenches will include the use of a sufficient thickness of clean soil over the waste to preclude intrusion into the waste zone, which could result in airborne contamination. Additionally the maximization of compaction effectiveness should be balanced against the potential for intrusion into the waste zone and potential vibratory impacts on surrounding structures such as the LAW Vaults, IL Vaults, CIG Trenches, inter-area transfer line, steam lines, TRU pads, existing closure caps, etc. (Phifer 1991; Dendler 1993; TerraSystems 1999; Phifer and Serrato 2000)

Static surcharging applies much less static energy than dynamic compaction applies impact energy, therefore dynamic compaction is typically a much more effective subsidence treatment method. Dynamic compaction has been applied to both Slit Trenches and Engineered Trenches at SRS, whereas static surcharging has only been applied to Engineered Trenches (Phifer 1991; Phifer and Serrato 2000). Static surcharging may eliminate voids between containers, but it is not likely to crush typical containers and thereby eliminate voids within containers. Dynamic compaction is considered the most applicable subsidence treatment method for both the Engineered and Slit Trenches.

While structural stability of the Naval Reactor Waste Disposal Casks is expected to last for 8,000 years after final closure, the void space between casks must be appropriately filled with a structurally suitable material in order to support the closure cap and not produce differential subsidence. Due to the proximity of casks to each other typical heavy equipment used for soil compaction will not be able to be utilized to fill the void space between casks with compacted soil layers. This void space between casks may be appropriately filled by one of the following methods:

- Filling the void space between casks with Controlled Low-Strength Material (CLSM) or Flowable Fill
- The use of hand operated compaction equipment to fill up the void space between casks with compacted soil layers,
- Filling the void space between casks with granite aggregate or quartz sand,
- Filling the void space between casks with on site soils followed by a static surcharging, and/or
- Filling the void space between casks with on site soils and allowing sufficient time for the soil to self-compact. This might be performed in multiple lifts where each lift is allowed to self-compact prior to application of subsequent lifts. This might also have to be performed sufficiently prior to the end of the 100-year Institutional Control Period so that the soil is stable at the time of final closure cap installation.

The method most appropriate to filling the void space between casks at the lowest cost that achieves structural stability for closure cap installation will be determined.

The existing soils and interim runoff cover over which the closure cap will be constructed must be prepared prior to closure cap construction. The top 0.08 to 0.15 m (3 to 6 inches) of existing soils in these areas will be removed in order to remove any topsoil and vegetation present. The interim runoff cover will be removed as necessary to allow the underlying soil to be prepared for closure cap construction. These areas will then be rough graded to establish a base elevation for the closure cap. Finally these areas will be compacted with a vibratory roller, particularly the areas with interim soil covers, which have not been previously compacted. No such preparation will be required over the LAW Vaults, IL Vaults, or Naval Reactor Component Disposal Pads, since neither soil nor the interim runoff cover will exist over these facilities. Areas adjacent to these disposal units may require this preparation.

4.4.2.2 Final Closure Cap Construction

This section on closure cap construction provides sufficient information for planning purposes and to evaluate the constructibility of the conceptual closure system described herein, but it is not intended to constitute final design (i.e. final plans and specifications). Future revisions of the closure plan will describe the recommended tests to be performed during closure cap construction in order to provide appropriate Quality Assurance / Quality Control (QA/QC). Such tests will be included in the final project plans and specifications when prepared. The final plans and specification will include provisions for protecting the integrity of the E-Area LLWF closure cap during construction and protection of the existing closure caps adjacent to the E-Area LLWF.

The closure cap, installed above each operationally/interimly closed disposal unit, will consist of the layers outlined in Table 4-3 from top to bottom (also see Figure 4-1). Table 4-3 also includes the minimum thickness of each layer and its anticipated saturated hydraulic conductivity.

Table 4-3 Closure Cap Layers from Top to Bottom (Phifer 2004)

Layer	Minimum Layer Thickness (inches)	Saturated Hydraulic Conductivity (cm/s)
Topsoil	6	1.00E-03 [2, 5]
Upper Backfill	30	1.00E-04 [2, 5]
Erosion Barrier	12	3.97E-04 [3, 5]
Geotextile Filter Fabric	~0.1	1.00E-01 [4, 6]
Middle Backfill	12	1.00E-04 [2, 5]
Geotextile Filter Fabric	~0.1	1.00E-01 [4, 6]
Drainage Layer	12	1.00E-01 [2, 6]
GCL	~0.2 [1]	5.00E-09 [4, 7]
Lower Backfill	40 (minimum)	1.00E-04 [2, 5]

NOTES:

[1] USEPA 2001

[2] WSRC 2002

[3] Phifer and Nelson 2003

[4] GSE 2002

[5] The saturated hydraulic conductivity for these layers has been estimated for modeling purposes. It is neither a minimum nor maximum.

[6] The saturated hydraulic conductivity for these layers is a minimum allowable.

[7] The saturated hydraulic conductivity for this layer is a maximum allowable.

The following are additional generic closure cap design details:

- The top surface of the closure cap will be sloped between three to five percent to promote run-off and minimize erosion.
- The side slope of the closure cap will be at a maximum 3 horizontal to 1 vertical (3:1 or 19.5 degrees) to promote slope stability.
- The closure cap will be constructed to have minimal impact on area operations and infrastructure.

The lower backfill is controlled compacted backfill that will be utilized to create the required contours and provide structural support for the rest of the overlying closure cap. It will be used to produce the 3 to 5 percent top slopes and the maximum 3:1 side slopes of the closure cap. Therefore the thickness of this lower backfill layer will vary, but in all cases it will have a minimum thickness of 3.3-ft (40 inches) over all disposal units. The maximum thickness will depend upon the closure cap aerial geometry and the drainage paths. This layer is not intended to act as an infiltration barrier, but it is intended to provide a suitable base for installation of the GCL. It will be placed in a manner that prevents or minimizes possible contamination. The lower backfill soils will be obtained from on-site sources. Only on-site soil classified as SC or CL (clayey sands or sandy clays with low plasticity) shall be used. Borrow areas will be pre-qualified prior to use. The lower backfill shall be placed in lifts not to exceed 9 inches in uncompacted thickness in areas where hand-operated mechanical compaction equipment is used and not to exceed 12 inches in uncompacted thickness in areas where self-propelled or towed mechanical compaction equipment is used. Each lift shall be compacted to at least 90% of the maximum dry density per the Modified Proctor Density Test (ASTM D1557 [ASTM 1992a]) or 95% per the Standard Proctor Density Test (ASTM D698 [ASTM 1992]). Each lift shall also be placed within specified tolerances of the optimum moisture content. If the surface of a lift is smooth drum rolled for protection prior to placement of a subsequent lift, that lift will be scarified prior to placement of the subsequent lift to ensure proper bonding between lifts. The top lift, upon which the GCL will be placed, shall be proof-rolled with a smooth drum roller to produce a surface satisfactory for placement of the GCL. All work in association with the lower backfill shall be performed in accordance to the approved plans and specifications.

The GCL is the sole hydraulic barrier layer for the closure cap. The GCL shall have a maximum through plane saturated hydraulic conductivity of 5.0×10^{-9} cm/s. The GCL shall be obtained from the manufacturer in rolls, which are on the order of 15 ft wide by 150 ft long. The GCL rolls shall be stored flat and kept dry. The GCL shall be placed directly on top of the lower backfill, which would have been appropriately contoured and smooth drum rolled. Placement of the rolls of GCL shall consist of unrolling the GCL roll per the manufacturer's directions directly onto the surface of the controlled compacted backfill, producing a GCL panel. The GCL shall not be placed during periods of precipitation or under other conditions that could cause the bentonite to hydrate prematurely (i.e. prior to placement of 1 foot of sand on top of it). GCL panels shall be overlapped a minimum 6 inches on panel edges and a minimum of 1 ft on panel ends. The minimum overlap shall consist of bentonite containing portions of the GCL overlapping from each panel. The geotextile only portions of the GCL shall not be included in the minimum overlap. Loose granular bentonite shall be placed between overlapping panels at a rate of 1.8 kg per linear meter (¼ pound per linear foot). The GCL shall be inspected for rips, tears, displacement, and premature hydration prior to placement of the sand on top of it. Any rips, tears, displacement, and premature hydration shall be repaired per the manufacturer's directions prior to placement of the sand on top of it. The overlying 1 foot coarse sand drainage layer shall be placed in a single lift on top of the GCL per the manufacturer's directions in order to avoiding damaging the GCL. No equipment used to place the sand shall come into direct contact with the GCL. At the end of each working day, the uncovered edge of the GCL (i.e. that portion that does not have the sand on it) shall be protected with a waterproof sheet that is secured adequately with ballast to avoid premature hydration. All work in association with placement of the GCL shall be performed in accordance to the approved plans and specifications (USEPA 2001; GSE 2002).

The coarse sand drainage layer will be placed on top of the GCL to form a lateral drainage layer and to provide the necessary confining pressures to allow the GCL to hydrate appropriately. The coarse sand drainage layer will be hydraulically connected to the overall facility drainage system in order to divert and transport as much infiltrating water as possible through the coarse sand drainage layer to the facility drainage system and away from the underlying disposal units. Computer simulations of flow through the cover, conducted for the PA (McDowell-Boyer et al. 2000) show that the coarse sand drainage layer will carry away a major portion of the water that is assumed to normally infiltrate past the evapotranspiration zone of the closure cap at the E-Area LLWF (40 cm/yr). The coarse sand shall consist of material with a hydraulic conductivity of at least of 1×10^{-1} cm/sec and it shall be free of any materials deleterious to either the underlying GCL or overlying geotextile. The coarse sand drainage layer shall be placed in a single 1 foot lift on top of the GCL per the GCL manufacturer's directions in order to avoiding damaging the GCL. The sand layer will be fine graded to the required contours. No equipment used to place the sand shall come into direct contact with the GCL; the equipment used to place and fine grade the sand shall be low ground pressure equipment that is driven on top of the previously placed 1 foot thick sand layer. No compactive effort shall be applied to the sand layer other than that provided by the equipment used to place and fine grade it. All work in association with placement of the sand drainage layer shall be performed in accordance to the approved plans and specifications.

An appropriate geotextile filter fabric shall be placed on top of the coarse sand drainage layer to provide filtration between the sand and the overlying middle backfill. Koerner (1990) defines filtration with a geotextile as:

> "The equilibrium fabric-to-soil system that allows for free liquid flow (but no soil loss) across the plane of the fabric over an indefinitely long period of time."

