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RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION ON THE DRAFT SECTION 3116 DETERMINATION FOR SALT WASTE DISPOSAL AT THE SAVANNAH RIVER SITE

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LIST OF ACRONYMS

ACI	American Concrete Institute
ACRI	Analytic and Computational Research, Inc.
ALARA	As Low As Reasonably Achievable
ARP/MCU	Actinide Removal Process Modular CSSX Unit
ASME	American Society of Mechanical Engineering
ASTM D 5084	American Society for Testing and Materials
ATG	Atmospheric Technologies Group
CAP88	Clean Air Act Assessment Package-1988
CCTV	Close Circuit Television
CFR	Code of Federal Regulations
CHA	Consolidated Hazards Analysis
CHAP	Consolidated Hazards Analysis Process
CLSM	Controlled Low Strength Material
CSSX	Caustic Side Solvent Extraction
DDA	Deliquification Dissolution and Adjustment
DSA	Documented Safety Analysis
DWPF	Defense Waste Processing Facility
EPA	Environmental Protection Agency
EQ3	Computer code
FFA	Federal Facilities Agreement
FRN	Federal Register Notice
GCL	Geosynthetic Clay Liner
GS	General Service
GSA	General Separations Area
HELP	Hydrologic Evaluation of Landfill Performance
HHW	High Heat Waste
HLW	High Level Waste
IC	Institutional Control
ICRP	International Commission on Radiation Protection
ISMS	Integrated Safety Management System
ITP	In-Tank Precipation Facility
LADTAP	Computer code
LADTAP XL	Spreadsheet version of computer code
LCS	Low Curie Salt
LHW	Low Heat Waste
LIP	Limit Interim Processing
LLW	Low Level Radioactive Waste
MCU	Modular CSSX Unit
MINTEQ	Computer code
MMES	Martin Marietta Energy Systems, Inc.
MST	Monosodium Titanate
NAS	National Academy of Science
NCRP	National Council on Radiation Protection and Measurements
NCS	Non-Crystalline Solids

LIST OF ACRONYMS

NDAA	National Defense Authorization Act
NIP	No Interim Processing
NQA	Nuclear Quality Assurance
NRC PA	Nuclear Regulatory Commission Performance Assessment
NRC	Nuclear Regulatory Commission
OLI	Computer code
PA	Performance Assessment
PHRQPITZ	Computer code
PI	Principal Investigator
PODD	Performance Objective Demonstration Document
PORFLOW	Computer code
PS	Production Support
QA	Quality Assurance
QA/QC	Quality Assurance/Quality Control
QAMP	Quality Assurance Management Plan
QAMP	Quality Assurance Management Program
QAP's	Quality Assurance Procedures
RAI	Request for Additional Information
RCRA	Resource Conservation and Recovery Act
ROM	Rough Order Magnitude
RPA	Radiological Performance Assessment
SA	Special Analysis
SAIC	Science Applications International Corporation
SC DHEC	South Carolina Department of Health and Environmental Control
SDF	Saltstone Disposal Facility
SER	Safety Evaluation Report
SFT	Saltstone Feed Tank
SPF	Saltstone Processing Facility
SRNL	Savannah River National Laboratory
SRS	Savannah River Site
SRTC	Savannah River Technology Center
SSC	Systems, Structures, and Components
SWPF	Salt Waste Processing Facility
TBP	Tetraphenylborate
TCLP	Toxicity Characteristic Leaching Procedure
TOA	Trioctylamine
TOTA1 VOLUme	Program commands on parameter
TSR	Technical Safety Requirements
USDA	United States Department of Agriculture
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
USNRC	United States Nuclear Regulatory Commission
UZ	Unsaturated Zone
WAC	Waste Acceptance Criteria
WCP	Waste Compliance Plan

LIST OF ACRONYMS

WCS	Waste Characterization System
WD	Section 3116 Waste Determination
WSRC	Westinghouse Savannah River Company
WTU	Waste Treatment Unit
XRD	X-ray Diffraction

Introduction

The Nuclear Regulatory Commission (NRC) issued a Request for Additional Information (RAI) (NRC, 2005) on the *Draft Section 3116 Determination [for] Salt Waste Disposal [at the] Savannah River Site* (DOE, 2005). This document contains comprehensive responses to each RAI comment, with associated reference materials cited, after consultation/clarification discussions with the NRC.

Numerous RAI responses reflect information from two new documents issued subsequent to submittal of the Draft Section 3116 Determination for NRC review: the 2005 Special Analysis and the Saltstone Performance Objective Demonstration Document (PODD).

Since initial design and facility construction, the Saltstone Facility has undergone revisions in the anticipated radiological inventory and the models used to evaluate compliance with performance objectives. Thus, over the course of time, the performance objective compliance evaluations have been calculated in various documents to reflect new information and methodologies. The current Performance Assessment (PA) was approved in 1992 and was based upon disposal of decontaminated salt solution from the In-Tank Precipitation Facility (ITP). A Special Analysis was approved in 2002 to account for suspension of the ITP process and disposal of low curie salt solution.

The latest information on the Saltstone Disposal Facility feed solutions, updated modeling methods, updated closure cap design and evaluations are captured in the 2005 Special Analysis (Cook et al. 2005), which supplements the Saltstone Performance Assessment (1992; Addendum 1998) and supersedes the 2002 Saltstone Special Analysis.

The second new document is the Performance Objective Demonstration Document (PODD), which demonstrates and documents that the solidified low-activity salt streams from the SRS salt processing activities meet the performance objectives set out in Subpart C of Part 61 of Title 10, Code of Federal Regulations (Rosenberger et al. 2005). The PODD describes the process, analysis methods, input/assumptions, results and references necessary to demonstrate compliance with the performance objectives of 10 CFR 61.41 through 10 CFR 61.44. The PODD is being issued concurrently to the RAI response document.

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P. 2005. *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Revision 0, May 2005.

DOE. 2005. *Draft Section 3116 Determination Salt Waste Disposal Savannah River Site*, DOE–WD–2005–001, February 2005.

NRC. 2005. *REQUEST FOR ADDITIONAL INFORMATION ON THE DRAFT SECTION 3116 DETERMINATION FOR SALT WASTE DISPOSAL AT THE SAVANNAH RIVER SITE*, Scott C. Flanders to Mark A. Gilbertson, May 26, 2005.

Rosenberger, K. H., Rogers, B. C. & Cauthen, R. K. 2005. *Saltstone Performance Objective Demonstration Document*, CBU-PIT-2005-00146, Revision 0, June 2005.

NRC Comment 1: Major assumptions are not clearly listed and the basis for many assumptions (or the approach to verify the assumptions) is not provided. Concerns about specific assumptions are described below in additional comments; this comment is focused on DOE's overall approach to assumptions.

Basis: Many of the assumptions are not sufficiently supported to determine whether they are appropriate (e.g., the gravel drain layer of the cap acts as an erosion barrier for 10,000 years or the saltstone degrades at a rate similar to limestone). Many of the assumptions are about key features or processes that directly determine estimated performance. Independent analysis by NRC staff suggests that if key assumptions are not met then there may not be reasonable assurance that the performance objectives can be met.

Path Forward: In a general section or in each relevant section, provide a list of key assumptions, and the basis for the assumption or the approach to verify the assumption. In general, assumptions should have a documented approach to achieve verification (e.g., the future work to confirm the accuracy of the assumption should be described) or a basis that clearly demonstrates that the assumptions are reasonably conservative in which case verification is not necessary.

SRS Response: It is recognized that this is a general comment that is applicable to the "Draft Section 3116 Determination [for] Salt Waste Disposal [at the] Savannah River Site" (reference 4 in the NRC RAI), its associated references, and all future Waste Determination (WD) efforts. It is understood that the documents provided in support of a 3116 WD must provide sufficient detail to permit independent assessment of the key assumptions and their impact on the arguments associated with the 3116 criteria. Three key documents have been prepared or revised in support of the Request for Additional Information responses, and each contains the relevant assumptions, along with the supporting rationale, as appropriate, for one of the following sections of the Salt Waste Disposal WD where independent verification is appropriate:

Section 5 – The Waste Has Had Highly Radioactive Radionuclides Removed to the Maximum Extent Practical (See reference: Reboul 2005)

Section 6 – The Waste Does Not Exceed Concentration Limits in 10 CFR 61.55 (See reference: d'Entremont et al. 2005)

Section 7 – The Waste Will Be Disposed of in Accordance with the Performance Objectives Set Out in 10 CFR 61, Subpart C (See reference: Rosenberger et al. 2005)

References:

DOE, February 28, 2005, *Draft Section 3116 Determination Salt Waste Disposal Savannah River Site*, DOE-WD-2005-001.

Reboul, S. H., June 2005, *Removal of Highly Radioactive Nuclides from SRS Salt Waste*, CBU-PIT-2005-00141, Revision 0.

d'Entremont, P. D. & Drumm, M. D., June 2005, *Radionuclide Concentrations in Saltstone*, CBU-PIT-2005-00013, Revision 3.

Rosenberger, K. H., Rogers, B. C. & Cauthen, R. K., June 2005, *Saltstone Performance Objective Demonstration Document*, CBU-PIT-2005-00146, Revision 0.

NRC Comment 2: A number of calculations, in particular many described in Reference 1, were not presented in sufficient detail to allow independent verification of the results.

Basis: Results cannot be independently verified without:- details of the grout and concrete degradation calculations (see Comment 40) - details of the pathway screening analysis for milk and meat consumption

- Kd values used in the groundwater pathway calculations (see Comments 48 and 58 for specific details)

- details of the parametric analysis of concrete degradation carried out to identify the combinations that might lead to significant degradation (pg. 3-73 of [1])

- details of the calculations use to estimate the values of the Horizontal Velocity of the Aquifer and Vertical Velocity of the Unsaturated Zone (UZ) that are described as being "Calibrated vs. NO3 arrival time" (pg. 5-5 of [3])

- values of the vertical thickness of the grid blocks that the contaminants are averaged over (pg. 3-83 of [1])

- values of the soil shielding properties assumed in the inadvertent intruder analyses

Path Forward: Provide the information necessary to allow independent verification of the calculations in the reports. Complete responses to other comments should provide sufficient detail to allow for independent verification.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded[1] by the Vault 4 Special Analysis (Cook et al. 2005).

The Department of Energy recognizes that this is a general comment applicable to the Salt Waste Determination (reference 4 of the RAI), its associated references, and all future Waste Determination efforts. It is understood that calculations developed to support the conclusions of the Waste Determination must be described in sufficient detail to allow independent verification of the results. In response to the specific RAIs that follow, the references have been cited to this end. Specific responses to the areas cited in this RAI are described below.

Results cannot be independently verified without details of the grout and concrete degradation calculations (see Comment 40).

This comment is addressed in the response to NRC Comments 32, 40, and 43.

[1] The 2005 Vault 4 Special Analysis (SA) replaces the 2002 SA. Applicable data and calculations in the 2002 SA have been rolled into and reproduced in the 2005 Vault 4 SA.

Results cannot be independently verified without details of the pathway screening analysis for milk and meat consumption.

As explained in the response to NRC Comment 66, SRS has used pathway screening to determine that only those pathways resulting from transport by groundwater and air are important. The groundwater pathway analysis includes pathways resulting from the consumption of milk and meat. The individual pathways examined are those in the LADTAP and CAP88 pathways analysis computer programs.

Results cannot be independently verified without details of the K_d *values used in the groundwater pathway calculations (see Comments 48 and 58 for specific details).*

This comment is addressed in the responses to NRC Comments 48 and 58.

Results cannot be independently verified without details of the parametric analysis of concrete degradation carried out to identify the combinations that might lead to significant degradation (pg. 3-73 of [1]).

This comment is addressed in the responses to NRC Comment 32.

Results cannot be independently verified without details of the calculations used to estimate the values of the Horizontal Velocity of the Aquifer and Vertical Velocity of the Unsaturated Zone (UZ) that are described as being "Calibrated vs. NO_3 *arrival time" (pg. 5-5 of [3..)*

The method used to calibrate the PATHRAE code to the results for the intact and degraded scenarios in the 1992 PA (Cook et al. 2002) was to adjust only the vertical and horizontal water velocities so that the time of the peak nitrate flux and concentration at the 100-meter well were in agreement with the PA results. The values shown for these parameters in Tables 5-2 and 5-4 (attached) produced the results given in Table 5-3 and 5-5 (attached).

Results cannot be independently verified without details of the values of the vertical thickness of the grid blocks that the contaminants are averaged over (pg. 3-83 of [1]).

The volume of each of the source nodes in the model used in the 2005 SA (Cook et al. 2005), in cubic feet, is given in Table A-13 (attached).

Results cannot be independently verified without details of the values of the soil shielding properties assumed in the inadvertent intruder analyses.

Section 2.3.2 of Lee 2004 (attached) provides the basis for the external Dose Conversion Factors used in the 2005 SA. Appendix B of the same report tabulates the

external pathway shielding dose coefficients used in the intruder analysis where soil shielding was used.

References:

Cook, J. R., Kocher, D. C., McDowell-Boyer, L., and Wilhite, E. L., 2002, *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility,* Westinghouse Savannah River Company, Aiken, South Carolina.

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina, May 2005.

Lee, P. L., 2004, *Inadvertent Intruder Analysis Input for Radiological Performance Assessments*. WSRC-TR-2004-00295, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina, July 22, 2004.

Table 5-2. Saltstone Intact Case Benchmarking Input Parameters*

Property	Value	Source
Length of Facility	650 m	Map Measurement
Width of Facility	1000 m	Map Measurement
Density of Aquifer	1600 kg/m^3	Z-Area PA, page 3-77
Longitudinal Dispersivity	3 m	Z-Area PA, page A-40
Transverse Dispersion	0	Assumption
Vertical Dispersion	0	Assumption
Residual Saturation	0.7	Z-Area PA, page C-12
Sat. Conductivity of Vertical Zone	3.2 m/y (1 x 10^{-5} cm/s)	Z-Area PA, Table 3.3-1
No. of Mesh Points	20	PATHRAE Suggestion
Cover Thickness	3.6 m	Z-Area PA, pages 2-61, 62, 71
Waste Thickness	7.3 m	Z-Area PA, page 2-61
Waste Volume	1.14 x 10^6 m^3	Z-Area PA, page 2-58 (30x30x7.3x174)
Effective Diffusion Length in Waste	7.3 m	Saltstone thickness, Z-Area PA page 2-61
Effective Diffusion Length in Vault Wall	0.76	Vault thickness, Z-Area PA, page 2-61
Effective Diffusion Coefficient Waste	5 x 10^{-9} cm^2/sec / R_d	Z-Area PA, page A-34
Effective Diffusion Coefficient Vault	1 x 10^{-8} cm^2/sec / R_d	Z-Area PA, page A-34
Distance to Well	100 m	USDOE Order 435.1
Well Distance Off Centerline	0 m	Assumption
Density of Waste	1700 kg/m^3	Z-Area PA, page 2-56
Water Infiltration to Waste	1.75 x 10^{-3} m/y	Z-Area PA, Table 4.1-1
Horizontal Velocity of Aquifer	1.2 m/y	Calibrated vs. NO_3 arrival time
Porosity of Aquifer	0.40	Z-Area PA, Table 3.3-3
Distance from waste to Aquifer	6.1 m (20 ft.)	Z-Area PA, Fig. A.1-9
Vertical velocity in Unsaturated Zone	9.8 x 10^{-4} m/y	Calibrated vs. NO_3 arrival time
Well Screen Length	10 m	Thickness of top node
Porosity of Unsaturated Zone	0.44	Z-Area PA, Table 3.3-1
Bulk Density of Soil	1.6 g/m^3	Z-Area PA, page. 3-77

* Cook, J. R., Kocher, D. C. McDowell-Boyer, L., and Wilhite, E. L. 2002. *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility,* Westinghouse Savannah River Company, Aiken, South Carolina.

Table 5-3. Results of Benchmarking of Intact Case*

Radionuclide	PA Results		PATHRAE Results	
	Peak Concentration, pCi/L	Time of Peak, y	Peak Concentration, pCi/L	Time of Peak, y
Se-79	1.2×10^{-2}	2.1×10^{5}	3.5×10^{-1}	2.0×10^{5}
Tc-99	6.7×10^{-7}	1.6×10^{6}	6.4×10^{-7}	1.4×10^{6}
Sn-126	4.0×10^{-11}	9.2×10^{5}	3.0×10^{-10}	7.9×10^{5}

* Cook, J. R., Kocher, D. C. McDowell-Boyer, L., and Wilhite, E. L. 2002. *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility,* Westinghouse Savannah River Company, Aiken, South Carolina.

Table 5-4. Saltstone Degraded Case Benchmarking Input Parameters*

Property	Value	Source
Length of Facility	650 m	Map Measurement
Width of Facility	1000 m	Map Measurement
Density of Aquifer	1600 kg/m^3	Z-Area PA, page 3-77
Longitudinal Dispersivity	3 m	Z-Area PA, page A-40
Transverse Dispersion	0	Assumption
Vertical Dispersion	0	Assumption
Residual Saturation	0.7	Z-Area PA, page C-12
Sat. Conductivity of Vertical Zone	3.2 m/y (1 x 10^{-5} cm/s)	Z-Area PA, Table 3.3-1
No. of Mesh Points	20	PATHRAE Suggestion
Cover Thickness	3.6 m	Z-Area PA, pages 2-61, 62, 71
Waste Thickness	7.3 m	Z-Area PA, page 2-61
Waste Volume	1.14 x 10^6 m^3	Z-Area PA, page 2-58 (30x30x7.3x174)
Effective Diffusion Length in Waste	1.5 m	½ distance between cracks
Effective Diffusion Length in Vault Wall	0.76	Vault thickness
Effective Diffusion Coefficient Waste	5 x 10^{-9} cm^2/sec / R_d	Z-Area PA, page A-34
Effective Diffusion Coefficient Vault	1 x 10^{-8} cm^2/sec	Assumption – No vault in PA degraded model
Distance to Well	100 m	USDOE Order 435.1
Well Distance Off Centerline	0 m	Assumption
Density of Waste	1700 kg/m^3	Z-Area PA, page. 2-56
Water Infiltration to Waste	1.75 x 10^{-3} m/y	Z-Area PA, Table 4.1-1
Horizontal Velocity of Aquifer	1.2 m/y	Calibrated vs. NO_3 arrival time
Porosity of Aquifer	0.40	Z-Area PA, Table 3.3-3
Distance from waste to Aquifer	6.1 m	Z-Area PA, Fig. A.1-9
Vertical velocity in Unsaturated Zone	1.8 x 10^{-2} m/y	Calibrated vs. NO_3 arrival time
Well Screen Length	10 m	Thickness of top node
Porosity of Unsaturated Zone	0.44	Z-Area PA, Table 3.3-1
Bulk Density of Soil	1.6 g/m^3	Z-Area PA, page 3-77

* Cook, J. R., Kocher, D. C. McDowell-Boyer, L., and Wilhite, E. L. 2002. *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility,* Westinghouse Savannah River Company, Aiken, South Carolina.

Table 5-5. Results of Benchmarking of Degraded Case*

Radionuclide	PA Results		PATHRAE Results	
	Peak Concentration, pCi/L	Time of Peak, y	Peak Concentration, pCi/L	Time of Peak, y
H-3	$<10^{-12}$		3.6×10^{-21}	4.3×10^{2}
C-14	7.8×10^{-5} (PA*13)[a]	7.3×10^{3}	2.1×10^{-3}	1.0×10^{4}
Se-79	5.7×10^{1}	1.5×10^{4}	1.5×10^{2}	2.3×10^{4}
Sr-90	$<10^{-12}$		$< 10^{-21}$	
Tc-99	1.5×10^{2}	2.4×10^{3}	2.5×10^{2}	2.8×10^{3}
Sn-126	2.9×10^{-2}	9.2×10^{5}	6.8×10^{-1}	3.4×10^{5}
I-129	9.9×10^{-1}	3.2×10^{3}	3.6×10^{-1}	4.3×10^{3}
Cs-137	$<10^{-12}$		$< 10^{-21}$	
Pu-238	$<10^{-12}$		$< 10^{-21}$	
Am-241	$<10^{-12}$		$< 10^{-21}$	

[a] Per WSRC 1998.

* Cook, J. R., Kocher, D. C. McDowell-Boyer, L., and Wilhite, E. L. 2002. *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility,* Westinghouse Savannah River Company, Aiken, South Carolina.

Table A-13
Source Node Locations and Volumes*

I	J	K	XC	YC	ZC	VOL
13	13	14	21350.0	11750.0	230.110	5.1200E+04
13	14	14	21350.0	11850.0	230.650	5.0900E+04
13	15	14	21350.0	11950.0	231.306	5.0525E+04
14	12	14	21450.0	11650.0	229.997	5.1250E+04
14	13	14	21450.0	11750.0	230.353	5.1100E+04
14	14	14	21450.0	11850.0	230.822	5.0850E+04
14	15	14	21450.0	11950.0	231.405	5.0500E+04
15	10	14	21550.0	11450.0	229.486	5.1525E+04
15	11	14	21550.0	11550.0	229.935	5.1250E+04
15	12	14	21550.0	11650.0	230.340	5.1050E+04
15	13	14	21550.0	11750.0	230.699	5.0925E+04
16	11	14	21650.0	11550.0	230.306	5.1075E+04
					TOTAL	6.1215E+05

* Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., Special Analysis: Revision of Saltstone Vault 4 Disposal Limits, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

2.3.2 External DCFs

External DCFs for uniformly distributed contamination at an infinite depth with no shielding and at 15 cm are taken from USEPA FGR 12 (USEPA 1993). External DCFs in FGR 12 represent the 50-year committed EDE per unit of activity of soil contaminated at various depths. Like the internal DCFs, they are reported in SI units (Sv/yr per Bq/m^3). They are converted to standard units for input into the model by multiplying the FGR DCF by 3.7 x 10^6. External DCFs in rem/yr per μCi/m^3 for selected radionuclides are listed in APPENDIX A. Zero DCF in the table, intruder application input file (Koffman 2004), and USEPA (1993) indicate that the photon energies are not sufficient for contribution to external dose.

For soil contaminated at various depths shielded by a layer of clean soil, external dose coefficients for absorbed dose at 1 m from a mono-energetic source were estimated by Kocher (1985). A comprehensive list of absorbed dose rates at finite thicknesses were provided by Kocher (2004) based on the work presented in Kocher (1985). These data were used to estimate shielding effective dose coefficients at various shielding thicknesses with contamination at finite depths.

$$DC_{EDE}(t) = 0.8 * DC_{AD}(t) * 1\times10^{-6}\frac{Ci}{\mu Ci} * 3.15\times10^{7}\frac{\sec}{year} \qquad \text{(Eq. 2.3-1)}$$

where

$DC_{EDE}(t)$ = shielding effective dose coefficient for finite thickness (t) (rem*cm^3/year*Ci)

$DC_{AD}(t)$= shielding absorbed dose coefficient for finite thickness from Kocher (2004) (rad*cm^3/sec*Ci)

CF= time conversion (3.15 x 10^7 sec/year)

For contamination distributed at an infinite depth, the DC_{EDE} in Eq. 2.3-1 should be summed for all depths below the desired finite depth.

$$DC_{EDE}(\text{inf}) = \sum_{t=t_{ref}}^{t_{max}} DC_{EDE}(t) \qquad \text{(Eq. 2.3-2)}$$

where

DC_{EDE} (inf) = shielding effective dose coefficient for infinite depth (rem*cm^3/year*Ci)

t_{ref} = reference finite shielding thickness

t_{max} = max shielding thickness.

Coefficients for shielding depths of 5 and 100 cm are used in the intruder analysis model (Koffman 2004) to estimate dose coefficients at various depths for the residential exposure scenario. Dose coefficients at those depths are listed in APPENDIX B. Dose coefficients for no shielding (0 cm) listed in APPENDIX B were not used in Koffman (2004) but are taken from USEPA (1993) and listed in APPENDIX A.

NRC Comment 3: In general, insufficient support is provided for models used in the analysis. See Comments 28, 41, 43, and 55.

Basis: A fundamental component of completing a performance assessment (PA) is the development of adequate support for the numerical modeling results. It is understood that for a performance assessment model involving long periods of time and potential exposures to humans and the environment, model validation in the traditional sense cannot be achieved. However, adequate model support is essential to have confidence that the conceptual models utilized were reasonably correct. Previous review comments from the DOE PA peer review group and DOE Headquarters indicated a need for DOE-SRS to address key uncertainties and to verify and validate models. In 1993 [2] it was indicated that SRS was seeking appropriate near-field monitoring technology to validate models and assumptions used in the PA. The response to OPS-DTZ-95-0001 in Reference 2 indicates a variety of activities that would possibly be undertaken to address key uncertainties and to verify and validate models.

Path Forward: Provide a description of the near-field monitoring technology that has been evaluated or employed to validate models and assumptions used in the PA. Provide an update on the activities listed in the response to OPS-DTZ-95-0001 [2] that have been accomplished.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005). Additional detail about the 2005 SA and the Performance Objective Demonstration Document (PODD) is summarized before NRC RAI #17.

Studies related to the testing activities listed in OPS-DTZ-95-0001 (WSRC 1998, Item A12.) and related to Saltstone performance analyses include:

1. Improving our knowledge of surface water and groundwater patterns under the entire SRS (including the area beneath the Saltstone disposal site).

A 1999 regional groundwater flow model covering approximately 2/3 of the Savannah River Site and calibrated to numerous well water levels and stream baseflow estimates suggests that the average recharge rate over upland areas is 12.5 in/yr or 32 cm/yr (Flach et al. 1999, Table 4-1). A value of 40 cm/yr is assumed for uncapped conditions in the 1992 PA (Section 3.3.1.1) and infiltration peaks at 46 cm/yr for fully-degraded (native soil) conditions in the 2005 SA (Cook et al. 2005 referencing Phifer 2004, Table 1). A sensitivity analysis involving the same model implies that the average vertical conductivity of the Gordon Confining Unit is less than or equal to about 1.E-4 ft/d (Flach et al. 1999, Tables 4-4 and 4-5).

The groundwater flow model used in the 2005 SA assumes a value of 1.E-5 ft/d, which produces higher horizontal flow rates in the water table aquifer compared to a setting of 1.E-4 ft/d.

2. Improving computer modeling techniques to better represent field conditions (i.e., geochemical interactions) and groundwater flow patterns.

The groundwater model in the 1992 PA has been superseded in a 2005 SA for Saltstone Vault 4 (Cook et al. 2005). The current model spanning the General Separations Area (GSA) has a heterogeneous model conductivity field derived from extensive characterization data including 85 pumping and 481 slug tests, 258 laboratory permeability measurements, and nearly 37,500 lithology data records. The latter are based on foot-by-foot visual descriptions of drill core, and geophysical logs. Model development and attributes are primarily discussed by Flach and Harris (1999) and Flach (2004). The latter describes porting of an earlier FACT code model to the PORFLOW code.

SRNL has an on-going program to study the interaction of key radionuclides with site soils in order to determine site-specific K_d values for these species. (see Cook 2000 and Kaplan 2004)

3. Confirming that the closure concept described in the Z-Area RPA can be implemented with existing engineering techniques.

The closure concept used in the Vault 4 Special Analysis was designed using standard engineering calculations and available materials and standard construction techniques (Phifer and Nelson 2003).

4. Infiltration studies to test the effect of various closure components (e.g., clay caps with gravel drainage layers) and vegetative cover (grass, bamboo) on the rate of infiltration at SRS.

Computer experiments have been conducted to test the components of the closure concept, including the vegetative cover. These experiments have been used to help in the dimensions and order of placement of the various components of the cover system. (See Appendices E through N of Phifer and Nelson 2003).

5. Improved modeling of the effects of cracking on long-term performance (present case in Z-Area RPA is considered bounding, due to simplifying assumptions used in the semi-analytical model).

Because of improvements in computer hardware and software it became possible to explicitly model the effects of cracks in the analysis presented in the Vault 4 Special Analysis (Section A.4 of Cook et al. 2005)

Recently, field monitoring data from the Vadose Zone Monitoring System at Slit Trenches #1 in E-Area[2] was compared to a preliminary vadose zone closure model for that disposal unit (Flach et al. 2005). Figure 3-1 compares data from portions of the trenches receiving generic tritium disposals, and Figure 3-2 shows results for tritium embedded in concrete rubble from demolition of Building 232-F. In both cases, the monitoring data is scaled to average linear waste inventory, producing units of pCi/L per Ci of inventory per cm of trench length. Time refers to elapsed time following burial. The predicted and observed concentrations are comparable, with the model peak generally over-predicting the data. The slit trench PORFLOW model is similar to the Saltstone Vault 4 vadose zone model used in the 2005 SA (Cook et al. 2005, Section 2.1), with differences centering on the type of disposal unit modeled. The favorable comparisons shown in Figures 3-1 and 3-2 give confidence that vadose zone moisture movement and contaminant transport outside the waste zone are adequately represented in the Saltstone Vault 4 model.

References:

Cook, J. R. 2000. *Special Analysis: Updated Analysis of the Effect of Wood Products on Trench Disposal Limits at the E-Area Low-Level Waste Facility*. WSRC-RP-2000-00523. Revision 0. Westinghouse Savannah River Company, Aiken, South Carolina.

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005

Flach, G. P., M. K. Harris, R. A. Hiergesell, A. D. Smits and K. L. Hawkins. *Regional Groundwater Flow Model for the C,K,L, and P Reactor Areas, Savannah River Site, Aiken, South Carolina (U)*. WSRC-TR-99-00248, Rev. 0. September 1999.

Flach, G. P., L. B. Collard, M. A. Phifer, K. P. Crapse, K. L. Dixon, L. D. Koffman and E. L. Wilhite. *Preliminary Closure Analysis for Slit Trenches #1 and #2*. WSRC-TR-2005-00093, Rev. 0. March 2005.

Kaplan, D. I. 2004. *Recommended Geochemical Input Values for the Special Analysis of the Slit/Engineered Trenches and Intermediate Level Vault*, WSRC-RP-2004-00267, Revision 0. Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A. 2004. Interoffice Memorandum to J. R. Cook, et al, *Vault #4 Closure Cap Estimated Infiltration for Years 50,000 to 1,000,000*, SRT-EST-2004-00103, December 17, 2004. Westinghouse Savannah River Company, Aiken, South Carolina.

[2] E-Area is another low level waste disposal facility at the SRS. It is not included in the scope of this 3116 Determination for Salt Waste Disposal.

Phifer, Mark A. and Nelson, Eric A. 2003. *Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest*. WSRC-TR-2003-00436. Westinghouse Savannah River Company, Savannah River Site, Aiken, SC.

WSRC. *Addendum to the Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility at the Savannah River Site*, WSRC-RP-98-00156. April 1998.

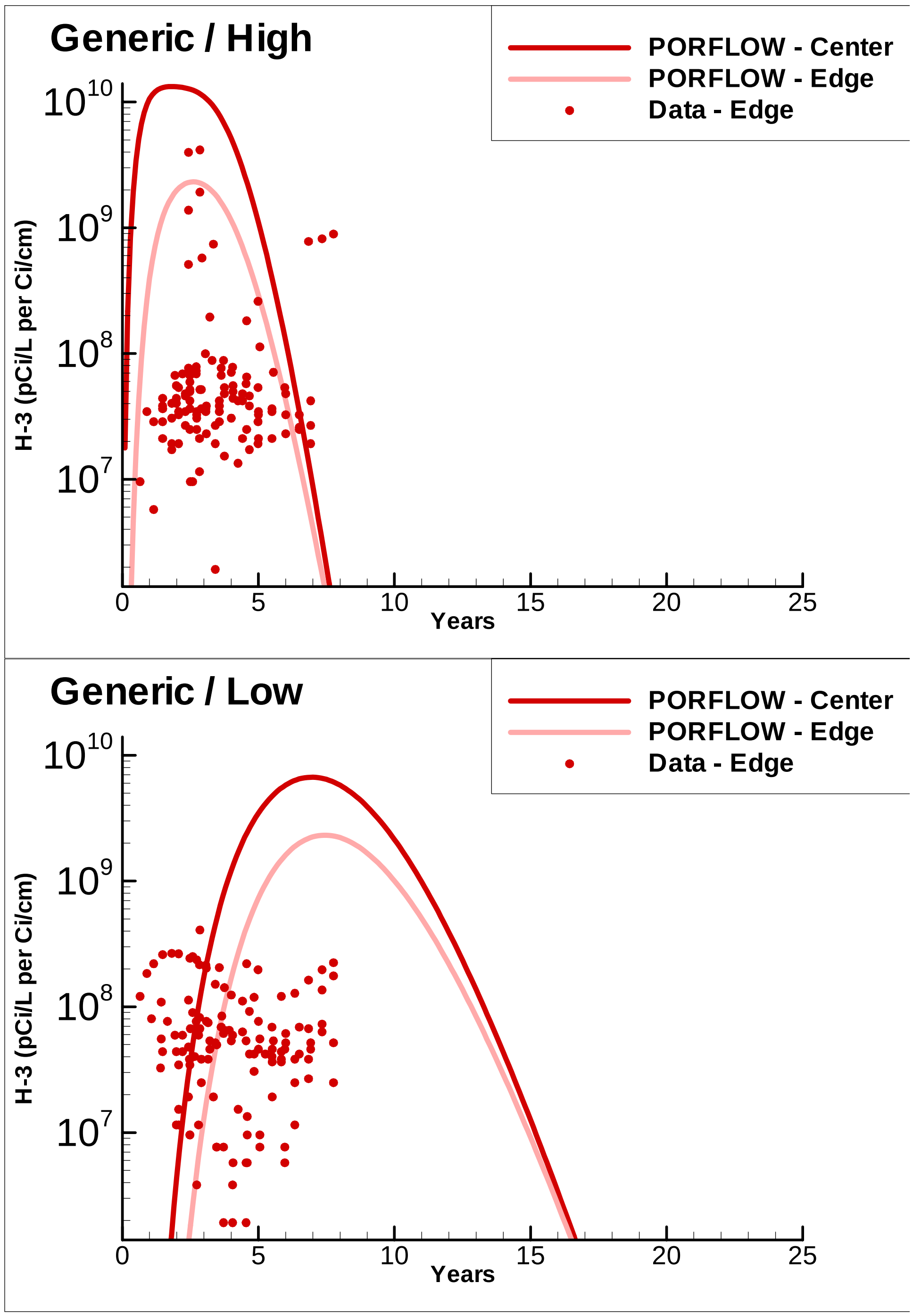

Figure 3-1. Comparison of Vadose Zone Monitoring System field data from Slit Trenches #1 to predictions from a PORFLOW preliminary closure analysis model. Both plots show data from trench segments receiving generic tritium disposals. The upper and lower plots show data from the upper and lower half of the vadose zone, respectively. (Flach et al. 2005)

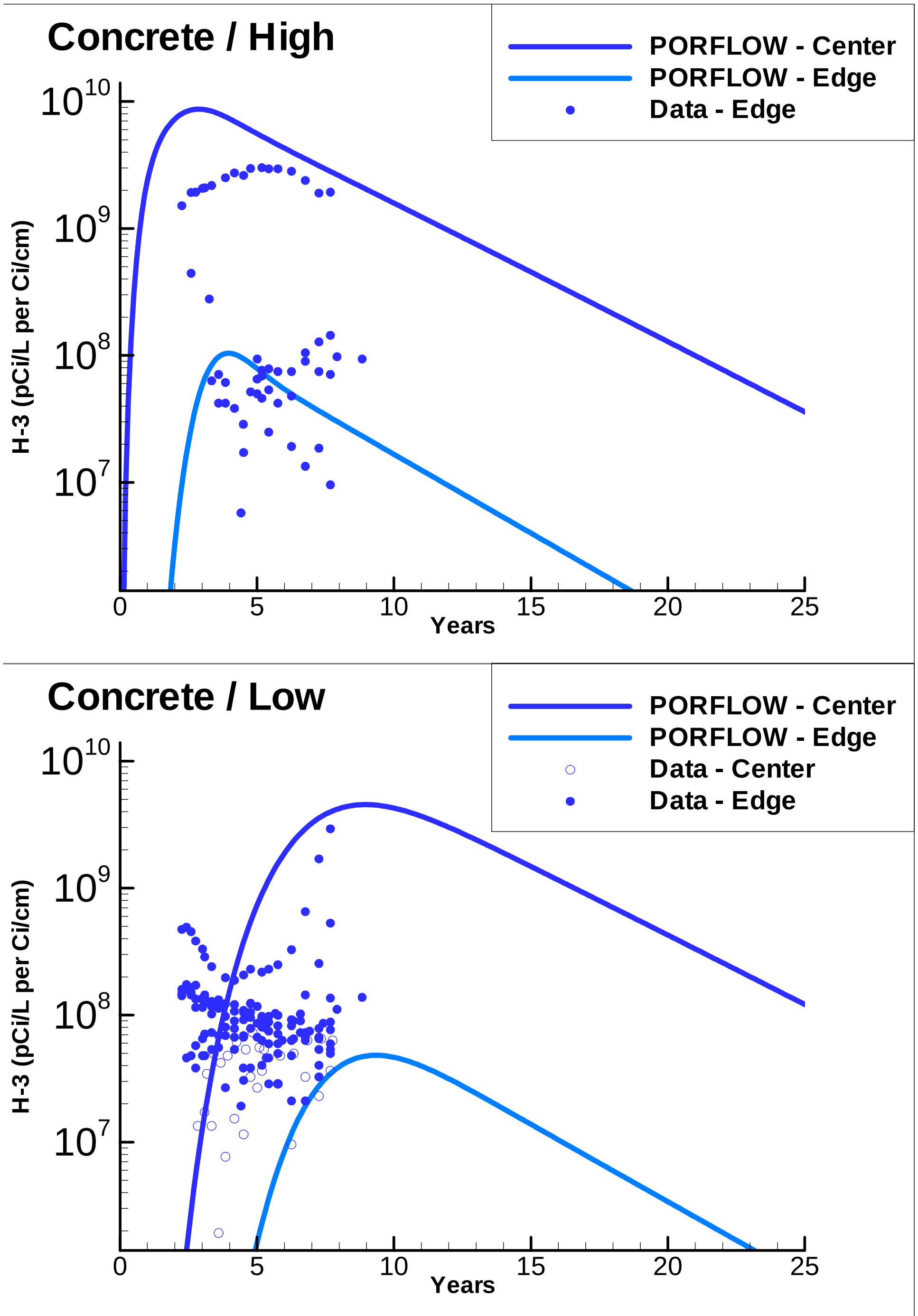

Figure 3-2. Comparison of Vadose Zone Monitoring System field data from Slit Trenches #1 to predictions from a PORFLOW preliminary closure analysis model. Both plots show data from trench segments receiving tritium embedded in concrete disposals. The upper and lower plots show data from the upper and lower half of the vadose zone, respectively. (Flach et al. 2005)

NRC Comment 4: There is contradictory information regarding the dose resulting from releases from the saltstone facility for the groundwater pathway.

Basis: The approach in Reference 4 was to scale previous estimates in Reference 1 of groundwater doses based on the current expected waste composition. The resulting maximum groundwater pathway dose in 10,000 years using this approach was 0.2 mrem/yr [4]. However, the analysis in Reference 5 seems to indicate that the groundwater pathway doses would be 6.8 mrem/yr at 10,000 years, which is significantly greater than the doses provided in the draft section 3116 determination [4].

Path Forward: Explain why the more recent calculations in Reference 5 were not used or referenced in the draft waste determination. Explain the differences between the two calculations and clarify the dose estimated for the groundwater pathway.

SRS Response: The 10,000-year maximum dose of 6.3 mrem/yr from Cook 2005, Table 4-8 is a dose to the maximum exposed target organ and not the dose to the whole body (Note: 6.8 mrem/yr is erroneously quoted in the Basis section of this RAI). The dose information from Cook 2005 was converted to doses to the whole body, thyroid and maximum target organ in Rosenberger 2005. The resulting doses referenced in the draft Salt Waste Determination (DOE 2005) of 0.2 mrem/yr whole body, 6.3 mrem/yr to the thyroid and 0.04 mrem/yr to any other organ are taken from Rosenberger 2005.

The dose results reported in the draft Salt Waste Determination (DOE 2005) have been updated using data from the 2005 Vault 4 Special Analysis (Cook et al. 2005) to reflect the most recent modeling results and a revised facility projected inventory (d'Entremont & Drumm 2005). The new dose results are described in the Saltstone Performance Objective Demonstration Document (PODD) (Rosenberger et al. 2005). The new dose results to demonstrate compliance are obtained by conservatively assuming that the entire inventory of salt waste radioactivity (including the existing Saltstone inventory in Vaults 1 and 4 and the projected inventory for all future waste disposed of at the Saltstone Disposal Facility) is located in Vault 4. The resultant inventory is presented in Table 4-1 below. The projected inventory (Table 4-2, Column 3) is compared to the Vault 4 limits (Table 4-2, Column 2) from Cook et al. 2005. Based on the all-pathways performance objective of 25 mrem/yr and the sum-of-fractions of the inventory limits, the result is a total whole body dose of 2.3 mrem/yr as presented in Table 4-2. EPA (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 indicate that, for salt waste disposal at the Saltstone Disposal Facility using the conservative assumption of the entire inventory being present in Vault 4, 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 (Rosenberger et al. 2005).

Table 4-1

Radionuclide	Vault 1 (Ci) *	Vault 4 Current (Ci) *	Future Additions (Ci) **	Total Inventory (Ci)
H-3	2.73E+01	2.94E+01	9.37E+03	9.43E+03
C-14	1.28E+00	2.35E-01	5.18E+02	5.20E+02
Al-26			2.35E+01	2.35E+01
Ni-59	3.46E-02	9.09E-03	2.81E+00	2.85E+00
Se-79	3.02E-01	2.57E-02	8.91E+01	8.94E+01
Sr-90	1.31E-02	3.17E-01	7.43E+03	7.43E+03
Nb-94	2.51E-03	9.91E-04	7.23E-04	4.22E-03
Tc-99	1.08E+02	2.35E+01	3.30E+04	3.31E+04
Sn-126	9.97E-01	5.66E-02	4.50E+02	4.51E+02
I-129	1.12E-01	8.16E-02	1.78E+01	1.80E+01
Ra-226			1.30E+01	1.30E+01
Np-237	4.49E-03	4.87E-03	2.11E+00	2.12E+00

* Vault 1 and 4 current inventory from Crapse et al. 2004

** Future salt waste additions from d'Entremont & Drumm 2005, assuming **all** future salt waste radionuclides would be placed in Vault 4

Table 4-2

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

References:

Cook, J. R., February 24, 2005, *Estimated All Pathways and Inadvertent Intruder Doses From Saltstone Disposal Using Updated Salt Waste Compositions*, WSRC-RP-2005-01402, Revision 0.

