RAI Responses 1-4

RESPONSE TO RAI COMMENT 1
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
d'Entremont et al. 2005	Appendix B, "Assumption Summary for Curie Balance" (Pages 36-37) enclosed following response	
Draft Section 3116 Determination Salt Waste Disposal SRS, DOE-WD-2005-001	Provided to NRC during original WD submittal; representative excerpts enclosed following response	
Reboul 2005	Representative excerpts of assumptions (Pages 21-26) are enclosed following the response.	
Rosenberger et al. 2005	Representative excerpts of assumptions (Pages 23-35, Section 4.1.4, "Groundwater Pathway Simulation Input and Assumptions" and Pages 38-40, Section 4.2.4, "Analysis Inputs/Assumptions") are enclosed following the response.	

*Excerpt Locations:

1. Excerpt included within response: The excerpt is included within the text of the response or is appended to the response.
2. Excerpt enclosed following response: The excerpt is enclosed on a separate sheet or sheets following the response.
3. Representative excerpt(s) enclosed following response: Representative excerpts from a document that is wholly or largely applicable are enclosed following the response.
4. Other

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CBU-PIT-2005-00013
REVISION: 3
June 21, 2005

KEYWORDS:
Tank Farm, Salt Program,
Waste Solidification, Class C,
Permit, Saltstone

RETENTION: PERMANENT
CLASSIFICATION: U
Does not contain UCNI
Paul D. d'Entremont
6/21/05 ADC/RO

Radionuclide Concentrations in Saltstone

P. D. d'Entremont, 766-H
M.D. Drumm, 766-H

Approval:

for

L. B. Romanowski, Manager,
CBU Salt Disposition Planning

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9. Appendix B—Assumption Summary for Curie Balance

This section describes the assumptions used in the calculations in this report. Most of these assumptions are described elsewhere in the report, so most of the information in this section is redundant. The purpose of the section is to capture all the assumptions in one place to facilitate easier understanding.

The following assumptions made for Tanks 41, 25, and 28 were taken directly from the Interim Strategy[10]:

- ^{137}Cs concentrations and total curies
- Salt levels
- Interstitial liquid is 30% of saltcake volume

For soluble radionuclides, the fraction of the original curies in the tank that is transferred in each batch of DDA is the same as the fraction of ^{137}Cs curies transferred.

Supernatant activities are taken from Tank Radionuclide Inventories[11], For each radionuclide in each tank, the total radionuclide inventory was divided by the total supernatant inventory to calculate the concentration of that radionuclide in the tank..

Due to the dynamic nature of Tank 41, the Tank 41 supernatant concentration was calculated separately. To estimate the Tank 41 supernatant concentration before salt dissolution activities began, the Tank 41 pre-dissolution supernatant activity given in the Interim Strategy (2.5 Ci/gal) was used along with the methodology in Tank Radionuclide Inventories[11], i.e., the majority of radionuclides are calculated on a ratio to ^{137}Cs basis, and some are constant for all supernatant.

The only nuclides of consequence for saltcake are ^{14}C, ^{22}Na and ^{26}Al, which are assumed to be at the same concentration in all tanks. The saltcake activity was taken from the Tank Radionuclide Inventories[11]. The saltcake inventories for all other radionuclides are negligible and were not included in the calculation.

The volume of saltcake dissolved by each batch was determined from the volume of salt solution sent to each batch, 1.0 gal of saltcake makes 2.8 gal of salt solution.[12][13]

Composition of sludge[11] was converted from the given total radionuclide inventory and total mass of dry sludge, to an activity per mass basis. Tank 41 had tank specific sludge, Tanks 25 and 28 are assumed to have the same composition as Tank 26 because Tank 26 was the evaporator feed tank when the salt in Tanks 25 and 28 was deposited.

Salt solution from DDA tanks contains 200 mg/L of sludge (after dissolution, starts out at 600 mg/L[13] but is reduced to 200 after settling[14]).

Volumes of each batch, both salt solution and DWPF recycle are taken from the Interim Strategy. DWPF recycle is assumed to have the same composition as Tank 21[11].

ARP batches are filtered only (no MST) per the Interim Strategy. Thus, the only soluble radionuclide that is reduced in processing is ^{137}Cs, which is removed by MCU (e.g., soluble plutonium and strontium are not reduced). ^{137}Cs decontamination factor is 12[15].

Batch 0 concentrations are assumed to be the same as currently in Tank 50[11].

Inventory of radionuclides from SWPF to Saltstone is calculated by summing up soluble inventory from DDA and ARP/MCU going to Saltstone. This sum is subtracted from the total soluble inventory provided and then the SWPF Decontamination Factors are applied. SWPF Decontamination Factors are taken from the Integrated Material Balance[15] for a 12-hour MST strike and are listed below.

Sr	20
Cs	40000
U	1.35
Np	2.4
Pu	5.5
Am	4.6
Cm	1.7

The total volume of salt solution sent to Saltstone from SWPF is 95.8 Mgal[16].

References:

[10] M.J. Mahoney and P.D. d'Entremont, "Interim Salt Processing Strategy Planning Baseline", CBU-PED-2004-00027, Revision 0, August 27, 2004

[11] H.Q. Tran, "Tank Radionuclide Inventories", CBU-PIT-2005-00138, Revision 0, June 14, 2005

[12] Q.L. Nguyen and J.A. Pike, "Tank 41 Low Curie Salt (LCS) 1st Salt Dissolution Batch Analysis", WSRC-TR-2003-00191, Revision 0, June 3, 2003

[13] R.A. Jacobs., "Additional Inputs to WSMS for Preliminary Hazards Analysis", HLW-SDT-99-0014, Revision 0, February 3, 1999

[14] J.M. Gillam, "Settling of Insoluble Solids in Supernate from Salt Dissolution", X-CLC-H-00546, Revision 0, March 2005

[15] H.H. Elder, "Integrated Material Balance Input Data Summary", CBU-PED-2004-00033, Revision 0, September 10, 2004

[16] M.A. Rios-Armstrong, "Decontaminated Salt Solution Volume to be Transferred to the Saltstone Disposal Facility from Salt Treatment and Disposition Activities," CBU-PIT-2005-00031, February 13, 2005

DOE-WD-2005-001
February 28, 2005

Draft Section 3116 Determination

Salt Waste Disposal

Savannah River Site

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3/24/2005

5.0 THE WASTE HAS HAD HIGHLY RADIOACTIVE RADIONUCLIDES REMOVED TO THE MAXIMUM EXTENT PRACTICAL

Section 3116 (a)(2) of the NDAA provides in pertinent part:

> [T]he term "high level waste" does not include radioactive waste resulting from the reprocessing of spent nuclear fuel that the Secretary of Energy..., in consultation with the Nuclear Regulatory Commission..., determines –
>
> ***
>
> (2) has had highly radioactive radionuclides removed to the maximum extent practical[.]

5.1 RADIONUCLIDES CONSIDERED

For the purpose of this draft 3116 Determination, the radionuclides considered in detail are: Cs-137 (including its daughter, Ba-137m), Sr-90 (including its daughter, yttrium (Y)-90), the actinides (isotopes of U, Pu, Am, Np, and Cm), selenium (Se)-79, technetium (Tc)-99, iodine (I)-129, and tin (Sn)-126[10].

The short-lived fission products Cs-137 and Sr-90 and their equilibrium daughters, Ba-137m and Y-90[11], are by far the predominant sources of radioactivity present in the SRS salt waste. Based on process and sampling knowledge as reflected in the current WCS database, more than 99% [2] of the current radioactivity in the SRS tank salt waste is associated with these two radionuclides and their daughters. Indeed, Cs-137 and its daughter Ba-137m alone account for over 95% of the

[10] DOE has reviewed the inventory of 41 radionuclides in the salt waste in the SRS waste tanks, as reflected in the current Waste Characterization System (WCS) database. WCS is discussed in further detail in Appendix 2. The radionuclides considered in detail for removal in this draft 3116 Determination take into account scientific expertise, knowledge, and health physics principles as applied to the SRS salt waste, and include those radionuclides in Tables 1 and 2 in 10 CFR 61.55 that are in the SRS salt waste and are in quantities such that they may be important to meeting the performance objectives in 10 CFR 61, Subpart C. All radionuclides in Tables 1 and 2 are considered in Section 6.0 and , where relevant, Section 7 of this draft 3116 Determination. However, radionuclides with less than five-year half-lives, H-3, C-14, Co-60, and Ni-63 are present in concentrations so low (well below Class A concentration limits) that they are not discussed for the purposes of removal in Section 5.0. The radionuclides considered in detail for the purposes of removal also include other radionuclides that are not in the above referenced tables that may be important to meeting the performance objectives in 10 CFR 61, Subpart C. Some of the radionuclides considered in detail in this draft 3116 Determination may not be considered in detail in other 3116 Determinations if the circumstances or waste forms do not warrant such consideration.

[11] Cs-137, and its daughter Ba-137m, are typically considered as a single radionuclide for human health protection purposes because the half-life of Ba-137m is so short that it only exists when Cs-137 is present. The same is true for Sr-90 and its daughter Y-90. Accordingly, the discussions that follow in this draft 3116 Determination focus on Cs-137 or Sr-90 since approaches that are effective in removing Cs-137 and Sr-90 also remove Ba-137m and Y-90, respectively.

6.0 THE WASTE DOES NOT EXCEED CONCENTRATION LIMITS IN 10 CFR 61.55

Section 3116 of the NDAA provides in relevant part:

> [T]he term "high-level radioactive waste" does not include waste from reprocessing of spent nuclear fuel that the Secretary of Energy...in consultation with the Nuclear Regulatory Commission...determines –
>
> ***
>
> (3)(A) does not exceed concentration limits for Class C low-level waste as set out in section 61.55 of title 10, Code of Federal Regulations...[.]

The NRC regulations at 10 CFR 61.55 categorize low-level radioactive waste intended for near surface disposal as Class A, Class B, or Class C. To make the waste classification determination, the waste concentrations for specified radionuclides are compared to concentration limits defined in 10 CFR 61.55. The radionuclides and their associated limits are specified in two separate tables within 10 CFR 61.55 which are reproduced below.

Table 6.1: 10 CFR 61.55 Table 1

Radionuclides (Long-lived)	Concentration (Ci/m^3)
C-14	8
C-14 in activated metal	80
Ni-59 in activated metal	220
Nb-94 in activated metal	0.2
Tc-99	3
I-129	0.08
Alpha Emitting Transuranic (TRU) nuclides with half-life greater than 5 years	100[1]
Pu-241	3,500[1]
Cm-242	20,000[1]

[1] Units are in nanocuries per gram.

7.0 THE WASTE WILL BE DISPOSED OF IN ACCORDANCE WITH THE PERFORMANCE OBJECTIVES SET OUT IN 10 CFR PART 61, SUBPART C

Section 3116 of the NDAA provides in relevant part:

[T]he term "high-level radioactive waste" does not include waste from reprocessing of spent nuclear fuel that the Secretary of Energy...in consultation with the Nuclear Regulatory Commission...determines –

***

(3)(A) [W]ill be disposed of –

(i) in compliance with the performance objectives set out in subpart C of part 61 of title 10, Code of Federal Regulations[.]

7.1 10 CFR PART 61 PERFORMANCE OBJECTIVES

Subpart C of 10 CFR Part 61 lists one general requirement and four performance objectives, which are reproduced below.

7.1.1 Section 61.40, General Requirement

Land disposal facilities must be sited, designed, operated, closed, and controlled after closure so that reasonable assurance exists that exposures to humans are within the limits established in the performance objectives in Sections 61.41 through 61.44.

7.1.2 Section 61.41, Protection of the General Population from Releases of Radioactivity

Concentrations of radioactive material which may be released to the general environment in ground water, surface water, air, soil, plants, or animals must not result in an annual dose exceeding an equivalent of 25 millirems to the whole body, 75 millirems to the thyroid, and 25 millirems to any other organ of any member of the public. Reasonable effort should be made to maintain releases of radioactivity in effluents to the general environment as low as is reasonably achievable.

CBU-PIT-2005-00141
REV. 0
June 30, 2005

KEYWORDS:
Salt Disposition
Highly Radioactive Nuclide
Sr-90, Cs-137, TRU
DDA, ARP, MCU, SWPF
Removal Efficiency

RETENTION: PERMANENT
CLASSIFICATION: U
Does not contain UCNI

Removal of Highly Radioactive Nuclides from SRS Salt Waste

S. H. Reboul

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Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
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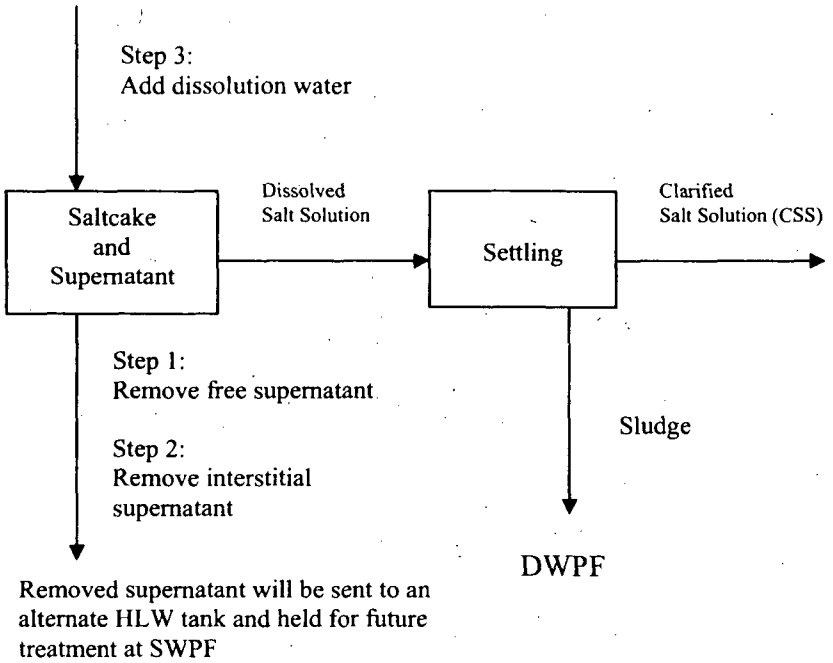
Prepared for U.S. Department of Energy Under Contract No. DE-AC09-96S

Planned Treatment Processes and Projected Removal Efficiencies

Deliquification, Dissolution, and Adjustment (DDA):



The DDA process relies on two removal mechanisms, removal of supernatant fluid through pumping/draining and removal of suspended solids (sludge) through gravity settling/clarification. As shown in Step 1 of the flow diagram, the DDA process is initiated when free supernatant solution (supernatant above saltcake) is pumped from the tank. During Step 2, interstitial supernatant fluid is drained/removed from the saltcake after a well is generated through the saltcake. All fluid removed is sent to an alternate tank for future treatment at the SWPF. In Step 3, the saltcake is dissolved and transferred to a settling tank. Following a settling period, the clarified salt solution (CSS) is decanted out of the tank and dispositioned to SPF. In the future, the settled solids will ultimately be removed from the tank and dispositioned to DWPF. Note that early batches of CSS containing elevated Cs-137 concentrations will undergo further treatment via ARP/MCU before being dispositioned to SPF.

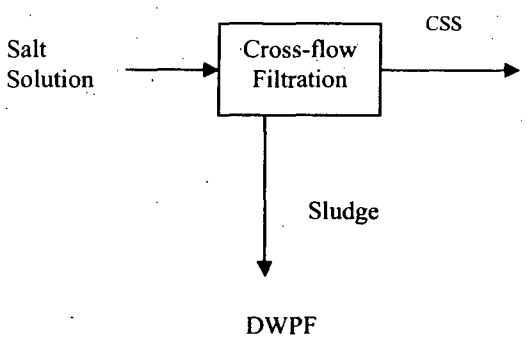
In determining the overall removal efficiencies of DDA, the following individual removal efficiencies are assumed. Deliquification typically removes 50% of the supernatant solution (Shah and Hopkins, 2004), with a lower bound of 30% and an upper bound of 70% (these assumptions incorporate the lessons learned from Tank 41 salt). For a thirty day period, gravity settling typically removes two-thirds of the suspended solids (Gillam, 2005), with a lower bound of 50% and an upper bound of 80%. Given the magnitude of these variabilities, the uncertainty of the overall removal efficiency is typically ± 20%, regardless of the soluble/insoluble distribution.

Removal efficiencies for the highly radioactive nuclides are given in Table 7. Nominal removal efficiencies range from 50% to 66%, depending on the solubility of the constituent (50% for highly soluble constituents; 66% for highly insoluble constituents). For Sr-90, the nominal removal efficiency is 66%, with a lower bound of 46% and an upper bound of 86%. For Cs-137, the nominal removal efficiency is 50%, with a lower bound of 30% and an upper bound of 70%. For TRU, the nominal removal efficiency is 63%, with a lower bound of 43% and an upper bound of 83%.

Table 7
Removal of Highly Radioactive Nuclides Using DDA

Radionuclide	Projected Removal Efficiency, %		
	Nominal	Lower Bound	Upper Bound
Sr-90	66	46	86
Cs-137	50	30	70
Pu-238	63	43	83
Am-241	66	46	86
Cm-244	66	46	86
Pu-239	59	39	79
α-emitting TRU	63	43	83

Actinide Removal Process (ARP) w/o Monosodium Titanate (MST):



The ARP process (w/o MST sorption) relies on one removal mechanism, removal of suspended solids (sludge) by cross-flow filtration. Removed solids are dispositioned to DWPF. CSS is dispositioned to SPF.

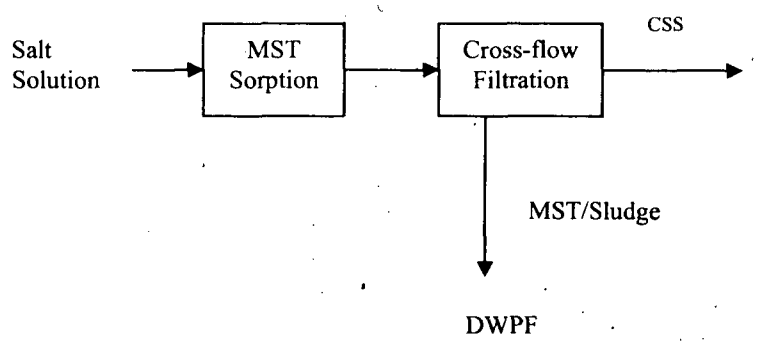
Cross-flow filtration is assumed to nominally remove 100% of the suspended solids, although it is recognized that actual removal will be slightly lower. A lower bound of 99.5% removal is assumed, based on industrial filtration experience.

Removal efficiencies for the highly radioactive nuclides are given in Table 8. For Sr-90, the removal efficiencies are high (98.0 – 99.9%), due to the low solubility which makes particulate removal significant. In contrast, for Cs-137, the removal efficiencies are negligible, due to the high solubility which makes particulate removal insignificant. For TRU, the range of removal efficiencies is relatively broad (51 – 93%), reflecting the expectation that appreciable quantities of both soluble and insoluble phases will be present.

Table 8
Removal of Highly Radioactive Nuclides Using ARP w/o MST

Radionuclide	Projected Removal Efficiency, %		
	Nominal	Lower Bound	Upper Bound
Sr-90	99.6	98.0	99.9
Cs-137	~ 0	~ 0	~ 0
Pu-238	75	43	92
Am-241	98.8	94.9	99.7
Cm-244	98.8	94.8	99.7
Pu-239	54	23	82
α-emitting TRU	78	50	93

ARP w/ MST:



The ARP process (w/ MST sorption) relies on two removal mechanisms, removal of soluble constituents by MST sorption and removal of suspended solids (MST and sludge) by cross-flow filtration. Removed solids are dispositioned to DWPF. CSS is dispositioned to SPF.

Duration of the MST strike is assumed to be 24 hours. Assumed MST decontamination factors (DFs) are given in the table below. Nominal DFs are those reported by d'Entremont (2005) for a twenty four hour duration strike. Lower and upper bounding DFs are those reported by Le (2005) under conditions of four to twenty four hour duration strikes. Assumptions regarding efficiency of the cross-flow filter are the same as in the previous case (ARP w/o MST).

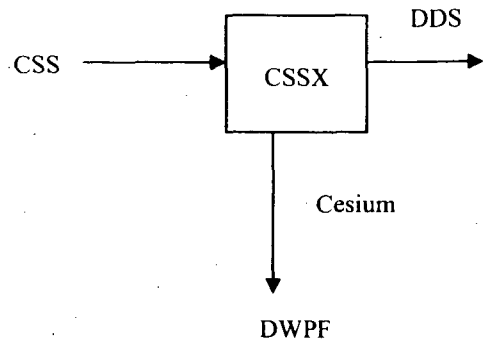
Constituent	ARP MST Soluble Phase Decontamination Factor		
	Nominal	Lower Bound	Upper Bound
Strontium	130	20	130
Cesium	0	0	0
Plutonium	13	5.5	13
Americium	1.7	1.0	4.6
Curium	1.7	1.0	1.7

Removal efficiencies for the highly radioactive nuclides are given in Table 9. For Sr-90, the removal efficiencies are extremely high (99.4 – 99.999%), due to a) the very low solubility of strontium that makes particulate removal significant and b) the very high removal efficiency of MST for soluble phase strontium. For Cs-137, the removal efficiencies are negligible due to a) the high solubility of cesium that makes particulate removal insignificant and b) the inability of MST to sorb soluble phase cesium. For TRU, the removal efficiencies are relatively high (96 – 99%), due to the combination of low solubility and reasonably high soluble phase removal. Clearly, the combination of MST and cross-flow filtration is an effective treatment for Sr-90 and TRU nuclides.

Table 9
Removal of Highly Radioactive Nuclides Using ARP w/ MST

Radionuclide	ARP w/ MST Projected Removal Efficiency, %		
	Nominal	Lower Bound	Upper Bound
Sr-90	99.997	99.4	99.999
Cs-137	~ 0	~ 0	~ 0
Pu-238	98.1	89.4	99.9
Am-241	99.3	94.9	99.9
Cm-244	99.3	94.8	99.8
Pu-239	96.4	85.8	98.6
α-emitting TRU	98.1	90.1	99.9

Modular Caustic Side Solvent Extraction Unit (MCU):

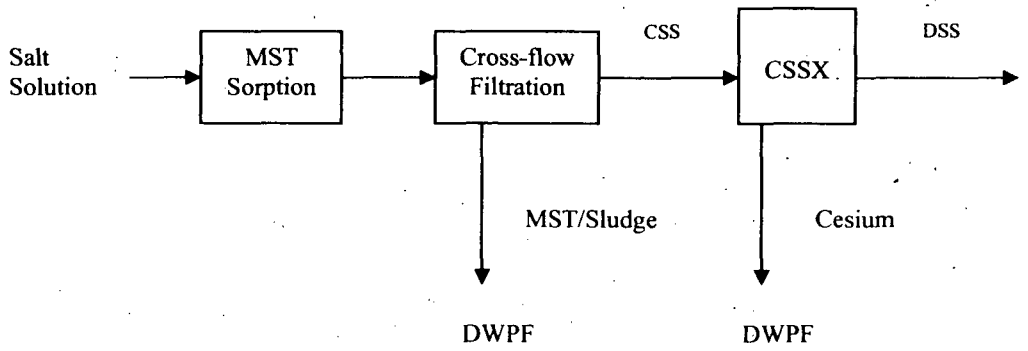


The MCU process relies on one removal mechanism, removal of soluble phase cesium by liquid-liquid extraction utilizing the Caustic Side Solvent Extraction (CSSX) technology. In this process, CSS is the feed stream and the effluents include a concentrated cesium stream that is dispositioned to DWPF and a decontaminated salt solution (DSS) that is dispositioned to SPF.

For MCU, a DF of 12 is assumed for soluble phase cesium (d'Entremont, 2005). For Sr-90 and TRU nuclides, the MCU removal efficiency is assumed to be zero.

The nominal removal efficiency for Cs-137 is 91%, with a lower bound of 90% and an upper bound of 92%.

Salt Waste Processing Facility (SWPF) Treatment:



The SWPF treatment process relies on three removal mechanisms: 1) removal of soluble constituents by MST sorption; 2) removal of suspended solids by cross-flow filtration; and 3) removal of cesium by liquid-liquid extraction utilizing CSSX. In this process, salt solution is first treated with MST and then

filtered to produce a CSS that is subsequently treated with CSSX. The removed solids and the concentrated cesium streams are dispositioned to DWPF, and the DSS stream is dispositioned to SPF.

Duration of the MST strike is assumed to be 12 hours (Parsons, 2004). Assumed DFs for the MST treatment are given in the table below. Nominal MST DFs are those reported by d'Entremont (2005) for a twelve hour duration strike. Lower and upper bounding MST DFs are those reported by Le (2005) under conditions of four to twenty four hour duration strikes. Assumptions regarding efficiency of the cross-flow filter are the same as in the previous ARP cases. For SWPF, the CSSX DF for soluble phase cesium is assumed to be 40,000 (d'Entremont, 2005).

Constituent	SWPF MST Soluble Phase Decontamination Factor		
	Nominal	Lower Bound	Upper Bound
Strontium	20	20	130
Cesium	0	0	0
Plutonium	5.5	5.5	13
Americium	4.6	1.0	4.6
Curium	1.0	1.0	1.7

Removal efficiencies for the highly radioactive nuclides are given in Table 10. For Sr-90, the removal efficiencies are very high (99.4 to 99.999%), due to the combination of effective particulate removal and high soluble phase decontamination. For Cs-137, the removal efficiencies are extremely high (99.990 to 99.998%, respectively), due to the extremely high removal efficiency of CSSX for soluble phase cesium. For TRU, the removal efficiencies are high (91 to 99%), although lower than those of Sr-90 and Cs-137. Clearly, the SWPF treatments offer an effective means of removing Sr-90, Cs-137, and TRU nuclides.

Table 10
Removal of Highly Radioactive Nuclides Using SWPF

Radionuclide	SWPF Projected Removal Efficiency, %		
	Nominal	Lower Bound	Upper Bound
Sr-90	99.98	99.4	99.999
Cs-137	99.998	99.990	99.998
Pu-238	95.5	89.4	99.4
Am-241	99.7	94.9	99.94
Cm-244	98.8	94.8	99.8
Pu-239	91.6	85.8	98.6
α-emitting TRU	96	90	99.5

CBU-PIT-2005-00146
Revision 0

SALTSTONE
PERFORMANCE OBJECTIVE DEMONSTRATION DOCUMENT
(U)

PREPARED BY:
Kent H. Rosenberger
Bernice C. Rogers
R. Kim Cauthen

JUNE 2005

APPROVED for Release for
Unlimited (Release to Public)

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under
Contract Number DE-AC09-96SR18500

Conduct of Engineering Manual, Procedure 2.60, Technical Reviews and Procedure 2.31 Engineering Calculations).

Software QA is conducted in accordance with the requirements of the WSRC 1Q Manual through the development and execution of Software Quality Assurance Plans. This procedure fulfills the requirements of DOE Order O414.1A, *Quality Assurance*, 10 Code of Federal Regulations (CFR) 830 Subpart A, "Quality Assurance Requirements"

- HELP has undergone substantial verification through the EPA. (See Appendix D) Enhancements to the model have been made to improve predictions and consequently the current version of HELP has been accepted by EPA and the regulated community as an appropriate tool for estimating water balance at landfills.

- The PORFLOW Software Quality Assurance Plan (Collard, 2002) describes the controls for the software and presents results of software grading and testing and acceptance results. Additionally the software vendor states that over 100 publications and project reports on the benchmarking, verification and application of the model are available. (See Appendix D for further description)

- LADTAP verification has been conducted to ensure results are consistent with expected results. Description of the verification process and results are contained in the User's Manual. (Simpkins, 2004a)

4.1.4 Groundwater Pathway Simulation Input Parameters and Assumptions

The dose estimates for the SDF were generated from the modeling efforts contained in the 2005 SA (Cook et al., 2005). The 2005 SA documents improvements in modeling methods, closure cap design and updated saltstone inventory due to facility changes. The 2005 SA recalculates both groundwater and air transport.

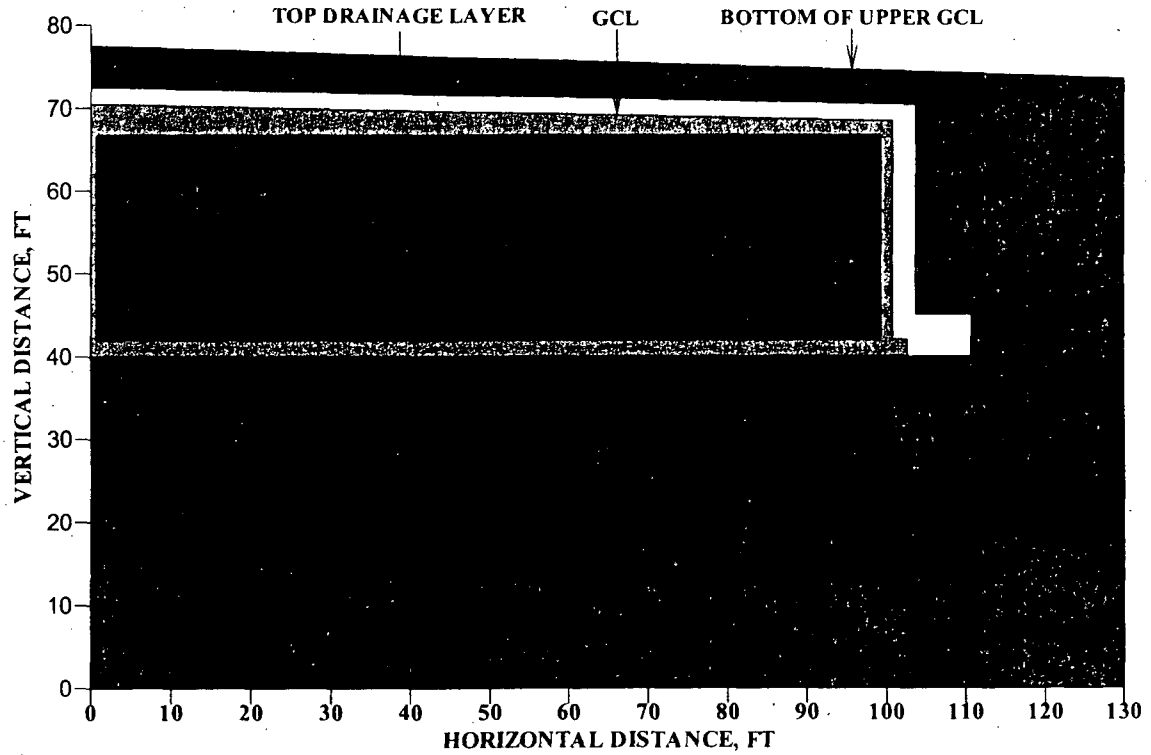
This section provides the inputs to the three simulation models used to generate the dose calculations and exposure pathways from contaminants contained in the groundwater.

The 2005 SA describes the evaluation models in the following manner. The dimensions of the vault and lower portion of the closure are summarized in Table 3-1. The "concrete" zone above the saltstone grout pour level (at 66.75 ft) includes the top portion of the center and exterior walls and the concrete roof. The drainage layer is a gravel/sand mixture. It is used to reduce water perching above the vault. Test modeling results indicate that perching water can increase water flow rate through the vault, which results in a higher contaminant leaching rate. The drainage layer is divided into three sections: top, vertical and bottom. The initial hydraulic conductivities in these sections are the same. However, these conductivities degrade at different rates (Phifer, 2004) as will be

described later. Because the backfill is largely soil excavated during vault construction, it is assumed that the backfill soil has the same properties as the native soil. There is a GCL above the vault roof. Since the hydraulic conductivity of the saltstone grout and the vault is less than or equal to the conductivity of the GCL (10^{-9} cm/sec), the lower GCL is ignored in the simulation.

The HELP model was used to simulate water movement in the unsaturated zone. The modeling domain is defined as the bottom of the upper GCL to the top of the saturated zone. The PORFLOW simulates transport from the bottom of the upper GCL to the water table and to the compliance point. Figure 4-2 shows the domain of the PORFLOW simulation.

Figure 4-2. Conceptual Model for Saltstone Vault 4 (Cook et al., 2005)



It should be noted that only one half of the vault in the short dimension was modeled to take advantage of symmetry in the long dimension.

The hydraulic conductivities used in the simulation for the engineered porous media (saltstone grout, concrete, and gravel drain layers) were measured by Core Lab (Yu et al., 1993). These measured values are used for the first 100 years. The hydraulic conductivities are assumed to increase for saltstone grout and concrete in the ensuing

years. Table 4-2 shows the time periods used in the model as well as the assumptions in changing conditions of the cap that defines the time period. For instance, institutional controls for the first 100 years are assumed to maintain the cap intact. Phifer (2003) discusses in Chapters 3 and 4 the degradation over time. The mechanisms assumed to impact the hydraulic properties of the closure cap are pine forest succession, erosion and colloidal clay migration. These degradation mechanisms are the subject of a 2003 evaluation (Phifer, 2003). The changes in hydraulic properties as the closure cap degrades are presented in Table 4-3.

Table 4-2. Material Property Results for HELP Modeling (Phifer, 2003)

Year	Vegetation	Topsoil Layer Thickness (inches)	Erosion Barrier Saturated Hydraulic Conductivity (cm/s)	Middle Backfill Layer Saturated Hydraulic Conductivity (cm/s)
0	Bamboo	6	3.97E-04	1.00E-04
100	Bamboo	5.980	3.97E-04	1.20E-04
300	Pine Forest	5.940	3.98E-04	1.60E-04
550	Pine Forest	5.890	3.99E-04	2.30E-04
1,000	Pine Forest	5.800	4.01E-04	4.60E-04
1,800	Pine Forest	5.640	4.06E-04	1.60E-03
3,400	Pine Forest	5.320	4.15E-04	3.20E-03
5,600	Pine Forest	4.880	4.27E-04	3.20E-03
10,000	Pine Forest	4.0	4.51E-04	3.20E-03
Year	Upper Drainage Layer Saturated Hydraulic Conductivity (cm/s)	One Square Centimeter Holes in Upper GCL[1] (#/acre)	Lower Drainage Layer Saturated Hydraulic Conductivity (cm/s)	
0	1.00E-01	0	1.00E-01	
100	8.60E-02	0	1.00E-01	
300	6.30E-02	7,432	9.98E-02	
550	4.30E-02	26,013	9.89E-02	
1,000	2.10E-02	59,458	9.61E-02	
1,800	6.30E-03	118,916	8.96E-02	
3,400	3.20E-03	237,832	7.56E-02	
5,600	3.20E-03	401,341	5.62E-02	
10,000	3.20E-03	728,360	1.74E-02	

[1] Number of HELP model installation defects

Table 4-3. Saturated Hydraulic Conductivities (cm/sec) (Cook et al., 2005)

Time (years)	0 to 100	100 to 300	300 to 550	550 to 1,000	1000 to 1,800	1,800 to 3,400	3,400 to 5,600	5,600 to 10,000
			Horizontal conductivity:					
Nati/Back	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04	1.00E-04
Drain Bot	1.00E-01	9.99E-02	9.97E-02	9.90E-02	9.71E-02	9.30E-02	8.63E-02	7.46E-02
Drain Ver	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
Drain Top	1.00E-01	9.99E-02	9.93E-02	9.75E-02	9.28E-02	8.25E-02	6.58E-02	3.66E-02
Concrete	1.00E-12	5.20E-12	1.29E-11	3.16E-11	7.64E-11	1.98E-10	4.19E-10	1.00E-09
Saltstone	1.00E-11	3.00E-11	5.50E-11	1.00E-10	1.80E-10	3.40E-10	5.60E-10	1.00E-09
			Vertical conductivity:					
Drain Bot	9.52E-02	6.45E-02	2.70E-02	8.94E-03	3.34E-03	1.41E-03	7.25E-04	3.93E-04
Drain Top	8.89E-02	4.21E-02	1.29E-02	3.78E-03	1.36E-03	5.69E-04	2.91E-04	1.57E-04

The GCL has a saturated hydraulic conductivity of 5.0E-09 cm/sec as quoted by the manufacturer (GSE, 2002).

As time progresses fines intrude into the gravel layer and will begin to plug the drainage layer from the bottom. The cumulative amount of pluggage (Phifer, 2004) is estimated in Table 4-4. Until complete pluggage occurs (post 10,000 years) there will be no ponding and subsequent hydraulic pressure on the waste form. Therefore cracks in the waste form can be ignored due to adequate suction head in the waste form as indicated in Appendix A.4 of Cook et al., (2005).

Table 4-4. Plugged-Zone Thickness as a Function of Time (Phifer, 2004;Freeze and Cherry, 1979)

Time (years)	Plugged-Zone Thickness (feet)
0	0
100	0.0005
300	0.005
550	0.022
1,000	0.08
1,800	0.21
3,400	0.49
5,600	0.88
10,000	1.66

The initial hydraulic conductivity is 10^{-1}cm/sec for the gravel zone.

The lower GCL is expected to degrade over time impacting the infiltration rate through the layer. Table 4-5 (Phifer, 2004) presents the rates used in the simulation.

Table 4-5. Infiltration Rates Used as Upper Boundary Conditions (Phifer, 2004)

Time Interval	Infiltration Rate (in/yr)
0 to 100	0.39
100 to 300	1.73
300 to 550	5.48
550 to 1,000	9.97
1,000 to 1,800	12.90
1,800 to 3,400	13.90
3,400 to 5,600	14.06
5,600 to 10,000	14.09

The molecular diffusion coefficients chosen for use in the PORFLOW model are within the range reported for ionic solutes in porous media. The values are near the end of the lower range for concrete and saltstone grout. Table 4-6 presents the coefficients used in the modeling.

Table 4-6. Molecular Diffusion Coefficients (Domenico and Schwartz, 1990)

Porous Media	cm^2/sec	$cm^2/year$
Native/Backfill Soil	5.E-05	1.58E+02
Drainage Layer	5.E-05	1.58E+02
Saltstone	5.E-09	1.58E-01
Concrete	1.E-08	3.15E-01

Climate changes and cycles were evaluated. Data necessary for inclusion in the HELP model was synthesized using data from SRS Weather Stations. The data used in the model is presented in Table 4-7 and 4-8.

Table 4-7. Average Monthly SRS Temperature and Precipitation Data (Phifer and Nelson, 2003)

Month	Average Temperature (°F)	Average Precipitation (inches)
January	46.3	4.38
February	50.0	3.95
March	57.2	4.68
April	64.3	2.91
May	72.1	3.56
June	78.4	4.99
July	81.6	5.43
August	80.3	5.41
September	75.2	3.93
October	65.1	3.12
November	56.7	2.96
December	48.8	3.45

Table 4-8. Synthetic Daily Temperature and Precipitation Statistics over 100 Years (Phifer and Nelson, 2003)

	Average	Median	Standard Deviation	Minimum	High
Daily Temperature (°F)	64.73	66.50	14.24	19.40	92.70
Yearly Temperature (°F)	64.73	64.69	0.83	62.40	66.89
Daily Precipitation (inches)	0.13	0.00	0.37	0.00	6.87
Yearly Precipitation (inches)	48.96	48.83	7.74	29.28	68.99

The HELP model employs many input parameters. Tables 4-9 and 4-10 present several of the site specific input parameters necessary.

Table 4-9. Site Specific Input Parameters-Area and Initial Moisture for the HELP Model (Phifer, 2003)

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area	19.63 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.

Table 4-10. Site Specific Input Parameter Values-Curve Numbers (Phifer, 2003)

CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope	3%
Slope length	450 ft.
Soil Texture	5 (HELP model default soil texture)
Vegetation	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number	54.4

Table 4-11 provides the actual HELP modeling values used for the initial time of 0 years. HELP model input parameters for subsequent years are found in Phifer (2003) through 10,000 years. Each of these cases accounts for an increasing degradation of the cap.

Table 4-11. HELP Model Input Data (0 Years) (Phifer, 2003)

Input Date:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	19.63 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3%
Slope length =	450 ft.
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 54.4	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Upper Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Middle Backfill	4	1 (vertical percolation layer)
Upper Drainage Layer	5	2 (lateral drainage layer)
Upper GCL	6	3 (barrier soil liner)
Lower Backfill	7	1 (vertical percolation layer)
Lower Drainage Layer	8	2 (lateral drainage layer)
Lower GCL	9	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (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	1	12	-	0.06	0.056	0.052	0.056
4	1	12	-	0.37	0.24	0.136	0.24
5	2	12	-	0.38	0.08	0.013	0.08
6	3	0.2	-	0.75	0.747	0.40	0.75
7	1	58.57	-	0.37	0.24	0.136	0.24
8	2	24	-	0.38	0.08	0.013	0.08
9	3	0.2	-	0.75	0.747	0.40	0.75

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 are missing from the table

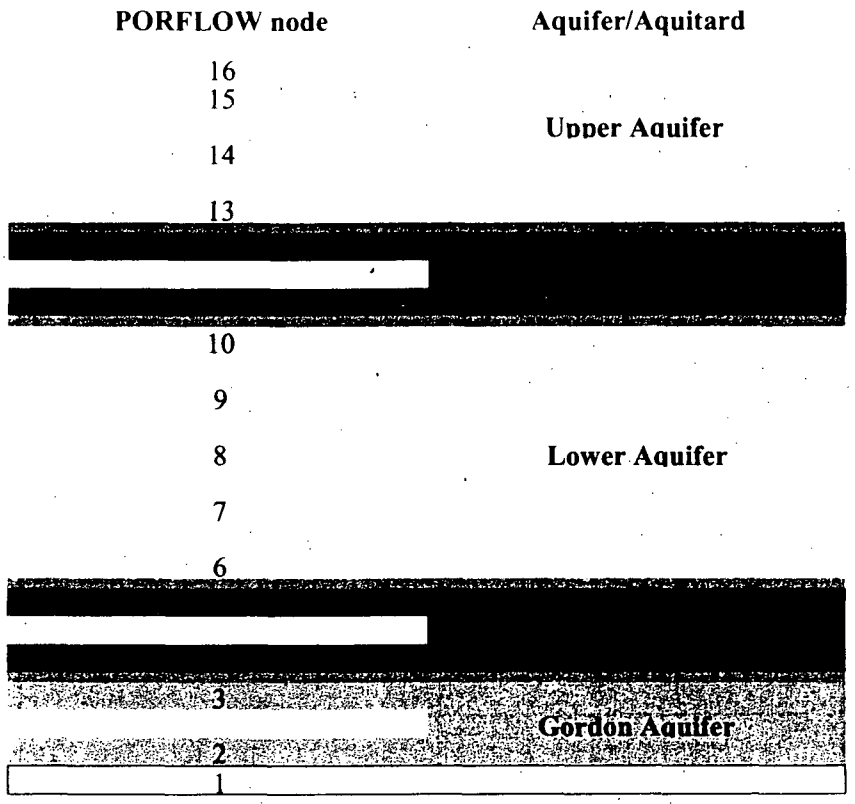
Table 4-11. HELP Model Input Data (0 Years) (Phifer, 2003) (continued):

	Layer Type	Sat. Hyd. Conductivity((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	1	3.97E-04	-	-	-	-	-
4	1	1.00E-04	-	-	-	-	-
5	2	1.00E-01	450	3	-	-	-
6	3	5.00E-09	-	-	-	-	-
7	1	1.00E-04	-	-	-	-	-
8	2	1.00E-01	150	11.4	-	-	-
9	3	5.00E-09	-	-	-	-	-

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1	-	-	-	-
2	1	-	-	-	-
3	1	-	-	-	-
4	1	-	-	-	-
5	2	-	-	-	-
6	3	-	-	-	-
7	1	-	-	-	-
8	2	-	-	-	-
9	3	-	-	-	-

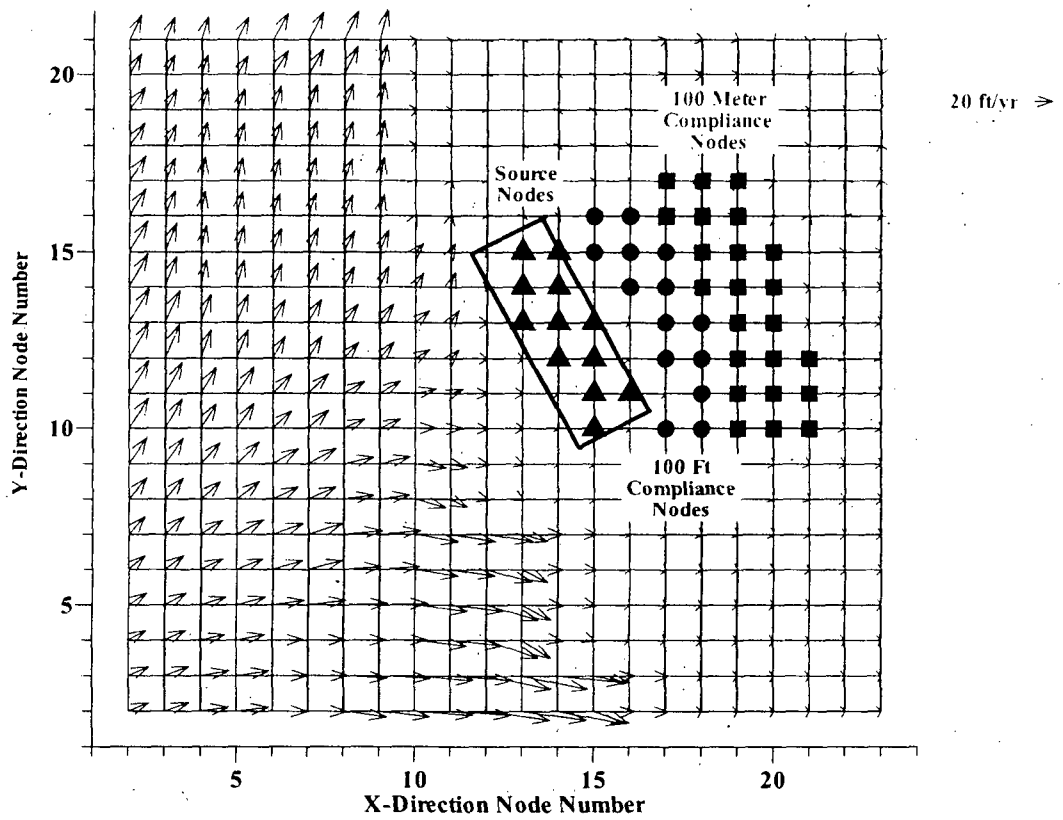
Once flow of contaminants, as a function of time, has been established through the vadose zone, the PORFLOW model simulates the transport in the groundwater to the compliance point located 100 meters away from the disposal facility. Aquifer transport simulations (Cook et al., 2005) are based on a groundwater model encompassing the General Separations Area (GSA) (Flach, 2004; Flach and Harris, 1999). The Savannah River Site F-, E-, H-, S- and Z-Areas are included in the GSA. Saltstone disposal units reside in Z-Area. The model domain is bounded by Fourmile Branch to the south, Upper Three Runs to the north, F-area to the west, and McQueen Branch to the east as shown in Figure 3-1. Vertically the model extends from the ground surface to the top of the Crouch Branch confining unit. The major hydrostratigraphic units from top to bottom are the Upper Three Runs or water table aquifer, Gordon confining unit, and Gordon aquifer. The Upper Three Runs aquifer contains a "upper" and "lower" aquifer zones separated by the "tan clay confining zone". Figure 4-3 presents the vertical stratigraphy used in the model.