The geotextile filter fabric shall have a minimum thickness of 0.1 in, a minimum through plane saturated hydraulic conductivity of 0.1 cm/s, and an apparent opening size small enough to appropriately filter the overlaying backfill. The geotextile shall be obtained from the manufacturer in rolls, which are on the order of 15 ft wide by 300 ft long or greater. The geotextile rolls shall be stored flat, kept dry, protected from ultraviolet light exposure. The geotextile shall be placed directly on top of the coarse sand drainage layer, which would have been appropriately contoured and determined to be free of materials deleterious to the geotextile. Placement of the rolls of geotextile shall consist of unrolling the geotextile roll down slope per the manufacturer's directions directly onto the surface of the sand, producing a geotextile panel. Adjacent geotextile panels shall be seamed using heat seaming or stitching methods per the manufacturer's directions. The in place geotextile panels shall be held down with sandbags or approved equivalent until replaced with the overlying middle backfill to prevent the geotextile from being blown out of place. The in place geotextile panels shall not be exposed to direct sun light for more than 7 days prior to placement of the overlying middle backfill. The in place geotextile shall be inspected for rips, tears, wrinkling, and displacement prior to placement of the middle backfill on top of it. Any rips, tears, wrinkling, and displacement shall be repaired per the manufacturer's directions prior to placement of the middle backfill on top of it. The initial loose lift of the overlying middle backfill shall be placed in a single lift on top of the geotextile per the manufacturer's directions in order to avoiding damaging the geotextile. No equipment used to place the backfill shall come into direct contact with the geotextile. The feet of any compaction equipment used on the backfill shall be sized so that compaction of the backfill does not damage the geotextile. All work in association with placement of the geotextile shall be performed in accordance to the approved plans and specifications. (Koerner 1990; GSE 2002)

The middle backfill will be a 1-ft thick layer used to store water for evapotranspiration. The middle backfill soils will be obtained from on-site sources. Only on-site soil classified as SC or CL (clayey sands or sandy clays with low plasticity) shall be used. Borrow areas will be pre-qualified prior to use. The initial loose lift of the middle backfill shall be placed in a single lift on top of the geotextile per the manufacturer's directions in order to avoiding damaging the geotextile. No equipment used to place the backfill shall come into direct contact with the geotextile. It shall be driven only on top of previously placed backfill. The feet of any compaction equipment used on the backfill shall be sized so that compaction of the backfill does not damage the geotextile. The middle backfill shall be placed in lifts not to exceed 9 inches in uncompacted thickness in areas where hand-operated mechanical compaction equipment is used and not to exceed 12 inches in uncompacted thickness in areas where self-propelled or towed mechanical compaction equipment is used. Each lift shall be compacted to at least 85% of the maximum dry density per the Modified Proctor Density Test (ASTM D1557 [ASTM 1992a]) or 90% per the Standard Proctor Density Test (ASTM D698 [ASTM 1992]). Each lift shall also be placed within specified tolerances of the optimum moisture content. If the surface of a lift is smooth drum rolled for protection prior to placement of a subsequent lift, that lift will be scarified prior to placement of the subsequent lift to ensure proper bonding between lifts. The backfill will be fine graded to the required contours. All work in association with the controlled compacted backfill shall be performed in accordance to the approved plans and specifications.

An appropriate geotextile shall be placed on top of the middle backfill and below the erosion barrier to provide filtration between the middle backfill and the overlying erosion barrier and to prevent soil piping of the middle backfill. The geotextile shall have a minimum thickness of 0.1 in and an apparent opening size small enough to appropriately filter the middle backfill and prevent it from migrating through the overlying erosion barrier. The geotextile shall be obtained from the manufacturer in rolls, which are on the order of 15 ft wide by 300 ft long or greater. The geotextile rolls shall be stored flat, kept dry, protected from ultraviolet light exposure. The geotextile shall be placed directly on top of the middle, which would have been appropriately contoured and determined to be free of materials deleterious to the geotextile. Placement of the rolls of geotextile shall consist of unrolling the geotextile roll down slope per the manufacturer's directions directly onto the surface of the middle, producing a geotextile panel. Adjacent geotextile panels shall be seamed using heat seaming or stitching methods per the manufacturer's directions. The in place geotextile panels shall be held down with sandbags or approved equivalent until replaced with the overlying erosion barrier to prevent the geotextile from being blown out of place. The in place geotextile panels shall not be exposed to direct sun light for more than 7 days prior to placement of the overlying erosion barrier. The in place geotextile shall be inspected for rips, tears, wrinkling, and displacement prior to placement of the erosion barrier on top of it. Any rips, tears, wrinkling, and displacement shall be repaired per the manufacturer's directions prior to placement of the erosion barrier on top of it. The overlying erosion barrier shall be placed in a single lift on top of the geotextile per the manufacturer's directions in order to avoiding damaging the geotextile. No equipment used to place the erosion barrier shall come into direct contact with the geotextile. All work in association with placement of the geotextile shall be performed in accordance to the approved plans and specifications. (Koerner 1990; GSE 2002)

The erosion barrier will be placed on top of the middle backfill and overlying geotextile to form a barrier to erosion and to provide minimal water storage for evapotranspiration. The erosion barrier has been sized based upon the maximum precipitation event for a 10,000-year return period. The maximum precipitation event for a 10,000-year return period is 3.3 inches over a 15-minute accumulation period (Table XIX from Weber et al. 1998). Based upon this precipitation event a one foot thick layer of 2-inch to 6-inch granite stone with a d_{50} (i.e. median size) of 4 inches has been selected for use as the erosion barrier (sizing based upon Logan 1977; Goldman et al. 1986; NCSU 1991). In order to prevent the loss of overlying material into the erosion barrier and to reduce the saturated hydraulic conductivity of the erosion barrier layer, the granite stone will be filled with a Controlled Low Strength Material (CLSM) or Flowable Fill. (Phifer and Nelson 2003) The granite stone shall be free of any materials deleterious to the underlying geotextile. The granite stone shall be placed in a single 1-foot lift on top of the geotextile. No equipment used to place the stone shall come into direct contact with the underlying geotextile; the equipment used to place the stone shall be low ground pressure equipment that is driven on top of the previously placed 1 foot thick stone. No compactive effort shall be applied to the stone other than that provided by the equipment used to place it. After placement of the stone CLSM or Flowable Fill shall be applied on top of the stone in a manner that allows the CLSM or Flowable Fill to penetrate into all the voids within the stone layer. Alternate methods of erosion barrier placement similar to the placement of roller-compacted concrete shall be considered. All work in association with placement of the erosion barrier shall be performed in accordance to the approved plans and specifications.

The upper backfill will be a 2.5-ft thick layer used to bring the elevation of the closure cap up to that necessary for placement of the topsoil. The upper backfill will also store water for evapotranspiration. The upper backfill soils will be obtained from on-site sources. Only on-site soil classified as SC or CL (clayey sands or sandy clays with low plasticity) shall be used. Borrow areas will be pre-qualified prior to use. The initial loose lift of the upper backfill shall be placed in a single lift on top of the erosion control barrier in order to avoiding damaging the erosion control barrier. No equipment used to place the upper backfill shall come into direct contact with the erosion control barrier. It shall be driven only on top of previously placed backfill. The feet of any compaction equipment used on the backfill shall be sized so that during compaction of the backfill the feet do not directly run on the erosion control barrier. The upper backfill shall be placed in lifts not to exceed 9 inches in uncompacted thickness in areas where hand-operated mechanical compaction equipment is used and not to exceed 12 inches in uncompacted thickness in areas where self-propelled or towed mechanical compaction equipment is used. Each lift shall be compacted to at least 85% of the maximum dry density per the Modified Proctor Density Test (ASTM D1557 [ASTM 1992a]) or 90% per the Standard Proctor Density Test (ASTM D698 [ASTM 1992]). Each lift shall also be placed within specified tolerances of the optimum moisture content. If the surface of a lift is smooth drum rolled for protection prior to placement of a subsequent lift, that lift will be scarified prior to placement of the subsequent lift to ensure proper bonding between lifts. The upper backfill will be fine graded to the required contours. All work in association with the upper backfill shall be performed in accordance to the approved plans and specifications.

The upper most soil layer of the closure cap shall consist of soils capable of supporting a vegetative cover (i.e. topsoil). The topsoil in conjunction with the vegetative cover will store water and promote evapotranspiration. The topsoil shall be placed in a single 0.5-ft lift on top of the upper backfill. The equipment used to place and fine grade the topsoil shall be low ground pressure equipment. No compactive effort shall be applied to the topsoil other than that provided by the equipment used to place and fine grade it. Measures shall be taken to minimize erosion of the topsoil layer prior to the establishment of the vegetative cover. Any such erosion shall be repaired by the installation subcontractor until such time as the vegetative cover has been established and the closure cap has been accepted as constructed per the approved plans and specifications by the Professional Engineer providing certification of the closure cap construction. All work in association with the topsoil shall be performed in accordance to the approved plans and specifications.

A vegetative cover will be established to promote runoff, minimize erosion, and promote evapotranspiration. The topsoil will be fertilized, seeded, and mulched to provide a vegetative cover. The initial vegetative cover shall be a persistent grass. This initial grass will provide erosion control while the final vegetative cover is being established. During seeding and establishment of the initial grass, appropriate mulch, erosion control fabric, or similar substances will protect the surface. The area will be repaired through transplanting or replanting to ensure that a self-maintaining cover is developed. If it is determined that bamboo is a climax species that prevents or greatly slows the intrusion of pine trees, it will be planted as the final vegetative cover. Pine trees are typically assumed to be the most deeply rooted naturally occurring climax plant species at SRS, which will degrade the GCL through root penetration, whereas bamboo is a shallow-rooted species, which will not degrade the GCL. Additionally bamboo evapotranspirates year-round in the SRS climate, minimizes erosion, and can sustain growth with minimal maintenance. A study conducted by the U.S. Department of Agriculture (USDA) Soil Conservation Service has shown that two species of bamboo (*Phyllostachys bissetii* and *Phyllostachys rubromarginata*) will quickly establish a dense ground cover (Salvo and Cook 1993). All work in association with the vegetative cover shall be performed in accordance to the approved plans and specifications.