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., May 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-00074, Revision 0.

Crapse, K. P., Chandler, T. E. and Cook, J. R., November 15, 2004, *FY 2004 Annual Review Saltstone Disposal Facility (Z-Area) Performance Assessment (Covering the Performance Period FY 1999-2004)*, WSRC-RP-2004-00649, Revision 0.

DOE, February 28, 2005, *Draft Section 3116 Determination Salt Waste Disposal Savannah River Site*, DOE-WD-2005-001.

d'Entremont, P. D. & Drumm, M. D., June 2005, *Radionuclide Concentrations in Saltstone*, CBU-PIT-2005-00013, Revision 3.

EPA, 1988, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11, EPA 520/1-88-020.

Rosenberger, K. H., February 24, 2005, *Estimated All Pathways Organ Doses From Saltstone Disposal Using Updated Salt Waste Compositions*, CBU-PIT-2005-00043, Revision 1.

Rosenberger, K. H., Rogers, B. C. & Cauthen, R. K., June 2005, *Saltstone Performance Objective Demonstration Document*, CBU-PIT-2005-00146, Revision 0.

NRC Comment 5: It is unclear how public and worker exposures will be maintained As Low As Reasonably Achievable (ALARA) during operations.

Basis: Although it is stated that projected worker exposures will be an order of magnitude below 5 rem per year (pg. 68 of [4]), no reference was given to support. Worker and public exposures from the saltstone facility were significantly less than 5 rem per year for past operations, however the source material used in past operations had significantly less activity than the waste in the current waste determination. Thus, past worker doses cannot be used to bound future worker doses.

Path Forward: Provide estimates of worker and public exposures for the saltstone processing and disposal facilities using current estimated waste activities. Describe specific actions, controls, or processes that will be used to ensure that these exposures will be maintained ALARA.

SRS Response: All radiological work performed at SRS is conducted in accordance with Manual 5Q, the site's Radiological Control Manual. Compliance with Manual 5Q ensures that SRS workers meet all the requirements of 10 CFR 835. 10 CFR 835 requires DOE facilities to develop and implement plans and measures to maintain occupational radiation exposures as low as is reasonably achievable (ALARA). An effective ALARA process includes effective consideration, planning, and implementation of both physical design features (including engineering controls) and administrative controls to balance the risks of occupational radiation exposure against the benefits arising out of the authorized activity. Section 7.2.3.15 of the draft Salt Waste Determination describes the design requirements and process for SRS facility modifications and new design.

As part of the design process for the 0.2 Ci/gal modifications to the Saltstone Facility, dose rate calculations are being performed to determine the shielding requirements for the facility. These dose rate calculations are driving various facility modifications such as:

- Modifying the Process Room crane to make it remotely operable from the Control Room
- Placing shielding on the grout line to the vaults
- Installing a lockable steel door on the Saltstone Feed Tank (SFT) dike area to limit access
- Installing two new shield walls inside the Process Room
- Installing lead shielding on major process equipment
- Installing quick disconnects on all process lines
- Designing all major pieces of process equipment to be easily replaced to reduce time of exposure during maintenance activities
- Installing a remotely operated leachate collection system on the vaults
- Installing closed-circuit television (CCTV) cameras to allow operators to take remote instrumentation readings in radiation areas

- Installing new High Radiation Area physical controls around specific areas to prevent inadvertent access

Although the design dose rate calculations are not yet finalized, DOE has estimated a total facility annual dose of approximately 1.5 rem (d'Entremont el al. 2005) distributed over the entire Saltstone workforce. The 0.2 Ci/gal Saltstone modifications will ensure that worker exposures will be designed to limit individual worker exposures to 1 rem/year as required by 10 CFR 835.

The preliminary dose rate calculations are also being used as input to the Consolidated Hazards Analysis (CHA) process to determine the unmitigated direct radiation exposure to the workers as a result of various accident scenarios. These consequences are being evaluated by the CHA team to determine what controls are required in order to prevent/mitigate worker exposure during various accident scenarios. The conclusions of revised CHA will be documented in the revised Documented Safety Analysis (DSA). The DSA will also specify the estimated dose to the public as a result of various postulated accident scenarios.

As part of the Final Radiological Design Summary Report for the 0.2 Ci/gal modifications to the Saltstone Facility, a time and motion study will be conducted prior to facility startup to verify that the annual dose to operators and maintenance personnel meets requirements. Any issues identified during the time and motion study will be accommodated by facility design/operating changes as appropriate.

To ensure that doses meet annual worker requirements, SRS continuously tracks worker doses and issues reports (Freeman 2005a). In addition, SRS strives to maintain doses ALARA and thus sets an annual administrative control level that is significantly less than the 5 rem/year Federal limit and is 0.8 rem/year for 2005 (Freeman 2005b).

To ensure that doses meet annual public requirements, SRS continuously monitors the site and regional environment through a variety of monitoring and sampling methods. The SRS annual environmental report (WSRC 2004) reports monitoring and sampling results and provides pathway doses.

References

d'Entremont, P. D., Hill, P. J., Ketusky, E. T. & Sheppard, R. E. 2005. Cost and Benefit Evaluation for Three Salt Treatment Cases at SRS. CBU-PIT-2005-00150, Revision 0, June 2005.

Freeman, A. D. 2005a. *April 2005 Radiological Performance Indicators*. ESH-RPS-2005-00104.

Freeman, A. D. 2005b. *Westinghouse Savannah River Company 2005 ALARA Goals (U)*. ESH-RPS-2005-00009, Revision 0, January 2005.

WSRC. 2004. *Savannah River Site Environmental Report for 2003*. WSRC-TR-2004-00015.

NRC Comment 6: The Modular CSSX Unit (MCU) and Salt Waste Processing Facility (SWPF) technologies use organic materials to effect Cs-137 removal. Given the potential for explosion [4] with the use of an organic material in processing Tank 48 waste, it is important to ensure that the impacts associated with the use of organic materials in the MCU and SWPF processes has been adequately considered for the saltstone processing and disposal facilities.

Basis: Tetraphenylborate, an organic material employed for Cs-137 removal in the failed In-Tank Precipitation process, has resulted in an explosion hazard for Tank 48 Waste. The selected caustic side solvent extraction (CSSX) process for MCU and SWPF intend to use novel organic based materials for Cs-137 removal from salt wastes. The safety analysis report for the saltstone processing facility indicates that the explosion scenario resulting from benzene generation from Tank 48 waste was the bounding accident for radiological risk to workers. The safety analysis report does not address the organic material in the waste streams resulting from MCU and SWPF.

Path Forward: Provide justification that the current safety analysis report for saltstone processing adequately bounds the radiological risk to workers from explosion hazards associated with organic materials in the waste, including waste resulting from the MCU and SWPF processes.

SRS Response: The existing documented safety analysis (DSA) for the Saltstone Processing Facility (SPF) (WSRC 2004a) does not address the organic material in the waste streams resulting from the MCU and SWPF. Processing of the salt waste streams from the MCU and SWPF facilities is a future activity that is not included in the current SPF DSA. Likewise, processing of the salt waste stream from Tank 48 disposition is also a future activity that is not included in the SPF DSA.

The SPF DSA is written to describe the current SPF process. As is described in section 7.2.3.14 of the Salt Waste Determination (WD) (DOE 2005), before the SPF process is modified, including the addition of a new waste stream for processing or modification to the existing salt waste stream, a Consolidated Hazards Analysis (CHA) is performed to identify potential hazards associated with the modification, classify those hazards and evaluate the consequence and frequency of each of the hazards identified. The CHA process is described in detail in the CHA methodology manual (WSRC 2005a). A summary description of the process follows.

The CHA is a team based evaluation lead by a trained CHA Process (CHAP) Lead. It integrates elements of multiple hazards analysis, e.g. process hazards analysis, fire hazards analysis, emergency protection hazards analysis, etc. into a single evaluation. The scope of work to be performed (consistent with defined scopes of work from the Integrated Safety Management System (ISMS)) is evaluated using a structured, team-based approach to apply advanced process risk management techniques.

This systematic approach to hazards identification and control provides the CHAP team with a detailed understanding of the safety functions needed to define the design of safety controls and specify associated standards.

The existing CHA is provided (WSRC 2004b) to show the details of the CHAP analysis. As was stated previously, processing of salt waste streams from MCU, SWPF and Tank 48 are future activities and are not included in this revision of the CHA. The CHA includes hazard identification, facility/process segmentation, facility hazard categorization, screening of common industrial hazards, unmitigated hazard analysis, periodic process hazards review, mitigated hazard analysis, and identification of the Systems, Structures, and Components (SSCs) and programs credited as controls for the associated hazards and functional classification of the SSCs. Frequency and consequences of accident events are binned to determine relative risk ranking so that those events that pose the greatest risk to the Public, Co-Located Worker, and the Facility Worker can be further evaluated and/or functionally classified as described in the CHA methodology manual.

The DSA will incorporate the CHA results and will provide the basis for any controls required to achieve safe operations in the SPF. Those controls will be documented in the Technical Safety Requirements (TSR) document for the SPF. Some examples of controls that could be considered to be typical for this type of process would include temperature limits on the processes, requirements for ventilation (flowrates, differential pressure across interfaces, purge ventilation intervals (time), tank level control, etc.), concentration controls in the feed streams, etc.

To prepare for the implementation of the future activities (salt waste processing from MCU, SWPF and Tank 48), the hazard analysis and DSA revision process described above will be followed according to the individual project schedules for MCU, SWPF and Tank 48. This process will analyze the hazards associated with the potential for organic material in these waste streams and identify appropriate controls to protect the facility workers in accordance with section 7.2.3.15 of the Draft WD. All analysis, documentation of the analysis and the implementation of the TSR controls must be complete prior to authorization from the DOE to Westinghouse Savannah River Company (WSRC) to implement the new processes.

Implementation processes for the DSA and TSR are provided in the Safety Basis Implementation Procedure in the Safety Documentation Manual (WSRC 2005b). The steps associated with the implementation of safety documents include: determine Safety Basis requirements, develop implementation actions, complete equipment modifications, prepare facility procedures and databases, develop training packages, train facility personnel, validate and verify implementation and conduct readiness assessments. These steps are described in additional detail in the reference procedure. Note that any changes to the Safety Basis require approval of the DOE and may not be implemented until DOE approves the changes and issues their Safety Evaluation Report (SER).

By way of information only, WSRC is in the process of obtaining information to understand the potential hazards associated with the processing of organic materials in the SPF and Saltstone Disposal Facility (SDF). WSRC and DOE are currently evaluating solvent carryover from the CSSX processes that will be integral to the MCU and SWPF, organic evolution rates from grout, organic decomposition rates in grout, solvent carryover mitigation processes, SDF vault vapor space characteristics, factors that effect organic evolution rates from grout such as curing temperatures, etc. All of this information will be considered when the CHA process is applied to these future waste streams.

The information and process knowledge to date, as well as the other measures DOE requires, demonstrate that DOE has adequately considered the impacts associated with the processing and disposal of organic bearing salt waste. This consideration of potential impacts provides reasonable assurance that there will be no explosions or release of source, special nuclear, or byproduct materials during disposal operations.

References:

Westinghouse Savannah River Company, 2004a, WSRC-SA-2003-00001, "Saltstone Facility Documented Safety Analysis," Revision 2, November 2004.

U.S. DOE, 2005, DOE-WD-2005-001, "Draft Section 3116 Determination Salt Waste Disposal Savannah River Site," February 2005.

Westinghouse Savannah River Company, 2005a, WSRC-IM-2002-00003, "Consolidated Hazards Analysis Process (CHAP) Methodology Manual," Revision 3, March 2005.

Westinghouse Savannah River Company, 2004b, WSRC-TR-2001-00574, "Saltstone Facility Consolidated Hazards Analysis (U)," Revision 4, September 2004.

Westinghouse Savannah River Company, 2005b, Manual 11Q, Facility Safety Documentation Manual, Procedure 1.11, Revision 0, "Safety Basis Implementation," January 2005.

NRC Comment 7: Footnote 2 on page 9 of Reference 4 states that "In 1997, following consultation with the NRC...DOE operationally closed Tanks 17 and 20." The consultation with NRC was not complete until June 30, 2000, when NRC sent its final Technical Evaluation Report to DOE.

Path Forward: Revise the wording so as to correctly describe the timeline of events regarding previous tank closures.

SRS Response: Footnote 2 on page 9 of the Salt Waste Determination (reference 4 in the NRC RAI) will be changed to more accurately represent the chronology of events: "SRS has a total of 51 underground waste storage tanks. In 1997, following approval of closure modules by the State of South Carolina, DOE operationally closed Tanks 17 and 20. On June 30, 2000, the NRC issued to DOE its final Technical Evaluation Report confirming the SRS approach used in closing these tanks."

Reference:

"U. S. Nuclear Regulatory Commission Review of the Department of Energy at Savannah River High-Level Waste Tank Closure Methodology," Enclosure to Letter, Kane to Schepens, June 30, 2000, "Savannah River Site High Level Waste Tank Closure: Classification of Residual Waste as Incidental"

NRC Comment 8: Footnote 30 on page 51 of Reference 4 states that "The NRC has stated: 'The dose methodology used in 10 CFR 61 Subpart C is different from that used in the newer 10 CFR 20 Subpart E. However, the resulting allowable doses are comparable and NRC expects DOE to use the newer methodology in 10 CFR 20 Subpart E.'" The NRC made this statement in its Decommissioning Criteria for the West Valley Demonstration Project at the West Valley Site, Final Policy Statement (Feb. 1, 2002, 67 FR 5003), not in relation to waste determination activities under the National Defense Authorization Act of Fiscal Year 2005 (NDAA).

Path Forward: Revise the wording so that it does not imply that the NRC made this statement in relation to the NDAA. A more appropriate reference for NRC's guidance on dose methodology for compliance with 10 CFR 61 can be found in NUREG-1573.

SRS Response: Reference 26 of the "Draft 3116 Determination [for] Salt Waste Disposal [at the] Savannah River Site" will be changed *from* U.S. NRC, "Decommissioning Criteria for the West Valley Demonstration Project (M-32) at the West Valley Site; Final Policy Statement," February 2002 *to* U.S. NRC, "NUREG-1573, A Performance Assessment Methodology for Low Level Radioactive Waste Disposal Facilities: Recommendations of NRC's Performance Assessment Working Group," pp. 3-77, October 31, 2000.

Footnote 30 on page 51 will be revised to invoke NUREG-1573 rather than the West Valley Policy Statement:

The NRC has stated: "The NRC performance objective set forth in Section 61.41, is based on the [International Commission on Radiation Protection Publication 2] ICRP 2 dose methodology (ICRP, 1959), but current health physics practices follow the dose methodology used in Part 20, which is currently based on ICRP 30 methodology (ICRP, 1979).…For internal consistency…it is recommended that the performance assessment be consistent with the methodology approved by the NRC in Part 20 for comparison with the performance objective" [26]. Based on this guidance, radiological doses in this document and in applicable supporting documents are calculated in accordance with the newer methodology in 10 CFR Part 20. This newer methodology calculates dose in total effective dose equivalent (TEDE) versus the organ doses of the earlier methodology.

Reference 26 is also cited on page 60 of the "Draft 3116 Determination [for] Salt Waste Disposal [at the] Savannah River Site" in Section 7.2.3, "Protection of Individual During Operations (10 CFR 61.43)". This citation is not deemed necessary and will be deleted.

References:

U.S. NRC, "NUREG-1573, A Performance Assessment Methodology for Low Level Radioactive Waste Disposal Facilities: Recommendations of NRC's Performance Assessment Working Group," pp. 3-7

NRC Comment 9: The draft 3116 determination [4] should specify that the requirement of meeting the performance objectives of 10 CFR 61, Subpart C, applies -5- whether or not the waste meets Class C concentrations.

Basis: Several statements are made in Reference 4 that imply that the performance objectives of 10 CFR 61, Subpart C, do not apply to waste that meets Class C concentrations. For example, the first paragraph of page 27 states "This includes waste that falls within one of the classes set out in Section 61.55, as well as waste that will be disposed of so as to meet the performance objectives of Subpart C of Part 61."

Path Forward: Revise wording throughout Reference 4 to clarify that the waste must meet performance objectives of 10 CFR 61, Subpart C, regardless of its classification, as specified in the NDAA.

SRS Response: The draft 3116 determination will be revised to make clear that the waste, regardless of its classification, must meet performance objectives of 10 CFR 61 Subpart C. The last sentence in the first paragraph of page 27 will be reworded to state: "This includes waste that meets the performance objectives of 10 CFR Part 61, Subpart C and which either falls within the classes set out in 10 CFR 61.55 or for which DOE has consulted with NRC concerning DOE's disposal plan." In addition, the third sentence in the second paragraph of page 27 will be changed to read: "This is because waste that meets the third criterion would be waste that the Secretary, in consultation with the NRC, has determined will be disposed of in a manner that meets the Part 61 Subpart C performance objectives, and which falls within one of the classes of waste that the NRC has specified are considered generally acceptable for near-surface disposal or for which the Secretary has consulted with NRC concerning DOE's disposal plan." No other passages in the "Draft 3116 Determination [for] Salt Waste Disposal [at the] Savannah River Site" have been found to suggest that the performance objectives of 10 CFR 61, Subpart C, do not apply to waste that meets Class C concentrations.

NRC Comment 13: Detailed technical information on technologies considered for the treatment of Tank 48 waste as well as a cost-benefit analysis that compares alternative treatment methods are needed to provide reasonable assurance that highly radioactive radionuclides will be removed to the maximum extent practical.

Basis: The proposed disposal strategy for Tank 48 waste is to dilute the Tank 48 waste with other low-activity waste prior to processing it into grout for disposal at the SDF (pg. 40 of [4]). This strategy will add an estimated 0.8 MCi to the grout, increasing its radioactivity by 30 percent. A detailed cost-benefit analysis describing the various methods of waste removal considered by DOE before selecting this preferred method for treating Tank 48 waste is needed to provide reasonable assurance that the highly radioactive radionuclides will be removed to the maximum extent practical.

Path Forward: Provide a description of the various methods of waste removal considered and reasons for selecting the preferred method for disposal of the Tank 48 waste. Include a cost-benefit analysis to show that the technology chosen represents the optimum solution for disposal of the Tank 48 waste.

SRS Response: Tank 48 currently contains approximately 0.24 Mgal of a relatively low-activity salt solution containing potassium and cesium tetraphenlyborate (TPB) salts. (See NRC Comment 12 for a discussion on relative curie concentrations of Cs-137.) These salts were generated during an earlier unsuccessful effort to prepare salt waste for disposal, known as the In-Tank Precipitation (ITP) process. Dispositioning the unique waste in Tank 48 allows the use of up to 1.3 million gallons (Mgal) of space in this tank to support sludge removal and treatment in the Defense Waste Processing Facility (DWPF), and earliest possible full Salt Waste Processing Facility (SWPF) operation. As discussed later in this response, any other available new-style tank that could substitute in place of Tank 48 would result in an increase in the number of curies sent to the Saltstone Disposal Facility (SDF).

The organic nature of TPB salts requires them to be stored separately from other tank waste. This is because TPB can break down into benzene and other organic compounds and can form a potentially explosive mixture in the vapor space of a waste tank if not carefully managed. Unlike Tank 48, other tanks are not equipped with safety systems required to manage this flammable mixture.

In addition, this waste cannot be processed through the DWPF because the breakdown of TPB in sufficient quantities in the DWPF melter could pose safety concerns. Currently, there is no practically available or contemplated technology that could be used to remove additional radioactivity and dispose of that radioactivity using DWPF. Accordingly, the waste in Tank 48 will be processed without further removal of radionuclides.

Tank 48 currently contains a relatively small number of curies, approximately 0.8 MCi, when compared to other waste tanks. No other available new-style tank that could substitute in place of Tank 48 contains salt waste that can be disposed of and result in less than 0.8 MCi being sent to SDF. To gain the equivalent tank space that will be provided by processing Tank 48, another waste tank would need to undergo processing during the Interim Salt Processing period. Since the ARP/MCU facilities are already fully utilized once available, the only other treatment option available would be to dispose of the waste from a different tank by the Deliquification, Dissolution and Adjustment (DDA) process. As outlined in Table 12-4 in the response to NRC Comment 12, Tanks 48, 41, 25 and 28 were the tanks selected as most suitable for DDA processing and are already planned to be processed. Tanks 31, 44, 45, and 46 are the remaining tanks suitable for DDA processing. Table 13-1 below compares the curies in these tanks to the 0.8 MCi in Tank 48 (Tran 2005).

Table 13-1. Comparison of Total Curies in Tanks 31, 44, 45, 46 and 48.

Waste Tank	Total Curies (MCi)
31	11.0
44	6.6
45	5.8
46	10.5
48	0.8

As indicated by Table 13-1, Tank 48 contains significantly less curies than the other remaining tanks suitable for DDA processing. Therefore, if Tank 48 is not dispositioned and an alternate tank must be processed to support sludge removal and the earliest possible full capacity SWPF operation, there would be a significant increase in the number of curies disposed at SDF.

The Tank 48 disposition strategy was to develop SRS 'in-house' options and, in a parallel effort, to solicit and evaluate vendor bids on the design and installation of a waste treatment unit (WTU) specifically capable of treating the organic component of the Tank 48 waste.

The most recent effort built upon the previous work that was documented in the HLW Tank 48 Disposition Alternatives Identification Phase I and II Summary Report (WSRC 2002), and research data developed by Savannah River National Laboratory (SRNL) (Lambert and Fink 2003, Fowler 2004, Zapp and Mickalonis 2003, Lambert et al. 2003, Peters et al. 2003, Lambert and Stallings 2003). The options were developed to sufficient maturity to allow major risks to be identified, rough order of magnitude (ROM) cost estimates to be developed and preliminary schedule durations to be estimated.

The Department of Energy (DOE) developed weighted evaluation criteria to compare alternatives relating to organic destruction including: cost, schedule, safety basis,

research and development, operations, regulatory and downstream process impacts. The options for each of the alternatives were scored to determine a relative listing of viability. A description of the options considered, including the associated ROM cost and expected major risks are provided in Attachment 13-1. The evaluation of alternative methods for disposition of the tetraphenylborate (TPB) in Tank 48 (WSRC 2003a, Dean 2004) resulted in the recommendation of two options:

1) Aggregation of material from Tank 48 with DWPF recycle and subsequent disposal in the Saltstone Disposal Facility (SDF).
2) In-Situ Thermal Decomposition using heat in combination with pH reduction and catalyst addition.

The evaluation further stated that "the selected strategies are not without risk, and will require additional evaluations and testing before a disposition plan can be finalized."

The research and development testing necessary to support development of operating conditions and Safety Basis input parameters was conducted for the In-Situ Thermal Decomposition option (Peters and Lambert et al. 2004). Based on the results of the testing, the use of In-Situ Decomposition was eliminated as a Tank 48 TPB disposition option (Maxwell 2004). The option was eliminated following extensive laboratory testing in which no set of operating parameters could be identified for safe and effective operation that achieved the required end state. Evaluation of similar factors to support the Aggregation approach determined that it was viable as a selected strategy.

Given that the Tank 48 waste disposal is a future activity, the development of the Safety Basis and associated laboratory testing is still ongoing. These activities will be completed according to the project schedule as needed to support processing. However, testing to date on the Aggregation option has been favorable (Cozzi 2004, Peters and Barnes et al. 2004). The management systems in place to assure that safety and environmental requirements are met are described in the responses to NRC Comments 6, 37, and 57.

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Lambert, D. P., and Fink, S. D., 2003, *Downstream Impacts of Tank 48 In-Tank and Out-of Tank Processing Alternatives*, WSRC-RP-2003-00588, Westinghouse Savannah River Company, Aiken, South Carolina.

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Tran, H. Q., 2005, *Tank Radionuclide Inventories*, CBU-PIT-2005-00138, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

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WSRC, 2003b, *SRS Tank 48H Materials Treatment*, G-SOW-H-00032, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Zapp, P. E., and Mickalonis, J. I., 2003, *Electrochemical Tests of Carbon Steel in Simulated Waste Containing Fenton's Reagent*, WSRC-TR-2003-00445, Westinghouse Savannah River Company, Aiken, South Carolina.

Attachment 13-1 – Tank 48 Alternative Descriptions

A brief discussion of each of the selected Tank 48 treatment alternative processes, from the fundamental chemistry perspective, is provided below. Table 13-2 provides an overview comparison of the treatment options.

1. Aggregation

The Aggregation process dispositions the potassium and cesium tetraphenylborate salts (KTPB/CsTPB) in Tank 48 by combining Tank 48 waste with DWPF recycle and other Tank 50 influent waste streams for subsequent disposal in the Saltstone Disposal Facility (SDF). Aggregation is a batch process. A maximum TPB concentration of 3000 mg/L will be sent to Saltstone. In the Aggregation process, DWPF recycle will be transferred from Tank 21, 22, 23 or 24 to Tank 48 and/or Tank 50. The Tank 48 material will be transferred to Tank 50 and processed to the Saltstone Facility for final disposal. Prior to addition of any DWPF recycle material, the free hydroxide concentration will be adjusted by addition of 50 wt% caustic to minimize significant benzene production. During Aggregation, DWPF recycle will also be added to Tank 48, agitated and transferred to Tank 50. It is estimated that approximately 3.4 million gallons of DWPF recycle along with approximately 160,000 gallons of 50 wt% hydroxide are required to meet the objective (Fowler 2005). The cost of this option is estimated at $15 million.

2. In-Situ Thermal Decomposition

The In-situ Thermal Decomposition process uses elevated temperature in combination with decreased pH, via nitric acid addition, and catalytic hydrolysis, using palladium, to decompose the TPB in Tank 48. The benzene generated from the decomposition would be controlled so that it would be swept from the tank using the nitrogen purge ventilation system and released through the stack. The salt solution remaining after decomposing the TPB would then be processed through an existing treatment facility. The research and development testing necessary to support operating conditions and Safety Basis input definition was conducted for the In-Situ Thermal Decomposition option (Peters and Lambert et al. 2004). Based on the results of testing, the use of In-Situ Decomposition was eliminated as a Tank 48 TPB disposition option (Maxwell 2004). The cost for the In-Situ Thermal Decomposition option is estimated to be approximately $12 Million.

3. Thermal Degradation Using Fluidized Bed Steam Reforming

Superheated steam and redox reactions are used to evaporate liquids, convert organic compounds into carbon dioxide and water, reduce nitrates and nitrites to elemental nitrogen, and convert reactive chemicals to a stable waste product or liquid that incorporates almost all of the radionuclides. Off-gases from the steam reformer vessel are treated to neutralize corrosive acids or bases so that the only emissions released to the atmosphere from the process ideally are carbon dioxide and water vapor.

This alternative utilizes a fluidized bed to maximize the reactive surface area, maximizing the reaction efficiency. The typical reaction temperature ranges from 600 to 800°C. Steam reforming would process the Tank 48 material "as-is" and therefore does not require any pH adjustment. Steam reforming keeps the operating inventory of Tank 48 material small (< 5 wt% of the fluidized bed) which minimizes the material at risk. Steam reforming facilities are currently being successfully used for treating industrial wastes and commercial reactor ion exchange resin (WSRC 2002, WSRC 2003a). The estimated cost of this option is >$40M. This option would require a subcontract and was eliminated due to its funding, schedule and need for additional technical development to address potential downstream impacts.

4. **Catalytic Oxidation Using Fenton's Reagent**

   Under moderately acidic conditions (pH 3-5), the combination of hydrogen peroxide and ferrous ion efficiently produce hydroxyl free radicals, which are highly oxidizing. This combination of hydrogen peroxide and iron is known as Fenton's reagent. In the presence of dissolved organic compounds, these free radicals oxidize the organic compounds and convert them into carbon dioxide and water. The TPB salts are sufficiently soluble under these conditions to permit this oxidation reaction to proceed and destroy the organic character of the Tank 48 material. However, at this pH range, the risk of corrosion to the mild carbon of Tank 48 is too great and the process would be limited to an out-of-tank facility. At higher pH conditions, the effectiveness of the reaction is diminished. The advantage of operating a Fenton's reagent process at a higher pH range (mildly alkaline) would be the ability to perform the operation in Tank 48 along with the lower production of benzene during the decomposition process.

   The DWPF Salt Cell was also evaluated as a potential location. An advantage to performing the Fenton's reagent option out-of-tank is the processing of small batches which minimizes the material at risk. Cost for the In-Tank Fenton's Reagent is estimated to be approximately $17 Million. Cost for the installation of the Fenton's process in the DWPF Salt Cell is estimated to be approximately $50 Million (WSRC 2003a, Dean 2004).

5. **Catalytic Hydrolysis Using Metals and Decreased pH**

   Use of catalytic metals such as copper or palladium can increase the degradation rate of organics in solution, through enhanced hydrolysis. Such reactions were effectively used for increasing the degradation rate of NaTPB in former Tank 49 waste. The resulting benzene was removed through the existing nitrogen purge ventilation system. Tank 48 has a similar nitrogen purge ventilation system. If this process could be performed at mildly alkaline conditions, then the hydrolysis could be done in Tank 48. If the pH range for the hydrolysis must be neutral or acidic, then the process must be done out-of-tank. Cost for the In-Tank Catalytic option is estimated to be approximately $12 Million. The testing completed for In-Situ Thermal eliminated this option as being effective for the KTPB/CsTPB waste in Tank 48 (WSRC 2003a, Dean 2004, Maxwell 2004).

6. **Accelerated Degradation Using Elevated Temperatures and Decreased pH**

Natural thermal degradation of TPB is a function of temperature and pH. At ambient tank temperatures and high pH conditions, the natural degradation rate is relatively low. At higher temperatures and lower pH conditions, the natural degradation rate is expected to be higher. The cost for the In-Tank Thermal Hydrolysis option is estimated to be approximately $11 Million. This option was eliminated following extensive laboratory testing in which no set of operating parameters could be identified for safe and effective operation that achieved the required end state (WSRC 2002, WSRC 2003a, Dean 2004, Maxwell 2004).

7. **Subcontractor Waste Treatment Unit**

The use of a waste treatment unit (WTU) constructed by a subcontractor was also evaluated. The subcontractor would provide the materials and services required to design, fabricate, inspect, test, document, and deliver a WTU to the Savannah River Site. The subcontractor would also provide technical support and oversight for WSRC field installation, examination, testing, startup and operation (WSRC 2003b). No further technologies beyond those already discussed were identified for a subcontractor supplied WTU. This option was eliminated due to funding resources.

Table 13-2 Tank 48 Organics Disposition Options Comparison Chart. (WSRC 2002, WSRC 2003a, Dean 2004)

Option Evaluated	**Aggregation**	**In-Situ Thermal**	**Steam Reforming (Subcontractor Waste Treatment Unit)**	**In-Tank Fenton's Hydrolysis**	**Salt Cell Fenton's Hydrolysis**	**In-Tank Catalytic Hydrolysis**	**Elevated Temperature & Decreased pH**	**Out of Tank Fenton's (Subcontractor Waste Treatment Unit)**
Total Project Cost (ROM)	~$15M	~$12M	>$40M	~$17M	~$50M	~$12M	~$12M	>$40M
Schedule - Critical Path	23 mo	27 mo	27 mo	30 mo	42 mo	27 mo	27 mo	27 mo
Risk Level	Moderate / High	Moderate	High	High	High	Moderate	Moderate	High
Significant Risks	Permit/Regulatory Benzene generation requires equipment modifications to Tank 50 and/or SPF	Organic destruction efficiency does not meet end state criteria	Subcontracting a fast track R&D project Product compatibility with downstream processes	Organic destruction efficiency does not meet end state criteria Reduced Tank service life due to corrosion	DWPF Canister waste loading Salt Cell Modification	Organic destruction efficiency does not meet end state criteria	Organic destruction efficiency does not meet end state criteria	Subcontracting a fast track R&D project

NRC Comment 14: Additional information is needed to support the conclusion that treating waste with the ARP only if Sr and actinide removal are needed for the waste to meet Class C limits is consistent with removal of highly radioactive radionuclides to the maximum extent practical and maintains doses ALARA.

Basis: The waste determination indicates (pg. 17 of [4]) that after the completion of the ARP, waste will only be sent to the ARP unit if Sr and actinide removal is necessary for the waste to meet Class C limits. However, no basis has been provided to support the conclusion that this approach is consistent with removal of highly radioactive radionuclides to the maximum extent practical or maintains doses ALARA. Evidence is necessary to support the conclusion that it would be impractical to send more of the waste to the ARP once the ARP is built or that the risk reduction that could be achieved by sending more of the waste to the ARP is negligible.

Path Forward: Provide the basis, including quantitative and qualitative costs and benefits, to support a decision that individual batches of waste will not need to be processed through the ARP process. Demonstrate that this approach is consistent with removal of highly radioactive radionuclides to the maximum extent practical and maintains doses ALARA. The response should address the risk reduction that would be achieved by treating more of the waste with the ARP as compared to sending only the waste that would not otherwise meet Class C limits. The response also should address the negative impacts of sending more of the waste to the ARP once it is built, such as monetary costs and potential impacts on schedule.

SRS Response: Recognizing that the Salt Waste Processing Facility (SWPF) cannot be constructed, permitted, and operated until approximately 2009, the two-part interim processing approach described in the draft Salt Waste Section 3116 Determination [for] Waste Disposal [at the] Savannah River Site (Salt Waste Determination) accelerates risk reduction through processing the minimal amount of some of the lowest activity salt waste (i.e., minimize the curies sent to the Saltstone Disposition Facility (SDF)) to create the necessary tank space for continued sludge removal and treatment in the Defense Waste Processing Facility (DWPF), and the earliest possible full SWPF operation. (See responses to NRC Comments 10, 11, 12 and 13)

One of the input bases to the development of the two-part interim processing strategy, and to any future revisions, is to remove radionuclides to the maximum extent practical while still creating the necessary tank space for continued risk reduction through sludge removal and vitrification to borosilicate glass, and earliest possible full SWPF operation. ARP/MCU are

expected to come online in approximately 2007. ARP/MCU will remove approximately 92% (Campbell 2004) of the Cs-137/Ba-137m while also removing insoluble solids which contain the majority of the Sr-90 and actinides. The ARP facilities will also have the capability to remove soluble Sr-90 and actinides through MST strikes.

The two-part interim processing strategy reflected in the Salt Waste Determination was based on preliminary ARP process flowsheet information. A detailed ARP process flowsheet (Subosits 2004) was recently issued which demonstrates the performance of MST strikes is no longer anticipated to be the processing throughput limiting step. Based on this new flowsheet information, it is now planned that MST strikes will be conducted on all salt solution processed through ARP, even if the salt solution already does not exceed Class C concentration limits, as long as throughput can be maintained, with adequate margin, to support necessary tank space needs. An acceptable operational margin can be determined after some operational experience is obtained from operating the ARP/MCU facilities. This is in alignment of the objective to minimize curies to SDF while still meeting tank space objectives.

This emergent information will require revisions to applicable sections of the Salt Waste Determination. In particular, the following sections will require revision.

On page 17 of the Salt Waste Determination, the following paragraph:

> If sample analyses indicate that salt waste requires removal of soluble Sr-90 and actinides in order to meet Class C concentrations limits in 10 CFR 61.55 in the grouted waste form, the waste will be received into either of the two MST Strike Tanks. Waste received in MST Strike Tank #1 or #2 will be adjusted with water to approximately 5.6 Molar sodium concentration to provide optimum conditions for sorption of Sr-90 and actinides onto MST. Following the addition of MST to either Strike Tank, the contents will be agitated for a reaction period between 4 and 24 hours based on the curie concentration of the soluble actinides to be removed. The resulting slurry will be transferred from either of the strike tanks into the Filter Feed Tank (FFT). If sample analyses demonstrate that decontamination of the salt solution to meet Class C concentration limits in the grouted waste form can be achieved without removal of soluble actinides and Sr-90, then the waste will be transferred without MST treatment from the Tank Farm directly to the FFT for ARP filter-only processing.

should be revised to state the following:

> Based on current process flowsheet information, MST strikes will be conducted on all salt solution processed through ARP, even if the salt solution already does not exceed Class C concentration limits in 10 CFR 61.55 in the grouted waste form, as long as throughput can be maintained, with adequate margin, to support necessary tank space needs. The waste will be received into either of the two MST Strike Tanks. Waste received in MST Strike Tank #1 or #2 will be adjusted with water to approximately 5.6 Molar sodium concentration to provide optimum conditions for sorption of Sr-90 and actinides onto MST.
>
> Following the addition of MST to either Strike Tank, the contents will be agitated for a reaction period between 4 and 24 hours based on the curie concentration of the soluble actinides to be removed. The resulting slurry will be transferred from either of the strike tanks into the Filter Feed Tank (FFT). The ARP facilities will be used to remove soluble Sr-90 and actinides through MST strikes, as long as tank space objectives can be met with appropriate operational margin. If emergent technical or processing information becomes known that indicates that tank space objectives cannot be met AND the soluble actinides in the original salt solution are sufficiently low (i.e., below Class C concentration limits) to achieve the necessary tank space recovery prior to SWPF start-up, the stream will only be filtered prior to being sent to MCU.

On pages 38 and 39 of the Salt Waste Determination, the following sentences:

> The ARP facilities will also have the capability to remove soluble Sr-90 and actinides through MST strikes. If the soluble actinides in the original salt solution are sufficiently low (i.e., below Class C concentration limits), to achieve the necessary tank space recovery prior to SWPF start-up, the stream will only be filtered prior to being sent to MCU.

should be revised to state the following:

> The ARP facilities will be used to remove soluble Sr-90 and actinides through MST strikes[25], as long as tank space

> objectives can be met with appropriate operational margin. If emergent technical or processing information becomes known that indicates that tank space objectives cannot be met AND the soluble actinides in the original salt solution are sufficiently low (i.e., below Class C concentration limits), to achieve the necessary tank space recovery prior to SWPF start-up, the stream will only be filtered prior to being sent to MCU.

Footnote 25 on page 39 of the Salt Waste Determination:

> [25] The current Interim Salt Processing Strategy does not generally contemplate MST strikes of the salt solutions that will be batched through ARP/MCU but an 8-hour MST strike will be performed if necessary to meet Class C limits for disposal of DSS in SDF or if throughputs can be maintained at 1.5 Mgal per year even if strikes are not necessary to meet Class C concentration limits.

should be revised to state the following:

> [25] The duration of the MST strikes of the salt solutions will be dependent on the concentration of the Sr-90 and actinides present, and will range from 4 to 24 hours.

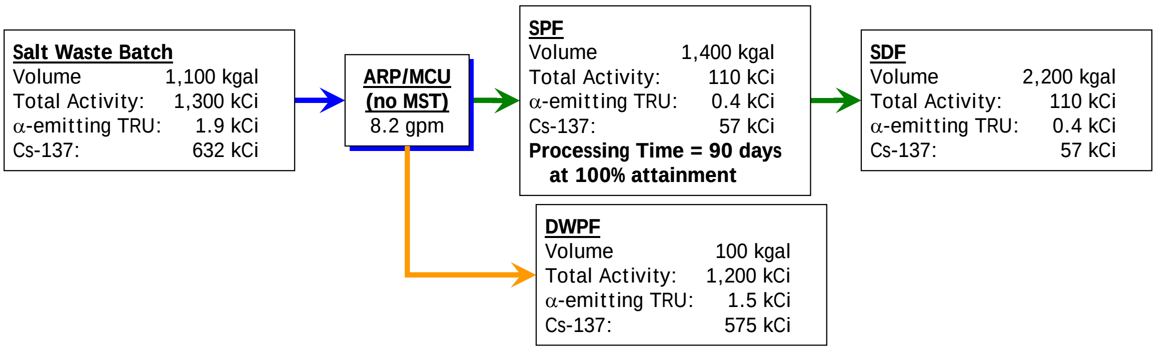
The objective of the Two-part interim processing strategy is to run the interim treatment processes available to minimize curies to SDF while still meeting the tank space objectives. The processing philosophy of minimizing curies to SDF while still meeting tank space objectives can best be illustrated with the following hypothetical example that demonstrates the logic that will be used in making such an evaluation.

A batch of salt solution feed (Batch 1) is prepared and available for processing through to ARP/MCU for treatment before processing at the SPF. Removal of the total volume from the batch is required by a specific time to meet the tank space objectives to support sludge processing and earliest possible full SWPF operation. Processing Plans A and B have Batch 1 being processed through ARP/MCU with no MST strike and with a 24-hour MST strike, respectively. Note that the Total Activity curie numbers shown below include daughter products of Cs-137 and Sr-90.

Processing Plan A (No MST Strike):

Assuming:

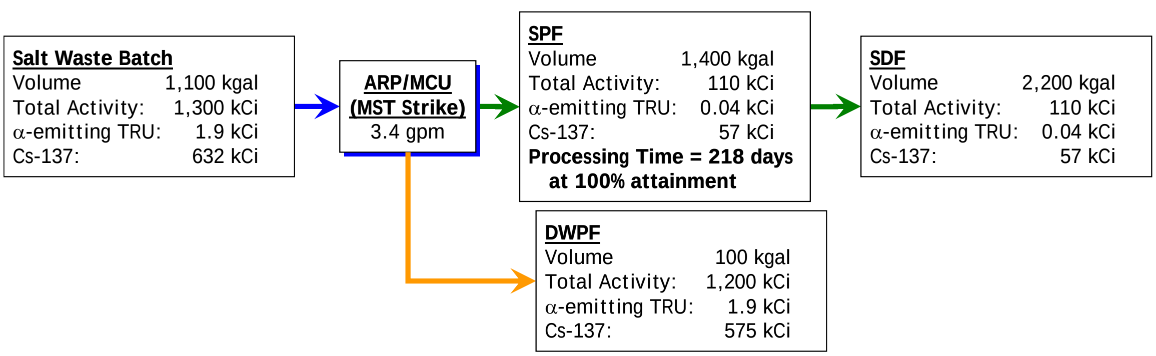
- Processing rate through ARP/MCU is 8.2 gpm



Processing Plan B (24-Hour MST Strike):

Assuming:

- Processing rate through ARP/MCU is 3.4 gpm



A comparison of the two cases in the example shown above reveals that even though both processing plans do not exceed Class C concentration limits for disposition to SDF, Processing Plan B results in less alpha emitting transuranic (TRU) curies [40 Ci for Plan B (~98% removal of transuranics) versus 400 Ci (~78% removal of transuranics) for Plan A] being sent to the SDF. However, the total curies, which include the daughter products for Cs-137 and Sr-90, are the same for both cases (~110 kCi – when rounded to the nearest kCi). From a processing duration perspective, it takes ~140% longer (~218 processing days at 100% attainment versus ~90 processing days) to fully disposition the volume in Batch 1. If the processing duration for either

case meets tank space objectives, then Processing Plan B would be implemented since it results in fewer curies being sent to SDF. However, if emergent technical or processing information indicates that tank space objectives cannot be met due to the longer processing duration of Processing Plan B, then Processing Plan A would be implemented.