Figure 4-3. Schematic of the Aquifer/Aquitard System Model (Cook et al., 2005)



The location of the source and 100 meter compliance nodes for input into the PORFLOW model are shown in Figure 4-4. Groundwater flow is for the upper aquifer.

Figure 4-4. Locations of Source Nodes and Compliance Nodes (Cook et al., 2005)



The distribution coefficients (K_d) used for the modeling runs and their origin are presented in Table 4-12.

Table 4-12. Modeling Distribution Coefficients (K_d) (Cook et al., 2005)

K_d Values and References used in the Vault 4 Special Analysis								
Element	Soil K_d (mL/g)	ref	Gravel K_d (mL/g)	ref	Clay K_d (mL/g)	ref	Saltstone Grout and Vault K_d (mL/g)	ref
NO_3	0		0		0		0	
H	0	a	0	a	0	b	0	c
C	2	d	2	d	1	e	5000	c
K	3	f			5	f	2	f
Co	8	f			96	f	100	f
Ni	400	e	400	e	650	e	100	c
Se	36	f	5	g	76	f	0.1	c
Kr	0	f			0	f	0	f
Sr	10	j	10	j	110	e	1	c
Zr	600	e	600	e	3300	e	5000	c
Nb	160	e	160	e	900	e	500	c
Tc	0.1	f	0.1		0.1	f	1000	c
Sn	130	e	130	e	670	e	1000	c
I	0.6	h	0.6	h	1	e	2	c
Cs	330	i	330	i	1900	e	20	c
Eu	1900	f			8400	f	5000	f
Pb	270	e	270	e	550	e	500	c
Bi	450	f	450	f	12000	f	5000	f
Po	150	e	150	e	3000	e	500	k
Rn	0	f			0	f	0	f
Ra	500	e	500	e	9100	e	50	c
Ac	450	e	450	e	2400	e	5000	l
Th	3200	e	3200	e	5800	e	5000	c
Pa	550	e	550	e	2700	e	5000	c
U	800	m	800	m	1600	e	2000	c
Np	5	e	5	e	55	e	5000	c
Pu	370	f			6500	f	5000	f
Pu_56	15	f			50	f	5000	f
Am	1900	e	1900	e	8400	e	5000	c
Cm	4000	e	4000	e	6000	e	5000	c
Cf	510	a	510	a	8400	l	5000	l

a	NCRP, 1996, Table 4-1, page 44
b	Used value for "soil"
c	Bradbury and Sarott, 1995, Table 4, page 42, Region II Reducing
d	McIntyre, 1988
e	Sheppard and Thibault, 1990, Table 1, page 472
f	Kaplan, 2004, Table 5, page 15
g	Kaplan et al., 1998, Table 6, page 9 for Se
h	Hoeffner, 1984a, Table 2, page 5 for I
i	Hoeffner, 1984b, Table I, page 27 for Cs
j	Hoeffner, 1985, Figure 4, page 30 for Sr
k	Assumed to be the same as for Pb
l	Assumed to be the same as for Am
m	Serkiz and Johnson, 1994, Figure 4-12, page 69

The following information in Table 4-13 from the HELP modeling is also needed for the PORFLOW evaluation.

Table 4-13. Inputs for PORFLOW Vadose Zone Modeling (Phifer, 2003)

Year	Infiltration through Upper GCL (in/yr)	Lower Drainage Layer Saturated Hydraulic Conductivity (cm/s)
0	0.36	1.00E-01
100	0.41	1.00E-01
300	3.05	9.98E-02
550	7.90	9.89E-02
1,000	12.04	9.61E-02
1,800	13.76	8.96E-02
3,400	14.03	7.56E-02
5,600	14.08	5.62E-02
10,000	14.09	1.74E-02

4.1.5 Groundwater Pathway Code Results

The calculated maximum groundwater concentrations at any time between 100 and 10,000 years for a one curie inventory of each radionuclide in Vault 4 was entered into the LADTAP XL code in order to calculate doses via all pathways (resident farmer) as indicated in Figure 4-1. Table 4-14 presents the calculated mrem/Ci on an annual basis for those radionuclides for which an inventory limit of less than 1.0E+20 Ci is necessary assuming a performance objective of 25 mrem/yr to the whole body. The table includes the dose per radionuclide for each of the modeled pathways and assumes that the maximum concentration for each radionuclide occurs concurrently. The sensitivity for vault performance after 10,000 years is presented in section 8.4.

8 gm/m^3 to 11 gm/m^3 (USDOE, 1991 and USEPA, 1991). The CAP88 code has been verified by the EPA (Chaki, 2002).

Selenium-79 is not contained within the CAP88 dose factor library; therefore a hand calculation using the methods in Simpkins (1999) was used to estimate the dose at 100 m. The hand calculation is based on formulas found in NRC Regulatory Guides (1977a, 1977b). The calculated dose is based on direct plume shine, inhalation, and ingestion of vegetables, meat, and milk exposed to airborne radioactivity, though there is no shine component from Se-79. The meteorological and consumption data come from the same sources as for CAP88, but the dose conversion factors come from the USDOE (1988b, 1988c).

4.2.4 Analysis Inputs/Assumptions

4.2.4.1 Diffusion Flux Rates

PORFLOW was used to evaluate transient radionuclide transport through the soil cover above Saltstone Vault 4, as presented in Figures 3-4 and 3-5 and Table 3-1, in order to determine the gaseous radionuclide flux at the land surface.

The evaluation (Cook et al., 2005) assumed the following forms for the gaseous state of the radionuclides:

- C-14 exists as part of the CO_2 molecule
- Cl-36, H-3, and I-129 exist as diatomic gasses
- Sb-125, Se-79, Sn-121m, and Sn-126 exist as monatomic gasses.

The PORFLOW code used only the diffusive and net decay terms and disabled the advection term. Flow field was assumed to be isobaric and isothermal. The boundary conditions imposed on the model were

- No-flux specified for all radionuclides along sides and bottom
- Radionuclide concentrations set to 0 at land surface.

Values for total porosity and long-term residual saturation of the closure cap materials were based on the investigation summarized in Phifer and Nelson (2003) and are given in Table 4-15.

Table 4-15. Porosity, Residual Saturation and Air-Filled Porosity Values (Phifer and Nelson, 2003)

Layer Material	Representative Porosity	Long-term Residual Saturation	Air-filled Porosity
Erosion Barrier	0.07	0.83	1.19E-02
Upper Backfill	0.38	0.63	1.39E-01
Upper Drainage	0.38	0.58	1.58E-01
Lower Backfill	0.37	0.72	1.04E-01
Lower Drainage	0.31	0.5	1.60E-01
Concrete	0.18	0.99	2.00E-03
Saltstone	0.42	0.99	4.00E-03

Molecular diffusion coefficients for each radionuclide were calculated based on the effective open air diffusion coefficient of radon, as reported in Nielson et al. (1984). The calculated coefficients are given in Table 4-16.

Table 4-16. Effective Air-Diffusion Coefficients for Each Radionuclide/Compound, by Material (Nielson et al., 1984)

Radionuclide	Saltstone and Concrete (m^2/yr)	Lower Drainage (m^2/yr)	Lower Backfill (m^2/yr)	Upper Drainage and Upper Backfill (m^2/yr)	Erosion Barrier (m^2/yr)
$^{14}CO_2$	4.86E-01	1.39E+01	6.24E+00	1.04E+01	1.73E+00
$^{36}Cl_2$	3.88E-01	1.11E+01	4.99E+00	8.31E+00	1.39E+00
$^{3}H_2$	1.34E+00	3.84E+01	1.73E+01	2.88E+01	4.80E+00
$^{129}I_2$	2.05E-01	5.85E+00	2.63E+00	4.39E+00	7.32E-01
^{125}Sb	2.95E-01	8.41E+00	3.78E+00	6.30E+00	1.05E+00
^{126}Sb	2.93E-01	8.38E+00	3.77E+00	6.28E+00	1.05E+00
^{79}Se	3.70E-01	1.06E+01	4.76E+00	7.93E+00	1.32E+00
^{121m}Sn	2.99E-01	8.55E+00	3.85E+00	6.41E+00	1.07E+00
^{126}Sn	2.93E-01	8.38E+00	3.77E+00	6.28E+00	1.05E+00

4.2.4.2 Dose Release Factors

The dose release factors (DRF) to the maximally exposed individuals (MEI) were determined at 100 m (Simpkins, 2004b). The release was assumed to be from ground level and to occur over one year. CAP88 was used to calculate the DRF due to a point source, except for Se-79 which used hand calculations. CAP88 has the ability to handle area source, but the model is not deemed to be appropriate close to the source (Moore et al., 1979). Instead, hand calculations were performed for a point versus area source for average meteorological conditions (D stability, 4.5 m/s wind speed) (USDOE, 1997), and the ratio used to determine the CAP88 point source DRF decrease due to an area release. Using the Pasquill Briggs Diffusion coefficient (Moore et al., 1979), the vertical diffusion coefficient at 100 m was calculated to be 5.6 m (Simpkins, 2004b). The sector-average relative air concentration for a point source was estimated to be 8.1E-04 s/m^3 using a Gaussian plume equation (USNRC, 1977b). The sector-average relative air concentration for an area source the size of Vault 4 was estimated to be 1.0E-04 s/m^3 using the formula by Napier, (2002) a factor of 8 below the point source estimate. The CAP88 point source values were reduced by a factor of 5 to determine the Vault 4 DRFs. The reduction factor was reduced from 8 to 5 to account for the fact that actual meteorological data was not used.

4.2.4.3 MEI Dose

The dose to the MEI from 1 Ci of radionuclide in the vault was determined by multiplying the dose release factor at 100 m by the maximum diffusion flux rate calculated after 100 yrs. Note: Due to the short half-life of Sb-125 (2.77 yrs), its maximum dose to the MEI occurs at the site boundary during the 100-yr period of institutional control.

4.2.5 Analysis Results

The radionuclide Sb-126 is a daughter product of, and in equilibrium with, Sn-126. Therefore, the dose for Sb-126 is not calculated individually, but combined into the dose for Sn-126 (Cook et al., 2005). The SDF Vault 4 dose results due to air pathways are presented in Table 4-17 (Simpkins, 2004b).

RESPONSE TO RAI COMMENT 2
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
Cook et al. 2002	Tables 5-2, 5-3, 5-4, and 5-5 included within response	
Cook et al. 2005	Table A-13 included within response	
Lee 2004 (WSRC-TR-2004-00245)	Section 2.3.2 "External DCFs" included within response	

*Excerpt Locations:

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RESPONSE TO RAI COMMENT 3
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
Cook 2000 (WSRC-RP-2000-00523)	Entire document enclosed following response	
Cook et al. 2005 (WSRC-TR-2005-00074)	Representative excerpt(s) enclosed following response	executive summary, Section 2.1 and Section A.4 extracted
Flach et al. 1999 (WSRC-TR-99-00248)	Excerpt enclosed following response	Abstract and Tables 4-1, 4-4, 4-5 extracted
Flach 2004 (WSRC-TR-2004-00106)	Representative excerpt(s) enclosed following response	introduction extracted
Flach et al. 2005 (WSRC-TR-2005-00093)	Representative excerpt(s) enclosed following response	Section 2.6 extracted
Kaplan 2004 (WSRC-RP-2004-00267)	Entire document enclosed following response	
Phifer and Nelson 2003 (WSRC-TR-2003-00436)	Representative excerpt(s) enclosed following response	exec summary and app E-N
Phifer 2004 (SRNL-EST-2004-00103)	Excerpt enclosed following response	Table 1
WSRC 1992 (WSRC-RP-92-1360)	Representative excerpt(s) enclosed following response	Section 3.3.1
WSRC 1998 (WSRC-RP-98-00156) (OPS-DTZ-95-00001)	Excerpt enclosed following response	Item A12

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Special Analysis: Updated Analysis of the Effect of Wood Products on Trench Disposal Limits at the E-Area Low-Level Waste Facility

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Summary

This Special Analysis (SA) develops revised radionuclide inventory limits for trench disposal of low-level radioactive waste in the presence of wood products in the E-Area Low-Level Waste Facility. These limits should be used to modify the Waste Acceptance Criteria (WAC) for trench disposal. Because the work on which this SA is based employed data from tests using 100% wood products, the 40% limitation on wood products for trench (i.e slit or engineered trench) disposal is not needed in the modified WAC.

Introduction

Some types of low-level radioactive waste (LLW) (e.g. wood, job control waste) contain cellulosic material (i.e., wood products) that will degrade in the environment to form organic matter. Dissolved organic matter (DOM) may influence the mobility of radionuclides in the disposal environment.

The original E-Area performance assessment (PA) (MMES, et al, 1994) did not consider the impact of DOM on radionuclide mobility. Thus, in order to dispose of waste containing wood products, a Savannah River Technology Center study (Myers and Serkiz, 1996) used data available from the literature to estimate the increased mobility of radionuclides in the presence of DOM. The increased mobility was reflected in a decrease in the partition coefficient (K_d) for the affected radionuclides. The K_d is an empirical measure of the extent to which a radionuclide is retained on the soil. The K_d is the ratio of the radionuclide concentration in the soil to that in the soil water:

$$Kd\ (mL/g) = \frac{Soil\ Concentration\ (pCi/g)}{Water\ Concentration\ (pCi/mL)}$$

In performance assessments of LLW disposal systems, the K_d is a very important parameter. The effect of the K_d is to slow the migration of radionuclides through the soil-water system. The slower migration rate provides additional time for the radionuclide to decay than would be the case if the radionuclide migrated at the same rate as the groundwater (i.e. $K_d = 0$). Although the PA calculations are performed using a three-dimensional groundwater flow and transport model, the effect of decreasing K_d can be estimated using a one-dimensional model.

In the one-dimensional model, the length of the flow path from the disposed waste to the point of assessment (i.e. a hypothetical well located where the radionuclide groundwater concentration would be greatest outside of a 100-m buffer zone surrounding the waste) is divided into segments defined by the concentration of DOM. Since the K_d delays the migration of radionuclides along the subsurface flow path, the one-dimensional model need only consider the length of the flow path and the K_d. The flow path length in combination with the K_d effectively gives the time required for the radionuclide to traverse the path. This, then, provides a measure of the radionuclide decay while traversing the path. If the K_d decreases, the travel time is reduced; therefore, the amount of radioactive decay would be less and the radionuclide concentration would increase.

In the earlier study (Myers and Serkiz, 1996), the subsurface flow path was divided into only two segments, one where there was no projected effect from DOM and one where the concentration of DOM was high enough to affect the K_d. The length of each of the flow path segments was multiplied by the Kd appropriate to that segment and the sum of these two products was divided by the total flow path length. This resulted in an effective K_d for the entire flow path. The effective K_d was then used to estimate a revised radionuclide inventory limit by ratio with the K_d used in the PA. These calculations are illustrated below:

$$Kd_{(weighted)} = \frac{A * Kd_{(aff)} + B * Kd_{(PA)}}{A + B}$$

Where: $K_{d(weighted)}$ = the weighted average K_d

A = the length of the flow path where the K_d is affected by dissolved organic matter

$K_{d(aff)}$ = the reduced K_d caused by the dissolved organic

matter

B = the length of the flow path where the K_d is not affected by dissolved organic matter

$K_{d(PA)}$ = the unaffected K_d (i.e. the K_d used in the PA)

$$\text{Revised Inventory Limit} = \text{PA Inventory Limit } x \frac{K_d(weighted)}{K_d(PA)}$$

Since the study (Myers and Serkiz, 1996) employed literature data based on laboratory tests using approximately 40% wood products by weight, the revised radionuclide limits could only be used if accompanied by a restriction that the amount of wood products emplaced in the trench could not exceed 40 % by weight. Thus, the revised trench disposal WAC included both the revised radionuclide inventory limits and the 40% restriction on the quantity of wood products that could be emplaced.

Discussion

This special analysis (SA) was conducted to provide a basis for removing the 40% restriction on the disposal of wood products and to update the radionuclide inventory limits for trench disposal in the presence of wood products. The results of a recent study (Serkiz, 2000) provide updated partition coefficients (i.e. K_d) for a number of elements as a function of the concentration of dissolved organic matter (DOM). To develop a basis for improving the estimation of the effect of DOM on radionuclide K_d, the distribution of DOM in the subsurface environment was calculated using the PORFLOW computer program. The trench disposal conceptual model from the PA (McDowell-Boyer, 2000) was used. The sixteen foot thick waste zone was assigned a constant DOM concentration of 1000 mg/L, the approximate solubility limit for this material determined by Serkiz (Serkiz, 2000). The DOM was assigned a K_d of 0.008 mL/g and a biologic decay rate of 0.3 per year (Serkiz, 2000). The uncapped flow field of 40 cm/year was used. The flux of DOM calculated by the vadose zone model was used as input into the performance assessment saturated zone model. The relatively low flux rate and the amount and velocity of the saturated zone water lowered the concentration of DOM to less than 1 mg/L in the saturated zone (i.e. the water table aquifer).

The results of the DOM modeling, shown in Figure 1, is that three DOM concentrations are significant – 1000 mg/L in the waste zone, 100 mg/L in the vadose zone and <1 mg/L in the saturated zone. Table 1 presents the revised K_ds as a function of DOM concentration for the elements affected by DOM. The K_d values are from Serkiz (2000).

The unaffected (DOM = 0) K_ds for cesium and uranium are the result of recent work using SRS soils from the immediate vicinity of the E-Area disposal facility (Johnson, 1995), and Serkiz (2000) recommended using these values for performance assessments at SRS. These K_ds are significantly different than those used in the performance assessment. For cesium the change was a decrease from 330 mL/g to 18 mL/g. For uranium the change was an increase from 35 to 800.

The overall effect of changes in K_d along the flow path from the waste to the point of assessment was determined by calculating a weighted-average K_d for each of the affected elements. To do this, the K_d in

each DOM concentration zone was multiplied by the path length in that zone. The sum of these products was divided by the total path length. In the PA (McDowell-Boyer, 2000), the average path length in the waste zone is 10 feet, the thickness of the vadose zone is 25 feet and the distance to the point of assessment in the saturated zone is 400 feet. The calculation is illustrated below:

$$K_{d(weighted)} = \frac{A * K_{d(waste\ zone)} + B * K_{d(vadose\ zone)} + C * K_{d(saturated\ zone)}}{A + B + C}$$

Where: $K_{d(weighted)}$ = the weighted average K_d

A = the length of the flow path in the waste zone (i.e. 10 feet)

$K_{d(waste\ zone)}$ = the reduced K_d caused by the dissolved organic matter in the waste zone

B = the length of the flow path in the vadose zone (i.e. 25 feet)

$K_{d(vadose\ zone)}$ = the reduced K_d caused by the dissolved organic matter in the vadose zone

C = the length of the flow path in the saturated zone (i.e. 400 feet)

$K_{d(saturated\ zone)}$ = the unaffected K_d in the saturated zone (i.e. the K_d used in the PA)

The weighted average K_ds are given in Table 2.

The method employed by Myers and Serkiz (1996) was used to adjust disposal limits derived in the PA (McDowell-Boyer et al., 2000) using the weighted-average K_d values. The method uses the equation

$$Adjusted\ Inventory = PA\ Inventory\ x\ \frac{K_d(weighted)}{K_d(PA)}$$

The PA-derived trench disposal limits and the adjusted trench disposal limits are both given in Table 3. The new work in Serkiz (2000) is based on experimental data employing 100% wood products, in contrast with the earlier study (Myers and Serkiz, 1996) that relied on literature data from a study employing only 40% wood products. Therefore, WAC based on the adjusted radionuclide inventory limits determined in this report for trench disposal will no longer require the 40% by weight limitation on wood products.

Conclusions

The effects of the adjusted groundwater-based trench disposal limits are shown in Table 4. For most of the radionuclides affected, the changes are relatively small. Two exceptions are cesium and uranium. The causes of these changes are the changes in recommended soil K_ds for these elements in areas unaffected by dissolved organic carbon. For cesium the change was from 330 mL/g to 18 mL/g. For uranium the change was an increase from 35 to 800. This makes ^{135}Cs second to ^{3}H in the ranking of limit versus projected inventory. Groundwater-based disposal limits for each uranium isotope increased by a factor of 23. The radionuclide inventory limits in Table 4, rather than the corresponding limits in the PA (i.e., Table 7.1-3) should be used in developing WAC. Per an unreviewed disposal question (UDQ) evaluation (Wilhite, 2000) the radionuclide inventory limits developed in this work are applicable to the engineered trench, if radionuclide package or concentration guidelines are derived from the inventory limits by dividing the inventory limits by the volumetric waste capacity of the entire engineered trench.

The methodology used in this report is likely to overestimate the effect of K_d reduction in the waste zone in the release of radionuclides. A more rigorous analysis should be performed as part of the PA maintenance program to refine these estimates.

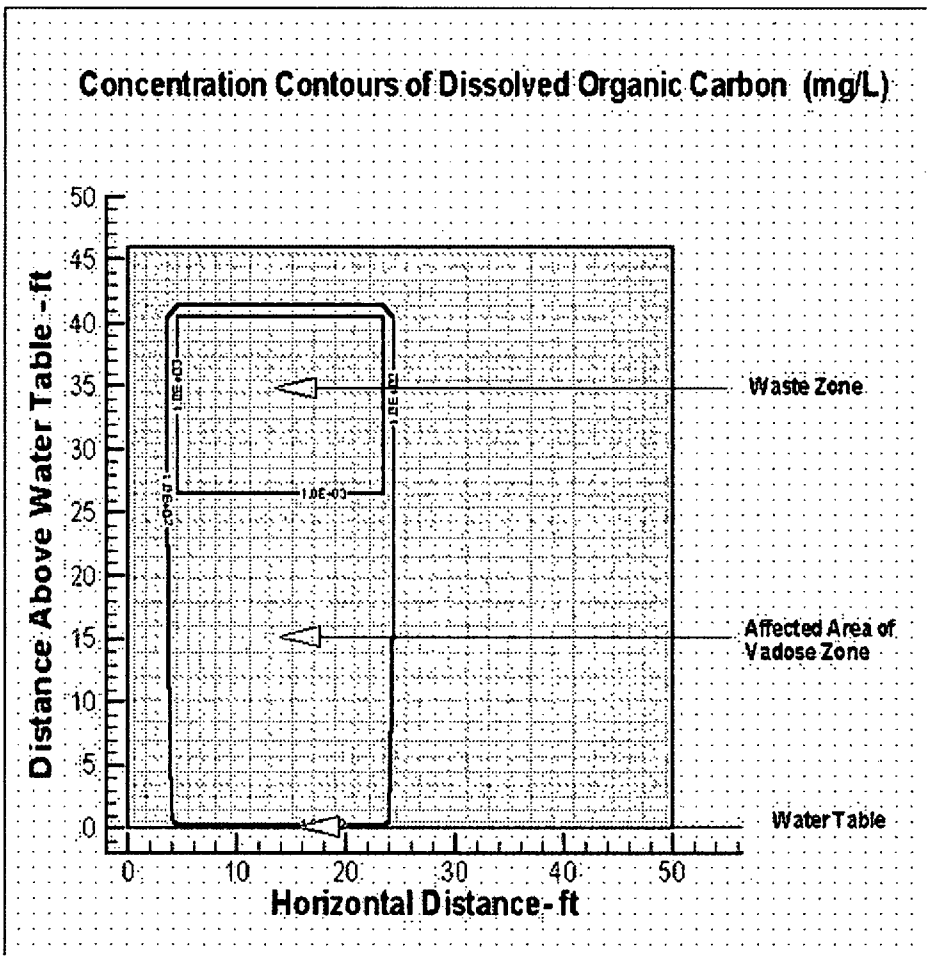

Table 1. Kd (mL/g) as a Function of Dissolved Organic Matter

Concentration for Elements of Interest to the Groundwater Pathway			
Element	DOM = 1000 mg/L	DOM = 100 mg/L	DOM = 1 mg/L
Ni	2.2	3.8	400
Sr	0.1	0.1	10
Sn	0.7	1.2	130
Cs	5	5	18
Th	18	31	3200
U	4	8	800
Np	1	1	5
Pu	1	1	100
Am	10	18	1900
Cm	22	38	4000
Cf	3	5	510

Table 2. Weighted-average Kd Values	
Element	Weighted-Average Kd (mL/g)
Ni	368
Sr	9
Sn	120
Cs	17
Th	2945
U	736
Np	5
Pu	92
Am	1748
Cm	3681
Cf	469

Table 3. Adjusted Trench Disposal Limits Based on Groundwater Pathway		
Radionuclide	PA Limit, curies	Adjusted Limit, curies
Ni-59	3.7E+02	3.4E+02
Sr-90	5.7E+02	5.2E+02
Sn-126	4.1E+01	3.8E+01

Cs-135	3.9E+02	2.0E+01
Th-232	7.2E+05	6.6E+05
U-232	1.4E+01	2.9E+02
U-233	2.4E+00	5.0E+01
U-234	8.5E+00	1.8E+02
U-235	4.9E+00	1.0E+02
U-236	9.6E-02	2.0E+00
U-238	2.4E-01	5.0E+00
Np-237	4.8E-02	4.8E-02
Pu-238	2.8E+02	2.6E+02
Pu-239	9.6E-01	8.8E-01
Pu-240	1.2E+00	1.1E+00
Pu-241	7.2E+03	6.6E+03
Pu-242	1.7E-02	1.6E-02
Pu-244	1.8E-02	1.7E-02
Am-241	2.4E+02	2.2E+02
Am-243	9.0E-01	8.3E-01
Cm-242	1.8E+05	1.7E+05
Cm-244	4.3E+02	4.0E+02
Cf-252	1.6E+08	1.5E+08

Table 4 Adjusted Inventory Limits for Slit Trenches; Limiting Pathway; Comparison t Projected Inventory. Entries in bold are changes from performance assessment [a]

Radionuclide [b]	Inventory limit [c] Ci/5 trenches	Limiting pathway [d]	Projected inventory Ci/5 trenches	Ratio of invent projected inv
H-3	6.3E+00	gw	4.10E+00	1.5E+00
C-14	2.7E+00	air	7.50E-03	3.6E+02
Ni-59	**3.4E+02**	gw	6.53E-03	**5.2E+04**
Co-60	7.3E+08	post drilling	5.95E-02	1.2E+10
Ni-63	2.8E+05	post drilling	1.77E-02	1.6E+07
Se-79	1.1E+02	gw	3.58E-05	3.1E+06
Rb-87	3.1E-01	gw	0.00E+00	----[f]

Sr-90 +d	**5.2E+02**	gw	1.40E-01	**3.7E+03**
Zr-93 +d	2.8E+01	gw	0.00E+00	----[f]
Tc-99	5.5E-01	gw	2.43E-03	2.2E+02
Pd-107	4.1E+01	gw	0.00E+00	----[f]
Cd-113m	2.4E+04	post drilling	0.00E+00	----[f]
Sn-121m	1.2E+06	post drilling	0.00E+00	----[f]
Sn-126 +d	**3.8E+01**	**gw**	4.50E-04	**8.4E+04**
I-129	5.2E-04	gw	2.98E-07	1.8E+03
Cs-135	**2.0E+01**	gw	8.78E-01	**2.3E+01**
Cs-137 +d	2.1E+04	post drilling	8.78E-01	2.4E+04
Sm-151	6.1E+06	post drilling	0.00E+00	----[f]
Eu-154	8.1E+06	post drilling	4.43E-04	1.8E+10
Th-228	5.5E+19	post drilling	5.93E-04	> 1E20
Th-232 +d	1.3E+00	agriculture	5.93E-04	2.2E+03
U-232 +d	**2.9E+02**	gw	0.00E+00	----[f]
U-233 +d	**5.0E+01**	gw	8.25E-08	**6.1E+08**
U-234 +d	**1.8E+02**	gw	5.38E-03	**3.4E+04**
U-235 +d	**1.0E+02**	gw	1.75E-04	**5.7E+05**
U-236	**2.0E+00**	gw	5.00E-04	**4.0E+03**
Np-237 +d	4.8E-02	gw	1.53E-05	3.2E+03
U-238 +d	**5.0E+00**	gw	2.70E-03	**1.8E+03**
Pu-238 +d	**2.6E+02**	gw	5.05E-03	**5.2E+04**
Pu-239 +d	**8.8E-01**	gw	1.37E-03	**6.4E+02**
Pu-240 +d	**1.1E+00**	gw	2.68E-04	**4.1E+03**
Am-241 +d	**2.2E+02**	gw	2.19E-02	**1.0E+04**
Pu-241 +d	**6.6E+03**	gw	1.45E-02	**4.6E+05**
Pu-242 +d	**1.6E-02**	gw	6.03E-06	**2.6E+03**
Am-242m +d	8.1E+02	post drilling	0.00E+00	

				----[f]
Am-243 +d	**8.3E-01**	gw	1.97E-06	**4.2E+05**
Pu-244+d	**1.7E-02**	gw	0.00E+00	----[f]
Cm-242 +d	**1.7E+05**	gw	0.00E+00	----[f]
Cm-243	1.8E+04	post drilling	0.00E+00	----[f]
Cm-244 +d	**4.0E+02**	gw	3.58E-04	**1.1E+06**
Cm-245+d	3.7E+01	agriculture	0.00E+00	----[f]
Cm-246	1.4E+02	agriculture	0.00E+00	----[f]
Cm-247 +d	7.1E-01	gw	0.00E+00	----[f]
Cm-248 +d	3.6E+01	agriculture	0.00E+00	----[f]
Bk-249 +d	2.8E+04	agriculture	0.00E+00	----[f]
Cf-249 +d	6.9E+01	agriculture	0.00E+00	----[f]
Cf-250 +d	4.8E+04	agriculture	0.00E+00	----[f]
Cf-251	5.2E+01	agriculture	0.00E+00	----[f]
Cf-252 +d	4.5E+06	agriculture	0.00E+00	----[f]

[a] McDowell-Boyer, 2000.
[b] "+d" indicates potentially-significant short- and long-lived daughters are accounted for in the limit.
[c] Inventory limit based on consideration of peak groundwater concentration outside 100-m buffer zone around disposal units and inadvertent intruder doses.
[d] Refers to intruder scenario, groundwater ingestion pathway ("gw"), or air pathway, whichever is more restrictive with respect to developing inventory limits.
[e] A ratio that is one or greater indicates the projected inventory is less than the estimated inventory limit and the performance objectives are met.
[f] Projected inventory is zero; therefore, assume performance objectives are met.

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Revision 0

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SPECIAL ANALYSIS: REVISION OF SALTSTONE VAULT 4 DISPOSAL LIMITS (U)

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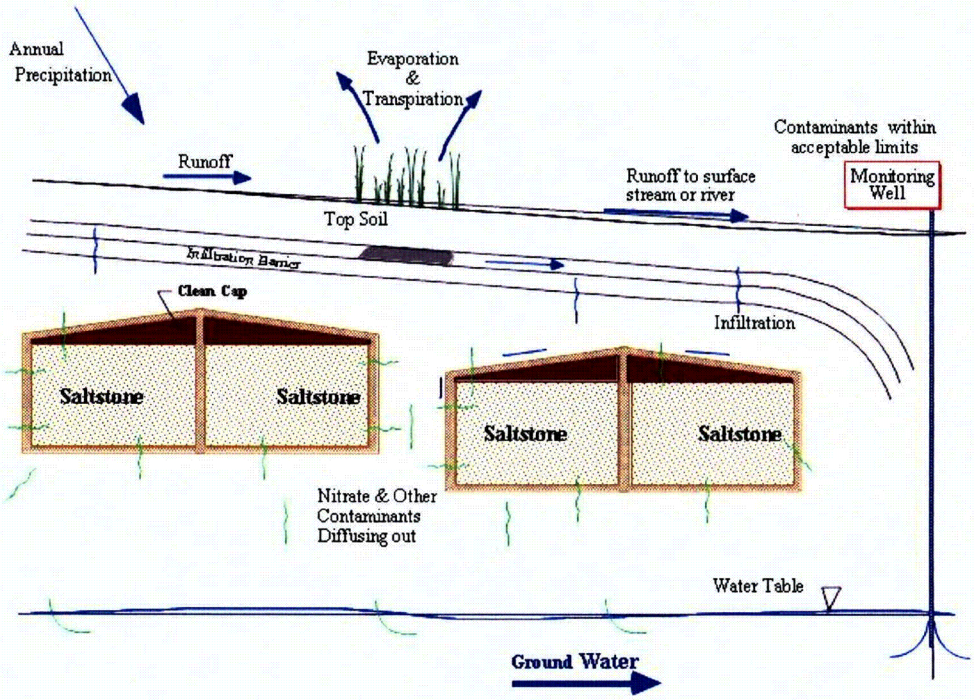
MAY 26, 2005



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EXECUTIVE SUMMARY

New disposal limits have been computed for Vault 4 of the Saltstone Disposal Facility based on several revisions to the models in the existing Performance Assessment and the Special Analysis issued in 2002. The most important changes are the use of a more rigorous groundwater flow and transport model, and consideration of radon emanation. Other revisions include refinement of the aquifer mesh to more accurately model the footprint of the vault, a new plutonium chemistry model accounting for the different transport properties of oxidation states III/IV and V/VI, use of variable infiltration rates to simulate degradation of the closure system, explicit calculation of gaseous releases and consideration of the effects of settlement and seismic activity on the vault structure. The disposal limits have been compared with the projected total inventory expected to be disposed in Vault 4. The resulting sum-of-fractions of the 1000-year disposal limits is 0.2, which indicates that the performance objectives and requirements of DOE 435.1 will not be exceeded. This SA has not altered the conceptual model (i.e., migration of radionuclides from the Saltstone waste form and Vault 4 to the environment via the processes of diffusion and advection) of the Saltstone PA (MMES 1992) nor has it altered the conclusions of the PA (i.e., disposal of the proposed waste in the SDF will meet DOE performance measures). Thus a PA revision is not required and this SA serves to update the disposal limits for Vault 4. In addition, projected doses have been calculated for comparison with the performance objectives laid out in 10 CFR 61. These doses are 0.05 mrem/year to a member of the public and 21.5 mrem/year to an inadvertent intruder in the resident scenario over a 10,000-year time-frame, which demonstrates that the 10 CFR 61 performance objectives will not be exceeded. This SA supplements the Saltstone PA and supersedes the two previous SAs (Cook et al. 2002; Cook and Kaplan 2003).

2.0 GROUNDWATER ANALYSIS

2.1 Methodology

The groundwater pathway analysis for each radionuclide involves two steps. First a vadose zone flow and transport simulation is done to estimate flux to the water table for a disposed radionuclide parent and any subsequent progeny. Then saturated zone flow and transport modeling is used to estimate the groundwater concentration(s) at a hypothetical well placed 100 meters down-gradient from the disposal unit.

The vadose zone flow model was developed to reflect the current Z-Area closure concept (Phifer and Nelson 2003), which calls for a geosynthetic cover system instead of a kaolin cap as assumed in the 1992 PA. After completion of the institutional control period, infiltration is predicted to gradually increase over time as the closure system degrades due to phenomena such as intrusion of deep-rooted plants (e.g., trees) and silting of drainage layers (Phifer 2004). While it is assumed that tree root penetration will contribute to closure system degradation, tree roots should not penetrate into the Saltstone, itself, and uptake radionuclides for the following reasons:

- Several layers of the multi-layered cover system above the vault roof are frequently at or near saturation. Since tree roots are opportunistic and seek sources of water, the roots will concentrate in these layers above the vault roof, which contain significant water.
- While roots might penetrate to the vault roof, the concrete roof presents a hardened surface over which roots are more likely to extend along rather than penetrate.
- The pore fluid within Saltstone is essentially a salt solution (brackish water) which the trees could not utilize.
- It is unlikely that roots would be able to extract water from Saltstone due to the matrix potential within Saltstone.

The purpose of the deeper roots of pine trees is to seek sources of water. The multi-layered cover system will produce local zones of saturated water in the drainage layers overlying the barrier layers. The pine tree roots will tend to follow these layers rather than attempt to penetrate to deeper levels since it is much easier for the roots to extract water from saturated soil than unsaturated soil. Therefore, pine tree roots are not expected to penetrate the vault roof.

A potential PA concern is the effects of cracks developing in the Saltstone monolith over time. A structural analysis (Peregoy 2003) predicts that cracks will develop and their aperture will increase with increasing time. However, the analysis shows that the cracks will open either at the top or at the bottom and will be pinched closed at the opposite end. Therefore, no through-wall cracks will develop. A separate modeling study (Yu and Cook 2004) concluded that cracks of this nature have very little effect on contaminant transport rate. Based on this finding cracks are not considered in this SA.

The conceptual model describes the materials, layout, and dimensions of the SDF. Figure 2-1 depicts the conceptual model used for the Vault No. 4. The Saltstone monolith is approximately 200×600×25 ft. Only half of a vault in the short dimension is modeled, taking advantage of symmetry. The top of the modeling domain is the bottom of the upper GCL layer. Infiltration through this layer as a function of time is calculated by the HELP code (USEPA 1994a, 1994b). The constant infiltration rate is used as a flow boundary condition at the top of the modeling domain. The bottom of the modeling domain is the water table. Capillary pressure at the water table is set to zero to simulate 100% water saturation. The vertical boundary through the center of the vault is modeled as a no-flow boundary due to symmetry. The right boundary is also assumed to be a no-flow boundary because it is sufficiently far away from the vault and the predominant

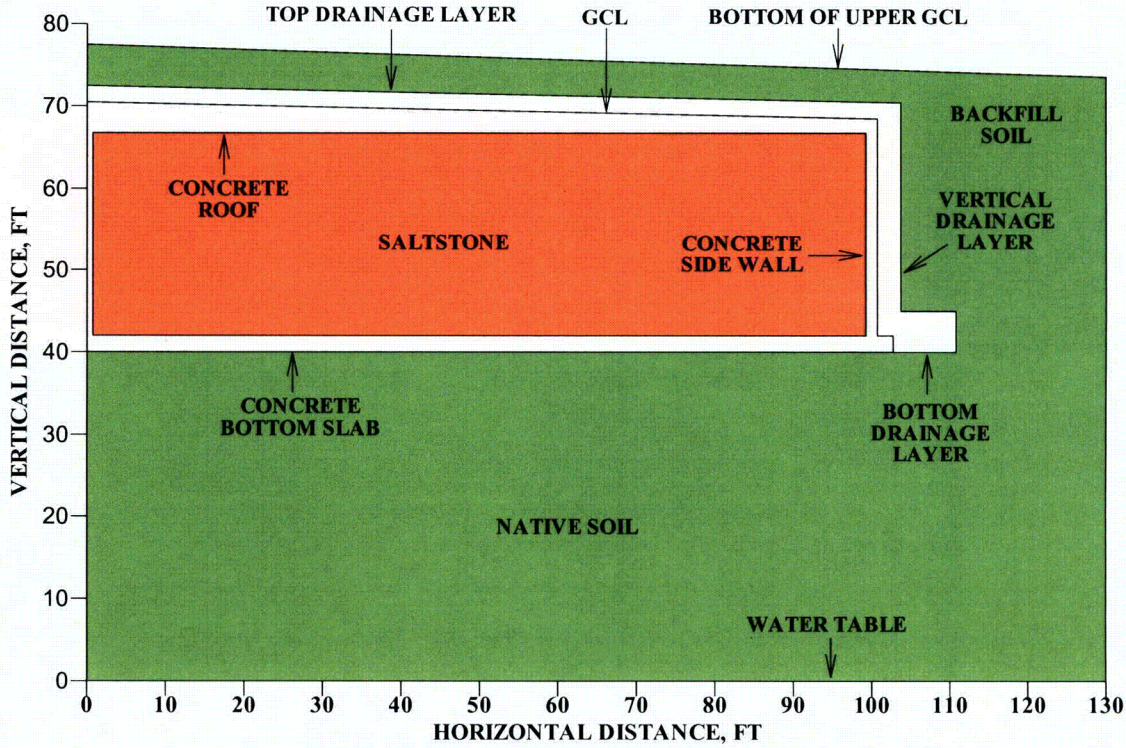


Figure 2-1. Conceptual Model for the Saltstone Vault No. 4

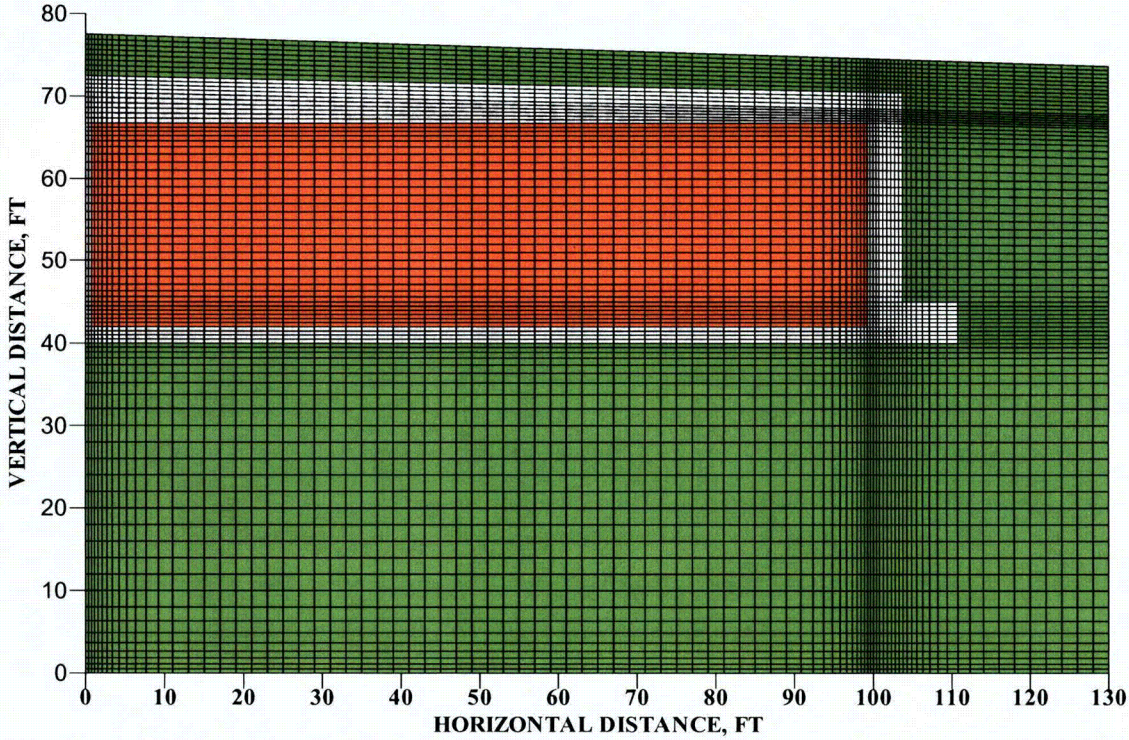


Figure 2-2. Modeling Grid

contaminant transport mechanism is downward convection. Figure 2-2 shows the gridding used in the model.