Similar closure caps to that described within this closure plan have been constructed at SRS. These closure caps include:

- The Mixed Waste Management Facility (MWMF) Closure, which utilized compacted kaolin as the hydraulic barrier layer,
- The F and H-Area Seepage Basin (F&HSB) Closure, which included a sand drainage layer and utilized compacted kaolin as the hydraulic barrier layer,
- The M-Area Settling Basin (MSB) Closure, which included a sand drainage layer and utilized a combination of a flexible membrane liner (FML) and compacted kaolin as the hydraulic barrier layers,
- The Low-level Radioactive Waste Disposal Facility (LLRWDF) Closure, which included a GeoNet drainage layer and utilized a combination of a FML, and a GCL as the hydraulic barrier layers, and
- The Sanitary Landfill Closure, which included a GeoNet drainage layer and utilized a combination of a FML, and a GCL as the hydraulic barrier layers.

SRS has much experience with the construction and subsequent maintenance of closure caps, including those utilizing GCLs and drainage layers. The conceptual closure cap described within this closure plan is similar to these previously successfully installed caps. It includes materials of construction that were successfully used in these previous caps. Therefore it is known with certainty that the conceptual closure cap described within this closure plan can be successfully constructed. Based upon this conceptual design, it appears that there is sufficient area to construct the disposal units and overlying closure caps. However a fairly substantial thickness of controlled compacted backfill will be required to create the required contours for those portions of the closure cap overlying the LAW Vaults and Naval Reactor Component Disposal Pads.

4.4.2.3 Integrated Drainage System

This section on the integrated drainage system provides sufficient information for planning purposes and to evaluate the functionality of the conceptual drainage system described herein, but it is not intended to constitute final design (i.e. final plans and specifications). The final plans and specification will include provisions for protecting the integrity of the E-Area LLWF closure cap during construction and protection of the existing closure caps adjacent to the E-Area LLWF.

The existing E-Area LLWF drainage system may be improved, as necessary, prior to site preparation and closure cap installation in order to accommodate anticipated increases in runoff and sediment transport, produced due to the construction activities. Temporary erosion control measures such as silt fences, hay bales, etc. will be utilized as necessary. Sedimentation basins will be constructed as necessary. The improvements will be made to meet the construction site's drainage requirements, to minimize infiltration over disposal units, to prohibit localized flooding, to minimize sediment transport off site, and to prohibit runoff from the construction site onto adjacent closure caps and/or facilities. Additionally the vegetative cover will be established as quickly as possible as construction is completed on any particular portion of the closure system. All work in association with storm water management and erosion control during the construction activities shall be performed in accordance to the approved plans and specifications.

The final configuration of the integrated drainage system will tie into the existing E-Area LLWF drainage system as improved to accommodate E-Area LLWF final closure to the extent practical. Runoff from the closure caps and lateral drainage out the closure cap sand drainage layers will be directed to a system of rip-rap lined ditches, which will direct the water away from the disposal units and E-Area LLWF as a whole. The rip-rap lined ditches will be constructed in between individual closure caps and around the perimeter of the E-Area LLWF. The ditches will discharge into sedimentation basins as necessary for sediment control.

The top surface of the closure caps will be sloped to between 3 to 5 percent, the slope lengths will be minimized to the extent practical, and a vegetative cover will be established. This will be done in order to maximize sheet flow of runoff and minimize rill or gully flow of runoff so that erosion of the closure cap will be minimized. The side slopes of the closure caps, which will be sloped at a maximum 19.5 degrees (3 horizontal to 1 vertical), will be rip-rap lined, as necessary, to minimize erosion caused by flow off the top of the closure cap and out the closure cap's sand drainage layer. All ditches, channels, and culverts will be designed to convey non-erosive flow in order to minimize erosion potential. In areas of potential erosion, erosion and sediment control measures will be used in an effort to protect surface soils from erosion and to retain migrating soils on site.

4.4.3 Institutional Control

USDOE has committed to a term of institutional control of not less than 100 years following final closure of the E-Area LLWF. During this time periodic inspections will be conducted and maintenance activities will be performed as needed.

4.4.4 Unrestricted Release of Site

The current SRS Future Use Plan states that the entire Savannah River Site will never be released for unrestricted use. In particular, the plan states that the central portion of the SRS, which includes the E-Area LLWF, will only be used for industrial purposes (USDOE 1998). This is consistent with the PA assumption of 100 years of restricted use for the intruder scenario.

4.5 Monitoring

4.5.1 Operational Closure Period

During the operational (25 years) period, the E-Area LLWF will have a monitoring program in place. The program will include a vadose zone monitoring system around and underneath trench disposal units, scheduled sampling and analysis of any water found in vault disposal unit sumps, and visual inspection of all disposal units as discussed in the *E-Area Monitoring Program for the E-Area Low-Level Radioactive Waste Facility* (WSRC 2000). Additional details of the monitoring system will be included as the monitoring plan develops.

4.5.2 Interim Closure / Institutional Control Period

Following interim closure and during the institutional control period, the E-Area LLWF will be part of the overall SRS Environmental Monitoring Program. Groundwater samples will be taken on a regularly scheduled basis. The samples will be analyzed for constituents that could indicate release of contaminants from the E-Area LLWF.

Periodic inspections of the interim closure system will be performed. Maintenance activities necessary for continued system performance will be conducted as required.

Some subsidence may occur during the 100-year institutional control period. Inspection and maintenance programs will be implemented to address any such occurrences.

5.0 CLOSURE SCHEDULE

As discussed previously, the E-Area LLWF is in the early stages of its planned operational life. This closure plan reflects the currently available information based on the facility's operational status. As operations continue, the closure plan will be updated to reflect the most current operational features that must be considered during closure. The schedule for final closure of the facility will be developed five years prior to completion of waste emplacement activities.

6.0 RECOMMENDED CLOSURE CONSIDERATIONS

A number of items have been reviewed by a panel consisting of SWD and SRTC representatives for consideration in association with future revisions to the E-Area LLWF Closure Plan and PA.. The items are summarized below, along with appropriate disposition for each.

Consideration Item		Disposition
1	The closure cap described within this closure plan is essentially a minimal closure cap using a GCL as the sole hydraulic barrier layer to infiltration. Additional barrier layers could be added to the closure cap to further reduce infiltration to the waste zone. It should be determined if disposal unit radiological inventories could be increased with the addition of more effective barrier layers.	Assigned to PA maintenance BIN list

Consideration Item		Disposition
2	Directing closure cap runoff and flow from the closure cap sand drainage layers to perimeter infiltration galleries should be investigated as a means to reduce the concentrations of the controlled subsurface release of radionuclides from the E-Area LLWF. Additionally it should be determined if disposal unit radiological inventories could be increased with the use of infiltration galleries.	Assigned to PA maintenance BIN list
3	Low-Activity Waste Vaults, Intermediate-Level Vaults, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches), and Naval Reactor Component Disposal Pads subsidence potentials should be determined similar to that of the Engineered Trenches as documented in WSRC-RP-2001-00613 (Phifer and Wilhite 2001).	Assigned to PA maintenance plan BIN list
4	The PA does not currently take into account waste compression and subsequent increase in radionuclide concentration that will occur due to failure, collapse, and subsidence of the disposal units and waste. The PA should be updated to take this into account. This may be significant for the Low-Activity Waste Vaults, Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), and Naval Reactor Component Disposal Pads.	Assigned to PA maintenance plan BIN list.
5	A conceptual understanding of the physical configuration of the entire system after failure should be developed and the implications of this configuration for the PA should be considered.	Assigned to PA maintenance plan BIN list.
6	The assumption that infiltration past the evapotranspiration zone of the soil column at the estimated time of disposal unit failure reverts back to that of pre-capping conditions (i.e. 40 cm/year (15.7 inches/year)) past the evapotranspiration zone of the soil column should be reevaluated in light of the estimated subsidence potential of each disposal unit. Significant subsidence could result in increased infiltration over this value due to depressions created by subsidence that limit or prohibit runoff and promote infiltration.	Assigned to PA maintenance plan BIN list.
7	The potential for differential subsidence and its impact upon the intruder scenarios should be considered in the PA.	Assigned to PA maintenance plan BIN list.
8	Subsidence is anticipated to occur during the 100-year institutional control period for portions of Slit Trenches containing bulk waste, which will require maintenance of the interim runoff cover. Applying dynamic compaction to the slit trenches, to minimize required interim runoff cover maintenance during the 100-year institutional control period, should be evaluated.	Assigned to PA maintenance plan BIN list.

	Consideration Item	Disposition
9	Some Slit Trench subsidence is anticipated to occur after the 100-year institutional control period due to the collapse of containers with significant void space. Using dynamic compaction on the slit trenches to minimize subsidence due to the collapse of containers after the 100-year institutional control period should be evaluated. This could help justify an assumption in the PA that the closure cap will remain intact significantly beyond the 100-year institutional control period.	Assigned to PA maintenance plan BIN list. This has been incorporated into Revision 4 of the closure plan.
10	The most appropriate method to fill void space between casks at the Naval Reactor component Disposal Pads to achieve structural stability for closure cap installation should be evaluated. Potential methods include: - Using Controlled Low Strength Material (CLSM) or Flowable Fill to fill the void space between casks (CLSM, or Flowable Fill, is a sand, cement, water mixture with a low cement content), - Using hand-operated compaction equipment to fill the void space between casks with compacted soil layers, - Filling the void space between casks with granite aggregate or quartz sand using a crane, - Filling the void space between casks with on site soils using a crane followed by static surcharging, and/or a combination of the above	Assigned to PA maintenance plan BIN list.
11	In the PA, the HELP model should be considered for use in determining the quantity of infiltration passing through the hydraulic barrier layer of the closure cap. This output from the HELP model could then be utilized as input to the PA's two-dimensional vadose zone model. This would eliminate the need to assume an infiltration rate of 40 cm/year (15.7 inches/year) past the evapotranspiration zone of the closure cap.	Assigned to PA maintenance plan as part of next PA revision
12	The closure cap over the Low-Activity Waste Vaults is assumed to fail due to subsidence when the vault itself is assumed to structurally fail at an estimated 3,100 years after final closure. An evaluation should be performed to determine if the closure cap might fail due to erosion or other factors prior to the 3,100 years.	Assigned to PA maintenance plan as part of next PA revision Revision 4 of the closure plan assumes final closure cap degradation prior to vault failure