The analyses performed and reported in the Performance Objective Demonstration Document (PODD) to demonstrate compliance with the Performance Objectives in 10 CFR 61 assumed that no MST strikes were performed in the ARP process (i.e., that none of the soluble Sr-90 or the actinides were removed by the ARP process). This same assumption was used in demonstrating compliance with Class C concentration limits. Therefore, if any such evaluation as that described above was performed with a subsequent decision made not to strike, it would not impact the analyses performed to support this waste determination.

In summary, the plan is that MST strikes will be conducted on all salt solution processed through ARP, even if the salt solution already does not exceed Class C concentration limits, as long as throughput can be maintained, with adequate margin, to support necessary tank space needs. An acceptable operational margin can be determined after some operational experience is obtained from operating the ARP/MCU facilities. This is in alignment of the objective to minimize curies to SDF while still meeting tank space objectives.

References:

Campbell, S. G., 2004,*"Preliminary Material Balance for the Modular CSSX Unit,"* CBU-SPT-2004-00059, Revision 1, June 22, 2004.

Subosits, S. G., 2004, "Actinide Removal Process Material Balance with Low Curie Salt Feed", X-CLC-S-00113, Rev. 0, September 2004.

NRC Comment 17: The results of software verification are not provided for some software routines (e.g., PORFLOW).

Basis: The 1992 performance assessment [1] indicates in Appendix F that results of verification and benchmarking shall be recorded in an appendix of the performance assessment report. However, these results are not found in an appendix to the report. In addition, some of the results presented earlier in the sensitivity analysis for vault release showed lack of convergence, which possibly indicates that the model was being applied outside of the range over which it was verified.

Path Forward: Provide a summary of the results of verification and benchmarking performed for software used in the performance assessment.

SRS Response: Federal rule 10 CFR 830.120, Subpart A establishes quality requirements for Department of Energy (DOE) contractors conducting activities, including providing items and services that affect, or may affect, nuclear safety of DOE facilities. The Department has also developed DOE Order 414.1B, "Quality Assurance" and its associated manuals to ensure quality assurance for all products and services provided by DOE and its contractors. DOE contractors are required to via the S/RID process to identify and incorporate the requirements of 10 CFR 830 and DOE Order 414.1B in their company-level procedures and processes. At SRS, DOE-Savannah River has developed a Quality Assurance Program Manual (SRM 414.1.1.C) which describes its quality assurance program as required by DOE Order 414.1B. The commercial consensus standard upon which the DOE-Savannah River QAP is primarily based is ASME NQA-1-2000, "Quality Assurance Requirements for Nuclear Facility Applications."

The information below describes the Quality Assurance Program implemented by Westinghouse Savannah River Company (WSRC), DOE's operating contractor at the Savannah River Site. This information also describes the software quality assurance plan and test case results for PORFLOW and the software quality assurance for the HELP model, an additional software code used in the performance assessment.

Software Quality Assurance Requirements

General WSRC requirements for software quality assurance are described in *1Q Quality Assurance Manual*, page 5. The hierarchy of documents is described in *1Q Quality Assurance Manual* as follows:

1. WSRC-1-01, Management Policies, MP 4.2, "Quality Assurance"

MP 4.2 contains the WSRC President's policy statement regarding the Company's commitment to provide products and services which meet or exceed the requirements and expectations of our customers. The WSRC Quality Assurance Program is to be implemented in a manner to support implementation of WSRC's imperatives of safety, disciplined operations, cost effectiveness, continuous improvement, and teamwork. WSRC has established and implemented an Integrated Safety Management System (ISMS). The quality assurance (QA) program is consistent with and an integral part of the WSRC ISMS. The policy requires that the program include appropriate procedures to comply with legal, regulatory, contractual, and corporate requirements related to quality. The policy also requires that the WSRC QA program comply with DOE O 414.1B, 10 CFR 830, Subpart A and the WSRC QA Management Plan. The QA Program applies in a manner which contributes to the safe, reliable, and environmentally sound operation of the SRS. It incorporates a graded approach commensurate with risk in the definition and application of QA/QC requirements. The QA Program provides for the prevention of errors as well as the detection and correction of deficient conditions and incorporates an assessment process for identifying opportunities for continuous improvement. The focus of quality improvement is to reduce the variability of every process that influences the quality and value of the WSRC's products or services.

2. WSRC-RP-92-225, "Quality Assurance Management Plan"

The WSRC Quality Assurance Management Plan (QAMP) describes the requirements and responsibilities for execution of the WSRC QA Program for implementing DOE O 414.1B and 10 CFR 830 Subpart A. American Society of Mechanical Engineers Nuclear Quality Assurance (ASME NQA)-1, "Quality Assurance Requirements for Nuclear Facilities" and other consensus standards are used in the development of the WSRC QA Program. The plan has been jointly approved by WSRC and DOE-SR and serves as the basis for the establishment of the procedures contained in this manual.

3. Procedure Manual 1Q, Quality Assurance Manual

This manual provides the structure and procedures for achieving and verifying the WSRC requirements for quality. The manual consists of a series of Quality Assurance Procedures (QAPs) which describe applicable quality assurance requirements.

Furthermore, *1Q Quality Assurance Manual*, page 4 states:

> The WSRC QA Program has been developed to be responsive to the requirements of DOE O 414.1B, Quality Assurance and DOE Safety Rule Title 10 CFR 830 Subpart A, Quality Assurance Requirements. Because of the size and complexity of the Savannah River Site (SRS) and its varied products, services, and missions, the program has been defined in a standard framework of company policy, procedures, and instructions to be used by the implementing organizations to perform quality-related activities. These documents shall, as a minimum, include all of the requirements of WSRC-RP-92-225, "WSRC Quality Assurance Management Plan (QAMP)" criteria for which the implementing organizations have responsibility.

1Q Quality Assurance Manual implements all the requirements stated above. A software quality assurance plan for Porflow was developed to satisfy the Software Quality Assurance Procedure 20-1 of the *1Q Quality Assurance Manual*.

PORFLOW Software Quality Assurance Plan Description

The PORFLOW Software Quality Assurance Plan (Collard, 2002) presents the software controls to be applied to PORFLOW. The plan also includes the results of the software grading and the testing and acceptance results. A description of applicable verification and benchmark test cases starts on page 26 of the plan (included in Appendix) (Collard 2002).

The plan relies on the "validation" test cases described in ACRi, Inc. 1994. The test cases provide comparisons with published analytical results and with benchmark cases commonly used by similar computer programs. The pertinent and applicable test cases are described and discussed in the plan. Because the results from ACRi, Inc. 1994 were analyzed using an earlier version of PORFLOW, modifications in input files were required by the vendor. In some cases, the models described by the modified input files for the new PORFLOW version did not exactly correspond with the models described by the original input files for the earlier PORFLOW version. A typical example is that the new version moves the boundary nodes from outside the physical model to the edge of the physical model, and in some cases this adjustment was not correctly implemented. An incorrect adjustment may result, for example, in a 710-foot model width versus the case width of 700 feet. All model results were compared graphically by ACRi, Inc. 1994 and even in the cases where the adjustments were not correctly implemented,

the model results almost matched the published case results. Discrepancies were discussed in the plan, (Collard, 2002) and were assessed as being insignificant.

Supporting Qualitative Evidence for Quality Assurance

While not directly included in the plan, widespread usage of the program and peer review provides additional confidence that the program works properly. The on-line PORFLOW user's manual (ACRi, Inc. 2005) attests to the usage and testing, where it states:

> **PORFLOWTM** is also distinguished from other computer models by the diversity of its users. Commercial, research and educational organizations in 15 countries are using the software. Among its users are: U.S. DOE, USGS, U.S.NRC, U.S.Army, Southwest Research Institute, Idaho National Engineering Laboratory, Oak Ridge National Laboratory, Savannah River Laboratory, Battelle Pacific Northwest Laboratory, ANDRA (France), SCK-CEN (Belgium), AECL (Canada), Westinghouse, Lockheed Martin, Fluor Daniel, Rockwell, and a large number of other commercial organizations. Over 100 publications and project reports on the benchmarking, verification and application of **PORFLOWTM** are currently available.
>
> **PORFLOWTM** has been extensively peer-reviewed. Idaho National Engineering Laboratory, Battelle Pacific Northwest, and Prof. Allan Freeze of the University of British Columbia have formally reviewed **PORFLOWTM** or its derivatives. Additionally, it has been reviewed by ANDRA (France), BAe-SEMA (UK), British Petroleum (UK), Exxon Production Research, Failure Analysis Associates Inc., Fluor Daniel Inc., Gaz de France (France), SAIC, Shell Oil, SOHIO, and Westinghouse Hanford Company.

The analyses in the 1992 Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (SA) (reference 3 in the NRC RAI) have been superseded by the Vault 4 SA (Cook et al. 2005). The NRC reviewer noted correctly that the PORFLOW runs performed in support of the 1992 Saltstone PA show a lack of convergence. It has since been determined that this lack of convergence was caused by the use of too large of time increments. In the 2005 Vault 4 SA small grids and time increments were utilized to assure convergence.

PORFLOW References

ACRi, Inc. 1994. Analytic and Computational Research, Incorporated, *PORFLOW Validation Version 2.50*. Bel Air, California.

ACRi, Inc. 2005. *PORFLOW User's Manual, Version 5.0, Rev:5,* http://www.acri-us.com/download/papers/PORFLOW.pdf

Collard, L. B., 2002. *Software Quality Assurance Plan for the PORFLOW Code*, WSRC-SQP-A-00028, Westinghouse Savannah River Company, Aiken, SC 29808, September 20, 2002

U.S. DOE 2001. *DOE M 435.1-1 Radioactive Waste Management Manual,*June 19,2001.

U.S. DOE 2004. *DOE O 414.1A, Quality Assurance*, September 29, 1999.

WSRC 2003. *1Q Quality Assurance Manual*, Procedure 20-1 Software Quality Assurance (and pages 4-5), Rev. 8, October 16, 2003

HELP Software Quality Assurance

The Hydrologic Evaluation of Landfill Performance (HELP) model is a quasi-two-dimensional water balance model designed to conduct landfill water balance analyses. The model requires the input of weather, soil, and design data. It provides estimates of runoff, evapotranspiration, lateral drainage, vertical percolation, hydraulic head, and water storage for the evaluation of various landfill designs. Personnel at the U.S. Army Engineer Waterways Experiment Station in Vicksburg, Mississippi developed the HELP model, under an interagency agreement with the United States Environmental Protection Agency (USEPA). HELP model version 3.07, issued on November 1, 1997, is the latest version of the model available from the Waterways Experiment Station. Documentation for the HELP model is provided in the following USEPA documents:

- USEPA (U.S. Environmental Protection Agency). 1994a. *The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3*, EPA/600/R-94/168a, Office of Research and Development, United States Environmental Protection Agency, Washington, DC. September 1994.

- USEPA (U.S. Environmental Protection Agency). 1994b. *The Hydrologic Evaluation of Landfill Performance (HELP) Engineering Documentation for Version 3*, EPA/600/R-94/168b, Office of Research

and Development, United States Environmental Protection Agency, Washington, DC. September 1994.

USEPA 1994b provides the assumptions and limitations associated with the HELP model. A substantial effort was made to provide verification of HELP model version 1.0 which has been documented within the following two USEPA documents:

- USEPA (U.S. Environmental Protection Agency). 1987a. *Verification of the Hydrologic Evaluation of Landfill Performance (HELP) Model Using Field Data*, EPA/600/2-87/050, Office of Research and Development, United States Environmental Protection Agency, Cincinnati, Ohio. July 1987.

- USEPA (U.S. Environmental Protection Agency). 1987b. *Verification of the Lateral Drainage Component of the HELP Model Using Physical Models*, EPA/600/2-87/049, Office of Research and Development, United States Environmental Protection Agency, Cincinnati, Ohio. July 1987.

Within USEPA 1987a, the following was concluded from the verification performed:

> Simulations of 20 landfill cells from seven sites were performed using the Hydrologic Evaluation of Landfill Performance (HELP) model. Results were compared with field data to verify the model and to identify shortcomings. … The field measurements of the various water budget components varied greatly from cell to cell despite some having identical designs. Consequently, the precision of the verification effort is fairly low, but the study demonstrates that the HELP model is a useful tool for realistically estimating landfill water budgets. Simulation results generally fell within the range of field observations.
>
> A sensitivity analysis of the HELP model was performed to examine the effects of the major design parameters on components of the water budget for landfills. Hydraulic conductivity values for the topsoil, lateral drainage layers, and clay liners are the most important parameters in determining the water budget components. These parameters are particularly important in estimating the percolation through the landfill.

> Based upon this verification modifications to the model have been made to improve predictions. Version 3.07 of the HELP model, issued on November 1, 1997, is the most current version. Based upon this extensive HELP model documentation and verification, it has been accepted by the USEPA and the regulated community as an appropriate water balance model for the examination of landfill designs.

In general, for problems that are simple extensions of previous problems, such as examining an additional nuclide, the PI need do no further testing. For new problems, the PI reviews the test cases that were documented to see if they adequately address the requirements for the new problem. If previous test cases are sufficient, then the PI documents that fact with some justification. If previous test cases are sufficient, then the PI documents that fact with some justification. If previous test cases are not sufficient, then the PI executes new test cases and documents the results either before modeling the new problem, or in parallel with the new problem, although there is some risk in performing both in parallel.

CONCLUSIONS OF VALIDATION TESTING

PORFLOW has been tested previously by international experts such as Allan Freeze and by the Southwest Research Center for the Nuclear Regulatory Commission (Collard,1998).

Some of the casas for which PORFLOW has been validated are as follow:

- Vadose zone flow problems with multiple soil types
- Vadose zone contaminant transport problems with multiple soil types and simple chemistry
- Aquifer flow problems with multiple soil types
- Aquifer contaminant transport problems with multiple soil types and simple chemistry.

Cases with contaminant sources were documented. Multiphase and nonisothermal cases were not documented.

The high level of testing by experts and the extensive test cases included indicates that PORFLOW has been applied for SRS cases with the expectation of correct program performance.

APPENDIX - Applicable Verification and Benchmark Test Cases-This Appendix is a quote from the reference (Collard, 2002)

"DESCRIPTION OF APPLICABLE VERIFICATION AND BENCHMARK TEST CASES

Each test case that directly affects the use of PORFLOW at SRS is described below. Of special interest are those test cases that include the flow of water in the vadose zone and the aquifer and the transport of contaminants by diffusion and advection.

Given the above-stated PORFLOW changes and the requisite changes in the input files, each applicable verification and benchmark test case will be described in further detail.

<u>Verification Test Cases</u>

The verification cases are generally simple and can be compared to analytic solutions.

<u>*Verification Test Case 3*</u>
Verification Test Case 3 examines the Theis solution for transient drawdown. On the GRID command line the descriptor NODES was added. This ensures that the numbers on the command are interpreted as nodes rather than corners and provides consistency between old and new versions of PORFLOW. This descriptor appears throughout most of the test cases and will not be discussed further.

The first node was moved from 0.0 to 0.25 (halfway between the original 0.0 and 0.50) but the last node at 2000 was not moved to 1900.0 (halfway between the original 1800.0 and 2000.0). This likely caused little change in the results and it is unknown which, if either set of input is accurate.

On the BOUNDARY command line for Y, the "-2" was replaced by "Y-" as required. The DIAGNOSTIC and OUTPUT commands were changed with no impact on actual results, because the key information was saved in the archive file, "V3.ARC."

<u>*Verification Test Case5*</u>
Verification Test Case 5 involves coupled flow and heat transfer in a regional flow system. While isothermal models are typically executed at SRS, results from a nonisothermal case that involves flow is applicable in that it demonstrates that the flow portion operates correctly.

For this test case the number of nodes was increased from 41 by 41 to 42 by 42. Rather than specifying the location for each node, the RANGE command was used as a substitute. These develop an identical model, except that in the second case the mesh is finer. Of possible concern would be the location of sources, however, only boundary conditions are applied. The boundary conditions changed according to the convention of "-1" changing to "X-", etc. The nonzero gradient for temperature at the lower Y boundary correctly switched signs. Finally, some of the output specifications were modified.

Verification Test Case 6

Verification Test Case 6 involves three-dimensional transport of a contaminant, which is very important to SRS modeling. It consists of a homogeneous, isotropic medium with an infinite horizontal source on the upper surface and a constant horizontal flow. This case very closely mimics most aquifer cases developed at SRS, except that the more complex subsurface consisting of multiple material types is lacking.

For this case, both sets of input coordinates are consistent, but are slightly incorrect. The extent of the X-direction is described as being 3700 m long. The coordinates ranged from –700 to 3000 in both cases. However, they are node locations by default for the older PORFLOW version and are node locations in the newer PORFLOW version by the NODE descriptor (corners are the default), rather than the desired corner locations.

Similarly the extent of the Y-direction is described as being 800 m long. The original node coordinates ranged from –10 to 800. This placed the lowest node in the range at the correct location because the corner of the physical model would be at zero, halfway between –10 and +10 for the first and second nodes. However the upper corner would be at 745, halfway between the 800 and the 690 of the next to highest node in the range. The more recent data set extends from 0 to 800 but it specifically calls out the data as nodes, which is incorrect because it should have been corner data.

The extent of the Z-direction is described as 56 m. The original data ranged from -56 to 0.05. Only the upper node is at the correct location because the corner would be at zero, halfway between –0.05 and +0.05. The new data ranges from –50 to 0 as nodes. This is incorrect because the lower location has been changed from –56 to –50.

The boundary conditions are set to zero flux at all boundaries except the lower X boundary where the concentration is set to zero. This caused the input line to be changed from "-1" to "X-". However, PORFLOW changed the definition of the flux condition on a boundary command. Originally the flux option meant that advection could still move contaminants across the

boundary, but in the more recent PORFLOW versions, even this is prevented. Typically contaminants are transported to a boundary but cannot penetrate it, thus they rapidly accumulate at the boundary. If only results in the interior of the model are important, then this effect is minor only affecting the mass balance.

The geometric property was omitted in the newer version, thus the calculation of the properties of the host porous matrix at the element interface would default to the harmonic mean.

Integration of the concentration by the CONDIF approach was omitted in the newer version. The CONDIF approach as described in Runchal, 1997 is provided below.

"The numerical integration starts with the assumption of an integration profile for the state variable. Two different kinds of profiles are employed. These are the first- and second-order polynomial profiles and the exponential profile. These integration profiles result, respectively, in the 'upwind', and the central difference and, the exponential schemes. The first two are schemes combined in a hybrid scheme. The central difference scheme, which provides second-order accuracy, is the preferred scheme. However, use of the central difference scheme may result in numerical instabilities if the magnitude of the local value of the grid Peclet number exceeds 2. With U, δL and Γ, respectively, as the velocity component, grid interval and diffusivity in a given direction, the grid Peclet number, Pe, is defined as:

$$Pe = U \ \delta L / \Gamma. \qquad (4.2.1)$$

The local value of the Peclet number at each grid node is constantly monitored in each direction. If $Pe > 2$, then the numerical scheme automatically shifts to the 'upwind' formulation. This method of enhancing stability is known as the hybrid scheme (Runchal, 1972). The hybrid scheme has second-order accuracy if the $Pe < 2$; otherwise, it is only first-order accurate. Because upwinding results in an increasing amount of numerical diffusion as the angle between the velocity vector and the grid lines increases, PORFLOW™ allows the use of an exponential numerical scheme (Spalding, 1972) to represent the exact solution of the one-dimensional form of transport equations without sources. Th eexponential scheme cannot be accurately classified; however, in practice, it is known to decrease numerical dispersion if the flow is primarily unidirectional and source terms are small. Otherwise, its accuracy is comparable to that of the hybrid scheme. An alternate method to obtain numerical stability with second-order accuracy is that of the CONDIF scheme (Runchal, 1987b) which is a modified central-difference scheme. It is a

second-order member of the TVD family of numerical schemes (Harten 1983) that leads to an unconditionally stable formulation. A third option which is available is that of a version of the QUICK scheme (Leonard 1979) which has been adapted for nonorthogonal grids.

The user controls the method of evaluation of the integrals, which is equivalent to the selection of a 'basis function' in the finite-element technique. For most problems, the hybrid scheme is sufficient. If the grid is very coarse, then the CONDIF or the QUICK scheme should be employed.

ACRI 1994 states:

> The maximum Peclet number for the grid employed is 5.5 and themaximum Courant number is 0.04. Since the Peclet number is almost three times the desired value of 2, some numerical errors may be present. These results could be improved by smaller grid size.

Personal communication with Runchal indicated that results from the newer PORFLOW version were in close agreement with earlier results. Thus, in spite of removing the CONDIF control that helps compensate for a coarse grid the results were quite reasonable.

The text states that the problem is symmetric in the lateral (y) direction, hence only half the domain was simulated. The text and the figure show a domain of 800 m with the source in the center. If only half the domain in the y direction were modeled, the model would encompass only 400 m, but the input file encompasses 800 m, thus the text and the input file are inconsistent.

No original convergence criteria were specified thus it defaulted to 0.001. The revised convergence was 1.E-7, which is much tighter.

Minor changes to the diagnostics, history and output selections were noted. The solution originally was set to about 1.58E8 seconds in uniform steps of about 3.15E4 seconds. The revision started with steps of 2.E3 seconds that increased to a maximum of 5E6 seconds. These are all subjective. While the magnitude of the Courant number would increase, if the problem has stabilized by the time it becomes large, there should be minimal effect on the final results.

Verification Test Case 7

Verification Test Case 7 involves Philip's horizontal unsaturated flow case where a wetting front is initiated by a pressure change at one boundary. Primarily, only minor changes were noted in the GRID command, and

adjusting the BOUNDARY command, the DIAGNOSTIC command and the OUTPUT command. The extent in the X-direction should be 20 cm, but because node locations are used the actual extent of the physical model is shortened slightly.

Verification Test Case 8

Verification Test Case 8 involves Philip's vertical unsaturated column that is similar to the Philip's horizontal column, but the column is vertical so that capillary and gravity forces can take effect. In both cases the range for the Y coordinate is set to 15 cm. In the original version of PORFLOW, the default was for nodes, which generated a slightly shorted physical domain. In the newer PORFLOW version, the default is for corners, which matches the physical domain with the text. Minor changes are apparent in that the order of some commands has changed, the BOUNDARY input has been modified and the DIAGNOSTIC and OUTPUT commands have been adjusted.

Verification Test Case 9

Verification Test Case 9 involves steady-state infiltration from a line source to a water table. This case involves modeling the vadose zone with the water table as its lower boundary, similar to the vadose zone modeling at SRS.

Here the coordinates are specified by the range option. The range option in the original PORFLOW version used corners rather than nodes as the default (contrary to statements in the user's manual). Both data sets for coordinates are correct.

Minor changes to the GRID command, BOUNDARY commands, the DIAGNOSTIC command and the OUTPUT command were noted between the two sets of input files. The boundary condition for the pressure at the Y-face changed from "interface" to "value." The original PORFLOW allowed the user to prescribe a value at the node with "value" or a value at the element interface, i.e., at the edge of the physical model with "interface." Because the newer version of PORFLOW moves the location of the boundary node to the edge of the physical model, the "value" and the "interface" are synonymous and are equivalent to the previous "interface." "Interface" has been omitted from the newer PORFLOW, so older input sets that relied on the "value" may produce different results if used with the newer PORFLOW.

The relation between the pressure and the saturation is expressed as a Brooks & Corey relationship in the original data set, but as an exponential relationship in the subsequent data set.
For a steady-state solution the difference apparently has minimal effect on the final results.

Verification Test Case 10
Verification Test Case 10 involves free-surface Boussinesq flow with recharge from one side in a semi-infinite, unconfined aquifer. The extent of the model in the X-direction is 200 m. Both data sets employ a minimum and maximum for the X that apparently properly describes the physical model. However, the earlier version of PORFLOW used a default of nodes, thus the physical model would have been slightly smaller than the defined model. The Y-direction had an extent of 11 m. The original model prescribed nodes that extended from 0 to 11.1. The physical boundaries would have been from 1 to 11, or only 10 m in extent. The more recent data set prescribes nodes from 0 to 11, and because the boundary nodes in the later PORFLOW are aligned with the physical model boundaries this prescription is correct.

Initial conditions were originally prescribed with the INITIAL command. The more recent version uses a combination of the SET command and a BOUNDARY command with the same effect.

The convergence is tightened from 1E-6 to 1E-10 in the later data set, although the maximum number of iterations is reduced from 1000 to 25 producing a tradeoff.

The BOUNDARY command, DIAGNOSTIC command and the OUTPUT command are modified. The DIAGNOSTIC command is misspelled as DIAGNOSITC in both versions, but PORFLOW only relies on the first four characters, thus the operation of the model will not be affected.

Verification Test Case 11
Verification Test Case 11 involves free-surface Boussinesq flow with seepage from the surface in an unconfined aquifer. All the comments for Verification Test Case 10 apply here.

Benchmark Test Cases

The benchmark test cases produce solutions that are compared to solutions from other computer codes, because typically the cases are too complex to afford analytic solutions. All the test cases "have been used previously for validation of other computer codes" (ACRI, 1994). Having test cases that were important enough to use for validation of other computer codes indicates that they are excellent candidates for the PORFLOW validation.

Benchmark Test Case 1
Benchmark Test Case 1 involves two-dimensional transient infiltration. The model size is described as being 15 cm in the X-direction and 10 cm in the Y-direction. The original data set provided a minimum and a maximum for the X-direction as 0 and 0.15 m. Given the default of nodes, the size of the physical domain would be slightly short, by 0.01 m. The Y coordinate was described as a range of 0.1 m, which would be correct. For the later PORFLOW version, because the boundary nodes are aligned with the edge of the physical model, the same BOUNDARY commands with the NODE modifier produce a correct model.

Other minor changes are found in the BOUNDARY command, the DIAGNOSTIC command and the OUTPUT command.

Output results were compared with results from the TOUGH computer program.

Benchmark Test Case 2
Benchmark Test Case 2 involves two-dimensional steady-state infiltration. The model size is 150 m in the X direction and 35 m in the Y direction (the figure shows a Y range of 42 m). The original data set had a range in the X coordinate from 0 to 150 for the nodes. It would have ranged from 2.5 to 147.5 for the physical model or only 145 m, rather than the intended 150 m. The Y coordinate ranged from –0.1 to 36 for the nodes. The range for the physical model would have been 0 to 35, which was correct.

The newer data set defined ranges that were correct. The newer data set increased the number of nodes in the X-direction from 31 to 32. This helped align the corners (or cell faces) at 5 m intervals. The number of nodes in the Y-direction remained at 33. The original data set had distances between node locations that varied from 0.2 m to 2 m to provide better resolution near the location of the phreatic surface. Specifying a range forces all distances to equal values and that resolution is lost.

The older version specified a datum of 0,0 while none was specified for the newer data set, but because the defaults are zero these are equivalent.

The BOUNDARY commands were changed to reflect the new format. The boundary condition along the upper X boundary was correctly applied by increasing the location from 31 to 32 that matched the number of nodes in the X direction. The boundary condition at Y+ was a flux of –1 in the original (downward) and +1 in the newer data set (into the domain which is downward).

The convergence criterion was loosened from 1E-5 to 1E-3 with a maximum iteration count changed from a default of 100 to 500. The original data set required that the problem be solved for 4 years while the late data set required a steady state solution. As long as a satisfactory solution is achieved, the convergence criterion difference is not important.

The output region for the newer data set was selected for nodes 1,1 to 999,999 with an interval of 2,2. This allowed half of the data to be skipped. PORFLOW allows the 999,999 upper limit even though the size of the problem domain is only 32 by 33.

The results from this test case were compared with FEMWATER results.

Benchmark Test Case 3

Benchmark Test Case 3 is a simulation of the Jornada Test Trench in an extremely dry heterogeous soil. The area was heavily instrumented and infiltration experiments were conducted. This case qualifies both as a validation case and as a short-term field validation case. Because the SRS site is a much wetter site the value of the field validation is limited. However, it is much more difficult to simulate extremely dry conditions thus this is a challenging test case.

The extent of the model is 800 cm in the X direction and 650 cm in the Y direction. The original data set had a range of X-direction nodes from –5 to 820 and X-direction corners from 0 to 800 that properly described the physical model. Similarly the range of Y-direction nodes was from -655 to 5 and X-direction corners from –650 to 0. The newer data set took advantage of the boundary nodes' locations at the edge of the physical boundary and placed the lower and upper nodes at the proper locations of 0 and 800 for the X direction and –650 and 0 for the Y direction.

The BOUNDARY commands were modified to conform to the new convention. The flux for the pressure equation at the upper Y boundary was a

–2 cm/day in the original data set (downward) while in the newer data set it was +2 cm/day (inward), but it is also downward.

The DIAGNOSTIC command was modified to report less often and its location was moved.

Two convergence criteria were provided in the newer data set, but none in the original data set. One CONVERGENCE command is for FLOW that is not described in either user's manual, although an example is provided in the newer user's manual. The CONVERGENCE command for pressure in the newer data set is equivalent to the default criterion.

This benchmark case was compared to results from the FLASH code and the TRACER3D code.

NRC Comment 18: Quality assurance (QA) implementing procedures are not adequately described for data verification.

Basis: The models, processes, and decisions rely on a large variety of documents, as well as other sources such as databases. The quality assurance implementing procedures that have been applied to the work have not been adequately presented, nor have examples of the implementation of the aforementioned procedures been provided. Some values, such as inventory values, are the result of a number of calculations that are not easily verified. Additionally, a list of editorial comments and potential errata are found at the end of this request for additional information.

Path Forward: The QA implementing procedures applied to References 1-4 should be provided and summarized. The application of the implementing procedures should be demonstrated by providing appropriate document and data review packages.

SRS Response: Federal Rule 10 CFR 830.120, Subpart A establishes quality requirements for Department of Energy (DOE) contractors conducting activities, including providing items and services that affect, or may affect, nuclear safety of DOE facilities. The Department has also developed DOE Order 414.1B, "Quality Assurance" and its associated manuals to ensure quality assurance for all products and services provided by DOE and its contractors. DOE contractors are required to via the S/RID process to identify and incorporate the requirements of 10 CFR 830 and DOE Order 414.1B in their company-level procedures and processes. At SRS, DOE-Savannah River has developed a Quality Assurance Program (QAP) Manual (SRM 414.1.1.C) which describes its quality assurance program as required by DOE Order 414.1B. The commercial consensus standard upon which the DOE-Savannah River QAP is primarily based is ASME NQA-1-2000, "Quality Assurance Requirements for Nuclear Facility Applications."

For Westinghouse Savannah River Company (WSRC), the DOE prime contractor at SRS, the QA implementing procedure for performing reviews of technical work is found in SRS Procedure E7 Conduct of Engineering Manual, Procedure 2.60, *Technical Reviews* (WSRC, 2005). The end use of data drives the level of review required. Design Verification, the highest level review, must be performed for work affecting Safety Significant/Safety Class systems. Design Check is the next lower level of review and is required for all Production Support (PS) and General Service (GS) design output documents. Because the work associated with the Performance Assessment and associated documents are not associated with Safety Significant or Safety

Class systems, the Design Check represents the appropriate level of rigor; NRC RAI references 1-4 were reviewed at the Design Check level.

A design checker assures the technical accuracy of the design document by performing the following Design Check activities:

- A mathematical check, if appropriate;
- A review for correct use of technical input, including quality requirements;
- A review of the approach used and reasonableness of the output; and
- An administrative check (page numbers, etc.)

A design checker must meet the following criteria to perform a Design Check:

- Did not participate in the development of the portion of the document being checked;
- Is knowledgeable in the area of the design or analysis for which they review;
- Is capable of performing similar design or analysis activities; and
- Has security clearance for access to sufficient information to perform the Design Check.

Between 2002 and 2004 the Savannah River National Laboratory (SRNL) developed, piloted and then implemented technical review guidelines incorporating the E7 Manual requirements for performing Design Checks and Design Verification by document review (WSRC, 2004a). These guidelines also meet the requirements for review of Type 2 Calculations contained in Manual E7, 2.31, *Engineering Calculations* (WSRC, 2004b). The guidelines provide a flowchart to map the SRNL technical review process, lines of inquiry for performing reviews, a checklist for communicating instructions and best management practices to set a benchmark for management expectations (see Attachment 18-1 for examples).

Current modeling and supporting studies in the latest Saltstone Special Analysis (Cook et al. 2005) were reviewed using the SRNL Design Check guidelines. A selection of these review packages has been attached to demonstrate application of the SRNL technical review process. The 2005 Special Analysis, which supplements the 1992 Performance Assessment and supersedes the 2002 Special Analysis, has also undergone internal WSRC management and customer reviews as well as review and approval by DOE-SR. DOE-SR augmented its review by including a member of DOE's Low-Level Waste Federal Review Group from the DOE Nevada Field Office.

References:

WSRC, 2005. SRS Conduct of Engineering Manual E7, Procedure 2.60, *Technical Reviews*, Revision 6, 3-25-05.

WSRC, 2004a. *Savannah River National Laboratory Technical Report Design Check Guidelines*, WSRC-IM-2002-00011, Revision 2, August 2004.

WSRC, 2004b . SRS Conduct of Engineering Manual E7, Procedure 2.31, *Engineering Calculations*, Revision 8, 12-10-04.

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U),* WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. March 31, 2005.

ATTACHMENT 18-1

Examples of Design Check Packages

VADOSE ZONE PORFLOW DESIGN CHECK
Work by Andy Yu, Check by Sebastian Aleman
(Saltstone Vault 4 Special Analysis, WSRC-TR-2005-00074, Section 2.0)

1. The half-life of Np-239 used in the analysis was not converted from days to years. I traced the error back to Greg Flach's spreadsheet. Update the half-life and specific activity of Np-239 in the Am-243 and Cm-247 decay chains.

Revised half-life for Np-239.

2. The half-life of Nb-95m used in the analysis was not converted from hours to years. The correct value was found in Greg Flach's spreadsheet. Update the half-life and specific activity of Nb-95m in the Nb-95m decay chain.

Revised half-life for Nb-95m to 9.88E-03.

3. A VALU= 0 boundary condition was applied at the watertable (Y- boundary) for all vadose zone transport runs. This boundary condition sets the convective flux at the watertable to zero and only allows diffusive flux at the watertable. The natural and appropriate boundary condition at an outflow boundary (watertable) is to numerically compute both convective and diffusive fluxes. This is implemented in PORFLOW by not specifying any boundary condition at Y-. You cannot arbitrarily decide which part of the physics should be turned on or off. It is not appropriate or good physics to turn off either convective (VALU=0) or diffusive flux (GRAD=0) at the watertable. I do not support the (VALU=0) or (GRAD=0) boundary conditions at the watertable.

We will use the Gradient = 0 boundary condition for the production runs.. Test runs have shown that this give the same result as the "no boundary condition" case, but it produces a mass balance error of 0.02% rather than 2.5 %. This boundary condition is documented in the PORFLOW manual.

4. The FC array (convective flux at face) was not updated for time periods TI02 to TI08 during postprocessing of the START.ARC input files. The impact was that the convective fluxes for time period TI01 were used for all vadose transport runs. To avoid this error in future runs, a single PORFLOW transport run can be generated for each species where the appropriate steady-state flow field is read in when there is a change in the flow field. This has been discussed and you now know how to implement this feature.

The technique for running a number of flow fields within one transport run has been implemented, and will be used for the production runs.

5. There should be a consistent methodology for implementation of the Pu special chemistry redox model. Your implementation is different from what I have reviewed in the past. The previous design checks I performed had the parent of Pu decaying to Pu in the (3,4) oxidation state (f1=1 and f2=0). The impact is minor but there should be a consistent approach across all analyses.

This was a refinement Greg and I came up with during his design check.

6. There is no need to specify a half-life for NO3. Just remove that statement from the input deck.

The half life value for nitrate has been removed.

7. For each time period, specify an appropriate time frequency for writing out the contaminant flux to ensure that there is sufficient temporal resolution to capture the peak in the contaminant flux to the watertable. I also suggest that you use all contaminant flux points that were generated for the entire vadose run as the source term to the aquifer runs. Do not try to sample or filter any of the points generated. We need to see the whole time history of the contaminant flux to the watertable. Not a filtered subset.

The 100 data points used were sampled from thousands of output record. The resulting curve is smooth and continuous and represents the results with the required degree of accuracy. While the computational power exists to use all of the output data, there is little benefit to doing so for this project. This comment is noted and will be considered for future work.

8. Choose timesteps that are reasonable. Most of your transport runs start with timesteps of 1e-9 years.

An initial time step if 1E-6 years will be used in the production runs.

9. What is the rationale for choosing which decay chains will be analyzed and where to terminate the chain (reference)? For example, the Pu-238 chain terminates with U-234 which has a half-life of 24600 years. U-234 is also analyzed as a parent with 4 progeny. Should not the U-234 chain be continued when analyzing the Pu-238 as a parent? I think this is especially important if you plan to run simulations beyond 10000 years.

This issue is being addressed as a sensitivity study. The decay chains used currently are those that we have been using for many years.

10. All simulations should be run beyond reaching the peak contaminant flux at the watertable to ensure that the peak concentrations at the 100m well are reached for all parent and progeny. A 10,000 or 1,000, 000 simulation time may not be sufficient to capture all the peak contaminant fluxes at the watertable.

The current guidelines for performance assessment calculations are that they will be done for a 10,000 year time of assessment. Therefore, the production runs are set up to do just that. We plan on conducting a sensitivity study to look at longer time periods. Runs will be made on selected species for times out to a million years as part of that work.

Design Check Instructions for Groundwater Saturated Zone Flow and Transport Calculations for the Vault 4 Special Analysis

Work by Andy Yu, Check by Sebastian Aleman

(Saltstone Vault 4 Special Analysis, WSRC-TR-2005-00074, Section 2.0)

Requirements for performing reviews of technical reports are defined in Procedure Manual E-7, 2.40, "Design Verification and Checking", and the complementary manual WSRC-IM-2002-00011 Rev. 1 "Technical Report Design Check Guidelines" provides additional guidance. General lines of inquiry are defined in Table 1 of the latter. The purpose of these instructions is to define specific lines of inquiry appropriate for the Vault 4 Special Analysis. The specific instructions given below are intended to supplement the general lines of inquiry, rather than constrain the scope of design checking.

Groundwater Analysis

Following a general inspection of the groundwater pathway analysis and associated PORFLOW input and output files, the following specific checks are requested. A spot check of one radionuclide and inventory will typically be a sufficient check that pre- and post-processing algorithms/software are working correctly.

1. A rock porosity of 0.42 is specified in all the saturated zone transport decks. This value is inconsistent with the GSA_PORFLOW value of 0.25. Please update all input decks to use 0.25.
2. There is no need to scale the fractional release by the total volume of the source nodes when you generate the SOUR.DAT file. The SOUR command with the TOTA and VOLU modifiers will distribute the fractional release to each source node based on the ratio of the volume of the source node to the total volume of source nodes. You can still scale by 10^{12} to get you to pico-mole.
3. I still recommend no sampling of data points when generating the SOUR.DAT file. There are negligible run time differences between a 100 point sample and the full dataset of points. If you wish to invoke your 100 point sampling, please generate a Tecplot file using your post-processor which contains two zones. One zone containing the 100 point samples, the other zone containing all the data points.

<u>aquifer flow</u>

- *verify that the volumetric flow rate (FC) and saturation (S) fields computed for the refined zoom-in grid are consistent with those from the GSA_PORFLOW flow model*

  The volumetric flow rate (FC) array interpolated from the GSA_PORFLOW to the refined zoom-in model is correct based on 3-D particle tracking comparisons. Direct comparison of the FC arrays for both models is not a trivial task. Since the velocity components (u, v, w) are computed from the FC array, an indirect comparison would be to view 3-D particle tracking (stream traces) from the same (x,y,z) positions in both models. Figures 18-1 and 18-2 show 3-D stream traces from source nodes in Vault 1 and Vault 4, respectively, for the

GSA_PORFLOW model. Figures 18-3 and 18-4 show 3-D stream traces from source nodes in Vault 1 and Vault 4, respectively, for the GSA zoom model. A comparison of Figures 18-1 and 18-3 using 5-year timing markers shows excellent agreement for Vault 1. A comparison of Figures 18-2 and 18-4 using 5-year timing markers shows excellent agreement for Vault 4. These results give good confidence that the FC array was interpolated correctly to the zoom-in model.

The water saturation array (S) is spot checked by looking at a subset of the node locations near the watertable. The following table shows the comparison.

x (feet)	**y (feet)**	**z (feet)**	**GSA_PORFLOW Saturation**	**GSA Zoom Saturation**
21450	11850	230.822	0.557	0.837
21450	11950	231.405	0.466	0.837
21650	11550	230.306	0.464	0.568
21350	11750	230.110	0.661	1.000
21350	11750	225.479	0.947	1.000
21350	11750	222.158	1.000	1.000

The GSA Zoom model water saturations appear to be higher than the GSA_PORFLOW values. The differences are probably due to cell size (coarse to fine) and interpolation.

<u>aquifer transport</u>

- *verify that the contaminant flux transient assigned to aquifer source nodes has been correctly computed from vadose zone simulation output*

  Since the vadose zone simulations have not been completed, verification will be deferred until the Tecplot files showing the 100 sample points and the full dataset are available for each vadose zone run.

- *verify that the aquifer source nodes have been correctly defined*

  All the aquifer source nodes are located within the areal extent of Vault 4 (see Figure 18-2 stream trace origins). Nine out the twelve source nodes are located in fully saturated cells. The following three aquifer source nodes are located in partially saturated cells.

I	J	K	Saturation
14	14	14	0.8366
14	15	14	0.8366
16	11	14	0.568

This is a departure from the current methodology for selecting aquifer source nodes. That is, selecting the first cell top to bottom that is completely saturated.