The vadose zone flow simulation was performed as a sequence of steady-state runs approximating average conditions during a number of time intervals over 10,000 years based on the HELP code results. Time zero is when closure operations are complete. Material properties were varied for each time interval to represent degradation of the closure system, the Saltstone waste form, and the vault. These properties are given in Appendix A.

A total of 45 radionuclides were selected for analysis based on a screening study for the SRS Low Level Waste Facility (Cook and Wilhite 2004). Nitrate was also run in the analysis because it occurs in high concentrations and has a relatively low groundwater limit.

The new plutonium chemistry implemented for the trench disposal units in the E-Area Low-Level Waste Facility (Cook 2002, Kaplan 2004) has been included in the present special analysis. The Pu (III/IV) oxidation state is far more abundant than Pu (V/VI), but the latter is significantly more mobile in sediments: a soil-solute distribution coefficient of K_d = 370 mL/g is assumed for Pu (III/IV) versus K_d = 15 mL/g for Pu (V/VI). Although present in trace amounts, the relatively high mobility of Pu (V/VI) could potentially lead to a significant contribution to the dose at the 100-meter well. The two pairs of oxidation states are tracked separately in the vadose zone transport simulations to accommodate the difference in mobility.

In addition to the geochemistry modifications described above, some distribution coefficients were updated to reflect current knowledge. Appendix A provides a complete listing of K_d values used in the groundwater analysis and other key input data such as, radionuclides analyzed, half-lives, atomic mass, concentration limits, solubility limits, and assumed decay chains.

The FACT code model of the General Separations Area (GSA) was recently superseded by an equivalent model using the PORFLOW code, in order to consolidate PA subsurface flow and transport modeling to a single software product (Flach 2004). The flow field computed by GSA/PORFLOW is used in the present study. GSA/PORFLOW is a regional scale model with a mesh resolution in the horizontal plane of 200 ft, compared to a width of about 200 ft for Vault 4.

Figure 2-3 illustrates locations of the existing Vaults, 1 and 4, and the aquifer model mesh. Figure 2-3 also shows the extent of the aquifer flow and transport model (blue border) and the mesh resolution in the horizontal plane (light gray dashes). Particle tracking results starting from the four corners of the combined facility indicate the groundwater flow direction. Time markers (red dots) are shown every 10 years of travel. Figure 2-3 indicates a possibility of plume overlap, which is the subject of a sensitivity study presented in Section 7.

2.2 Results

The magnitude and time of maximum concentration, the Maximum Contaminant Level (MCL) (USEPA 2004) and the Vault 4 inventory limit for the key radionuclides for two time periods of interest, 1000 years and 10,000 years, are given in Tables 2-1 and 2-2, respectively. These limits for the groundwater pathway are compared with limits derived for the other pathways and with the projected Vault 4 inventory in Section 7. For the projected Vault 4 inventory, none of the radionuclides produces a significantly large fraction of the groundwater limit.

Plots of fractional flux and concentration for each radionuclide modeled with PORFLOW are presented in Appendix A.

A.4 Impact of Macroscopic Cracks on Saltstone Vault 4 Performance

Vertical cracks or fractures spanning the entire Saltstone Vault 4 width and height are predicted to occur at 30 ft intervals, coinciding with construction joints, in response to static settlement and earthquakes. For the assumed properties of saltstone (10^{-11} cm/s conductivity), the literature indicates cracks can be neglected when the suction head exceeds approximately 200 cm in saltstone. Such conditions are predicted to occur during the 0-10,000 year period. This conclusion applies regardless of crack geometry, i.e., open at top, open at bottom, or through-crack.

A.4.1 Introduction

Peregoy (2003) analyzed the structural behavior of Saltstone Vault 4 in response to forecast static settlement and earthquakes. Approximately vertical cracks or fractures spanning the entire Vault 4 width and height were predicted to occur at 30 ft intervals, coinciding with construction joints. In the structural simulations, these macroscopic cracks were observed to open at either the top or bottom, while remaining in close contact at the opposite end of the fracture face, the latter forming a "hinge" of sorts. The cracks developed gradually over time (Peregoy 2003, Figure 9, Figure 10 and Table 2). Predicted mean crack sizes are summarized in Table A-20.

Table A-20. Summary of mean crack sizes at specific times.

Cracks open at bottom

Time (yr)	Crack width at open end (in)	Average width (in)
100	0.06	0.03
500	0.18	0.09
1000	0.30	0.15
2500	0.63	0.31
5000	1.15	0.58
10000	2.18	1.09

Cracks open at top

Time (yr)	Crack width at open end (in)	Average width (in)
100	0.01	0.004
500	0.03	0.015
1000	0.06	0.03
2500	0.16	0.08
5000	0.31	0.16
10000	0.62	0.31

Under a positive pressure condition, cracks or fractures in the saltstone monolith would be liquid-filled and form preferential pathways for infiltrating water compared to the surrounding low permeability matrix (10^{-11} cm/s). Under negative pressure or suction, the impact of cracks on saltstone performance is not immediately clear. The purpose of this Section is to assess the effect of macroscopic cracks on moisture movement through Saltstone Vault 4 under a range of hydraulic conditions and crack dimensions.

A.4.2 Flow Regimes

Water flow through a rough walled crack in a porous medium occurs in at least three distinct regimes:

1. Saturated flow, that is, liquid completely filling the aperture.
2. "Thick" film flow on each crack wall, where water is present as a film completely filling surface pits and grooves and the air-water interface is relatively flat.
3. "Thin" film flow, where water recedes into surface pits/grooves by capillary forces and adheres to flat surfaces by adsorption.

The saturated flow regime occurs at positive or very slightly negative pressures. The "thick" and "thin" film flow regimes occur at increasing negative pressures or suction in the surrounding porous medium. Each flow regime is analyzed separately below in the context of a uniform crack width.

An implicit assumption in these analyses is that the source of liquid to the crack is steady rather than episodic/transient, and that the resulting fracture flow is steady. Unsteady fracture flow has been observed at laboratory scale and inferred at field scale (Persoff and Pruess 1995; Su et al. 2001; Nativ et al. 1995; Fabryka-Martin et al. 1996; Pruess 1999). At laboratory scale, unsteady flow appears to be associated with relatively low suctions in a variable aperture setting. Under these conditions, water fills the smaller apertures while larger apertures are desaturated. At field scale (e.g. Yucca Mountain), unsteady flow has been inferred under high matrix suction. Temporal and spatial variations in infiltration and physical heterogeneity are thought to be factors leading to episodic flow.

The planned Saltstone closure cover system is expected to insulate cracks from episodic rainfall and lead to a relatively steady influx of water. Saltstone itself is expected to exhibit uniform properties in comparison with fractured geologic media. Cracks forming from differential settlement and seismic events are expected to be unsaturated. All of these conditions favor steady flow in Saltstone Vault 4.

A.4.3 Saturated Flow

The height of capillary liquid rise H between two parallel surfaces of aperture b is given by (e.g. Looney and Falta 2000)

$$H = \frac{2\sigma}{\rho g b} \tag{A-20}$$

where σ is surface tension, ρ is liquid density, and g is gravitational acceleration. In the context of a fracture subject to a given pressure P in the surrounding matrix, the aperture will be liquid filled under the condition

$$P > -\frac{2\sigma}{b} \tag{A-21}$$

where suction is indicated by a negative pressure value (e.g. Wang and Narasimhan 1985). The equivalent permeability of the fracture is

$$k = \frac{b^2}{12} \tag{A-22}$$

and the hydraulic conductivity is

$$K = \frac{\rho g k}{\eta} = \frac{\rho g b^2}{12\eta} \tag{A-23}$$

where η is liquid viscosity. Figure 1 shows hydraulic conductivity as a function of aperture for water at 20°C. Note that even narrow cracks have a high conductivity compared to cementitious materials.

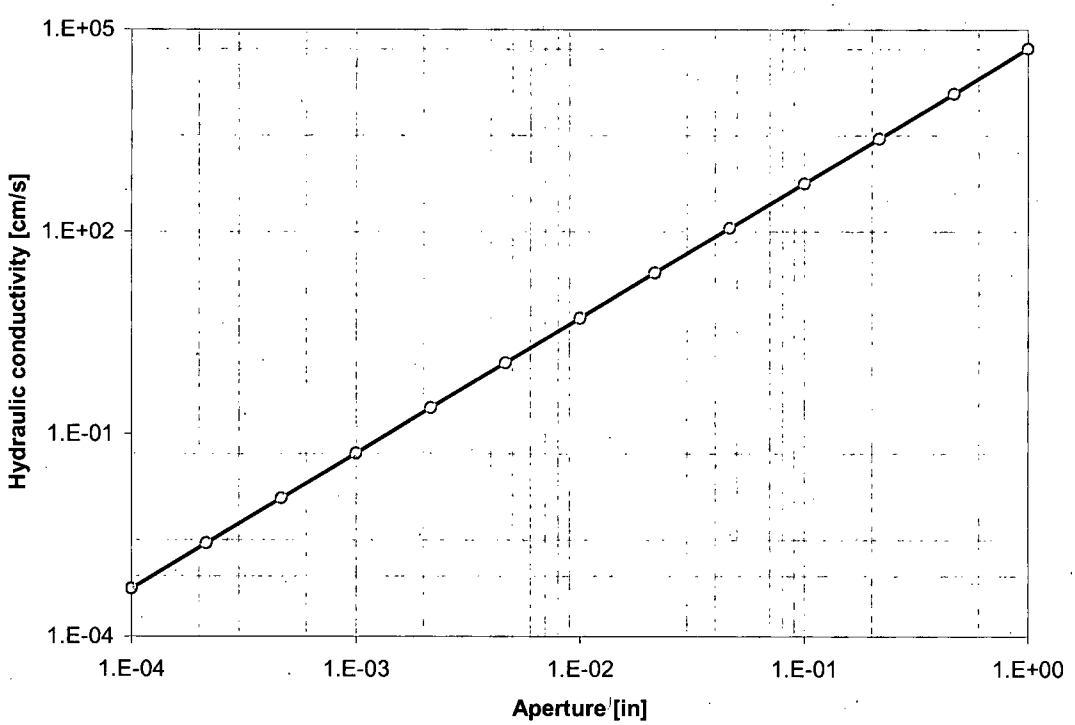


Figure A-77. Hydraulic conductivity of saturated cracks as a function of aperture.

A.4.4 Film Flow

When $P < -2\sigma/b$, liquid can no longer span an aperture and the crack will desaturate. For this condition, a rough fracture face can be conceptually simplified as a repeating series of vertical flat surfaces and V-shaped grooves to facilitate further analysis, following Or and Tuller (2000, Figure 1). At pressures slightly below $-2\sigma/b$, liquid will completely fill a groove and form a flat liquid-vapor interface. At a sufficiently low pressure, liquid will recede into the corner of the groove and be retained by capillary forces. Under this condition, the matric potential

$$\mu = \frac{P}{\rho} = gH \tag{A-24}$$

determines the radius of the liquid vapor interface in a groove (Or and Tuller 2000, Figure 2):

$$r(\mu) = -\frac{\sigma}{\rho\mu} \tag{A-25}$$

For a groove of depth L and angle γ, the maximum radius accommodated by the groove geometry is

$$r_c = \frac{L\tan(\gamma/2)}{\cos(\gamma/2)} \tag{A-26}$$

The critical pressure defining the transition between flat and curved interfaces is

$$P_c = -\frac{\sigma}{r_c} \tag{A-27}$$

and is the result of combining equations (A-24) through (A-26). Thus the three flow regimes identified earlier occur over the following pressure ranges for the assumed geometry of the fracture face:

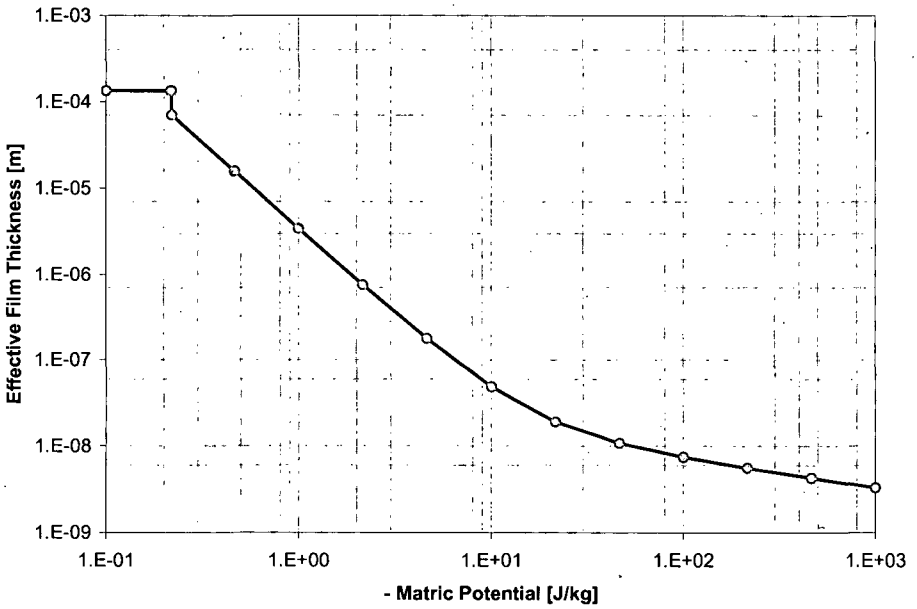
1. Saturated flow: $P > -\frac{2\sigma}{b}$
2. "Thick" film flow: $-\frac{\sigma}{r_c} < P < -\frac{2\sigma}{b}$
3. "Thin" film flow: $P < -\frac{\sigma}{r_c}$

Liquid not being held by capillary suction will adhere to the remaining surfaces of the fracture face as a thin film. Considering only van der Waal forces, liquid adsorption on solid surfaces can be characterized by

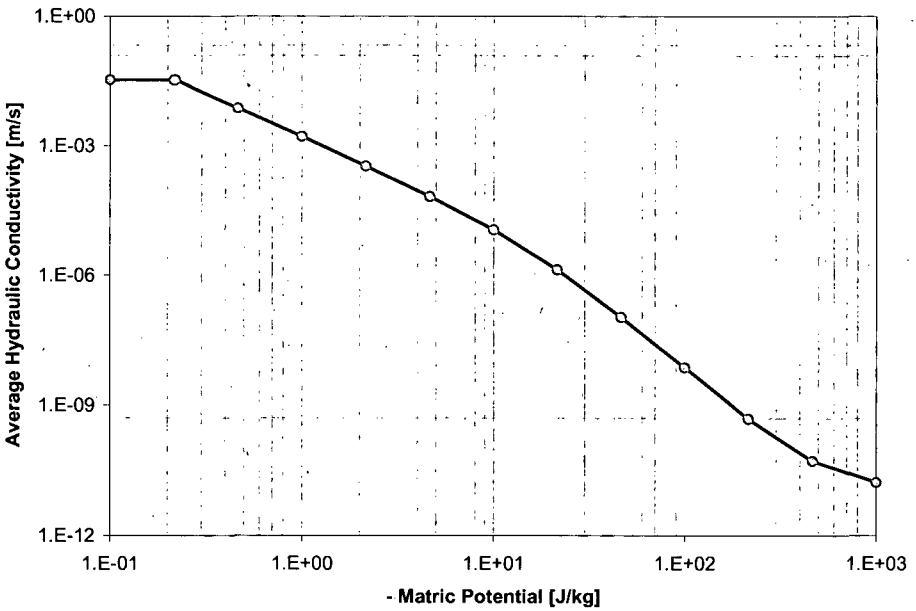
$$h(\mu) = \left[\frac{A_{svl}}{6\pi\rho\mu}\right]^{1/3} \tag{A-28}$$

where h is film thickness and A_{svl} is a Hamaker constant.

Liquid held in groove corners by capillary suction and adhering as a thin film to remaining surfaces flows downward under the force of gravity. Or and Tuller (2000) present a detailed analysis of the liquid area and average velocity associated with corner and film flows, which is summarized in the Appendix. Figures A-78a and A-78b illustrate equivalent film thickness and average hydraulic conductivity for a representative "rough" fracture surface (Or and Tuller 2000, Figure 6a). The critical matric potential defining the transition between "thick" and "thin" film flow is μ_c = -0.22 J/kg or approximately 2 cm of suction head. A discontinuity in film thickness is observed in Figure 6a at this matric potential.



(a)



(b)

Figure A-78. Predicted film flow behavior for a representative "rough" fracture face with $L = 5 \times 10^{-4}$ m and $\gamma = 60°$: a) equivalent film thickness, and b) average hydraulic conductivity.

A.4.5 Application to Saltstone Vault 4

Under saturated flow conditions, the thickness of saltstone transmitting the same flow as a saturated crack under the same hydraulic gradient is

$$D_{saltstone} = \frac{K_{crack} b}{K_{saltstone}} \tag{A-29}$$

where b is the aperture and K_{crack} is defined by Figure A-77. For the assumed Saltstone Vault 4 hydraulic conductivity of 10^{-11} cm/s, even a small crack is significant because of the extreme conductivity contrast. During the 10,000-50,000 year period, Saltstone Vault 4 is predicted to experience ponding on the upper surface. Cracks should be considered under these positive pressure conditions.

Similarly, the equivalent thickness of saltstone for unsaturated flow is

$$D_{saltstone} = \frac{2K_A D_A}{K_{saltstone}} \tag{A-30}$$

where the factor of two results from consideration of flow down both sides of the crack, D_A the average film thickness (e.g. Figure A-78a), and K_A is average conductivity (e.g. Figure 2b). Figure 3 defines the suction head required to desaturate a fixed width crack and the equivalent saltstone thickness, for the aperture conditions assumed in Figure A-78.

For example, at a suction of 100 cm, cracks larger than 6×10^{-4} inches will be unsaturated according to equation (A-27). Therefore the exact geometry of the crack, i.e. open at top or bottom, has little impact on the end result. The equivalent saltstone thickness, assuming a conductivity of 10^{-11} cm/s, would be about 3 ft. At lower suctions, the equivalent thickness increases rapidly. Conversely, thickness rapidly decreases at higher suction. During the 0-10,000 year period, Saltstone Vault 4 is predicted to experience a suction of around 1200 cm. At this suction, unsaturated crack flow is predicted to be negligible ($D_{saltstone} \approx 10^{-3}$ ft from Figure A-79). An informal sensitivity study that varied groove depth (L), angle (γ), and spacing (β in Or and Tuller (2000)) indicates this conclusion is not sensitive to the particular values assumed in Figure A-79.

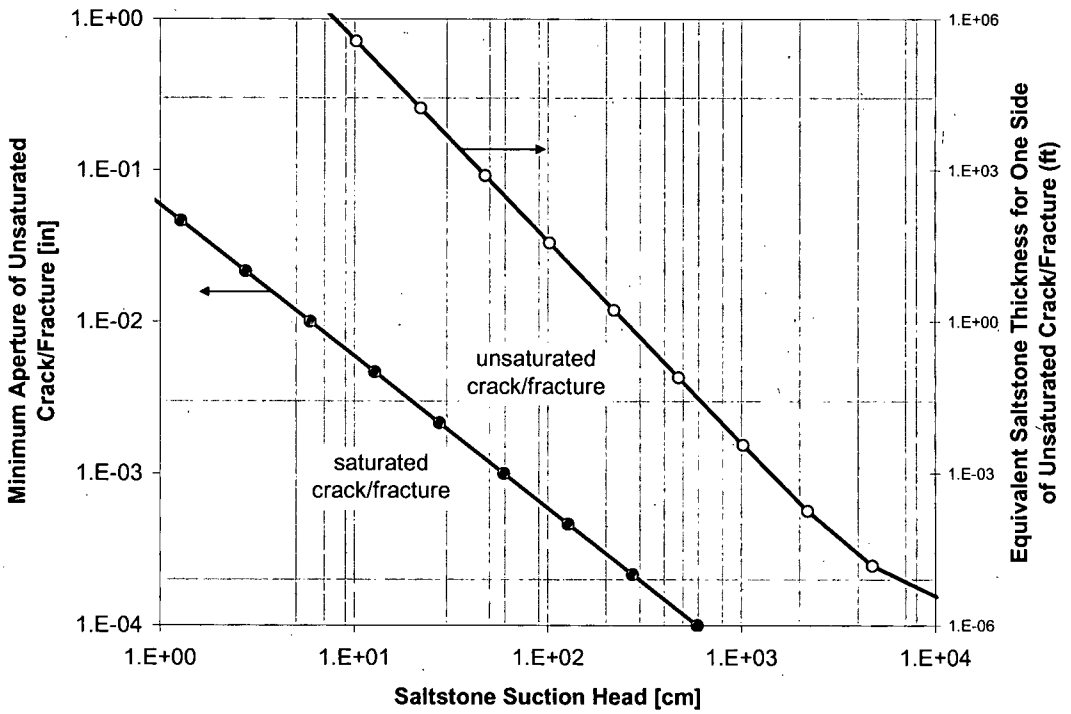


Figure A-79. Minimum unsaturated aperture and equivalent saltstone thickness for film flow down crack faces.

A.4.6 Conclusions

Macroscopic cracks forming in Saltstone Vault 4, whether pinched at top or bottom or through-wall, can be neglected when the suction head exceeds approximately 200 cm. Such conditions are predicted to occur during the 0-10,000 year period. At lower suction or positive pressure conditions, crack flow may be significant.

A.4.7 Details from Or and Teller Reference

The key equations and relationships needed to reproduce Figure 6a in Or and Tuller (2000) are summarized below:

Matric potential

$$\mu = \frac{P}{\rho} = gH \tag{A-31}$$

Film thickness adsorbed to surface under tension

$$h(\mu) = \left[\frac{A_{svl}}{6\pi\rho\mu}\right]^{1/3} \tag{A-32}$$

Corner radius under capillary retention

$$r(\mu) = -\frac{\sigma}{\rho\mu} \tag{A-33}$$

Critical matric potential

$$\mu_c = -\frac{\sigma\cos(\gamma/2)}{\rho L\tan(\gamma/2)} \tag{A-34}$$

Critical radius of curvature ($r < r_c$)

$$r_c = \frac{L\tan(\gamma/2)}{\cos(\gamma/2)} \tag{A-35}$$

Corner area for $\mu < \mu_c$

$$A_{C1}(\mu) = r(\mu)^2\left[\frac{1}{\tan(\gamma/2)} - \frac{\pi(180-\gamma)}{360}\right] \tag{A-36}$$

Corner area for $\mu \geq \mu_c$

$$A_{C2} = L^2\tan(\gamma/2) \tag{A-37}$$

Film area for $\mu < \mu_c$

$$A_{F1}(\mu) = h(\mu)\left\{\beta L + 2\left[\frac{L}{\cos(\gamma/2)} - \frac{r(\mu)}{\tan(\gamma/2)}\right]\right\} \tag{A-38}$$

Film area for $\mu \geq \mu_c$

$$A_{F2}(\mu) = h(\mu)\{\beta L + 2(1-\delta)L\tan(\gamma/2)\} \tag{A-39}$$

Smooth vertical surface film flow (Tokunaga and Wan 1997; Or and Tuller 2000)

$$\bar{v} = \frac{\rho g}{3\eta}h^2 \tag{A-40}$$

Corner vertical flow (Or and Tuller 2000)

$$\bar{v} = \frac{\rho g}{\varepsilon\eta}r^2 \tag{A-41}$$

where

$$\varepsilon = \exp\left[\frac{b + d\gamma}{1 + c\gamma}\right] \tag{A-42}$$

and $b = 2.124$, $c = -0.00415$ and $d = 0.00783$ for $10° < \gamma < 150°$.

Hydraulic conductivity

$$K \equiv \bar{v} \tag{A-43}$$

Average hydraulic conductivity (velocity) for $\mu < \mu_c$

$$K_{A1} = \frac{K_F A_{F1} + K_C A_{C1} \delta}{A_{F1} + A_{C1}} \tag{A-44}$$

Average hydraulic conductivity (velocity) for $\mu \geq \mu_c$

$$K_{A1} = \frac{K_F A_{F2} + K_C A_{C2} \delta}{A_{F2} + A_{C2}} \tag{A-45}$$

Width of representative surface element

$$W = \beta L + 2L \tan(\gamma / 2) \tag{A-46}$$

Effective film thickness

$$D = \frac{A_F + A_C}{W} \tag{A-47}$$

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Regional Groundwater Flow Model for C, K, L, and P Reactor Areas, Savannah River Site, Aiken, South Carolina (U)

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September 1999

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Prepared for the U.S. Department of Energy Under
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ABSTRACT

A regional groundwater flow model encompassing approximately 100 mi^2 surrounding the C, K, L, and P reactor areas has been developed. The reactor flow model is designed to meet the planning objectives outlined in the *General Groundwater Strategy for Reactor Area Projects* by providing a common framework for analyzing groundwater flow, contaminant migration and remedial alternatives within the Reactor Projects team of the Environmental Restoration Department. The model provides a quantitative understanding of groundwater flow on a regional scale within the near surface aquifers and deeper semi-confined to confined aquifers. The model incorporates historical and current field characterization data up through Spring 1999. Model preprocessing is automated so that future updates and modifications can be performed quickly and efficiently. The CKLP regional reactor model can be used to guide characterization, perform scoping analyses of contaminant transport, and serve as a common base for subsequent finer-scale transport and remedial/feasibility models for each reactor area.

MODEL SUMMARY

The current groundwater flow model for C, K, L, and P reactor areas simulates groundwater flow within the area bounded to the north by Upper Three Runs, to the west by the Savannah River, to the south by Steel Creek and Meyers Branch, and to the east by a line between McQueen Branch and Par Pond. Vertically the model extends from ground surface to the top of the Meyers Branch confining system. The model confirms that groundwater flow in upper aquifers at the Savannah River Site is recharge driven, with streams intercepting flow from higher elevations. The underlying Gordon aquifer is strongly influenced by and discharges to the Savannah River and Upper Three Runs. Nearly all recharge within the CKLP reactor region discharges to streams within or bounding the same area, usually the nearest stream, with the balance entering the Gordon aquifer. Simulated flow directions agree with the conceptual model of groundwater flow. Model calibration targets include groundwater recharge estimates, stream baseflow data and estimates, and water level measurements from more than 1000 wells. Model conductivity values in the Gordon aquifer and confining units are set directly to prior estimates based on field data. For the Upper Three Runs aquifer unit, conductivity values are defined through calibration to the groundwater flow and hydraulic head targets.

The chosen areal grid is 70,000 feet on a side, with a horizontal resolution of 500 square feet. The grid consists of 140 elements along each horizontal axis. The vertical resolution varies depending on hydrogeologic unit and terrain/hydrostratigraphic surface variations. The top

surface of the mesh conforms to the ground surface. The bottom surface of the mesh coincides with the bottom of the Gordon aquifer unit. Interior node layers conform to the other stratigraphic surfaces. The "upper" aquifer zone of the Upper Three Runs aquifer includes the vadose zone and is represented by 3 finite-elements in the vertical direction. The "lower" aquifer zone of the Upper Three Runs aquifer contains 2 finite-elements, while the "tan clay" confining zone of the Upper Three Runs aquifer is represented by a single model element. The Gordon confining unit and Gordon aquifer unit are each assigned to one element, for a total of 8 vertical elements from ground surface to the bottom of the Gordon aquifer. The three-dimensional mesh is therefore 140×140×8 with 156,800 elements or 141×141×9 with 178,929 nodes. The finer vertical resolution in the "upper" zone of the Upper Three Runs aquifer is designed to support subsequent, finer-scale contaminant transport analyses.

Horizontal conductivity in the Gordon aquifer is set to 35 ft/day based on the extensive field data from wells at the SRS and in the region surrounding the site. The vertical conductivity of the Gordon confining unit is set to 10^{-4} ft/day in accordance with field measurements. Conductivity values within Upper Three Runs aquifer zones are set through model calibration to measured water levels. Horizontal conductivity in the "lower" aquifer zone is nominally 5.9 ft/day, and varies from 4 to 20 ft/day. Horizontal conductivity in the "upper" aquifer zone is nominally 8.3 ft/day, and varies from 0.25 to 40 ft/day. Vertical conductivity for the "tan clay" confining zone is nominally 3×10^{-3} ft/day, and varies between 1×10^{-4} and 4×10^{-3} ft/day. A typical ratio of horizontal to vertical conductivity is assumed to be 100 to 1. Approximate soil characteristic curves are adopted for the vadose zone in the numerical model. An effective porosity value of 25% is assumed when computing the pore velocity field.

Table 4-1. Calibration Summary for Groundwater Flow Targets

Flow target	Prior estimate	Range or Uncertainty	Model value (in/yr for recharge; ft^3/s otherwise)	Difference
Surface recharge	15 in/yr	10 – 16 in/yr	12.5 max. local (9.0 based on total area)	–17%
Meyers Branch base flow (headwaters to Road 9)	3.2	±20 – 25%	2.4	–25%
Steel Creek base flow (above Road B to Road A; includes L-Lake)	–2.2 (losing reach)	±40 – 45% or more	3.1 (drain BCs: +4.0 gen. head BCs: -0.9)	+5.3 ft^3/s
Pen Branch base flow (headwaters to Road A13; includes Indian Grave Branch)	13.3	±15 – 20%	13.5	+2%
Fourmile Branch base flow (headwaters to Road A12)	14.1	±15 – 20%	14.7	+4%
Upper Three Runs base flow (Road C to Road A)	4.5	±35 – 40% or more	6.0	+33%
L Lake	-	-	–0.9 (losing lake)	-
Par Pond (portion within model)	-	-	0.1	-
Caster Creek	2.9	-	2.7	-7%
Central Shops outfall creek	0.76	-	0.72	-5%
Indian Grave Branch (excluding K-18 outfall)	4.8	-	2.6	-45%
Indian Grave above Road B (excluding K-18 outfall)	2.3	-	1.0	-56%
Pen Branch above Indian Grave Branch	11	-	7.3	-34%
Pen Branch above Road B	1.9	-	5.3	+3.4 ft^3/s

Table 4-4. Summary of Uncertainty Cases

	GCU Kv		
Recharge	5×10^{-4} ft/day	10^{-4} ft/day	2×10^{-5} ft/day
15 in/yr	-	Case 1	(Case 5)
12.5 in/yr	Case 3	Nominal	Case 4
10 in/yr	(Case 6)	Case 2	-

Table 4-5. Calibration Summary for Uncertainty Cases

Calibration measure	Nominal	Case 1	Case 2	Case 3	Case 4
Overall RMS head residual (ft)	5.45	5.48	5.45	9.59	5.62
Gordon aquifer RMS head residual (ft)	3.4	3.3	3.5	3.4	3.1
"lower" UTRA RMS head residual (ft)	6.3	6.6	6.1	11.6	6.8
"upper" UTRA RMS head residual (ft)					
transmissive	5.2	5.2	5.4	11.1	5.5
AA	4.0	4.0	4.1	7.5	4.4
A/uu	7.0	6.8	7.2	10.0	6.4
Meyers Branch base flow residual (cfs)	-0.8	-0.2	-1.3	-2.1	-0.4
Steel Creek base flow residual (cfs)	+5.3	+6.0	+4.7	+4.2	+5.3
Pen Branch base flow residual (cfs)	+0.2	+3.2	-2.8	-5.3	+2.2
Fourmile Branch base flow residual (cfs)	+0.6	+3.9	-2.8	-6.9	+3.1
Upper Three Runs base flow residual (cfs)	+1.5	+2.2	+0.9	+6.1	-0.4
Nominal Gordon aquifer unit, Kh (ft/d)	35	35	35	96	8.8
Nominal "lower" UTR aquifer zone, Kh (ft/day)	5.9	7.7	4.4	0.7	7.8
Nominal "tan clay" UTR confining zone, Kv (ft/day)	3×10^{-3}	3×10^{-3}	3×10^{-3}	6×10^{-2}	1×10^{-3}
Nominal "upper" UTR aquifer zone, Kh (ft/day)	8.3	11	6.2	1.6	11.1

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KEY WORDS: PORFLOW code
FACT code
Groundwater flow

GROUNDWATER FLOW MODEL OF THE GENERAL SEPARATIONS AREA USING PORFLOW (U)

JULY 15, 2004

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1.0 INTRODUCTION

The E Area PA (McDowell-Boyer et al. 2000) includes a steady-state simulation of groundwater flow in the General Separations Area as a prerequisite for saturated zone contaminant transport analyses. The groundwater flow simulations are based on the FACT code (Hamm and Aleman 2000). The FACT-based GSA model was selected during preparation of the original PA to take advantage of an existing model developed for environmental restoration applications at the SRS (Flach and Harris 1997, 1999; Flach 1999). The existing GSA/FACT model was then slightly modified for PA use, as described in the PA document. FACT is a finite-element code utilizing deformed brick elements. Material properties are defined at element centers, and state variables such as hydraulic head are located at element vertices. The PORFLOW code (Analytic & Computational Research, Inc. 2000) was selected for performing saturated zone transport simulations of source zone radionuclides and their progeny. PORFLOW utilizes control volume discretization and the nodal point integration method, with all properties and state variables being defined at the center of an interior grid cell.

The groundwater flow calculation includes translating the Darcy velocity field computed by FACT into a form compatible for input to PORFLOW. The FACT velocity field is defined at element vertices, whereas PORFLOW requires flux across cell faces. For the present PA, PORFLOW cell face flux is computed in a two-step process. An initial face flux is computed from FACT as an average of the normal components of Darcy velocity at the four corners. The derived flux field approximately conserves mass, but not rigorously. Thus, the flux field is subsequently perturbed to force rigorous mass conservation on a cell-by-cell basis. The undocumented process used is non-unique and can introduce significant artifacts into the final flux field.

Another issue with using both FACT and PORFLOW for saturated modeling is the different mesh numbering systems used by the two codes. Both codes share the identical mesh, but the (I,J,K) element/cell numbering indices differ by one. The different numbering scheme has lead to errors in defining source zones.

The GSA groundwater model will soon be updated to reflect characterization and monitoring data acquired since the original development to support the Saltstone PA revision. The decision was made to also migrate from FACT to PORFLOW for groundwater flow simulations. The motivation is to consolidate all flow and transport analyses to a single software product, and avoid technical issues related to code differences, such as those discussed above.

This report describes how the FACT-based GSA flow model described in the PA has been converted to PORFLOW 5.95.0 (03 MAR 2004), the latest version available to Westinghouse Savannah River Company LLC under license from ACRi. Verification and validation testing pertaining to the new GSA/PORFLOW groundwater flow model following the PORFLOW Software QA Plan (Collard 2002) is also described.

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PRELIMINARY CLOSURE ANALYSIS FOR SLIT TRENCHES #1 AND #2

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2.6 Comparison of VZMS Results to PORFLOW Simulations

The purpose of this section is to compare field data from the vadose zone monitoring system (VZMS) at Slit Trench #1 to tritium concentrations predicted using the vadose zone model, as a model validation exercise. The VZMS is a network of sensors and sampling devices installed at the E-Area Low Level Waste Facility (LLWF) for the purpose of monitoring the downward flux of water and contaminants in the vadose zone near Slit Trenches #1. Vertical and angled lysimeters, installed as part of this system, are routinely sampled and analyzed for tritium. Sample results for those lysimeters near Slit Trench #1 are presented in Appendix D. These data were provided to SRNL in Excel format by Solid Waste & Infrastructure personnel (H. Holmes).

The field data collected from the VZMS were loaded into a Microsoft Access database to facilitate data manipulation and comparison to the model results. The raw tritium data were then adjusted to account for background contributions from rainwater not associated with waste disposal in the trenches. SRS currently maintains a network of rainwater sampling sites as part of the air surveillance program (WSRC, 2004). Results for the past several years from the Burial Ground North sampling location were used to establish a background tritium concentration in rainwater, which was estimated to be roughly 5000 pCi/L (cf. WSRC-TR-95-077, WSRC-TR-99-00301). The assumed background level of 5000 pCi/L was subtracted from the raw VZMS data to approximately isolate contributions from the slit trenches. Sampling results less than 5000 pCi/L were set to zero in the database.

The vadose zone model represents a two-dimensional cross-section with an implied unit thickness of 1 cm, and a specified inventory of 1 Ci. Thus, the units of output concentrations in the model are pCi/L per Ci of inventory per cm of trench length, i.e., pCi/L per Ci/cm. The VZMS data, which are in units of pCi/mL, were transformed to match the model output. To accomplish this task, the local linear inventory for each segment of the trenches was calculated based on the length of the segment and the activity contained within the segment. The total tritium activity contained in each segment of Slit Trench #1 was obtained from the Waste Information Tracking System (WITS). The local linear inventory for each trench segment was calculated from

$$I_l = \frac{A_i}{L_i} \tag{2.6-1}$$

where

I_l = local linear inventory, Ci/cm

A_i = activity of the trench segment, Ci

L_i = length of trench segment, cm

Each lysimeter was assigned to at least one segment based on its location. In some cases, lysimeters were assigned to multiple segments. In this case, the local linear inventory was calculated as follows.

$$I_l = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} L_i} \tag{2.6-2}$$

where n is the number of segments assigned to a lysimeter. In addition to the local linear inventory for each trench segment, an average, global, inventory (I_g) was calculated based on all the segment lengths and activities:

$$I_g = \frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} L_i} \tag{2.6-3}$$

Here n denotes the total number of trenches segments comprising Slit Trench #1.

After calculating the local and global (average) linear inventories for each segment, the concentration data were transformed based on the segment assignments given in Table 2.6-1. The transformation based on local inventory is:

$$C_l^* = \frac{C}{I_l} \tag{2.6-4}$$

where

C_l^* = local transformed concentration, pCi/L per Ci/cm

C = measured concentration, pCi/L

I_l = local linear inventory per trench segment, Ci/cm

Similarly, the global transformation is

$$C_g^* = \frac{C}{I_g} \tag{2.6-5}$$

C_g^* = global transformed concentration, pCi/L per Ci/cm

I_g = global linear inventory, Ci/cm

After transforming the concentration data, the sampling date for each measurement was transformed to elapsed time to match the elapsed time scale of the model output. The disposal history for each trench segment was obtained from WITS. An average burial time for each segment was calculated from the disposal history. The disposal data were in the form of activity disposed per tenth of year for the length of the disposal record. In order to compare to the model output, an average disposal time was calculated for each segment according to

$$\bar{t} = \frac{\sum A_i t_i}{\sum A_i} \tag{2.6-6}$$

where

$\bar{t}$ = average burial time, years

t_i = disposal time interval, years

A_i = activity disposed in segment per time interval t_i, Ci

The average burial time was used to scale the transformed VZMS data to time $t = 0$ in the model output. Therefore, the elapsed time since disposal for a transformed lysimeter measurement was

calculated simply by subtracting the average burial time from the sampling date (converted into years).

To compare to the model output, the transformed VZMS data were sorted based on position relative to the assigned trench segment boundary, and relative to depth below ground surface (bgs). Data from those lysimeters located on the edge of the trench segment were assigned the position "edge". Data from the angled lysimeters were assigned the position "center". To group the data by depth, those lysimeters located below a depth 30 ft bgs were assigned an elevation category of "low". Those above 30 ft bgs were assigned an elevation category of "high". These groupings are given in Table 2.6-1.

The data were also grouped by the waste type contained within the associated trench segment. The activity data reported in WITS is categorized by waste type; generic, non-stack concrete, and stack concrete (232-F). The transformed VZMS data for each segment were grouped according to the waste type containing the predominant amount of activity. Therefore, for a segment with the maximum activity associated with generic waste disposal, the data were assigned to a group called "generic". Likewise, if the maximum activity was associated with concrete rubble (stack or non-stack), the data were assigned to the grouping "concrete". These groupings are given in Table 2.6-2.

Concentration histories at four nodes in the model grid were recorded during PORFLOW vadose zone transport simulations (Figure 2.6-1). The four nodes correspond to the location groupings of edge/high, edge/low, center/high, and center/low. Figure 2.6-2 through 2.6-5 show the results of the simulations compared to the transformed VZMS data. Each of the four figures contains four plots. Plots a and b show the VZMS data for a shallow (high) lysimeter located at the center and edge of a trench segment and, plots c and d show the VZMS data for a deep (low) lysimeter located at the center and edge of a trench segment. Additionally, each plot contains two curves representing the model output according to depth for a lysimeter located at the center and edge of a trench segment. For example, Figures 2.6-2a and b show the same model output for the shallow depth (edge and center position) but, Figure 2.6-2a shows the VZMS data for the center position and Figure 2.6-2b shows the VZMS data for the edge position.

For Figures 2.6-2 and 2.6-3, the measured concentrations were filtered to exclude any values less than the Safe Drinking Water Act Maximum Contaminant Level (MCL). This was done to eliminate any artificially inflated transformed concentrations resulting from dividing by a small linear inventory (Equation 2.6-3). Figure 2.6-2 shows the comparison of the predicted concentrations to the remaining transformed concentrations based on the local linear inventory for the generic waste type. There are no shallow lysimeters at the center position for any of the trench segments. Therefore, no field data are shown in Figure 1a for the shallow depth, center position. The same comment applies to Figures 2.6-3a, 2.6-4a, and 2.6-5a. Figures 2.6-2b through 2.6-2d and Figures 2.6-3b through 2.6-3d show that most of the field data were eliminated by filtering the data with the MCL. Figure 2.6-2b (generic waste type) shows that for a shallow lysimeter at the edge position, the model under predicts the VZMS concentrations. These data were measured at lysimeter locations VL25 and VL 26 located near segments 14-5A and 14-5B. However, the model output for the center position more closely matches the VZMS data.

Differences between the VZMS data and the model predictions can possibly be attributed to the heterogeneity of the sediments beneath Slit Trench #1. Heterogeneous sediments beneath the trench segments would cause lateral spreading of the tritium plume to the edge of the trench where it would be subsequently measured in the VZMS lysimeters. Since the model does not account for this heterogeneity, it would tend to under predict concentrations at the edge of the trench at shallow depths. Therefore, it is reasonable to expect the model output from the center and edge position to bracket the VZMS results. Figures 2.6-2 through 2.6-5 show that the

predicted concentrations for the center and edge positions bracket the VZMS results well for the concrete waste type. However, for the generic waste type, the data is more scattered but generally less than the predicted concentrations. It should be noted that some of the lysimeters are more shallow than the trench bottom, assumed to be 20 ft bgs (9 out of 82 locations). In these cases, the edge/high model results would be expected to over-predict the measured concentration.

Figure 2.5-7 shows the simulated plume for both waste types at an elapsed time of 9 years. Figure 2.5-7a shows considerable spreading of the plume beneath the trench compared to the concrete waste type (Figure 2.5-7b). This is due to the differences in physical properties of the two waste types. Figure 2.5-1a shows the streamlines for the generic waste type. This figure shows that the streamlines bend in towards the trench for the generic waste type due to the higher conductivity of the waste zone. Once past the trench, the streamlines begin to spread out again in the native sediments. Conversely, for the concrete waste type depicted in Figure 2.5-1b, the streamlines bend around the trench due to the low conductivity of the waste and then bend inwards towards the centerline beneath the trench. This is reflected in the plume shape for the concrete waste type shown in Figure 2.5-7b where there is little spreading of the contaminant plume. The model results for the concrete waste type (Figures 2.6-3 and 2.6-5) bracket the VZMS data very well because there is limited plume spreading as shown in Figure 2.5-7b.

Figures 2.6-3a though d compare the predicted concentrations to the transformed concentrations based on the local linear inventory for the concrete waste type. These figures show that the predicted concentrations bracket the transformed VZMS data. This is most likely because the flow field around the concrete waste tends to limit spreading of the contaminant plume.

Figures 2.6-4 and 2.6-5 make a similar comparison based on the global inventory for the generic and concrete waste type. These data were not filtered based on the MCL and all the VZMS data are shown on the plots. Referencing concentrations to the global inventory may be more appropriate for deeper sample points where the effects of local inventory variation would be smeared due to heterogeneous infiltration and subsurface properties. Figures 2.6-4b through d show considerable scatter in the transformed VZMS data but none of the transformed concentrations exceed the maximum model prediction. Figures 2.6-5a through d show less scatter in the data and that the model predictions more closely bracket the dataset.