	Consideration Item	Disposition
13	The closure cap over the Intermediate-Level Vaults is assumed to hydraulically fail when the vault itself is assumed to hydraulically fail at an estimated 1,050 years after final closure. An evaluation should be performed to determine if the closure cap might fail due to erosion or other factors prior to the 1,050 years.	Assigned to PA maintenance plan as part of next PA revision. Revision 4 of the closure plan assumes final closure cap degradation prior to vault failure
14	The PA should be updated to specifically include the Engineered Trench, since the Engineered Trench is operated differently than the Very-Low-Activity Waste Disposal Trenches (Slit Trenches).	Have funded work to evaluate Engineered Trench subsidence. Will incorporate information into PA revisions as available.
15	Engineered Trench failure has been assumed to occur "200 to 300 years after burial for B-25s that are not dynamically compacted" (Phifer and Wilhite 2001; Jones and Phifer 2002). Work should continue to better estimate the anticipated time period of B-25 structural collapse following burial.	Have funded work to evaluate Engineered Trench subsidence. Will incorporate information into PA revisions as available.
16	Recently, waste containers other than B-25s (SeaLand containers) have been placed in Engineered Trench #1. SeaLand containers are also anticipated to be used in Engineered Trench #2 (S. R. Reed to W. E. Jones, pers. com. October 28, 2003). The effect of using these containers along with or in place of B-25s should be evaluated with respect to structural integrity over time.	Have funded work to evaluate Engineered Trench subsidence. Will incorporate information into PA revisions as available.
17	Work should continue to determine the optimal timing for using static surcharging and/or dynamic compaction on the Engineered Trenches to achieve more efficient subsidence potential reduction results.	Have funded work to evaluate Engineered Trench subsidence. Will incorporate information into PA revisions as available
18	Using static surcharging on the Engineered Trenches prior to interim runoff cover installation should be investigated as a means to filling voids between stacks of boxes, thereby minimizing cover maintenance during the 100-year institutional control period. Such static surcharging may help to eliminate voids between containers, which could potentially cause subsidence during the institutional control period.	Have funded work to evaluate Engineered Trench subsidence. Will incorporate information into PA revisions as available
19	The assumption, under pre-capping conditions, of an infiltration rate of 40 cm/year past the evapotranspiration zone of the soil column should be re-evaluated for disposal units with an operational soil cover.	Assigned to PA maintenance plan as a special study.

	Consideration Item	Disposition
20	The use of an interim runoff covers over Engineered Trenches, Very-Low-Activity Waste Disposal Trenches (Slit Trenches), and Cement-Stabilized Encapsulated Waste Disposal Trenches (Components-In-Grout Trenches) should be evaluated as an additional operational closure provision to reduce infiltration during the 25-year operational period. It should be determined if disposal unit radiological inventories could be increased with the addition of a temporary cover.	Assigned to PA maintenance plan as a special study.
21	The PA should be updated to reflect changes in closure cap configuration outlined within Revision 4 of the closure plan.	Assigned to next PA revision. Will be in PA maintenance plan.
22	Future revisions to the PA and closure plan should discuss the fate of non-disposal facilities located within the boundaries of the E-Area LLWF.	Addressed in current plan (see Section 4.0).
23	A global evaluation of possible alternatives to managing the inherent subsidence potential of B-25 boxes and the resulting life-cycle costs should be performed.	Addressed in WSRC (2001) and have funded work to evaluate Engineered Trench subsidence Will incorporate any additional information into PA revisions as available.
24	Consideration should be given in future revisions of the Closure Plan to unit consistency throughout the document. International system of units (SI) and English units are mixed within the current version.	Will be addressed in the next closure plan revision and made consistent with the next PA revision.
25	The maximum uniform vault floor loads of 4.9×10^6 kg/m^2 for the IL Vaults and 2.8×10^6 kg/m^2 for the LAW Vaults should be verified.	These loading values will be verified and both the PA and Closure Plan will be revised as needed in the next revisions.
26	A surface treatment for the interim runoff cover should be selected from Table 4-2 or another source that can be installed at a low cost, has a low installed permeability (<1E-07 cm/s), maximizes runoff, and can be easily repaired at a low cost.	To be assigned as a new item to PA maintenance BIN list
27	HELP modeling should be performed to verify and quantify the infiltration associated with the interimly closed disposal units.	To be assigned as a new item to PA maintenance BIN list

	Consideration Item	Disposition
28	It should be determined whether or not bamboo is a self-maintaining climax species in the SRS area that prevents or greatly slows the intrusion of pine trees. If so its use as the final vegetative cover on the final closure cap could greatly slow degradation of the cap.	To be assigned as a new item to PA maintenance BIN list
29	The distance that must be maintained between dynamic compaction performance on Engineered and Slit Trenches and other E-Area structures and disposal units should be determined and specified within the closure plan.	To be determined and included within the next revision of the closure plan
30	After LAW and IL Vault structural failure, it is assumed that the overlying closure cap will subside and infiltration will increase. The infiltration increase can be minimized, by locating the closure cap apex over the vault centerlines. Run on from adjacent intact areas of the closure cap into the subsided area is minimized by this configuration	Will be addressed in the next closure plan revision

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APPENDIX A
HELP MODEL RESULTS

Within revision 2 of the closure plan the previous closure cap, kaolin hydraulic barrier layer was replaced with a GCL. The equivalence, in term of minimizing infiltration, of an equivalent GCL closure cap to the previous kaolin closure cap has been evaluated utilizing the Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994; USEPA 1994a). To demonstrate equivalence, the two and a half foot thick kaolin layer (Figure A-1) was replaced with a 0.2 inch thick GCL and backfill was added to make up the difference in thickness. No other changes were made in order to have a direct comparison between the kaolin and GCL. The previous kaolin closure cap consisted from top to bottom of 0.15 m of topsoil, 0.76 m of backfill, a geotextile fabric, 0.3 m of gravel, 0.76 m of kaolin clay, and 0.9 m of backfill (See Figure A-1). An equivalent GCL closure cap would consist from top to bottom of 0.15 m of topsoil, 0.76 m of backfill, a geotextile fabric, 0.3 m of gravel, a 0.005 m GCL, and 1.67 m of backfill (see Figure A-2). Both result in a total soil thickness of 2.9 m. See the detailed information provided below concerning the HELP model percolation estimates for both the previous kaolin closure cap and an equivalent GCL closure cap. The HELP model estimate for the average annual percolation out the bottom of the previous kaolin closure cap was 0.0177 m/year (i.e. amount of water reaching the top of the operationally/interimly closed disposal unit). Whereas the HELP model estimate for the average annual percolation out the bottom of an equivalent GCL closure cap was 0.006 m/year. The percolation out an equivalent GCL closure cap was estimated to be approximately a third of that estimated for the previous kaolin closure cap, thus demonstrating that an equivalent GCL closure cap is equivalent to or better than the previous kaolin closure cap.

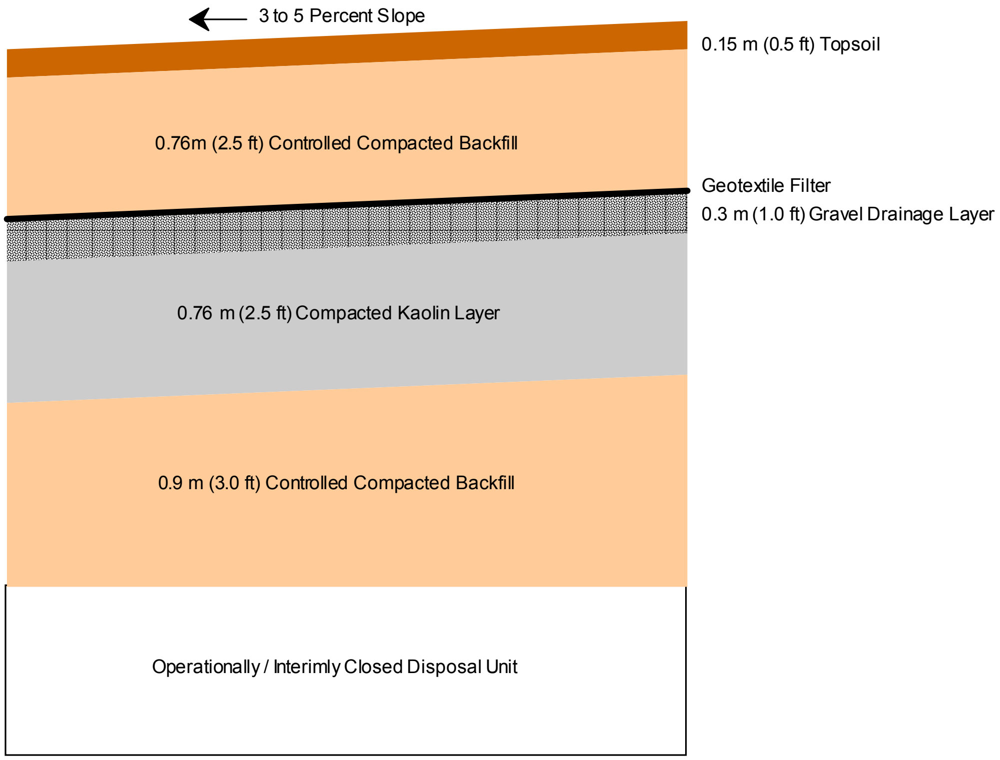

Figure A-1 Previous Kaolin Closure Cap Configuration

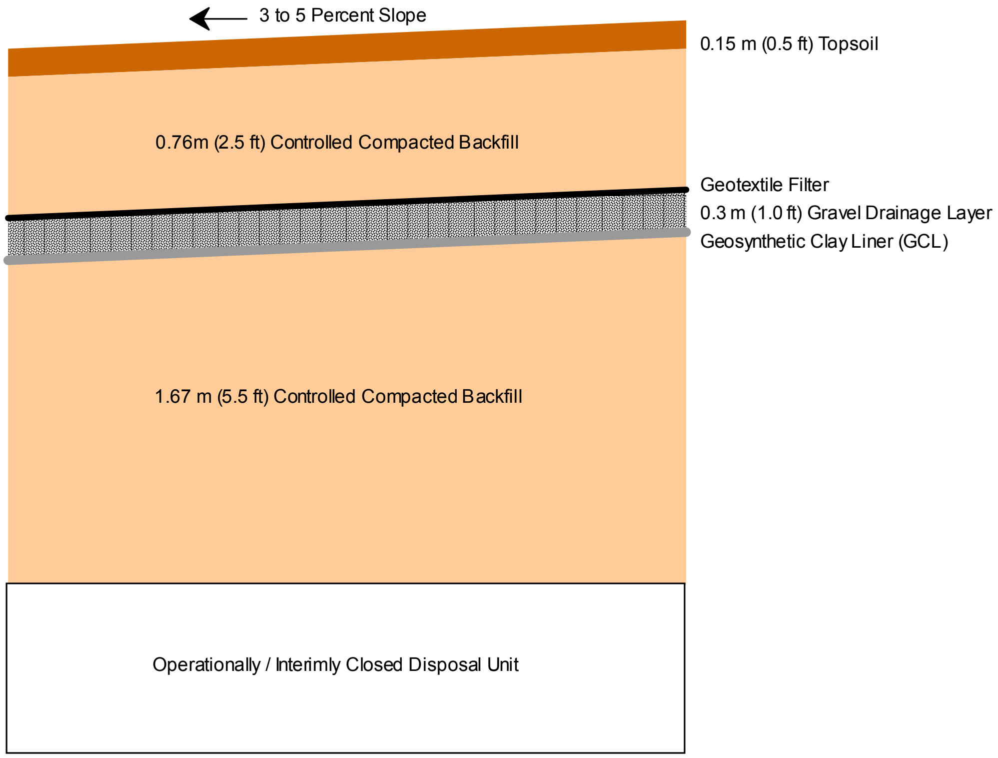

Figure A-2 Equivalent Geosynthetic Clay Liner Closure Cap Configuration

Table A-1, Previous Kaolin Closure Cap HELP Model Input
Input file: Ekao1.d10; Output file: Ekao1out.out