Stream traces from Vault 1 (Figure 18-1 or 18-3) indicate an advective travel time under 10 years to reach Vault 4. What is the impact of upstream potential sources from Vault 1 on plume interaction with Vault 4?

- *verify that nodes representing a maximum concentration outside a 100 foot (for nitrate) or 100 meter (for radionuclides) buffer zone have been adequately identified*

The nodes representing the maximum concentration outside a 100 foot or 100 meter buffer zone are shown in Figure 18-5. I cannot determine at this time if these nodes are adequate to capture the maximum concentration until a small subset of aquifer runs with revised internal sources are executed and results from the STAT command are reviewed.

- *spot check that post-processing steps to calculate limits have been correctly performed*

There are no post-processing steps available to the design check to adequately determine whether limits have been correctly calculated. The design check does not have access to the algorithms or the software used by the modeler to calculate limits.

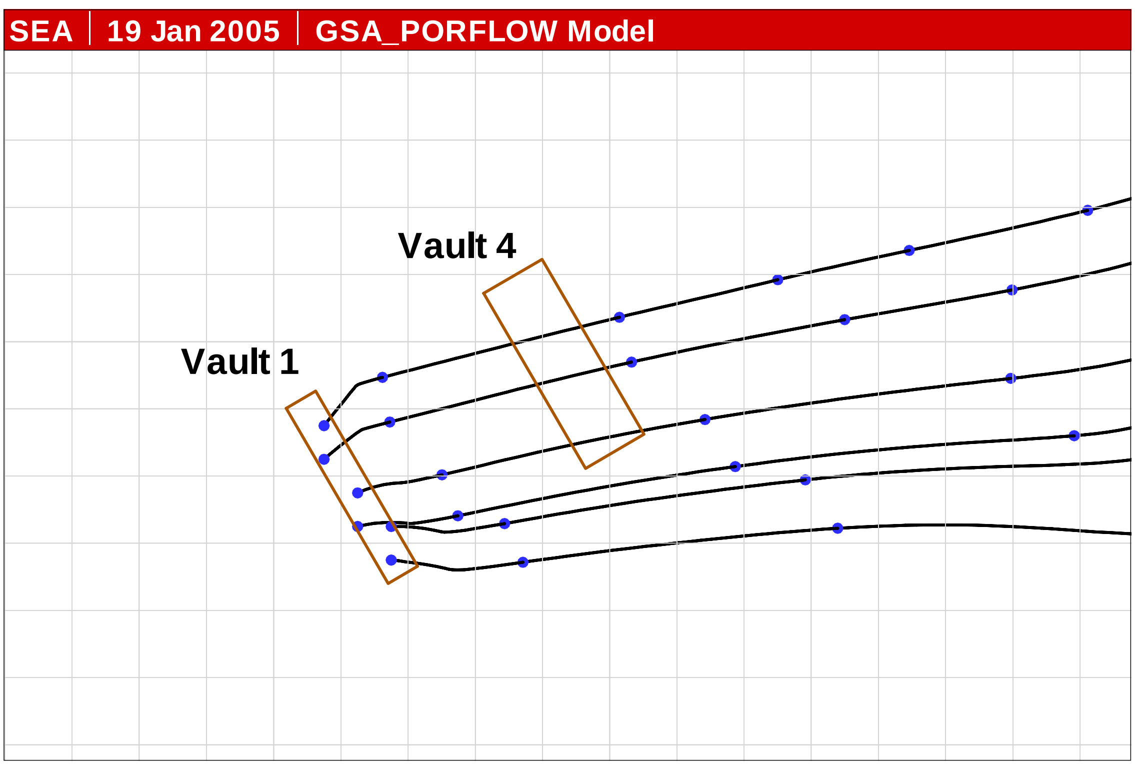


Figure 18-1.3-D stream traces from Vault 1 with 5-year timing markers for the GSA_PORFLOW Model

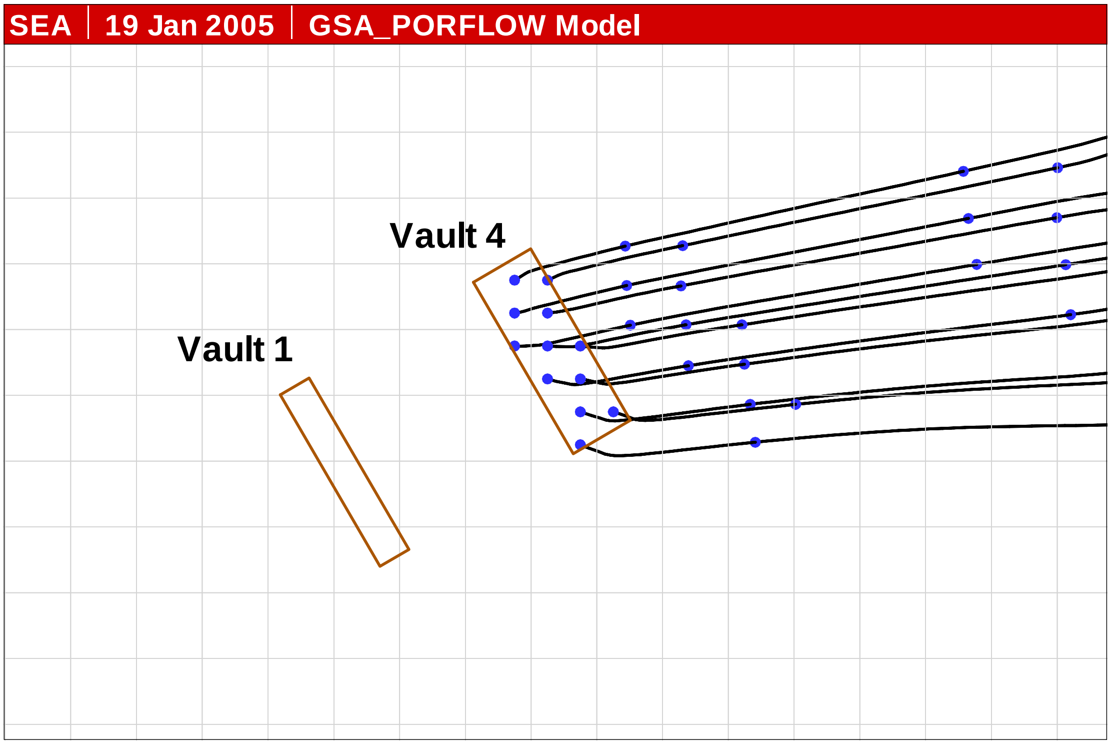


Figure 18-2. 3-D stream traces from Vault 4 with 5-year timing markers for the GSA_PORFLOW Model

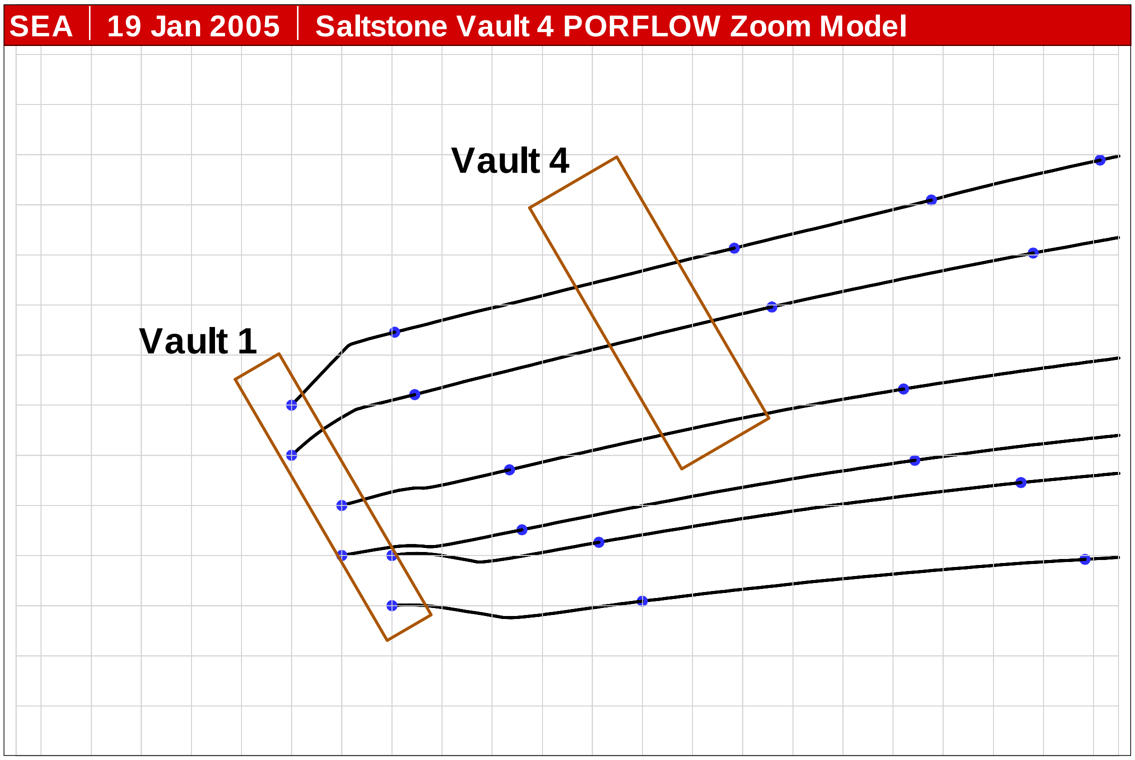


Figure 18-3. 3-D stream traces from Vault 1 with 5-year timing markers for the GSA Zoom Model

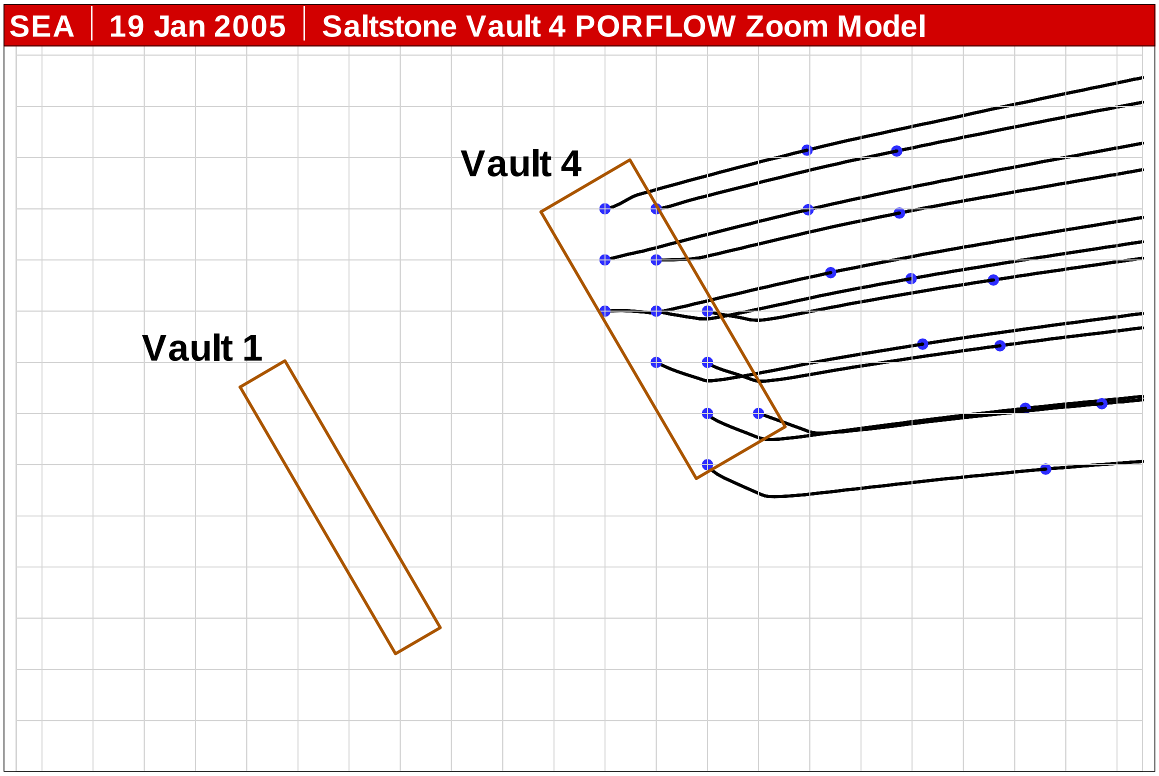


Figure 18-4. 3-D stream traces from Vault 4 with 5-year timing markers for the GSA Zoom Model

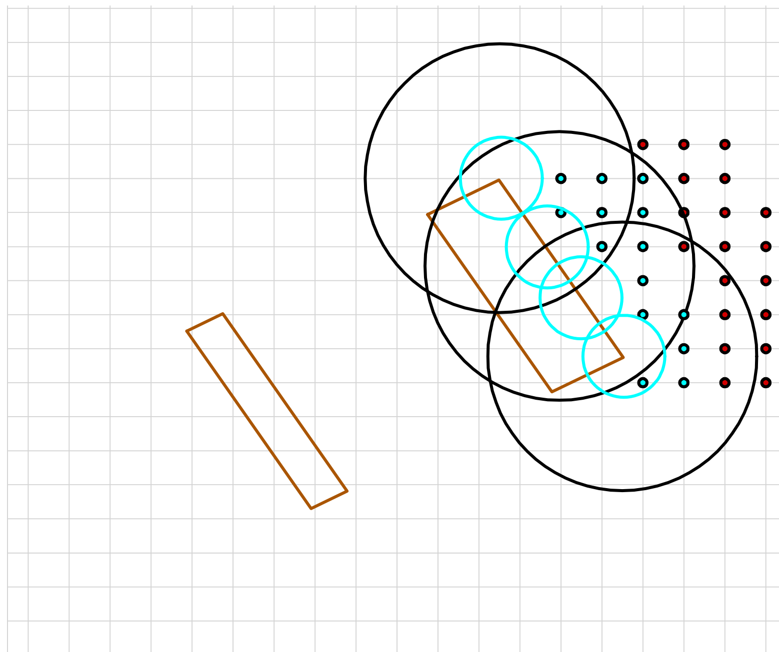


Figure 18-5. 100 foot and 100 meter well locations relative to Vault 4

Sebastian Aleman/WSRC/Srs
03/01/2005 10:28 AM
To
Tom Butcher/SRNL/Srs@Srs, Jim Cook/WSRC/Srs@srs
cc

Subject
Design Check of SDF Vault 4 Input Decks

I have completed my check of the SDF Vault 4 input decks for the vadose and aquifer runs. My suggestions were correctly implemented and I found no errors in the input desks.

Thanks

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Intruder Design Check
Work by Jim Cook, Check by Larry Koffman
(Saltstone Vault 4 Special Analysis, WSRC-TR-2005-00074, Section 3.0)

January 26, 2005

To: Jim Cook

From: Larry Koffman

Design Check of Intruder Calculations for Saltstone Vault 4

Per the design check instructions, I have checked the inputs for Saltstone Vault 4 and find that the inputs are correct per the referenced documents.

- The volumes and geometry factors for both vaults agree with the information given in document WSRC-TR-2002-00456 by Cook et al.
- The closure cap configuration given in Table 4.7-1 of the document by Phifer and Nelson (2003) shows that the transient layer model may be represented as a 36" soil cover above a 12" erosion barrier followed by various materials that can be summed to represent a 107" backfill.
- The clean pour and roof have variable thickness but the 18" minimum that you obtained by personal communication from Tim Chandler represents a conservative value to use.

The above inputs are correctly used in the input file *DisposalUnitInput.xls* as reproduced in Table B-2.

I have checked your results provided against my own independent calculations and have confirmed that you ran the Intruder application correctly for all three cases: resident scenario from 100-1000 years, resident scenario from 100-10000 years, and post-drilling scenario from 1000-10000 years. As you note, for the post-drilling scenario to be run, the degradation time for the Concrete/Grout layer in Table B-2 must be set to zero (in the input file *DisposalUnitInput.xls*) and the institutional control time must be set to 1000 within the application. For your information, I provide an explanation below of why this must be done with the current version of the Intruder application.

I checked your draft document SA App B 012005_jrc.doc and have confirmed that Tables B-3, B-4, and B-5 contain the correct results for the scenario listed in each table heading.

Prior to Table B-3 I suggest that you add an explanation of the entry "---" that appears in the tables. Following is a suggestion that you can adapt as desired.

> In the following tables the entry "---" in the Time of Limit column means that the dose calculation is always zero so there is no limit. For cases where there is a time given, there may be an entry "---" in one or both of the limit columns. In this case the entry "---" indicates a limit value greater than or equal to the threshold value of 1E+20.

The Word document *Components_Case3.doc* gives the detailed contribution from each member of a parent's decay chain and I have verified that the files you provided for the three scenarios are correct should you decide to use these.

How to Run the Post-Drilling Scenario for Vault 4

The current version of the Intruder application has a transient layer model that was designed to mimic assumptions used in previous intruder analyses. It incorporates erosion of soil-like material over time and it incorporates degradation of impenetrable material, such as grout, such that it becomes soil-like after some period of time. However, the current model assumes that the degradation of impenetrable material does not begin until the material is exposed, i.e. until all material above it has eroded. Because the erosion barrier remains intact, the grout in Vault 4 is never exposed and thus never degrades according to the current model. Since the grout remains impenetrable, the post-drilling scenario can not occur within the 10,000 year period of interest.

After discussion with you, we realize that this model is deficient and that we need to modify the model in the future to be more flexible. You wanted to be able to run the post-drilling scenario from 1,000 to 10,000 years. This can be accomplished by altering the input in a way that will allow post-drilling to initiate at a specified time. If we artificially set the degradation time for grout to zero then the grout becomes penetrable and post-drilling will initiate at the end of institutional control. If we set the end of institutional control to 1,000 years, then post-drilling begins at this time, which is the desired scenario.

Design Check Instructions for Saltstone Atmospheric Pathway Evaluations

Work by Bob Hiergesell, Check by Jim Cook

(Saltstone Vault 4 Special Analysis, WSRC-TR-2005-00074, Section 4.0)

Files associated with this design check:

AirEval.doc – the main text document for Appendix C

DiffusionCoefficients.xls – 1 worksheet for Calc. of air radionuclide diff. coefs. based on Rn-222; 2'nd containing other basic information.

SaltstoneGridding.xls – 2 worksheets, 1 indicating material properties for use in analysis, 2'nd for determination of y-axis gridding used in the 1-D porflow model.

Saturation.xls – calculation of air porosity, using material properties and resid. Sat. information.

Output.xls – two worksheets, one for C-14, Cl-36, H-3, I-129, Sb-125, and Se-79 and the other for Sn-126, Sn-121m and Sb-126. Porflow has a maximum of 7 contaminants that can be simulated at one time, thus necessitating this division.

Each worksheet contains the Total Cumulative Outflux and the Insantaneous Diffusive Outflux, from which charts are constructed for inclusion in the text document, AirEval.doc.

DoseCalc.xls – Calculation of Vault 4 disposal limits

C-C7.dat – Porflow input file for C-14, Cl-36, H-3, I-129, Sb-125, and Se-79 simulation.

Sn-Sb.dat – Porflow input file for Sn-126, Sn-121m and Sb-126 simulation.

Please review the main text report contained in **AirEval.doc**

Things to spot check:

1. Y-axis gridding in **SaltstoneGridding.xls** corresponds with values entered in **C-C7.dat** and **Sn-Sb.dat**

OK

No response needed.

2. Half-lives for elements are correct and entered properly in **C-C7.dat** and **Sn-Sb.dat**

Nuclear Wallet Card half life for tritium is 12.33 years, file has 12.28 years

Response. Tritium half-life of 12.33 years was utilized in follow-up simulations.

3. Calculation of molecular diffusion coefficients are correctly made in **DiffusionCoefficients.xls** and entered into **C-C7.dat** and **Sn-Sb.dat**.

The spreadsheet calculated the diffusion coefficients using the average mass of each element, rather than the isotopic mass. For example, for tritium the mass is given as 1.008, while it should be 3.000. All values in column K need to be adjusted with the exception of Tc-99 and Rn-222.

As it stands, the wrong numbers are correctly transcribed into the input files.

Response. The molecular weights were re-evaluated and updated. Information on the gaseous chemical compounds formed by the radionuclides, or whether the gaseous element form is monatomic or diatomic, and the associated molecular weights of each are indicated in Table 2. These values were utilized in follow-up simulations.

4. Verify that the Porflow simulation logic in **C-C7.dat** and **Sn-Sb.dat** is appropriate for making the air-diffusion calculations for the identified radionuclides.

I think the value of tortuosity on 0.66 is inappropriate for saltstone and concrete.

Response. To address this issue effective air diffusion coefficients, D_{eff}, were re-calculated for each of the 9 radionuclides based on using an effective Rn-222 diffusion coefficient as the reference. The new values were coupled with a tortuosity of 1.0 in follow-up simulations. This combination is a more appropriate representation of actual conditions.

5. The graphs in **Output.xls** are correct for the labeled radionuclides

The graphs appear consistent with the calculated results.

No response needed.

6. Data in Tables 2, -3 and -5 are correctly transcribed from **SaltstoneGridding.xls, DiffusionCoefficients.xls, Saturation.xls** and **DoseCalc.xls.**

Table 2 – Spreadsheet has representative porosity and air filled porosity of erosion barrier as 0.07 and 0.0119, Table has 0.075 and 0.0128.

Response. Information in Table 2 is now included in Table 3 and has been updated to be consistent with the spreadsheet.

Air filled porosity for lower drainage layer are inconsistent between spreadsheet and table (0.155 and 0.16. The number of significant digits should be consistent fro each column in Table 2.

Response. This information is now in Table 3 and each number has been rounded to 2 decimals throughout the table.

Table 3 – The isotopic masses and resulting diffusion coefficients need to be corrected per item 3 above.

Response. The isotopic masses were corrected and utilized in follow up simulations. This information has been introduced into the updated Table 2.

Table 4 - We need to factor in the results from Miles and Kim before we can complete the dose and limit calculations

Response. The results of the investigation you refer to (documented in SRNL-EST-2004-00071) are incorporated in the results section, where the partitioning of the radionuclides between gas and aqueous forms was used adjust the raw peak fluxes to reflect fluxes associated with air-diffusion of only the equilibrium gas concentration of each radionuclide.

7. Verify that Vault 4 disposal limits in **DoseCalc.xls** have been correctly calculated, given the peak instantaneous flux values for each radionuclide.

*We need to factor in the results from Miles and Kim before we can complete the dose and limit calculations***.**

Response. Doses to the exposed individual at both 100 m and at the SRS boundary were re-calculated using the new flux values. The new dose calculations were then used to calculate Vault 4 disposal limits for the radionuclides.

Design Check Instructions for Saltstone Vault 4 Rn-222 Evaluation

Work by Bob Hiergesell, Check by Jim Cook

(Saltstone Vault 4 Special Analysis, WSRC-TR-2005-00074, Section 5.0)

Files associated with this design check:

RadonEval.doc – the main text document for Appendix D
DiffusionCoefficients.xls – 1 worksheet for Calc. of air radionuclide diff. coefs. based on Rn-222; 2'nd containing other basic information, 3'rd has Rn-222 parent radionuclide and regeneration rate calculations.
SaltstoneGridding.xls – 2 worksheets, 1 indicating material properties for use in analysis, 2'nd for determination of y-axis gridding used in the 1-D porflow model.
Saturation.xls – calculation of air porosity, using material properties and resid. Sat. information.
Rn222InstFlux.xls – A worksheets containing output for each parent radionuclide evaluated, and one worksheet called "All" which contains data and a graph for all the radionuclides. One worksheet for calc. of Vault 4 limits.
Pu238.dat, Ra226.dat, Th230.dat, U234.dat and U238.dat – Porflow input files.

Please review the main text report contained in **RadonEval.doc**

Things to spot check:

1. That the Y-axis gridding in **SaltstoneGridding.xls** corresponds with values entered in the Porflow input files **Pu238.dat, Ra226.dat, Th230.dat, U234.dat and U238.dat**

OK

No response needed.

2. That half-lives for elements and the regeneration coefficient are correctly transcribed from **DiffusionCoefficients.xls** into the Porflow input files **Pu238.dat, Ra226.dat, Th230.dat, U234.dat** and **U238.dat.**

U-238 chain should use Pa-234m with branching ratio of 1 and half life of 1.17 minutes.

Response - Agree that Pa-124m should be used with its half life of 1.17 minutes. Re-simulation of the U-238 chain using the updated half-life was conducted and indicated a miniscule reduction in peak Rn-222 fluxes at the land surface.

Nuclear Wallet card has half life of Ra-226 as 1600 yrs

Response - All of the simulations were re-run using 1.6E+2 instead of 1.62E+3 for Ra-226 half-life, and the Pa-234m half life of 1.17 minutes was also incorporated into the runs. Modification of these half-lives also necessitated an update to the REGEneration terms for: Pa-234m from Th-234, U-234 from Pa-234m, Ra-226 from Th-234 and Rn-222 from Ra-226

Regeneration coefficients are calculated properly.

Respone – several of the Regeneration terms had to be modified as noted in the previous response.

3. Verify that the air porosity has been correctly calculated in **SaltstoneGridding.xls (Matl.Properties tab)** and entered into the Porflow input files accurately.

Lower drainage layer air porosity calculated as 0.155, input as 0.16.

Response. Table 2 has been changed to 0.16

4. Verify that the Porflow simulation logic in is appropriate for making the Rn-222-diffusion calculations for the identified radionuclides.

I believe the combination of the air diffusion coefficient and a tortuosity of 0.66 is inappropriate for saltstone and concrete.

Response. The Rn-222 air diffusion coefficient, D_m, used in the simulations was changed to an effective Rn-222 air diffusion coefficient, D_{eff}, and the default tortuosity of 1.0 was re-enabled for all material types in the simulation, not just for saltstone and concrete.

5. Verify that the graphs in **Rn222InstFlux.xls** (see the "All" tab) are correct for the labeled radionuclides

The graphs are correctly labeled and are properly represent the printed results.

No response needed.

6. Verify that data in Tables 2 and 3 in **RadonEval.doc** are correctly transcribed from **SaltstoneGridding.xls (Matl.Properties tab)** and **Rn222InstFlux.xls** and verify that Vault 4 disposal limits have been correctly calculated.

Table 2 – Erosion Barrier representative porosity is 0.07 in spreadsheet and 0.075 in Table 2; Air porosity of Lower Drainage Layer should be 0.155 (see above).

Response. Table 2 has been amended.

Table 3 – I suggest limiting Table 3 numbers to two significant digits, which will eliminate the inconsistencies with the spreadsheet.

Response. Table 3 has been amended.

NRC Comment 19: It is not clear that the deterministic approach employed by DOE is reasonably conservative, and the sensitivity analysis is too limited to conclude that uncertainties have been adequately addressed.

Basis: Page 4-31 of Reference 1 indicates that part of the rationale for not performing a quantitative analysis of uncertainty is the inability to predict conditions in the future, especially beyond several decades. However, it is precisely in circumstances such as the ones described, when knowledge about the future evolution of the site or waste is limited, that an uncertainty analysis should be used to determine how significant the effects of the uncertainties may be. The sensitivity analysis provided is dispersed throughout the various reports, and different analyses pertain to different designs and different inventories. Therefore, interpretation of the results is difficult. Only limited consideration has been given to the combinations of uncertainties to evaluate in sensitivity analysis.

The objective of the performance assessment calculations is to quantitatively estimate the system performance for comparison to the performance objectives of 10 CFR 61, Subpart C. The sensitivity analyses should identify the assumptions and parameters that affect the quantitative estimate of performance by evaluating the effects of changing the values of input variables or changing model structures. Uncertainty analyses should provide a tool for understanding, in quantitative terms, the effect of parameter and model uncertainties. These uncertainties should be described by considering a reasonable range of conditions, processes, or events to test the robustness of the SDF in comparison to the performance objectives. For example, an uncertainty analysis should address how changes in important uncertain parameters, such as parameters relevant to the radionuclide source term, engineered barrier degradation, and infiltration rate, affect the performance of the overall disposal system.

In the performance assessment [1] and the special analysis [3], the sensitivity and uncertainty analyses are frequently presented in the form of qualitative arguments, including discussions of the rationale for selecting particular scenarios and parameter values.

Path Forward: Expand the quantitative sensitivity and uncertainty analysis and document it for the current design and radiological composition of the waste to demonstrate that compliance with the performance objectives of 10 CFR 61, Subpart C can be reasonably assured. DOE should consider evaluating select combinations of uncertainty in key parameters. For example: waste composition, Kd values for radionuclides in waste and geologic materials, infiltration to the waste (gradual and/or discrete failure of the engineered caps upper and lower layers), soil-to-plant transfer factors, hydraulic properties of the waste and vault (saturated hydraulic conductivity and effective diffusivity), oxidation of a fraction of the waste, and hydraulic conductivity of the aquifer.

Because one purpose of a sensitivity analysis is to examine the importance of various assumptions, the response should address the degree of reliance on various assumptions identified in the response to Comment 1. For example, the response should address reliance on the full performance of the infiltration cap and gravel drain by illustrating the fraction of full performance necessary for the site to meet the performance objectives of 10 CFR 61, Subpart C as a function of time.

SRS Response: Introduction

The analyses in the Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (SA) (Cook et al. 2005).

The sensitivity and uncertainty analysis has been expanded for the current radiological composition of the waste to demonstrate compliance with the performance objectives of 10 CFR 61, Subpart C.

Sensitivity of Key Radionuclides to Model Parameters

A series of Saltstone Vault 4 sensitivity calculations were performed using PORFLOW (ACRi, Inc. 2005) to quantify the impact of key model parameter settings on groundwater contaminant concentrations and dose at the 100 meter compliance well through 10,000 years. PORFLOW is a software tool for multiphase fluid flow, heat and mass transfer in fractured porous media. Four radionuclides were chosen for this study: H-3, C-14, Se-79, and I-129; these radionuclides are the major contributors to dose from all pathways in the Vault 4 SA. The key model parameters addressed in this sensitivity analysis are:

- Base Case (Nominal), lower and upper bounding infiltration values through the upper geosynthetic clay liner (GCL) provided by Phifer (2005). The changes in infiltration rates through the upper GCL reflect three different land use scenarios which impact the effectiveness and longevity of the Vault 4 closure cap. The different infiltration rates also impact the hydraulic properties of the lower drainage layer and the vault base drainage layer due to transport and accumulation of silt in the drainage layers. Higher infiltration rate through the upper GCL results in higher transport rates of silt through the drainage layers and more rapid accumulation of silt.
- Saturated hydraulic conductivities of the saltstone waste form and the vault concrete. The saturated hydraulic conductivities were varied by an order of magnitude about the values used in the Saltstone Vault 4 SA. The rates at which the hydraulic conductivities of the saltstone grout and concrete increase over time were varied about the values used in the SA.

- Relative permeability of the saltstone waste form and the vault concrete. The relative permeability was set to unity.
- Molecular diffusion coefficient of each species in the saltstone waste form and vault concrete. The molecular diffusion coefficients were varied by an order of magnitude about the values used in the Saltstone Vault 4 SA.
- Distribution coefficients of C-14, I-129 and Se-79. The distribution coefficients (K_d) were set to zero for these species in the vadose and aquifer transport simulations.
- Chemical reducing property. Reducing or oxidation properties primarily influence distribution coefficient values. The distribution coefficient (K_d) of Tc in both saltstone grout and the vault was set to 1 (recommended value for oxidizing concrete) and 0 (pessimistic assumption) mL/g in the vadose zone portion of the simulations.

Tables 19-1 and 19-2 summarize the scenario runs for each of the radionuclide and the corresponding sensitivity setting of each key modeling parameter. Scenario run 1 represents the nominal or base case for each contaminant species. The nominal designation shown in Tables 19-1 and 19-2 refer to the value of the model parameter setting used in the Saltstone Vault 4 SA. The sensitivity runs include scenario runs 2 through 19. The following paragraphs discuss what the different scenario runs represent and a basis for selection of the parameter setting.

The sensitivity of the peak contaminant flux and concentration to different land use scenarios above the Saltstone Vault 4 is captured by scenario runs 2 and 3. The nominal case (Scenario 1) assumes a 100-year institutional control (bamboo cover) period followed by a pine forest cover. Scenario 2 is a land-use scenario with a continuous bamboo cover. Scenario 3 is a land-use scenario with a 100-year institutional control followed by farming and eventually a pine forest cover. Figure 19-1 shows the infiltration rate through the upper GCL for the three different land use scenarios. Each curve in Figure 19-1 represents a series of time period segments where the infiltration rate for the time period has been averaged. The type of land use impacts the effectiveness and longevity of the Vault 4 closure cap.

The different infiltration rates also impact the hydraulic properties of the lower drainage layer and the vault base drainage layer due to transport and accumulation of silt in the drainage layers. Higher infiltration rate through the upper GCL results in higher transport rates of silt through the drainage layers and more rapid accumulation of silt. The variation over time of the saturated horizontal conductivity of the lower drainage layer and the vault base drainage layer is shown in Figures 19-2 and 19-4, respectively. Similarly, the variation over time of the saturated vertical conductivity of the lower drainage layer and the vault base drainage layer is shown in Figures 19-3 and 19-5, respectively.

In both cases, there is a substantial reduction in the performance of the horizontal drainage layers over time. At the high infiltration rate (scenario 3), there is potential for ponding of water above the lower drainage layer.

Scenarios 4 and 5 address the rate at which the concrete vault saturated hydraulic conductivity increases with time due to degradation of the concrete as the result of chemical attack or cracking. The nominal value for the concrete vault is assumed to increase by three orders of magnitude over 10,000 years as shown in Figure 19-6. The functional form for the increase in conductivity over time is documented in the Saltstone Vault 4 SA and is based on engineering judgment to reflect conservative behavior. Scenarios 4 and 5 show an increase in the concrete vault conductivity of two to four orders of magnitude over 10,000 years, respectively.

In scenarios 6 and 7, the concrete vault saturated hydraulic conductivity is varied by an order of magnitude about the nominal value over the entire simulation period. The nominal rate of increase in conductivity due to degradation over time is used. Figure 19-7 shows the nominal condition and the sensitivity values.

Scenarios 8 and 9 address the rate at which the saltstone saturated hydraulic conductivity increases with time due to degradation of the saltstone as the result of chemical attack or cracking. The nominal value for the saltstone waste form is assumed to increase by two orders of magnitude over 10,000 years as shown in Figure 19-8. Scenarios 7 and 8 show an increase in the concrete vault conductivity of one to three orders of magnitude over 10,000 years, respectively.

In scenarios 10 and 11, the saltstone grout saturated hydraulic conductivity is varied by an order of magnitude about the nominal value over the entire simulation period. The nominal rate of increase in conductivity, due to degradation, over time is used. Figure 19-9 shows the nominal condition and the sensitivity values.

Scenario 12 is a combined sensitivity based on scenarios 3, 5 and 9. A high infiltration rate with degraded horizontal drain performance (scenario 3) is combined with highest rate increase in saturated hydraulic conductivity of the concrete vault and saltstone grout over time.

The relative permeability of the concrete vault and the saltstone waste form was set to unity in scenario 13. This was done to address uncertainties in the water retention curves for the concrete vault and saltstone grout.

The molecular diffusion coefficients for each species in the concrete vault were varied an order of magnitude about their nominal values shown in Table A-9 of the Saltstone Vault 4 SA. Scenarios 14 and 15 address this sensitivity.

The molecular diffusion coefficients for each species in the saltstone waste form were varied an order of magnitude about their nominal values shown in Table A-9 of the Saltstone Vault 4 SA. Scenarios 16 and 17 address this sensitivity.

Scenario 18 is a combined sensitivity run of scenarios 15 and 17 for each contaminant species. The molecular diffusion coefficients for each species are an order of magnitude higher than nominal for the concrete vault and the saltstone waste form in this scenario.

A distribution coefficient of zero was used throughout the vadose and aquifer zone transport simulations for C-14, I-129 and Se-79 for Scenario 19. This case is not considered credible, but it does show the importance of the distribution coefficient in the model calculations.

The predicted peak fractional fluxes to the water table and peak concentrations for C-14, H-3, I-129 and Se-79 are shown in Tables 19-3 to 19-6, respectively. All the radionuclides except H-3 appear to show the logical trend of lower/higher peak concentration with lower/higher sensitivity setting for a given parameter.

In Table 19-4, the nominal case (scenario 1) for H-3 has a higher peak concentration than scenario 3 as a result of a higher infiltration rate over the first 800 years.

The H-3 peak concentration appears to be insensitive to changes in the concrete vault and saltstone grout saturated hydraulic conductivity over the ranges assumed in the sensitivity analysis.

<u>Sensitivity Results Expressed as Dose from All Pathways</u>

The peak fractional concentrations and the revised inventory of radionuclides in Vault 4 (see response to RAI Comment 62) were used to calculate peak radionuclide concentrations over 10,000 years. The peak concentrations were input to the LADTAP program (Simpkins 2004) to calculate the all-pathways dose for each of the scenarios. The resulting doses are shown in Table 19-7. The doses range from 0.02 mrem/year for scenario 2 (decreased infiltration due to continuous bamboo cover) to 38 mrem/year for scenario 19 (all radionuclide distribution coefficients set to zero). These sensitivity analyses provide reasonable assurance that the performance objectives will be achieved.

Sensitivity of Technetium-99 to K_d

Three additional sensitivity runs were made to explore the sensitivity of Tc-99 to its distribution coefficient in saltstone grout and the vault concrete. Technetium scenario run 1 uses the nominal settings for all parameters in the Vault 4 SA, similar to scenario run 1 as outlined in Tables 19-1 and 19-2. Technetium scenario run 2 reduced the K_d for Tc-99 in saltstone grout and the vault concrete from 1000 to 1 mL/g, the value recommended for oxidizing concrete (Bradbury and Sarott, Table 4, page 42, Region II Reducing, attached). Technetium scenario run 3 reduced the K_d for Tc-99 to zero, a very pessimistic value. The results are shown in Table 19-8. Using the revised Vault 4 inventory and the LADTAP program, these results can be expressed as doses. The Tc-99 dose from run 1 is 1.70E-13 mrem/year, that from run 2 is 3.36E+00 mrem/year and that from run 3 is 9.54E+01 mrem/year. Work on the loss of reducing capacity in saltstone grout has shown that after 10,000 years 3% of the saltstone grout will have become oxidized (Kaplan and Hang, 2003, Figure 5, page 13, attached). Assuming that the 3% of the saltstone grout is oxidized at time zero, the doses from scenarios 2 and 3 can be approximated by taking 3% of the doses for scenarios 2 and 3, 0.10 and 2.9 mrem/year, respectively.

Sensitivity to Vault Radionuclide Inventory

The sensitivity of the groundwater all-pathways dose to the inventory of radionuclides in Vault 4 was considered. The remaining available volume in Vault 4 will accommodate all of salt waste batches 0 through 7 and about half of batch 8 (see the response to NRC Comment 65). Two hypothetical vault 4 inventories were developed by assuming that two additional vaults the same size as Vault 4 would be built and would receive the salt waste after Vault 4 was filled. The first of these two hypothetical vaults, designated Vault X, would receive the remaining half of salt waste batch 8 (d'Entremont & Drumm 2005), all of batch 9 and the remaining 11.9 million gallons would be SWPF waste. The second vault, designated Vault Y, would receive only SWPF waste.

The peak fractional concentrations for the nominal case (i.e., scenario run 1 for H-3, C-14, Se-79, and I-129 and technetium scenario run 1) were converted to doses using the three vault inventories as outlined above and the LADTAP program. The results are a dose of 5.12E-02 mrem/year for Vault 4, 2.85E-01 mrem/year for Vault X, and 3.21E-01 for Vault Y.

Summary and Conclusion

The sensitivity analysis for Vault 4 has been considerably expanded to include key parameters and key radionuclides. The results of the sensitivity analyses, when converted to dose, provide reasonable assurance that the Saltstone Disposal Facility will not exceed the 10 CFR 61 Subpart C performance objectives.

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Scenario Run	Sensitivity Settings		
	Infiltration	**Vadose Zone Concrete Hydraulic Conductivity**	**Vadose Zone Saltstone Hydraulic Conductivity**
1	IC to Pine Forest	Nominal	Nominal
2	Continuous Bamboo Cover	Nominal	Nominal
3	IC to Farm to Pine Forest	Nominal	Nominal
4	IC to Pine Forest	$\alpha = 1.0$	Nominal
5	IC to Pine Forest	$\alpha = 2.0$	Nominal
6	IC to Pine Forest	0.1×Ksat	Nominal
7	IC to Pine Forest	10×Ksat	Nominal
8	IC to Pine Forest	Nominal	$\alpha = 0.5$
9	IC to Pine Forest	Nominal	$\alpha = 1.5$
10	IC to Pine Forest	Nominal	0.1×Ksat
11	IC to Pine Forest	Nominal	10×Ksat
12	IC to Farm to Pine Forest	$\alpha = 2.0$	$\alpha = 1.5$
13	IC to Pine Forest	$k_r = 1$	$k_r = 1$
14	IC to Pine Forest	Nominal	Nominal
15	IC to Pine Forest	Nominal	Nominal
16	IC to Pine Forest	Nominal	Nominal
17	IC to Pine Forest	Nominal	Nominal
18	IC to Pine Forest	Nominal	Nominal
19	IC to Pine Forest	Nominal	Nominal

Table 19-1. Sensitivity scenarios and settings for infiltration, vadose zone concrete and saltstone grout hydraulic conductivity.