In summary, the predicted concentrations are consistent with the VZMS field data in an overall sense. In general, model predictions from the center and edge of the trench can be expected to bracket the VZMS field data. More scatter is observed in the field data for the generic waste type than the concrete waste type. This is because the generic waste type has a higher conductivity than the native sediments which results in a flow field conducive to spreading of the contaminant plume beneath the trench. Because the concrete waste type has a low conductivity, water tends to flow around the trench and bend sharply in towards the centerline once below the trench. This limits plume spreading and scatter in the field data. Model predictions matched the VZMS data transformed based upon the global inventory of Slit Trench #1 better than that transformed based upon the local inventory. This may be due in part to the uncertainty associated with assigning trench segments to lysimeters.

Table 2.6- 1 Lysimeter Location, Depth, Associated Segments, Position Relative to the Segment, and Elevation Relative to the Model Grid.

Station_ID	UTM-E (m)	UTM-N (m)	Depth (cm)	Segment	Position	Elevation
AL-1 (45')	438226	3683678	1372	14-1A	Center	Low
AL-2 (45')	438231	3683700	1372	14-1A, 14-1B	Center	Low
AL-3 (45')	438235	3683721	1372	14-1B	Center	Low
AL-4 (45')	438240	3683744	1372	14-1C	Center	Low
AT-5 (23')	438236	3683759	701	14-1C	Edge	High
AT-5 (33')	438236	3683759	1006	14-1C	Edge	Low
AT-5 (42')	438236	3683759	1280	14-1C	Edge	Low
AT-5 (57')	438236	3683759	1737	14-1C	Edge	Low
AT-6 (24')	438237	3683764	732	14-1C	Edge	High
AT-6 (34')	438237	3683764	1036	14-1C	Edge	Low
AT-6 (43')	438237	3683764	1311	14-1C	Edge	Low
AT-6 (55')	438237	3683764	1676	14-1C	Edge	Low
AT-7 (12')	438231	3683765	366	14-1C	Edge	High
AT-7 (23')	438231	3683765	701	14-1C	Edge	High
AT-7 (42')	438231	3683765	1280	14-1C	Edge	Low
AT-7 (54')	438231	3683765	1646	14-1C	Edge	Low
AT-8 (23')	438225	3683708	701	14-1A, 14-1B	Edge	High
AT-8 (31')	438225	3683708	945	14-1A, 14-1B	Edge	Low
AT-8 (35')	438225	3683708	1067	14-1A, 14-1B	Edge	Low
AT-8 (46')	438225	3683708	1402	14-1A, 14-1B	Edge	Low
AT-8 (55')	438225	3683708	1676	14-1A, 14-1B	Edge	Low
AT-9 (28')	438190	3683656	853	14-3A	Edge	High
AT-9 (36')	438190	3683656	1097	14-3A	Edge	Low
AT-9 (47')	438190	3683656	1433	14-3A	Edge	Low
AT-9 (56')	438190	3683656	1707	14-3A	Edge	Low
AT-10 (23')	438209	3683771	701	14-3C	Edge	High
AT-10 (32')	438209	3683771	975	14-3C	Edge	Low
AT-10 (43')	438209	3683771	1311	14-3C	Edge	Low
AT-10 (53')	438209	3683771	1615	14-3C	Edge	Low
VL-1 (28')	438180	3683658	853	14-4A	Edge	High
VL-1 (A: 32-47')	438180	3683658	975	14-4A	Edge	Low
VL-1 (B: 32-47')	438180	3683658	975	14-4A	Edge	Low
VL-1 (C: 32-47')	438180	3683658	975	14-4A	Edge	Low
VL-1 (56')	438180	3683658	1707	14-4A	Edge	Low
VL-2 (9.5')	438213	3683770	290	14-3C	Edge	High
VL-2 (19.5')	438213	3683770	594	14-3C	Edge	High
VL-2 (24')	438213	3683770	732	14-3C	Edge	High
VL-2 (42.6')	438213	3683770	1298	14-3C	Edge	Low
VL-2 (58')	438213	3683770	1768	14-3C	Edge	Low
VL-3 (19')	438207	3683660	579	14-00, 14-1A, 14-2A	Edge	High
VL-3 (24.7')	438207	3683660	753	14-00, 14-1A, 14-2A	Edge	High
VL-3 (32')	438207	3683660	975	14-00, 14-1A, 14-2A	Edge	Low
VL-3 (47.3')	438207	3683660	1442	14-00, 14-1A, 14-2A	Edge	Low
VL-3 (58')	438207	3683660	1768	14-00, 14-1A, 14-2A	Edge	Low
VL-4 (9.75')	438222	3683768	297	14-2C	Edge	High

Station_ID	UTM-E (m)	UTM-N (m)	Depth (cm)	Segment	Position	Elevation
VL-4 (20')	438222	3683768	610	14-2C	Edge	High
VL-4 (24.5')	438222	3683768	747	14-2C	Edge	High
VL-4 (43')	438222	3683768	1311	14-2C	Edge	Low
VL-4 (58')	438222	3683768	1768	14-2C	Edge	Low
VL-5 (23')	438235	3683753	701	14-1C	Edge	High
VL-5 (32.5')	438235	3683753	991	14-1C	Edge	Low
VL-5 (41.5')	438235	3683753	1265	14-1C	Edge	Low
VL-24 (13')	438171	3683660	396	14-5A	Edge	High
VL-24 (18')	438171	3683660	549	14-5A	Edge	High
VL-24 (26')	438171	3683660	792	14-5A	Edge	High
VL-24 (32')	438171	3683660	975	14-5A	Edge	Low
VL-24 (43')	438171	3683660	1311	14-5A	Edge	Low
VL-25 (20')	438174	3683691	610	14-5A, 14-5B	Edge	High
VL-25 (30.5')	438174	3683691	930	14-5A, 14-5B	Edge	Low
VL-25 (41.5')	438174	3683691	1265	14-5A, 14-5B	Edge	Low
VL-26 (13')	438181	3683721	396	14-5B, 14-5C	Edge	High
VL-26 (19')	438181	3683721	579	14-5B, 14-5C	Edge	High
VL-26 (21')	438181	3683721	640	14-5B, 14-5C	Edge	High
VL-26 (31')	438181	3683721	945	14-5B, 14-5C	Edge	Low
VL-26 (40')	438181	3683721	1219	14-5B, 14-5C	Edge	Low
VL-27 (18')	438185	3683751	549	14-5C	Edge	High
VL-27 (29')	438185	3683751	884	14-5C	Edge	High
VL-27 (39')	438185	3683751	1189	14-5C	Edge	Low
VL-28 (10.5)	438195	3683774	320	14-5C	Edge	High
VL-28 (24)	438195	3683774	732	14-5C	Edge	High
VL-28 (33.5)	438195	3683774	1021	14-5C	Edge	Low
VL-28 (46)	438195	3683774	1402	14-5C	Edge	Low

Table 2.6- 2 Segment Properties for Slit Trench #1.

Segment	Length (cm)	Total Activity (Ci)	Inventory (Ci/cm)	Waste Type
14-00	1662	3.38E-06	2.03E-09	Generic
14-1A	4612	0.00E+00	0.00E+00	Generic
14-1B	3108	8.78E-01	2.83E-04	Concrete
14-1C	3108	1.92E+00	6.18E-04	Concrete
14-1EXP	4905	3.42E-03	6.97E-07	Generic
14-2A	3054	3.74E-01	1.22E-04	Concrete
14-2B	3066	3.60E-04	1.18E-07	Concrete
14-2C	4556	1.50E-09	3.29E-13	Generic
14-2EXP	4808	3.42E-03	7.11E-07	Generic
14-3A	3693	1.67E-03	4.51E-07	Generic
14-3B	4279	4.95E-02	1.16E-05	Generic
14-3C	3548	2.25E-01	6.36E-05	Generic
14-3EXP	4936	4.60E-02	9.32E-06	Generic
14-4A	3145	4.45E-04	1.42E-07	Generic
14-4B	2802	2.10E-04	7.50E-08	Generic
14-4C	3186	2.53E-02	7.95E-06	Generic
14-4D	1343	7.07E-05	5.26E-08	Generic
14-4EXP	4904	3.42E-03	6.97E-07	Generic
14-5A	3073	5.09E-04	1.66E-07	Generic
14-5B	3123	8.89E-03	2.85E-06	Generic
14-5C	5449	4.46E-01	8.19E-05	Generic
14-1A, 14-1B			5.65E-04	Generic
14-5A, 14-5B			3.13E-07	Generic
14-5B, 14-5C			5.50E-06	Generic
14-00, 14-1A, 14-2A			6.10E-09	Concrete
Global	76360	3.99E+00	5.22E-05	Concrete

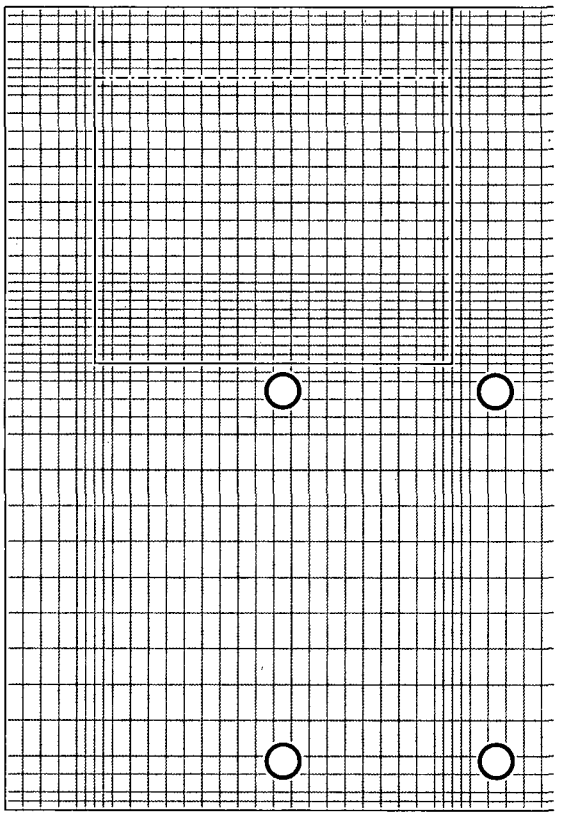
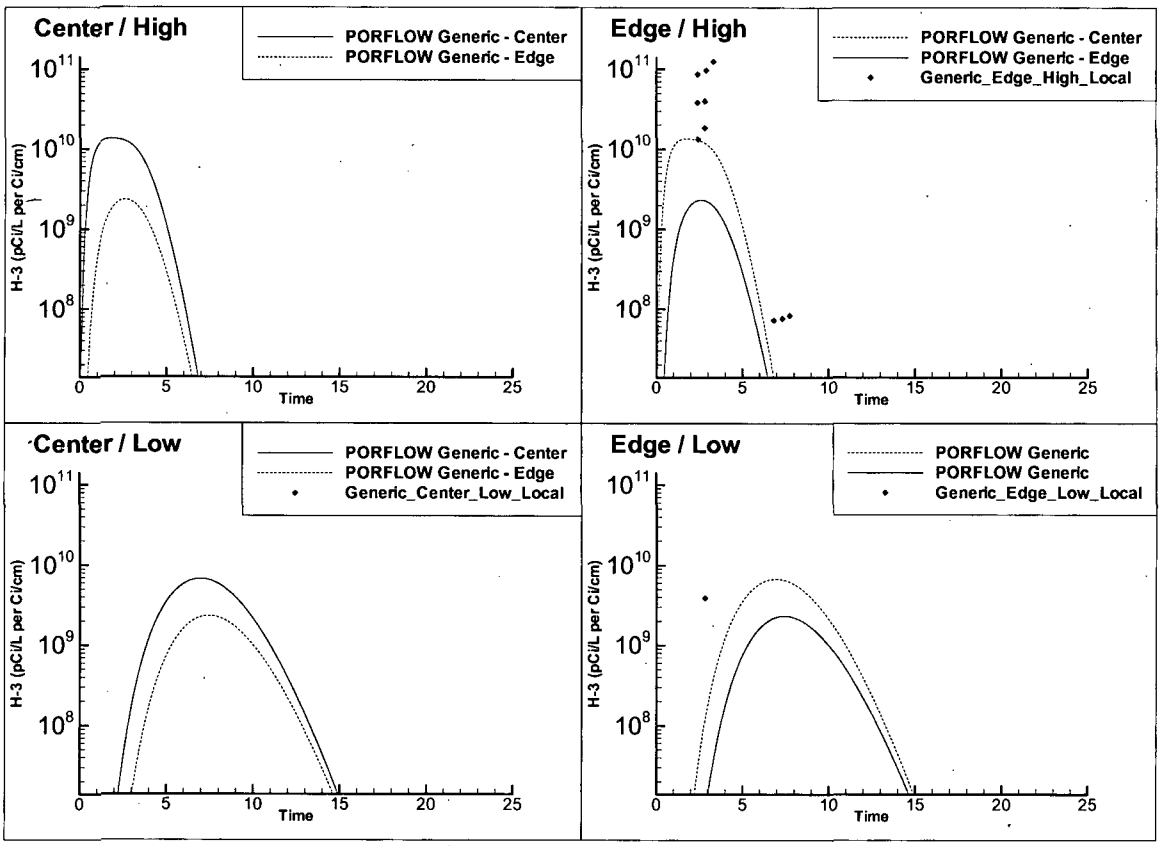


Figure 2.6- 1 Approximate locations of the 4 monitoring nodes corresponding to high/low and center/edge positions.



(c) (d)

Figure 2.6- 2 Concentration Based On Local Linear Inventory For The Generic Waste Type At Positions (A) Center/High, (B) Edge/High, (C) Center/Low, And (D) Edge/Low.

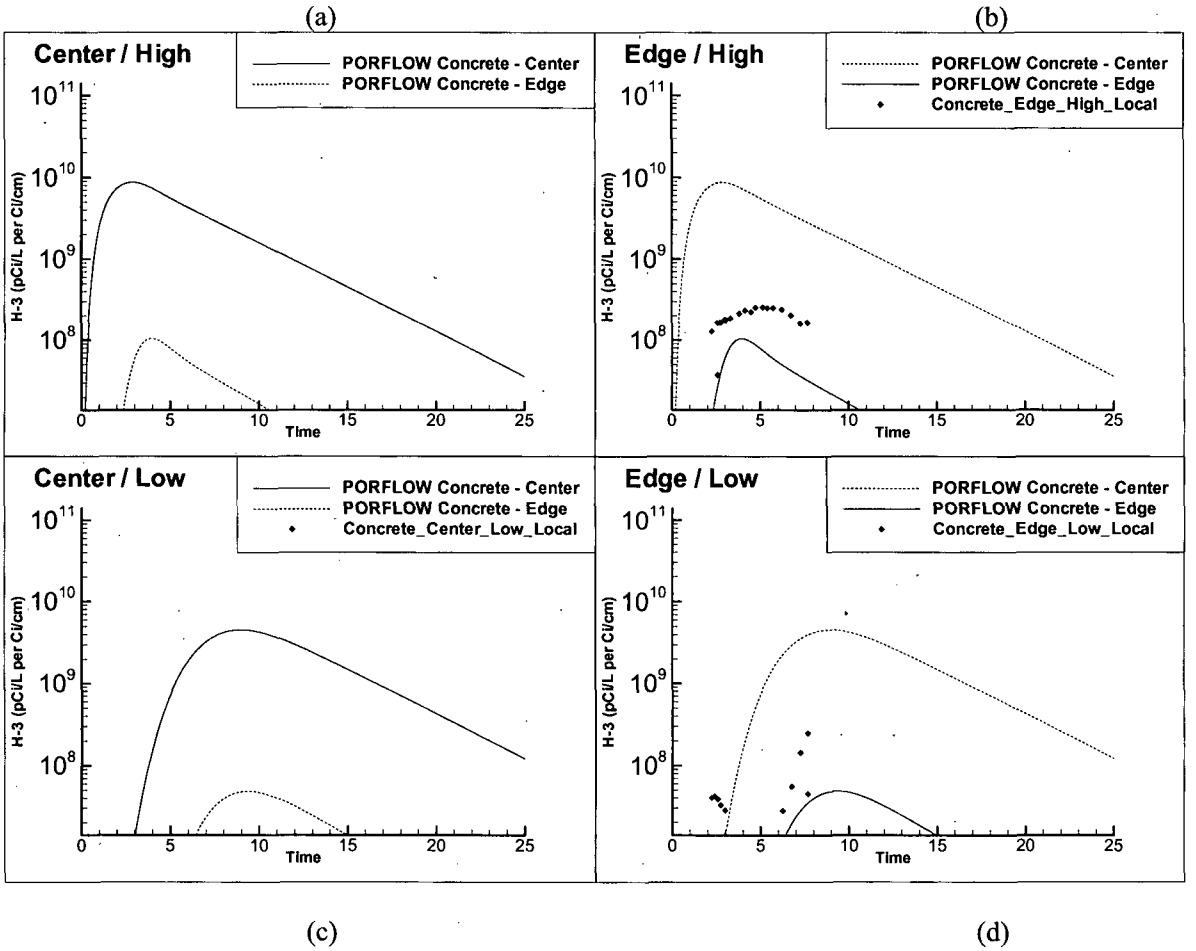


Figure 2.6- 3 Concentration Based On Local Linear Inventory For The Concrete Waste Type At Positions (A) Center/High, (B) Edge/High, (C) Center/Low, And (D) Edge/Low.

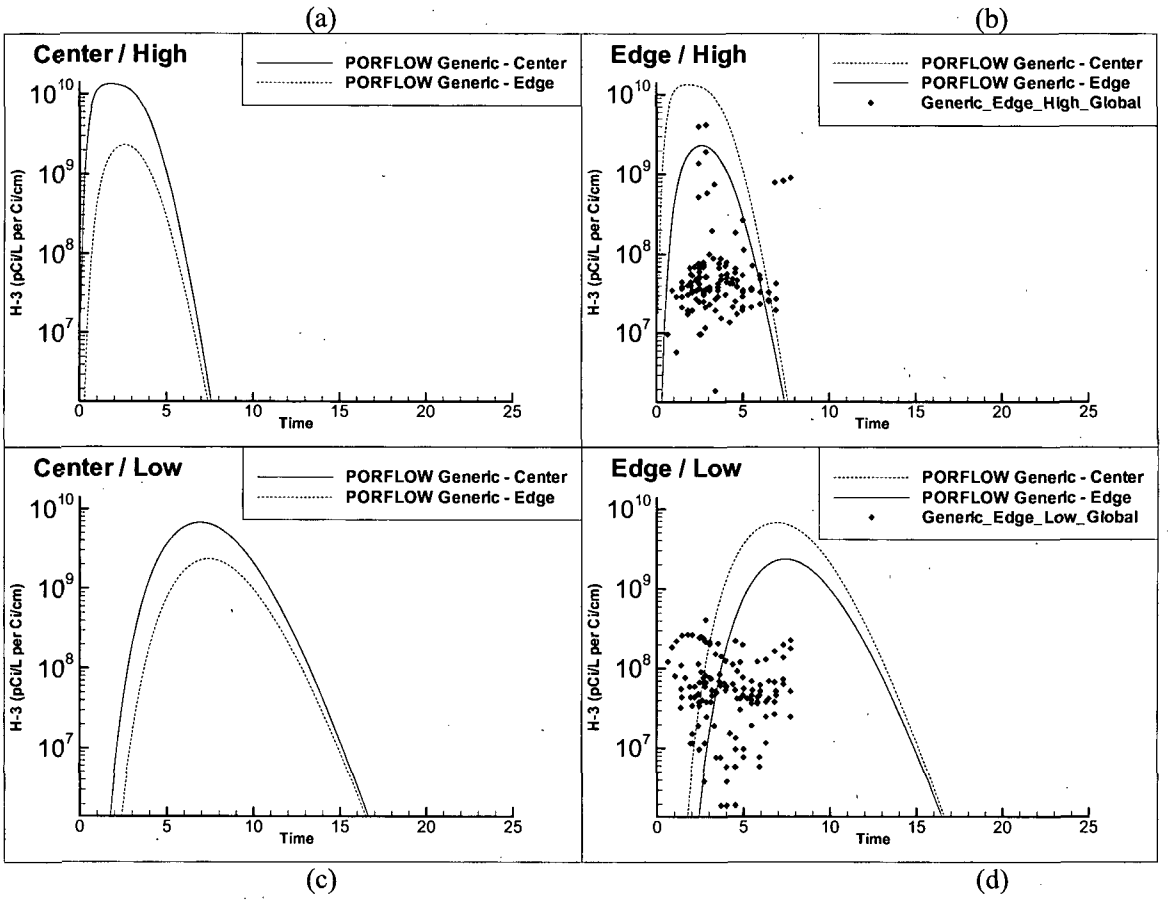


Figure 2.6- 4 Concentration Based On Global Inventory For The Generic Waste Type At Positions (A) Center/High, (B) Edge/High, (C) Center/Low, And (D) Edge/Low.

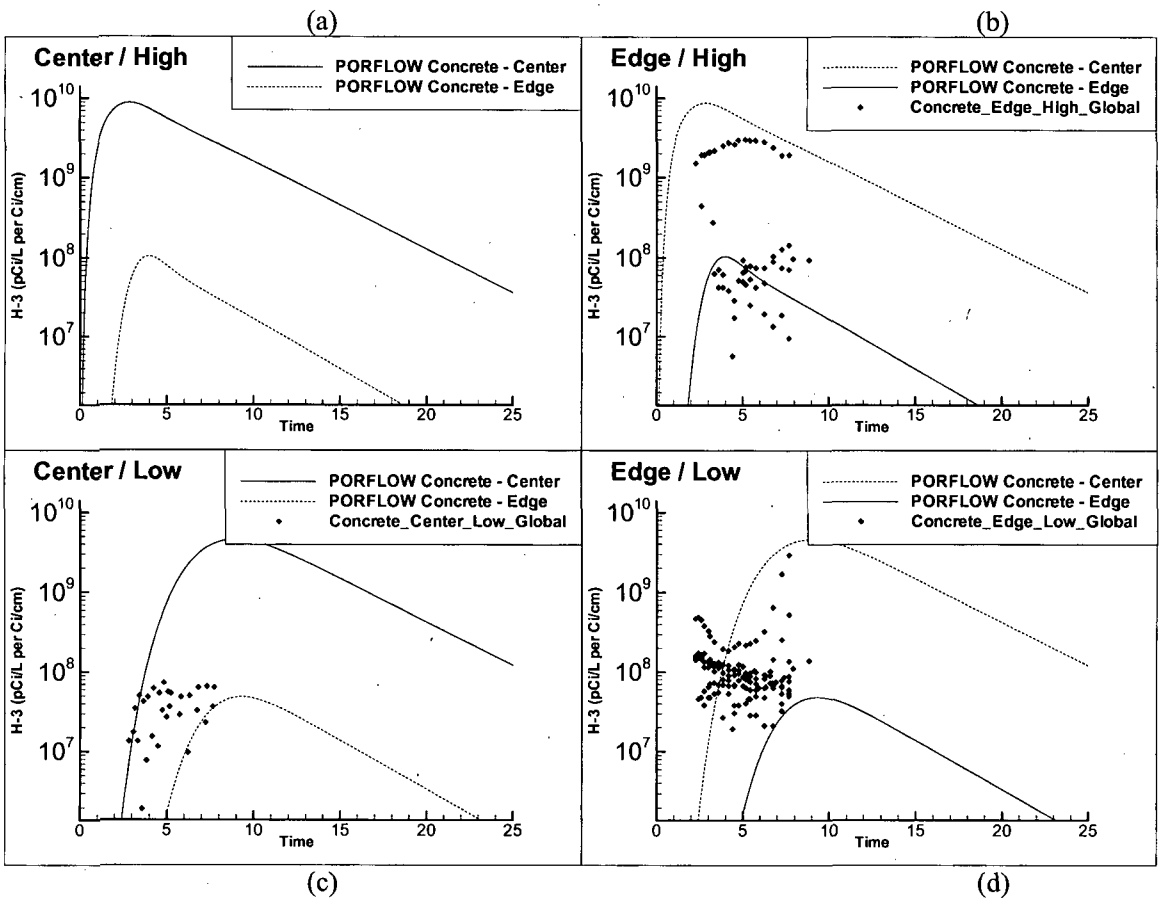


Figure 2.6- 5 Concentration Based On Global Inventory For The Concrete Waste Type At Positions (A) Center/High, (B) Edge/High, (C) Center/Low, And (D) Edge/Low.

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Recommended Geochemical Input Values for the Special Analyses of the Slit/Engineered Trenches and Intermediate Level Vault

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July 23, 2004

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ACRONYMS

CDP	Cellulose Degradation Products
DOC	Dissolved Organic Carbon
Kd	Distribution Coefficient
SRS	Savannah River Site

1.0 ABSTRACT

Selected geochemical input values are provided for the Slit and Engineered Trenches Special Analysis and the Intermediate Level Vault Special Analysis. Only input values for parameters that have new information related to them or that have recently been recognized as being important to the special analysis are discussed. These parameters are 1) plutonium geochemistry (conceptual model and input values), and 2) Kd values for select radionuclides. Due to the differences in the geochemical environment expected at these two disposal locations, the Kd values are expected to differ. The Intermediate Level Vault will create a relatively high pH environment (pH ~10), whereas the Slit and Engineered Trenches will create an environment high in organic matter.

2.0 OBJECTIVE

The objective of this report is to provide geochemical input values for the Slit/Engineered Trenches Special Analysis and the Intermediate Level Vault Special Analysis. Special analyses are calculations conducted to provide information used to determine the amount of radioactive waste that can be safely disposed at a given site. The intent of this document is to provide technical justification for the selection of some, but not all the geochemical input values used in the special analysis. Input values for parameters that have new information related to them or that have recently been recognized as being important to the special analysis are discussed. These parameters are:

1) plutonium geochemistry (conceptual model and input values),
2) Bi, Ca, Cl, K, Mo and Se Kd values as a function of cellulose degradation products (CDPs) or pH for the Slit/Engineered Trench Special Analysis, and
3) Al, Bi, Co, Eu, K, Kr, Mo, Pu(III/IV), Pu(V/VI), Rn, and Se for the Intermediate Level Vault Special Analysis.

3.0 PLUTONIUM GEOCHEMISTRY CONCEPTUAL MODEL FOR THE SLIT/ENGINEERED TRENCH SPECIAL ANALYSIS

There have been several recent reports on Pu geochemistry in the SRS subsurface environment that have direct applicability to these special analyses (Kaplan and Wilhite 2001; Kaplan et al. 2001; Powell et al. 2002; Kaplan et al. 2003; Kaplan et al. 2004a; Kaplan et al. 2004b).

The conceptual model for Pu geochemistry and colloid-facilitated transport was first proposed by Cook (2002). Plutonium is assumed to exist in three forms: Pu(III/IV), Pu(V/VI), and $Pu_{colloids}$. Pu(III/IV), Pu in the +3 and +4 oxidation states, has one set of geochemical parameters, Pu(V/VI), another set of parameters, and $Pu_{colloids}$, Pu in the colloidal form, a third

set of parameters. Based on laboratory work using SRS sediments (as well as other sediments), Pu(III/IV) is much less mobile than Pu(V/VI) (Kaplan et al. 2001; Powell et al. 2002; Kaplan et al. 2003; Kaplan et al. 2004a; Kaplan et al. 2004b). Pu(III/IV) is also much more abundant than Pu(V/VI) in the SRS subsurface environment because of natural mineralogy, redox, and pH conditions.

One of the key factors controlling Pu(III/IV) and Pu(V/VI) sorption is assumed to be concentration of cellulose degradation products (CDPs; e.g., wood, paper, and cardboard). CDPs decrease the tendency of Pu to sorb to sediments by 1) reducing the system pH, and 2) promoting the formation of weakly binding Pu-dissolved organic matter (DOC) complexes. To date, no Pu Kd measurements as a function of CDPs concentrations have been made. However, Serkiz (2000) reported a strong correlation between pH and CDP concentrations. The input Kd values were selected from experiments in which pH was varied (Powell et al. 2002). The intent was use the pH variable as a proxy for DOC concentration. One limitation of this approach is that only the pH effect of DOC and not the effect of DOC-Pu complexes is captured by this approach to selecting Kd values, thereby producing a potentially non-conservative estimate. To minimize this potential problem, the minimum Kd value for a specific pH condition was selected. The waste source term is assumed to have an infinite amount of cellulose to form CDP, i.e., CDP is produced throughout the modeling period. More details about the CDP-radionuclide interaction model and its assumptions are presented by Serkiz (2000).

The colloid model is simplistic and reflects a first attempt at accounting for this potential vector of transporting Pu. The model is devoid of mechanism and is based on a field experiment conducted in a nearby site on the SRS, F-Area (Kaplan et al. 1994). It is anticipated that as more information about Pu colloidal transport is made available, this model will be modified as part of the performance assessment maintenance program. $Pu_{colloids}$ concentration in the flow path is assumed to exist at a concentration similar to that measured in F-Area (Kaplan et al. 1994) and to move at the same rate as water, i.e., to have a Kd value of 0 mL/g. All Pu in the source exists as Pu(III/IV) because Pu(IV) is the oxidation state it was disposed as and because of the natural tendency of Pu to convert to Pu(IV) (Kaplan et al. 2004a). CDPs do not influence $Pu_{colloids}$ Kd values (because they already have a Kd value of 0 mL/g). More details about the Pu geochemistry model and its assumptions are presented in Section 3.4 and in Cook (2002).

3.1 Proton Sorption to Sediment and Background pH

Prior to modeling Pu transport, pH or proton concentrations in the sediment need to be modeled so that the appropriate pH-dependent Kd value can be selected for each node in the reactive-transport model. A Freundlich-sorption isotherm will be used to describe proton sorption to the E-Area sediment, using the approach first proposed by Brewer and Sochor (2002) and data generated from SRS sediment by Kaplan (2003). The non-linear (Eq. 1) and linear (Eq. 2) forms of the Freundlich-sorption isotherm are as follows:

$$S = kC^n \tag{1}$$

$$\log[S] = \log[k] + n\log[C] \tag{2}$$

where

S = sorbed phase concentration,
k = Freundlich absorption constant,
C = aqueous phase concentration, and
n = Freundlich exponent.

Brewer and Sochor (2002; page 52) reported that the value for n is 0.38 and the value for k is 396 $L^{0.38}\mu g^{0.62}/kg$.

To establish background pH levels, Hiergesell (2004) used historic groundwater monitoring data from wells in the flow path of a hypothetical plume from the Slit/Engineered Trench Facility in E-Area. The flow path was established by using groundwater flow simulations. Three wells were identified as existing in the hypothetical plume, BG 96, BGX 6D, and HMD 4D. All field pH values for each of these wells were extracted from the SRS ERDMS database (Table 1). Based on this data, an assignment of a site background pH of 5.5 is appropriate. Assuming a lower background pH yields a conservative estimate because most metals and radionuclides have enhanced transport under acidic conditions.

Table 1. pH levels in 3 wells located in a hypothetical plume emanating form the Slit/Engineered Trench Facility in E-Area; data used to estimate background pH at E-Area.

Well	Mean pH	Median pH	# of Measurements
BG 96	5.4	5.5	15
BGX 6D	6.2	6.2	24
HMD 4D	5.7	5.7	23

3.2 Pu(III/IV) Geochemistry

- Pu(III/IV) adsorbs to the sediment in a linear and reversible manner, as described by the Kd construct (Eq. 3).

$$Pu(III/IV)_{aq} + S_s \bullet \quad Pu(III/IV)S_s; \text{ where } S_s = \text{sediment} \qquad (3)$$

- Kd values vary as a function of pH (more specifically, as a function of CDP concentrations; see Section 3.0).

- Once adsorbed to the sediment, the Pu(III/IV) slowly oxidizes to Pu(V/VI). Oxidation of Pu(III/IV) to Pu(V/VI) occurs through a reversible, first-order kinetic process:

$$Pu(III/IV)S_s \rightarrow Pu(V/VI)S_s; \text{ where } S_s = \text{sediment.} \qquad (4)$$

3.3 Pu(V/VI) Geochemistry

Pu(V/VI) geochemistry is treated similar to Pu(III/IV), namely it adsorbs and then undergoes a redox reaction, reduction.

- Sorption is described by Kd values that quantify the reaction in equation 5:

$$Pu(V/VI)_{aq} + S_s \bullet \quad Pu(V/VI)S_s; \text{ where } S_s = \text{sediment.} \qquad (5)$$

- Kd values vary as a function of pH (more specifically, as a function of CDP concentrations; see Section 3.0).

- Once adsorbed to the sediment, the Pu(V/VI) quickly reduces to Pu(III/IV). Reduction of Pu(V/VI) to Pu(III/IV) occurs through a reversible, first-order kinetic process:

$$Pu(V/VI)S_s \rightarrow Pu(III/IV)S_s; \text{ where } S_s = \text{sediment.} \qquad (6)$$

3.4 $Pu_{colloids}$ Geochemistry

3.4.1 General Description

Modeling colloid facilitated transport of Pu in the SRS subsurface environment is greatly hindered by the paucity of data on the subject. Kaplan et al. (1994) measured Pu associated with a filterable fraction in groundwater recovered in F-Area, adjacent to E-Area. Measurements made from this study form the basis for the proposed conceptual model. This conceptual model is devoid of mechanism and is greatly simplified. As such, there is a great deal of uncertainty associated with the calculated results. However, we felt that it is important to start accounting for the possibility of this transport mechanism in the Special Analyses, with the intent of improving on the model as part of the performance assessment maintenance program as more experimental data becomes available (discussed in more detail in Section 8.0). The assumption that colloid facilitated transport occurs in the modeled system is conservative with respect to the groundwater risk calculation because it provides an additional vector for transporting Pu to the 100-m well. Details regarding how colloid facilitated transport of Pu is conceptualized in this model are presented below.

3.4.2 Detailed Description

Plutonium associated with a filterable fraction, was measured in F-Area (Kaplan et al. 1993). This data was used to form the basis for estimating colloidal Pu, $Pu_{colloid}$, in E-Area. Kaplan et al. (1993) reported total Pu concentrations in the F-Area Seepage Basin and $Pu_{colloids}$ concentrations in three wells located 30 m, 320 m and 550 m from the seepage basin. Because of considerable differences in pH and other geochemical parameters between E- and F-Area, the data at the 30-m and 320-m wells were not considered further. For simplicity, the ratio between the concentration of $Pu_{colloids}$ at the 550-m well to the concentration of Pu in vadose zone samples at the seepage basin is assumed to apply to solid waste disposed in trenches inside the E-Area.

The ratio between the Pu concentrations on colloids at a 550-m well and the liquid in the source zone was found to be 1.1E-3 in the field. It will be assumed that an estimated 550-m well concentration for the $Pu_{colloids}$ in E-Area should be calculated by multiplying the non-colloidal model's average initial concentration of the Pu in the liquid in the source zone by 1.1E-3 to match field observations at the other site.

The PA uses a hypothetical 100-m well to establish risk. $Pu_{colloids}$ concentrations may be expected to be greater at 100 m than 550 m from a well. To account for the shorter distance to the 100-m well, the model's 550-m well concentration should be multiplied by 550/100 to produce an estimate of the Pu colloid concentration in the 100-m well.

Plutonium concentrations reported by Kaplan et al. (1994) in the source well included colloids and non-colloids, while the concentrations at the distant wells consisted almost entirely of colloids. To best capture the value in the existing data, the ratio of the Pu colloid amount at the distant well to the Pu total amount at the source well will be directly added to modeling results for non-colloid Pu isotopes. As a conservative approach, that ratio will be applied to each and every Pu isotope. Although water from the source will not reach the 100-m well for several years, the ratio will be applied from time zero.

As the total source amount decays, the amount of the $Pu_{colloids}$ at the well will similarly decay. Progeny will be produced and included in the potential effects on a receptor. For example, if the ratio of $Pu_{colloids}$ concentration at the 100-m well to the source is 1E-3 and the initial quantity of source term for Pu-238 is 1000 Ci, then 1 Ci (1000 Ci * 1E-3) of Pu-238 would initially be at the well. After one half-life, the quantity of Pu-238 at the source would be reduced by one-half by decay as well as by leaching and diffusion. However, if only the decay is considered, then the quantity of Pu-238 at the source would be one-half or 500 Ci and the quantity of Pu-238 at the well as colloids would be reduced by half to 0.5 Ci. Progeny at the well are assumed to be generated and that they do not migrate away from the well.

To incorporate the above assumptions, the $Pu_{colloid}$ construct will be simulated as follows. Some of these recommendations are specifically designed to be compatible to the PORFLOW code used in the special analyses.

- Pu concentration fraction of the source to field measurements (Kaplan et al. 1994) is assigned as $WellFrac_{colloids}$.
- The source for the non-colloids modeled for the groundwater pathway is assigned as $Source_{all}$.
- The quantity of Pu colloids at the 100-m well is the product of these two factors: $Well_{colloid} = Source_{all} * WellFrac_{colloids}$.
- The quantity of Pu in $Well_{colloids}$ is simply decayed in place, thereby reducing the parent and generating progeny.
- Transport of $Pu_{colloid}$ is not retarded by the aquifer sediment, i.e., $Pu_{colloids}$ Kd value is 0 mL/g.
- $Pu_{colloid}$ does not have any assigned redox status, and as such its concentration is not influenced by the other two Pu fractions, Pu(III/IV) and Pu(V/VI).
- CDPs do not influence $Pu_{colloids}$ mobility or speciation.
- Pu associated with the colloids does not decay into daughter products. This is conservative with respect to the groundwater pathway risk calculation because the $Pu_{colloid}$ has a Kd of 0 mL/g. Many of the daughter products would likely desorb from colloids and would take on the much higher Kd value of a dissolved solute.

For ancestors of Pu that generate Pu, the same method will be applied with two exceptions. First, the starting quantity at the well will be for the $Source_{all}$ ancestor multiplied by the $WellFrac_{colloids}$. Second, none of the quantity of ancestors of Pu will be excluded from the effects that could potentially affect a receptor, because it is the Pu colloids being analyzed, not the ancestors.

In summary, $Pu_{colloid}$ will not be directly modeled for solid waste disposed in E-Area trenches to determine their concentrations at a 100-m well. Rather the effects of the colloids will be captured by separately calculating the 100-m well concentration for the colloids using the ratios presented above. The well concentration for the colloids can then be summed with the well concentration from the non-colloids to predict a total well concentration. Additional data and information about colloid generation at the E-Area site is necessary before a more direct approach to modeling Pu transport by colloids is possible (discussed in Section 8.0).

4.0 PLUTONIUM GEOCHEMISTRY CONCEPTUAL MODEL FOR THE INTERMEDIATE LEVEL VAULT SPECIAL ANALYSIS

The assumptions underlying how Pu geochemistry will be modeled in the Intermediate Level Vault Special Analysis are identical to those for the Slit/Engineered Trench Special Analysis (Section 3.0), except for two important differences. The first difference is that Pu sorption will not be influenced by CDPs, because little or no cellulose containing material will be disposed at the Intermediate Level Vault Facility. Thus, Pu Kd values appropriate for a pH 5.5 sediment (background; Section 3.1) will be used in the far field. The second difference is that $Pu_{colloids}$ will not be included. Insufficient conceptual and quantitative data is presently available to include this transport process in the model. As part of the performance assessment maintenance program, additional research needs to be directed at this issue (Section 8.0)

5.0 RECOMMENDED PLUTONIUM INPUT VALUES

Table 2. Recommended Input Values, Comments, and References for Plutonium Redox-Reaction Rates and Colloidal Transport (Conservative for Groundwater Pathway for Sandy Textured Sediment)

Parameter	Value	Units	Comment	Ref.
Reduction Rate: Pu(V/VI) → Pu(III/IV)	1E-3	1/hr	Best-fit value to data was calculated from a data set generated from a study involving a lysimeter containing SRS sediment and Pu(IV). The reduction rate was 1E-3 hr^{-1} (See Figure 3 in Reference 2). The lysimeter was exposed to natural rainfall for 11 years and this rate constant was estimated by applying a reactive transport code to a Pu-sediment concentration vs. depth data set. The first order reduction rate constant measured from a laboratory experiment was 1.1E-1 hr^{-1}, a faster rate, which was likely the result of better mixing obtained during the beaker-size laboratory study (See Figure S4 in Ref. 2). The slower reduction rate was selected in an effort to be conservative, i.e., the rate that Pu(V/VI) converts to the less mobile Pu(III/IV) will be slow.	1
Oxidation Rate: Pu(III/IV) → Pu(V/VI)	1.5E-8	1/hr	There are 2 estimates for this parameter using SRS sediment. One estimate was calculated from the same lysimeter data involving a Pu(IV) spike discussed above. An oxidation rate was fitted to the data set: 1E-8 1/hr. A laboratory measurement of this parameter, designed to provide highly accelerated oxidizing conditions, was 1e-6 1/hr. The highly oxidizing conditions created during the laboratory study could not be achieved in the SRS subsurface. The conservative oxidation rate was estimated by increasing the lysimeter oxidation rate by 50%, thereby increasing the rate that oxidation converts the less mobile form of Pu, Pu(III/IV), to Pu(V/VI).	1
$Pu_{colloids}$ concentration;	4.5E-3	wt-% of Inven-tory	This is the percent of Pu assumed to exist in the colloidal fraction. Pu was detected in F-area as a colloidal (filterable) fraction about 550m from the seepage basins, the point source: $[Pu]_{550m}/[Pu]_{0m}$ x 100 = $Pu_{colloid}$ concentration. This value was 0.0029% in a well 30 m from the point source, 0.0045% at a well 320 m from the point source, 0.0011% in a well 550 m from the point source, and <0.0002% in a well 1020 m from the point source. The largest value was selected.	2
$Pu_{colloid}$ Kd	0	mL/g	Conservative estimate assuming all the colloidal Pu is highly mobile and is not held up (retarded) by the subsurface sediment.	2

1. Kaplan et al. (2004); Figure 3.
2. Kaplan et al. (1994); Table 3.

Table 3. Pu(III/IV) and Pu(V/VI) and $Pu_{colloids}$ Kd Values as a Function of pH (Conservative for Groundwater Pathway for Sandy Textured Sediment)

DOC (mg C/L)	pH[a]	Pu(III/IV) Kd (mL/g) [b]	Pu(V/VI) Kd (mL/g) [b]	$Pu_{colloids}$ Kd (mL/g)
1000	4.5	220	8	0
100	4.75	270	8	0
30	5.0	310	8	0
10	5.25	350	9	0
1	5.5	370	15	0
<1	5.75	390	21	0
<1	6.0	1000	70	0
<1	pH 5.5 for Clayey Sediment [c]	6500	50	0

[a] Following the pH–DOC correlation described in by Serkiz (2000).

[b] Pu(III/IV) and Pu(V/VI) data taken from Powell et al. (2002): Subsurface Sandy Sediment, Figure 13 on page 33; and Appendix B on page 46. These Kd values were the lowest of 4 SRS sediments tested. The other 3 sediments generally had Kd values an order of magnitude greater than the Pu(IV) presented in this table.

[c] Pu(III/IV) and Pu(V/VI) data taken from Powell et al. (2002): Subsurface Clayey Sediment, Figure 13 on page 33; and Appendix B on page 47. These Kd values are for use in a clay layer included in the Special Analysis that is sufficiently deep that the concentration of dissolved organic matter will be assumed to be negligible, thus the pH in the clay layer is assumed to be 5.5.

6.0 RECOMMENDED Kd VALUES FOR USE IN THE SPECIAL ANALYSIS OF THE SLIT/ENGINEERED LLW TRENCHES

Table 4. Select Conservative (Low) Kd Values as a Function of pH for a Sand-textured Sediment For Use in the Special Analysis of the Slit/Engineered LLW Trenches.

pH [a]	Bi Kd [f] (mL/g)	Ca Kd [b] (mL/g)	Cl Kd (mL/g)	K Kd [e] (mL/g)	Mo Kd [d] (mL/g)	Se Kd [c] (mL/g)
4.5	2	0.1	0	2	3	36
4.75	4	0.1	0	2	3	36
5.0	13	0.2	0	3	3	36
5.25	80	4	0	3	3	36
5.5	450	10	0	3	3	36
5.75	--	10	0	4	3	36
6.0	--	10	0	4	3	36

[a] Following the conceptual model proposed by Serkiz (2000), pH values are used as a proxy for dissolved organic carbon.
[b] Serkiz (2000); page 16, Table 13. Assumed Ca Kd values are identical to those for Sr reported by Serkiz.
[c] Thibault et al. (1990); page 90, Table B-28. Assume either SeO_4^{2-} or SeO_3^{2-}. Se values range from 36 to 310 mL/g. Sand (pH 5.3) Kd = 70 mL/g; Sand (pH 6.0) Kd = 70 mL/g; Sand (pH 6.3) Kd = 36 mL/g. Increase in Kd as pH decreases is expected for anionic radionuclides; credit for this is not taken by Serkiz (2000) or in this table. Higher Se Kd values are reported by Thibault et al (1990) for sediments with finer texture.
[d] Thibault et al. (1990); page 79, Table B-28. Assume MoO_4^{2-}. Mo Kd values range from 1 to 400 mL/g. Mo Kd values in sand range from 1 to 8 mL/g. Mo Kd values tend to increase as pH decreases; again, credit for this is not taken by Serkiz (2000) or in this table.
[e] Kaplan and Serkiz (2000); page 26, Table 9. Two K adsorption Kd values were measured in pH 4.2 subsurface SRS sediment: 2 ± 1 and 6 ± 4 mL/g.
[f] Bi exists as either Bi(III) or Bi(0) across a wide range of pH, pH 2 to 11 (Pourbaix 1974). Importantly it does not form the oxidized, more mobile, +5 form under conditions expected in the SRS subsurface. As such, Bi Kd values provided in this table are those used by Serkiz (2000) for all Ac(III), a +3 element with approximately the same atomic weight as Bi (Bi atomic weight = 209; Ac atomic weight = 227). Assuming Bi exists as Bi(III) and not Bi(0) is conservative for the groundwater pathway because the latter is expected to be less mobile than the former.