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	100 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 in

CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %[1, 2]
Slope length =	350 ft[12]
Soil Texture =	5 (HELP model default soil texture)[3]
Vegetation =	4 (i.e., a good stand of grass)[3]
HELP Model Computed Curve Number = 55.2	

Layer[1, 2]	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Geotextile Fabric	Not modeled	Not modeled
Gravel	3	2 (lateral drainage layer)
Clay	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)

	Layer Type	Layer Thickness[1, 2] (in)	Soil Texture No.	Total Porosity[3] (Vol/Vol)	Field Capacity[3] (Vol/Vol)	Wilting Point[3] (Vol/Vol)	Initial Moisture[3] (Vol/Vol)
1	1	6		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	2	12		0.38	0.08	0.013	0.08
4	3	30		0.56	0.55	0.5	0.56
5	1	36		0.37	0.24	0.136	0.24

	Layer Type	Sat. Hyd. Conductivity[3] (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	2	1.00E-01	350[2]	3[1, 2]			
4	3	1.00E-07					
5	1	1.00E-04					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	2				
4	3				
5	1				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data is missing from the table.

[1] Cook et al. 2000

[2] McDowell-Boyer et al. 2000

[3] WSRC 2002

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************

PRECIPITATION DATA FILE:    D:\HELP3\Hweather\AUGPREC.D4
TEMPERATURE DATA FILE:      D:\HELP3\Hweather\AUGTEMP.D7
SOLAR RADIATION DATA FILE:  D:\HELP3\Hweather\AUGSOLAR.D13
EVAPOTRANSPIRATION DATA:    D:\HELP3\Hweather\AUGEVAP.D11
SOIL AND DESIGN DATA FILE:  D:\HELP3\Hearea\EKAO1.D10
OUTPUT DATA FILE:           D:\HELP3\Hearea\ekao1out.OUT

TIME:  14:19     DATE:   8/ 8/2002

******************************************************************************

     TITLE:  E-Area Kaolin Closure Cap

******************************************************************************

     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.

                                   LAYER  1
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =      6.00   INCHES
           POROSITY                   =     0.4000 VOL/VOL
           FIELD CAPACITY             =     0.1100 VOL/VOL
           WILTING POINT              =     0.0580 VOL/VOL
           INITIAL SOIL WATER CONTENT =     0.1100 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.100000005000E-02 CM/SEC

                                   LAYER  2
                                   --------

                     TYPE 1 - VERTICAL PERCOLATION LAYER
                         MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =    30.00   INCHES
           POROSITY                   =     0.3700 VOL/VOL
           FIELD CAPACITY             =     0.2400 VOL/VOL
           WILTING POINT              =     0.1360 VOL/VOL
           INITIAL SOIL WATER CONTENT =     0.2400 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-04 CM/SEC
```

```
                           LAYER  3
                           --------

               TYPE 2 - LATERAL DRAINAGE LAYER
                 MATERIAL TEXTURE NUMBER   0
   THICKNESS                   =     12.00   INCHES
   POROSITY                    =      0.3800 VOL/VOL
   FIELD CAPACITY              =      0.0800 VOL/VOL
   WILTING POINT               =      0.0130 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.0800 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.100000001000     CM/SEC
   SLOPE                       =      3.00   PERCENT
   DRAINAGE LENGTH             =    350.0    FEET

                           LAYER  4
                           --------

                 TYPE 3 - BARRIER SOIL LINER
                 MATERIAL TEXTURE NUMBER   0
   THICKNESS                   =     30.00   INCHES
   POROSITY                    =      0.5600 VOL/VOL
   FIELD CAPACITY              =      0.5500 VOL/VOL
   WILTING POINT               =      0.5000 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.5600 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.100000001000E-06 CM/SEC

                           LAYER  5
                           --------

             TYPE 1 - VERTICAL PERCOLATION LAYER
                 MATERIAL TEXTURE NUMBER   0
   THICKNESS                   =     36.00   INCHES
   POROSITY                    =      0.3700 VOL/VOL
   FIELD CAPACITY              =      0.2400 VOL/VOL
   WILTING POINT               =      0.1360 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.2400 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.999999975000E-04 CM/SEC

           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE # 5 WITH A
          GOOD STAND OF GRASS, A SURFACE SLOPE OF  3.%
          AND A SLOPE LENGTH OF  350. FEET.

SCS RUNOFF CURVE NUMBER              =    55.20
FRACTION OF AREA ALLOWING RUNOFF     =   100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =   100.000  ACRES
EVAPORATIVE ZONE DEPTH               =    22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE    =     4.500  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE   =     8.320  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE   =     2.524  INCHES
INITIAL SNOW WATER                   =     0.000  INCHES
INITIAL WATER IN LAYER MATERIALS     =    34.260  INCHES
TOTAL INITIAL WATER                  =    34.260  INCHES
TOTAL SUBSURFACE INFLOW              =     0.00   INCHES/YEAR
```

```
                     EVAPOTRANSPIRATION AND WEATHER DATA
                     -----------------------------------

          NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
                   AUGUSTA               GEORGIA

              STATION LATITUDE                       =  33.22 DEGREES
              MAXIMUM LEAF AREA INDEX                =   3.50
              START OF GROWING SEASON (JULIAN DATE)  =     68
              END OF GROWING SEASON (JULIAN DATE)    =    323
              EVAPORATIVE ZONE DEPTH                 =  22.0  INCHES
              AVERAGE ANNUAL WIND SPEED              =   6.50 MPH
              AVERAGE 1ST QUARTER RELATIVE HUMIDITY  =  68.00 %
              AVERAGE 2ND QUARTER RELATIVE HUMIDITY  =  70.00 %
              AVERAGE 3RD QUARTER RELATIVE HUMIDITY  =  77.00 %
              AVERAGE 4TH QUARTER RELATIVE HUMIDITY  =  73.00 %

          NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
                   COEFFICIENTS FOR    AUGUSTA             GEORGIA

                   NORMAL MEAN MONTHLY PRECIPITATION  (INCHES)

      JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
      -------     -------     -------     -------     -------     -------
        3.99        4.04        4.92        3.31        3.73        3.88
        4.40        3.98        3.53        2.02        2.07        3.20

          NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
                   COEFFICIENTS FOR    AUGUSTA             GEORGIA

              NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

      JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
      -------     -------     -------     -------     -------     -------
       46.00       47.50       54.80       63.20       71.00       77.40
       80.60       79.90       74.60       63.50       53.90       46.90

          NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
                   COEFFICIENTS FOR    AUGUSTA             GEORGIA
                     AND STATION LATITUDE  =  33.22 DEGREES

*******************************************************************************

          AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                         JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                         -------  -------  -------  -------  -------  -------
   PRECIPITATION
   -------------
     TOTALS                4.15     3.66     5.01     3.11     3.77     3.89
                           4.70     3.92     3.94     1.95     1.92     3.14

     STD. DEVIATIONS       2.23     1.64     2.60     1.49     2.22     2.03
                           2.29     2.17     2.27     1.48     1.20     1.76
```

```
   RUNOFF
   ------
     TOTALS                 0.001    0.000    0.008    0.001    0.000    0.000
                            0.001    0.022    0.005    0.000    0.000    0.000

     STD. DEVIATIONS        0.010    0.000    0.043    0.010    0.003    0.000
                            0.007    0.122    0.038    0.001    0.000    0.000

   EVAPOTRANSPIRATION
   ------------------
     TOTALS                 1.473    1.917    2.966    3.604    3.892    3.699
                            4.286    3.828    2.996    1.458    0.868    1.001

     STD. DEVIATIONS        0.258    0.257    0.510    0.746    1.494    1.480
                            1.586    1.388    1.098    0.600    0.216    0.228

   LATERAL DRAINAGE COLLECTED FROM LAYER  3
   ----------------------------------------
     TOTALS                 2.2235   1.8941   2.1596   1.1372   0.3601   0.2208
                            0.1733   0.2649   0.3401   0.3492   0.3212   0.9609

     STD. DEVIATIONS        1.7698   1.5678   1.8137   1.1155   0.6622   0.4944
                            0.3866   0.5402   0.6813   0.6580   0.6307   1.0791

   PERCOLATION/LEAKAGE THROUGH LAYER  4
   ------------------------------------
     TOTALS                 0.0972   0.0947   0.1051   0.0895   0.0488   0.0285
                            0.0275   0.0326   0.0323   0.0381   0.0368   0.0630

     STD. DEVIATIONS        0.0300   0.0206   0.0185   0.0289   0.0379   0.0400
                            0.0378   0.0420   0.0376   0.0459   0.0443   0.0450

   PERCOLATION/LEAKAGE THROUGH LAYER  5
   ------------------------------------
     TOTALS                 0.0683   0.0614   0.0749   0.0767   0.0637   0.0499
                            0.0495   0.0509   0.0502   0.0480   0.0456   0.0588