IC=Institutional Control

Scenario Run	Sensitivity Settings		
	Distribution Coefficient	Vadose Zone Concrete Diffusion Coefficient	Vadose Zone Saltstone Diffusion Coefficient
1	Nominal	Nominal	Nominal
2	Nominal	Nominal	Nominal
3	Nominal	Nominal	Nominal
4	Nominal	Nominal	Nominal
5	Nominal	Nominal	Nominal
6	Nominal	Nominal	Nominal
7	Nominal	Nominal	Nominal
8	Nominal	Nominal	Nominal
9	Nominal	Nominal	Nominal
10	Nominal	Nominal	Nominal
11	Nominal	Nominal	Nominal
12	Nominal	Nominal	Nominal
13	Nominal	Nominal	Nominal
14	Nominal	$0.1 \times D_M$	Nominal
15	Nominal	$10 \times D_M$	Nominal
16	Nominal	Nominal	$0.1 \times D_M$
17	Nominal	Nominal	$10 \times D_M$
18	Nominal	$10 \times D_M$	$10 \times D_M$
19	$k_d = 0$	Nominal	Nominal

Table 19-2. Sensitivity scenarios and settings for distribution coefficient, vadose zone concrete and saltstone grout molecular diffusion coefficient.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	3.44E-24	1.00E+04	1.18E-19	1.00E+04
2	1.06E-25	1.00E+04	3.69E-21	1.00E+04
3	7.37E-23	1.00E+04	2.48E-18	1.00E+04
4	1.00E-25	1.00E+04	3.50E-21	1.00E+04
5	1.12E-20	1.00E+04	3.83E-16	1.00E+04
6	1.00E-25	1.00E+04	3.51E-21	1.00E+04
7	1.42E-20	1.00E+04	4.88E-16	1.00E+04
8	6.18E-25	1.00E+04	2.13E-20	1.00E+04
9	1.24E-22	1.00E+04	4.17E-18	1.00E+04
10	5.78E-25	1.00E+04	1.99E-20	1.00E+04
11	1.35E-22	1.00E+04	4.56E-18	1.00E+04
12	7.31E-18	1.00E+04	2.44E-13	1.00E+04
13	6.02E-23	1.00E+04	2.05E-18	1.00E+04
14	2.67E-24	1.00E+04	9.09E-20	1.00E+04
15	1.91E-21	1.00E+04	6.67E-17	1.00E+04
16	2.74E-24	1.00E+04	9.34E-20	1.00E+04
17	4.37E-24	1.00E+04	1.50E-19	1.00E+04
18	9.97E-21	1.00E+04	3.49E-16	1.00E+04
19	1.29E-05	6.99E+03	4.64E-01	7.00E+03

Table 19-3. C-14 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	4.03E-13	1.20E+02	1.11E-08	1.25E+02
2	1.26E-14	1.52E+02	3.56E-10	1.56E+02
3	7.75E-15	1.69E+02	2.18E-10	1.74E+02
4	3.96E-13	1.20E+02	1.07E-08	1.25E+02
5	3.96E-13	1.20E+02	1.07E-08	1.25E+02
6	3.96E-13	1.20E+02	1.07E-08	1.25E+02
7	3.95E-13	1.20E+02	1.07E-08	1.25E+02
8	3.96E-13	1.20E+02	1.07E-08	1.25E+02
9	3.96E-13	1.20E+02	1.07E-08	1.25E+02
10	3.96E-13	1.20E+02	1.07E-08	1.25E+02
11	3.97E-13	1.20E+02	1.07E-08	1.25E+02
12	7.68E-15	1.70E+02	2.16E-10	1.75E+02
13	3.95E-13	1.20E+02	1.07E-08	1.25E+02
14	3.96E-13	1.20E+02	1.06E-08	1.25E+02
15	8.53E-10	1.18E+02	2.28E-05	1.23E+02
16	8.06E-14	1.20E+02	2.16E-09	1.25E+02
17	6.52E-13	1.20E+02	1.75E-08	1.25E+02
18	2.95E-09	1.18E+02	7.90E-05	1.23E+02

Table 19-4. H-3 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	1.29E-07	1.00E+04	4.62E-03	1.00E+04
2	1.11E-08	1.00E+04	3.96E-04	1.00E+04
3	4.10E-06	1.00E+04	1.46E-01	1.00E+04
4	8.49E-09	1.00E+04	3.04E-04	1.00E+04
5	1.25E-07	1.00E+04	4.50E-03	1.00E+04
6	8.20E-09	1.00E+04	2.94E-04	1.00E+04
7	1.27E-07	1.00E+04	4.56E-03	1.00E+04
8	1.75E-08	1.00E+04	6.28E-04	1.00E+04
9	5.61E-06	1.00E+04	2.00E-01	1.00E+04
10	1.73E-08	1.00E+04	6.21E-04	1.00E+04
11	5.87E-06	1.00E+04	2.10E-01	1.00E+04
12	1.46E-04	7.90E+03	5.28E+00	7.92E+03
13	3.20E-06	1.00E+04	1.14E-01	1.00E+04
14	9.28E-08	1.00E+04	3.31E-03	1.00E+04
15	1.60E-06	1.00E+04	5.76E-02	1.00E+04
16	1.02E-07	1.00E+04	3.63E-03	1.00E+04
17	1.66E-07	1.00E+04	5.94E-03	1.00E+04
18	3.17E-06	1.00E+04	1.14E-01	1.00E+04
19	3.24E-05	9.80E+03	1.17E+00	9.80E+03

Table 19-5. I-129 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	7.11E-07	1.00E+04	1.83E-02	1.00E+04
2	2.46E-07	1.00E+04	7.92E-03	1.00E+04
3	2.90E-06	1.00E+04	7.33E-02	1.00E+04
4	4.07E-07	1.00E+04	1.24E-02	1.00E+04
5	6.16E-07	1.00E+04	1.95E-02	1.00E+04
6	4.07E-07	1.00E+04	1.26E-02	1.00E+04
7	6.13E-07	1.00E+04	1.93E-02	1.00E+04
8	4.60E-07	1.00E+04	1.48E-02	1.00E+04
9	2.12E-06	1.00E+04	4.84E-02	1.00E+04
10	4.61E-07	1.00E+04	1.49E-02	1.00E+04
11	2.16E-06	1.00E+04	4.99E-02	1.00E+04
12	1.64E-05	1.00E+04	3.96E-01	1.00E+04
13	1.88E-06	1.00E+04	4.52E-02	1.00E+04
14	5.70E-07	1.00E+04	1.31E-02	1.00E+04
15	1.64E-06	1.80E+03	5.61E-02	3.52E+03
16	6.21E-07	1.00E+04	1.49E-02	1.00E+04
17	8.89E-07	1.00E+04	2.41E-02	1.00E+04
18	6.90E-06	3.68E+03	2.44E-01	4.79E+03
19	3.22E-05	9.70E+03	1.16E+00	9.71E+03

Table 19-6. Se-79 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for all scenario runs.

Scenario Run	Dose (mrem/year)
1	5.12E-02
2	2.12E-02
3	2.81E-01
4	3.31E-02
5	5.42E-02
6	3.36E-02
7	5.39E-02
8	3.97E-02
9	2.47E-01
10	4.00E-02
11	2.57E-01
12	4.18E+00
13	1.87E-01
14	3.66E-02
15	1.83E-01
16	4.16E-02
17	6.74E-02
18	7.15E-01
19	3.78E+01

Table 19-7. All-Pathways Doses from the Sensitivity Scenarios.

Scenario Run	Peak Fractional Flux (mole/yr/mole)	Peak Time (years)	Peak Concentration (pCi/L/Ci)	Peak Time (years)
1	5.61E-20	1.00E+04	2.02E-15	1.00E+04
2	1.10E-06	1.00E+04	3.98E-02	1.00E+04
3	3.13E-05	9.50E+03	1.13E+00	9.52E+03

Table 19-8. Tc-99 predicted peak fractional flux to the water table and peak concentration at the 100 meter compliance well for technetium scenario runs.

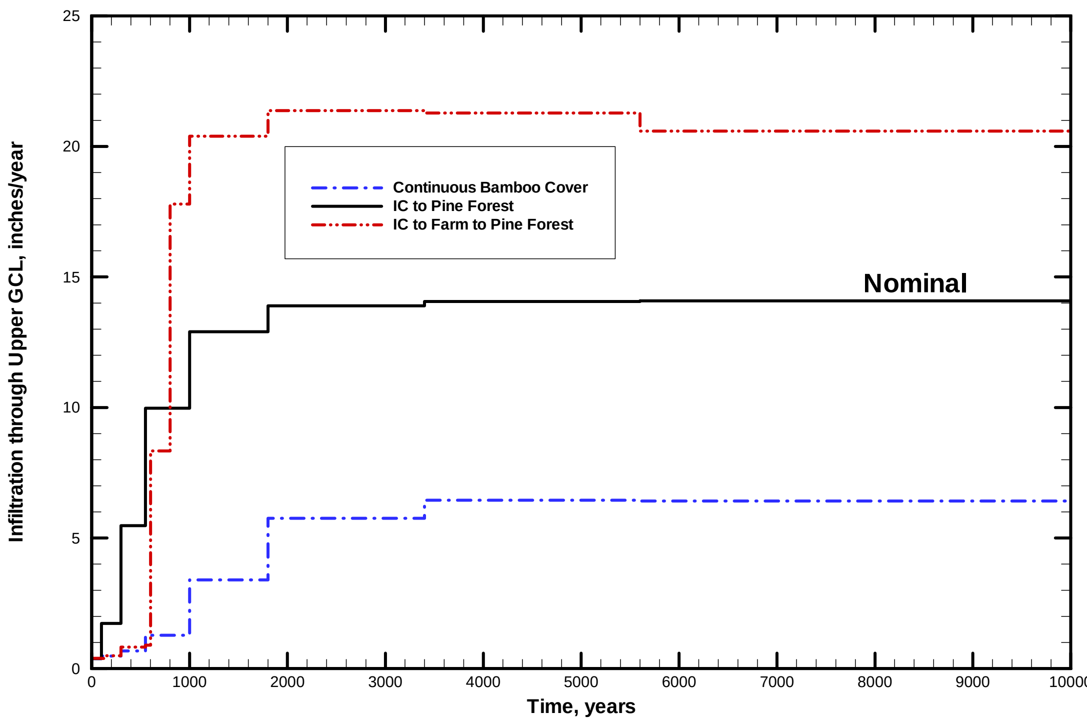

Figure 19-1. Infiltration rate through the Upper GCL for three different land use scenarios.

IC=Institutional Control

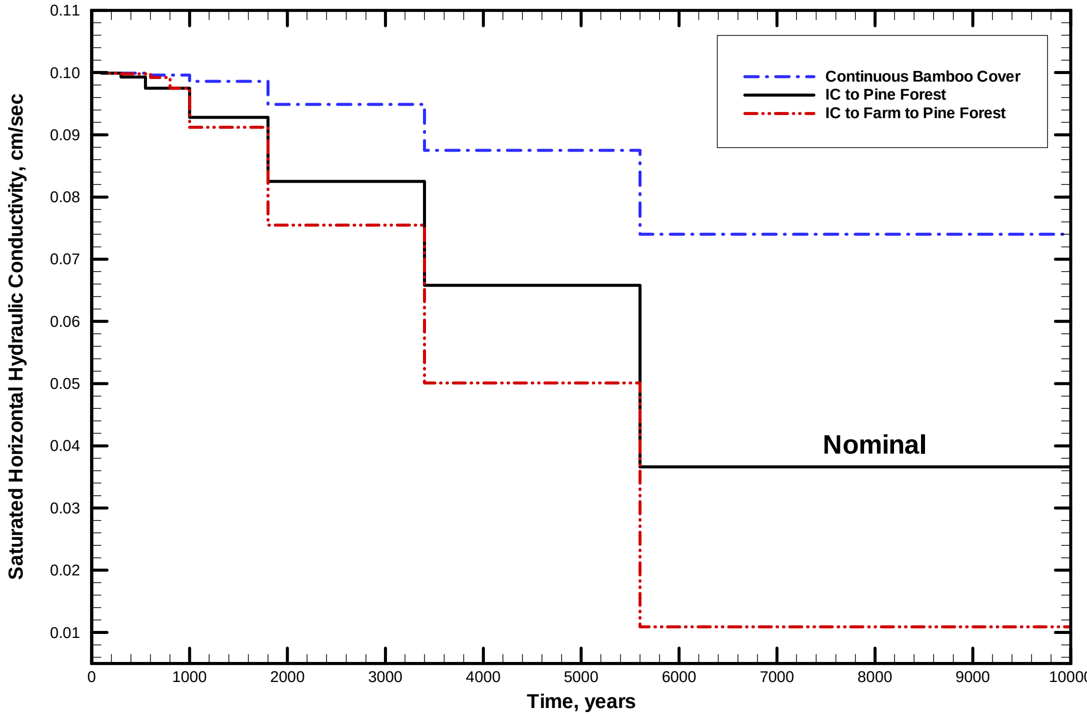

Figure 19-2. Saturated horizontal hydraulic conductivity of the lower drainage layer for three different land use scenarios.

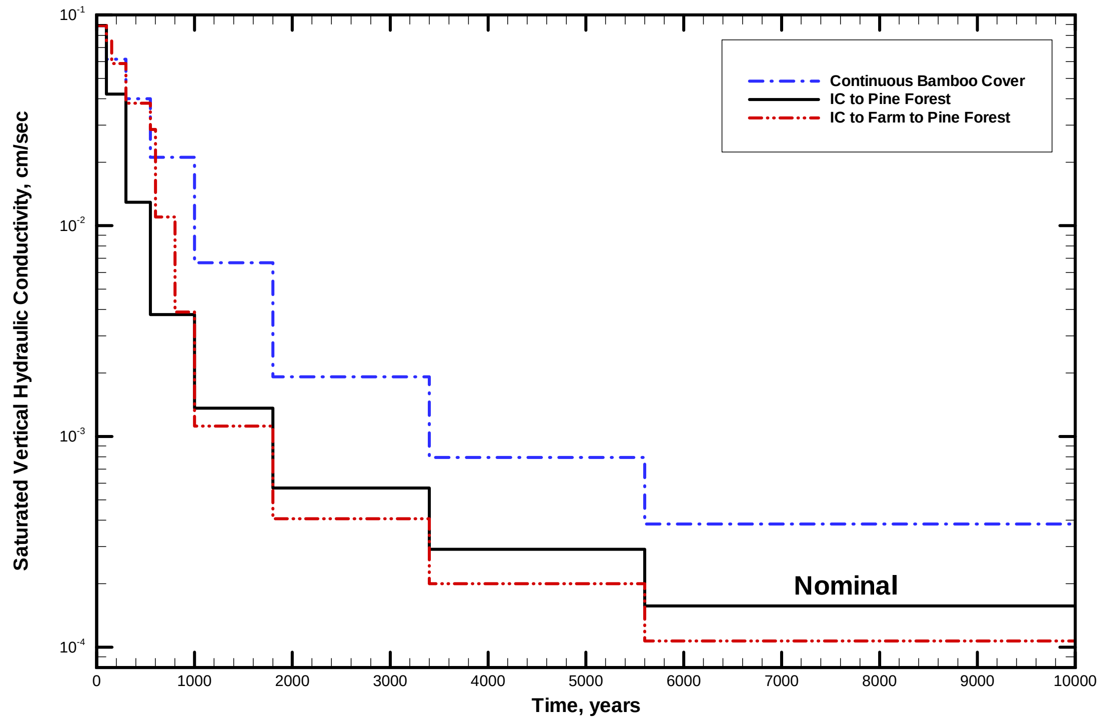

Figure 19-3. Saturated vertical hydraulic conductivity of the lower drainage layer for three different land use scenarios.

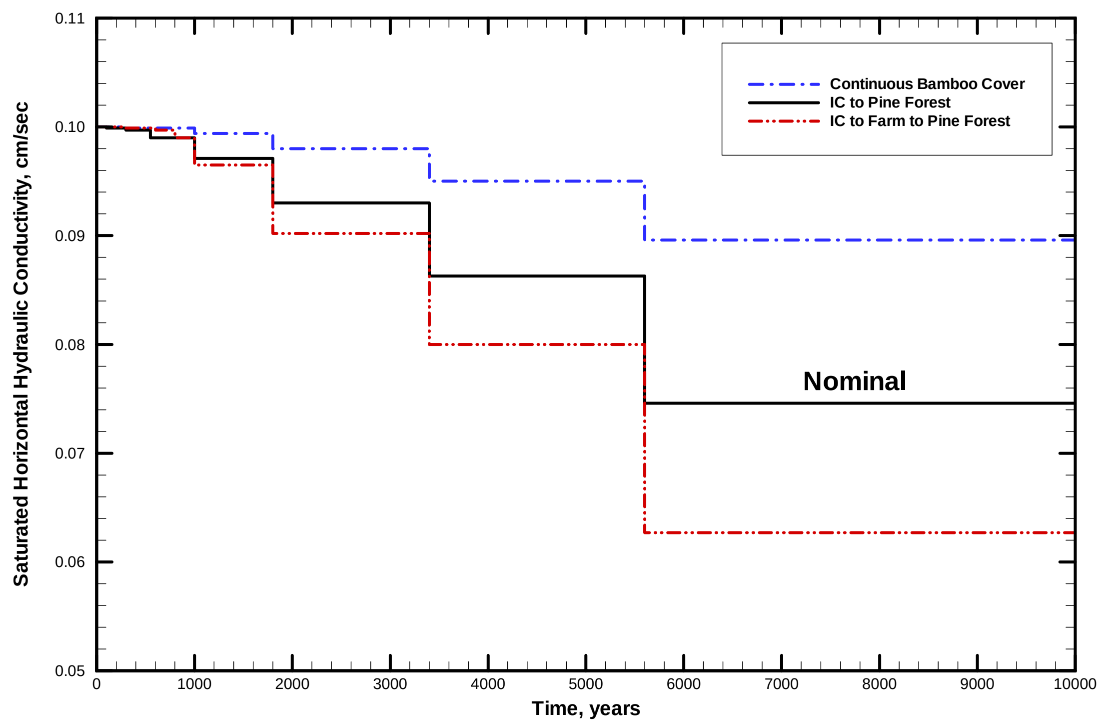

Figure 19-4. Saturated horizontal hydraulic conductivity of the vault base drainage layer for three different land use scenarios.

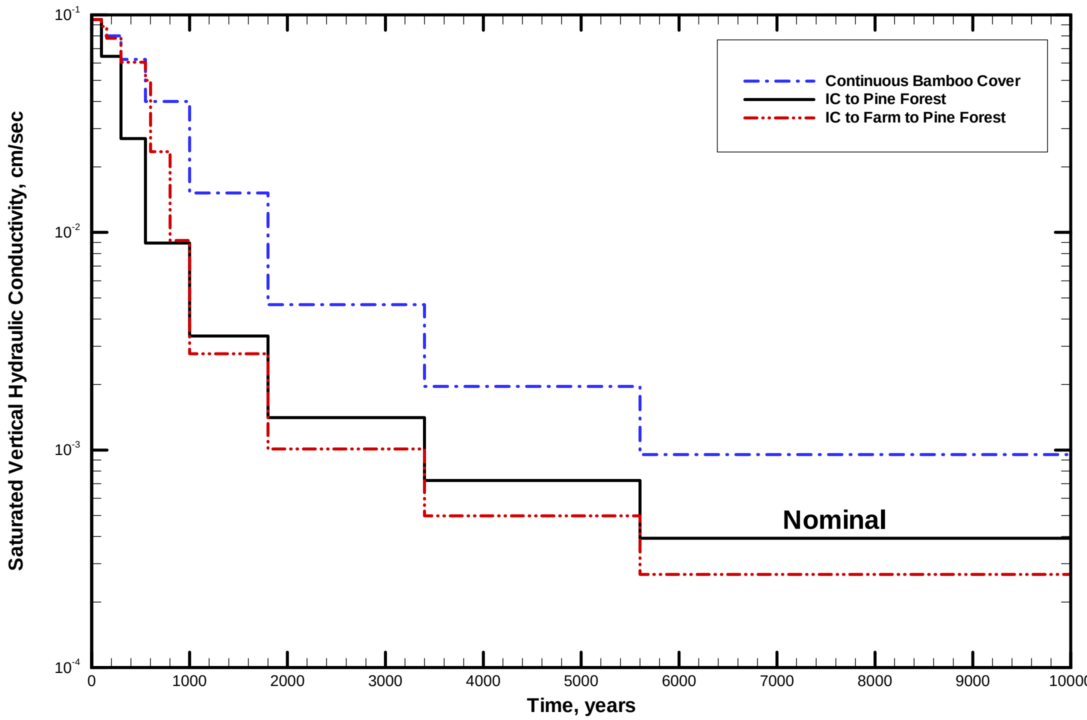

Figure 19-5. Saturated vertical hydraulic conductivity of the vault base drainage layer for three different land use scenarios. IC=Institutional Control

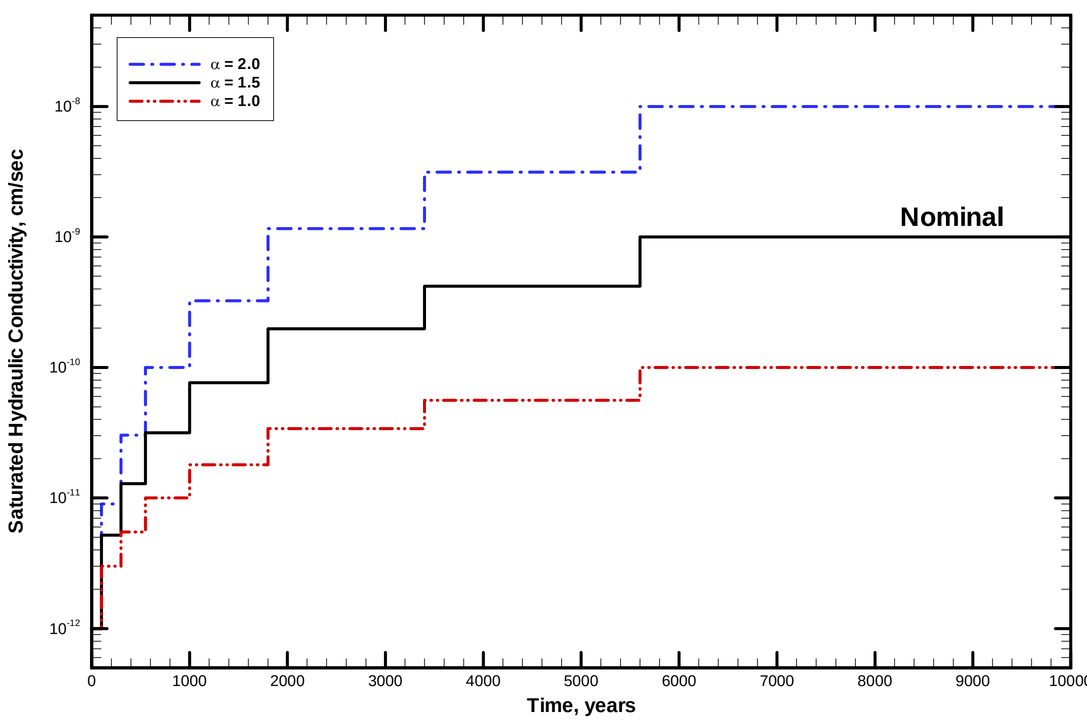

Figure 19-6. Saturated hydraulic conductivity of the vault concrete for three different degradation scenarios.

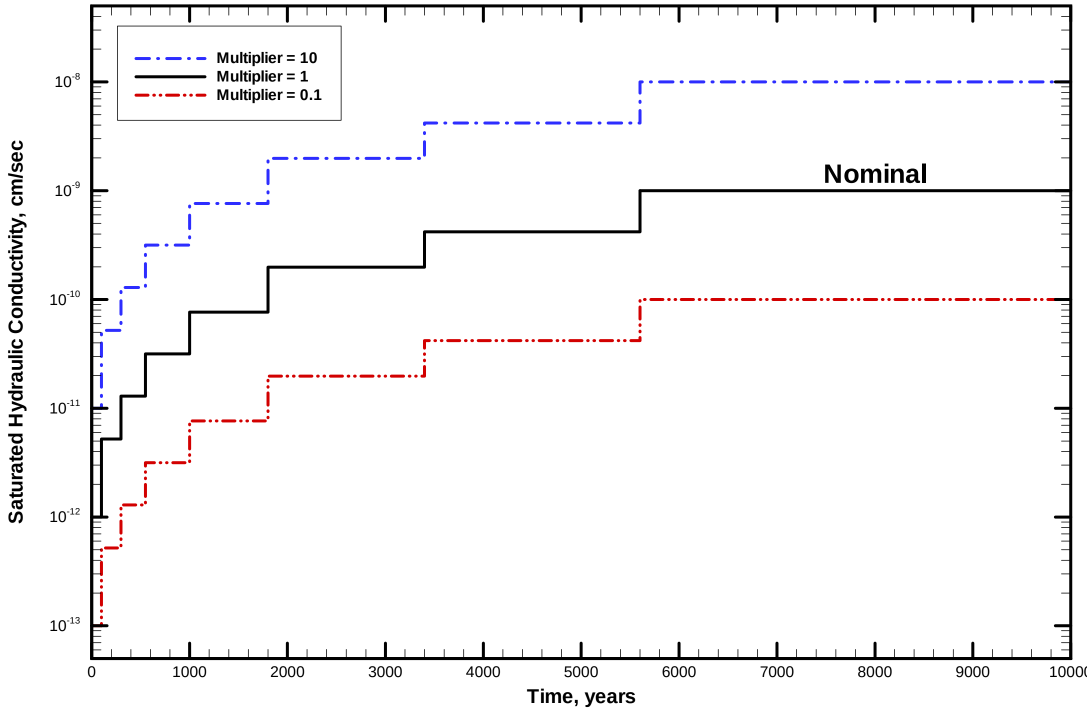

Figure 19-7. Saturated hydraulic conductivity of the vault concrete for an order of magnitude change about nominal conditions.

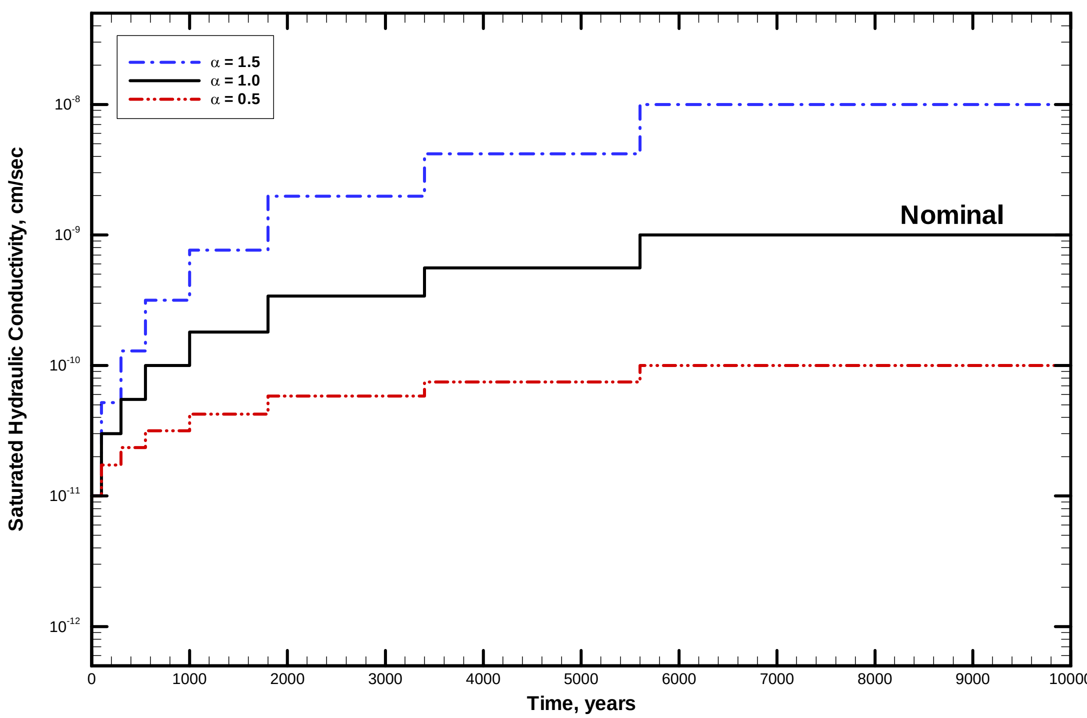

Figure 19-8. Saturated hydraulic conductivity of the saltstone for three different degradation scenarios.

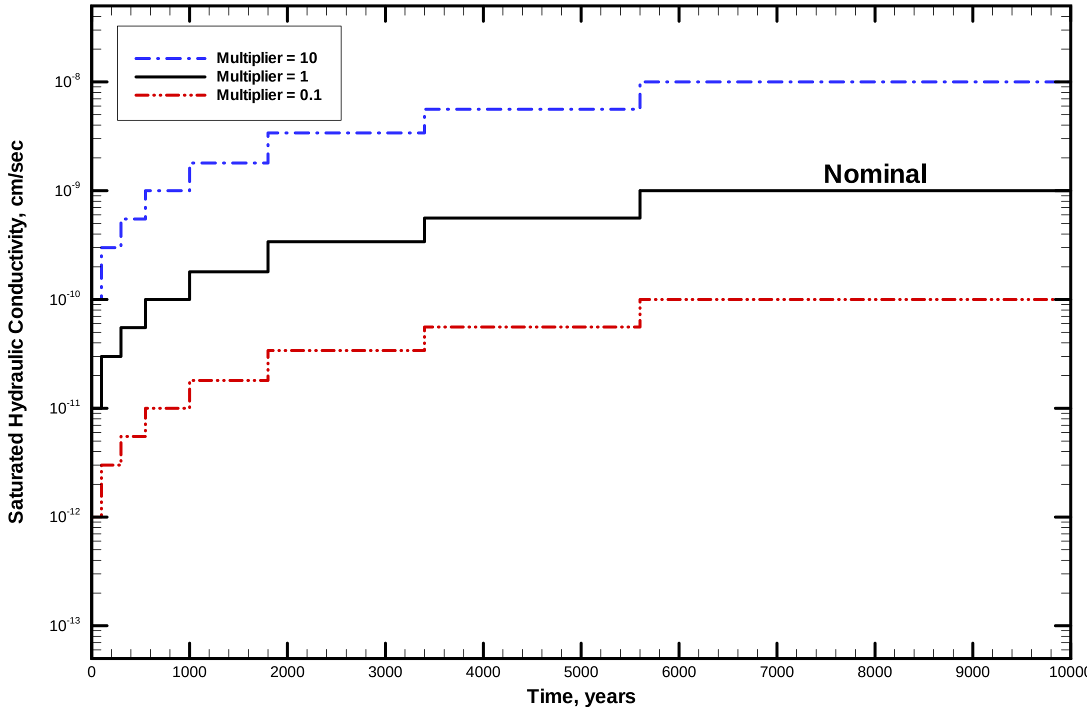

Figure 19-9. Saturated hydraulic conductivity of the saltstone for an order of magnitude change about nominal conditions.

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Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment

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Table 4: Sorption Database.

Element	State of Cement Degradation (see Fig. 2)					
	Region I		Region II		Region III	
	Oxid.	Red.	Oxid.	Red.	Oxid.	Red.
H (HTO)	0	0	0	0	0	0
CO_3^{2-}	see section 5.2.7					
Cl	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
Mn	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Ni	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Se	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0	0
Sr	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Zr	5	5	5	5	1	1
Nb	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Mo	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0	0
Tc	10^{-3}	1	10^{-3}	1	0	10^{-1}
Pd	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Ag	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Sn	1	1	1	1	10^{-1}	10^{-1}
I	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	0	0
Cs	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$
Pb	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Ra	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Th	5	5	5	5	1	1
Pa	5	5	5	5	10^{-1}	1
U	2	5	2	5	10^{-1}	1
Np	5	5	5	5	10^{-1}	1
Pu	5	5	5	5	1	1
Am	5	5	5	5	1	1
Cm	5	5	5	5	1	1

The elements are listed according to increasing atomic number. All distribution ratios are in units of $m^3 \, kg^{-1}$. Data selection procedures are described in the text.

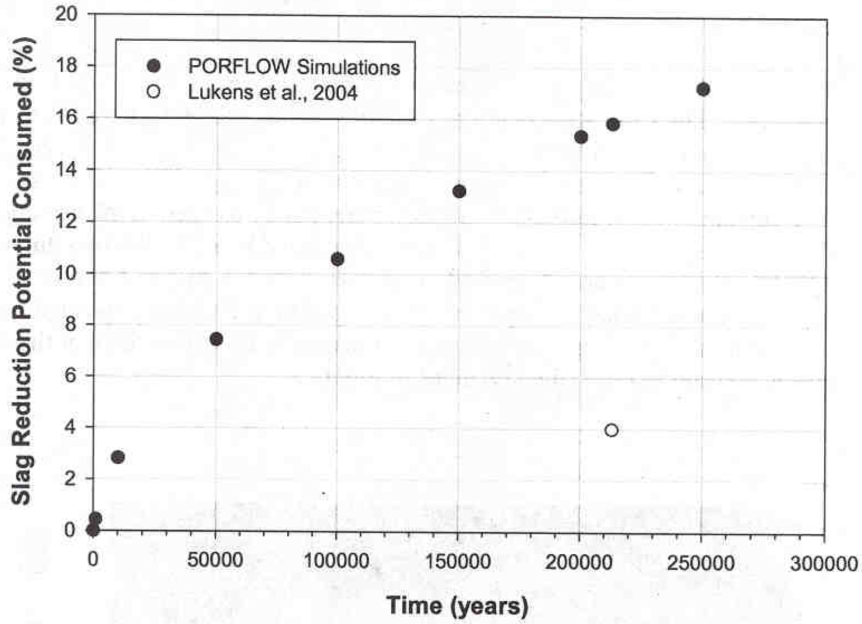


Figure 5. Consumption of Slag Reduction Potential by Oxygen in Infiltrating Water

In Figure 6, the penetration depth is plotted vs. time for all sides. These data can be used to adjust the data in Figure 5 to be consistent with the final dimensions of the saltstone facility. The penetration depth is defined as the distance in the saltstone where oxidation occurred, i.e., the reduction capacity was <9.25E-3 meq e^-/g_{solid}. The penetration depth at the midpoint of the side is presented in Figure 6. The data are not smooth due to the very slow nature of the modeled process and the long time required for changes to move from one node to the next. At the expense of appreciably longer simulation times, data smoothness could be improved by rerunning the simulations using a finer mesh size. Also, Figure 6 clearly shows that the left and right sides exhibit different penetration depth. On the left side (cracks), oxygen diffuses directly through grout. On the right side, oxygen diffuses through the vault concrete side first before reaching grout. Concrete and grout have different transport properties as shown in Table 2, hence, resulting in different diffusion pattern.

NRC Comment 20: Evaluation of the impact of natural cycling of climates is not provided.

Basis: As indicated in NRC's NUREG-1573, the sensitivity of the results to the natural cycling of climates over the analysis period should be considered in a performance assessment for a low-level waste facility [8]. Changes in infiltration rates and depth to water table as well as fluvial erosion rates and degradation mechanisms or rates for engineered barriers should be considered.

Path Forward: Provide an evaluation of the potential impacts of the natural cycling of climates.

SRS Response: Within NUREG-1573 Section 3.2.1.2 the Performance Assessment Working Group (PAWG) stated that consideration of changes in climate (i.e., glaciation, interglacial rise in sea level, global climate change, etc.) are considered unnecessary speculation and therefore do not need to be quantified in LLW performance assessment modeling. The PAWG states the following relative to the natural cycling of climates that should be considered within a Performance Assessment:

> However, a key aspect of an LLW performance assessment is determining how variations in precipitation result in varying rates of percolation into disposal units and of recharge to the water table. The PAWG recommends using historical and current weather data, and other site information (e.g., field tests) to establish a broad range of infiltration rates that may be used to simulate both wetter and drier conditions than the current average. Sensitivity analyses performed as part of the LLW performance assessment will provide some insight into the effects that such variations could have on the dose calculations. The PAWG believes that the treatment of infiltration in this manner will allow an analyst to consider the effects of broad variations in weather, without the need for speculating on how climate might change.

As seen the NUREG-1573 definition of the natural cycling of climates primarily focuses upon variations in precipitation as determined from historical and current weather data.

Current modeling in the Vault 4 Special Analysis (SA) (Cook et al. 2005) does consider natural cycling of climates as defined by NUREG-1573. The Vault 4 SA considers both variations in precipitation and temperature as determined from Savannah River Site (SRS) and Augusta, Georgia historical and current weather data. Additionally, consideration has been given to changes in vegetation, erosion, infiltration, and water table elevations and the influence of precipitation and temperature variations on these items as appropriate. These items are discussed below in the following sections:

- Temperature and Rainfall,

- Vegetation, Erosion, and Infiltration, and
- Water Table Elevations.

Temperature and Precipitation

The temperature and precipitation data, utilized to determine infiltration through the upper geosynthetic clay liner (GCL) (see the response to NRC Comment 24 for the closure cap configuration), were generated as outlined within Phifer and Nelson 2003, Section 3.0. Actual temperature data for the past 30 years and actual precipitation data over the past 34 years was used to come up with monthly averages as shown in Table 20-1. Synthetic daily weather data for temperature and precipitation over 100 years was generated utilizing the Hydrologic Evaluation of Landfill Performance (HELP) model synthetic weather option (USEPA 1994a and USEPA 1994b) based on the data from Table 20-1. The data was generated using the HELP Augusta, Georgia default weather database modified with the Savannah River Site (SRS) specific average monthly temperature and precipitation data. This 100- year synthetic daily temperature and precipitation data is statistically shown in Table 20-2.

The SRS specific average monthly temperature and precipitation data was obtained from the Savannah River Technology Center (SRTC) Atmospheric Technologies Group (ATG) web site located at http://shweather.srs.gov/servlet/idg.Weather.Weather (SRTC – ATG 2003). The average monthly temperature data covers the time period from 1972 to 2002. The average monthly precipitation data is from the SRS 200-F Weather Station and covers the time period from 1968 to 2002.

Table 20-1. Average Monthly SRS Temperature and Precipitation Data (Phifer and Nelson, 2003)

Month	Average Temperature (^oF)	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 20-2. Synthetic Daily Temperature and Precipitation Statistics over 100 Years (Statistical analysis based on data from Phifer and Nelson, 2003)

	Average	Median	Standard Deviation	Minimum	High
Daily Temperature (^oF)	64.73	66.50	14.24	19.40	92.70
Yearly Temperature (^oF)	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 100-year temperature and precipitation data sets as described by Table 20-2 along with the degraded closure cap material property data sets (the response to NRC Comment 28 provides information on the closure cap degradation over time) were utilized as input to the HELP model in order to determine the average annual infiltration through the upper GCL for each year since closure modeled (typically at year 0, 100, 300, 550, 1,000, 1,800, 3,400, 5,600, and 10,000). Use of the 100-year temperature and precipitation data sets as described by Table 20-2 for determination of the average annual infiltration for each year modeled ensured that the impact of natural temperature and precipitation cycling was explicitly factored into the average annual infiltration determined by the HELP modeling. Although the HELP Model can only look at a 100 year set of data, the

model is approved by the US Corps of Engineers and the USEPA as the industry standard for modeling landfill water budgets. Subsequently, the average annual infiltration through the upper GCL for each year modeled was then utilized as the upper flow boundary condition for the vadose zone PORFLOW modeling performed by Cook et al. 2005, Section A.2. This, therefore, ensured that the impact of natural temperature and precipitation cycling was implicitly factored into the vadose zone PORFLOW modeling. See the response to NRC Comment 24 for additional information on the relationship between the HELP and PORFLOW models.

Additionally, as outlined in more detail in the response to the NRC Comment 22, the erosion barrier was sized based upon the maximum precipitation event for a 10,000-year return period (Phifer and Nelson 2003, Appendix K). The maximum precipitation event for a 10,000-year return period is 3.3 inches over a 15-minute accumulation period (Weber et al. 1998, Table XIX).

Vegetation, Erosion, and Infiltration

Sensitivity analyses have been performed considering different land use scenarios with different vegetation that results in different erosion rates (Phifer and Nelson 2003, Phifer 2003, Phifer 2004). Table 20-3 lists each of the land use scenarios and the associated vegetation and erosion rates. These various land use scenarios also result in different rates of closure cap degradation and thus infiltration rates. Figure 20-1 provides the infiltration through the upper GCL over time for each of the scenarios. As can be seen in Figure 20-1, the higher erosion rates associated with corn farming immediately followed by pine forest succession result in the highest long-term infiltration rates.

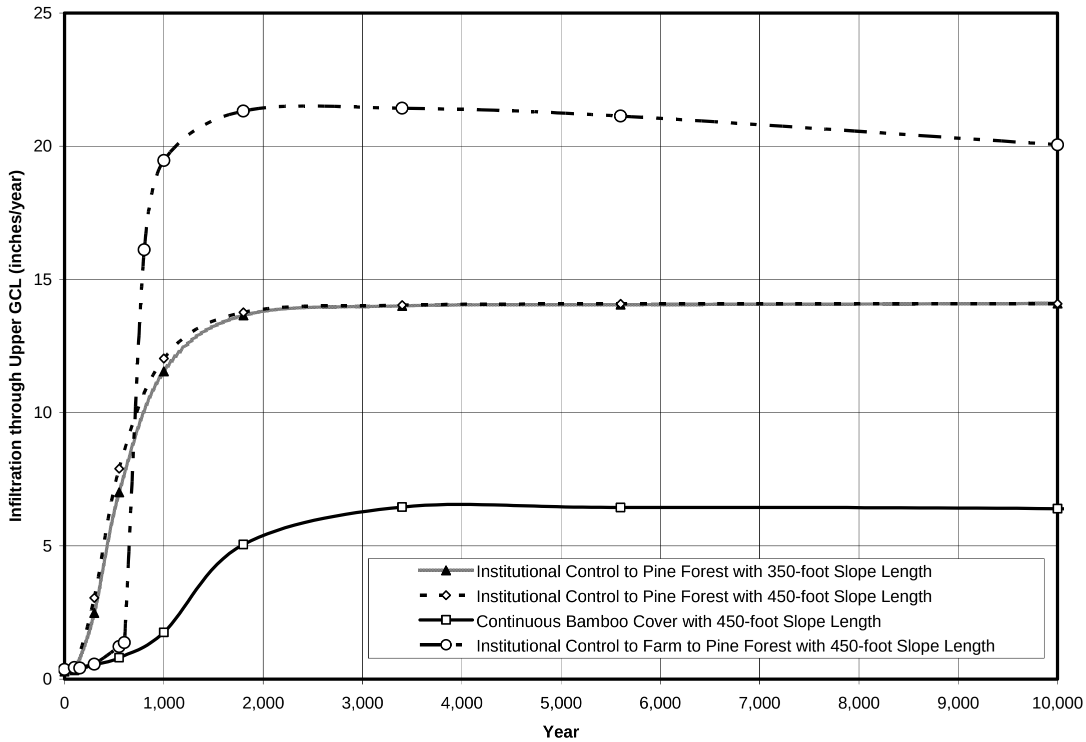
The higher erosion rates facilitate this increase in long-term infiltration by increasing the impact of pine tree root penetration on the upper GCL and by reducing the effectiveness of evapotranspiration as a water removal mechanism. Cook et al. 2005 did not look at sensitivity to infiltration, however, the extreme infiltration rates from Figure 20-1 have been utilized to aid in addressing the NRC Comment 19 in relation to the sensitivity to infiltration.