7.0 RECOMMENDED KD VALUES FOR USE IN THE SPECIAL ANALYSIS OF THE INTERMEDIATE LEVEL VAULT

Table 5. Select Conservative (Low) Kd Values (mL/g) for Use in the Special Analysis of the Intermediate Level Vault.

	Soil	Grout (non-reducing)	Clay	Concrete (reducing)
Co	8[a]	100[l]	96[b]	100[l]
Se	36[c]	0.1[e]	76[d]	0.1[f]
Kr	0	0	0	0
Eu	1900[g]	5000[g]	8400[g]	5000[g]
Rn	0	0	0	0
Pu(III/IV)	370[h]	100[i]	6500[h]	5000[i]
Pu(V/VI)	15[h]	100[i]	50[h]	5000[i]
K	3[c]	2[f]	5[k]	2[f]
Mo	3[c]	1[n]	13[m]	1[n]
Bi	450[i]	5000[p]	12,000[q]	5000[p]
Al	40[r]	5000[p]	12,000[q]	5000[p]
^{14}C (K-Basin Waste)	No estimate	No estimate	No estimate	5000[i]
^{99}Tc	0.1[j]	1[o]	0.1[j]	1000[o]
^{99}Tc (K-Basin Waste)	No estimate	No estimate	No estimate	1000[o]
^{129}I (K-Basin Waste)	No estimate	No estimate	No estimate	2[f]

[a] Hoeffner (1985); E-Area sediment, no pH adjustment, Figure 1; page 22.
[b] Neiheisel (1983); based on SRS E-Area conditions; Table 4 & Figure 6.
[c] Table 4 in this document. Assuming background pH in soil is 5.5.
[d] Thibault et al. (1990); Page 90, Kd values for clay sediments between pH 5 – 6 were reported as 76, 140, 80, 246, and 170 mL/g.
[f] Bradbury and Sarott (1995). I and Tc are reported by Bradbury and Sarott. Assumed K Kd values were identical to Cs Kd values reported by Bradbury and Sarott.
[g] Assumed Kd values for Eu are identical to those for Am. Values reported here are taken from McDowell-Boyer et al. (2000), Table 4.1-4, page 4-16. The accuracy of the Am Kd values was not evaluated.
[h] Table 3 in this document. Assuming background pH in soil is 5.5.
[i] McDowell-Boyer et al. (2000), Table 4.1-4, page 4-16. The accuracy of the Kd values reported in this reference was not evaluated.
[j] Kaplan (2003); TcO_4^- Kd values in SRS sediment varied from 0.2 at pH 3 to -0.1 at pH >5 (negative Kd values, an anion exclusion, is possible for anions. This indicates that the anion is repulsed from by the sediment's negative charge to move faster than the average groundwater velocity.)

[k] Thibault et al. (1990); Table 2 on page 7 and Table 9 on page 14.
[l] Bradbury and Sarott (1995); assumed Co sorption behavior was similar to that of reported by Bradbury and Sarott for Ni. Both elements are divalent cation that share a number of inorganic chemistry behavior.
[m] Thibault et al. (1990), page79, Table B-20. They report seven Kd values for "silt-clay" textured sediments ranging from 13 to 400 mL/g, medium = 40 mL/g.
[n] Bradbury and Sarott (1995), page 42, Table 4. Assumed Mo is an anion and used lowest Kd reported by Bradbury and Sarott for anions, that for Tc.
[o] McDowell-Boyer et al. (2000), page 4-16, Table 4.1-4.
[p] Bradbury and Sarott (1995), page 42, Table 4. Assumed Am(III) as analogue.
[q] Thibault et al. (1990), page 11, Table 6. Used Ce(III) as an analogue, selected minimum value of reported range.
[r] Thibault et al. (1990), page 9, Table 4. Used Ce(III) as an analogue, selected minimum value of reported range.

8.0 ADDITIONAL DATA NEEDS

There are two important research topics that could reduce uncertainty and improve accuracy in future performance assessment and special analysis calculations: 1) colloid facilitated transport, and 2) the influence of cellulose degradation products on radionuclide sorption to sediments. Theory underlying colloid facilitated transport of contaminants is fairly advanced (Tien 1989). However, there are few examples of successful applications of this theory to natural conditions (Tien 1989). This is due to a number of factors, including the need for site specific data. To better understand and to reduce uncertainty associated with the $Pu_{colloid}$ calculation in the special analysis, site specific colloid-removal efficiency values (λ; a kinetic term describing colloid removal by a porous media) must be measured. As Kd values are contaminant and sediment specific, so is λ; it is sediment and colloid specific. Another related subject that requires additional research is whether concrete structures, such as the Intermediate Level Vault, create colloids that can move through SRS sediments and act as a vector for radionuclide transport. Initial research indicated that immediately after concrete was placed in a column of sediment, colloid concentrations in the leachate were high, but that they returned to negligible concentrations within a short time period, less than a dozen pore volumes (equivalent to a couple of weeks of subsurface flow in E-area) (Serkiz et al. 2000).

The second important research area for future performance assessments and special analyses is the impact of cellulose degradation products on radionuclide Kd values. As described in this document (Section 3.0), it is being addressed in a rather indirect manner. Serkiz (2000) had information about the influence of pH on select radionuclide Kd values. He also measured a correlation between total organic carbon in the aqueous phase and sediment pH. He then combined these two results to produce estimates of the influence of CDPs on Kd values. More direct measurements are needed. Such measurements have been initiated with a wide range of elements, including Ce, Cs, Eu, Ni, K, Rh, Sr, Th, and Zr. It is anticipated that the results from this work will greatly reduce uncertainty and improve accuracy of future calculations.

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KEY WORDS:
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Performance Assessment
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SALTSTONE DISPOSAL FACILITY CLOSURE CAP CONFIGURATION AND DEGRADATION BASE CASE: INSTITUTIONAL CONTROL TO PINE FOREST SCENARIO (U)

SEPTEMBER 22, 2003

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Prepared for the U.S. Department of Energy under Contract No. DE-AC09-96SR18500

1.0 EXECUTIVE SUMMARY

The Performance Assessment (PA) for the Saltstone Disposal Facility (SDF) is currently under revision. As part of the PA revision and as documented herein, the closure cap configuration has been reevaluated and closure cap degradation mechanisms and their impact upon infiltration through the closure cap have been evaluated for the institutional control to pine forest, land use scenario. This land use scenario is considered the base case land use scenario. This scenario assumes a 100-year institutional control period following final SDF closure during which the closure cap is maintained. At the end of institutional control, it is assumed that a pine forest succeeds the cap's original bamboo cover. Infiltration through the upper hydraulic barrier layer of the closure cap as determined by this evaluation will be utilized as the infiltration input to subsequent PORFLOW vadose zone contaminant transport modeling, which will also be performed as part of the PA revision.

The reevaluation of the closure cap configuration has resulted in the following primary changes to the closure cap configuration:

- The previous kaolin hydraulic barriers have been replaced with geosynthetic clay liners (GCL).
- The drainage system configuration has been revised to decrease the drainage slope lengths.
- An erosion barrier separate from and above the upper drainage layer has been added.
- A backfill layer has been added between the erosion barrier and the upper drainage layer to help promote evapotranspiration.
- The previous grout layer directly above the vault has been replaced with soil.
- The thickness of the lower drainage layer has been increased, a vertical drainage layer has been added along the sides of the vaults, and a drainage layer has been added at the base of the vaults to minimize the hydraulic head on top of the vaults.

The impacts of pine forest succession, erosion, and colloidal clay migration as degradation mechanisms on the hydraulic properties of the closure cap layers over time have been estimated and the resulting infiltration through the closure cap has been evaluated. The primary changes caused by the degradation mechanisms that result in increased infiltration are the formation of holes in the upper GCL by pine forest succession and the reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers. Erosion can also result in significant increases in infiltration if it causes the removal of soil layers, which provide water storage for the promotion of evapotranspiration. For this scenario, infiltration through the upper GCL was estimated at approximately 0.29 inches/year under initial intact conditions, it increased to approximately 11.6 inches/year at year 1000 in nearly a linear fashion, and it approached an asymptote of around 14.1 inches/year at year 1800 and thereafter. At year 1800, it was estimated that holes covered approximately 0.3 percent of the GCL due to root penetration, and that this resulted in an infiltration near that of typical background infiltration (i.e. as though the GCL were not there at all). This demonstrated that a very small area of holes essentially controlled the hydraulic performance of the GCL.

Appendix E, Kaolin Closure Cap HELP Model Input Data and Output File (output file name: ZKAOout.OUT)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.75 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	600 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 53.4	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Gravel Drainage	3	2 (lateral drainage layer)
Kaolin	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)
Gravel Drainage	6	2 (lateral drainage layer)
Kaolin	7	3 (barrier soil liner)
Clean Grout	8	1 (vertical percolation layer)
Concrete Vault Roof	9	3 (barrier soil liner)
Clean Grout	10	1 (vertical percolation layer)
Saltstone	11	1 (vertical percolation layer)
Concrete Vault Floor	12	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (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	12		0.37	0.24	0.136	0.24
6	2	6		0.38	0.08	0.013	0.08
7	3	19.68		0.56	0.55	0.5	0.56
8	1	39.37		0.19	0.18	0.17	0.18
9	3	4		0.19	0.18	0.17	0.19
10	1	16		0.19	0.18	0.17	0.18
11	1	288		0.42	0.41	0.40	0.41
12	3	30		0.19	0.18	0.17	0.19

Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity (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	600	3			
4	3	1.00E-07					
5	1	1.00E-04					
6	2	1.00E-01	100	2			
7	3	1.00E-07					
8	1	1.00E-08					
9	3	1.00E-12					
10	1	1.00E-08					
11	1	5.00E-12					
12	3	1.00E-12					

	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				
6	2				
7	3				
8	1				
9	3				
10	1				
11	1				
12	3				

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 are missing from the table.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\ZPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\ZTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\ZSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\ZEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hsdfgcl\ZKAO.D10
OUTPUT DATA FILE:            D:\HELP3\Hsdfgcl\ZKAOout.OUT

TIME:  13:41     DATE:   9/ 8/2003

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

     TITLE:  SDF with Kaolin Hydraulic Barriers

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

     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              =    600.0    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                    =     12.00   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  6
                         --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      6.00   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                        =      2.00   PERCENT
DRAINAGE LENGTH              =    100.0    FEET
```

```
                    LAYER  7
                    --------

          TYPE 3 - BARRIER SOIL LINER
          MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     19.68   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  8
                    --------

      TYPE 1 - VERTICAL PERCOLATION LAYER
          MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     39.37   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 CM/SEC

                    LAYER  9
                    --------

          TYPE 3 - BARRIER SOIL LINER
          MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      4.00   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1900 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999996000E-12 CM/SEC

                    LAYER 10
                    --------

      TYPE 1 - VERTICAL PERCOLATION LAYER
          MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     16.00   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 CM/SEC
```

```
                         LAYER 11
                         --------

            TYPE 1 - VERTICAL PERCOLATION LAYER
                MATERIAL TEXTURE NUMBER   0
THICKNESS                    =    288.00   INCHES
POROSITY                     =      0.4200 VOL/VOL
FIELD CAPACITY               =      0.4100 VOL/VOL
WILTING POINT                =      0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.4100 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.499999998000E-11 CM/SEC

                         LAYER 12
                         --------

                TYPE 3 - BARRIER SOIL LINER
                MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     30.00   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1900 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999996000E-12 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  600. FEET.

SCS RUNOFF CURVE NUMBER              =     53.40
FRACTION OF AREA ALLOWING RUNOFF     =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      2.750  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     =    174.507  INCHES
TOTAL INITIAL WATER                  =    174.507  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
4.38	3.95	4.68	2.91	3.56	4.99
5.43	5.41	3.93	3.12	2.96	3.45

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
46.30	50.00	57.20	64.30	72.10	78.40
81.60	80.30	75.20	65.10	56.70	48.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.30 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	4.56	3.57	4.76	2.74	3.60	4.97
	5.81	5.32	4.41	2.99	2.75	3.41
STD. DEVIATIONS	2.44	1.60	2.47	1.31	2.12	2.60
	2.83	2.95	2.54	2.28	1.72	1.90

```
RUNOFF
------
  TOTALS                  0.003    0.000    0.004    0.000    0.000    0.002
                          0.026    0.091    0.016    0.006    0.002    0.000

  STD. DEVIATIONS         0.018    0.000    0.025    0.000    0.002    0.013
                          0.091    0.402    0.083    0.058    0.012    0.003

EVAPOTRANSPIRATION
------------------
  TOTALS                  1.577    2.093    3.072    3.552    3.665    4.140
                          4.898    4.523    3.387    1.618    0.948    1.114

  STD. DEVIATIONS         0.221    0.237    0.582    0.761    1.525    1.546
                          1.589    1.379    1.040    0.607    0.207    0.206

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                  2.4848   2.0047   1.8532   1.0712   0.2768   0.3025
                          0.5594   0.7664   0.7046   0.7530   0.9169   1.5199

  STD. DEVIATIONS         1.7495   1.5257   1.4823   1.0559   0.4504   0.5969
                          0.8343   1.0433   1.0462   1.0915   1.2005   1.3094

PERCOLATION/LEAKAGE THROUGH LAYER  4
-------------------------------------
  TOTALS                  0.1088   0.1025   0.1094   0.0924   0.0610   0.0362
                          0.0549   0.0650   0.0611   0.0575   0.0644   0.0870

  STD. DEVIATIONS         0.0247   0.0134   0.0163   0.0308   0.0365   0.0422
                          0.0451   0.0477   0.0454   0.0496   0.0478   0.0432

LATERAL DRAINAGE COLLECTED FROM LAYER  6
----------------------------------------
  TOTALS                  0.0098   0.0088   0.0076   0.0049   0.0014   0.0014
                          0.0024   0.0033   0.0030   0.0032   0.0039   0.0060

  STD. DEVIATIONS         0.0070   0.0076   0.0059   0.0049   0.0017   0.0024
                          0.0032   0.0041   0.0042   0.0047   0.0049   0.0050

PERCOLATION/LEAKAGE THROUGH LAYER  7
-------------------------------------
  TOTALS                  0.0983   0.0943   0.1019   0.0879   0.0597   0.0348
                          0.0524   0.0617   0.0581   0.0543   0.0605   0.0807

  STD. DEVIATIONS         0.0206   0.0104   0.0135   0.0285   0.0354   0.0406
                          0.0429   0.0451   0.0427   0.0465   0.0448   0.0398

PERCOLATION/LEAKAGE THROUGH LAYER  9
-------------------------------------
  TOTALS                  0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
```

```
PERCOLATION/LEAKAGE THROUGH LAYER 12
------------------------------------
  TOTALS                 0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

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

DAILY AVERAGE HEAD ON TOP OF LAYER  4
-------------------------------------
  AVERAGES               2.9385   2.5424   2.1286   1.2770   0.3153   0.3561
                         0.6372   0.8776   0.8437   0.8722   1.0792   1.7312

  STD. DEVIATIONS        2.3444   2.0783   1.7453   1.3185   0.5130   0.7025
                         0.9503   1.2034   1.2793   1.2947   1.4130   1.4915

DAILY AVERAGE HEAD ON TOP OF LAYER  7
-------------------------------------
  AVERAGES               0.0028   0.0027   0.0022   0.0014   0.0004   0.0004
                         0.0007   0.0009   0.0009   0.0009   0.0011   0.0017

  STD. DEVIATIONS        0.0020   0.0024   0.0017   0.0014   0.0005   0.0007
                         0.0009   0.0012   0.0012   0.0013   0.0015   0.0014

DAILY AVERAGE HEAD ON TOP OF LAYER  9
-------------------------------------
  AVERAGES              38.9764  38.9764  38.9764  38.9764  38.9764  38.9764
                        38.9764  38.9764  38.9764  38.9765  38.9877  39.1551

  STD. DEVIATIONS        3.9367   3.9366   3.9366   3.9366   3.9366   3.9366
                         3.9366   3.9365   3.9365   3.9357   3.8236   2.1494

DAILY AVERAGE HEAD ON TOP OF LAYER 12
-------------------------------------
  AVERAGES               0.2497   0.2502   0.2507   0.2512   0.2517   0.2522
                         0.2527   0.2532   0.2537   0.2542   0.2547   0.2552

  STD. DEVIATIONS        0.1788   0.1790   0.1791   0.1792   0.1794   0.1795
                         0.1797   0.1798   0.1800   0.1801   0.1802   0.1804

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

****

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 100

	INCHES		CU. FEET	PERCENT
PRECIPITATION	48.90	(7.734)	488145.2	100.00
RUNOFF	0.150	(0.4314)	1498.22	0.307
EVAPOTRANSPIRATION	34.587	(3.6267)	345261.66	70.729
LATERAL DRAINAGE COLLECTED FROM LAYER 3	13.21358	(5.51072)	131904.562	27.02158
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.90010	(0.18841)	8985.244	1.84069
AVERAGE HEAD ON TOP OF LAYER 4	1.300	(0.560)		
LATERAL DRAINAGE COLLECTED FROM LAYER 6	0.05562	(0.02278)	555.262	0.11375
PERCOLATION/LEAKAGE THROUGH LAYER 7	0.84447	(0.17396)	8429.896	1.72692
AVERAGE HEAD ON TOP OF LAYER 7	0.001	(0.001)		
PERCOLATION/LEAKAGE THROUGH LAYER 9	0.00013	(0.00001)	1.333	0.00027
AVERAGE HEAD ON TOP OF LAYER 9	38.992	(3.778)		
PERCOLATION/LEAKAGE THROUGH LAYER 12	0.00001	(0.00000)	0.125	0.00003
AVERAGE HEAD ON TOP OF LAYER 12	0.252	(0.180)		
CHANGE IN WATER STORAGE	0.894	(1.8150)	8927.78	1.829

****

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

              PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
  ---------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
     PRECIPITATION                                6.87         68579.773

     RUNOFF                                       2.641        26366.4102

     DRAINAGE COLLECTED FROM LAYER  3             0.34039       3397.91162

     PERCOLATION/LEAKAGE THROUGH LAYER  4         0.006927        69.14656

     AVERAGE HEAD ON TOP OF LAYER  4             31.091

     MAXIMUM HEAD ON TOP OF LAYER  4             44.664

     LOCATION OF MAXIMUM HEAD IN LAYER  3
           (DISTANCE FROM DRAIN)                168.6 FEET

     DRAINAGE COLLECTED FROM LAYER  6             0.00255         25.45078

     PERCOLATION/LEAKAGE THROUGH LAYER  7         0.003405        33.99449

     AVERAGE HEAD ON TOP OF LAYER  7              0.022

     MAXIMUM HEAD ON TOP OF LAYER  7              0.045

     LOCATION OF MAXIMUM HEAD IN LAYER  6
           (DISTANCE FROM DRAIN)                  0.8 FEET

     PERCOLATION/LEAKAGE THROUGH LAYER  9         0.000000         0.00368

     AVERAGE HEAD ON TOP OF LAYER  9             39.370

     PERCOLATION/LEAKAGE THROUGH LAYER 12         0.000000         0.00035

     AVERAGE HEAD ON TOP OF LAYER 12              0.605

     SNOW WATER                                   2.36         23561.8457


     MAXIMUM VEG. SOIL WATER (VOL/VOL)                    0.3693

     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	1.6122	0.2687
2	9.2094	0.3070
3	2.9619	0.2468
4	16.8000	0.5600
5	2.8800	0.2400
6	0.4809	0.0801
7	11.0208	0.5600
8	91.5443	2.3252
9	0.7600	0.1900
10	2.8860	0.1804
11	118.0860	0.4100
12	5.7000	0.1900
SNOW WATER	0.000	

****
****

Appendix F, GCL Closure Cap HELP Model Input Data and Output File (output file name: ZGCLout.OUT)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.75 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	600 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 53.4	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Gravel Drainage	3	2 (lateral drainage layer)
GCL	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)
Gravel Drainage	6	2 (lateral drainage layer)
GCL	7	3 (barrier soil liner)
Clean Grout	8	1 (vertical percolation layer)
Concrete Vault Roof	9	3 (barrier soil liner)
Clean Grout	10	1 (vertical percolation layer)
Saltstone	11	1 (vertical percolation layer)
Concrete Vault Floor	12	3 (barrier soil liner)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (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	0.2		0.75	0.747	0.40	0.75
5	1	61.28		0.37	0.24	0.136	0.24
6	2	6		0.38	0.08	0.013	0.08
7	3	0.2		0.75	0.747	0.40	0.75
8	1	39.37		0.19	0.18	0.17	0.18
9	3	4		0.19	0.18	0.17	0.19
10	1	16		0.19	0.18	0.17	0.18
11	1	288		0.42	0.41	0.40	0.41
12	3	30		0.19	0.18	0.17	0.19

Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity (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	600	3			
4	3	5.00E-09					
5	1	1.00E-04					
6	2	1.00E-01	100	2			
7	3	5.00E-09					
8	1	1.00E-08					
9	3	1.00E-12					
10	1	1.00E-08					
11	1	5.00E-12					
12	3	1.00E-12					

	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				
6	2				
7	3				
8	1				
9	3				
10	1				
11	1				
12	3				

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 are missing from the table.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\ZPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\ZTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\ZSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\ZEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hsdfgcl\ZGCL.D10
OUTPUT DATA FILE:            D:\HELP3\Hsdfgcl\ZGCLout.OUT

TIME:  14: 4     DATE:   9/ 8/2003

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

     TITLE:  SDF with GCL Hydraulic Barriers

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

     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              =    600.0    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                    =     61.28   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  6
                          --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      6.00   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                        =      2.00   PERCENT
DRAINAGE LENGTH              =    100.0    FEET
```

```
                        LAYER  7
                        --------

              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  8
                        --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     39.37   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 CM/SEC

                        LAYER  9
                        --------

              TYPE 3 - BARRIER SOIL LINER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      4.00   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1900 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999996000E-12 CM/SEC

                        LAYER 10
                        --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     16.00   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 CM/SEC
```

```
                              LAYER 11
                              --------

            TYPE 1 - VERTICAL PERCOLATION LAYER
                MATERIAL TEXTURE NUMBER   0
THICKNESS                     =    288.00   INCHES
POROSITY                      =      0.4200 VOL/VOL
FIELD CAPACITY                =      0.4100 VOL/VOL
WILTING POINT                 =      0.4000 VOL/VOL
INITIAL SOIL WATER CONTENT    =      0.4100 VOL/VOL
EFFECTIVE SAT. HYD. COND.     =  0.499999998000E-11 CM/SEC

                              LAYER 12
                              --------

                TYPE 3 - BARRIER SOIL LINER
                MATERIAL TEXTURE NUMBER   0
THICKNESS                     =     30.00   INCHES
POROSITY                      =      0.1900 VOL/VOL
FIELD CAPACITY                =      0.1800 VOL/VOL
WILTING POINT                 =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT    =      0.1900 VOL/VOL
EFFECTIVE SAT. HYD. COND.     =  0.999999996000E-12 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  600. FEET.

SCS RUNOFF CURVE NUMBER              =     53.40
FRACTION OF AREA ALLOWING RUNOFF     =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      2.750  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     =    158.814  INCHES
TOTAL INITIAL WATER                  =    158.814  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
4.38	3.95	4.68	2.91	3.56	4.99
5.43	5.41	3.93	3.12	2.96	3.45

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
46.30	50.00	57.20	64.30	72.10	78.40
81.60	80.30	75.20	65.10	56.70	48.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.30 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	4.56	3.57	4.76	2.74	3.60	4.97
	5.81	5.32	4.41	2.99	2.75	3.41
STD. DEVIATIONS	2.44	1.60	2.47	1.31	2.12	2.60
	2.83	2.95	2.54	2.28	1.72	1.90

```
RUNOFF
------
  TOTALS                  0.003    0.000    0.004    0.000    0.000    0.002
                          0.026    0.091    0.016    0.006    0.002    0.000

  STD. DEVIATIONS         0.018    0.000    0.025    0.000    0.002    0.013
                          0.091    0.402    0.083    0.058    0.012    0.003

EVAPOTRANSPIRATION
------------------
  TOTALS                  1.577    2.093    3.072    3.552    3.665    4.140
                          4.898    4.523    3.387    1.618    0.948    1.114

  STD. DEVIATIONS         0.221    0.237    0.582    0.761    1.525    1.546
                          1.589    1.379    1.040    0.607    0.207    0.206

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                  2.5156   2.0329   1.8990   1.1200   0.3310   0.3276
                          0.5907   0.8023   0.7404   0.7845   0.9469   1.5559

  STD. DEVIATIONS         1.7225   1.4881   1.4548   1.0346   0.4554   0.6029
                          0.8376   1.0435   1.0421   1.0900   1.1974   1.3076

PERCOLATION/LEAKAGE THROUGH LAYER  4
-------------------------------------
  TOTALS                  0.0831   0.0667   0.0627   0.0390   0.0149   0.0135
                          0.0214   0.0281   0.0265   0.0277   0.0321   0.0509

  STD. DEVIATIONS         0.0600   0.0483   0.0451   0.0329   0.0139   0.0189
                          0.0261   0.0326   0.0332   0.0350   0.0370   0.0404

LATERAL DRAINAGE COLLECTED FROM LAYER  6
----------------------------------------
  TOTALS                  0.0632   0.0574   0.0647   0.0457   0.0168   0.0097
                          0.0165   0.0224   0.0214   0.0234   0.0265   0.0441

  STD. DEVIATIONS         0.0359   0.0328   0.0490   0.0498   0.0299   0.0173
                          0.0234   0.0276   0.0278   0.0315   0.0340   0.0372

PERCOLATION/LEAKAGE THROUGH LAYER  7
-------------------------------------
  TOTALS                  0.0055   0.0052   0.0057   0.0054   0.0051   0.0037
                          0.0037   0.0041   0.0041   0.0040   0.0038   0.0046

  STD. DEVIATIONS         0.0010   0.0003   0.0005   0.0006   0.0010   0.0018
                          0.0021   0.0021   0.0020   0.0022   0.0022   0.0020

PERCOLATION/LEAKAGE THROUGH LAYER  9
-------------------------------------
  TOTALS                  0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                          0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
```

```
PERCOLATION/LEAKAGE THROUGH LAYER 12
------------------------------------
  TOTALS                 0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

  STD. DEVIATIONS        0.0000   0.0000   0.0000   0.0000   0.0000   0.0000
                         0.0000   0.0000   0.0000   0.0000   0.0000   0.0000

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

DAILY AVERAGE HEAD ON TOP OF LAYER  4
-------------------------------------
  AVERAGES               2.9612   2.5731   2.1798   1.3331   0.3770   0.3855
                         0.6729   0.9179   0.8851   0.9080   1.1145   1.7722

  STD. DEVIATIONS        2.2668   2.0100   1.7106   1.2862   0.5187   0.7096
                         0.9541   1.2017   1.2714   1.2926   1.4093   1.4894

DAILY AVERAGE HEAD ON TOP OF LAYER  7
-------------------------------------
  AVERAGES               0.0180   0.0179   0.0184   0.0134   0.0048   0.0029
                         0.0047   0.0064   0.0063   0.0067   0.0078   0.0126

  STD. DEVIATIONS        0.0102   0.0101   0.0139   0.0146   0.0085   0.0051
                         0.0067   0.0078   0.0082   0.0090   0.0100   0.0106

DAILY AVERAGE HEAD ON TOP OF LAYER  9
-------------------------------------
  AVERAGES              36.6549  36.7017  36.7318  36.7451  36.7596  36.7745
                        36.7868  36.8013  36.8153  36.9449  36.9863  37.0511

  STD. DEVIATIONS        9.7025   9.6681   9.6484   9.6246   9.5965   9.5579
                         9.5181   9.4721   9.4285   9.1439   9.0721   8.9966

DAILY AVERAGE HEAD ON TOP OF LAYER 12
-------------------------------------
  AVERAGES               0.2207   0.2211   0.2216   0.2221   0.2225   0.2230
                         0.2234   0.2239   0.2244   0.2249   0.2253   0.2258

  STD. DEVIATIONS        0.1681   0.1683   0.1684   0.1686   0.1687   0.1689
                         0.1691   0.1692   0.1694   0.1695   0.1697   0.1698

*******************************************************************************
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AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 100

	INCHES		CU. FEET	PERCENT
PRECIPITATION	48.90	(7.734)	488145.2	100.00
RUNOFF	0.150	(0.4314)	1498.22	0.307
EVAPOTRANSPIRATION	34.587	(3.6267)	345261.66	70.729
LATERAL DRAINAGE COLLECTED FROM LAYER 3	13.64682	(5.46763)	136229.328	27.90754
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.46665	(0.17502)	4658.361	0.95430
AVERAGE HEAD ON TOP OF LAYER 4	1.340	(0.553)		
LATERAL DRAINAGE COLLECTED FROM LAYER 6	0.41170	(0.16798)	4109.838	0.84193
PERCOLATION/LEAKAGE THROUGH LAYER 7	0.05488	(0.00855)	547.854	0.11223
AVERAGE HEAD ON TOP OF LAYER 7	0.010	(0.004)		
PERCOLATION/LEAKAGE THROUGH LAYER 9	0.00013	(0.00003)	1.265	0.00026
AVERAGE HEAD ON TOP OF LAYER 9	36.813	(9.418)		
PERCOLATION/LEAKAGE THROUGH LAYER 12	0.00001	(0.00000)	0.125	0.00003
AVERAGE HEAD ON TOP OF LAYER 12	0.223	(0.169)		
CHANGE IN WATER STORAGE	0.105	(1.8211)	1045.84	0.214

****

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

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
      ---------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
        PRECIPITATION                            6.87         68579.773

        RUNOFF                                   2.641        26366.4102

        DRAINAGE COLLECTED FROM LAYER  3         0.34038       3397.85840

        PERCOLATION/LEAKAGE THROUGH LAYER  4     0.026449       264.02802

        AVERAGE HEAD ON TOP OF LAYER  4         30.903

        MAXIMUM HEAD ON TOP OF LAYER  4         44.441

        LOCATION OF MAXIMUM HEAD IN LAYER  3
              (DISTANCE FROM DRAIN)             168.2 FEET

        DRAINAGE COLLECTED FROM LAYER  6         0.01393       139.03853

        PERCOLATION/LEAKAGE THROUGH LAYER  7     0.000275        2.74099

        AVERAGE HEAD ON TOP OF LAYER  7          0.123

        MAXIMUM HEAD ON TOP OF LAYER  7          0.237

        LOCATION OF MAXIMUM HEAD IN LAYER  6
              (DISTANCE FROM DRAIN)              3.7 FEET

        PERCOLATION/LEAKAGE THROUGH LAYER  9     0.000000        0.00368

        AVERAGE HEAD ON TOP OF LAYER  9         39.370

        PERCOLATION/LEAKAGE THROUGH LAYER 12     0.000000        0.00035

        AVERAGE HEAD ON TOP OF LAYER 12          0.560

        SNOW WATER                               2.36         23561.8457


        MAXIMUM VEG. SOIL WATER (VOL/VOL)                0.3693

        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	1.6122	0.2687
2	9.2094	0.3070
3	2.9835	0.2486
4	0.1500	0.7500
5	14.7072	0.2400
6	0.4867	0.0811
7	0.1500	0.7500
8	12.5600	0.3190
9	0.7600	0.1900
10	2.8858	0.1804
11	118.0856	0.4100
12	5.7000	0.1900
SNOW WATER	0.000	

****
****

Appendix G, GCL Closure Cap without Vault Layer HELP Model Input Data and Output File (output file name: ZGCLAout.OUT)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.75 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	600 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 53.4	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Gravel Drainage	3	2 (lateral drainage layer)
GCL	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)
Gravel Drainage	6	2 (lateral drainage layer)
GCL	7	3 (barrier soil liner)
Clean Grout	8	1 (vertical percolation layer)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (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	0.2		0.75	0.747	0.40	0.75
5	1	61.28		0.37	0.24	0.136	0.24
6	2	6		0.38	0.08	0.013	0.08
7	3	0.2		0.75	0.747	0.40	0.75
8	1	39.37		0.19	0.18	0.17	0.18

Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity (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	600	3			
4	3	5.00E-09					
5	1	1.00E-04					
6	2	1.00E-01	100	2			
7	3	5.00E-09					
8	1	1.00E-08					

	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				
6	2				
7	3				
8	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 are missing from the table.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\ZPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\ZTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\ZSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\ZEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hsdfgcl\ZGCLA.D10
OUTPUT DATA FILE:            D:\HELP3\Hsdfgcl\ZGCLAout.OUT

TIME:  11:11     DATE:   9/ 9/2003

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

     TITLE:  SDF with GCL Hydraulic Barriers w/o Vault

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

     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              =    600.0    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                    =     61.28   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  6
                         --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      6.00   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                        =      2.00   PERCENT
DRAINAGE LENGTH              =    100.0    FEET
```

```
                          LAYER  7
                          --------

              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  8
                          --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     39.37   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 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  600. FEET.

SCS RUNOFF CURVE NUMBER              =     53.40
FRACTION OF AREA ALLOWING RUNOFF     =    100.0     PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      2.750   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     =     31.394   INCHES
TOTAL INITIAL WATER                  =     31.394   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
4.38	3.95	4.68	2.91	3.56	4.99
5.43	5.41	3.93	3.12	2.96	3.45

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
46.30	50.00	57.20	64.30	72.10	78.40
81.60	80.30	75.20	65.10	56.70	48.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.30 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	4.56	3.57	4.76	2.74	3.60	4.97
	5.81	5.32	4.41	2.99	2.75	3.41
STD. DEVIATIONS	2.44	1.60	2.47	1.31	2.12	2.60
	2.83	2.95	2.54	2.28	1.72	1.90

```
RUNOFF
------
  TOTALS                  0.003    0.000    0.004    0.000    0.000    0.002
                          0.026    0.091    0.016    0.006    0.002    0.000

  STD. DEVIATIONS         0.018    0.000    0.025    0.000    0.002    0.013
                          0.091    0.402    0.083    0.058    0.012    0.003

EVAPOTRANSPIRATION
------------------
  TOTALS                  1.577    2.093    3.072    3.552    3.665    4.140
                          4.898    4.523    3.387    1.618    0.948    1.114

  STD. DEVIATIONS         0.221    0.237    0.582    0.761    1.525    1.546
                          1.589    1.379    1.040    0.607    0.207    0.206

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                  2.5156   2.0329   1.8990   1.1200   0.3310   0.3276
                          0.5907   0.8023   0.7404   0.7845   0.9469   1.5559

  STD. DEVIATIONS         1.7225   1.4881   1.4548   1.0346   0.4554   0.6029
                          0.8376   1.0435   1.0421   1.0900   1.1974   1.3076

PERCOLATION/LEAKAGE THROUGH LAYER  4
-------------------------------------
  TOTALS                  0.0831   0.0667   0.0627   0.0390   0.0149   0.0135
                          0.0214   0.0281   0.0265   0.0277   0.0321   0.0509

  STD. DEVIATIONS         0.0600   0.0483   0.0451   0.0329   0.0139   0.0189
                          0.0261   0.0326   0.0332   0.0350   0.0370   0.0404

LATERAL DRAINAGE COLLECTED FROM LAYER  6
----------------------------------------
  TOTALS                  0.0632   0.0574   0.0647   0.0457   0.0168   0.0097
                          0.0165   0.0224   0.0214   0.0234   0.0265   0.0441

  STD. DEVIATIONS         0.0359   0.0328   0.0490   0.0498   0.0299   0.0173
                          0.0234   0.0276   0.0278   0.0315   0.0340   0.0372

PERCOLATION/LEAKAGE THROUGH LAYER  7
-------------------------------------
  TOTALS                  0.0055   0.0052   0.0057   0.0054   0.0051   0.0037
                          0.0037   0.0041   0.0041   0.0040   0.0038   0.0046

  STD. DEVIATIONS         0.0010   0.0003   0.0005   0.0006   0.0010   0.0018
                          0.0021   0.0021   0.0020   0.0022   0.0022   0.0020

PERCOLATION/LEAKAGE THROUGH LAYER  8
-------------------------------------
  TOTALS                  0.0048   0.0046   0.0047   0.0042   0.0040   0.0036
                          0.0031   0.0039   0.0044   0.0048   0.0045   0.0046

  STD. DEVIATIONS         0.0022   0.0019   0.0019   0.0016   0.0015   0.0016
                          0.0017   0.0020   0.0022   0.0022   0.0021   0.0021
```

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

  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES               2.9612   2.5731   2.1798   1.3331   0.3770   0.3855
                           0.6729   0.9179   0.8851   0.9080   1.1145   1.7722

    STD. DEVIATIONS        2.2668   2.0100   1.7106   1.2862   0.5187   0.7096
                           0.9541   1.2017   1.2714   1.2926   1.4093   1.4894

  DAILY AVERAGE HEAD ON TOP OF LAYER  7
  -------------------------------------
    AVERAGES               0.0180   0.0179   0.0184   0.0134   0.0048   0.0029
                           0.0047   0.0064   0.0063   0.0067   0.0078   0.0126

    STD. DEVIATIONS        0.0102   0.0101   0.0139   0.0146   0.0085   0.0051
                           0.0067   0.0078   0.0082   0.0090   0.0100   0.0106

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

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

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                      INCHES            CU. FEET       PERCENT
                                  -------------------  -------------  ---------
 PRECIPITATION                     48.90    (   7.734)    488145.2     100.00

 RUNOFF                             0.150   (  0.4314)      1498.22      0.307

 EVAPOTRANSPIRATION                34.587   (  3.6267)    345261.66     70.729

 LATERAL DRAINAGE COLLECTED        13.64682 (  5.46763)   136229.328   27.90754
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH        0.46665 (  0.17502)     4658.361    0.95430
   LAYER  4

 AVERAGE HEAD ON TOP                1.340 (     0.553)
   OF LAYER  4

 LATERAL DRAINAGE COLLECTED         0.41170 (  0.16798)     4109.838    0.84193
   FROM LAYER  6

 PERCOLATION/LEAKAGE THROUGH        0.05488 (  0.00855)      547.854    0.11223
   LAYER  7

 AVERAGE HEAD ON TOP                0.010 (     0.004)
   OF LAYER  7

 PERCOLATION/LEAKAGE THROUGH        0.05136 (  0.01570)      512.680    0.10503
   LAYER  8

 CHANGE IN WATER STORAGE            0.053   (  1.8213)       533.49      0.109
```

****

****

PEAK DAILY VALUES FOR YEARS 1 THROUGH 100

	(INCHES)	(CU. FT.)
PRECIPITATION	6.87	68579.773
RUNOFF	2.641	26366.4102
DRAINAGE COLLECTED FROM LAYER 3	0.34038	3397.85840
PERCOLATION/LEAKAGE THROUGH LAYER 4	0.026449	264.02802
AVERAGE HEAD ON TOP OF LAYER 4	30.903	
MAXIMUM HEAD ON TOP OF LAYER 4	44.441	
LOCATION OF MAXIMUM HEAD IN LAYER 3 (DISTANCE FROM DRAIN)	168.2 FEET	
DRAINAGE COLLECTED FROM LAYER 6	0.01393	139.03853
PERCOLATION/LEAKAGE THROUGH LAYER 7	0.000275	2.74099
AVERAGE HEAD ON TOP OF LAYER 7	0.123	
MAXIMUM HEAD ON TOP OF LAYER 7	0.237	
LOCATION OF MAXIMUM HEAD IN LAYER 6 (DISTANCE FROM DRAIN)	3.7 FEET	
PERCOLATION/LEAKAGE THROUGH LAYER 8	0.000454	4.53332
SNOW WATER	2.36	23561.8457

MAXIMUM VEG. SOIL WATER (VOL/VOL) 0.3693

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	1.6122	0.2687
2	9.2094	0.3070
3	2.9835	0.2486
4	0.1500	0.7500
5	14.7072	0.2400
6	0.4867	0.0811
7	0.1500	0.7500
8	7.4390	0.1889
SNOW WATER	0.000	

****
****

Appendix H, GCL Closure Cap with 300-foot Slope Lengths: HELP Model Input Data and Output File (output file name: ZGCLBout.OUT)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.75 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	300 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 55.70	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Gravel Drainage	3	2 (lateral drainage layer)
GCL	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)
Gravel Drainage	6	2 (lateral drainage layer)
GCL	7	3 (barrier soil liner)
Clean Grout	8	1 (vertical percolation layer)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (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	0.2		0.75	0.747	0.40	0.75
5	1	61.28		0.37	0.24	0.136	0.24
6	2	6		0.38	0.08	0.013	0.08
7	3	0.2		0.75	0.747	0.40	0.75
8	1	39.37		0.19	0.18	0.17	0.18

Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity (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	300	3			
4	3	5.00E-09					
5	1	1.00E-04					
6	2	1.00E-01	100	2			
7	3	5.00E-09					
8	1	1.00E-08					

	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				
6	2				
7	3				
8	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 are missing from the table.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\ZPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\ZTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\ZSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\ZEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hsdfgcl\ZGCLB.D10
OUTPUT DATA FILE:            D:\HELP3\Hsdfgcl\ZGCLBout.OUT

TIME:  14:22     DATE:   9/ 9/2003

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

     TITLE:  SDF with GCL Hydraulic Barriers w/o Vault - 300 ft slope

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

     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              =    300.0    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                    =     61.28   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  6
                         --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      6.00   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                        =      2.00   PERCENT
DRAINAGE LENGTH              =    100.0    FEET
```

```
                         LAYER  7
                         --------

              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  8
                         --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     39.37   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 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  300. FEET.

SCS RUNOFF CURVE NUMBER              =     55.70
FRACTION OF AREA ALLOWING RUNOFF     =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      2.750  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     =     31.394  INCHES
TOTAL INITIAL WATER                  =     31.394  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
4.38	3.95	4.68	2.91	3.56	4.99
5.43	5.41	3.93	3.12	2.96	3.45

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
46.30	50.00	57.20	64.30	72.10	78.40
81.60	80.30	75.20	65.10	56.70	48.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.30 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	4.56	3.57	4.76	2.74	3.60	4.97
	5.81	5.32	4.41	2.99	2.75	3.41
STD. DEVIATIONS	2.44	1.60	2.47	1.31	2.12	2.60
	2.83	2.95	2.54	2.28	1.72	1.90

RUNOFF

TOTALS	0.004	0.000	0.005	0.000	0.000	0.002
	0.028	0.092	0.017	0.007	0.003	0.001
STD. DEVIATIONS	0.022	0.000	0.029	0.000	0.004	0.017
	0.095	0.407	0.090	0.059	0.018	0.005

EVAPOTRANSPIRATION

TOTALS	1.577	2.093	3.072	3.552	3.663	4.141
	4.898	4.522	3.385	1.619	0.948	1.114
STD. DEVIATIONS	0.221	0.237	0.582	0.760	1.525	1.545
	1.588	1.379	1.039	0.606	0.207	0.206

LATERAL DRAINAGE COLLECTED FROM LAYER 3

TOTALS	2.7198	1.9175	1.9198	0.9387	0.2679	0.3500
	0.6494	0.8286	0.7516	0.8016	1.0071	1.7041
STD. DEVIATIONS	1.9146	1.5264	1.6505	0.9614	0.5082	0.6713
	0.9538	1.1603	1.1657	1.1916	1.2786	1.4652

PERCOLATION/LEAKAGE THROUGH LAYER 4

TOTALS	0.0459	0.0336	0.0340	0.0188	0.0078	0.0073
	0.0129	0.0159	0.0146	0.0151	0.0184	0.0298
STD. DEVIATIONS	0.0290	0.0230	0.0249	0.0148	0.0083	0.0113
	0.0155	0.0187	0.0186	0.0196	0.0205	0.0231

LATERAL DRAINAGE COLLECTED FROM LAYER 6

TOTALS	0.0377	0.0312	0.0281	0.0169	0.0041	0.0050
	0.0093	0.0122	0.0111	0.0118	0.0148	0.0244
STD. DEVIATIONS	0.0244	0.0241	0.0222	0.0175	0.0072	0.0099
	0.0137	0.0164	0.0168	0.0173	0.0200	0.0214

PERCOLATION/LEAKAGE THROUGH LAYER 7

TOTALS	0.0053	0.0050	0.0054	0.0048	0.0038	0.0021
	0.0032	0.0035	0.0034	0.0030	0.0033	0.0044
STD. DEVIATIONS	0.0009	0.0004	0.0004	0.0011	0.0015	0.0020
	0.0021	0.0022	0.0021	0.0024	0.0023	0.0020

PERCOLATION/LEAKAGE THROUGH LAYER 8

TOTALS	0.0042	0.0040	0.0041	0.0037	0.0035	0.0025
	0.0023	0.0034	0.0040	0.0043	0.0038	0.0040
STD. DEVIATIONS	0.0021	0.0018	0.0019	0.0016	0.0015	0.0015
	0.0018	0.0021	0.0022	0.0023	0.0021	0.0019

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

  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES               1.5490   1.1978   1.0934   0.5524   0.1525   0.2060
                           0.3699   0.4719   0.4423   0.4588   0.5927   0.9705

    STD. DEVIATIONS        1.0904   0.9559   0.9400   0.5658   0.2894   0.3951
                           0.5432   0.6608   0.6860   0.6873   0.7524   0.8344

  DAILY AVERAGE HEAD ON TOP OF LAYER  7
  -------------------------------------
    AVERAGES               0.0107   0.0097   0.0080   0.0050   0.0012   0.0015
                           0.0026   0.0035   0.0033   0.0033   0.0044   0.0069

    STD. DEVIATIONS        0.0069   0.0075   0.0063   0.0052   0.0021   0.0029
                           0.0039   0.0047   0.0049   0.0049   0.0059   0.0061

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

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

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                     INCHES            CU. FEET       PERCENT
                                 -------------------  -------------   ---------
 PRECIPITATION                    48.90    (   7.734)    488145.2     100.00

 RUNOFF                            0.159   (  0.4376)      1589.92      0.326

 EVAPOTRANSPIRATION               34.584   (  3.6252)    345236.75     70.724

 LATERAL DRAINAGE COLLECTED       13.85619 (  5.60386)   138319.391   28.33571
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH       0.25391 (  0.08917)     2534.642    0.51924
   LAYER  4

 AVERAGE HEAD ON TOP               0.671 (     0.272)
   OF LAYER  4

 LATERAL DRAINAGE COLLECTED        0.20657 (  0.08364)     2062.071    0.42243
   FROM LAYER  6

 PERCOLATION/LEAKAGE THROUGH       0.04729 (  0.00857)      472.059    0.09670
   LAYER  7

 AVERAGE HEAD ON TOP               0.005 (     0.002)
   OF LAYER  7

 PERCOLATION/LEAKAGE THROUGH       0.04386 (  0.01447)      437.847    0.08970
   LAYER  8

 CHANGE IN WATER STORAGE           0.050   (  1.5780)       499.25     0.102
```

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

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

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
      ---------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------    -------------
         PRECIPITATION                            6.87        68579.773

         RUNOFF                                   2.652       26478.3203

         DRAINAGE COLLECTED FROM LAYER  3         0.66708      6659.09082

         PERCOLATION/LEAKAGE THROUGH LAYER  4     0.015959      159.31087

         AVERAGE HEAD ON TOP OF LAYER  4         18.567

         MAXIMUM HEAD ON TOP OF LAYER  4         25.422

         LOCATION OF MAXIMUM HEAD IN LAYER  3
               (DISTANCE FROM DRAIN)             90.4 FEET

         DRAINAGE COLLECTED FROM LAYER  6         0.00820        81.82230

         PERCOLATION/LEAKAGE THROUGH LAYER  7     0.000232        2.31170

         AVERAGE HEAD ON TOP OF LAYER  7          0.072

         MAXIMUM HEAD ON TOP OF LAYER  7          0.141

         LOCATION OF MAXIMUM HEAD IN LAYER  6
               (DISTANCE FROM DRAIN)              2.5 FEET

         PERCOLATION/LEAKAGE THROUGH LAYER  8     0.000417        4.16049

         SNOW WATER                               2.36        23561.8457

         MAXIMUM VEG. SOIL WATER (VOL/VOL)                 0.3689

         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	1.6127	0.2688
2	9.2087	0.3070
3	2.6521	0.2210
4	0.1500	0.7500
5	14.7072	0.2400
6	0.4851	0.0809
7	0.1500	0.7500
8	7.4293	0.1887
SNOW WATER	0.000	

****
****

Appendix I, GCL Closure Cap with 100-foot Slope Lengths: HELP Model Input Data and Output File (output file name: ZGCLCout.OUT)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.75 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	100 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 59.30	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Gravel Drainage	3	2 (lateral drainage layer)
GCL	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)
Gravel Drainage	6	2 (lateral drainage layer)
GCL	7	3 (barrier soil liner)
Clean Grout	8	1 (vertical percolation layer)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (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	0.2		0.75	0.747	0.40	0.75
5	1	61.28		0.37	0.24	0.136	0.24
6	2	6		0.38	0.08	0.013	0.08
7	3	0.2		0.75	0.747	0.40	0.75
8	1	39.37		0.19	0.18	0.17	0.18

Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity (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	100	3			
4	3	5.00E-09					
5	1	1.00E-04					
6	2	1.00E-01	100	2			
7	3	5.00E-09					
8	1	1.00E-08					

	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				
6	2				
7	3				
8	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 are missing from the table.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\ZPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\ZTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\ZSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\ZEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hsdfgcl\ZGCLC.D10
OUTPUT DATA FILE:            D:\HELP3\Hsdfgcl\ZGCLCout.OUT

TIME:  14:29     DATE:   9/ 9/2003

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

     TITLE:  SDF with GCL Hydraulic Barriers w/o Vault - 100 ft slope

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

     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              =    100.0    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                    =     61.28   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  6
                         --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      6.00   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                        =      2.00   PERCENT
DRAINAGE LENGTH              =    100.0    FEET
```

```
                          LAYER  7
                          --------

              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  8
                          --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     39.37   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 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  100. FEET.