     STD. DEVIATIONS        0.0261   0.0274   0.0314   0.0300   0.0421   0.0463
                            0.0447   0.0438   0.0405   0.0428   0.0379   0.0346

-------------------------------------------------------------------------------
                AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------

   DAILY AVERAGE HEAD ON TOP OF LAYER  4
   -------------------------------------
     AVERAGES               1.4774   1.3848   1.4366   0.7822   0.2392   0.1516
                            0.1152   0.1760   0.2335   0.2320   0.2205   0.6384

     STD. DEVIATIONS        1.1759   1.1651   1.2086   0.7710   0.4400   0.3395
                            0.2569   0.3589   0.4678   0.4372   0.4330   0.7170

*******************************************************************************
```

```
*******************************************************************************

      AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                      INCHES            CU. FEET        PERCENT
                                -------------------   -------------   ---------
  PRECIPITATION                 43.17    (   6.687)   15669877.0     100.00

  RUNOFF                         0.039   (  0.1327)      14039.40      0.090

  EVAPOTRANSPIRATION            31.987   (  3.5741)   11611458.00     74.101

  LATERAL DRAINAGE COLLECTED    10.40492 (  4.72693)   3776984.750   24.10347
    FROM LAYER  3

  PERCOLATION/LEAKAGE THROUGH    0.69413 (  0.17077)    251969.141     1.60798
    LAYER  4

  AVERAGE HEAD ON TOP            0.591 (    0.269)
    OF LAYER  4

  PERCOLATION/LEAKAGE THROUGH    0.69802 (  0.21741)    253379.594     1.61699
    LAYER  5

  CHANGE IN WATER STORAGE        0.039   (  1.6844)      14012.33      0.089

*******************************************************************************
```

```
******************************************************************************

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
   ------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
      PRECIPITATION                              5.05       1833150.120

      RUNOFF                                     0.937       340151.7500

      DRAINAGE COLLECTED FROM LAYER  3           0.58159     211117.06200

      PERCOLATION/LEAKAGE THROUGH LAYER  4       0.005733      2081.23364

      AVERAGE HEAD ON TOP OF LAYER  4           20.566

      MAXIMUM HEAD ON TOP OF LAYER  4           28.825

      LOCATION OF MAXIMUM HEAD IN LAYER  3
            (DISTANCE FROM DRAIN)              103.9 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER  5       0.006716      2437.83325

      SNOW WATER                                 2.14        776934.3750

      MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.3504

      MINIMUM VEG. SOIL WATER (VOL/VOL)                  0.1147

       ***  Maximum heads are computed using McEnroe's equations.  ***

            Reference:  Maximum Saturated Depth over Landfill Liner
                        by Bruce M. McEnroe, University of Kansas
                        ASCE Journal of Environmental Engineering
                        Vol. 119, No. 2, March 1993, pp. 262-270.

******************************************************************************
```

```
*******************************************************************************

                   FINAL WATER STORAGE AT END OF YEAR  100
    -----------------------------------------------------------------------
                    LAYER        (INCHES)       (VOL/VOL)
                    -----        --------       ---------
                      1            1.6334         0.2722