Table 20-3. Sensitivity Scenarios

Scenario	Vegetation	Erosion Rates	References
Institutional Control to Pine Forest with 350-foot slope length [1]	Bamboo Pine Forest	1.8E-04 in/yr [4] 1.1E-04 in/yr [5] 1.8E-04 in/yr [4] 1.1E-04 in/yr [5]	Phifer and Nelson 2003
Institutional Control to Pine Forest with 450-foot slope length [1]	Bamboo Pine Forest	2.0E-04 in/yr [4] 1.2E-04 in/yr [5] 2.0E-04 in/yr [4] 1.2E-04 in/yr [5]	Phifer 2003
Continuous Bamboo Cover with 450-foot slope length [2]	Bamboo	2.0E-04 in/yr [4] 1.2E-04 in/yr [5]	Phifer 2004
Institutional Control to Farm to Pine Forest with 450-foot slope length [3]	Bamboo Corn Pine Forest	2.0E-04 in/yr [4] 1.2E-04 in/yr [5] 0.11 in/yr [4] 0.067 in/yr [5] not applicable	Phifer 2004

[1] It is assumed that bamboo is maintained on the closure cap during the 100-year institutional control period, but is succeeded by pine forest after institutional control.
[2] It is assumed that bamboo is the climax species which precludes other vegetation.
[3] It is assumed that bamboo is maintained on the closure cap during the 100-year institutional control period. Then corn is grown until erosion to the erosion barrier occurs after which a pine forest succeeds.
[4] This is the erosion rate for the 6-inch topsoil layer under the conditions of this scenario for the vegetation shown.
[5] This is the erosion rate for 30-inch upper backfill layer under the conditions of this scenario for the vegetation shown.

Figure 20-1. Sensitivity Scenario Infiltration Rates over Time
(Phifer and Nelson, 2003, Phifer 2004, Phifer 2003)

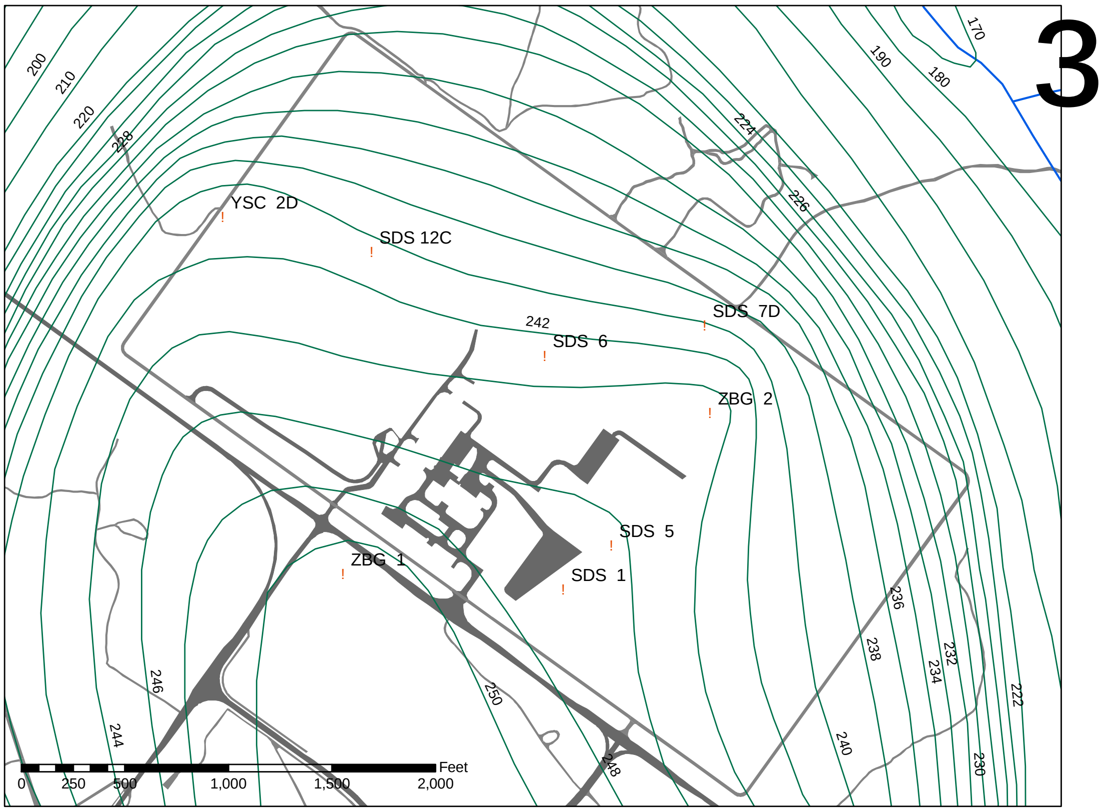


Water Table Elevations

All Saltstone vaults are built so that the bottom of the base slab (bottom) is a minimum of 5 feet above the probable maximum water table. The probable maximum water table elevation for selected wells at the Saltstone Disposal Facility (SDF) was determined by Cook 1983, and a probable maximum water table map (Figure 20-2) for the entire area was developed by Hiergesell 2005. Precipitation data for Aiken, South Carolina has been recorded since 1854, precipitation data for SRS has been recorded since 1952, and water table elevation data has been collected at SRS (in S-Area) since 1952. The largest recorded rainfall for Aiken, South Carolina occurred in 1964 with S-Area monitoring well data recording the resulting change in the water table. There is limited water table elevation data for the Saltstone (Z-Area). However, the monitoring well location in S-Area is close to the monitoring wells in Z-Area, and the overlapping time frame for these wells in S-Area and Z-Area allowed extrapolation of S-Area water well data from the 1964 maximum water table elevation to a maximum water table elevation for Saltstone (Z-Area).

Table 20-4 provides an evaluation of existing vaults 1 and 4 relative to the probable maximum and average water table elevations beneath the vaults. Cook et al. 2005 PORFLOW modeling (Figure A-2.) utilized a 40-foot vadose zone beneath Vault #4 consistent with the average water table elevation (see Table 20-4).

Figure 20-2. SDF Probable Maximum Water Table Map (Hiergesell 2005)



Notes to Figure 20-2:

- Probable maximum water table contours given in feet above mean sea level (ft-msl).
- 2-foot probable maximum water table contour intervals utilized.
- Location of monitoring wells SDS 1, SDS 5, SDS 6, SDS 7D, SDS 12C, YSC 2D, ZBG 1, and ZBG 2 are shown.

Table 20-4. Vaults 1 and 4 Versus Probable Maximum and Average Water Table Elevations

Vault	Bottom of Vault Elevation (ft-msl)	Probable Maximum Water Table Elevation beneath Vault (ft-msl)	Height above Probable Maximum Water Table (ft)	Average Water Table Elevation beneath Vault (ft-msl)	Height above Average Water Table (ft)
1	283	~248	35	~232	51
4	269	~246	23	~230	39

References:

Cook, J. R. 1983. Estimation of High Water Table Levels at the Saltstone Disposal Site (Z-Area), DPST-83-607, E. I. du Pont de Nemours, Inc., Aiken, South Carolina.

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina.

Hiergesell, R. A. 2005. Saltstone Disposal Facility: Determination of the Probable Maximum Water Table Elevation, Rev. 0, WSRC-TR-2005-00131, Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A. and Nelson, E. A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A. 2003. Saltstone Disposal Facility Mechanically Stabilized Earth Vault Closure Cap Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00523, Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A. 2004. Saltstone Disposal Facility Mechanically Stabilized Earth Vault Closure Cap Degradation: Sensitivity Analysis (U), Rev. 0, WSRC-TR-2004-00049, Westinghouse Savannah River Company, Aiken, South Carolina.

SRTC – ATG (Savannah River Technology Center (SRTC) Atmospheric Technologies Group (ATG)). 2003. Web site: http://shweather.srs.gov/servlet/idg Weather.Weather

USEPA (U.S. Environmental Protection Agency). 1994a. *The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3*, EPA/600/R-94/168a, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 1994b. *The Hydrologic Evaluation of Landfill Performance (HELP) Engineering Documentation for Version 3*, EPA/600/R-94/168b, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

Weber, A. H., Weber, J. H., Parker, M. J., and Hunter, C. H. 1998. *Tornado, Maximum Wind Gust, and Extreme Rainfall Event Recurrence Frequencies at the Savannah River Site (U)*, WSRC-TR-98-00329, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC Comment 21: It is unclear how the potential contribution from multiple vaults has been considered.

Basis: Although it is stated that the dose to the groundwater receptor is evaluated at a point that is at least 100 m downgradient of the SDF, the exact location of the receptor with respect to the vaults is unclear. The saltstone disposal facility may contain up to 15 vaults. The contaminant plumes from seven or more of these vaults may overlap, depending on the orientation of the vaults and the projected groundwater flowpaths. In addition, Figure 3.4-7 of Reference 1 suggests that there may be a difference in the hydraulic gradient projected for individual vaults.

Path Forward: Describe how the impact from multiple vaults has been considered. Demonstrate that the 100 m location is the point of maximum dose downgradient from the vaults.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The PORFLOW input files used in the 1992 PA (MMES 1992) are shown in Section C.2, Figure C.2-5 (Attached). This shows the input file for mass transport simulation for nitrate in the intact saltstone case. The two LOCAte SOURce statements define the sources of nitrate from the two groupings of vaults as depicted in Figures 3.4-8 and 3.4-9 (Attached). The contaminant flux determined for each vault was input in that vault's location in the saturated zone model. Figure C.2-5, Figure 3.4-8, and Figure 3.4-9 are included below.

The Vault 4 Special Analysis (Cook et al. 2005) considered only Vault 4. The upcoming revision of the Saltstone PA will evaluate all vaults projected for disposal in the Saltstone Disposal Facility. The Performance Objective Demonstration Document (PODD) (Rosenberg et al. 2005) documents the groundwater doses resulting from locating the entire salt waste radioactive material inventory in Vault 4. The result is an all-pathways dose of 2.3 mrem/yr (PODD Table 4-19). This represents the maximum possible dose due to plume overlap since it simulates the maximum plume.

The groundwater concentrations reported represent the maximum concentration outside the 100-meter buffer zone around the Saltstone Disposal Facility, accounting for overlap of contaminant plumes from individual vaults. The groundwater transport model output was searched for the maximum concentration downgradient of the 100-meter buffer zone. The maximum was found to be at or near the 100-meter in all cases.

References:

Cook, J. R., Wilhite, E. L, Hiergesell, R. A., and Flach, G. P., *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005

MMES 1992. *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, Martin Marietta Energy Systems, Inc., EG&G Idaho, Westinghouse Hanford Company, and Westinghouse Savannah River Company, 1992, Westinghouse Savannah River Company, Aiken, South Carolina.

Rosenberg, K. H., Rogers, B. C., and Cauthen, R. K., June 2005, *Saltstone Performance Objective Demonstration Document*, CBU-PIT-2005-00146, Revision 0. Westinghouse Savannah River Company, Aiken, South Carolina.

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TITLe CONTAMINANT TRANSPORT EXPANDED GRID
/File Z53Ni.DAT  Nov 11, 1992
/Contaminant transport modeling for NITRATE; 0.175 cm recharge
/Intact vaults/saltstone
/Update for Phase 111 modeling on 3/19/92 by pmk /ekr
/ Units are in cm per year
GRID 48 by 49 by 13
COORdinate X    -30.48    12192    23774.4    47853.6  78638.4  108051.6
                128016    134112 / 138531.6  143256    146304   149352
                152400    155448   158496     161544    164592   167640
                170688    173736   176784     179832    182880   185928
                188976    192024   195072     198120    201168   204216
                207264    210312   213360     218846.4  222504   225552
                228600    231648   235610.4   240792    243840   249936
                257251.2  262128   265176     268224    277215.6 288432.2
/
COORdinate Y    -30.48    18897.6  45537.12   62605.92  72725.28 76200
                79248     82296    85344      88392     91440    94488
                97536     100584   103632     106680    109728   112776
                115824    118872   121920     124968    128016   131064
                134112    137160   140208     143256    146304   149352
                152400    155448   158496     161544    167579   170688
                173736    176784   179832     182880    185928   192024
                198912    210312   219456     228600    237744   255209
                276545
COORdinate Z    1524    1828.8   3048    4267.2  4572    4724.4
                4876.8  5486.4   5791.2  6096    6400.8  6705.6
                9144
/
/
READ 'Zout1b.ACR'
/
ZONE 1                            $Zone 6/7/8, Barnwell-McBean
ZONE 2 from (1,1,5) to (48,49,6) $Zone 5b, Green Clay
ZONE 3 from (1,1,1) to (48,49,4) $Zone 5a, Congaree
ZONE 4 from (1,1,12) to (48,49,13) $Zone 6/7/8, no diffusion zone
/
ROCK density = 2.65; porosity = .30, .40, .30 for zones 1 to 4
TRANsport Kd = 0, md = 158., Ld = 300., Td= 30. for zones 1 to 3
TRANsport Kd = 0, md = 0., Ld = 0., Td= 0. for zone 4
/No DECAy half life for Nitrate
/
INITial C = 0.0 everywhere
BOUNdary C at -1 FLUX =0.0
BOUNdary C at +1 FLUX =0.0
BOUNdary C at -2 FLUX =0.0
BOUNdary C at +2 FLUX =0.0
BOUNdary C at -3 FLUX =0.0
BOUNdary C at +3 FLUX =0.0
/
DISAble FLOW
DIAGnostic U and C at 31,20,11
HISTory for C TABLE at (29,35,1) (29,35,2) (29,35,3)(29,35,4)(29,35,5)
     (29,35,6)(29,35,7)(29,35,8)(29,35,9)(29,35,10) frequency=10
LOCAte SOURce #1 from (14,7,11) to (30,22,11)  $fraction/cc-yr
LOCAte SOURce #2 from (22,24,11) to (29,32,11)
SOURce  at #1 for C VOLUmetric 12 sets (0,0)(36.1,2.002e-24)
              (199.3,1.184e-20)(487.,1.044e-19)(1185.,1.104e-18)
              (1784.,2.113e-18)(2711.,3.082e-18)(4406.,3.713e-18)
              (6187.,3.84e-18)(7087.,3.848e-18)(7987.,3.845e-18)
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Fig. C.2-5. Example PORFLOW-3D input file for mass transport simulation in groundwater (nitrate-intact saltstone case).

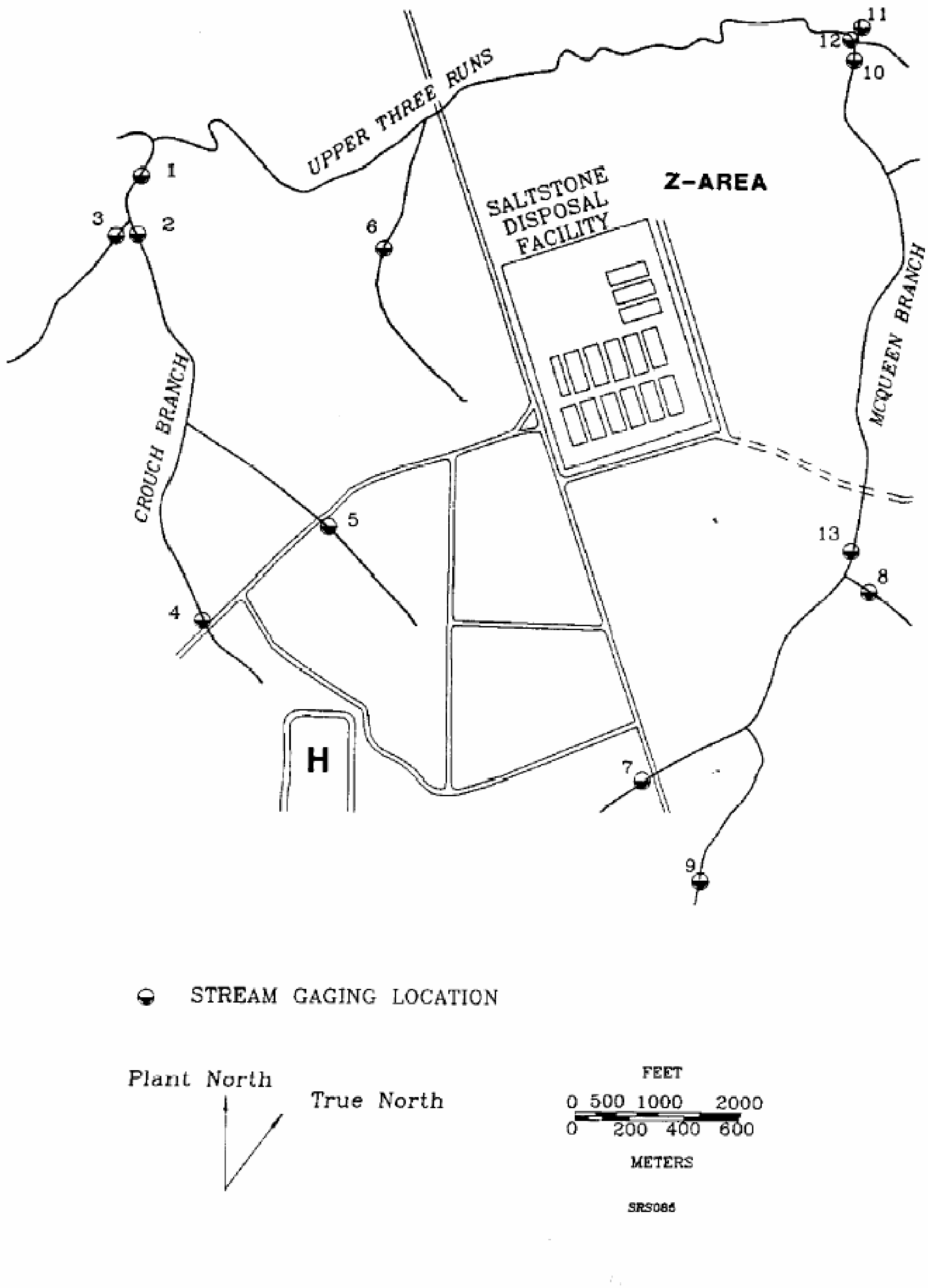


Fig. 3.4-8. Locations of stream-gauging stations in creeks near Z-Area.

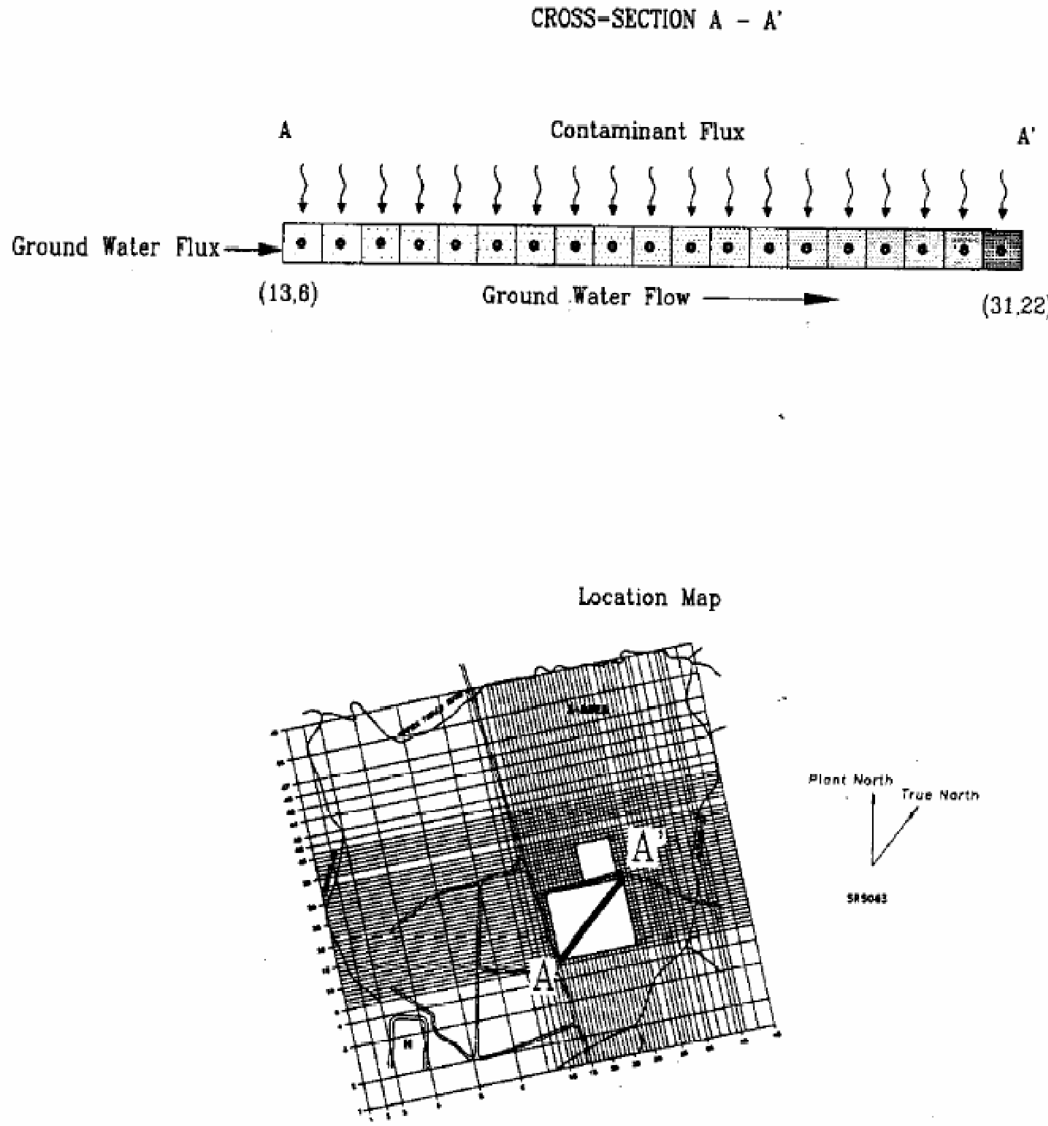


Fig. 3.4-9. Illustration of SDF source area in PORFLOW-3D grid.

NRC Comment 22: The basis for the 10,000 year effectiveness of the gravel layer as an erosion barrier is not provided. It is unknown whether the erosion controls have been designed based on guidance (e.g., NUREG-1623 [9]).

Basis: It is assumed in the analysis that erosion will stop once the gravel layer at 91 cm below the ground surface is reached. However, no basis is provided to support the assumption that the gravel layer will be 100% effective from 1000 yrs to 10,000 yrs. This assumption is key because it is the basis for eliminating the agricultural intruder scenario. Doses from the agricultural intruder scenario could be significant. In Reference 1, the "best estimate" doses resulting from a waste with much lower activity than the DDA waste ranged from 50-110 mrem/yr. Furthermore, much of that dose resulted from consumption of plants contaminated with Tc, and the soil-to-plant concentration factor may have been too low (see Comment 56).

Path Forward: Provide the basis for the conclusion that the gravel layer will prevent erosion from the time it is exposed to 10,000 years after site closure. Alternately, if it is found that this conclusion cannot be supported, scenarios that were screened out on the basis of the performance of the erosion barrier should be reevaluated.

SRS Response: The Nuclear Regulatory Commission (NRC) provides the following guidance in NUREG-1623, Section 2.1.2, relative to potential radioactive releases due to erosion:

> …stabilization designs must provide reasonable assurance of control of radiological hazards for a 1,000-year period, to the extent practical, but in any case, for a minimum 200-year period. The NRC staff has concluded that the risks from tailings can be accommodated by a design standard that requires that there be reasonable assurance that the tailing remain stable for a period of 1,000 (or at least 200) years, preferably with reliance placed on passive controls (such as earth and rock covers), rather than routine maintenance.

Further NUREG-1623, Section 3.0, provides various options for the design of erosion resistant cover systems including stable soil covers, riprap lining systems, and sacrificial soil covers. Within this section the NRC staff state the following:

> The placement of riprap protective covers is considered by the NRC staff to be the most effective method of assuring long-term stability.

Two NRC recommended methods for providing erosion stability have been utilized for the Saltstone closure cap to provide redundancy. First, the Saltstone closure cap has been designed to have a stable soil cover with relatively flat slopes, short slope lengths, and a vegetative cover (in NUREG-1623, Section 3.2.1, the NRC staff acknowledge that good grass covers can be established in the eastern United States). Second, the closure

cap has been designed with a riprap erosion barrier located three feet deep in order to prevent erosion below this depth. In fact the soil overlaying the erosion barrier could be sacrificial without significantly degrading the functionality of the closure cap.

The Saltstone Disposal Facility (SDF) or Z-Area is located on a local topographic high with surface elevations generally ranging from 260 to 300 ft-msl with the extreme southeast portion of the area dipping to 240 ft-msl. The nearest stream, McQueen Branch, drains an area of approximately 4.3 square miles and is at an elevation of approximately 190 ft-msl. Z-Area ranges from 50 to 110 feet above McQueen Branch and is well out of the flood plain of any nearby stream. Z-Area is not subject to flooding from nearby streams but could be subject to extreme precipitation events. Based upon these conditions the erosion barrier has been designed in essential conformance with the methodology outlined in NUREG-1623, Appendix D Section 2.0 for riprap design for top slopes. The methodology utilized for design of the erosion barrier is outlined below and deviations from the 1992 Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) are noted.

The basis for closure cap erosion control has been modified in the 2005 Vault 4 Special Analysis (SA) (Cook et al. 2005) from that assumed in the 1992 Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) and the 2002 SA (reference 3 in the NRC RAI). The 1992 PA and 2002 SA assumed that the upper gravel drainage layer would function as both a drainage layer and an erosion barrier to maintain a material thickness of 3 meters (119 inches) above the vault roof. In the 2005 SA (Cook et al. 2005), the drainage layer and erosion barrier functions have been separated into two separate layers and a basis for the 10,000 year longevity of the erosion barrier has been provided (Phifer and Nelson 2003). Discussions concerning the separation of the erosion barrier from the drainage layer and the basis of the erosion barrier's longevity are provided below.

The drainage layer and erosion barrier functions have been separated into two separate layers because these two functions cannot be readily reconciled within one layer (Phifer and Nelson 2003). To function as a drainage layer, the grain size of the material needs to be balanced between the need for a fairly high saturated hydraulic conductivity and the need to minimize the infiltration of overlying fines. Such an infiltration of fines would negatively impact the saturated hydraulic conductivity. To function as an erosion barrier the grain size of the material needs to be large enough to prevent material transport by erosion. Separating these two functions into two separate layers simplifies design of the erosion barrier by focusing the design solely on the need to address longevity versus erosion as outlined below.

The erosion barrier stone was sized as outlined in Phifer and Nelson 2003, Section 4.3 and Appendix K. It was 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 (Weber et al. 1998 Table XIX). The following conservative assumptions were made in sizing the stone of the erosion barrier:

- It was assumed that the entire 3.3 inches of rainfall over a 15 minute period (i.e., 10,000-year return period) resulted in runoff (i.e., no infiltration occurs).

- It was assumed that there is no lag period due to the length of the flow path (i.e., all the rainfall over the entire area immediately becomes discharge out the end of the area).

- Flow was assumed to be continuous at the rate determined over the 15 minute period.

Based upon this precipitation event, a one-foot thick layer of 2-inch to 6-inch granite stone with a d50 (i.e., median size) of 4 inches has been selected for use as the erosion barrier (sizing based upon Logan 1977 (Figure C-3); Goldman et al. 1986 (Section 7.7b, Rock Linings); NCSU 1991 (Section 6.15, Riprap)). Appendix K of Phifer and Nelson 2003 provides the calculations associated with this size selection. Additionally, in order to prevent the loss of overlying material into the erosion barrier and to reduce the saturated hydraulic conductivity of the erosion barrier layer, voids between the granite stone will be filled with a Controlled Low Strength Material (CLSM) a flowable fill of a lean cement/fly ash/sand/water mixture). This adds further conservativism to the erosion barrier, since the increased resistance provided by the CLSM or Flowable Fill was not considered in sizing the granite stone.

As previously stated, the erosion barrier has been designed in essential conformance to the methodology outlined in NUREG-1623, Appendix D, Section 2.0 for riprap design for top slopes, and the associated assumptions (see above) are conservative relative to the NUREG-1623, Appendix D methodology. Therefore, the erosion barrier has been designed in accordance with applicable guidance to maintain a minimum material thickness of 3 meters (119 inches) above the vault roof over 10,000 years. On this basis, the intruder agriculture scenario was not considered within the 2005 Vault 4 SA (Cook et al. 2005), since this scenario is based upon intruding into the waste with a 3-meter excavation.

References:

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. March 31, 2005.

Goldman, S. J., Jackson, K., and Bursztynsky, T. A. 1986. Erosion and Sediment Control Handbook, McGraw-Hill Publishing Company, New York.

Logan, C. A. 1997. *Soil and Water Conservation in Developing Areas*, SC-40-0014-1190, South Carolina Land Resources Conservation Commission. June 1977.

NCSU (North Carolina State University). 1991. *Erosion and Sediment Control – Field Manual*, State of North Carolina. February 1991.

Phifer, M. A. and Nelson, E. A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina. September 22, 2003.

Weber, A. H., Weber, J. H., Parker, M. J., and Hunter, C. H. 1998. *Tornado, Maximum Wind Gust, and Extreme Rainfall Event Recurrence Frequencies at the Savannah River Site (U)*, WSRC-TR-98-00329, Westinghouse Savannah River Company, Aiken, South Carolina. September 1998.

NRC Comment 23: The current analysis may not have been adequately updated based on recommended changes to the hydraulic conductivity of the clay layer.

Basis: Reference 2 suggests that the hydraulic conductivity of the clay used in the 1992 PA was too small (7.6E-9 cm/s compared to ~1E-7 cm/s) resulting in simulated infiltration that was lower than would otherwise be expected. However, the 2002 Special Analysis [3] and the results in the waste determination [4] are based on the 1992 value for infiltration through the lower infiltration barrier.

Path Forward: Provide updated PA results that used the new value for hydraulic conductivity of the clay layers of the engineered cap or provide a basis for using the smaller value.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al 2005).

The current closure cover design uses a geosynthetic clay liner (GCL) for the barrier layers. In the Vault 4 Special Analysis, this material is assigned an initial saturated hydraulic conductivity of 5 x 10^{-9} cm/sec (Table 3.0-2 in Phifer and Nelson 2003, see below), based on information supplied by a manufacturer, GSE, who uses ASTM D 5084 to determine hydraulic conductivity (see manufacturer fact sheet below).

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., Special Analysis: Revision of Saltstone Vault 4 Disposal Limits, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

GSE (GSE Lining Technology, Inc.). 2002. Web site: http://www.gseworld.com/findproducts.htm

Phifer, Mark A. and Nelson, Eric A. 2003. *Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest.* WSRC-TR-2003-00436. Westinghouse Savannah River Company, Savannah River Site, Aiken, SC.

Table 3.0-2. HELP Model Required Soil Property Data

Layer	Saturated Hydraulic Conductivity (cm/sec)	Total Porosity (Vol/Vol)	Field Capacity (Vol/Vol)	Wilting Point (Vol/Vol)
Topsoil [1]	1.00E-03	0.4	0.11	0.058
Backfill [1]	1.00E-04	0.37	0.24	0.136
Gravel Drainage [1]	1.00E-01	0.38	0.08	0.013
Kaolin [1]	1.00E-07	0.56	0.55	0.5
GCL	**5.00E-09** [2]	**0.75** [3]	**0.747** [3]	**0.40** [3]
Clean grout [1]	1.00E-08	0.19	0.18	0.17
Concrete vault roof and floor [1]	1.00E-12	0.19	0.18	0.17
Saltstone [1]	5.00E-12	0.42	0.41	0.4

[1] WSRC (2002)
[2] GSE (2002)
[3] USEPA (1994a) and USEPA (1994b)

GSE

GSE STANDARD PRODUCTS

Product Data Sheet

Bentofix® Thermal Lock® EC GCL

Bentofix® Thermal Lock® **"EC"** geosynthetic clay liner (GCL) is a lightly needlepunched reinforced composite comprised of a uniform layer of granular sodium bentonite encapsulated between a woven and a nonwoven geotextile. It is intended for use on relatively flat slope surfaces where minimal internal shear strength is required.

Product Specifications

GEOTEXTILE PROPERTIES	TEST METHOD	FREQUENCY	VALUE (ENGLISH)	VALUE (SI)
Product Code			BFIX1000EC	
Cap Nonwoven, Mass/Unit Area	ASTM D 5261	1/200,000 ft² (1/20,000 m²)	3.0 oz/yd² Typical	100 g/m² Typical
Bottom Scrim Woven, Mass/Unit Area	ASTM D 5261	1/200,000 ft² (1/20,000 m²)	3.1 oz/yd² Typical	105 g/m² Typical
BENTONITE PROPERTIES				
Swell Index	ASTM D 5890	1/100,000 lb (50,000 kg)	24 ml/2 g min	24 ml/2 g min
Moisture Content	ASTM D 4643	1/100,000 lb (50,000 kg)	12% max	12% max
Fluid Loss	ASTM D 5891	1/100,000 lb (50,000 kg)	18 ml max	18 ml max
FINISHED GCL PROPERTIES				
Bentonite, Mass/Unit Area[1]	ASTM D 5993	1/40,000 ft² (1/4,000 m²)	0.75 lb/ft² MARV	3.66 kg/m² MARV
Tensile Properties, Tensile Strength[4] Grab Strength[2] Grab Elongation[2]	 ASTM D 6768 ASTM D 4632 ASTM D 4632	 1/40,000 ft² (1/4,000 m²)	 30 lb/in MARV 80 lb Typical 100% Typical	 5 kN/m MARV 354 N Typical 100% Typical
Peel Strength[3]	ASTM D 4632 ASTM D 6496	1/40,000 ft² (1/4,000 m²)	5 lb Typical 0.8 lb/in Typical	22 N Typical 140 N/m Typical
Hydraulic Conductivity[4]	ASTM D 5084	1/Week	5×10^{-11} m/sec max	5×10^{-11} m/sec max
Index Flux[4]	ASTM D 5887	1/Week	1×10^{-8} m³/m²/sec max	1×10^{-8} m³/m²/sec max
Internal Shear Strength[5]	ASTM D 6243	Periodically	100 psf Typical	4.8 kPa Typical
ROLL DIMENSIONS				
Width x Length	Typical	Every Roll	15.5 ft x 150 ft	4.7 m x 45.7 m
Area per Roll	Typical	Every Roll	2,325 ft²	216 m²
Packaged Weight	Typical	Every Roll	2,600 lb	1,179 kg

NOTES:
- [1] Oven-dried measurement. Equates to 0.84 lb/ft² (4.1 kg/m²) when indexed to a 12% moisture content.
- [2] Measured at maximum peak, in weakest principal direction. Elongation is provided for reference only.
- [3] Modified to use a 4 in (100 mm) wide grip. The maximum peak of five specimens averaged.
- [4] 4 in (100 mm) wide sample, average of 5 specimens.
- [5] Typical peak value for specimen hydrated for 24 hours and sheared under a 200 psf (9.6 kPa) normal stress.

DS044ec R08/05/03

Americas	GSE Lining Technology, Inc.	Houston, Texas	800-435-2008	281-443-8564	Fax: 281-230-8650
Europe/Middle East/Africa	GSE Lining Technology GmbH	Hamburg, Germany		49-40-767420	Fax: 49-40-7674233
Asia/Pacific	GSE Lining Technology Company Ltd.	Bangkok, Thailand		66-2-937-0091	Fax: 66-2-937-0097

This product data sheet is also available on our website at:

www.gseworld.com

NRC
Comment 24: The technical evaluation of the performance of the engineered cap over thousands of years is incomplete. A number of items are not adequately addressed in the numerical simulations of the engineered cap to estimate infiltration to the wasteform. These include:

1) Heterogeneity and field-scale properties of emplaced materials
2) Temporal variations in precipitation (infiltration) that could result in dessication of the clay layer(s), especially when considered with erosion that results in decreasing thickness of the water balance portion of the cap
3) Uncertainty in moisture characteristic curve properties
4) Realistic combinations of near surface processes such as erosion and biointrusion. Page 3-29 of Reference 1 indicates that the Florida Harvester Ant can be expected to burrow to a depth of more than 2 meters (5% of the time).

Basis: In the 1998 Addendum (Section 2-3 of the SRT-WED-93-203 attachment) [2], it is calculated that, in the case of degraded (fractured) saltstone, if the clay/gravel drain fails, the offsite drinking water dose will increase from 0.6 to 80 mrem/yr. The offsite drinking water dose calculated in Reference 5 is 6.8 mrem/yr. If a similar increase in the offsite drinking water dose were to occur if the clay/gravel drain were to fail given the higher inventories, it seems the performance objective may be exceeded by a significant margin. In addition, sensitivity analysis of the numerical simulation results of infiltration through the engineered cap is limited.

Much of the information used in the analysis is based on very limited information or literature sources (e.g., moisture characteristic curves). For instance, the values selected for gravel indicate that the curve selected represents the more drainable end of the spectrum. A conservative choice would be to select a curve from the less drainable end of the spectrum. In addition, the results in Figure A.1-11 show that the saturation under the vaults in the backfill are approaching values where the curve fit previously given for the moisture characteristic curve was not very good.

Path Forward: Technical basis is needed for the specific items found in the comment above. Sensitivity analysis of engineered cap performance should be performed considering the specific items found above (e.g., items 1 to 4). A diagram of water fluxes through discrete points in the engineered cap should be provided to aid in understanding of the simulations.

SRS Response: The analyses in the Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (SA) (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The closure cap configuration, degradation, and infiltration estimates within the Vault 4 SA (Cook et al. 2005) have been modified from those assumed within the Saltstone

PA (reference 1 in the NRC RAI), the 1998 PA Addendum (reference 2 in the NRC RAI), and the 2002 SA. The primary modifications made to the closure cap configuration include (Phifer and Nelson 2003, Section 4.7):

- The controlled compacted clay (kaolin) liners have been replaced with geosynthetic clay layers (GCL);
- An erosion barrier separate from and above the upper drainage layer has been added, and
- The lower drainage layer thickness has been increased from 6 inches to 2 feet; a 3-foot wide vertical drainage layer has been added along the sides of the vaults, and a 5-foot-thick by 10-foot-long drainage layer has been added at the base of the vaults.

The following are reasons, pertinent to this NRC RAI, that the controlled compacted clay (kaolin) layers were replaced with GCLs (Phifer and Nelson 2003, Section 4.1):

- A GCL has a lower saturated hydraulic conductivity than compacted kaolin.
- Emplaced GCLs generally have a greater consistency than emplaced compacted kaolin. This is due to the fact that GCLs are manufactured to a high degree of consistency as established by standard manufacturing quality control (QC) measures (ASTM D 5889), whereas compacted kaolin has no comparable manufacturing quality control. Additionally installation of GCLs generally only requires visual verification (ASTM D 6102), whereas installation of compacted kaolin requires significant Quality Assurance / Quality Control (QA/QC) testing.
- A GCL has the ability to self-heal rips or holes, whereas compacted kaolin does not. Additionally a GCL can undergo repeated cycles of dehydration and hydration without negative impacts to the GCL's saturated hydraulic conductivity, whereas compacted kaolin may irreversibly shrink, crack, and incur increases in its saturated hydraulic conductivity.
- A GCL incurs less negative impact due to differential settlement, freezing-thawing cycles, and wetting-drying cycles than a compacted kaolin layer.

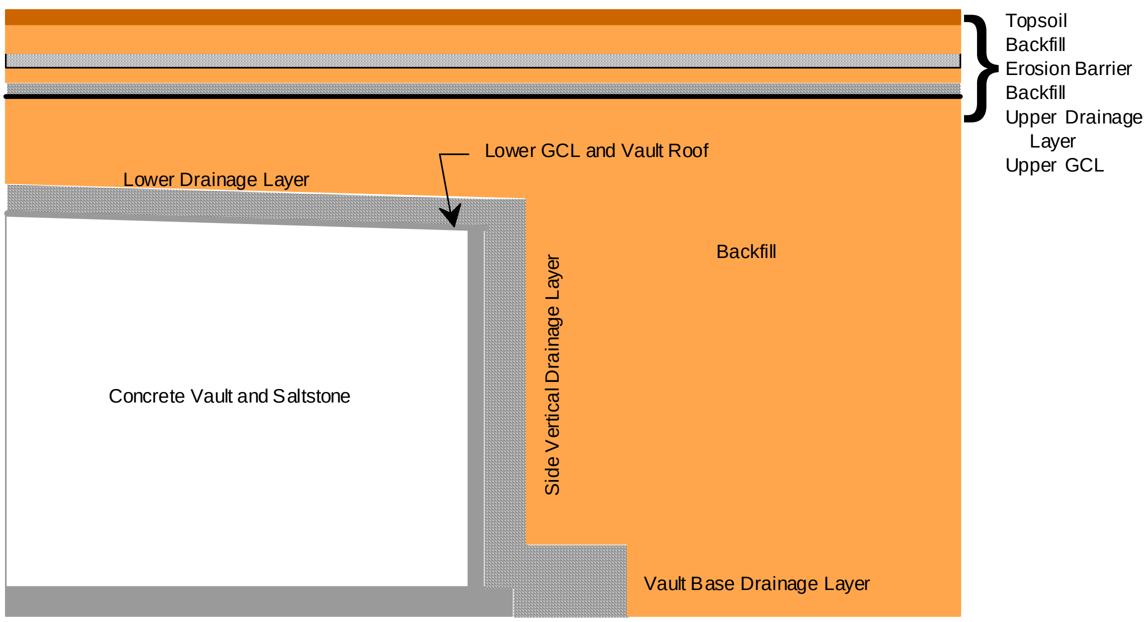
As outlined in more detail in the response to NRC Comment 22, an erosion barrier separate from and above the upper drainage layer has been added.

The drainage layer and erosion barrier functions have been separated into two separate layers because these two functions cannot be readily reconciled within one layer. The erosion barrier has been sized based upon the maximum precipitation event for a 10,000-year return period (Phifer and Nelson 2003, Section 4.3 and Appendix K).

The thickness of the lower drainage layer has been increased and drainage layers have been added along the sides and at the base of the vaults to facilitate the diversion of water around the vaults for an extended period of time (Phifer and Nelson 2003, Section 4.6). Based upon sensitivity analyses, it has been estimated that the lower drainage layer will silt-in between year 8,300 and 26,250 (Phifer 2004, Table 20-2). The drainage layers on the side and base will last even longer.