SCS RUNOFF CURVE NUMBER              =     59.30
FRACTION OF AREA ALLOWING RUNOFF     =    100.0     PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      2.750   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     =     31.394   INCHES
TOTAL INITIAL WATER                  =     31.394   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
4.38	3.95	4.68	2.91	3.56	4.99
5.43	5.41	3.93	3.12	2.96	3.45

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
46.30	50.00	57.20	64.30	72.10	78.40
81.60	80.30	75.20	65.10	56.70	48.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.30 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	4.56	3.57	4.76	2.74	3.60	4.97
	5.81	5.32	4.41	2.99	2.75	3.41
STD. DEVIATIONS	2.44	1.60	2.47	1.31	2.12	2.60
	2.83	2.95	2.54	2.28	1.72	1.90

```
RUNOFF
------
  TOTALS                  0.008    0.000    0.007    0.000    0.001    0.004
                          0.030    0.097    0.021    0.009    0.005    0.002

  STD. DEVIATIONS         0.033    0.002    0.039    0.001    0.008    0.025
                          0.103    0.412    0.105    0.076    0.029    0.012

EVAPOTRANSPIRATION
------------------
  TOTALS                  1.577    2.094    3.073    3.552    3.661    4.142
                          4.899    4.521    3.383    1.619    0.948    1.114

  STD. DEVIATIONS         0.221    0.236    0.583    0.761    1.526    1.545
                          1.588    1.376    1.040    0.606    0.206    0.205

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                  2.8404   1.8064   1.9410   0.7881   0.2634   0.3693
                          0.6900   0.8272   0.7728   0.8094   1.0651   1.8093

  STD. DEVIATIONS         2.0166   1.4806   1.7564   0.8554   0.5610   0.6997
                          1.0203   1.2362   1.2608   1.2568   1.3137   1.5625

PERCOLATION/LEAKAGE THROUGH LAYER  4
-------------------------------------
  TOTALS                  0.0192   0.0137   0.0148   0.0081   0.0033   0.0035
                          0.0060   0.0070   0.0063   0.0065   0.0083   0.0132

  STD. DEVIATIONS         0.0105   0.0076   0.0090   0.0052   0.0040   0.0048
                          0.0066   0.0076   0.0077   0.0079   0.0081   0.0090

LATERAL DRAINAGE COLLECTED FROM LAYER  6
----------------------------------------
  TOTALS                  0.0138   0.0095   0.0097   0.0045   0.0013   0.0018
                          0.0033   0.0042   0.0037   0.0040   0.0051   0.0087

  STD. DEVIATIONS         0.0098   0.0078   0.0085   0.0048   0.0026   0.0034
                          0.0049   0.0059   0.0060   0.0061   0.0065   0.0076

PERCOLATION/LEAKAGE THROUGH LAYER  7
-------------------------------------
  TOTALS                  0.0051   0.0047   0.0051   0.0042   0.0020   0.0017
                          0.0026   0.0029   0.0025   0.0025   0.0030   0.0042

  STD. DEVIATIONS         0.0009   0.0006   0.0008   0.0014   0.0016   0.0018
                          0.0021   0.0021   0.0020   0.0023   0.0022   0.0019

PERCOLATION/LEAKAGE THROUGH LAYER  8
-------------------------------------
  TOTALS                  0.0038   0.0035   0.0037   0.0033   0.0031   0.0017
                          0.0018   0.0027   0.0033   0.0036   0.0031   0.0034

  STD. DEVIATIONS         0.0019   0.0017   0.0018   0.0016   0.0015   0.0014
                          0.0016   0.0018   0.0019   0.0022   0.0019   0.0018
```

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

  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES               0.5392   0.3758   0.3685   0.1546   0.0500   0.0724
                           0.1310   0.1570   0.1516   0.1536   0.2089   0.3435

    STD. DEVIATIONS        0.3828   0.3080   0.3334   0.1678   0.1065   0.1373
                           0.1937   0.2347   0.2473   0.2386   0.2577   0.2966

  DAILY AVERAGE HEAD ON TOP OF LAYER  7
  -------------------------------------
    AVERAGES               0.0039   0.0030   0.0028   0.0013   0.0004   0.0005
                           0.0009   0.0012   0.0011   0.0011   0.0015   0.0025

    STD. DEVIATIONS        0.0028   0.0024   0.0024   0.0014   0.0007   0.0010
                           0.0014   0.0017   0.0018   0.0017   0.0019   0.0022

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

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

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                     INCHES            CU. FEET       PERCENT
                                 -------------------  -------------   ---------
 PRECIPITATION                    48.90    (   7.734)    488145.2     100.00

 RUNOFF                            0.184   (  0.4500)      1840.76      0.377

 EVAPOTRANSPIRATION               34.582   (  3.6301)    345217.16     70.720

 LATERAL DRAINAGE COLLECTED       13.98232 (  5.63497)   139578.500   28.59364
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH       0.11001 (  0.03372)     1098.130     0.22496
   LAYER  4

 AVERAGE HEAD ON TOP               0.226 (    0.091)
   OF LAYER  4

 LATERAL DRAINAGE COLLECTED        0.06947 (  0.02813)      693.469    0.14206
   FROM LAYER  6

 PERCOLATION/LEAKAGE THROUGH       0.04051 (  0.00806)      404.381     0.08284
   LAYER  7

 AVERAGE HEAD ON TOP               0.002 (    0.001)
   OF LAYER  7

 PERCOLATION/LEAKAGE THROUGH       0.03717 (  0.01300)      371.090     0.07602
   LAYER  8

 CHANGE IN WATER STORAGE           0.045   (  1.3391)       444.28      0.091
```

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

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

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
    ---------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
      PRECIPITATION                              6.87         68579.773

      RUNOFF                                     2.676        26710.3457

      DRAINAGE COLLECTED FROM LAYER  3           1.24822      12460.30660

      PERCOLATION/LEAKAGE THROUGH LAYER  4       0.006415        64.03636

      AVERAGE HEAD ON TOP OF LAYER  4            7.344

      MAXIMUM HEAD ON TOP OF LAYER  4            9.882

      LOCATION OF MAXIMUM HEAD IN LAYER  3
            (DISTANCE FROM DRAIN)               32.7 FEET

      DRAINAGE COLLECTED FROM LAYER  6           0.00360         35.90605

      PERCOLATION/LEAKAGE THROUGH LAYER  7       0.000197         1.96719

      AVERAGE HEAD ON TOP OF LAYER  7            0.032

      MAXIMUM HEAD ON TOP OF LAYER  7            0.063

      LOCATION OF MAXIMUM HEAD IN LAYER  6
            (DISTANCE FROM DRAIN)                1.2 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER  8       0.000412         4.11374

      SNOW WATER                                 2.36         23561.8457


      MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.3683

      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	1.6121	0.2687
2	9.2096	0.3070
3	2.1126	0.1760
4	0.1500	0.7500
5	14.7072	0.2400
6	0.4828	0.0805
7	0.1500	0.7500
8	7.4201	0.1885
SNOW WATER	0.000	

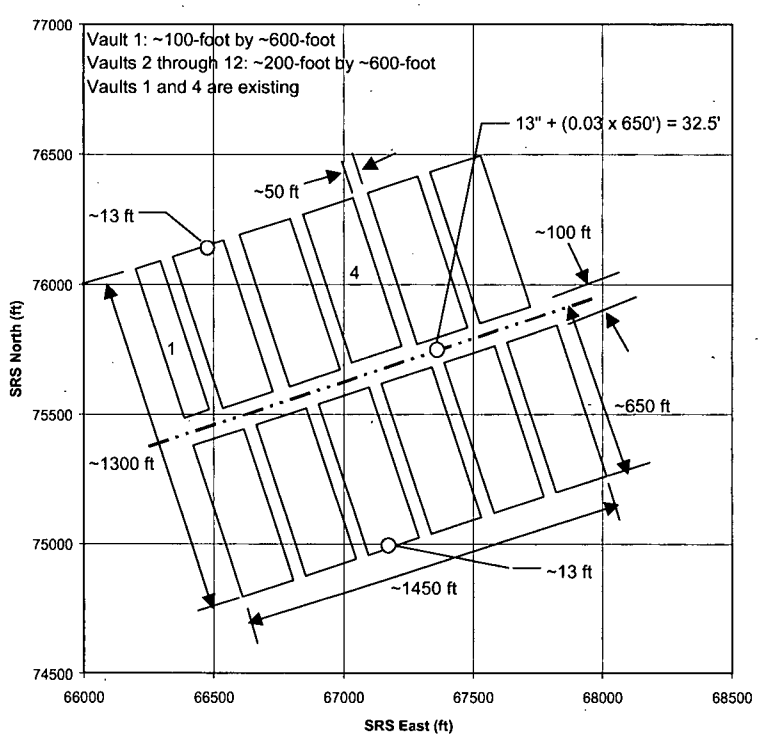
****
****

Appendix J, Drainage System Configuration, Soil Fill Volume and Ditch Lengths Calculations

Relative soil fill volumes and drainage ditch lengths have been determined for each of the drainage system configurations. From Table 4.1-1 the minimum thickness of material over the vault has been determined to be approximately 13 feet. The calculated fill volume ignores the fill between vaults and outside the ~1300-foot by ~1450-foot footprint, since it is essentially the same for all configurations.

Replacement GCL Closure Cap	
Layer	Minimum Thickness (inches)
Topsoil	6
Backfill	30
Drainage Layer	12
GCL	0.2
Backfill	61.28
Drainage Layer	6
GCL	0.2
Clean Grout	39.37
Total	~155 inches (~13 feet)

600-Foot, Slope Length Drainage System Configuration Soil Fill Volume and Drainage Ditch Length Calculation (also see Figure 4.2-1):



Fill volume = (13' × (1300' × 1450')) + 2 × (½ × 650' × (32.5' – 13') × 1450')

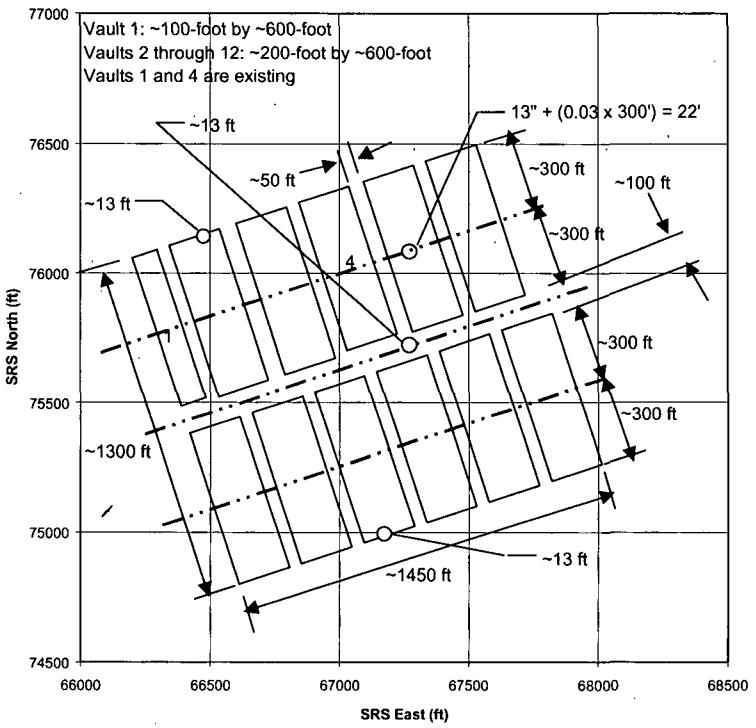
Fill volume = 42,883,750 ft^3 ÷ 27 yd^3 / ft^3

Fill volume ≈ 1,588,300 yd^3

Ditch length (also see Figure 4.2-1) = (2 × 1450') + 1300'

Ditch length = 4,200 ft

300-Foot, Slope Length Drainage System Configuration Soil Fill Volume and Drainage Ditch Length Calculation (also see Figure 4.2-2):



Fill volume = (13' × (1300' × 1450')) + 4 × (½ × 300' × (22' – 13') × 1450')

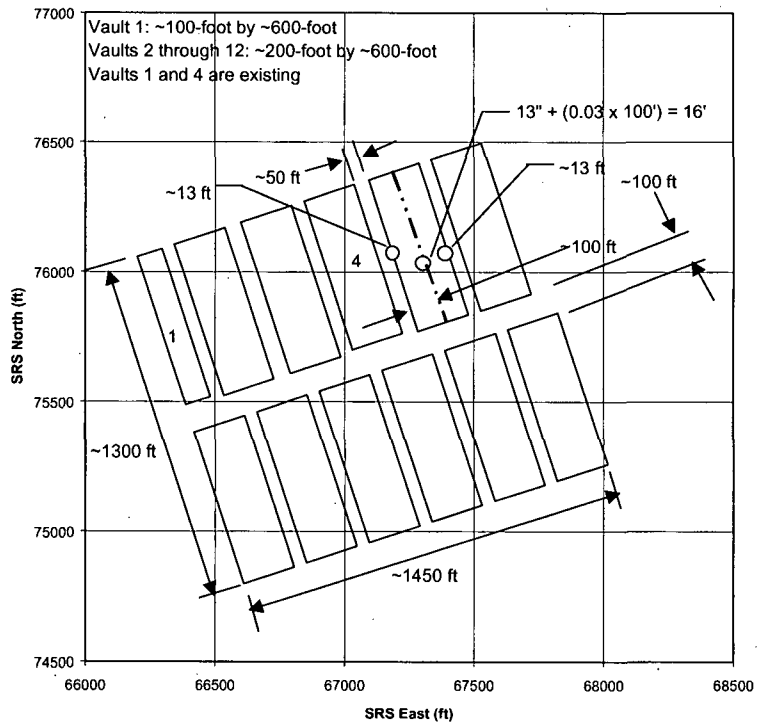
Fill volume = 32,335,000 ft^3 ÷ 27 yd^3 / ft^3

Fill volume ≈ 1,197,600 yd^3

Ditch length (also see Figure 4.2-2) = (3 × 1450') + 1300'

Ditch length = 5,650 ft

100-Foot, Slope Length Drainage System Configuration Soil Fill Volume and Drainage Ditch Length Calculation (also see Figure 4.2-3):



Fill volume = (13' × (1300' × 1450')) + 24 × (½ × 100' × (16' – 13') × 600')

Fill volume = 26,665,000 ft^3 ÷ 27 yd^3 / ft^3

Fill volume ≈ 987,600 yd^3

Ditch length (also see Figure 4.2-3) = (14 × 650') + (3 × 1450')

Ditch length = 13,450 ft

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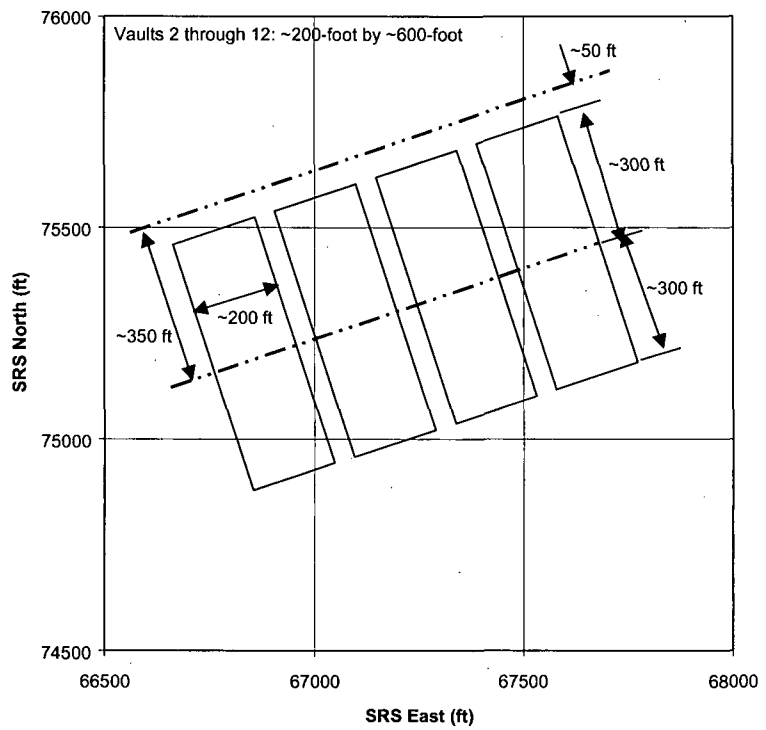
Appendix K, Erosion Barrier Sizing and Material Properties

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)). The figure below shows that the maximum drainage length is 350 feet over a 200-foot wide vault.



Determine the maximum flow (Q in ft^3/s) resulting from the 3.3-inch over a 15-minute accumulation period rainfall event:

To be conservative it has been assumed that all rainfall results in runoff and that there is no lag period due to the 350-foot flow path (that is all the rainfall over the entire area immediately becomes discharge out the end of the area).

$$Q = \frac{(P/12\ in/ft)\times(350'\times 200')}{D\times 60\ \min/hr\times 60\ s/\min}$$, where P = precipitation in inches and D = duration in hours

$$Q = 1.62\frac{P}{D}$$, where P = 3.3 inches and D = 15 minutes = 0.25 hours

$$Q = 1.62\frac{3.3}{0.25}\ ft^3/s$$, over a 200-foot width

$Q = 21.4\ \text{ft}^3/\text{s}$, over a 200-foot width

Determine the approximate depth of flow using Manning's equation (Clark et al. 1977):

$V = \frac{1.49}{n} R^{2/3} S^{1/2}$, where V = velocity, fps; n = coefficient of roughness;

R = hydraulic radius, ft; and S = slope

$V = Q/A$, where V = velocity, ft/s; Q = flow, ft^3/s; A = area, ft^2

$Q = 21.4\ \text{ft}^3/\text{s}$, over a 200-foot width (i.e. b)

$A = bd$, where b = width, ft; d = depth, ft

$A = 200d\ ft^2$

insert values:

$$V = \frac{21.4\ ft^3/s}{200d\ ft^2}$$

Assume the use of 2-inch to 6-inch granite stone with a d_{50} (i.e. median size) of 4 inches. From Figure 7.29 of Goldman (1986): n = 0.033

$R = A/wetted\ \ perimeter = A/(b + 2d)$

$R = 200d/(200 + 2d)$

3% slope (see Section 2.0): S = 0.03

insert values:

$$\frac{21.4}{200d} = \frac{1.49}{0.033}\left(\frac{200d}{200+2d}\right)^{2/3}(0.03)^{1/2}$$

$$0.0137 = d\left(\frac{200d}{200+2d}\right)^{2/3}$$

Given d	0.0137
0.1	0.0215
0.08	0.0148
0.075	0.0133
0.076	0.0136

$d \approx 0.076$

Determine if the use of a 2-inch to 6-inch granite stone with a d_{50} (i.e. median size) of 4 inches is satisfactory to perform as an erosion barrier for a 10,000-year return period, maximum precipitation event:

b/d = 200'/0.076' = 2632, therefore b/d > 50.

From Figure 7.30 of Goldman (1986): Since the b/d > 50 then the P/R is greater than 60.

From Figure 7.31 of Goldman (1986): With a slope (S) of 0.03, a flow (Q) of 21.4 ft^3/s, and a P/R > 60, the minimum d_{50} of the stone must be approximately 3 inches.

Therefore the use of a 2-inch to 6-inch granite stone with a d_{50} (i.e. median size) of 4 inches is satisfactory to perform as an erosion barrier for a 10,000-year return period, maximum precipitation event.

The selection of the 2-inch to 6-inch granite stone as an erosion barrier is also satisfactory versus Figure C-3 of Logan 1997.

Based upon NCSU 1991 the 2-inch to 6-inch granite stone is a common sized erosion control stone. NCSU 1991 also indicates the minimum thickness of the erosion control stone must be 1.5 times the maximum stone diameter. That is the thickness must be at least 9 inches for a maximum 6-inch stone. A 12-inch thickness of 2-inch to 6-inch granite stone with a d_{50} (i.e. median size) of 4 inches will be utilized as the erosion barrier.

Determine the combined soil material properties for the 2-inch to 6-inch granite stone filled with CLSM or Flowable Fill:

The porosity of the 2-inch to 6-inch granite stone with a d_{50} (i.e. median size) of 4 inches is taken as 0.397 based upon the porosity of poorly graded gravel from USEPA 1994a and USEPA 1994b.

Typical CLSM or Flowable Fill properties based upon a May 8, 2003 personal conversation with Christine A. Langton:

Typical CLSM consists of sand with a porosity of 30%, with the pore space filled with 50% porosity binder and has a saturated hydraulic conductivity of 1.0E-03 cm/s.

Based upon this information the following are the assumed properties of the CLSM:

Property	Property Value
Saturated Hydraulic Conductivity	1.0E-03 cm/s
Porosity	$0.30 \times 0.50 = 0.15$
Field Capacity [1]	0.14
Wilting Point [1]	0.13

[1] Field capacity is assumed to be 0.01 less than the porosity, and the wilting point is assumed to be 0.01 less than the field capacity based upon the porosity-wilting point-field capacity relationship of the clean grout and concrete vault roof and floor, which like the CLSM uses cement as the binder.

The matrix of an individual granite stone itself is considered impermeable and non-porous. The porosity of a layer of granite stone is considered to be 0.397. When the granite stone porosity is filled with CLSM, the resultant hydraulic properties, which are area or volume based, become that of the CLSM times the granite stone porosity. The resultant hydraulic properties are shown below:

Property	Property Value
Saturated Hydraulic Conductivity	1.0E-03 cm/s $\times$ 0.397 = 3.97E-04 cm/s
Porosity	$0.15 \times 0.397 = 0.06$
Field Capacity [1]	$0.14 \times 0.397 = 0.056$
Wilting Point [1]	$0.13 \times 0.397 = 0.052$

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Appendix L, GCL Closure Cap with Erosion Barrier: HELP Model Input Data and Output File (output file name: ZGCLDout.OUT)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.75 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	300 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 55.70	

Layer	Layer Number	Layer Type
Topsoil	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Erosion Barrier	3	1 (vertical percolation layer)
Gravel Drainage	4	2 (lateral drainage layer)
GCL	5	3 (barrier soil liner)
Backfill	6	1 (vertical percolation layer)
Gravel Drainage	7	2 (lateral drainage layer)
GCL	8	3 (barrier soil liner)
Clean Grout	9	1 (vertical percolation layer)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (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	1	12		0.06	0.056	0.052	0.056
4	2	12		0.38	0.08	0.013	0.08
5	3	0.2		0.75	0.747	0.40	0.75
6	1	49.28		0.37	0.24	0.136	0.24
7	2	6		0.38	0.08	0.013	0.08
8	3	0.2		0.75	0.747	0.40	0.75
9	1	39.37		0.19	0.18	0.17	0.18

Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity (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	1	3.97E-04					
4	2	1.00E-01	300	3			
5	3	5.00E-09					
6	1	1.00E-04					
7	2	1.00E-01	100	2			
8	3	5.00E-09					
9	1	1.00E-08					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	1				
3	1				
4	2				
5	3				
6	1				
7	2				
8	3				
9	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 are missing from the table.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\ZPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\ZTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\ZSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\ZEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hsdfgcl\ZGCLD.D10
OUTPUT DATA FILE:            D:\HELP3\Hsdfgcl\ZGCLDout.OUT

TIME:  13:14     DATE:   9/11/2003

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

     TITLE:  SDF GCL Closure Cap with Erosion Barrier

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

     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 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     12.00   INCHES
POROSITY                     =      0.0600 VOL/VOL
FIELD CAPACITY               =      0.0560 VOL/VOL
WILTING POINT                =      0.0520 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.0560 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.396999996000E-03 CM/SEC

                         LAYER  4
                         --------

            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              =    300.0    FEET

                         LAYER  5
                         --------

             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  6
                         --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     49.28   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  7
                              --------

                 TYPE 2 - LATERAL DRAINAGE LAYER
                   MATERIAL TEXTURE NUMBER   0
THICKNESS                     =      6.00   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                         =      2.00   PERCENT
DRAINAGE LENGTH               =    100.0    FEET

                              LAYER  8
                              --------

                 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  9
                              --------

              TYPE 1 - VERTICAL PERCOLATION LAYER
                   MATERIAL TEXTURE NUMBER   0
THICKNESS                     =     39.37   INCHES
POROSITY                      =      0.1900 VOL/VOL
FIELD CAPACITY                =      0.1800 VOL/VOL
WILTING POINT                 =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT    =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.     =  0.999999994000E-08 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  300. FEET.

SCS RUNOFF CURVE NUMBER              =     55.70
FRACTION OF AREA ALLOWING RUNOFF     =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      2.750  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     =     29.186  INCHES
TOTAL INITIAL WATER                  =     29.186  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
4.38	3.95	4.68	2.91	3.56	4.99
5.43	5.41	3.93	3.12	2.96	3.45

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
46.30	50.00	57.20	64.30	72.10	78.40
81.60	80.30	75.20	65.10	56.70	48.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.30 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	4.56	3.57	4.76	2.74	3.60	4.97
	5.81	5.32	4.41	2.99	2.75	3.41
STD. DEVIATIONS	2.44	1.60	2.47	1.31	2.12	2.60
	2.83	2.95	2.54	2.28	1.72	1.90

```
RUNOFF
------
  TOTALS                  0.004    0.000    0.005    0.000    0.000    0.002
                          0.028    0.092    0.017    0.007    0.003    0.001

  STD. DEVIATIONS         0.022    0.000    0.029    0.000    0.004    0.017
                          0.095    0.407    0.090    0.059    0.018    0.005

EVAPOTRANSPIRATION
------------------
  TOTALS                  1.577    2.093    3.072    3.552    3.663    4.141
                          4.898    4.522    3.385    1.619    0.948    1.114

  STD. DEVIATIONS         0.221    0.237    0.582    0.760    1.525    1.545
                          1.588    1.379    1.039    0.606    0.207    0.206

LATERAL DRAINAGE COLLECTED FROM LAYER  4
----------------------------------------
  TOTALS                  2.7170   1.9209   1.9205   0.9442   0.2679   0.3494
                          0.6484   0.8294   0.7509   0.8010   1.0050   1.7014

  STD. DEVIATIONS         1.9146   1.5272   1.6493   0.9645   0.5076   0.6708
                          0.9529   1.1598   1.1644   1.1900   1.2786   1.4634

PERCOLATION/LEAKAGE THROUGH LAYER  5
-------------------------------------
  TOTALS                  0.0458   0.0336   0.0340   0.0189   0.0078   0.0073
                          0.0129   0.0159   0.0145   0.0151   0.0183   0.0297

  STD. DEVIATIONS         0.0290   0.0231   0.0248   0.0149   0.0083   0.0113
                          0.0155   0.0186   0.0186   0.0196   0.0205   0.0231

LATERAL DRAINAGE COLLECTED FROM LAYER  7
----------------------------------------
  TOTALS                  0.0377   0.0313   0.0281   0.0169   0.0041   0.0050
                          0.0092   0.0122   0.0111   0.0117   0.0148   0.0243

  STD. DEVIATIONS         0.0245   0.0241   0.0223   0.0175   0.0072   0.0099
                          0.0137   0.0164   0.0168   0.0172   0.0200   0.0213

PERCOLATION/LEAKAGE THROUGH LAYER  8
-------------------------------------
  TOTALS                  0.0053   0.0050   0.0054   0.0048   0.0038   0.0021
                          0.0032   0.0035   0.0034   0.0030   0.0033   0.0044

  STD. DEVIATIONS         0.0009   0.0004   0.0004   0.0011   0.0015   0.0020
                          0.0021   0.0022   0.0021   0.0024   0.0023   0.0020

PERCOLATION/LEAKAGE THROUGH LAYER  9
-------------------------------------
  TOTALS                  0.0042   0.0040   0.0041   0.0037   0.0035   0.0025
                          0.0023   0.0034   0.0040   0.0043   0.0038   0.0040

  STD. DEVIATIONS         0.0021   0.0018   0.0019   0.0016   0.0015   0.0015
                          0.0018   0.0021   0.0022   0.0023   0.0021   0.0019
```

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

  DAILY AVERAGE HEAD ON TOP OF LAYER  5
  -------------------------------------
    AVERAGES               1.5474   1.2000   1.0938   0.5557   0.1526   0.2056
                           0.3693   0.4724   0.4419   0.4590   0.5914   0.9690

    STD. DEVIATIONS        1.0904   0.9567   0.9393   0.5676   0.2891   0.3948
                           0.5427   0.6605   0.6852   0.6889   0.7525   0.8334

  DAILY AVERAGE HEAD ON TOP OF LAYER  8
  -------------------------------------
    AVERAGES               0.0107   0.0098   0.0080   0.0050   0.0012   0.0015
                           0.0026   0.0035   0.0033   0.0033   0.0044   0.0069

    STD. DEVIATIONS        0.0070   0.0075   0.0063   0.0052   0.0021   0.0029
                           0.0039   0.0047   0.0049   0.0049   0.0059   0.0061

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

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

     AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                      INCHES            CU. FEET       PERCENT
                                  -------------------  -------------   ---------
 PRECIPITATION                     48.90    (  7.734)    488145.2      100.00

 RUNOFF                             0.159   (  0.4376)     1589.92       0.326

 EVAPOTRANSPIRATION                34.584   (  3.6252)   345236.75      70.724

 LATERAL DRAINAGE COLLECTED        13.85602 (  5.60343)  138317.703    28.33536
   FROM LAYER  4

 PERCOLATION/LEAKAGE THROUGH        0.25393 (  0.08919)    2534.904     0.51929
   LAYER  5

 AVERAGE HEAD ON TOP                0.671 (    0.272)
   OF LAYER  5

 LATERAL DRAINAGE COLLECTED         0.20659 (  0.08366)    2062.242     0.42246
   FROM LAYER  7

 PERCOLATION/LEAKAGE THROUGH        0.04730 (  0.00857)     472.150     0.09672
   LAYER  8

 AVERAGE HEAD ON TOP                0.005 (    0.002)
   OF LAYER  8

 PERCOLATION/LEAKAGE THROUGH        0.04387 (  0.01447)     437.938     0.08971
   LAYER  9

 CHANGE IN WATER STORAGE            0.050   (  1.5846)      500.72      0.103
```

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

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

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
   ---------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------    -------------
      PRECIPITATION                              6.87          68579.773

      RUNOFF                                     2.652         26478.3203

      DRAINAGE COLLECTED FROM LAYER  4           0.66742        6662.50342

      PERCOLATION/LEAKAGE THROUGH LAYER  5       0.017625        175.93739

      AVERAGE HEAD ON TOP OF LAYER  5           20.526

      MAXIMUM HEAD ON TOP OF LAYER  5           27.534

      LOCATION OF MAXIMUM HEAD IN LAYER  4
            (DISTANCE FROM DRAIN)               94.3 FEET

      DRAINAGE COLLECTED FROM LAYER  7           0.00825          82.39084

      PERCOLATION/LEAKAGE THROUGH LAYER  8       0.000232          2.31596

      AVERAGE HEAD ON TOP OF LAYER  8            0.073

      MAXIMUM HEAD ON TOP OF LAYER  8            0.142

      LOCATION OF MAXIMUM HEAD IN LAYER  7
            (DISTANCE FROM DRAIN)                2.5 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER  9       0.000417          4.16577

      SNOW WATER                                 2.36          23561.8457


      MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.3689

      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	1.6127	0.2688
2	9.2087	0.3070
3	0.7200	0.0600
4	2.6188	0.2182
5	0.1500	0.7500
6	11.8272	0.2400
7	0.4851	0.0809
8	0.1500	0.7500
9	7.4293	0.1887
SNOW WATER	0.000	

****
****

Appendix M, GCL Closure Cap with Erosion Barrier without Layer Above: HELP Model Input Data and Output File (output file name: ZGCLEout.OUT)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.75 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	300 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 55.70	

Layer	Layer Number	Layer Type
Erosion Barrier	1	1 (vertical percolation layer)
Gravel Drainage	2	2 (lateral drainage layer)
GCL	3	3 (barrier soil liner)
Backfill	4	1 (vertical percolation layer)
Gravel Drainage	5	2 (lateral drainage layer)
GCL	6	3 (barrier soil liner)
Clean Grout	7	1 (vertical percolation layer)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	12		0.06	0.056	0.052	0.056
2	2	12		0.38	0.08	0.013	0.08
3	3	0.2		0.75	0.747	0.40	0.75
4	1	49.28		0.37	0.24	0.136	0.24
5	2	6		0.38	0.08	0.013	0.08
6	3	0.2		0.75	0.747	0.40	0.75
7	1	39.37		0.19	0.18	0.17	0.18

Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	3.97E-04					
2	2	1.00E-01	300	3			
3	3	5.00E-09					
4	1	1.00E-04					
5	2	1.00E-01	100	2			
6	3	5.00E-09					
7	1	1.00E-08					

	Layer Type	Geomembrane Pinhole Density (#/acre)	Geomembrane Instal. Defects (#/acre)	Geomembrane Placement Quality	Geotextile Transmissivity (cm^2/sec)
1	1				
2	2				
3	3				
4	1				
5	2				
6	3				
7	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 are missing from the table.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\ZPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\ZTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\ZSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\ZEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hsdfgcl\ZGCLE.D10
OUTPUT DATA FILE:            D:\HELP3\Hsdfgcl\ZGCLEout.OUT

TIME:  13:20     DATE:   9/11/2003

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

     TITLE:  SDF GCL Closure Cap with Erosion Barrier w/o Layers Above

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

     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                    =     12.00   INCHES
          POROSITY                     =      0.0600 VOL/VOL
          FIELD CAPACITY               =      0.0560 VOL/VOL
          WILTING POINT                =      0.0520 VOL/VOL
          INITIAL SOIL WATER CONTENT   =      0.0560 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.396999996000E-03 CM/SEC

                                  LAYER  2
                                  --------

                       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              =    300.0    FEET
```

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

              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  4
                         --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     49.28   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  5
                         --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      6.00   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                        =      2.00   PERCENT
DRAINAGE LENGTH              =    100.0    FEET

                         LAYER  6
                         --------

              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 7

TYPE 1 - VERTICAL PERCOLATION LAYER
MATERIAL TEXTURE NUMBER 0

THICKNESS	=	39.37	INCHES
POROSITY	=	0.1900	VOL/VOL
FIELD CAPACITY	=	0.1800	VOL/VOL
WILTING POINT	=	0.1700	VOL/VOL
INITIAL SOIL WATER CONTENT	=	0.1800	VOL/VOL
EFFECTIVE SAT. HYD. COND.	=	0.999999994000E-08	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 300. FEET.

SCS RUNOFF CURVE NUMBER	=	55.70	
FRACTION OF AREA ALLOWING RUNOFF	=	100.0	PERCENT
AREA PROJECTED ON HORIZONTAL PLANE	=	2.750	ACRES
EVAPORATIVE ZONE DEPTH	=	22.0	INCHES
INITIAL WATER IN EVAPORATIVE ZONE	=	1.472	INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE	=	4.520	INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE	=	0.754	INCHES
INITIAL SNOW WATER	=	0.000	INCHES
INITIAL WATER IN LAYER MATERIALS	=	21.326	INCHES
TOTAL INITIAL WATER	=	21.326	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
4.38	3.95	4.68	2.91	3.56	4.99
5.43	5.41	3.93	3.12	2.96	3.45

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
46.30	50.00	57.20	64.30	72.10	78.40
81.60	80.30	75.20	65.10	56.70	48.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.30 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	4.56	3.57	4.76	2.74	3.60	4.97
	5.81	5.32	4.41	2.99	2.75	3.41
STD. DEVIATIONS	2.44	1.60	2.47	1.31	2.12	2.60
	2.83	2.95	2.54	2.28	1.72	1.90
RUNOFF						
TOTALS	0.006	0.004	0.003	0.000	0.001	0.001
	0.016	0.108	0.025	0.024	0.002	0.000
STD. DEVIATIONS	0.058	0.038	0.022	0.000	0.005	0.009
	0.084	0.489	0.176	0.242	0.024	0.000
EVAPOTRANSPIRATION						
TOTALS	1.358	1.587	2.054	1.861	2.218	2.878
	3.281	2.874	2.255	1.246	1.005	1.119
STD. DEVIATIONS	0.349	0.324	0.608	0.649	0.868	1.060
	1.009	0.967	0.807	0.582	0.378	0.258

LATERAL DRAINAGE COLLECTED FROM LAYER 2

TOTALS	3.0387	2.0814	2.6351	1.2252	1.3185	1.8157
	2.4332	2.4101	2.1355	1.6761	1.6490	2.1015
STD. DEVIATIONS	1.8462	1.3747	1.7448	0.9330	1.2766	1.3091
	1.6307	1.5874	1.5994	1.5751	1.2951	1.4246

PERCOLATION/LEAKAGE THROUGH LAYER 3

TOTALS	0.0509	0.0361	0.0449	0.0234	0.0245	0.0320
	0.0418	0.0418	0.0372	0.0301	0.0293	0.0367
STD. DEVIATIONS	0.0280	0.0209	0.0265	0.0142	0.0198	0.0201
	0.0250	0.0247	0.0249	0.0245	0.0202	0.0215

LATERAL DRAINAGE COLLECTED FROM LAYER 5

TOTALS	0.0425	0.0341	0.0372	0.0227	0.0184	0.0260
	0.0349	0.0372	0.0319	0.0260	0.0253	0.0307
STD. DEVIATIONS	0.0234	0.0237	0.0220	0.0185	0.0171	0.0195
	0.0228	0.0226	0.0221	0.0239	0.0209	0.0208

PERCOLATION/LEAKAGE THROUGH LAYER 6

TOTALS	0.0055	0.0050	0.0055	0.0052	0.0048	0.0048
	0.0053	0.0054	0.0052	0.0050	0.0047	0.0054
STD. DEVIATIONS	0.0005	0.0003	0.0003	0.0005	0.0013	0.0011
	0.0009	0.0005	0.0008	0.0010	0.0014	0.0005

PERCOLATION/LEAKAGE THROUGH LAYER 7

TOTALS	0.0052	0.0047	0.0049	0.0047	0.0047	0.0044
	0.0049	0.0052	0.0051	0.0051	0.0046	0.0048
STD. DEVIATIONS	0.0016	0.0014	0.0014	0.0013	0.0014	0.0014
	0.0016	0.0015	0.0014	0.0014	0.0014	0.0015

AVERAGES OF MONTHLY AVERAGED DAILY HEADS (INCHES)

DAILY AVERAGE HEAD ON TOP OF LAYER 3

AVERAGES	1.7338	1.3021	1.5053	0.7212	0.7523	1.0705
	1.3934	1.3887	1.2671	0.9607	0.9723	1.1970
STD. DEVIATIONS	1.0598	0.8672	1.0037	0.5496	0.7292	0.7739
	0.9408	0.9359	0.9662	0.9151	0.7672	0.8117

DAILY AVERAGE HEAD ON TOP OF LAYER 6

AVERAGES	0.0121	0.0106	0.0106	0.0067	0.0052	0.0076
	0.0099	0.0106	0.0094	0.0074	0.0075	0.0088
STD. DEVIATIONS	0.0067	0.0074	0.0063	0.0054	0.0049	0.0057
	0.0065	0.0064	0.0065	0.0068	0.0062	0.0059

****

****

AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS 1 THROUGH 100

	INCHES		CU. FEET	PERCENT
PRECIPITATION	48.90	(7.734)	488145.2	100.00
RUNOFF	0.191	(0.5795)	1903.15	0.390
EVAPOTRANSPIRATION	23.736	(2.5079)	236943.02	48.539
LATERAL DRAINAGE COLLECTED FROM LAYER 2	24.51993	(6.02946)	244770.219	50.14291
PERCOLATION/LEAKAGE THROUGH LAYER 3	0.42872	(0.09264)	4279.733	0.87673
AVERAGE HEAD ON TOP OF LAYER 3	1.189	(0.294)		
LATERAL DRAINAGE COLLECTED FROM LAYER 5	0.36676	(0.09191)	3661.148	0.75001
PERCOLATION/LEAKAGE THROUGH LAYER 6	0.06188	(0.00375)	617.755	0.12655
AVERAGE HEAD ON TOP OF LAYER 6	0.009	(0.002)		
PERCOLATION/LEAKAGE THROUGH LAYER 7	0.05833	(0.01465)	582.280	0.11928
CHANGE IN WATER STORAGE	0.029	(0.9482)	285.46	0.058

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

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

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
    ---------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
      PRECIPITATION                              6.87         68579.773

      RUNOFF                                     2.764        27590.2207

      DRAINAGE COLLECTED FROM LAYER  2           0.65872       6575.71533

      PERCOLATION/LEAKAGE THROUGH LAYER  3       0.015045       150.18440

      AVERAGE HEAD ON TOP OF LAYER  3           17.492

      MAXIMUM HEAD ON TOP OF LAYER  3           23.943

      LOCATION OF MAXIMUM HEAD IN LAYER  2
            (DISTANCE FROM DRAIN)               87.6 FEET

      DRAINAGE COLLECTED FROM LAYER  5           0.00903         90.15614

      PERCOLATION/LEAKAGE THROUGH LAYER  6       0.000238         2.37423

      AVERAGE HEAD ON TOP OF LAYER  6            0.080

      MAXIMUM HEAD ON TOP OF LAYER  6            0.155

      LOCATION OF MAXIMUM HEAD IN LAYER  5
            (DISTANCE FROM DRAIN)                2.6 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER  7       0.000396         3.94843

      SNOW WATER                                 2.36         23561.8457


      MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.2055

      MINIMUM VEG. SOIL WATER (VOL/VOL)                  0.0343

       ***  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	0.7232	0.0603
2	3.4047	0.2837
3	0.1500	0.7500
4	11.8282	0.2400
5	0.4873	0.0812
6	0.1500	0.7500
7	7.4420	0.1890
SNOW WATER	0.000	

****
****

Appendix N, GCL Closure Cap with Erosion Barrier without Layer Above Plus Additional Backfill Layer: HELP Model Input Data and Output File (output file name: ZGCLFout.OUT)

Input Data:

Input Parameter (HELP Model Query)	Generic Input Parameter Value
Landfill area =	2.75 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 inches
CN Input Parameter (HELP Model Query)	CN Input Parameter Value
Slope =	3 %
Slope length =	300 ft
Soil Texture =	5 (HELP model default soil texture)
Vegetation =	4 (i.e., a good stand of grass)
HELP Model Computed Curve Number = 55.70	

Layer	Layer Number	Layer Type
Erosion Barrier	1	1 (vertical percolation layer)
Backfill	2	1 (vertical percolation layer)
Gravel Drainage	3	2 (lateral drainage layer)
GCL	4	3 (barrier soil liner)
Backfill	5	1 (vertical percolation layer)
Gravel Drainage	6	2 (lateral drainage layer)
GCL	7	3 (barrier soil liner)
Clean Grout	8	1 (vertical percolation layer)

	Layer Type	Layer Thickness (in)	Soil Texture No.	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)	Initial Moisture (Vol/Vol)
1	1	12		0.06	0.056	0.052	0.056
2	1	12		0.37	0.24	0.136	0.24
3	2	12		0.38	0.08	0.013	0.08
4	3	0.2		0.75	0.747	0.40	0.75
5	1	37.28		0.37	0.24	0.136	0.24
6	2	6		0.38	0.08	0.013	0.08
7	3	0.2		0.75	0.747	0.40	0.75
8	1	39.37		0.19	0.18	0.17	0.18

Input Data (continued):

	Layer Type	Sat. Hyd. Conductivity (cm/sec)	Drainage Length (ft)	Drain Slope (%)	Leachate Recirc. (%)	Recirc. to Layer (#)	Subsurface Inflow (in/yr)
1	1	3.97E-04					
2	1	1.00E-04					
3	2	1.00E-01	300	3			
4	3	5.00E-09					
5	1	1.00E-04					
6	2	1.00E-01	100	2			
7	3	5.00E-09					
8	1	1.00E-08					

	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				
6	2				
7	3				
8	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 are missing from the table.