                      2            8.9659         0.2989

                      3            2.4694         0.2058

                      4           16.8000         0.5600

                      5            8.2515         0.2292

                  SNOW WATER       0.000

*******************************************************************************
*******************************************************************************
```

Table A-2, Equivalent GCL Closure Cap HELP Model Input
Input file: Egcl1.d10; Output file: Egcl1out.out

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	100 acres
Percent of area where runoff is possible =	100%
Do you want to specify initial moisture storage? (Y/N)	Y
Amount of water or snow on surface =	0 in
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 % [1, 2]
Slope length =	350 ft [12]
Soil Texture =	5 (HELP model default soil texture) [3]
Vegetation =	4 (i.e., a good stand of grass) [3]
HELP Model Computed Curve Number = 55.2	

Layer [1, 2]	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Geotextile Fabric	Not modeled	Not modeled
Gravel	3	2 (lateral drainage layer)
Geosynthetic Clay Liner (GCL)	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)

	Layer Type	Layer Thickness [1, 2] (in)	Soil Texture No.	Total Porosity [3] (Vol/Vol)	Field Capacity [3] (Vol/Vol)	Wilting Point [3] (Vol/Vol)	Initial Moisture [3] (Vol/Vol)
1	1	6		0.4	0.11	0.058	0.11
2	1	30		0.37	0.24	0.136	0.24
3	2	12		0.38	0.08	0.013	0.08
4	3	0.20 [4]		0.75 [5]	0.747 [5]	0.400 [5]	0.75
5	1	65.8		0.37	0.24	0.136	0.24

	Layer Type	Sat. Hyd. Conductivity [3] (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	1.00E-03					
2	1	1.00E-04					
3	2	1.00E-01	350 [2]	3 [1, 2]			
4	3	5.00E-09 [6]					
5	1	1.00E-04					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	2				
4	3				
5	1				

The lack of values in the table for particular parameters in particular layers denotes that no HELP model input was required for that parameter in that layer. No data is missing from the table.

[1] Cook et al. 2000

[2] McDowell-Boyer et al. 2000

[3] WSRC 2002

[4] USEPA 2001

[5] USEPA 1994 and 1994a

[6] GSE 2002

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              HYDROLOGIC EVALUATION OF LANDFILL PERFORMANCE               **
**                HELP MODEL VERSION 3.07  (1 NOVEMBER 1997)                **
**                  DEVELOPED BY ENVIRONMENTAL LABORATORY                   **
**                    USAE WATERWAYS EXPERIMENT STATION                     **
**             FOR USEPA RISK REDUCTION ENGINEERING LABORATORY              **
**                                                                          **
**                                                                          **
******************************************************************************
******************************************************************************

PRECIPITATION DATA FILE:    D:\HELP3\Hweather\AUGPREC.D4
TEMPERATURE DATA FILE:      D:\HELP3\Hweather\AUGTEMP.D7
SOLAR RADIATION DATA FILE:  D:\HELP3\Hweather\AUGSOLAR.D13
EVAPOTRANSPIRATION DATA:    D:\HELP3\Hweather\AUGEVAP.D11
SOIL AND DESIGN DATA FILE:  D:\HELP3\Hearea\EGCL1.D10
OUTPUT DATA FILE:           D:\HELP3\Hearea\Egcl1out.OUT

TIME:  14:24     DATE:   8/ 8/2002

******************************************************************************

     TITLE:  E-Area GCL Closure Cap

******************************************************************************

     NOTE:  INITIAL MOISTURE CONTENT OF THE LAYERS AND SNOW WATER
              WERE SPECIFIED BY THE USER.

                                   LAYER  1
                                   --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
                            MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =      6.00   INCHES
           POROSITY                   =      0.4000 VOL/VOL
           FIELD CAPACITY             =      0.1100 VOL/VOL
           WILTING POINT              =      0.0580 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.1100 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.100000005000E-02 CM/SEC

                                   LAYER  2
                                   --------

                        TYPE 1 - VERTICAL PERCOLATION LAYER
                            MATERIAL TEXTURE NUMBER   0
           THICKNESS                  =     30.00   INCHES
           POROSITY                   =      0.3700 VOL/VOL
           FIELD CAPACITY             =      0.2400 VOL/VOL
           WILTING POINT              =      0.1360 VOL/VOL
           INITIAL SOIL WATER CONTENT =      0.2400 VOL/VOL
           EFFECTIVE SAT. HYD. COND.  =  0.999999975000E-04 CM/SEC
```

```
                           LAYER  3
                           --------

               TYPE 2 - LATERAL DRAINAGE LAYER
                 MATERIAL TEXTURE NUMBER   0
   THICKNESS                   =     12.00   INCHES
   POROSITY                    =      0.3800 VOL/VOL
   FIELD CAPACITY              =      0.0800 VOL/VOL
   WILTING POINT               =      0.0130 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.0800 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.100000001000     CM/SEC
   SLOPE                       =      3.00   PERCENT
   DRAINAGE LENGTH             =    350.0    FEET

                           LAYER  4
                           --------

                 TYPE 3 - BARRIER SOIL LINER
                 MATERIAL TEXTURE NUMBER   0
   THICKNESS                   =      0.20   INCHES
   POROSITY                    =      0.7500 VOL/VOL
   FIELD CAPACITY              =      0.7470 VOL/VOL
   WILTING POINT               =      0.4000 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.7500 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.499999997000E-08 CM/SEC

                           LAYER  5
                           --------

             TYPE 1 - VERTICAL PERCOLATION LAYER
                 MATERIAL TEXTURE NUMBER   0
   THICKNESS                   =     65.80   INCHES
   POROSITY                    =      0.3700 VOL/VOL
   FIELD CAPACITY              =      0.2400 VOL/VOL
   WILTING POINT               =      0.1360 VOL/VOL
   INITIAL SOIL WATER CONTENT  =      0.2400 VOL/VOL
   EFFECTIVE SAT. HYD. COND.   =  0.999999975000E-04 CM/SEC

           GENERAL DESIGN AND EVAPORATIVE ZONE DATA
           ----------------------------------------

 NOTE:  SCS RUNOFF CURVE NUMBER WAS COMPUTED FROM DEFAULT
          SOIL DATA BASE USING SOIL TEXTURE # 5 WITH A
          GOOD STAND OF GRASS, A SURFACE SLOPE OF  3.%
          AND A SLOPE LENGTH OF  350. FEET.

SCS RUNOFF CURVE NUMBER             =     55.20
FRACTION OF AREA ALLOWING RUNOFF    =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE  =    100.000  ACRES
EVAPORATIVE ZONE DEPTH              =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE   =      4.500  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE  =      8.320  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE  =      2.524  INCHES
INITIAL SNOW WATER                  =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS    =     24.762  INCHES
TOTAL INITIAL WATER                 =     24.762  INCHES
TOTAL SUBSURFACE INFLOW             =      0.00   INCHES/YEAR
```

```
                     EVAPOTRANSPIRATION AND WEATHER DATA
                     -----------------------------------

          NOTE:  EVAPOTRANSPIRATION DATA WAS OBTAINED FROM
                   AUGUSTA               GEORGIA

              STATION LATITUDE                       =  33.22 DEGREES
              MAXIMUM LEAF AREA INDEX                =   3.50
              START OF GROWING SEASON (JULIAN DATE)  =     68
              END OF GROWING SEASON (JULIAN DATE)    =    323
              EVAPORATIVE ZONE DEPTH                 =  22.0  INCHES
              AVERAGE ANNUAL WIND SPEED              =   6.50 MPH
              AVERAGE 1ST QUARTER RELATIVE HUMIDITY  =  68.00 %
              AVERAGE 2ND QUARTER RELATIVE HUMIDITY  =  70.00 %
              AVERAGE 3RD QUARTER RELATIVE HUMIDITY  =  77.00 %
              AVERAGE 4TH QUARTER RELATIVE HUMIDITY  =  73.00 %

          NOTE:  PRECIPITATION DATA WAS SYNTHETICALLY GENERATED USING
                   COEFFICIENTS FOR    AUGUSTA             GEORGIA

                   NORMAL MEAN MONTHLY PRECIPITATION (INCHES)

      JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
      -------     -------     -------     -------     -------     -------
        3.99        4.04        4.92        3.31        3.73        3.88
        4.40        3.98        3.53        2.02        2.07        3.20

          NOTE:  TEMPERATURE DATA WAS SYNTHETICALLY GENERATED USING
                   COEFFICIENTS FOR    AUGUSTA             GEORGIA

              NORMAL MEAN MONTHLY TEMPERATURE (DEGREES FAHRENHEIT)

      JAN/JUL     FEB/AUG     MAR/SEP     APR/OCT     MAY/NOV     JUN/DEC
      -------     -------     -------     -------     -------     -------
       46.00       47.50       54.80       63.20       71.00       77.40
       80.60       79.90       74.60       63.50       53.90       46.90

          NOTE:  SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
                   COEFFICIENTS FOR    AUGUSTA             GEORGIA
                     AND STATION LATITUDE  =  33.22 DEGREES

*******************************************************************************

          AVERAGE MONTHLY VALUES IN INCHES FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------

                          JAN/JUL  FEB/AUG  MAR/SEP  APR/OCT  MAY/NOV  JUN/DEC
                          -------  -------  -------  -------  -------  -------
   PRECIPITATION
   -------------
     TOTALS                 4.15     3.66     5.01     3.11     3.77     3.89
                            4.70     3.92     3.94     1.95     1.92     3.14

     STD. DEVIATIONS        2.23     1.64     2.60     1.49     2.22     2.03
                            2.29     2.17     2.27     1.48     1.20     1.76
```

```
   RUNOFF
   ------
     TOTALS                  0.001    0.000    0.008    0.001    0.000    0.000
                             0.001    0.022    0.005    0.000    0.000    0.000

     STD. DEVIATIONS         0.010    0.000    0.043    0.010    0.003    0.000
                             0.007    0.122    0.038    0.001    0.000    0.000

   EVAPOTRANSPIRATION
   ------------------
     TOTALS                  1.473    1.917    2.966    3.604    3.892    3.699
                             4.286    3.828    2.996    1.458    0.868    1.001

     STD. DEVIATIONS         0.258    0.257    0.510    0.746    1.494    1.480
                             1.586    1.388    1.098    0.600    0.216    0.228

   LATERAL DRAINAGE COLLECTED FROM LAYER  3
   ----------------------------------------
     TOTALS                  2.2744   1.9480   2.2212   1.1995   0.4058   0.2430
                             0.1953   0.2898   0.3632   0.3777   0.3494   0.9998

     STD. DEVIATIONS         1.7597   1.5512   1.7951   1.1072   0.6710   0.5116
                             0.4015   0.5577   0.6901   0.6763   0.6486   1.0907

PERCOLATION/LEAKAGE THROUGH LAYER  4
   ------------------------------------
     TOTALS                  0.0446   0.0389   0.0442   0.0260   0.0113   0.0066
                             0.0056   0.0075   0.0088   0.0090   0.0084   0.0209

     STD. DEVIATIONS         0.0313   0.0279   0.0316   0.0197   0.0123   0.0103
                             0.0083   0.0113   0.0132   0.0135   0.0129   0.0204

   PERCOLATION/LEAKAGE THROUGH LAYER  5
   ------------------------------------
     TOTALS                  0.0409   0.0377   0.0393   0.0300   0.0137   0.0083
                             0.0073   0.0090   0.0098   0.0112   0.0110   0.0209

     STD. DEVIATIONS         0.0208   0.0181   0.0186   0.0182   0.0128   0.0122
                             0.0102   0.0126   0.0127   0.0157   0.0158   0.0185

-------------------------------------------------------------------------------
                AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)
-------------------------------------------------------------------------------

   DAILY AVERAGE HEAD ON TOP OF LAYER  4
   -------------------------------------
     AVERAGES                1.5112   1.4240   1.4775   0.8250   0.2696   0.1668
                             0.1297   0.1925   0.2494   0.2509   0.2399   0.6643

     STD. DEVIATIONS         1.1692   1.1526   1.1962   0.7652   0.4458   0.3512
                             0.2667   0.3706   0.4738   0.4494   0.4454   0.7247

*******************************************************************************
```

```
*******************************************************************************

      AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                      INCHES            CU. FEET       PERCENT
                                -------------------   -------------   ---------
  PRECIPITATION                  43.17    (   6.687)   15669877.0     100.00

  RUNOFF                          0.039   (  0.1327)      14039.40      0.090

  EVAPOTRANSPIRATION             31.987   (  3.5741)   11611458.00     74.101

  LATERAL DRAINAGE COLLECTED     10.86704 (  4.74732)   3944736.500   25.17401
    FROM LAYER  3

  PERCOLATION/LEAKAGE THROUGH     0.23190 (  0.08776)     84181.508     0.53722
    LAYER  4

  AVERAGE HEAD ON TOP             0.617 (    0.270)
    OF LAYER  4

  PERCOLATION/LEAKAGE THROUGH     0.23893 (  0.07385)     86730.945     0.55349
    LAYER  5

  CHANGE IN WATER STORAGE         0.036   (  1.6897)      12909.36      0.082

*******************************************************************************
```

```
******************************************************************************

             PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
   ------------------------------------------------------------------------
                                             (INCHES)      (CU. FT.)
                                            ----------   -------------