Figure 24-1 provides the closure cap configuration utilized within the Vault 4 SA (Cook et al. 2005).

Figure 24-1. Saltstone Closure Cap Configuration (Phifer and Nelson 2003)



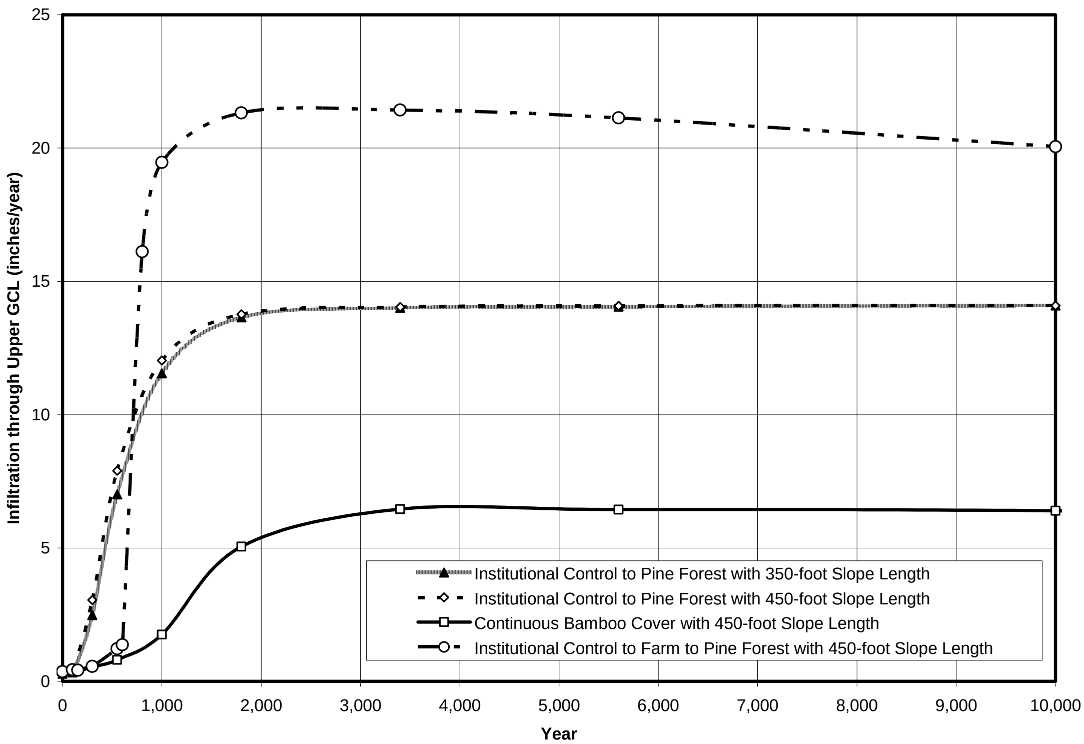
As outlined in more detail in the response to NRC Comment 28, the Vault 4 SA (Cook et al. 2005) does assume that the closure cap degrades over time as described by Phifer and Nelson 2003. Pine forest succession, erosion, and colloidal clay migration are the primary closure cap degradation mechanisms which have been modeled and assumed to significantly impact infiltration through the closure cap over time (Phifer and Nelson 2003, Sections 5.0 and 6.0 and Appendix P).

The degraded material properties have been utilized within the Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994a and USEPA 1994b) to estimate infiltration through the upper GCL over time per the methodology outlined by Phifer and Nelson 2003. The Vault 4 SA (Cook et al. 2005) utilized the infiltration through the upper GCL over time produced from the HELP modeling as the upper flow boundary condition for vadose zone PORFLOW modeling. The vadose zone PORFLOW modeling domain extends from the bottom of the upper GCL to the water table. This domain includes the lower drainage layer and the drainage layers along the sides and at the base of the vaults, which are assumed to degrade over time as

outlined by Phifer and Nelson 2003. This domain ignores the presence of the lower GCL altogether. Therefore, whether this GCL does or does not degrade over time is not relevant to the modeling.

As outlined in more detail in the responses to NRC Comments 20 and 30, sensitivity analyses have been performed considering different land use scenarios that produce different rates of closure cap degradation through the primary degradation mechanisms (pine forest succession, erosion, and colloidal clay migration). These different rates of closure cap degradation of these various land use scenarios result in different infiltration rates. Figure 24-2 provides the infiltration through the upper GCL over time for each of the scenarios (Phifer and Nelson 2003; Phifer 2003; and Phifer 2004). The extreme infiltration rates from Figure 24-2 have been utilized to aid in addressing NRC Comment 19 in relation to the sensitivity to infiltration.

Figure 24-2. Sensitivity Scenario Infiltration Rates over Time (Phifer 2004)



With the above background from the Vault 4 SA, the numbered items from NRC Comment 24, which are listed as not being adequately addressed in the numerical simulations of the engineered cap to estimate infiltration to the wasteform, are directly addressed below.

1) Heterogeneity and field-scale properties of emplaced materials

   Figure 24-1 and Table 24-1 provide the closure cap configuration. The primary layers which impact infiltration are the GCLs and drainage layers. Both of these

types of layers are engineered materials which will be procured from off site vendors based upon specific material specifications. The GCLs will be procured based upon the requirement for a specified dry weight of sodium bentonite per square foot of GCL (typically 0.75 $lbs.ft^2$) with a specified maximum saturated hydraulic conductivity (typically less than 5.0E-09 cm/s). The sand will be procured based upon grain size and a minimum saturated hydraulic conductivity (typically greater than 0.1 cm/s) requirements. QA/QC requirements will be implemented to ensure that these materials meet the minimum requirements. This will ensure material consistency.

Table 24-1. Closure Cap Configuration (Phifer 2004)

Layer	Thickness (inches)
Vegetation	Not applicable
Topsoil	6
Upper Backfill	30
Erosion Control Barrier	12
Middle Backfill	12
Geotextile Filter Fabric	-
Upper Drainage Layer	12
Upper GCL	0.2
Lower Backfill	58.65 (minimum)
Geotextile Filter Fabric	-
Lower Drainage Layer	24
Lower GCL	0.2
Side Vertical Drainage Layer	36
Vault Base Drainage Layer	60

Additionally the erosion control barrier and geotextile filter fabrics are also engineered materials which will be procured from off-site vendors based upon specific material specifications. The erosion control barrier will consist of a one foot thick layer of 2-inch to 6-inch granite stone with a d50 (i.e., median size) of 4 inches in which voids are filled with a Controlled Low Strength Material (CLSM) or Flowable Fill. The granite stone specifications will be a size-based specification and the Flowable Fill specification will be a mix-design specification (i.e., the quantities of water, sand, and cement will be specified). Again QA/QC requirements will be implemented to ensure that these materials meet the minimum requirements.

The topsoil and backfill layers will be obtained from on-site sources. The sources for these materials will be pre-qualified prior to utilization based upon the particular soil classification requirements specified for these soil materials. The pre-qualification will be determined based upon source area soil sampling and laboratory testing. During placement, the soil materials will be sampled and tested per a QA/QC plan to ensure that the soil materials continue to conform to the required soil classification. Acceptance of in-placed materials will be primarily based upon conformance to compaction requirements.

As discussed above, the bulk of the closure cap material layers utilized and in particular those that impact infiltration the most, will be engineered materials that will meet specified requirements. The modeling is based upon these minimal requirements. Therefore, there should be minimal heterogeneity within any one material type, and the field-scale properties should be fairly consistent.

2) Temporal variations in precipitation (infiltration) that could result in desiccation of the clay layer(s), especially when considered with erosion that results in decreasing thickness of the water balance portion of the cap

   As outlined above, the controlled compacted clay (kaolin) layers were replaced with GCLs. One of the primary reasons for this change is that GCLs are significantly more resistant to the impacts of wet and dry cycles than controlled compacted clay (kaolin) layers (Phifer and Nelson 2003). Also as outlined above, an erosion barrier overlying and separate from the upper drainage layer has been added. This erosion barrier ensures that a minimum of 3 feet of soil materials overlay the upper GCL and a minimum of approximately 10 feet overlay the lower GCL. This ensures that the GCLs are not in the most active evapotranspiration zone and that any fluctuation in water content is minimized.

3) Uncertainty in moisture characteristic curve properties

   The HELP model (USEPA 1994a and USEPA 1994b), which was utilized to determine infiltration through the upper GCL over time, does not utilize moisture characteristic curves within the model. The HELP model utilizes the total porosity, field capacity (at 0.33 bars), and wilting point (at 15 bars) rather than moisture characteristic curves. The porosity, field capacity, and wilting point values utilized within the HELP modeling were obtained from the following primary sources: WSRC 2002, Section 2.0; USEPA 1994a, Table 4; and USEPA 1994b, Tables 1 and 2.

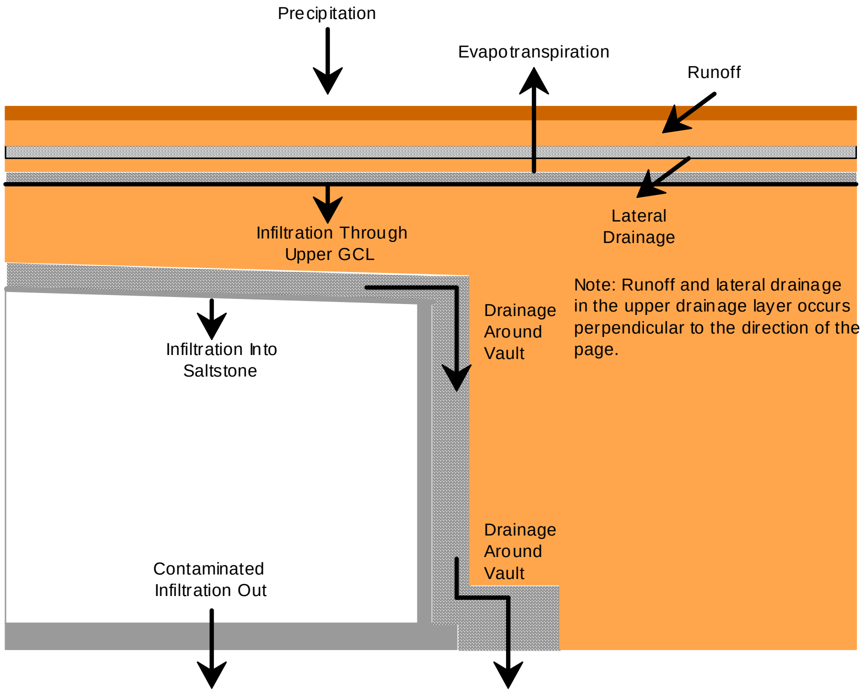
4) Realistic combinations of near surface processes such as erosion and biointrusion. Page 3-29 of Reference 1 indicates that the Florida Harvester Ant can be expected to burrow to a depth of more than 2 meters (5% of the time).

   As indicated above, near surface processes, including the bamboo-to-pine forest succession, erosion, and colloidal clay migration, have been considered in the degradation of the closure cap as described by Phifer and Nelson 2003, Sections 5.0 and 6.0 and Appendix P. The response to NRC Comment 28 also provides information on the impact of these near surface processes on closure cap degradation. The dominant mode of biointrusion that will produce closure cap degradation will be pine forest succession, which will result in root penetration through the upper GCL. Burrowing ants will not be a major mode of biointrusion resulting in closure cap degradation. While ants may burrow into the closure cap, they are typically precluded from burrowing through the upper GCL, due to its

near 100 percent saturation and the resulting GCL's bentonite consistency. Any effects of burrowing ants would be bounded by pine tree root penetration.

As requested, Figure 24-3 provides a conceptual diagram of water fluxes through the closure cap, which is consistent with the HELP and PORFLOW modeling.

Figure 24-3. Closure Cap Water Flux Conceptual Diagram



References:

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A. and Nelson, E. A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A. 2003. Saltstone Disposal Facility Mechanically Stabilized Earth Vault Closure Cap Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00523, Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A. 2004. Saltstone Disposal Facility Mechanically Stabilized Earth Vault Closure Cap Degradation: Sensitivity Analysis (U), Rev. 0, WSRC-TR-2004-00049, Westinghouse Savannah River Company, Aiken, South Carolina.

USEPA (U.S. Environmental Protection Agency) 1994a. *The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3*, EPA/600/R-94/168a, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

USEPA (U.S. Environmental Protection Agency) 1994b. *The Hydrologic Evaluation of Landfill Performance (HELP) Engineering Documentation for Version 3*, EPA/600/R-94/168b, Office of Research and Development, United States Environmental Protection Agency, Washington, DC.

WSRC (Westinghouse Savannah River Company) 2002. Saltstone Landfill Design Equivalency Demonstration (U), Rev. 0, WSRC-TR-2002-00236, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC Comment 25: The PA does not address the likely impact of rill and gully erosion on the integrity of the cover system.

Basis: Surface soil erosion is conservatively estimated at 1mm/year for cropland surrounding the Savannah River Site (Section 3.1.3.5 of [1]). At this rate, the 0.76-m backfill overlying the upper moisture barrier will be eroded in less than 800 years; however, this assumption implies that erosion is uniform, and does not account for the localized and often more severe impacts of gully erosion. High-intensity storms, common in the southeastern United States, could initiate and propagate gullies deep enough to penetrate the cover system after the institutional control period. This could result in fast flow pathways to the vault and saltstone monoliths.

Path Forward: Provide the additional technical basis and analysis to indicate that rill and gully erosion has been effectively considered in the PA.

SRS Response: The analyses in the Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) have been supplemented by the Vault 4 Special Analysis (SA) (Cook et al. 2005). Cook et al. (2005) has modified the closure cap configuration as outlined in Phifer and Nelson (2003) to more fully take into account erosion as a degradation mechanism. The primary modifications made to the closure cap configuration, which take into account erosion as a degradation mechanism, include (Phifer and Nelson (2003) Section 4.7):

- The slope length has been decreased,
- An erosion barrier separate from and above the upper drainage layer has been added, and
- The barrier layer has been lowered within the profile from 4 feet below ground surface to 6 feet below.

Decreasing the slope length decreases the overall rate of erosion and likelihood of rill and gully erosion. The addition of an erosion barrier separate from and above the upper drainage layer, allows the erosion barrier to be designed solely for its erosion barrier function rather than also including a lateral drainage function. This is outlined in more detail in response to NRC Comments 22 and 24. Lowering the barrier layer from 4 to 6 feet below ground surface, means that at the maximum extent of erosion (i.e., to the top of the erosion barrier), the barrier layer (i.e., geosynthetic clay liner, or GCL) will be 3 feet below ground surface rather than only 1-foot as in the Saltstone PA.

Among these features, the erosion barrier is the closure cap design feature that will have the greatest effect on minimizing the potential impact of rill and gully erosion. The erosion barrier has been designed based upon the maximum precipitation event for a 10,000-year return period (Phifer and Nelson 2003, Section 4.3 and Appendix K). The maximum precipitation event for a 10,000-year return period is 3.3 inches over a 15-minute accumulation period (Weber et al. 1998 Table XIX). Based upon this precipitation event, a one-foot thick layer of 2-inch to 6-inch granite stone with a d50 (i.e., median size) of 4 inches has been selected for use as the erosion barrier (sizing based upon Logan 1977 (Figure C-3); Goldman et al. 1986 (Section 7.7b, Rock Linings); NCSU 1991 (Section 6.15, Riprap)). Additionally, in order to prevent the loss of overlying material into the erosion barrier and to reduce the saturated hydraulic conductivity of the erosion barrier layer, the granite stone will be filled with a Controlled Low Strength Material (CLSM) a flowable fill of a lean cement/fly ash/sand/water mixture).

The following conservative assumptions were made in sizing the granite stone of the erosion barrier (Phifer and Nelson (2003) Appendix K), which result in assurance that the erosion barrier can withstand the impact of rill and gully erosion:

- It was assumed that the entire 3.3 inches of rainfall over a 15 minute period (i.e., 10,000-year return period) resulted in runoff (i.e., no infiltration occurs).
- It was assumed that there is no lag period due to the length of the flow path (i.e., all the rainfall over the entire area immediately becomes discharge out the end of the area).
- It was assumed that the CLSM or Flowable Fill provided no resistance to erosion.

While rill and gully erosion are possible on the closure cap, such erosion will not proceed through the erosion barrier. Additionally any impact that such rill and gully erosion could have on infiltration through the upper GCL layer (see the response to NRC Comment 24 for the closure cap configuration) is bounded by the sensitivity analyses which have been performed considering different land use scenarios (see the response to NRC Comments 20, 24, and 30 for additional information on the sensitivity analyses). Finally, since rill and gully erosion would stop at the erosion barrier and could not erode down to the upper GCL, such rill and gully erosion would tend to actually increase runoff from the closure cap and thereby reduce infiltration through the upper GCL. Therefore we have been conservative in our consideration of the impacts of erosion on infiltration (see the response to NRC Comment 30 for further information concerning the impacts of erosion on infiltration).

References:

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. March 31, 2005.

Goldman, S. J., Jackson, K., and Bursztynsky, T. A. 1986. Erosion and Sediment Control Handbook, McGraw-Hill Publishing Company, New York.

Logan, C. A. 19t7. *Soil and Water Conservation in Developing Areas*, SC-40-0014-1190, South Carolina Land Resources Conservation Commission. June 1977.

NCSU (North Carolina State University). 1991. *Erosion and Sediment Control – Field Manual*, State of North Carolina. February 1991.

Phifer, M. A. and Nelson, E. A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina. September 22, 2003.

Weber, A. H., Weber, J. H., Parker, M. J., and Hunter, C. H. 1998. *Tornado, Maximum Wind Gust, and Extreme Rainfall Event Recurrence Frequencies at the Savannah River Site (U)*, WSRC-TR-98-00329, Westinghouse Savannah River Company, Aiken, South Carolina. September 1998.

NRC Comment 26: Information about the performance and analysis of the engineered cap is in some cases limited.

Basis: The text on page A-14 of Reference 1 indicates that only the end half of the upper barrier needs to be simulated; however, the lateral boundaries are assigned no-flow. It is not clear that this approach adequately captures the total moisture flow through and around the cap. There may be significant lateral flow from the half of the barrier that is not being simulated. Text on page 6 of SRT-WED-93-203 in Reference 2 indicates that a factor of 13 change in the clay hydraulic conductivity only results in a factor of 2 change in infiltration, which is not intuitive.

Path Forward: Provide additional information that explains the analysis and results of the engineered cap simulations provided above.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al 2005). In the 2005 SA, the closure cap design was modified, and the new design is described below.

Saltstone Vault 4 is 600 feet long by 200 feet wide. The apex of the vault roof runs lengthwise (i.e., 600 feet) down its center, and the roof is sloped at 2 percent from the apex to the vault side, which results in a slope length of 100 feet. The closure cap above the vault will consist of the layers outlined in Table 26-1. The lower geosynthetic clay liner (GCL) and lower drainage layer will be located directly on top of the vault roof and will be at the same slope and slope length as the vault roof. The lower backfill layer, closest to the vault roof, will be placed and graded so that it is sloped at 3 percent along each length-wise half of the vault, resulting in a slope length of 300 feet over the vault. To create a slope perpendicular to that of the direction of slope of the roof, and a larger value (3% vs. 2%), the thickness of the lower backfill layer will vary (the minimum thickness of this layer is approximately 5 feet). The slope and slope length of the upper surface of the lower backfill layer will propagate upward through the remaining closure cap layers. Figure 26-1 provides a plot plan of Vault 4 illustrating the vault and closure cap slopes, and Figure 26-2 provides a cross-sectional view of the vault and closure cap.

Table 26-1. Closure Cap Configuration

Layer	Thickness (inches)
Vegetation	Not applicable
Topsoil	6
Upper Backfill	30
Erosion Control Barrier	12
Middle Backfill	12
Geotextile Filter Fabric	-
Upper Drainage Layer	12
Upper GCL	0.2
Lower Backfill	58.65 (minimum)
Geotextile Filter Fabric	-
Lower Drainage Layer	24
Lower GCL	0.2
Vault	-

Figure 26-1. Vault 4 and Closure Cap Plot Plan

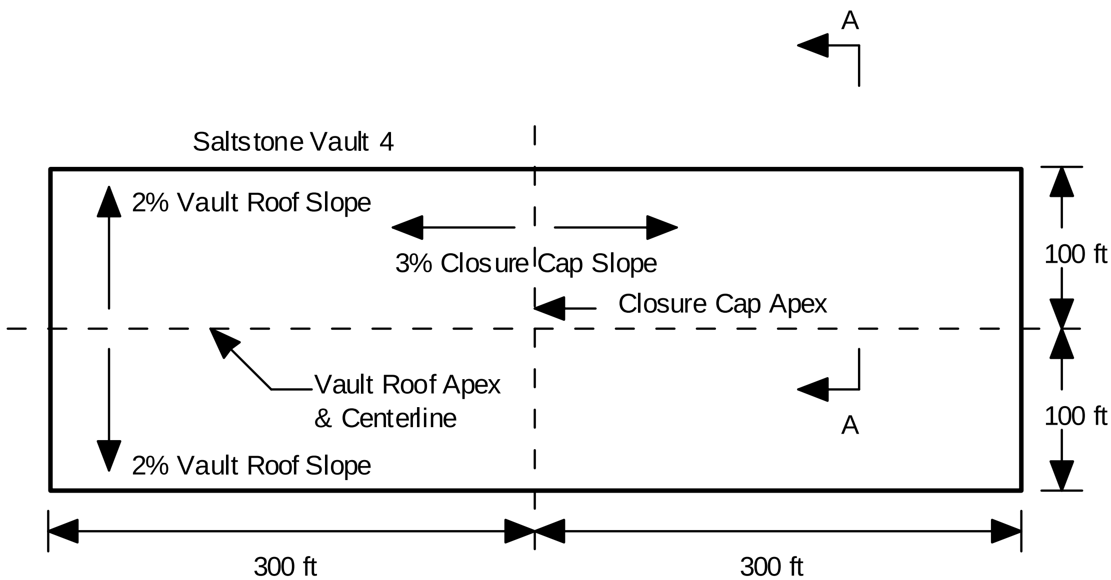
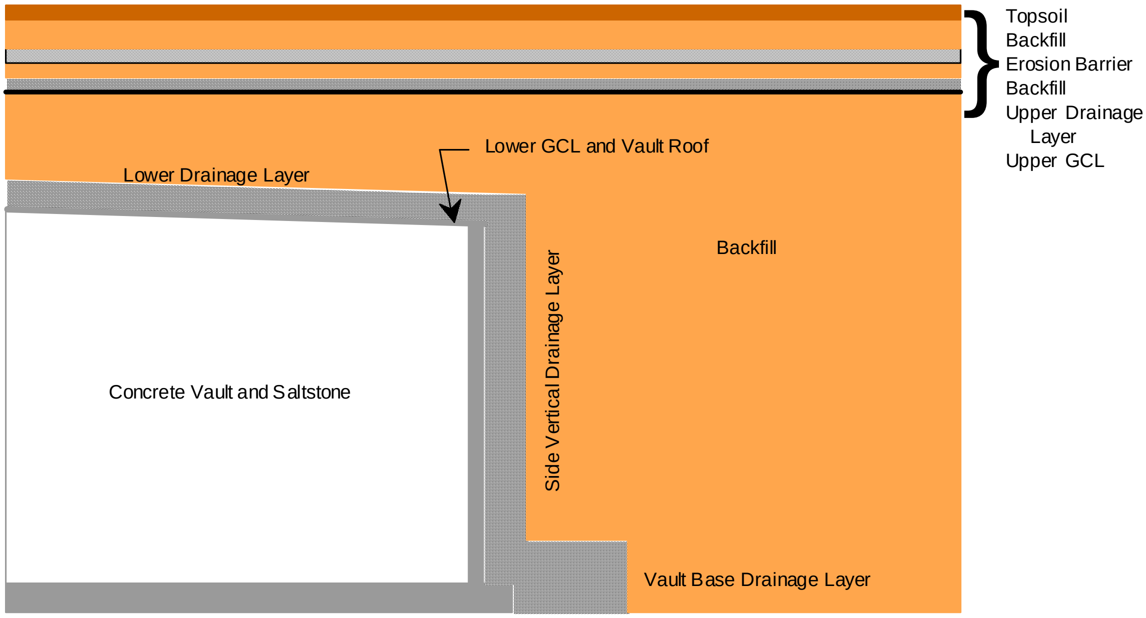


Figure 26-2. Vault 4 and Closure Cap Cross-Section (Section A-A)



The following two models were utilized in the 2005 SA (Cook et al. 2005 Section A.2.1) to analyze water flow through the closure cap / vault system:

- Hydrologic Evaluation of Landfill Performance (HELP) model (USEPA 1994a and USEPA 1994b), and
- PORFLOW (ACRI 2002).

Information concerning the HELP model and its verification can be found in the response to NRC Comment 17. The HELP model was utilized to provide estimates of runoff, evapotranspiration, lateral drainage, vertical percolation, hydraulic head, and water storage for the closure cap (see Figure 26-2). The primary HELP model output which was utilized in subsequent modeling was the infiltration through the upper GCL over time.

Information concerning the PORFLOW model and its verification also can be found in the response to NRC Comment 17. PORFLOW was utilized to model the vadose zone from the bottom of the upper GCL to the water table. The 2005 SA (Cook et al. 2005 Section A.2.1) states the following concerning the PORFLOW vadose zone model domain:

"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 geosynthetic clay liner (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 at the left side of Figure 26-3 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 contaminant transport mechanism is downward convection."

Figure 26-3 provides the conceptual model for the PORFLOW vadose zone model and Figure 26-4 provides the PORFLOW vadose zone modeling grid.

Figure 26-3. PORFLOW Vadose Zone Conceptual Model

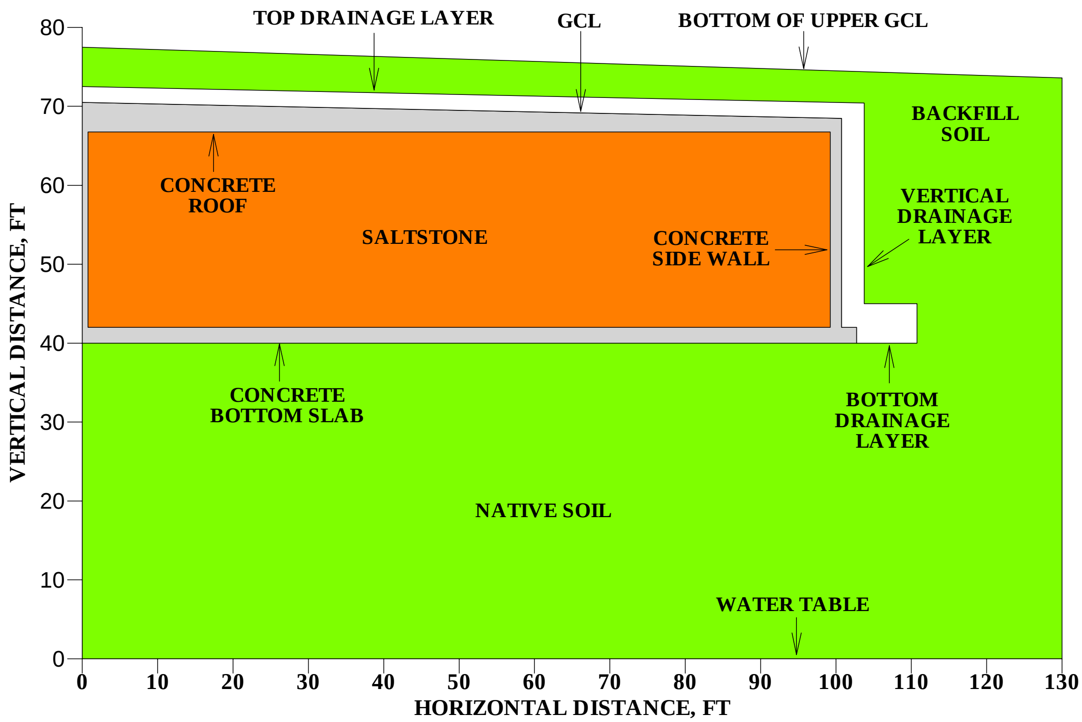
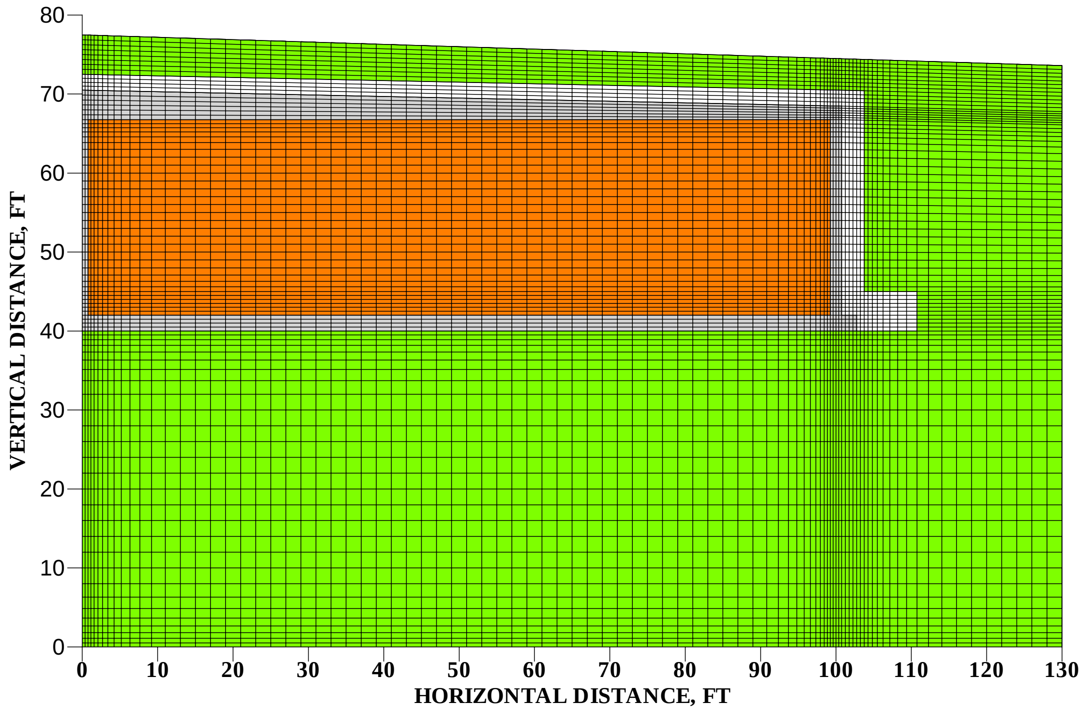


Figure 26-4. PORFLOW Vadose Zone Modeling Grid



As described above the model domain utilized within the 2005 SA (Cook et al. 2005), unlike that described in the 1992 PA (reference 1 in the NRC RAI) page A-14, was selected based upon actual vault and closure cap configurations and symmetry. The HELP model output of infiltration through the upper GCL over time is applicable for the entire area over Vault 4 (see Figure 26-1). The PORFLOW model grid is based upon symmetry of the vault roof. The apex of the vault roof divides the vault into two symmetrical halves. Since symmetry is about the apex of the vault (i.e., the highpoint), consideration of only one half of the cross-section produces no concern relative to adequately considering the total moisture flow through and around the cap and vault. There cannot be lateral flow from the half that is not being simulated into the one that is being simulated. Therefore, assigning this line of symmetry as a no flow boundary is appropriate. As stated in the 2005 SA (Cook et al. 2005 Section A.2.1), assignment of the right boundary as a no-flow boundary is appropriate "because it is sufficiently far away from the vault and the predominant contaminant transport mechanism is downward convection".

In the 1998 PA Addendum (reference 2 in the NRC RAI), the hydraulic conductivity of the upper moisture barrier (i.e., compacted clay layer) was varied to look at the impact of moisture barrier degradation on infiltration (see text on page 6 of SRT-WED-93-203 in Reference 2 in the NRC RAI). As stated previously, Reference 2 in the NRC RAI has been supplemented by the 2005 SA (Cook et al. 2005).

The 2005 SA (Cook et al. 2005) utilized pine tree root penetration rather than a hydraulic conductivity increase as the degradation mechanism. Therefore, rather than evaluating the previous factor of 13 change in clay hydraulic conductivity from Reference 2 in the NRC RAI, information on the impact of root penetration on infiltration is discussed below.

The upper GCL in the 2005 SA (Cook et al. 2005) was degraded over time by pine tree root penetration as outlined in Phifer and Nelson (2003). Phifer and Nelson (2003) state the following concerning the impact of pine tree root penetration on the upper GCL:

> Pine forest succession and associated root penetration results in holes through the" upper GCL. "This allows the overlying drainage layer to fill the holes after the roots decompose. The holes in the GCL essentially act as direct conduits from the upper drainage layer to the lower backfill layer. When saturated conditions occur in the drainage layer after major precipitation events, cones of depression are created around the holes in the GCL with a radius of influence much greater than the radius of the hole. This means that a small area of GCL holes can greatly reduce the lateral flow of water in the drainage layer and increase the vertical flow into the lower backfill.

In Phifer and Nelson (2003), holes covering only approximately 0.3 percent of the GCL 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."

Additional detail concerning analysis of the performance and degradation of the closure cap over time, as outlined in the 2005 SA (Cook et al. 2005) and Phifer and Nelson (2003), is provided in the response to NRC Comment 28.

References:

ACRI (Analytic & Computational Research, Inc.) 2002. PORFLOW User's Manual Version 5.0, Rev. 5, Analytic & Computational Research, Inc., Bel Air, California. March 25, 2002.

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. March 31, 2005.

Phifer, M. A. and Nelson, E. A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina. September 22, 2003.

USEPA (U.S. Environmental Protection Agency). 1994a. *The Hydrologic Evaluation of Landfill Performance (HELP) Model User's Guide for Version 3*, EPA/600/R-94/168a, Office of Research and Development, United States Environmental Protection Agency, Washington, DC. September 1994.

USEPA (U.S. Environmental Protection Agency). 1994b. *The Hydrologic Evaluation of Landfill Performance (HELP) Engineering Documentation for Version 3*, EPA/600/R-94/168b, Office of Research and Development, United States Environmental Protection Agency, Washington, DC. September 1994.

NRC Comment 27: Technical basis is required to support the decision to exclude degradation of the lower clay-gravel drain system from consideration in the PA.

Basis: In the report, it is noted that the assumption that the clay-gravel system remains intact is the sole nonconservative aspect of the fracture analysis of the saltstone wasteform (pg. 4-52 of [1]); however, no analysis is provided to justify adopting this nonconservative assumption.

The PA considers two distinct scenarios that affect the quantity of infiltrating water reaching the lower clay-gravel drain system that overlays the top of the concrete vaults. In the first scenario, the upper moisture barrier or cover system is assumed intact throughout the compliance period. In the second scenario, the upper moisture barrier is assumed completely degraded throughout the compliance period. When the cover system is intact, the water flux at the top of the lower clay-gravel drain system is 2 cm/yr. When the cover system is degraded, the water flux at the top of the lower clay-gravel drain system is assumed to be equal to the mean annual infiltration rate of 40 cm/yr. In the PA, these two scenarios are evaluated for the case where the vault and saltstone, which underlie the lower clay-gravel drain system, remain intact and for the case where the vault and saltstone are bisected by fractures that allow water to infiltrate through the wasteform.

The saturated hydraulic conductivity of the lower clay layer is assumed to be 0.24 cm/yr, which is greater than the saturated hydraulic conductivity of the intact saltstone (3.14E4 cm/yr), but less than the bulk saturated hydraulic conductivity of the fractured saltstone (cubic law estimate is approximately 107 cm/yr). Because the clay-gravel drain system is assumed to remain intact, and the saturated hydraulic conductivity of the clay layer (0.24 cm/yr) is less than the lowest water flux (2 cm/yr) to the drain system, the clay above the vault should remain saturated.

Under saturated conditions, flow to the vault and saltstone is controlled by the saturated hydraulic conductivity of the clay. If the saltstone is intact, the water flux is controlled by the saturated hydraulic conductivity of the intact saltstone. If the saltstone is degraded, the water flux is controlled by the saturated hydraulic conductivity of the clay layer.

The results of numerical and analytical models of water flow in the nearfield environments show that the water flow to the vault and saltstone wasteform is 0.175 cm/yr, regardless of whether the saltstone is intact or is degraded by fully penetrating vertical fractures, because of the presence of the functioning lower gravel/clay drain system. If the saltstone is degraded and the clay-gravel drain system is degraded, the water flux through the saltstone should approach the natural recharge rate of the system. Note that this last case requires a more complex unsaturated flow assessment.

Path Forward: Provide the technical basis for the decision to exclude the scenario of a degraded lower clay-gravel drain system from the PA, or demonstrate that the degraded clay-gravel drain system will limit the water flux through the degraded saltstone to 0.175 cm/yr or less.

SRS Response: The design of the lower clay-gravel drain system has been modified, the drainage layer is assumed to degrade over time, and the lower clay layer is ignored with respect to modeling within the Vault 4 Special Analysis (SA) (Cook et al. 2005). This Vault 4 SA supplements the 1992 Saltstone Performance Assessment (PA) and supersedes the 2002 Saltstone Special Analysis. These assumptions are in contrast to the assumptions made within the Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI).

The Saltstone PA assumes that the lower clay-gravel drain system consists of 0.5 m (1.64 ft) of controlled compacted clay (kaolin) overlain by 0.15 m (0.5 ft) of gravel drainage layer. It also assumes that the lower clay-gravel drain system does not degrade over time and includes the clay layer within the modeling.

The design of the closure cap has been modified as outlined within Phifer and Nelson (2003) (Section 4.7), replacing the Saltstone PA lower clay-gravel drain system with a geosynthetic clay liner (GCL) and 0.61 m (2 ft) sand drainage layer. Additionally a 3-foot wide vertical drainage layer was added along the side and a 5-foot-thick by 10-foot-long drainage layer was added at the base of Vaults 1 and 4. These changes were made to minimize the build-up of water on top of the vaults over 10,000 years even as the various drainage layers silts in over time. It is now also assumed that the lower drainage layer does silt in, thereby reducing the saturated hydraulic conductivity over time. Although a GCL will be emplaced between the vault roof and the lower sand drainage layer, current modeling (Cook et al. (2005) Section A.2.1) ignores the presence of the lower GCL altogether. Therefore, whether this lower GCL does or does not degrade over time is not relevant to the modeling.

These closure cap changes, the degradation of the lower drainage layer over time, and the elimination of the lower GCL from consideration are refinements that have been incorporated into the 2005 SA (Cook et al. 2005). Therefore, the degradation of the lower drainage layer over time results in increased infiltration through the degraded saltstone over time within the model.

References:

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. March 31, 2005

Phifer, M. A. and Nelson, E. A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina. September 22, 2003.

NRC Comment 28: The model support for the engineered cap performance is not sufficient to justify the performance of the cap over thousands of years without active monitoring and maintenance.

Basis: Model support is not provided for the numerical modeling results [1] that suggest the near-surface engineered cap would maintain exceptional performance for thousands of years. Text on page 5-5 of Reference 3 indicates the infiltration is 1.75 mm/yr for 10,000 years, which is ~0.1% of precipitation at a humid site. A number of near-surface processes were not considered in the numerical simulations (see Comment 24). In addition to addressing the technical issues in the numerical modeling, the numerical modeling must be supported with additional information. While the level of performance of the engineered cap in the analysis may possibly be achieved with active monitoring and maintenance, active monitoring and maintenance cannot be relied upon after the institutional control period ends (100 years). Information (e.g., analogs, field studies, experiments) is not provided to justify the numerical modeling results.

Path Forward: Provide the model support for the simulated performance of the engineered cap to limit infiltration, in particular for time periods in excess of hundreds of years.

SRS Response: Modeling performed within the 1992 Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) was performed for the following two cover (closure cap) cases:

- Intact Cover: Both the upper and lower clay-gravel drain systems are intact.
- Degraded Cover: The upper clay-gravel drain system has disappeared and the lower clay-gravel drain system is intact.

In both cases it was assumed that the lower clay-gravel drain system remained intact, did not degrade over time, and remained fully functional throughout time. This 1992 PA assumption resulted in an infiltration of 1.75 mm/yr over 10,000 years through the intact lower clay-gravel drain system for both the intact and degraded cover cases (reference 1 and 3 in the NRC RAI).

The analyses in the 1992 PA have been supplemented and those in the 2002 Saltstone Special Analysis (SA) (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005). First, the design of the closure cap including the lower clay-gravel drain system has been modified from that outlined in the 1992 PA to make it more resistant to degradation.

Second, Cook et al. 2005, in contrast to the 1992 PA and 2002 SA, does not assume that the lower clay-gravel drain system remains intact and fully functional over time. Cook et al. 2005 assumes that the drainage layer along with other layers do degrade over time, and the lower clay layer is ignored with respect to modeling (i.e., it is not even included in the model).

As outlined in detail within the response to NRC Comment 24, the current concept for the closure cap (Cook et al. 2005, Section 1.2, and Phifer and Nelson 2003, Section 4.0) has been modified from that outlined within the 1992 PA. In large part these modifications have been made to make the closure cap more resistant to degradation. The changes made, which make the closure cap more resistant to degradation, include:

- The controlled compacted clay (kaolin) layers (1992 PA) have been replaced with geosynthetic clay liners (GCL). A GCL has the ability to self-heal rips or holes, whereas compacted kaolin does not. Additionally, a GCL can undergo repeated cycles of dehydration and hydration without negative impacts to the GCL's saturated hydraulic conductivity, whereas compacted kaolin may irreversibly shrink, crack, and incur increases in its saturated hydraulic conductivity. A GCL incurs less negative impact due to differential settlement, freezing-thawing cycles, and wetting-drying cycles than a compacted kaolin layer. (Phifer and Nelson 2003, Section 4.1)

- An erosion barrier separate from and above the upper drainage layer has been added. This erosion barrier will prevent further erosion once it has been reached. The erosion barrier has been sized based upon the maximum precipitation event for a 10,000-year return period (Phifer and Nelson 2003, Section 4.3 and Appendix K). Additional detail on the erosion barrier is provided in the response to NRC Comment 22.