```
******************************************************************************
******************************************************************************
**                                                                          **
**                                                                          **
**              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\ZPREC.D4
TEMPERATURE DATA FILE:       D:\HELP3\Hweather\ZTEMP.D7
SOLAR RADIATION DATA FILE:   D:\HELP3\Hweather\ZSOLAR.D13
EVAPOTRANSPIRATION DATA:     D:\HELP3\Hweather\ZEVAP.D11
SOIL AND DESIGN DATA FILE:   D:\HELP3\Hsdfgcl\ZGCLF.D10
OUTPUT DATA FILE:            D:\HELP3\Hsdfgcl\ZGCLFout.OUT

TIME:  14:30     DATE:   9/11/2003

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

     TITLE:  SDF GCL CC with EB w/o Layers Above + Backfill Layer

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

    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                    =     12.00   INCHES
          POROSITY                     =      0.0600 VOL/VOL
          FIELD CAPACITY               =      0.0560 VOL/VOL
          WILTING POINT                =      0.0520 VOL/VOL
          INITIAL SOIL WATER CONTENT   =      0.0560 VOL/VOL
          EFFECTIVE SAT. HYD. COND.    =  0.396999996000E-03 CM/SEC

                                LAYER  2
                                --------

                   TYPE 1 - VERTICAL PERCOLATION LAYER
                       MATERIAL TEXTURE NUMBER   0
          THICKNESS                    =     12.00   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              =    300.0    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                    =     37.28   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  6
                         --------

            TYPE 2 - LATERAL DRAINAGE LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =      6.00   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                        =      2.00   PERCENT
DRAINAGE LENGTH              =    100.0    FEET
```

```
                          LAYER  7
                          --------

              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  8
                          --------

          TYPE 1 - VERTICAL PERCOLATION LAYER
              MATERIAL TEXTURE NUMBER   0
THICKNESS                    =     39.37   INCHES
POROSITY                     =      0.1900 VOL/VOL
FIELD CAPACITY               =      0.1800 VOL/VOL
WILTING POINT                =      0.1700 VOL/VOL
INITIAL SOIL WATER CONTENT   =      0.1800 VOL/VOL
EFFECTIVE SAT. HYD. COND.    =  0.999999994000E-08 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  300. FEET.

SCS RUNOFF CURVE NUMBER              =     55.70
FRACTION OF AREA ALLOWING RUNOFF     =    100.0    PERCENT
AREA PROJECTED ON HORIZONTAL PLANE   =      2.750  ACRES
EVAPORATIVE ZONE DEPTH               =     22.0    INCHES
INITIAL WATER IN EVAPORATIVE ZONE    =      3.072  INCHES
UPPER LIMIT OF EVAPORATIVE STORAGE   =      4.420  INCHES
LOWER LIMIT OF EVAPORATIVE STORAGE   =      1.984  INCHES
INITIAL SNOW WATER                   =      0.000  INCHES
INITIAL WATER IN LAYER MATERIALS     =     21.326  INCHES
TOTAL INITIAL WATER                  =     21.326  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
4.38	3.95	4.68	2.91	3.56	4.99
5.43	5.41	3.93	3.12	2.96	3.45

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
46.30	50.00	57.20	64.30	72.10	78.40
81.60	80.30	75.20	65.10	56.70	48.80

NOTE: SOLAR RADIATION DATA WAS SYNTHETICALLY GENERATED USING
COEFFICIENTS FOR AUGUSTA GEORGIA
AND STATION LATITUDE = 33.30 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	4.56	3.57	4.76	2.74	3.60	4.97
	5.81	5.32	4.41	2.99	2.75	3.41
STD. DEVIATIONS	2.44	1.60	2.47	1.31	2.12	2.60
	2.83	2.95	2.54	2.28	1.72	1.90

```
RUNOFF
------
  TOTALS                  0.004    0.000    0.006    0.001    0.000    0.002
                          0.040    0.134    0.044    0.010    0.000    0.000

  STD. DEVIATIONS         0.031    0.000    0.055    0.009    0.000    0.016
                          0.141    0.564    0.242    0.081    0.000    0.001

EVAPOTRANSPIRATION
------------------
  TOTALS                  1.659    2.104    2.895    2.496    2.881    3.557
                          3.996    3.546    2.743    1.474    1.054    1.275

  STD. DEVIATIONS         0.215    0.276    0.719    0.936    1.179    1.355
                          1.303    1.177    0.965    0.671    0.274    0.191

LATERAL DRAINAGE COLLECTED FROM LAYER  3
----------------------------------------
  TOTALS                  2.7984   1.7403   1.9427   0.7366   0.7235   1.1164
                          1.6743   1.7017   1.5392   1.2998   1.4241   1.9197

  STD. DEVIATIONS         1.9382   1.5057   1.7343   0.8774   1.0945   1.1278
                          1.4276   1.5065   1.4854   1.5479   1.3494   1.4770

PERCOLATION/LEAKAGE THROUGH LAYER  4
-------------------------------------
  TOTALS                  0.0470   0.0308   0.0341   0.0153   0.0142   0.0204
                          0.0296   0.0303   0.0276   0.0238   0.0255   0.0336

  STD. DEVIATIONS         0.0296   0.0229   0.0264   0.0139   0.0175   0.0176
                          0.0222   0.0231   0.0228   0.0249   0.0211   0.0226

LATERAL DRAINAGE COLLECTED FROM LAYER  6
----------------------------------------
  TOTALS                  0.0393   0.0290   0.0279   0.0143   0.0097   0.0158
                          0.0243   0.0258   0.0227   0.0191   0.0216   0.0281

  STD. DEVIATIONS         0.0252   0.0249   0.0229   0.0165   0.0148   0.0168
                          0.0204   0.0216   0.0207   0.0222   0.0217   0.0218

PERCOLATION/LEAKAGE THROUGH LAYER  7
-------------------------------------
  TOTALS                  0.0052   0.0048   0.0051   0.0043   0.0034   0.0038
                          0.0046   0.0049   0.0047   0.0042   0.0042   0.0050

  STD. DEVIATIONS         0.0011   0.0007   0.0011   0.0016   0.0020   0.0018
                          0.0016   0.0013   0.0014   0.0019   0.0017   0.0013

PERCOLATION/LEAKAGE THROUGH LAYER  8
-------------------------------------
  TOTALS                  0.0044   0.0041   0.0043   0.0040   0.0038   0.0033
                          0.0043   0.0049   0.0048   0.0047   0.0039   0.0042

  STD. DEVIATIONS         0.0018   0.0016   0.0017   0.0016   0.0017   0.0018
                          0.0020   0.0020   0.0018   0.0018   0.0016   0.0017
```

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

  DAILY AVERAGE HEAD ON TOP OF LAYER  4
  -------------------------------------
    AVERAGES               1.5955   1.0877   1.1064   0.4335   0.4121   0.6570
                           0.9535   0.9695   0.9060   0.7481   0.8383   1.0933

    STD. DEVIATIONS        1.1091   0.9449   0.9877   0.5164   0.6233   0.6637
                           0.8131   0.8590   0.8749   0.9132   0.7948   0.8412

  DAILY AVERAGE HEAD ON TOP OF LAYER  7
  -------------------------------------
    AVERAGES               0.0112   0.0091   0.0079   0.0042   0.0028   0.0046
                           0.0069   0.0073   0.0067   0.0054   0.0064   0.0080

    STD. DEVIATIONS        0.0072   0.0078   0.0065   0.0049   0.0042   0.0049
                           0.0058   0.0062   0.0061   0.0063   0.0064   0.0062

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

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

    AVERAGE ANNUAL TOTALS & (STD. DEVIATIONS) FOR YEARS    1 THROUGH  100
-------------------------------------------------------------------------------
                                      INCHES            CU. FEET       PERCENT
                                 -------------------  -------------   ---------
 PRECIPITATION                    48.90    (  7.734)    488145.2      100.00