      PRECIPITATION                           5.05       1833150.120

      RUNOFF                                  0.937       340151.7500

      DRAINAGE COLLECTED FROM LAYER  3        0.58117     210965.17200

      PERCOLATION/LEAKAGE THROUGH LAYER  4    0.017636      6401.95947

      AVERAGE HEAD ON TOP OF LAYER  4        20.539

      MAXIMUM HEAD ON TOP OF LAYER  4        28.777

      LOCATION OF MAXIMUM HEAD IN LAYER  3
            (DISTANCE FROM DRAIN)           103.8 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER  5    0.005610      2036.52515

      SNOW WATER                              2.14        776934.3750

      MAXIMUM VEG. SOIL WATER (VOL/VOL)                0.3504

      MINIMUM VEG. SOIL WATER (VOL/VOL)                0.1147

       ***  Maximum heads are computed using McEnroe's equations.  ***

            Reference:  Maximum Saturated Depth over Landfill Liner
                        by Bruce M. McEnroe, University of Kansas
                        ASCE Journal of Environmental Engineering
                        Vol. 119, No. 2, March 1993, pp. 262-270.

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                  FINAL WATER STORAGE AT END OF YEAR  100
    ----------------------------------------------------------------------
                   LAYER        (INCHES)       (VOL/VOL)
                   -----        --------       ---------
                     1            1.6334         0.2722

                     2            8.9659         0.2989

                     3            2.4793         0.2066

                     4            0.1500         0.7500

                     5           15.0897         0.2293

                 SNOW WATER       0.000

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APPENDIX B
REVISED CLOSURE SEQUENCE RELATIVE ESTIMATED COST

The relative estimated cost associated with the revised closure sequence for a 3.85 acre, Engineered Trench has been determined after the method outlined in Phifer and Wilhite (2001) for comparison to the previous closure sequence for a 3.85 acre, Engineered Trench as determined by Phifer and Wilhite (2001). The following are pertinent assumptions associated with this relative estimated cost:

- The interim runoff cover will consist of either a 30-mil high density polyethylene (HDPE) flexible membrane liner (FML) or geotextile reinforced asphalt surface treatment (for the purposes of this estimate, the cover with the higher cost will be assumed),
- The subsidence treatment method utilized will consist of an operational soil cover and tertiary dynamic compaction, and
- Relatively little subsidence will occur during the 100-year Institutional Control Period due to the structural integrity of the B-25 boxes during this period (it has been estimated that without prior dynamic compaction, the bulk of the anticipated subsidence will occur 200 to 300 years after burial.

Costs not directly transferable from Phifer and Wilhite (2001) have been estimated based upon the method outlined by Phifer and Wilhite (2001) and the cost data provided by Bhutani et al. (1993). All costs have been escalated from 1993 to 2001 based upon a yearly 3% inflation rate to be consistent with the costs presented within Phifer and Wilhite (2001).

The relative estimated cost summary is presented in the Table below. The Engineered Trench, B-25 box, tertiary dynamic compaction, and final closure cap costs are taken directly from Phifer and Wilhite (2001). The interim runoff cover, interim runoff cover O&M, and interim runoff cover subsidence repair costs, have been estimated below based upon the cost data provided by Bhutani et al. (1993).

Relative Estimated Cost Summary

Cost Element	Estimated Cost ($M)
Engineered Trench Cost) [1]	3.10
B-25 Box Cost [1]	10.79
Interim Runoff Cover Cost	1.12
Interim Runoff Cover Yearly O&M Cost	0.66
Interim Runoff Cover Resurfacing Cost	0.61
Interim Runoff Cover Subsidence Repair Cost	0.16
Tertiary Dynamic Compaction Cost [1]	3.58
Final Closure Cap Cost [1]	2.40
Total Cost	22.42

$M = Millions of Dollars

[1] Phifer and Wilhite 2001

The interim runoff cover will consist of either a 30-mil high-density polyethylene (HDPE) flexible membrane liner (FML) or geotextile reinforced asphalt surface treatment. The cost estimates for the FML and geotextile reinforced asphalt interim runoff covers have been estimated based upon the method outlined by Phifer and Wilhite (2001) Appendix A Section A-7 and the cost data provided by Bhutani et al. (1993) as shown below.

FML Interim Runoff Cover Construction Estimate (after Bhutani et al. 1993 and Phifer and Wilhite 2001)

FML Interim Runoff Cover Construction Activity	1993 2-Acre [1] ($)	1993 5-Acre [2] ($)
Site Pre-contouring	3,000	4,330
Foundation Soil Placement	65,040	162,610
FML Placement	39,420	98,580
Drainage Ditch Construction	4,010	10,030
Cover Survey	2,400	3,600
Direct Cost Subtotal	113,870	279,150
Clean up & Demobilization (5% of Direct Cost Subtotal)	5,694	13,958
Location Factor (40% of Direct Cost Subtotal)	45,548	111,660
Total Direct Cost	165,112	404,768
Indirect Costs (100% of Direct Costs)	165,112	404,768
Total 1993 Cost	330,224	809,536

FML = high density polyethylene (HDPE), flexible membrane liner (FML)

[1] From Bhutani et al. (1993) Appendix E-1

[2] From Bhutani et al. (1993) Appendix F-1

Geotextile Reinforced Asphalt Interim Runoff Cover Construction Estimate (after Bhutani et al. 1993 and Phifer and Wilhite 2001)

Geotextile Reinforced Asphalt Interim Runoff Cover Construction Activity	1993 2-Acre [3] ($)	1993 5-Acre [4] ($)
Site Pre-contouring	3,000	4,330
Foundation Soil Placement	65,040	162,610
Geotextile Reinforcement Placement	5,420	13,580
Asphalt Application	63,980	159,950
Drainage Ditch Construction	4,010	10,030
Cover Survey	2,400	3,600
Direct Cost Subtotal	143,850	354,100
Clean up & Demobilization (5% of Direct Cost Subtotal)	7,192	17,705
Location Factor (40% of Direct Cost Subtotal)	57,540	141,640
Total Direct Cost	208,582	513,445
Indirect Costs (100% of Direct Costs)	208,582	513,445
Total 1993 Cost	417,164	1,026,890

[3] From Bhutani et al. (1993) Appendix E-6

[4] From Bhutani et al. (1993) Appendix F-6

The cost of a 4.28 acre, interim runoff cover over a 3.85 acre, Engineered Trench has been determined and escalated from 1993 to 2001 based upon a yearly 3% inflation rate to be consistent with the costs presented within Phifer and Wilhite (2001):

> 8 years at a F/P factor of 1.2668 (Grant et al., 1976)
> The estimated costs associated with the geotextile reinforced asphalt surface treatment have been utilized, since they are greater than the FML cost.

$$Cost = 1.2668 \times \left(417{,}164 + \left(\left(1{,}026{,}890 - 417{,}164\right) \times \left(\frac{4.28 - 2}{5 - 2}\right)\right)\right)$$

$$Cost = 1{,}115{,}488$$

The cost estimate for the interim runoff cover yearly O&M has been estimated based upon the method outlined by Phifer and Wilhite (2001) Appendix A Section A-10 and the cost data provided by Bhutani et al. (1993) as shown below. The costs associated with an annual subsidence survey and vegetative cover maintenance, which are applicable to a final closure cap, are not applicable to an interim runoff cover and therefore have not been included.

Yearly Interim Runoff Cover O&M Estimate (Excluding Cap Subsidence Repair Costs) (after Bhutani et al. 1993 and Phifer and Wilhite 2001)

Interim Runoff Cover O&M Activities	1993 2-Acre ($/year)	1993 5-Acre ($/year)
Monthly Inspection	4,500	5,400
Total Yearly Interim Runoff Cover O&M Cost	4,500	5,400

The interim runoff cover O&M cost of a 4.28 acre, interim runoff cover over a 3.85 acre, Engineered Trench has been determined and escalated from 1993 to 2001 based upon a yearly 3% inflation rate to be consistent with the costs presented within Phifer and Wilhite (2001):

8 years at a F/P factor of 1.2668 (Grant et al., 1976)
100 year Institutional Control Period over which the interim runoff cover is maintained

$$Yearly\ Cost = 1.2668 \times \left(4{,}500 + \left(\left(5{,}400 - 4{,}500\right) \times \left(\frac{4.28 - 2}{5 - 2}\right)\right)\right)$$

$$Yearly\ Cost = 6{,}567$$

$$Costs\ over\ 100\ years = 100\ years \times \$6{,}567 / year$$

$$Costs\ over\ 100\ years = \$656{,}700$$

The cost estimate for resurfacing the 4.28 acre interim runoff cover has been estimated. It is based upon the information provided by Bhutani et al. (1993) and the assumption that the cover is resurfaced every ten years with a single coat of asphalt applied at a rate of 0.1 gallons per cubic yard.

Estimated applied hot asphalt using 3 passes at a rate of 0.5 gal/yd^2 for a total of 1.5 gal/yd^2 (Bhutani et al. 1993):

Acres	Labor ($)	Material ($)	Equipment ($)
2	32,532	21,688	9,760
5	81,330	54,220	24,399

Assumed conversion of the above estimate to a single coat of asphalt (i.e. a single pass) applied at a rate of 0.1 gallons per cubic yard:

- Assume that the labor cost is a third that from Bhutani et al.(1993), since only one pass is used rather than three,

- Assume that the material cost is 0.0667 (i.e. 0.1/1.5 = 0.0667) that from Bhutani et al.(1993), since on 0.1 gal/yd^2 rather than 1.5 gal/yd^2 is to be utilized, and
- Assume that the equipment cost cost is a third that from Bhutani et al.(1993), since only one pass is used rather than three.

Cost of 0.1 gal/yd^2 asphalt application for a two acre site:

$$Cost = \left(\frac{32{,}532}{3}\right) + (0.0667 \times 21{,}688) + \left(\frac{9{,}760}{3}\right) = 15{,}544$$

Cost of 0.1 gal/yd^2 asphalt application for a five acre site:

$$Cost = \left(\frac{81{,}330}{3}\right) + (0.0667 \times 54{,}220) + \left(\frac{24{,}399}{3}\right) = 38{,}859$$

Total costs for a 2-acre and a 5-acre site considering clean up and demobilization (i.e. 5% of direct costs) and the location factor (i.e. 40% of direct costs). Indirect costs are not included since this does not involve design or construction but is simply a planned maintenance activity.

Asphalt Resurfacing Activities	1993 2-Acre ($/ 10 years)	1993 5-Acre ($/ 10 years)
Asphalt Resurfacing	15,544	38,859
Clean up & Demobilization (5% of Direct Cost Subtotal)	777	1,943
Location Factor (40% of Direct Cost Subtotal)	6,218	15,544
Total Asphalt Resurfacing Cost	22,539	56,346

The interim runoff cover asphalt resurfacing cost of a 4.28 acre, interim runoff cover over a 3.85 acre, Engineered Trench has been determined and escalated from 1993 to 2001 based upon a yearly 3% inflation rate to be consistent with the costs presented within Phifer and Wilhite (2001):

8 years at a F/P factor of 1.2668 (Grant et al., 1976)
100 year Institutional Control Period over which the interim runoff cover is resurfaced every ten years

$$10\ year\ \cos t = 1.2668 \times \left(22{,}539 + \left((56{,}346 - 22{,}539) \times \frac{4.28 - 2}{5 - 2}\right)\right)$$

$$10\ year\ \cos t = 61{,}101$$

$$100\ year\ \cos t = 100\ years \times \$61{,}101/10\ years$$

$$100\ year\ \cos t = \$611{,}010$$

The cost estimate for the interim runoff cover subsidence repair has been estimated based upon the information provided by Bhutani et al. (1993). It has been escalated from 1993 to 2001 based upon a yearly 3% inflation rate to be consistent with the costs presented within Phifer and Wilhite (2001) as shown below.

Estimated Subsidence Repair Costs per Seven Foot Diameter Sink Hole (after Bhutani et al. 1993)

Interim Runoff Cover	Sinkhole Repair Cost [1] ($)
FML	8,000
Geotextile Reinforced Asphalt	8,000

[1] From Bhutani et al. (1993) Table C-1. Estimated Sinkhole Repair Costs

Estimated Number of Subsidence Repairs Required over 30 Years (after Bhutani et al. 1993)

1993 2-Acre (#)	1993 5-Acre (#)
3	6

[1] From Bhutani et al. (1993) Table C-2. Assumed Frequency of Repair Events for Estimating Cover Repair Costs

Estimated Number of Subsidence Repairs Required over 100 Years:

Assumed linear ratio of number of required subsidence repairs to time
Estimated number of subsidence events for a 3.85 acre Engineered Trench over a 30 year period:

$$Estimated\ \#\ of\ \ Subsidence\ Events = 3 + \left((6-3) \times \left(\frac{3.85-2}{5-2} \right) \right)$$

$$Estimated\ \#\ of\ \ Subsidence\ Events = 4.85$$

Estimated number of subsidence events for a 3.85 acre Engineered Trench over a 100 year period:

$$Estimated\ \#\ of\ \ Subsidence\ Events = 4.85 \times \left(\frac{100\ years}{30\ years} \right)$$

$$Estimated\ \#\ of\ \ Subsidence\ Events = 16.2$$

Estimated Cost of Subsidence Repairs Required over 100 Years:

8 years at a F/P factor of 1.2668 (Grant et al., 1976)

$$Costs\ over\ 100\ years = 1.2668 \times (16.2\ subsidence\ events \times \$8{,}000 / subsidence\ event)$$

$$Costs\ over\ 100\ years = 164{,}177$$

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APPENDIX C
TECHNICAL REPORT DESIGN CHECKLIST

TECHNICAL REPORT DESIGN CHECKLIST

Report Title: Closure Plan for the E-Area Low-Level Waste Facility
Reviewer: William E. Jones
Activity Code: —
Document No. WSRC-RP-2000-00425 Rev. 4
Current Date: 6-7-04
Authors(s): Cook, J.R., Phifer, M.A., Wilhite, E.L., Young, K.E., and Jones, W.E.
Date Needed:
Location of report and supplemental information: Final report available through document control. Detailed design information available through Mark A. Phifer. Detailed check of HELP modeling.

☑ Analytical/Experimental Approach
Instruction: In general, analytical approach is appropriate. The HELP modeling in particular is a widely accepted method for water-balance analysis.

☑ Mathematical Check
Instruction: General check for input magnitude and units consistency.

☑ Inputs
Instruction: Inputs appear applicable and representative.

☑ Assumptions
Instruction: Assumptions are reasable and clearly explained.

☑ Output
Instruction: Results make sense and output is clear.

☑ Transcription
Instruction: Post-processing software not used, and therefore not checked against final results.

Design check completed by: WE Jones Date: 6-7-04
Comment resolution accepted by: M A Phifer Date: 6/7/04
Date:

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