 RUNOFF                            0.242   (  0.6679)     2417.56       0.495

 EVAPOTRANSPIRATION               29.682   (  2.9830)   296295.75      60.698

 LATERAL DRAINAGE COLLECTED       18.61667 (  6.14783)  185840.937    38.07083
   FROM LAYER  3

 PERCOLATION/LEAKAGE THROUGH       0.33195 (  0.09598)    3313.694     0.67883
   LAYER  4

 AVERAGE HEAD ON TOP               0.900   (    0.298)
   OF LAYER  4

 LATERAL DRAINAGE COLLECTED        0.27766 (  0.09292)    2771.740     0.56781
   FROM LAYER  6

 PERCOLATION/LEAKAGE THROUGH       0.05421 (  0.00663)     541.156     0.11086
   LAYER  7

 AVERAGE HEAD ON TOP               0.007   (    0.002)
   OF LAYER  7

 PERCOLATION/LEAKAGE THROUGH       0.05068 (  0.01463)     505.949     0.10365
   LAYER  8

 CHANGE IN WATER STORAGE           0.031   (  1.1480)      313.35      0.064
```

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

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

                PEAK DAILY VALUES FOR YEARS    1 THROUGH  100
    ------------------------------------------------------------------------
                                                (INCHES)      (CU. FT.)
                                               ----------   -------------
      PRECIPITATION                              6.87         68579.773

      RUNOFF                                     3.050        30444.9980

      DRAINAGE COLLECTED FROM LAYER  3           0.68773       6865.29834

      PERCOLATION/LEAKAGE THROUGH LAYER  4       0.021956       219.17435

      AVERAGE HEAD ON TOP OF LAYER  4           25.619

      MAXIMUM HEAD ON TOP OF LAYER  4           33.687

      LOCATION OF MAXIMUM HEAD IN LAYER  3
           (DISTANCE FROM DRAIN)                104.6 FEET

      DRAINAGE COLLECTED FROM LAYER  6           0.00934         93.25857

      PERCOLATION/LEAKAGE THROUGH LAYER  7       0.000240         2.39750

      AVERAGE HEAD ON TOP OF LAYER  7            0.082

      MAXIMUM HEAD ON TOP OF LAYER  7            0.160

      LOCATION OF MAXIMUM HEAD IN LAYER  6
           (DISTANCE FROM DRAIN)                 2.7 FEET

      PERCOLATION/LEAKAGE THROUGH LAYER  8       0.000392         3.91279

      SNOW WATER                                 2.36         23561.8457


      MAXIMUM VEG. SOIL WATER (VOL/VOL)                  0.2009

      MINIMUM VEG. SOIL WATER (VOL/VOL)                  0.0902

       ***  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	0.8125	0.0677
2	3.3621	0.2802
3	3.1156	0.2596
4	0.1500	0.7500
5	8.9477	0.2400
6	0.4874	0.0812
7	0.1500	0.7500
8	7.4393	0.1890
SNOW WATER	0.000	

****
****

APPROVED for Release for
Unlimited (Release to Public)
6/23/2005

January 6, 2005 SRNL-EST-2004-00103

To: J. R. Cook, 773-43A
E. L. Wilhite, 773-43A
A. D. Yu, ALARA

From: M. A. Phifer, 773-42A

Vault #4 Closure Cap Estimated Infiltration for Years 50,000 to 1,000,000

Estimated infiltration through the upper geosynthetic clay liner (GCL) of the Vault #4 closure cap has been determined for years 50,000 through 1,000,000 consistent with that previously provided for years 0 through 10,000 in Phifer (2004). Additionally information on the hydraulic properties of the lower drainage layer, side vertical drainage layer, and vault base drainage layer are also provided. Table 1 provides the resulting Vault 4 PORFLOW input. The table also includes the previously provided information for years 0 through 10,000. Figure 1 provides a graphical depiction of the estimated infiltration through the upper GCL over time. Appendix A provides the associated calculations.

The Technical Report Design Check has been performed by William E. Jones, and all necessary corrections have been made based upon the results of this design check.

Reference:

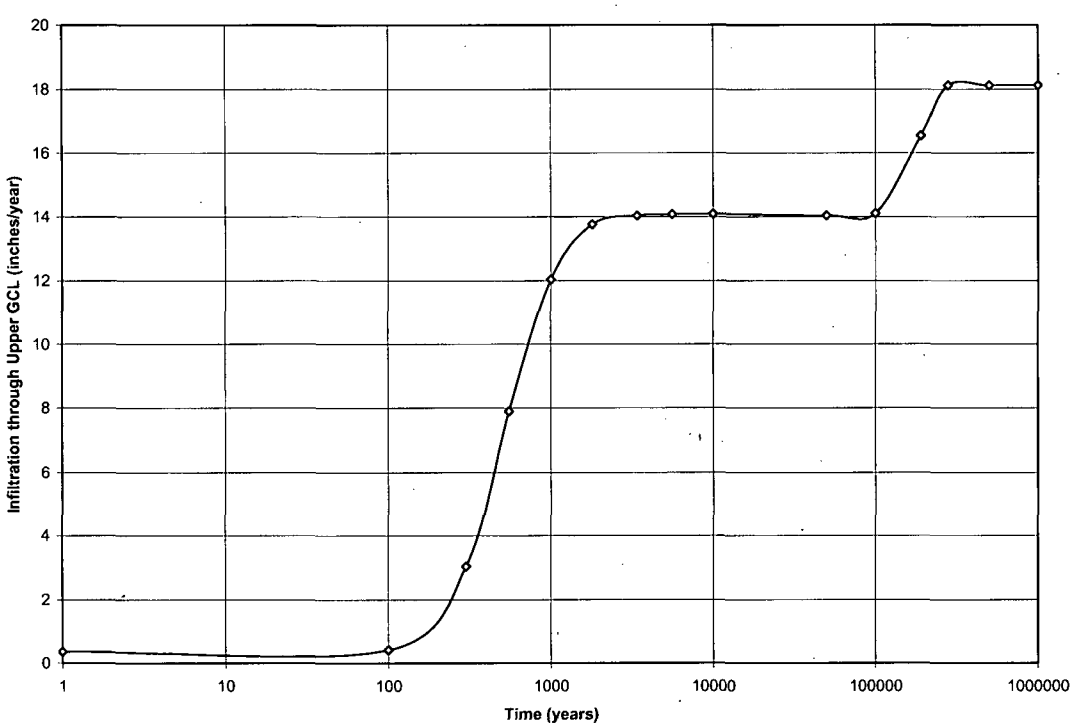
Phifer, M. A. 2004. *Vault 4 Infiltration and Hydraulic Conductivity Input for the Vadose Zone PORFLOW Modeling*, SRT-EST-2004-00068, Westinghouse Savannah River Company, Aiken, South Carolina. February 26, 2004.

CC: B. T. Butcher, 773-43A
R. S. Aylward, 773-42A
M. K. Harris, 773-42A
W. E. Jones, 773-42A
EST files

Table 1. Vault #4 PORFLOW Input

Year	Infiltration through Upper GCL (in/yr)	Lower Drainage Layer K_s (cm/s)	Height of Side Vertical Drainage Layer with a K_s of 0.1 cm/s [3] (cm/s)	Height of Side Vertical Drainage Layer with a K_s of 0000.1 cm/s [3] (cm/s)	Thickness of Upper Portion of the Vault Base Drainage Layer with a K_s of 0.1 cm/s [3] (feet)	Thickness of Lower Portion of the Vault Base Drainage Layer with a K_s of 0.0001 cm/s [3] (feet)
0	0.36	1.00E-01	23.5	0	5	0
100	0.41	1.00E-01	23.5	0	4.9995	0.0005
300	3.05	9.98E-02	23.5	0	4.995	0.005
550	7.90	9.89E-02	23.5	0	4.978	0.022
1,000	12.04	9.61E-02	23.5	0	4.92	0.08
1,800	13.76	8.96E-02	23.5	0	4.79	0.21
3,400	14.03	7.56E-02	23.5	0	4.51	0.49
5,600	14.08	5.62E-02	23.5	0	4.12	0.88
10,000	14.09	1.74E-02	23.5	0	3.34	1.66
50,000	14.04	1.00E-04	19.78	3.72	0	5
100,000	14.11	1.00E-04	10.94	12.56	0	5
190,000	16.54	1.00E-04	0	23.5	0	5
280,000	18.12	1.00E-04	0	23.5	0	5
500,000	18.12	1.00E-04	0	23.5	0	5
1,000,000	18.12	1.00E-04	0	23.5	0	5

Figure 1. Infiltration through the Upper GCL over Time



4/10980

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WSRC-RP-92-1360

RADIOLOGICAL PERFORMANCE ASSESSMENT FOR THE Z-AREA SALTSTONE DISPOSAL FACILITY (U)

JRC 2/4/93

Prepared for the
WESTINGHOUSE SAVANNAH RIVER COMPANY
Aiken, South Carolina

by

MARTIN MARIETTA ENERGY SYSTEMS, INC.
EG&G IDAHO, INC.
WESTINGHOUSE HANFORD COMPANY
WESTINGHOUSE SAVANNAH RIVER COMPANY

December 18, 1992

Rev. 0

3.3.1 Near-Field Model

The following discussion addresses the means by which radionuclides and nitrate released from the SDF would be transported in the near-field environment. The near-field environment is defined in this RPA as the portion of the subsurface environment extending from the ground surface to the water table. Conceptual models of flow and mass transport through both intact (Sect. 3.3.1.1) and fractured (Sect. 3.3.1.2) vaults are considered.

For the near-field models, a relatively complex numerical approach to simulating flow was adopted because the analysis required to predict the flow field around and through the facility. The flow of water through a variably-saturated system consisting of numerous materials with widely-varying hydraulic properties is not readily simulated analytically. The problem is highly non-linear, and flow in one material is affected by that in an adjacent material. Because the unsaturated zone is characterized by varying degrees of saturation, and this condition is further affected by the presence of the SDF, transit time is not readily estimated based on estimates of hydraulic conductivity or moisture characteristic curves that are available. Therefore, prediction of the flow regime under the conceptual facility based on assumed properties of materials present was necessary.

The flow regime in the subsurface was separated conceptually into three regions for purposes of analysis. These three regions are combined on the left side of Fig. 3.3-1. The first region is composed of the sediments near the surface, where evaporation and transpiration have a dynamic role in reversing the downward movement of water due to gravity. Below this region, but above the concrete vaults, is the region that includes the upper engineered moisture barrier, described in Sect. 2.4. The last region extends to the water table, and consists of the backfill sediment, the lower clay/gravel drain, the concrete vault, the saltstone waste form, and underlying native soil.

The conceptual model for water movement in the near field is as follows. Water infiltrates at the surface and either undergoes evapotranspiration through the surface and out of the domain, or penetrates the first region. This water is then available for subsurface runoff or infiltration through the second region. With the upper moisture barrier in place, the majority of this infiltrating water is diverted around the facility; however, some water penetrates this upper barrier. The lower clay/gravel drain system intercepts most of this penetrating water. A very small amount of water penetrates this lower barrier, most of which then flows around the vault and down to the water table. Some water penetrates the concrete roof and flows through the saltstone. The amount of water that penetrates the concrete and saltstone is dependent on the many factors, including the integrity of the vault and saltstone, as noted in Sect. 3.1.3.

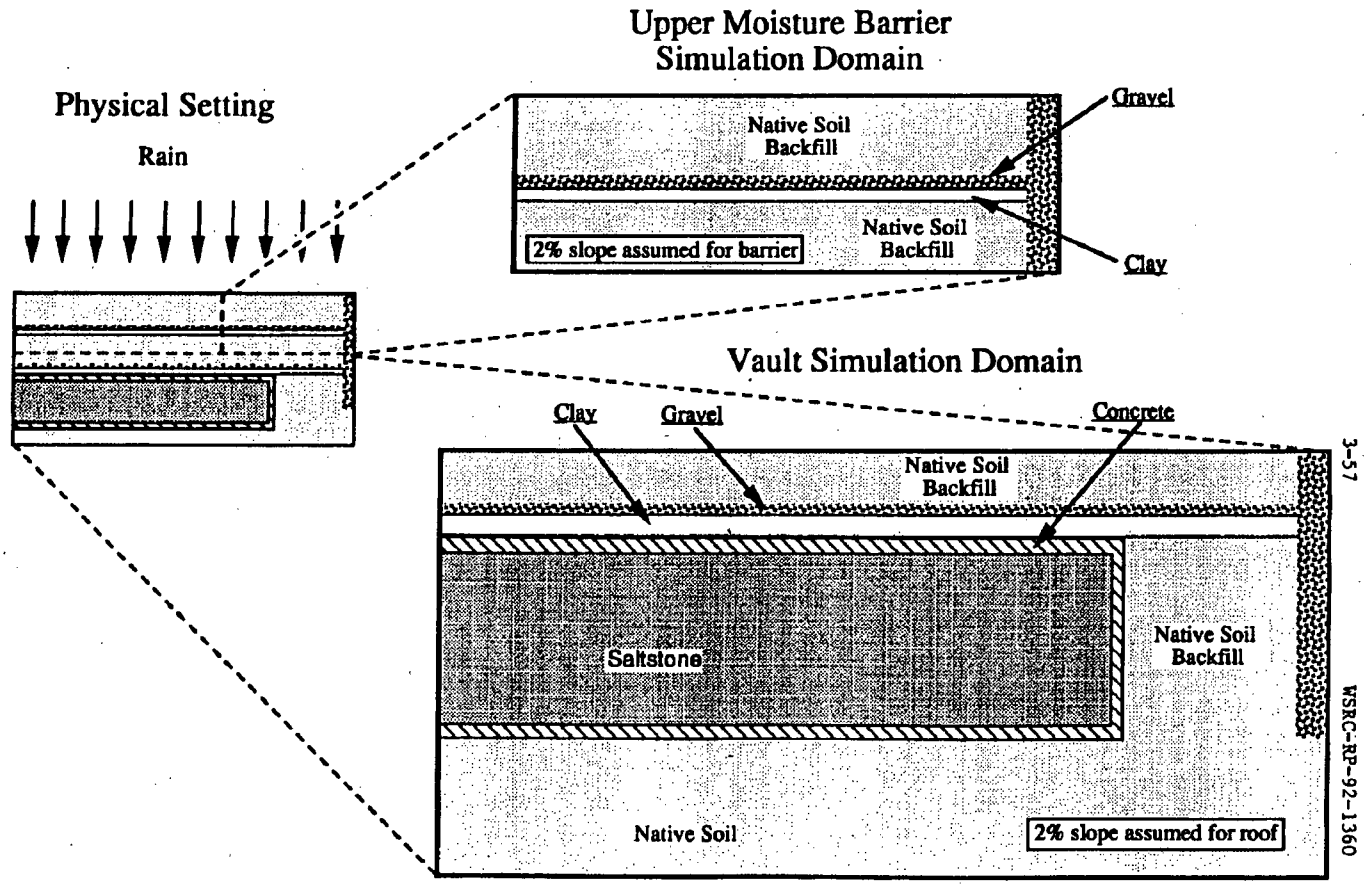

Fig. 3.3-1. Domains of the near-field conceptual model.

An assumption inherent in dividing the flow regime into these three regions is that contaminants escaping the vault do not diffuse upwards through the cover system. This assumption is imposed because flow from the upper region is determined before mass transport simulations are conducted. Mass transport simulations are only carried for the vault/saltstone domain. The basis for this assumption is that advection will dominate transport of contaminants once they are outside of the vault, and that contaminants that have diffused upward through the concrete roof of the vaults will be swept horizontally along the vault and down to the water table.

The conceptual model for mass transport involves several processes. These processes are diffusion, advection, dispersion, sorption, and radioactive decay. All of these processes, which were discussed in Sect. 3.1.2 as mechanisms also pertinent to release from the saltstone matrix, occur within each of the three material types considered in the near-field conceptual model (i.e., saltstone, concrete vault, and backfill soil).

This RPA addresses both an intact vault scenario and a degraded vault scenario (Sect. 3.1), based on the belief that some degree of degradation of the engineered barriers of the SDF will occur. The remainder of this discussion of the near-field conceptual model will distinguish aspects that are pertinent to the intact vault scenario (Sect. 3.3.1.1) and those pertinent to the degraded vault scenario (Sect. 3.3.1.2).

3.3.1.1 Intact vault model

Two scenarios were addressed with vaults and monoliths assumed to be intact (Sect. 3.1.3.5): 1) an intact vault with an intact upper moisture barrier (Sect. 2.4); and 2) an intact vault with a completely degraded upper moisture barrier, in which the permeability of the upper region is that of the backfill soil. In both cases, the lower clay/gravel drain system is assumed to be intact. In either scenario, the influx of water determined through the two upper regions (Fig. 3.3-1) is assumed constant. For a non-degraded cover system, no consideration is given to the time required for the flux through the cover to achieve steady-state in the subsequent flow and transport simulations; a steady-state flux through the cover is assumed at time zero. For the degraded cover scenario, the steady-state flux through the upper region is assumed to be equivalent to the average annual infiltration rate, or 40 cm/year determined in Appendix A.1.1. However, transient simulations are carried out for the lower region (Fig. 3.3-1) to evaluate the effect that placement of the vaults and cover system have on flow and transport in an environment accustomed to receiving an infiltration rate of 40 cm/year.

In order to assess the distribution, and subsequent mass transport through the lower region (Fig. 3.3-1) of the model for the intact vault scenario, several assumptions were required regarding the material properties of the saltstone, concrete vaults, surrounding soils and the properties of the potential contaminants. Consideration was given to the type and quality of data available, as well as to computational requirements.

Numerical simulation requires, for practical reasons, averaging of spatial properties. Thus, the conceptual model used to provide a framework for the numerical simulation of the near-field movement of water and contaminants from the SDF relies heavily on such averaging. The subsurface is treated as if it consists of five material types: 1) the backfill or native soil; 2) clay; 3) gravel; 4) concrete; and 5) the saltstone waste form. Each of these materials are treated as if they are homogeneous and isotropic.

Hydraulic properties for each material type are assumed to be adequately described by the following hydraulic parameters: saturated hydraulic conductivity, effective porosity, and moisture characteristic curve. The moisture characteristic curve describes the nonlinear relationship between the matrix potential or pressure head, the moisture content, and the hydraulic conductivity. Details and references for the data and expressions used to quantify the hydraulic properties for each material type in the near-field model are provided in Appendix A.1.2. A summary of hydraulic properties assumed is provided in Table 3.3-1.

In addition to hydraulic properties, assumptions to allow quantification of mass transport are necessary in the near-field model. Specifically, contaminant-specific sorption coefficients, diffusion coefficients, and radioactive decay constants are required. Dispersivities, which determine the spreading of a simulated contaminant plume, are also needed. Tables of these values for contaminants of significance, and references to their source are provided in Appendix A.1.2.1. Solubility considerations are not explicitly addressed in the near-field model, except through the use of media-specific sorption coefficients which do not distinguish surface sorption from precipitation or other processes causing immobilization.

3.3.1.2 Degraded Vault and Saltstone

Two scenarios were addressed for vaults and monoliths assumed to be degraded (i.e., cracks present, Sect. 3.1.3.5): 1) a degraded vault with an intact upper moisture barrier (Sect. 2.4); and 2) a degraded vault with a completely degraded upper moisture barrier, in which the permeability of the degraded cover is that of the backfill soil and the clay layer on top of the vault roof. The only parameter required from Table 3.3-1 for the degraded case is the hydraulic conductivity of the clay on the roof of the vault.

A simplified conceptual model is used to represent the degraded condition of the saltstone and surrounding concrete vault. Two factors contributed to this decision: 1) numerical difficulties associated with modeling fractures in a groundwater computer code and 2) large uncertainty associated with inputs such as the timing, frequency, and size of fractures in the saltstone. Sensitivity analyses are then used to consider a range of possible input values and provide an indication of the impact that changes in the inputs have on the results. Such analyses also provide a set of results that form an envelope around the possible results. Results of sensitivity analyses are discussed in this section and Sect. 4.2.1.

Table 3.3-1 Summary of hydraulic properties assumed in the near-field model

Material	K_s (cm s^{-1})	Effective porosity, θ_s	Residual moisture content, θ_r	α $(cm^{-1})^a$	n^a
Backfill	1.0×10^{-5}	0.44	na[b]	na[b]	na[b]
Clay	7.6×10^{-9}	0.39	0.115	8.2×10^{-4}	1.33
Gravel	0.5	0.38	0.010	8.2×10^{-2}	3.70
Concrete	1.0×10^{-10}	0.08	0.064	7.5×10^{-7}	1.57
Saltstone	1.0×10^{-11}	0.46	0.368	7.4×10^{-6}	4.41

[a] Fitting parameter for van Genuchten and Mualem expressions for moisture characteristic curves.

[b] A Stone's correlation curve was used to describe the moisture characteristic curve for the backfill.

[c] Saltstone, concrete, gravel, and backfill properties not required for fractured saltstone case.

The conceptual model of a degraded vault and saltstone waste form assumes, as discussed in Sect. 3.1.3.5, that: 1) all monoliths and vaults in the facility are fractured, 2) fractures occur every 3 m, 3) all fractures open simultaneously, 4) the fractures are assumed to open at closure of the facility, when remediation of cracks will no longer be routine, 5) transport is assumed to be diffusive (constant diffusion coefficient) out of the intact saltstone matrix and into the fracture where transport is assumed to be dominated by advection (i.e., the fracture case results are independent of the hydraulic conductivity of the saltstone), 6) the clay is assumed to sit immediately on top of the saltstone, and 7) the base of the saltstone is assumed to be adjacent to the backfill soil beneath the vault. Since the majority of the degradation occurs to the vault as opposed to the saltstone, for the vault is conservatively neglected as a barrier to transport. Thus, this case addresses flow and transport through the fractured saltstone. The fractures are assumed to be 0.005 cm in aperture; filling or plugging by soils or precipitates is not considered. Diffusion is assumed to be the only mechanism of transport of radionuclides and nitrate from the saltstone matrix to the fractures, and advection is assumed to be the only means of transporting these potential contaminants from the fractures to the soil beneath the vaults.

This simplified model is considered to be a bounding case on release from fractured vaults because fracturing of the vaults is expected to increase the effective permeability of the vaults, and thus increase radionuclide and nitrate release. The release rate would increase as the number of fractures increases. However, release rates for soluble species would likely decrease with time, as the resident pore water is flushed from the fracture, and diffusion from the saltstone matrix would then control the concentration in the fracture. Therefore, assuming simultaneous opening of all fractures is believed to represent an upper bound on release rates. Remediation of fractures that occur before closure involves filling with epoxy upon discovery. Degradation of the epoxy is likely to be a gradual process rather than immediate. Furthermore, shrinkage cracks in pours may be filled to some extent by subsequent pours. This would also reduce the flow rate through fractures.

Details of the various submodels that were used to adapt a model for flow and transport in fractures, to which semi-analytical solution techniques could be applied, are provided in Appendix A.1.3. Some of the critical assumptions, however, are noted here since they are fundamental to the conceptual approach and the resulting analytical model. One of the primary underlying assumptions is that the fractures remain saturated once they open. Another critical input necessary to evaluate the flow of water through a fracture is the height of water perched on fractured vaults. The intact vault model (Appendix A.1.2.1) was used to predict the depth of the perched water on the vault. Perched water is shown to occur on an intact vault, and the assumption of saturated flow is assumed to be reasonable. These assumptions are discussed in more detail in Appendix A.1.3.

For the fractured saltstone, effective flow rates and subsequent transport were estimated based on the methods described in Appendix A.1.3.

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ADDENDUM TO THE RADIOLOGICAL PERFORMANCE ASSESSMENT FOR THE Z-AREA SALTSTONE DISPOSAL FACILITY AT THE SAVANNAH RIVER SITE

Additional Information Supplied to the
DOE Performance Assessment Peer Review Panel and
DOE Headquarters in Support of Review, 1993-1997

Prepared by

WESTINGHOUSE SAVANNAH RIVER COMPANY
Aiken, South Carolina

Approved
For Release for Unlimited
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April 1998

WSRC-RP-98-00156 R0
pg. 138-143

Westinghouse
Savannah River Company

P O Box 616
Aiken, SC 29802

OPS-DTZ-95-0001

JAN 10 1995

To: M. S. Glenn
DOE-SR, 704-S

From: D. G. Thompson
Manager, Saltstone Facility

RESPONSE TO DOE-HQ COMMENTS ON ZAREA PERFORMANCE ASSESSMENT (u)

References:

1. USDOE Memorandum, R. P. Berube to J. E. Lytle, "SRS Saltstone Performance Assessment and Implementing Order DOE 5820.2A at LLW Disposal Facilities," March 25, 1994.

2. USDOE Memorandum, R. F. Pelletier to J. A. Coleman, "SRS Saltstone Performance Assessment," September 23, 1994.

3. Letter, H. F. Daugherty to V. W. Sauls, "Response to DOE-HQ on EAV Radiological Performance Assessment Comments," SWE-SWD-94-0247, September 30, 1994.

Dr. J. R. Fowler of our staff has the primary technical responsibility for the Z-Area Radiological Performance Assessment (RPA). As you requested, he has prepared responses to the comments from DOE-HQ (Ref. 1, 2) to assist you in the preparation of responses to EM-323.

Reference 3 provides information on programs funded at SRS relative to the E-Area vaults (EAV). Some of these programs are purposely designed to apply to any disposal or remediation site at the SRS (e.g., infiltration studies). Note that any committments by Saltstone Operations, relative to maintenance of the Radiological Performance Assessment for Z-Area, presumes adequate funding will be provided by the Department of Energy to support this activity.

A. Response to Comments from R. P. Berube (Reference 1)

1. **Compliance with Section III.3.a.(4): Comment on providing assurance that state agrees with SRS's interpretation of State requirements.**

   A statement will be added in the summary of the RPA that notes SCDHEC has issued operating permit for the disposal site and thus agrees that Z-Area disposal site complies with state requirements when the RPA is revised to incorporate the errata provided to the Peer Review Panel.

2. **Compliance with Section III.3.b. [NOTE: Only paragraphs (1) and (3) of this section apply to a PA for a specific disposal site, such as Z-Area. This section requires field organizations with disposal sites to prepare and maintain a site specific PA for disposal of waste and to monitor and/or test, as required, to evaluate actual and prospective performance and to validate or modify models used in PAs. EH felt that clear plans and schedules should be included for active programs as part of the maintenance of the RPA.]:**

   The requirements specified in this section of the Order are first addressed.

4. Compliance with III.3.a.2: "Clearly indicate how SRS proposes to maintain releases to the environment to be ALARA."

ALARA analysis was suggested for the site waste management system plan or system PA, rather than in a facility specific PA. A facility-specific PA simply provides technical support for the waste management plan and system PA. These principles should be applied even if waste disposal is not a part of a site's overall mission.

Present guidance for 5820.2A does not require an ALARA analysis for a PA covering a specific disposal site such as ZArea. This type of analysis and comparison is more appropriately done in conjunction with Environmental Assessments or Environmental Impact Statements as a part of selecting the preferred method of treatment and final disposal.

Please note, however, that ALARA has been used as a guiding principle throughout the evolution of the SRS HLW waste treatment, storage and disposal system, of which Z-Area is only one component. The decision to remove cesium and strontium from soluble waste at the SRS was included as a part of HLW treatment and disposal to adhere to the ALARA principle. Likewise, the historical evolution from saltcrete in trenches to saltstone in vaults was a direct result of applying the ALARA principle. The DWPF vitrification facilities, the saltstone facilities, in-tank treatment operations, the glass and saltstone waste forms, and the selected method of saltstone disposal are designed, controlled and operated with the ALARA principle as a guide. We agree that ALARA is a process and we have applied it at the SRS.

B. Response to Comments from R. F. Pelletier (Reference 2)

1. Order DOE 6430.1A, General Design Criteria: This comment requested that SRS address the applicability and compliance with 6430.1A, particularly sections 1324-5 and 1324-6.

ZArea facilities are low-hazard (category III) nuclear facilities. The design and construction of existing Z-Area facilities were completed prior to the issuance of 6430.1A. Since 6430.1A did not exist, ZArea facilities were designed and constructed to meet or exceed the specifications of 6430.1 for a low hazard facility.

Conformance with DOE requirements, including 6430.1A, is specifically addressed in the SAR for ZArea (WSRC-SA-3). Any future significant additions or modifications (i.e., future vaults) will comply with 6430.1A.

When 6430.1A was issued, WSRC contracted with United Engineers and Constructors (UE&C) to perform a compliance review of the design data for ZArea facilities against the requirements of 6430.1A to confirm that non-compliances, if any, would not impact safety or the environment. The review was completed in September 1990 (WSRC Report No. 864962). ZArea facilities meet or exceed the requirements for a low-hazard (category III) nuclear facility. One non-compliance with ANSI standard C21981 requirement for electrical panels was identified, but was determined not to be considered a deficiency for ZArea, since the design and installation of these panels were consistent with standard industrial practice, and the deviation did not impact safety or the environment.

Z-Area storage and treatment facilities comply with or exceed the requirements in 1324-5 and 1324-6 that are applicable to present operations. Storage tanks, transfer lines into the facility, and saltstone production equipment are doubly contained, as required by this section. Criticality is not credible in Z-Area, due to the low concentration of fissile materials in solutions processed and the saltstone produced. In the event of a DBE, complete failure of all containment facilities would have local consequences only, consistent with the requirements for a category III facility.

In terms of confinement systems, the monolithic saltstone waste form provides primary containment; the vault and temporary cover provide secondary containment until a layer of nonradioactive concrete is installed to provide permanent secondary containment during active disposal operations in Vault 1. Vault 4 will be

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retrofitted with a permanent roof structure and future vaults will be constructed with permanent roof structures prior to filling with saltstone to provide secondary containment. The change to a permanent roof prior to filling has been made to simplify interim vault closure operations and will significantly reduce the volume of job-control waste generated from continuing operations (ALARA), based on operating experience related to disposal operations in Vault 1. This change in vault construction and operations has been reviewed against the RPA, and does not require a revision of the RPA.

Final closure (clay layer, backfill, etc.) will provide the tertiary containment specified for disposal sites. The closure concept presented in the Z-Area RPA complies with applicable specifications in 1324-5.3 and all of 1324-6, including the specification of ongoing site maintenance.

2. Future land use for Saltstone site.

Minimal assumptions were made in the RPA for both Z-Area and EAV regarding future land use. Active institutional control of 100 yrs is specified in the Order. In these RPAs, we assumed the most conservative case -- release of the site for general public use. This is not meant to imply that the facility will actually be released for general, unrestricted use. Passive control (i.e., continued ownership and occasional inspection by the U.S. government) is more likely to be the case. This is a DOE policy issue that we cannot address in the context of the RPA, beyond calculating the potential impact to an intruder, as if he had free access to the site.

If guidance from DOE Headquarters changes to include application of the public performance objective to persons conducting activities within the disposal facility, the RPA can be revised accordingly.

3. Biointrusion.

See response to B2.

4. Intruder well water calculations.

We concur with the comment. Better guidance is needed on the intruder analyses to be done. If passive administrative controls are maintained in perpetuity, then the need for these calculations are eliminated. However, the calculations do show that even if this activity is assumed, the dose to the resident intruder is still quite small. The principal concern in Z-Area, if a well were drilled that compromised the closure cap, would be an increase in nitrate concentration in the underlying groundwater. Radioactive species would not increase significantly, even if the cap integrity or the vault integrity is compromised.

If guidance from DOE Headquarters changes to include application of the public performance objective to persons conducting activities within the disposal facility, the RPA will be revised accordingly.

40 CFR Part 141.

We agree with the observation. On page 1-9 and 1-10 of the Z-Area RPA, the more-modern method of dose calculation was described, and the proposed regulation was used as the basis for calculation. As noted in the discussion, using a single dose limit for all radionuclides provides a consistent and transparent regulatory approach.

DGT/jrf

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pg. 14b R:0

Distribution for OPS-DTZ-95-0001:

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A. Yu, WSRC, 773-A
Records

RESPONSE TO RAI COMMENT 4
ROADMAP TO REFERENCES

REFERENCED DOCUMENT	*EXCERPT LOCATION	REMARK
Cook 2005	Table 4-8 enclosed following response	
Cook et al. 2005	Table 6-1 enclosed following response	Data in Response 4, Table 4-2, Column 2 from Cook et al. 2005 Table 6-1
Crapse et al. 2004	Tables 4 and 5 enclosed following response	
d'Entremont and Drumm 2005	Table A-11 and A-12 enclosed following response	
DOE 2005		Doses referenced in Draft 3116 Determination from Rosenberger 2005
EPA 1988	Representative excerpt (Table 2.1 "Inhalation") enclosed following response	
Rosenberger 2005 (CBU-PIT-2005-00043)	Table 4 enclosed following response	
Rosenberger et al. 2005	Table 4-20 enclosed following response	

*Excerpt Locations:

1. Excerpt included within response: The excerpt is included within the text of the response or is appended to the response.
2. Excerpt enclosed following response: The excerpt is enclosed on a separate sheet or sheets following the response.
3. Representative excerpt(s) enclosed following response: Representative excerpts from a document that is wholly or largely applicable are enclosed following the response.
4. Other

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United States
Environmental Protection
Agency

Office of
Radiation Programs
Washington, DC 20460

EPA-520/1-88-020
September 1988

Radiation

EPA

Limiting Values of Radionuclide Intake And Air Concentration

and

Dose Conversion Factors For Inhalation, Submersion, And Ingestion

Federal Guidance Report No.11

Table 2.1, Inhalation, Cont'd.

Nuclide	Class/f_1	Committed Dose Equivalent per Unit Intake (Sv/Bq)							
		Gonad	Breast	Lung	R Marrow	B Surface	Thyroid	Remainder	Effective
Ga-72	D 1 10^{-3}	2.00 10^{-10}	9.75 10^{-11}	9.93 10^{-10}	1.77 10^{-10}	1.52 10^{-10}	7.53 10^{-11}	5.92 10^{-10}	**3.89 10^{-10}**
	W 1 10^{-3}	2.05 10^{-10}	6.86 10^{-11}	1.67 10^{-9}	9.44 10^{-11}	6.23 10^{-11}	3.99 10^{-11}	7.53 10^{-10}	**5.02 10^{-10}**
Ga-73	D 1 10^{-3}	1.55 10^{-11}	1.05 10^{-11}	4.14 10^{-10}	2.33 10^{-11}	3.50 10^{-11}	9.15 10^{-12}	1.39 10^{-10}	**1.01 10^{-10}**
	W 1 10^{-3}	7.82 10^{-12}	4.37 10^{-12}	5.54 10^{-10}	7.97 10^{-12}	9.85 10^{-12}	3.16 10^{-12}	1.09 10^{-10}	**1.03 10^{-10}**
Germanium									
Ge-66	D 1.0	1.85 10^{-11}	1.95 10^{-11}	3.45 10^{-10}	2.05 10^{-11}	1.87 10^{-11}	1.92 10^{-11}	4.22 10^{-11}	**6.52 10^{-11}**
	W 1.0	1.05 10^{-11}	1.45 10^{-11}	5.57 10^{-10}	1.48 10^{-11}	1.30 10^{-11}	1.37 10^{-11}	3.79 10^{-11}	**8.56 10^{-11}**
Ge-67	D 1.0	1.22 10^{-12}	1.63 10^{-12}	1.01 10^{-10}	1.66 10^{-12}	1.49 10^{-12}	1.47 10^{-12}	1.16 10^{-11}	**1.64 10^{-11}**
	W 1.0	3.90 10^{-13}	8.51 10^{-13}	1.10 10^{-10}	8.68 10^{-13}	7.39 10^{-13}	7.63 10^{-13}	2.61 10^{-12}	**1.44 10^{-11}**
Ge-68	D 1.0	1.54 10^{-10}	1.54 10^{-10}	2.36 10^{-9}	1.59 10^{-10}	1.52 10^{-10}	1.52 10^{-10}	2.54 10^{-10}	**4.49 10^{-10}**
	W 1.0	2.16 10^{-10}	7.50 10^{-10}	1.11 10^{-7}	7.17 10^{-10}	5.94 10^{-10}	6.90 10^{-10}	1.43 10^{-9}	**1.48 10^{-8}**
Ge-69	D 1.0	4.23 10^{-11}	4.59 10^{-11}	5.33 10^{-10}	4.81 10^{-11}	4.36 10^{-11}	4.53 10^{-11}	8.28 10^{-11}	**1.15 10^{-10}**
	W 1.0	3.00 10^{-11}	5.02 10^{-11}	1.44 10^{-9}	5.03 10^{-11}	4.35 10^{-11}	4.82 10^{-11}	1.02 10^{-10}	**2.27 10^{-10}**
Ge-71	D 1.0	1.20 10^{-12}	1.16 10^{-12}	2.53 10^{-11}	1.17 10^{-12}	1.15 10^{-12}	1.30 10^{-12}	2.08 10^{-12}	**4.35 10^{-12}**
	W 1.0	9.45 10^{-13}	1.36 10^{-12}	2.66 10^{-10}	9.22 10^{-13}	9.09 10^{-13}	1.02 10^{-12}	2.06 10^{-12}	**3.31 10^{-11}**
Ge-75	D 1.0	1.93 10^{-12}	1.96 10^{-12}	1.19 10^{-10}	1.98 10^{-12}	1.96 10^{-12}	1.94 10^{-12}	1.27 10^{-11}	**1.92 10^{-11}**
	W 1.0	5.78 10^{-13}	6.22 10^{-13}	1.39 10^{-10}	6.31 10^{-13}	6.15 10^{-13}	6.03 10^{-13}	4.20 10^{-12}	**1.83 10^{-11}**
Ge-77	D 1.0	4.42 10^{-11}	4.75 10^{-11}	1.07 10^{-9}	5.00 10^{-11}	4.66 10^{-11}	4.56 10^{-11}	1.12 10^{-10}	**1.89 10^{-10}**
	W 1.0	2.59 10^{-11}	3.43 10^{-11}	1.98 10^{-9}	3.56 10^{-11}	3.21 10^{-11}	3.18 10^{-11}	9.77 10^{-11}	**2.85 10^{-10}**
Ge-78	D 1.0	1.25 10^{-11}	1.34 10^{-11}	4.44 10^{-10}	1.38 10^{-11}	1.30 10^{-11}	1.29 10^{-11}	4.74 10^{-11}	**7.51 10^{-11}**
	W 1.0	4.59 10^{-12}	6.33 10^{-12}	5.51 10^{-10}	6.36 10^{-12}	5.74 10^{-12}	5.85 10^{-12}	2.74 10^{-11}	**7.75 10^{-11}**
Arsenic									
As-69	W 5 10^{-1}	9.99 10^{-13}	8.74 10^{-13}	9.52 10^{-11}	9.08 10^{-13}	7.18 10^{-13}	7.47 10^{-13}	4.03 10^{-12}	**1.32 10^{-11}**
As-70	W 5 10^{-1}	3.18 10^{-12}	5.36 10^{-12}	2.25 10^{-10}	5.26 10^{-12}	4.20 10^{-12}	4.70 10^{-12}	1.55 10^{-11}	**3.42 10^{-11}**
As-71	W 5 10^{-1}	1.16 10^{-10}	6.00 10^{-11}	1.53 10^{-9}	7.32 10^{-11}	5.26 10^{-11}	4.44 10^{-11}	3.68 10^{-10}	**3.44 10^{-10}**
As-72	W 5 10^{-1}	2.01 10^{-10}	1.09 10^{-10}	5.11 10^{-9}	1.20 10^{-10}	9.13 10^{-11}	8.85 10^{-11}	1.34 10^{-9}	**1.10 10^{-9}**
As-73	W 5 10^{-1}	3.01 10^{-11}	3.30 10^{-11}	6.94 10^{-9}	3.60 10^{-11}	3.31 10^{-11}	2.74 10^{-11}	2.76 10^{-10}	**9.34 10^{-10}**
As-74	W 5 10^{-1}	3.17 10^{-10}	2.91 10^{-10}	1.32 10^{-8}	3.04 10^{-10}	2.44 10^{-10}	2.55 10^{-10}	1.29 10^{-9}	**2.15 10^{-9}**
As-76	W 5 10^{-1}	7.54 10^{-11}	5.33 10^{-11}	5.02 10^{-9}	5.59 10^{-11}	4.90 10^{-11}	4.80 10^{-11}	1.24 10^{-9}	**1.01 10^{-9}**
As-77	W 5 10^{-1}	1.21 10^{-11}	1.13 10^{-11}	1.46 10^{-9}	1.15 10^{-11}	1.12 10^{-11}	1.11 10^{-11}	3.43 10^{-10}	**2.85 10^{-10}**
As-78	W 5 10^{-1}	3.55 10^{-12}	4.18 10^{-12}	5.07 10^{-10}	4.18 10^{-12}	3.54 10^{-12}	3.70 10^{-12}	3.04 10^{-11}	**7.22 10^{-11}**
Selenium									
Se-70	D 8 10^{-1}	1.16 10^{-11}	1.08 10^{-11}	2.28 10^{-10}	1.12 10^{-11}	9.43 10^{-12}	9.36 10^{-12}	4.56 10^{-11}	**4.75 10^{-11}**
	W 8 10^{-1}	3.80 10^{-12}	5.84 10^{-12}	2.61 10^{-10}	5.84 10^{-12}	4.74 10^{-12}	5.10 10^{-12}	1.82 10^{-11}	**3.96 10^{-11}**
Se-73	D 8 10^{-1}	3.70 10^{-11}	3.24 10^{-11}	4.83 10^{-10}	3.69 10^{-11}	3.21 10^{-11}	2.90 10^{-11}	1.18 10^{-10}	**1.14 10^{-10}**
	W 8 10^{-1}	2.24 10^{-11}	2.08 10^{-11}	7.05 10^{-10}	2.34 10^{-11}	1.93 10^{-11}	1.75 10^{-11}	8.92 10^{-11}	**1.24 10^{-10}**
Se-73m	D 8 10^{-1}	3.16 10^{-12}	2.85 10^{-12}	5.82 10^{-11}	3.17 10^{-12}	2.78 10^{-12}	2.56 10^{-12}	1.17 10^{-11}	**1.22 10^{-11}**
	W 8 10^{-1}	1.78 10^{-12}	1.75 10^{-12}	7.74 10^{-11}	1.94 10^{-12}	1.60 10^{-12}	1.50 10^{-12}	7.33 10^{-12}	**1.25 10^{-11}**
Se-75	D 8 10^{-1}	1.29 10^{-9}	1.08 10^{-9}	1.36 10^{-9}	1.54 10^{-9}	1.27 10^{-9}	8.52 10^{-10}	3.50 10^{-9}	**1.95 10^{-9}**
	W 8 10^{-1}	1.10 10^{-9}	1.09 10^{-9}	5.44 10^{-9}	1.50 10^{-9}	1.23 10^{-9}	8.39 10^{-10}	3.18 10^{-9}	**2.29 10^{-9}**
Se-79	D 8 10^{-1}	6.79 10^{-10}	6.79 10^{-10}	8.47 10^{-10}	6.79 10^{-10}	6.79 10^{-10}	6.79 10^{-10}	4.24 10^{-9}	**1.77 10^{-9}**
	W 8 10^{-1}	5.98 10^{-10}	5.98 10^{-10}	9.81 10^{-9}	5.98 10^{-10}	5.98 10^{-10}	5.98 10^{-10}	3.77 10^{-9}	**2.66 10^{-9}**
Se-81	D 8 10^{-1}	3.13 10^{-13}	3.15 10^{-13}	4.45 10^{-11}	3.15 10^{-13}	3.14 10^{-13}	3.14 10^{-13}	4.82 10^{-12}	**6.97 10^{-12}**
	W 8 10^{-1}	9.05 10^{-14}	9.32 10^{-14}	4.79 10^{-11}	9.34 10^{-14}	9.25 10^{-14}	9.26 10^{-14}	6.81 10^{-13}	**6.01 10^{-12}**
Se-81m	D 8 10^{-1}	2.14 10^{-12}	2.13 10^{-12}	1.37 10^{-10}	2.16 10^{-12}	2.13 10^{-12}	2.11 10^{-12}	2.06 10^{-11}	**2.39 10^{-11}**
	W 8 10^{-1}	6.02 10^{-13}	6.21 10^{-13}	1.59 10^{-10}	6.33 10^{-13}	6.21 10^{-13}	6.08 10^{-13}	6.35 10^{-12}	**2.13 10^{-11}**

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Key Words:
LLW Disposal

Retention:
Permanent

ESTIMATED ALL PATHWAYS AND INADVERTENT INTRUDER DOSES FROM SALTSTONE DISPOSAL USING UPDATED SALT WASTE COMPOSITIONS

James R. Cook

APPROVED for Release for
Unlimited (Release to Public)

NUCLEAR INFORMATION
ADC &
Reviewing
Official: A G Stevens - SRNL
(Name and Title)
Date: 2/24/05

FEBRUARY 24, 2005

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under Contract Number DE-AC09-96SR18500

SRNL

Table 4-5 Estimated Air Pathway Dose From ARP/MCU

Nuclide	ARP/MCU Salt Solution Ci/L[a]	1,000-year limit, Ci/L[b]	10,000-year limit, Ci/L[b]		ARP/MCU/1000-yr limit	ARP/MCU/10,000-yr limit
H-3	3.65E-06	4.20E-02	4.20E-02		8.69E-05	8.69E-05
C-14	4.02E-08	2.40E-04	2.40E-04		1.67E-04	1.67E-04
				SOF	2.54E-04	2.54E-04
				Air Dose[c]	2.54E-03	2.54E-03

a From Table 3-1, volume converted to liters by dividing by 3.785412 liters per gallon
b Tritium limits are from Reference 1, Tables 8-3 and 8-4; 14C limits are from Reference 9, Table 6
c Dose is in units of mrem/year

Table 4-6 Estimated Air Pathway Dose From SWPF

Nuclide	SWPF Salt Solution Ci/L[a]	1,000-year limit, Ci/L[b]	10,000-year limit, Ci/L[b]		SWPF/1000-yr limit	SWPF/10,000-yr limit
H-3	2.68E-06	4.20E-02	4.20E-02		6.39E-05	6.39E-05
C-14	4.08E-08	2.40E-04	2.40E-04		1.70E-04	1.70E-04
				SOF	2.34E-04	2.34E-04
				Air Dose[c]	2.34E-03	2.34E-03

a From Table 3-1, volume converted to liters by dividing by 3.785412 liters per gallon
b Tritium limits are from Reference 1, Tables 8-3 and 8-4; 14C limits are from Reference 9, Table 6
c Dose is in units of mrem/year

Table 4-7 Total Doses From Groundwater and Air Pathways for Each Waste Type

Salt Solution	1000-year Groundwater Dose, mrem/year	10,000-year Groundwater Dose, mrem/year	1000-year Air Dose, mrem/year	10,000-year Air Dose, mrem/year	1000-year Total Dose, mrem/year	10,000-year Total Dose, mrem/year
DDA	0.00E+00	3.29E+00	6.60E-03	6.60E-03	6.60E-03	3.30E+00
ARP/MCU	0.00E+00	1.49E+00	2.54E-03	2.54E-03	2.54E-03	1.49E+00
SWPF	0.00E+00	6.78E+00	2.34E-03	2.34E-03	2.34E-03	6.79E+00

Table 4-8 Total Doses From Groundwater and Air Pathways

Time Period	Dose, mrem/year
1000 years	2.63E-03
10,000 years	6.30E+00

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KEYWORDS:
Waste Determination, Saltstone,
Special Analysis

Track Number: 10065
RETENTION: PERMANENT

Estimated All Pathways Organ Doses From Saltstone Disposal Using Updated Salt Waste Compositions

APPROVED for Release for
Unlimited (Release to Public)
2/25/2005

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

Prepared for U.S. Department of Energy Under Contract No. DE-AC09-96S

Table 3: Individual Nuclide and Total Organ Annual Dose

	mrem/yr							
Target Organ	H-3	C-14	Se-79	Tc-99	Sn-126	I-129	Np-237	**Total**
Gonad	6.74E-04	1.95E-03	5.76E-04	6.63E-05	2.57E-06	3.51E-04	2.97E-04	**3.24E-03**
Breast	6.74E-04	1.95E-03	5.76E-04	6.63E-05	8.48E-07	8.41E-04	1.75E-07	**3.44E-03**
Lung	6.74E-04	1.95E-03	5.76E-04	6.63E-05	6.38E-07	4.19E-04	1.85E-07	**3.01E-03**
Red Marrow	6.74E-04	1.95E-03	5.76E-04	6.63E-05	2.90E-06	5.61E-04	2.64E-03	**5.79E-03**
Bone Surface	6.74E-04	1.95E-03	5.76E-04	6.63E-05	5.39E-06	5.51E-04	3.29E-02	**3.60E-02**
Thyroid	6.74E-04	1.95E-03	5.76E-04	1.78E-03	5.87E-07	6.30E+00	1.33E-07	**6.30E+00**
Remainder	6.74E-04	1.95E-03	3.64E-03	1.12E-03	1.42E-05	5.05E-04	2.54E-04	**7.49E-03**
Effective WB	**6.74E-04**	**1.95E-03**	**1.49E-03**	**4.33E-04**	**5.62E-06**	**1.89E-01**	**1.45E-03**	**1.95E-01**

Table 4: Calculated Annual Dose Versus Limits

Target Organ	Calculated mrem/yr	mrem/yr Limits	% of Limit
Gonad	3.2E-03	25	0.013
Breast	3.4E-03	25	0.014
Lung	3.0E-03	25	0.012
Red Marrow	5.8E-03	25	0.023
Bone Surface	3.6E-02	25	0.144
Thyroid	6.3E+00	75	8.405
Remainder	7.5E-03	25	0.030
Effective WB	1.9E-01	25	0.779

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Waste Solidification, Class C,
Permit, Saltstone

RETENTION: PERMANENT
CLASSIFICATION: U
Does not contain UCNI
Paul D. d'Entremont
6/21/05 ADC/RO

Radionuclide Concentrations in Saltstone

P. D. d'Entremont, 766-H
M.D. Drumm, 766-H

Approval:

for

L. B. Romanowski, Manager,
CBU Salt Disposition Planning

APPROVED for Release for
Unlimited (Release to Public)

Westinghouse Savannah River Company
Closure Business Unit
Planning Integration & Technology Department
Aiken, SC 29808

Prepared for U.S. Department of Energy Under Contract No. DE-AC09-96S

Table A- 11: Total Activity Sent to Saltstone

Ci	DDA	ARP/MCU	SWPF	Total
H-3	2.17E+03	5.75E+02	6.62E+03	9.37E+03
C-14	6.46E+01	1.72E+01	4.37E+02	5.18E+02
Co-60	4.61E+01	5.92E+00	5.75E+01	1.10E+02
Ni-59	4.45E-01	3.31E-02	2.34E+00	2.81E+00
Ni-63	9.48E+01	1.44E+01	1.40E+02	2.50E+02
Se-79	1.03E+00	1.23E+00	8.68E+01	8.91E+01
Sr-90	5.72E+03	3.84E+02	1.33E+03	7.43E+03
Y-90	5.72E+03	3.84E+02	1.33E+03	7.43E+03
Nb-94	3.15E-05	9.65E-06	6.82E-04	7.23E-04
Tc-99	3.56E+02	4.55E+02	3.22E+04	3.30E+04
Ru-106	2.52E+01	3.14E+01	2.22E+03	2.28E+03
Rh-106	2.52E+01	3.14E+01	2.22E+03	2.28E+03
Sb-125	1.15E+02	1.27E+02	9.00E+03	9.24E+03
Sn-126	4.93E+00	6.20E+00	4.39E+02	4.50E+02
I-129	2.06E-01	1.88E-01	1.74E+01	1.78E+01
Cs-134	2.44E+03	2.61E+02	5.55E+00	2.71E+03
Cs-135	4.22E+00	4.44E-01	9.42E-03	4.67E+00
Cs-137	1.22E+06	1.30E+05	2.76E+03	1.35E+06
Ba-137m	1.15E+06	1.23E+05	2.61E+03	1.28E+06
Ce-144	4.13E-01	8.17E-02	5.78E+00	6.27E+00
Pr-144	4.13E-01	8.17E-02	5.78E+00	6.27E+00
Pm-147	3.47E+02	5.29E+01	3.74E+03	4.14E+03
Eu-154	7.64E+01	1.25E+01	8.85E+02	9.74E+02
Th-232	6.52E-06	2.80E-07	1.04E-01	1.04E-01
U-232	9.93E-05	5.59E-09	2.13E-02	2.14E-02
U-233	9.86E-01	8.84E-03	1.22E+00	2.22E+00
U-234	3.07E+00	9.44E-03	8.34E-01	3.91E+00
U-235	6.16E-03	1.50E-04	5.75E-02	6.38E-02
U-236	1.43E-01	1.73E-03	1.58E-01	3.03E-01
U-238	6.38E-02	8.88E-04	5.00E+00	5.07E+00
Np-237	5.74E-01	7.83E-03	1.53E+00	2.11E+00
Pu-238	3.78E+03	4.71E+01	9.78E+03	1.36E+04
Pu-239	4.43E+01	6.93E-01	6.10E+02	6.55E+02
Pu-240	1.08E+01	2.36E-01	1.64E+02	1.75E+02
Pu-241	2.28E+02	4.14E+00	6.80E+03	7.03E+03
Pu-242	1.77E-03	2.64E-05	1.71E-01	1.72E-01
Am-241	1.29E+01	5.01E+00	7.70E+01	9.49E+01
Am-242m	5.39E-03	2.89E-03	4.44E-02	5.27E-02
Cm-244	1.60E+00	2.00E+00	8.35E+01	8.71E+01
Cm-245	1.57E-04	1.97E-04	8.22E-03	8.58E-03
Na-22	2.39E+02	8.55E+01	4.73E+03	5.05E+03
Al-26	8.98E-01	3.80E-01	2.22E+01	2.35E+01
Te-125m	2.81E+01	3.10E+01	2.20E+03	2.26E+03

Ci	DDA	ARP/MCU	SWPF	Total
Sb-126	6.91E-01	8.68E-01	6.15E+01	6.30E+01
Sb-126m	4.93E+00	6.20E+00	4.39E+02	4.50E+02
Sm-151	3.00E+02	5.93E+01	4.19E+03	4.55E+03
Eu-152	1.45E+00	2.87E-01	2.03E+01	2.20E+01
Eu-155	1.70E+01	3.35E+00	2.37E+02	2.57E+02
Ra-226	2.44E-01	2.13E-08	1.27E+01	1.30E+01
Ra-228	6.52E-06	2.80E-07	1.04E-01	1.04E-01
Ac-227	1.40E-06	3.42E-08	1.77E-05	1.91E-05
Th-229	2.80E-03	2.52E-05	4.70E-03	7.53E-03
Th-230	1.49E-03	2.60E-06	3.38E-02	3.53E-02
Pa-231	3.90E-06	9.49E-08	4.92E-05	5.32E-05
Pu-244	1.16E-05	1.21E-07	7.85E-04	7.96E-04
Am-243	4.85E-03	9.58E-04	1.47E-02	2.05E-02
Cm-242	4.46E-03	2.37E-03	9.85E-02	1.05E-01
Cm-243	2.84E-03	5.61E-04	2.33E-02	2.67E-02
Cm-247	5.48E-13	1.08E-13	4.49E-12	5.15E-12
Cm-248	5.71E-13	1.13E-13	4.68E-12	5.36E-12
Bk-249	4.17E-20	8.23E-21	5.81E-19	6.31E-19
Cf-249	3.16E-12	6.24E-13	4.41E-11	4.79E-11
Cf-251	1.08E-13	2.14E-14	1.51E-12	1.64E-12
Cf-252	3.51E-15	6.93E-16	4.90E-14	5.32E-14

Table A- 12: Concentrations Sent to Saltstone

Ci/gal	DDA	ARP/MCU	SWPF	Total
H-3	2.33E-04	2.03E-04	6.91E-05	8.68E-05
C-14	6.94E-06	6.05E-06	4.56E-06	4.80E-06
Co-60	4.96E-06	2.09E-06	6.00E-07	1.01E-06
Ni-59	4.78E-08	1.17E-08	2.44E-08	2.61E-08
Ni-63	1.02E-05	5.06E-06	1.47E-06	2.31E-06
Se-79	1.11E-07	4.32E-07	9.06E-07	8.25E-07
Sr-90	6.14E-04	1.35E-04	1.39E-05	6.88E-05
Y-90	6.14E-04	1.35E-04	1.39E-05	6.88E-05
Nb-94	3.38E-12	3.40E-12	7.12E-12	6.70E-12
Tc-99	3.82E-05	1.60E-04	3.36E-04	3.06E-04
Ru-106	2.71E-06	1.10E-05	2.32E-05	2.11E-05
Rh-106	2.71E-06	1.10E-05	2.32E-05	2.11E-05
Sb-125	1.24E-05	4.48E-05	9.39E-05	8.56E-05
Sn-126	5.30E-07	2.18E-06	4.58E-06	4.17E-06
I-129	2.21E-08	6.62E-08	1.81E-07	1.65E-07
Cs-134	2.63E-04	9.20E-05	5.79E-08	2.51E-05
Cs-135	4.53E-07	1.56E-07	9.84E-11	4.33E-08
Cs-137	1.31E-01	4.58E-02	2.89E-05	1.25E-02
Ba-137m	1.24E-01	4.34E-02	2.73E-05	1.18E-02
Ce-144	4.44E-08	2.88E-08	6.03E-08	5.81E-08

Ci/gal	DDA	ARP/MCU	SWPF	Total
Pr-144	4.44E-08	2.88E-08	6.03E-08	5.81E-08
Pm-147	3.73E-05	1.86E-05	3.90E-05	3.83E-05
Eu-154	8.21E-06	4.41E-06	9.24E-06	9.03E-06
Th-232	7.01E-13	9.87E-14	1.08E-09	9.63E-10
U-232	1.07E-11	1.97E-15	2.22E-10	1.98E-10
U-233	1.06E-07	3.11E-09	1.28E-08	2.06E-08
U-234	3.30E-07	3.32E-09	8.70E-09	3.62E-08
U-235	6.62E-10	5.27E-11	6.00E-10	5.91E-10
U-236	1.53E-08	6.09E-10	1.65E-09	2.80E-09
U-238	6.85E-09	3.13E-10	5.22E-08	4.70E-08
Np-237	6.17E-08	2.76E-09	1.59E-08	1.95E-08
Pu-238	4.06E-04	1.66E-05	1.02E-04	1.26E-04
Pu-239	4.76E-06	2.44E-07	6.36E-06	6.06E-06
Pu-240	1.16E-06	8.3E-08	1.71E-06	1.62E-06
Pu-241	2.45E-05	1.46E-06	7.1E-05	6.51E-05
Pu-242	1.9E-10	9.3E-12	1.78E-09	1.6E-09
Am-241	1.39E-06	1.76E-06	8.04E-07	8.8E-07
Am-242m	5.79E-10	1.02E-09	4.63E-10	4.88E-10
Cm-244	1.72E-07	7.06E-07	8.71E-07	8.07E-07
Cm-245	1.68E-11	6.95E-11	8.58E-11	7.94E-11
Na-22	2.57E-05	3.01E-05	4.93E-05	4.68E-05
Al-26	9.66E-08	1.34E-07	2.32E-07	2.18E-07
Te-125m	3.02E-06	1.09E-05	2.29E-05	2.09E-05
Sb-126	7.42E-08	3.06E-07	6.41E-07	5.84E-07
Sb-126m	5.3E-07	2.18E-06	4.58E-06	4.17E-06
Sm-151	3.23E-05	2.09E-05	4.37E-05	4.21E-05
Eu-152	1.56E-07	1.01E-07	2.11E-07	2.04E-07
Eu-155	1.82E-06	1.18E-06	2.47E-06	2.38E-06
Ra-226	2.63E-08	7.49E-15	1.33E-07	1.2E-07
Ra-228	7.01E-13	9.87E-14	1.08E-09	9.63E-10
Ac-227	1.51E-13	1.2E-14	1.85E-13	1.77E-13
Th-229	3.01E-10	8.86E-12	4.91E-11	6.98E-11
Th-230	1.6E-10	9.16E-13	3.53E-10	3.27E-10
Pa-231	4.19E-13	3.34E-14	5.13E-13	4.92E-13
Pu-244	1.24E-12	4.25E-14	8.19E-12	7.38E-12
Am-243	5.22E-10	3.37E-10	1.54E-10	1.9E-10
Cm-242	4.79E-10	8.33E-10	1.03E-09	9.76E-10
Cm-243	3.06E-10	1.98E-10	2.43E-10	2.48E-10
Cm-247	5.89E-20	3.8E-20	4.69E-20	4.77E-20
Cm-248	6.13E-20	3.96E-20	4.89E-20	4.97E-20
Bk-249	4.48E-27	2.9E-27	6.07E-27	5.85E-27
Cf-249	3.4E-19	2.2E-19	4.61E-19	4.44E-19
Cf-251	1.16E-20	7.52E-21	1.58E-20	1.52E-20
Cf-252	3.78E-22	2.44E-22	5.11E-22	4.93E-22
Vol (kgal)	9,305	2,840	95,800	107,945

CBU-PIT-2005-00146
Revision 0

SALTSTONE
PERFORMANCE OBJECTIVE DEMONSTRATION DOCUMENT
(U)

PREPARED BY:
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JUNE 2005

APPROVED for Release for
Unlimited (Release to Public)

Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under
Contract Number DE-AC09-96SR18500

Table 4-19. Evaluation of All-Pathways Doses

Radionuclide	10,000-Year Disposal Limit (Ci/Vault 4)*	Total Saltstone Inventory (Ci)	Fraction of 10,000-Year Disposal Limit	Dose (mrem/yr)
H-3	1.30E+12	9.43E+03	7.25E-09	1.81E-07
C-14	1.10E+08	5.20E+02	4.72E-06	1.18E-04
Al-26	2.31E+10	2.35E+01	1.02E-09	2.54E-08
Ni-59	1.58E+19	2.85E+00	1.81E-19	4.52E-18
Se-79	1.02E+03	8.94E+01	8.77E-02	2.19E+00
Sr-90	1.42E+17	7.43E+03	5.23E-14	1.31E-12
Nb-94	6.98E+17	4.22E-03	6.05E-21	1.51E-19
Tc-99	1.07E+17	3.31E+04	3.10E-13	7.74E-12
Sn-126	2.92E+19	4.51E+02	1.54E-17	3.86E-16
I-129	4.03E+03	1.80E+01	4.46E-03	1.12E-01
Ra-226	3.84E+16	1.30E+01	3.39E-16	8.46E-15
Np-237	8.93E+18	2.12E+00	2.37E-19	5.93E-18
		Totals	**9.21E-02**	**2.30E+00**

* Vault 4 inventory limits from Table 6-1 of Cook et al., (2005) based upon all-pathways dose limit of 25 mrem/yr to the whole body

The whole body dose is a result of two principle dose contributors: Se-79 and I-129. The whole body dose from these two radionuclides is principally a result of the ingestion pathway. USEPA (1988) values for ingestion dose conversion factors are utilized to determine doses to other organs by determining the ratio of the organ dose conversion factors to the whole body factor and multiplying by the known whole body dose. The final results (Table 4-20) indicate that for salt waste disposal at the SDF the all-pathways doses are 2.3 mrem/yr whole body, 4.6 mrem/yr to the thyroid and 5.3 mrem/yr to any other organ. This is compared to 10 CFR 61.41 performance objectives of 25 mrem to the whole body, 75 mrem to the thyroid and 25 mrem to any other organ and demonstrates that the 10 CFR 61.41 performance objectives are met by the SDF.

Table 4-20. 10 CFR 61.41 Demonstration Results

	10 CFR 61.41 Limit (mrem/year)	**SDF Calculated Dose (mrem/year)**
Whole Body	25	2.3
Thyroid	75	4.6
Any Other Organ	25	5.3

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WSRC-TR-2005-00074
Revision 0

KEY WORDS: Performance Assessment
Low-level Radioactive Waste Disposal

SPECIAL ANALYSIS: REVISION OF SALTSTONE VAULT 4 DISPOSAL LIMITS (U)

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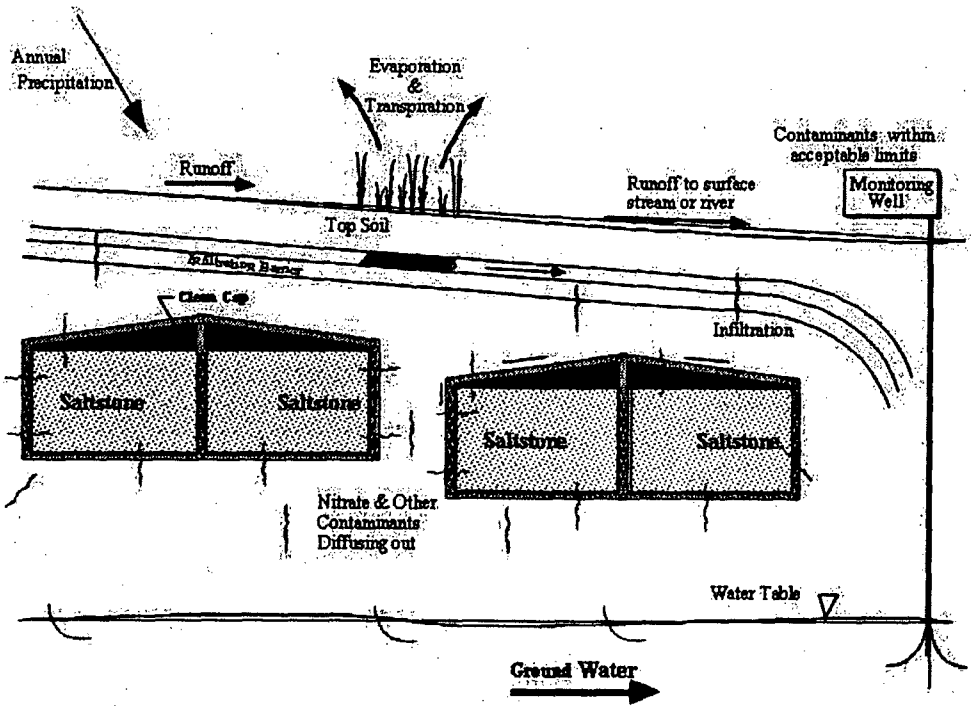
Gregory P. Flach

MAY 26, 2005



Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under Contract Number DE-AC09-96SR18500

SRNL
SAVANNAH RIVER NATIONAL LABORATORY

Table 6-1. All-Pathways Disposal Limits for Saltstone Disposal Vault 4

Radionuclide	1,000-Year Disposal Limit (Ci/Vault 4)	10,000-Year Disposal Limit (Ci/Vault 4)
H-3	1.30E+12	1.30E+12
C-14	1.10E+08	1.10E+08
Al-26	4.86E+18	2.31E+10
Cl-36	3.67E+19	5.15E+18
K-40	1.10E+09	1.31E+04
Ni-59		1.58E+19
Se-79	9.85E+06	1.02E+03
Rb-87		5.12E+09
Sr-90	1.42E+17	1.42E+17
Nb-93m	8.99E+08	1.46E+05
Nb-94		6.98E+17
Mo-93	3.46E+09	6.17E+05
Tc-99		1.07E+17
Pd-107		1.84E+17
Sn-126		2.92E+19
I-129	3.27E+08	4.03E+03
Ra-226		3.84E+16
Np-237		8.93E+18

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Key Words:
Disposal Authorization Statement,
Environmental Protection,
Stewardship

Retention: Permanent

FY 2004 Annual Review - Saltstone Disposal Facility (Z-Area) Performance Assessment (Covering the Performance Period FY 1999-2004)

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November 15, 2004

APPROVED for Release for
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Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

Table 4 Vault 1 Sum of Fractions.

Nuclide	Total Ci/vault 12/31/2003	10K Yr Limit Total Ci/vault	Fraction of 10K Yr Limit	1K Yr Limit Total Ci/vault	Fraction of 1K Year Limit
H-3	2.73E+01	1.05E+06	2.60E-05	1.05E+06	2.60E-05
C-14	1.28E+00	6.00E+03	2.14E-04	6.00E+03	2.14E-04
Co-57	NR	no limit	0.00E+00	no limit	0.00E+00
Ni-59	< 3.46E-02	no limit	0.00E+00	no limit	0.00E+00
Co-60	2.77E-03	1.50E+11	1.85E-14	1.50E+11	1.85E-14
Ni-63	9.38E-01	no limit	0.00E+00	no limit	0.00E+00
Se-79	3.02E-01	1.95E+03	1.55E-04	no limit	0.00E+00
Sr-90	1.31E-02	no limit	0.00E+00	no limit	0.00E+00
Nb-94	< 2.51E-03	4.25E+02	< 5.91E-06	4.25E+02	< 5.91E-06
Tc-99	1.08E+02	2.00E+05	5.42E-04	no limit	0.00E+00
Ru-103	NR	no limit	0.00E+00	no limit	0.00E+00
Ru-106	1.14E-02	no limit	0.00E+00	no limit	0.00E+00
Sb-124	NR	no limit	0.00E+00	no limit	0.00E+00
Sb-125	1.29E+00	no limit	0.00E+00	no limit	0.00E+00
Sn-126	9.97E-01	5.00E+02	1.99E-03	5.00E+02	1.99E-03
I-129	1.12E-01	1.00E+01	1.12E-02	no limit	0.00E+00
Ba-133	NR	no limit	0.00E+00	no limit	0.00E+00
Cs-134	NR	no limit	0.00E+00	no limit	0.00E+00
Cs-137	7.96E+00	5.00E+08	1.59E-08	5.00E+08	1.59E-08
Ce-141	NR	no limit	0.00E+00	no limit	0.00E+00
Pm-144	NR	no limit	0.00E+00	no limit	0.00E+00
Pm-146	NR	no limit	0.00E+00	no limit	0.00E+00
Sm-151	NR	no limit	0.00E+00	no limit	0.00E+00
Eu-152	*< 6.92E-03	1.65E+08	4.20E-11	1.65E+08	4.20E-11
Eu-154	< 2.01E-03	3.75E+09	< 5.36E-13	3.75E+09	< 5.36E-13
Eu-155	NR	no limit	0.00E+00	no limit	0.00E+00
U-232	NR	7.50E+04	NR	7.50E+04	0.00E+00
U-233/234	* 2.85E-01	1.00E+02	2.85E-03	4.55E+04	6.26E-06
U-235/236	* 3.17E-03	4.60E+04	6.89E-08	2.20E+05	1.44E-08
Np-237	< 4.49E-03	2.65E+04	< 1.69E-07	2.65E+04	< 1.69E-07
U-238	* 7.36E-03	2.80E+04	2.63E-07	2.80E+04	2.63E-07
Pu-238	* 9.63E-03	6.50E+06	1.48E-09	3.20E+08	3.01E-11
Pu-239/240	* 1.23E-02	9.00E+09	1.37E-12	no limit	0.00E+00
Pu-241	< 3.59E-02	3.95E+09	< 9.08E-12	5.50E+09	< 6.52E-12
Am-241	* 4.92E-04	1.25E+08	3.94E-12	1.75E+08	2.81E-12
Pu-242	* 9.03E-04	no limit	0.00E+00	no limit	0.00E+00
Am-243	NR	1.35E+05	NR	1.35E+05	NR
Cm-243/244	NR	6.00E+12	NR	6.00E+12	NR
Cf-251	NR	1.00E+06	NR	1.00E+06	NR
Sum of Fractions			< 1.70E-02		< 2.25E-03

NOTES:
1) All activity reported was calculated in Q-CLC-Z-00001, revision 6.
2) Activities listed as NR were not reported on applicable sample analyses.
3) Vault limits for C-14 based on Kaplan and Cook (2003) all other vault limits based on Cook et al. (2002), limits for Vault 1 were assumed to be half of the limit of Vault 4 based on volume.
4) * indicates a value calculated based on available data which was NR for one or more cells

Table 5 Vault 4 Sum of Fractions

Nuclide	Total Ci/vault 12/31/2003	10K Yr Limit Total Ci/vault	Fraction of 10K Yr Limit	1K Yr Limit Total Ci/vault	Fraction of 1K Yr Limit
H-3	2.94E+01	2.10E+06	1.40E-05	2.10E+06	1.40E-05
C-14	2.35E-01	1.20E+04	1.96E-05	1.20E+04	1.96E-05
Co-57	* 3.43E-04	no limit	0.00E+00	no limit	0.00E+00
Ni-59	< 9.09E-03	no limit	0.00E+00	no limit	0.00E+00
Co-60	6.83E-03	3.00E+11	2.28E-14	3.00E+11	2.28E-14
Ni-63	< 6.01E-02	no limit	0.00E+00	no limit	0.00E+00
Se-79	2.57E-02	3.90E+03	6.58E-06	no limit	0.00E+00
Sr-90	3.17E-01	no limit	0.00E+00	no limit	0.00E+00
Nb-94	< 9.91E-04	8.50E+02	< 1.17E-06	8.50E+02	< 1.17E-06
Tc-99	2.35E+01	4.00E+05	5.87E-05	no limit	0.00E+00
Ru-103	* 2.70E-05	no limit	0.00E+00	no limit	0.00E+00
Ru-106	6.14E-03	no limit	0.00E+00	no limit	0.00E+00
Sb-124	* 2.39E-02	no limit	0.00E+00	no limit	0.00E+00
Sb-125	9.39E-01	no limit	0.00E+00	no limit	0.00E+00
Sn-126	5.66E-02	1.00E+03	5.66E-05	1.00E+03	5.66E-05
I-129	8.16E-02	2.00E+01	4.08E-03	no limit	0.00E+00
Ba-133	NR	no limit	0.00E+00	no limit	0.00E+00
Cs-134	* 1.32E-02	no limit	0.00E+00	no limit	0.00E+00
Cs-137	1.68E+01	1.00E+09	1.68E-08	1.00E+09	1.68E-08
Ce-141	* 8.85E-06	no limit	0.00E+00	no limit	0.00E+00
Pm-144	* 7.45E-03	no limit	0.00E+00	no limit	0.00E+00
Pm-146	* 1.97E-04	no limit	0.00E+00	no limit	0.00E+00
Sm-151	*< 9.29E-04	no limit	0.00E+00	no limit	0.00E+00
Eu-152	*< 5.14E-03	3.30E+08	< 1.56E-11	3.30E+08	< 1.56E-11
Eu-154	< 9.03E-03	7.50E+09	< 1.20E-12	7.50E+09	< 1.20E-12
Eu-155	< 1.58E-03	no limit	0.00E+00	no limit	0.00E+00
U-232	* 9.46E-03	1.50E+05	6.31E-08	1.50E+05	6.31E-08
U-233/234	3.52E+00	2.00E+02	1.76E-02	9.10E+04	3.87E-05
U-235/236	6.81E-02	9.20E+04	7.41E-07	4.40E+05	1.55E-07
Np-237	4.87E-03	5.30E+04	9.18E-08	5.30E+04	9.18E-08
U-238	< 1.10E-01	5.60E+04	< 1.96E-06	5.60E+04	< 1.96E-06
Pu-238	6.78E-01	1.30E+07	5.22E-08	6.40E+08	1.06E-09
Pu-239/240	1.33E-01	1.80E+10	7.37E-12	no limit	0.00E+00
Pu-241	1.63E-02	7.90E+09	2.07E-12	1.10E+10	1.49E-12
Am-241	6.67E-02	2.50E+08	2.67E-10	3.50E+08	1.91E-10
Pu-242	< 8.03E-03	no limit	0.00E+00	no limit	0.00E+00
Am-243	* 1.30E-03	2.70E+05	4.81E-09	2.70E+05	4.81E-09
Cm-243/244	8.06E-02	1.20E+13	6.71E-15	1.20E+13	6.71E-15
Cf-251	* 2.47E-01	2.00E+06	1.23E-07	2.00E+06	1.23E-07
Sum of Fractions			< 2.18E-02		< 1.32E-04

NOTES:
1) All activity reported was calculated in Q-CLC-Z-00001, revision 6.
2) Activities listed as NR were not reported on applicable sample analyses.
3) Vault limits for C-14 based on Kaplan and Cook (2003) all other vault limits based on Cook et al. (2002)
4) * indicates a value calculated based on available data which was NR for one or more cells