- The barrier layer has been lowered within the profile from 4 feet below ground surface to 6 feet below. Lowering the barrier layer means that, at the maximum extent of erosion (i.e., to the top of the erosion barrier), the barrier layer (i.e., geosynthetic clay liner, or GCL) will be 3 feet below ground surface rather than only 1 foot as for the compacted kaolin layer in the Saltstone PA. This means that the GCL will experience less water content fluctuation than the compacted kaolin layer would have, since the GCL is below the typical evapotranspiration zone depth of 22 inches and the kaolin was not. (Phifer and Nelson 2003, Sections 2.0 and 4.7)

- The thickness of the lower drainage layer has been increased from the 6 inches outlined in the 1992 PA to two feet as described in Cook et al. 2005. This increase in thickness increases the time required for the layer to silt in. (Phifer and Nelson 2003, Sections 2.0 and 4.6)

The following conclusion was made in the Hydrologic Evaluation of Landfill Performance (HELP) model validation report (USEPA 1987):

A sensitivity analysis of the HELP model was performed to examine the effects of the major design parameters on components of the water budget for landfills. Hydraulic conductivity values for the topsoil, lateral drainage layers, and clay liners are the most important parameters in determining the water budget components. These parameters are particularly important in estimating the percolation through the landfill. Other design parameters tend to affect the apportionment among runoff, evapotranspiration, and lateral drainage from the cover.

Based upon the modified closure cap configuration and the USEPA sensitivity study (USEPA 1987), likely closure cap degradation mechanisms, which could most negatively impact the most important layers affecting the water budget (i.e., top soil, lateral drainage layers, and clay liners), were selected for analysis within the Vault 4 SA (Cook et al. 2005) as described by Phifer and Nelson 2003, Section 5.0. Pine forest succession, erosion, and colloidal clay migration are the primary closure cap degradation mechanisms which have been assumed to significantly impact these layers and therefore infiltration through the closure cap over time. 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, the reduction in the saturated hydraulic conductivity of the drainage layers due to colloidal clay migration into the layers, and erosion which can increase the impact of hole formation in the upper GCL and reduce the thickness of soil layers, which provide water storage for the promotion of evapotranspiration.

The basis for pine forest succession and subsequent root penetration is provided by Phifer and Nelson 2003, Sections 5.1 and 6.1. Pine trees are the most deeply rooted naturally occurring plants at the Savannah River Site (SRS). The extent of root penetration through the upper GCL degradation is based upon the assumed encroachment timing, density, longevity, root structure, and root decomposition of pine trees as derived from Bohm 1979, Burns and Hondala 1990, Ludovici et al. 2002, Taylor 1974, Ulrich et al. 1981, Walkinshaw 1999, and Wilcox 1968. For conservatism, root penetrations are assumed to be a direct conduit from the overlying lateral drainage layer to the underlying backfill layer immediately upon the death of a tree, and no GCL self-healing is assumed to occur. Based upon the current closure cap configuration, once an area of approximately 0.3 percent of the GCL is impacted by root penetration holes, the GCL essentially ceases to function as a barrier layer.

The basis for the erosion degradation mechanism is provided by Phifer and Nelson 2003, Section 5.2. Erosion has been estimated utilizing the Universal Soil Loss Equation consistent with the methodology outlined within Chapter 5, Estimating Soil Loss with the Universal Soil Loss Equation, from Goldman et al. 1986. Further details on erosion as a degradation mechanism are provided in the responses to NRC Comments 20, 22, 25, and 30.

The basis for the colloidal clay migration degradation mechanism is provided by Phifer and Nelson 2003, Sections 5.3, 6.1.3, and 6.1.4. The following is taken from Phifer and Nelson 2003, Section 5.3:

It is assumed that colloidal clay migrates from overlying backfill layers and accumulates in the drainage layers reducing the saturated hydraulic conductivity of the drainage layers over time. … Colloidal clay can exist in groundwater in concentrations up to 63 mg/L as measured by suspended solids (Puls and Powell 1991). Based upon this information and the previous assumption, it will be assumed that water flux driven colloidal clay migration at a concentration of 63 mg/L occurs from overlying backfill layers to the drainage layers. It will be further assumed that the colloidal clay accumulates in the drainage layer from the bottom up filling the void space of the drainage layer with clay at a density of 1.1 g/cm^3 (Hillel 1982). These assumptions are analogous to the formation of the B soil horizon as documented in the soil science literature. Clay translocation is a very slow process where discrete clay particles are washed out in slightly acidic conditions and deposited lower in the soil profile (McRae 1988). Evidence has been found that the B-horizon where the translocated clay is deposited may form at a rate of 10 inches per 5,000 years (Buol et al. 1973).

Table 28-1 provides the current closure cap configuration (Cook et al. 2005) and a complete listing of the assumed degradation mechanism for each of the closure cap layers. Utilizing the HELP model (USEPA 1994a and USEPA 1994b), the resulting infiltration through the upper GCL over time based upon this degradation is provided in Figure 28-1 (Phifer and Nelson 2003, Section 6.0).

The 2005 SA (Cook et al. 2005, Section A.2.1) utilized the infiltration through the upper GCL over time produced from the HELP modeling as the upper flow boundary condition for vadose zone modeling with PORFLOW. The vadose zone PORFLOW modeling domain extends from the bottom of the upper GCL to the water table. This domain includes the lower drainage layer which is assumed to degrade over time as outlined by Phifer and Nelson 2003. This domain ignores the presence of the lower GCL altogether. Therefore whether the lower GCL does or does not degrade over time is not relevant to the modeling.

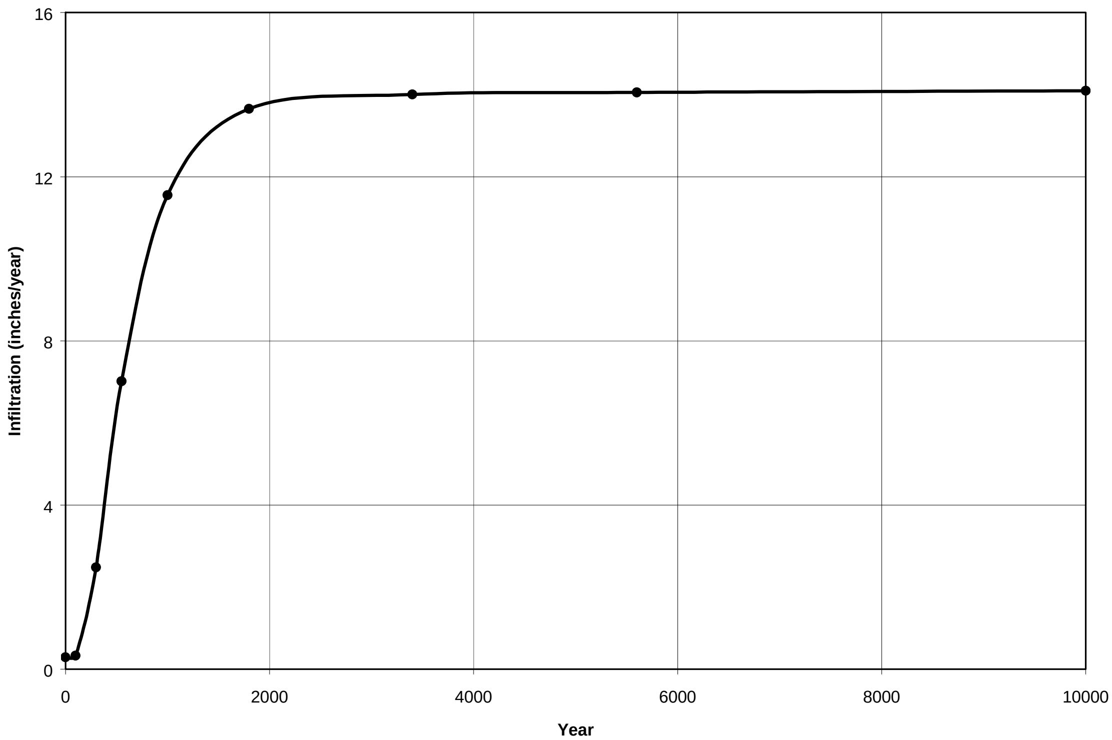
Additionally, as outlined in more detail in the responses to NRC Comments 20, 24, and 30, sensitivity analyses have been performed considering different land use scenarios that produce different rates of closure cap degradation through the primary degradation mechanisms (pine forest succession, erosion, and colloidal clay migration). These different rates of closure cap degradation based upon these various land use scenarios result in different infiltration rates. The maximum infiltration rates for the scenarios ranged from 6.46 to 21.42 inches/year within the 10,000 year interval. These extreme infiltration rates produced from these sensitivity analyses have been utilized to address the sensitivity of groundwater contaminant concentrations and all pathways doses to infiltration in the response to NRC Comment 19. The response to NRC Comment 19 concludes that all of these infiltration rates resulted in doses to a member of the public significantly less than 25 mrem/year.

Table 28-1. Closure Cap Configuration and Layer Degradation (Phifer and Nelson 2003)

Layer	Thickness (in)	Degradation Scenario
Vegetation[4]	Not applicable	Bamboo is maintained during the 100-year institutional control period, pine trees begin to encroach upon the bamboo at the end of institutional control, and a pine forest covers the cap 200 years after the end of institutional control.
Topsoil	6	Topsoil erosion occurs at 1.8E-04 inches per year.
Upper Backfill	30	Backfill erosion occurs at 1.1E-04 inches per years, after the topsoil layer has been depleted.
Erosion Control Barrier	12	Maintenance during institutional control period prevents degradation of the erosion control barrier. However pine forest succession and associated root penetration results in holes through the erosion control barrier. This does not impact its ability to function as an erosion barrier, however it allows the overlying backfill to fill the holes left after the roots decompose.
Middle Backfill	12	Colloidal clay migration from the 1-foot-thick middle backfill to the underlying 1-foot-thick upper drainage layer causes the saturated hydraulic conductivity to increase over time.
Geotextile Filter Fabric	-	For purposes of colloidal clay migration into the underlying drainage layer the geotextile filter fabric is assumed to be ineffective over the time period under consideration.
Upper Drainage Layer	12	Colloidal clay migration from the overlying 1-foot-thick backfill into the 1-foot-thick upper drainage layer causes the saturated hydraulic conductivity to decrease over time.
Upper GCL	0.2	Maintenance during institutional control period prevents degradation of the upper GCL. However pine forest succession and associated root penetration results in holes through the GCL. This allows the overlying drainage layer to fill the holes after the roots decompose.
Lower Backfill	58.65 (minimum)	None. While it is assumed that colloidal clay migration from this layer to the underlying lower drainage layer occurs, it is also assumed that the thickness of the lower backfill layer (almost 5-foot) relative to the lower drainage layer (2-foot) prevents the quantity of clay loss necessary to change the hydraulic properties of the lower backfill.
Geotextile Filter Fabric	-	For purposes of colloidal clay migration into the underlying drainage layer the geotextile filter fabric is assumed to be ineffective over the time period under consideration.
Lower Drainage Layer	24	Colloidal clay migration from the overlying ~5-foot-thick lower backfill into the 1-foot-thick lower drainage layer reduces its saturated hydraulic conductivity over time.
Lower GCL	0.2	None. Pine tree roots do not penetration to a sufficient enough depth to impact this layer. Additionally the underlying concrete vault roof along with the GCL produces a hard layer and continuous water saturation within and above these layers so that root elongation is stopped.
Side Vertical Drainage Layer	36	None, until the vault base drainage layer has been filled with colloidal clay.
Vault Base Drainage Layer	60	Colloidal clay migrates from the overlying ~30-foot-thick backfill into the 5-foot-thick drainage layer reduces its saturated hydraulic conductivity over time.

[4] Sensitivity analyses have been performed considering different land use scenarios, which consider different vegetative covers. See the responses to NRC Comments 20 and 30 for more complete information regarding these sensitivity analyses.

Figure 28-1. Infiltration through Upper GCL (Phifer and Nelson 2003)



References:

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NRC Comment 29: The technical basis for the persistence of the bamboo as an evapotranspiration barrier and for erosion control is not provided.

Basis: Bamboo is used in the design of the engineered cap to reduce infiltration through evapotranspiration and to limit erosion. Some types of bamboo flower and die, thereby a persistent colony is not established.

Introduction of deeper rooting species of flora may result in disruption of the engineered cap. DOE's simulation results in References 2 and 3 suggest that meeting the performance objectives is sensitive to the presence and effectiveness of the engineered cap.

Path Forward: If credit is taken for the bamboo in the performance assessment, then address the persistence of the bamboo in limiting infiltration and the ingress of deeper rooting species of flora over the analysis period.

SRS Response: It has been demonstrated in a study conducted by the USDA Soil Conservation Service (Salvo and Cook 1992) that two species of bamboo (Phyllostachys bissetii and Phyllostachys rubromarginatta) can quickly establish a dense ground cover in the upland areas of the Savannah River Site (SRS). A long-term study is currently ongoing to determine whether or not bamboo can competitively exclude all other vegetation after maintenance has been discontinued at the end of the 100 year institutional control period.

It has not yet been determined, through the long-term study, whether or not bamboo competitively excludes all other vegetation without maintenance. Therefore, the conservative assumption that it does not exclude other vegetation after the 100 year institutional control period has been made within the Vault 4 Special Analysis (SA) (Cook et al. 2005). This is in contrast to the assumptions made within the Saltstone Performance Assessment (PA), the 1998 PA Addendum, and the 2002 Special Analysis (SA) (references 1, 2, and 3, respectively, in the NRC RAI). Cook et al. (2005) does assume that the closure cap degrades over time through pine forest succession as described by Phifer and Nelson (2003) (Section 5.1). Pine trees are the most deeply rooted naturally occurring plants at SRS. It is assumed that a pine forest begins to encroach upon the closure cap immediately at the end of a 100-year institutional control period. Pine forest succession is assumed to primarily degrade the closure cap by replacing the bamboo, increasing the saturated hydraulic conductivity of the erosion control barrier, and resulting in the production of holes within the upper geosynthetic clay liner (GCL).

In addition, sensitivity analyses have been performed considering different land use scenarios, which consider different vegetative covers. See the responses to NRC Comments 20 and 30 for more complete information regarding these sensitivity analyses.

References:

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. March 31, 2005.

Phifer, M. A. and Nelson, E. A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina. September 22, 2003.

Salvo and Cook. 1993. Selection and Cultivation of Final Vegetative Cover for Closed Waste Sites at the Savannah River Site, SC, WSRC-MS-92-513, Waste Management `93 Conference, Tucson Arizona. February 29 – March 4, 1993.

NRC Comment 30: The physical removal of backfill soil due to erosion is not clearly reflected in the analysis of water flux through the engineered cover system for the degradation scenarios.

Basis: In the analysis of the degraded scenarios, cover degradation is considered only in terms of loss of the moisture diversion functionality of the upper moisture barrier by setting the upper flux boundary to the 40 cm/yr site infiltration rate. The physical domain adopted for the simulation of flow and mass transport beneath the upper moisture barrier (Section A.1.2.2 and Figure A.1-9 of [1]) does not indicate the physical removal (by erosion) of backfill, which produces this loss of functionality. The removal of backfill soil is expected to affect the flow paths and moisture distributions above the underlying clay/gravel drain system.

Path Forward: Provide the technical basis and analysis to demonstrate that the degraded scenarios have been appropriately simulated.

SRS Response: The analyses in the Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Saltsone Special Analysis (SA) (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

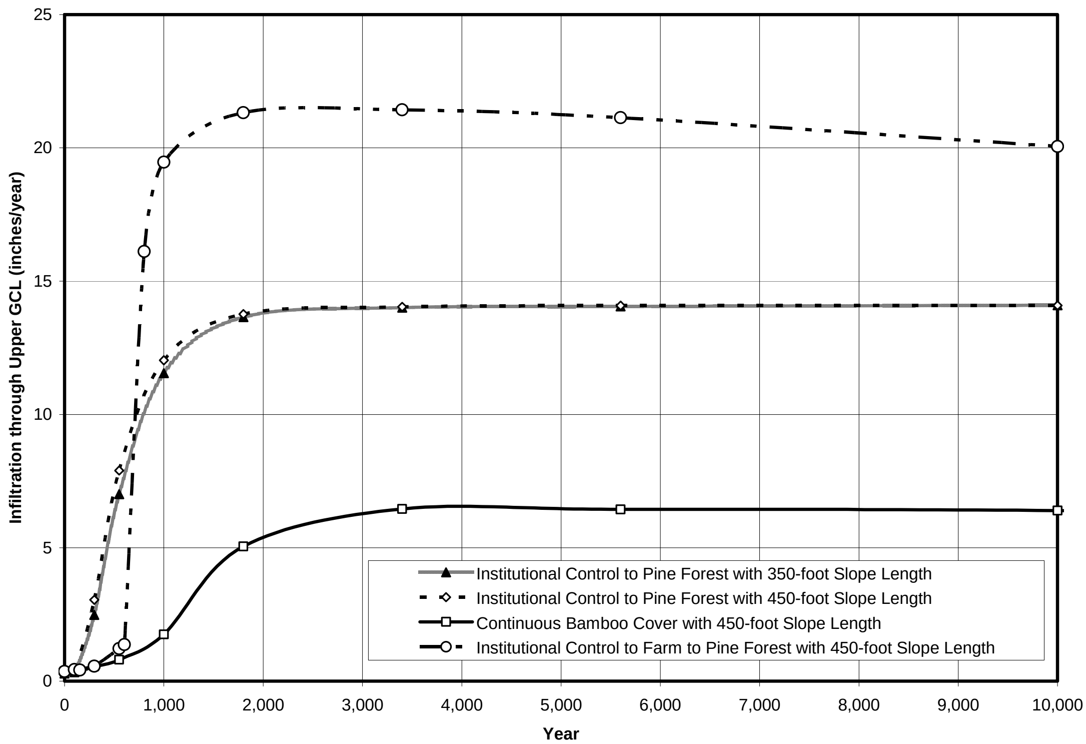
Current modeling in the 2005 Vault 4 SA, in contrast to the Saltstone PA, does consider the impact of erosion upon infiltration and does not assume a constant 40 cm/yr site infiltration rate as the upper flow boundary condition. Rather, the 2005 Vault 4 SA utilized the infiltration through the upper geosynthetic clay layer (GCL) over time produced from Hydrologic Evaluation of Landfill Performance (HELP) modeling as the upper flow boundary condition for vadose zone PORFLOW modeling (Phifer and Nelson 2003; USEPA 1994a; and USEPA 1994b). This infiltration through the upper GCL over time was determined based upon closure cap degradation through the following primary closure cap degradation mechanisms: pine forest succession, erosion, and colloidal clay migration. (The response to NRC Comment 28 provides a more complete explanation of the closure cap degradation.)

In addition, sensitivity analyses have been performed considering different land-use scenarios that result in different rates of closure cap degradation through each of the primary degradation mechanisms, including erosion. Table 30-1 provides an overview of the scenarios considered and the associated reference documents. Figure 30-1 provides the resulting infiltration through the upper GCL over time for each of the scenarios. The extreme infiltration rates from Figure 30-1 have been utilized to aid in addressing the NRC Comment 19 in relation to the sensitivity to infiltration.

Table 30-1. Sensitivity Scenarios

Scenario	Associated Documentation
Institutional Control to Pine Forest with 350-foot slope length	Phifer and Nelson 2003
Institutional Control to Pine Forest with 450-foot slope length	Phifer 2003
Continuous Bamboo Cover with 450-foot slope length	Phifer 2004
Institutional Control to Farm to Pine Forest with 450-foot slope length	Phifer 2004

Figure 30-1. Sensitivity Scenario Infiltration Rates over Time



References:

Cook, J. R., Wilhite, E. L., and Hiergesell, R. A. 2005. Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. March 31, 2005.

Phifer, M. A. and Nelson, E. A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00436, Westinghouse Savannah River Company, Aiken, South Carolina. September 22, 2003.

Phifer, M. A. 2003. Saltstone Disposal Facility Mechanically Stabilized Earth Vault Closure Cap Degradation Base Case: Institutional Control to Pine Forest Scenario (U), Rev. 0, WSRC-TR-2003-00523, Westinghouse Savannah River Company, Aiken, South Carolina. December 18, 2003.

Phifer, M. A. 2004. Saltstone Disposal Facility Mechanically Stabilized Earth Vault Closure Cap Degradation: Sensitivity Analysis (U), Rev. 0, WSRC-TR-2004-00049, Westinghouse Savannah River Company, Aiken, South Carolina. February 12, 2004.

NRC Comment 31: It is not clear that there is consistency of the simulated fractional release rates with the various leaching, durability, and lysimeter tests described in References 10-13.

Basis: Fractional release rates that were independently hand-calculated using the physical dimensions of an intact vault and the effective diffusion coefficients developed in site-specific experiments [10-13] are 2 or more orders of magnitude greater than the reported model-calculated values. It is not clear what processes or parameters in the numerical model are responsible for the differences.

Path Forward: Provide a comparison of the model-generated fractional release rates of NO3, Tc-99, I-129, Se-79, Np-237 to those generated based on the results of leaching experiments and lysimeter studies (e.g., those provided on page 2-54 of [1]), applying the appropriate correction and normalization factors.

SRS Response: During a meeting between the NRC and DOE on 6/8/05, it was determined that the hand calculations mentioned above did not include the effects of the concrete vault as a diffusion barrier. As described in Section 2.4.1.3 of the 1992 PA (Reference 1 in the NRC RAI), modeling studies showed that disposal in concrete vaults was needed to reduce the release rate of nitrate. Vault 4 was constructed with walls 0.46 m (1.5 ft) thick and a floor 0.76 m (2.5 ft) thick. These thicknesses of concrete serve as diffusion barriers which greatly attenuate the release of mobile constituents.

As a test, the lysimeter experiment whose results are plotted on page 2-54 of the 1992 PA (Reference 1 of the RAI) was set up as a PORFLOW run. Using information from McIntyre and Wilhite 1987 and the intact Saltstone properties used in Cook et al. 2005, a run was made for nitrate (K_d = 0 mL/g), Tc-99 with a K_d of 1000 mL/g (the value used to represent Saltstone with slag), and Tc-99 with a K_d of 1 mL/g (the value for non-slag Saltstone) in order to see if the results compared with the figure on page 2-54 of the 1992 PA. The original figure shown on page 2-54 of the 1992 PA and the results of the PORFLOW run are shown below. The PORFLOW input file for the case of nitrate and Tc with a K_d of 1 mL/g is also shown following the figures.

The range of the nitrate and technetium concentrations, as well as the ratios of Tc to NO_3 for Saltstone both with and without slag are quite similar in both sets of runs. Since the K_ds of I-192 and Se-79 are similar to the K_ds of nitrate (K_d = 0 mL/g) and Tc-99 (oxidizing K_d = 1 mL/g) these radionuclides should behave in a similar manner. These results give assurance that the PORFLOW computer program can provide a good representation of the lysimeter experiment with nitrate and technetium and that the parameters used in the Special Analysis model are reasonable representations of the actual materials in the system.

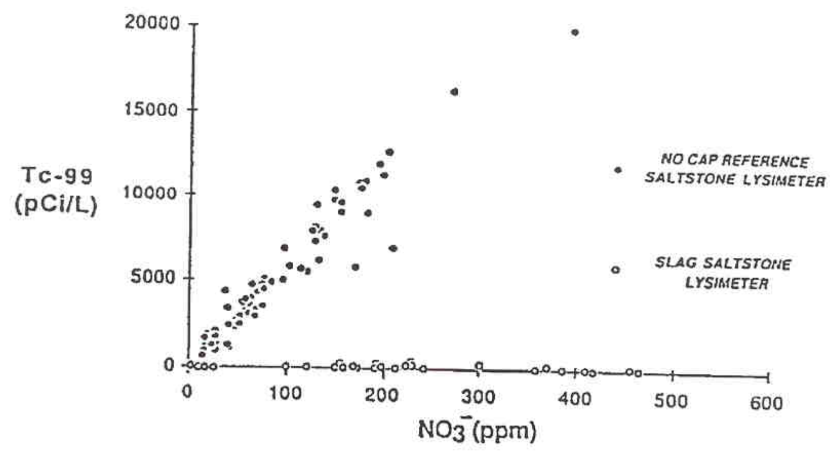
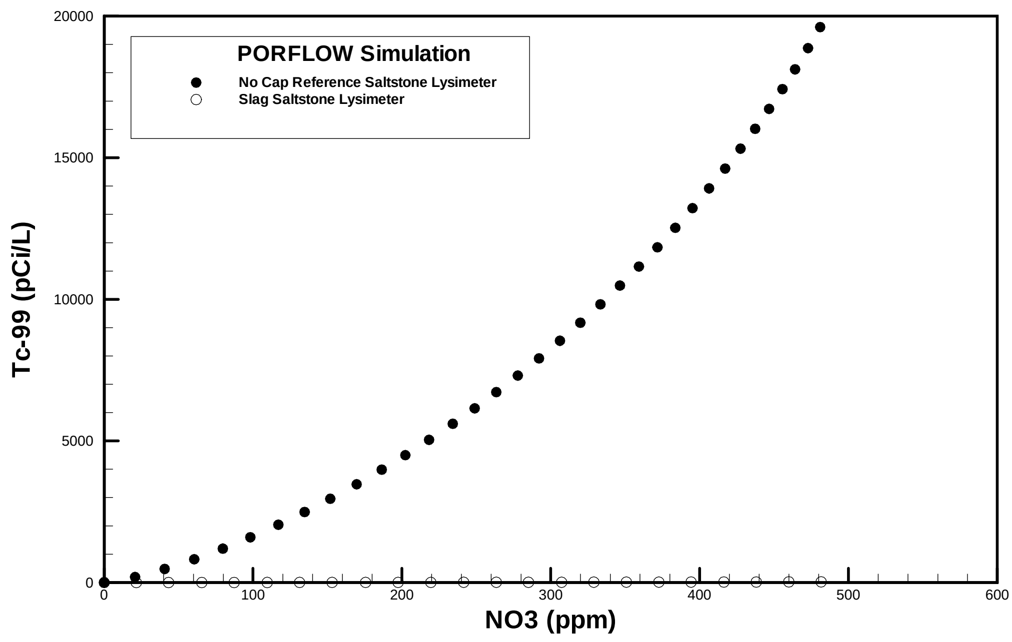


Fig. 2.4-2 Comparison of Technetium vs. Nitrate Leaching for Slag- and Cement-Based Saltstone Lysimeters.



```
! COMPONENTS = NO3 and Tc-99

TITLE Slag Saltstone Lysimeter VADOSE ZONE TRANSPORT RUN 0-730 days (Kd 1)
USER Sebastian Aleman
GRID 62 by 107

!-----------------------------------------------------------------------

!Native and Backfill Soil
MATErial type   1  from    1    1  to  62   107

!Drainage Layer
MATErial type   2  from    1    1  to  62   15  !Drain Bottom

!Slag Saltstone
MATErial type   3  from   22   56  to  41   77  !Saltstone

!=======================================================================

!Native Soil
FOR 1
MATErial  DENSity 2.65
MATErial  POROsity = .42  .42  .42
TRAN for C  Kd= 0.00E+00 diff= 4.32E+00 al= 0 at= 0
TRAN for C2 Kd= 1.00E-01 diff= 4.32E+00 al= 0 at= 0

!Drain Bot (Gravel)
FOR 2
MATErial DENSity = 2.65
MATErial POROsity =  0.38  0.38  0.38
TRAN for C  Kd= 0.00E+00 diff= 4.32E+00 al= 0 at= 0
TRAN for C2 Kd= 1.00E-01 diff= 4.32E+00 al= 0 at= 0

!Slag Saltstone
FOR 3
MATErial  DENSity 2.65
MATErial  POROsity = .42  .42  .42
TRAN for C  Kd= 0.00E+00 diff= 4.43E-04 al= 0 at= 0
TRAN for C2 Kd= 1.00E+00 diff= 4.43E-04 al= 0 at= 0

DECAy HALF LIFE for C2 7.7068E+07 day  !! Tc-99  2.1100E+05 year

LOCAte (22,56) to (41,77) ID=WAST

!=======================================================================

BOUN C  X- FLUX= 0.
BOUN C  X+ FLUX= 0.
!BOUN C Y- INTENTIONALLY LEFT OUT
BOUN C  Y+ FLUX= 0.

BOUN C2  X- FLUX= 0.
BOUN C2  X+ FLUX= 0.
!BOUN C2 Y- INTENTIONALLY LEFT OUT
BOUN C2  Y+ FLUX= 0.
```

```
!==========================================================================

SET INVEntory C   3.2181E+08  UNIForm  ID=WAST ! ppm/l
SET INVEntory C2  8.7681E+10  UNIForm  ID=WAST ! pCi/L/l

!==========================================================================

PROPerty for C C2 is HARMonic
MATRix C ADI 3
MATRix ITER = 100
LIMIt for C C2 minimum 0.

DIAG TIME C C2 at (31,7) every 100 steps

CONVergence for C C2 REFE LOCAl 1.e-6
OUTPut off

FLUX C   'NO3-Tc-99.FLX'   TIME 1.00E+00 day
FLUX C2  'NO3-Tc-99.FLX'   TIME 1.00E+00 day

! Statistic for C and C2
LOCAte (1,1) to (62,15) ID=MIXC
STATistics C    ID=MIXC   'MIXC-NO3.dat'    TIME 1. day
STATistics C2   ID=MIXC   'MIXC-Tc-99.dat'  TIME 1. day

!==========================================================================
! TIME INTERVAL TI01: 0 to 730 days
! READ STEADY-STATE FLOW ARCHIVE
READ 1 '..\..\..\VadoseZoneFlow\Yr-2\Lysimeter-flow.ARC' STARt
TIME = 0. days
SOLV C C2 AUTO 7.3E+02 1.E-04 1.01 0.1 1.E-06 2.0 1.E+6

END
```

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina.

McIntryre, P. F., and Wilhite, E. L., 1987, *Slag Saltstone Lysimeter: Monitoring During the First Two Years*, DPST-87-523, Savannah River Laboratory.

NRC
Comment 32: Page B-6 of Reference 1 indicates that empirical relationships for concrete degradation were used. It is not clear how it was ensured that the conditions under which the empirical relationships were developed were appropriate for application to vaults at SRS.

Basis: The empirical relationships used to estimate degradation were based on systems and a range of conditions that may or may not be appropriate for the application to vaults at SRS. Application of empirical models outside of their developed range can be a source of significant error. For the empirical sulfate and magnesium attack model, it is not clear if potential sources of Mg and SO4 different from current natural conditions were considered.

Path Forward: Justify that the empirical relationships used to estimate degradation are appropriate for the vaults at SRS. For the empirical sulfate and magnesium attack model, potential sources of Mg and SO4 different from current natural conditions (consistent with expected land uses) should be considered.

SRS Response: Concrete degradation information presented in Appendix B of the 1992 PA (MMES, 1992 / reference 1 of the RAI) was not used to generate degradation rates for the 1992 PA modeling effort or the subsequent 2005 Vault 4 Special Analysis (SA).

The empirical time-dependent relationships between concrete corrodents and concentrations in the 1992 PA Appendix B were compiled and used only to identify potential degradation mechanisms and to identify potential failure. The source of magnesium and sulfate ions/species in the case of the Saltstone concrete vaults is the saltstone grout itself. These ions are not present in appreciable concentrations in the Z-Area soil and are not required as components of the engineered barrier/cap system.

Instead of empirical degradation relationships, the following cause and effect approach was used in the 1992 PA and subsequently in the 2005 SA:

- Durability is defined as performance of design function for design lifetime.
- Degradation is defined as compromised durability.
- Degradation is expressed by cracking, phase changes (increased porosity) and/or loss of mass.
- Cracking results in an increase in hydraulic conductivity.
- Increased hydraulic conductivity results in increased leaching.

In the 1992 PA, the concentrations of contaminants in the groundwater were predicted for two cases:
1) Saltstone grout monolith and vault was assumed to remain intact.
2) Saltstone grout monolith and vault was assumed to be cracked every 3 meters parallel to the width of the vault. The cracking mechanisms were not specified,

but the cracks were assumed to be present when the landfill was closed. This cracking was modeled as a preferential flow path.

In the 2005 SA, two aspects of concrete degradation were considered: 1) cracking caused by differential settlement and seismic events and 2) internal and external mechanisms/processes which led to an increase in hydraulic conductivity over time. These processes include rebar corrosion, ettringite formation (sulfate attack), carbonation, and calcium hydroxide leaching.

A structural analysis predicted that cracks will develop from differential settlement and seismic events over a 10,000-year period and their apertures will increase with increasing time [Peregoy, 2003]. However, that analysis showed that the cracks will open either at the top or at the bottom and will be pinched closed at the opposite end. The 2005 Special Analysis, Section A.4, concluded that cracks of any geometry have very little effect on contaminant transport rate. Based on this finding, large-scale cracks [from seismic events and settlement] were not explicitly modeled in the 2005 SA [Cook et al. 2005, Section A.4].

In the 2005 SA, the groundwater pathway base case was updated to account for changes in the saturated hydraulic conductivities of the landfill components (backfill, drains, concrete, and saltstone grout) over time. The saturated hydraulic conductivity of the Saltstone vault concrete was increased from 1.0E-12 to 1.0E-09 cm/sec over 10,000 years [Cook et al. 2005, Section A.4, p. A-9]. This approach was intended to address the consequences of degradation (cracks) regardless of the mechanism and to eliminate: 1) numerical difficulties associated with modeling fracture networks in a groundwater computer code and 2) large uncertainties associated with inputs such as timing, frequency and size of fractures in the concrete vault. Sensitivity analyses for changes in hydraulic conductivity for the concrete vault and infiltration rates have been performed and are documented in the response to NRC Comment 19.

In summary, hydraulic performance rather than structural performance is the focus of the Saltstone vault degradation studies. The consequences of strength loss are minimal since the vault, including the roof, is completely supported by surrounding material. This is in contrast to the typical degradation studies performed for structural concrete.

References:

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005. *Special Analysis: Revisions of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-0004, Westinghouse Savannah River Company, Aiken, South Carolina.

MMES, 1992. *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, Martin Marietta Energy Systems, Inc., EG&G

Idaho, Westinghouse Hanford Company and Westinghouse Savannah River Company, 1992, Westinghouse Savannah River Company, Aiken, South Carolina.

Peregoy, W., 2003. *Saltstone Vault Structural Degradation Prediction*, T-CLC-Z-00006, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC Comment 33: Page 4-33 of Reference 1 indicates that the saturated hydraulic conductivity of slag saltstone has not been measured. Values for hydraulic conductivity and effective diffusivity of saltstone are based primarily on laboratory-scale samples.

Basis: The summarized Core Laboratories Report in Reference 2 provides data for saltstone, but does not specify if values were obtained for slag saltstone or how the samples were obtained and whether they were representative of field-emplaced conditions. Because of the scale of the saltstone vaults, the curing conditions (e.g., temperature and moisture) may be different from the conditions imposed on laboratory samples, resulting in differences in their physical properties such as saturated hydraulic conductivity. The saturated hydraulic conductivity of the slag saltstone is a key parameter because it can dictate whether the releases are advective or diffusive from intact saltstone. The sensitivity analysis for PORFLOW-3D demonstrates the high sensitivity of peak fractional fluxes to hydraulic properties of the saltstone and vault (pg. 4-35 of [1]). Peak fractional nitrate fluxes can be up to 100 times larger and many radionuclides would be expected to have similar behavior.

Path Forward: Provide the basis for the saturated hydraulic conductivity of slag saltstone and address the representativeness of the samples that were tested. Provide the basis that the values obtained on the laboratory samples are representative of field-achieved values.

SRS Response: Simulated (nonradioactive) salt solution was used to prepare all the slag saltstone grout test specimens used in the hydraulic conductivity determinations. These test specimens were prepared under laboratory conditions that simulated actual Saltstone processing. The samples were cured in poly bottles with lids for specified times as indicated in Table 33-1. Measurements on slag saltstone grout were performed at two different times by two different laboratories, the Materials Research Laboratory at the Pennsylvania State University (curing temperature = 38 ºC for various times between 7 and 360 days) and Core Laboratories, TX (ambient temperature curing for 28 days).

The samples tested at the Pennsylvania State University were prepared and cured in the university laboratories. At the time these measurements were made, the Materials Research Laboratory at the Pennsylvania State University was under contract with the US DOE (and formerly the Office of Nuclear Waste Isolation) to develop and test borehole plugging cementious materials for the Nevada Test Site and for potential geological repositories including one located in bedded salt. Consequently the laboratory staff was familiar with preparation and testing of cementious waste forms and especially with the difficulties of measuring hydraulic conductivities of cementious salt-containing materials.

Core Laboratories was selected to obtain independent measurements on the final saltstone grout formulation. Core Laboratories expertise includes routine and advanced rock property measurements and is a leading supplier of petrophysical services. The samples tested at Core Laboratories were prepared at the Savannah

River Site and shipped to Core Laboratories for hydraulic conductivity measurements.

Recognizing that saltstone grout hydraulic conductivity affects the performance assessment modeling results, sensitivity cases were performed on this variable. In the response to NRC Comment 19, the results of a number of sensitivity cases are presented, several of which deal with the saturated hydraulic conductivity of saltstone grout. One set perturbs the saturated hydraulic conductivity by an order of magnitude (one and three orders of magnitude increase versus two orders for the Base Case). Another set perturbs the degradation rate of the saltstone grout so that the saturated hydraulic conductivity increases at either a faster or slower rate than in the base case. The all-pathways doses calculated in these sensitivity cases varied from a low of 0.04 mrem/year to a high of 0.26 mrem/year, compared to the Base Case result of 0.051 mrem/year. (Note: The all-pathways dose reported in NRC Comment 4 is for all current and future waste additions to Saltstone. The 0.05 mrem/year in this response only reflects the projected final inventory of Vault 4.) All of these results are lower than the performance objective of 25 mrem/year and provide reasonable assurance that the Saltstone Disposal Facility (SDF) will be protective to the public.

The slag saltstone grout hydraulic permeability data used in the 1992 PA, 1998 PA Addendum and 2005 SA are summarized in Table 33-1.

Table 33-1. Summary of NonRadioactive Saltstone Hydraulic Conductivity Data.

Application [Reference]	Saltstone Hydraulic Conductivity Value	Basis [Reference]
1992 Saltstone Performance Assessment [MMES, 1992 WSRC-RP-92- 1360, Table 3.3-1, p. 3-60]	3.15E-03 cm/year (1E-11 cm/sec) *(1 darcy = 10^{-3} cm/sec)*	Pennsylvania State University, [Malek et al, 1985, DP-MS-85-9] Mix I (84-45) Cement = 7.5 wt%, Slag = 7.5 wt% Class F Fly Ash = 45 wt% Salt solution (29%salt) = 40 wt% Water permeability f(curing time at 38C) 7 days = a) 2.46E-03, b) 5.3E-07 darcy 28 days = a) no flow, less than value b) sample failure 56 days = a) < 10-8 darcy no flow, b) 1.6E-06 darcy 90 days = a) 1.49E-05 darcy, b) sample failure 180 days = a) 6.42E-08 darcy, b) 3.28E-06 darcy 360 days = a) 2.4 E-05 darcy Mix II (84-48) Cement = 15 wt% Slag = 18 wt% Class F Fly Ash = 27 wt% Salt solution (29%salt) = 40 wt% 7 days = a) no flow, b) no flow 28 days = a) 1.47E-06 darcy, b) 1.78E-07 darcy 56 days = a) no flow, b) sample failure 90 days = a) sample failure, b) 5.74E-07 darcy 180 days = a) 1.68E-04 darcy
1998 PA Addendum [WSRC-RP-98- 00156, Table 3, p.11 of the May 17, 1993 response]	Run 1: Intact Case K_{sat} = 1E-11 cm/sec Run 2: Fractured Case (fractures on 3 meter spacing across width of vault) K_{sat} = 1E-11 cm/sec Runs 3 & 4: Permeable Saltstone starting at t_0 to evaluate degraded cases K_{sat} = 1E-8 cm/sec	Core Laboratory Report [Yu, et. al., Section 2, page 2-2, WSRC RP-93-894] Saltstone (Nominal Composition, SC DHEC permit) Cement = 3 wt% Slag = 25 wt% Class F Fly Ash = 25 wt% Salt solution (29% salt) = 47 wt% Triplicate measurements cured at least 28 days and pre-saturated with brine Sample 1 = 3.4E-12 cm/sec Sample 3A = 2.8 E-12 cm/sec Sample 4* = 1.9E-12 cm/sec
2002 SA		Provided broader range of radionuclide limits.
2005 SA [Cook, et al, 2005, WSRC- TR-2005- 00074, Table A-4, p. A-9]	Increase Saltstone hydraulic conductivity from 1E-11 to 1E-09 cm/sec in 8 time intervals over 10,000 years	Approach adopted to address consequences of degradation regardless of the mechanism and to eliminated numerical difficulties associated with modeling fracture networks in the groundwater pathway computer code and to address large uncertainties associated with model inputs such as timing, frequency and size of fractures and difficulty in making measurements.
2005 Hydraulic Conductivity Sensitivity Studies	Sensitivity analysis to changes in hydraulic conductivities and degradation rates for components of the landfill.	Sensitivity studies were performed on the 2005 SA case. Extended ranges of hydraulic conductivity values and accelerated degradation rates for the components of the Saltstone landfill were evaluated. See Response 19 Cases 8, 9, 10, 11, and 12.

References:

Cook, J., Kocher, D., McDowell-Boyer, L., and Wilhite, E., 2002, *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility*, WSRC-TR-2002-00456, Rev. 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revisions of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-0004, Westinghouse Savannah River Company, Aiken, South Carolina.

MMES, 1992, *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, Martin Marietta Energy Systems, Inc., EG&G Idaho, Westinghouse Hanford Company and Westinghouse Savannah River Company, Westinghouse Savannah River Company, Aiken, South Carolina.

Malek, R., Roy, D. M., Barnes, M. W., and Langton, C. A., 1985, *Slag Cement – Low-Level Waste Forms at the Savannah River Plant*, DP-MS-85-9, E. I. du Pont de Nemours and Company.

Yu, A. D., Langton, C. A., Serrato, M., G., 1993, *Physical Properties Measurement Program (U)*, WSRC-RP-93-894, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2002, *Addendum to the Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility at the Savannah River Site*, WSRC-RP-98-00156, Rev. 0, Aiken, South Carolina.

NRC
Comment 34: The explanation for the observed behavior of effective permeability to liquid and gas for saltstone samples in the summarized Core Laboratories Report in Reference 2 is unclear.

Basis: The summarized Core Laboratories Report in Reference 2 provides data for saltstone for effective permeability to gas at residual water saturation that was 32,400 times higher than the specific permeability to brine. Similarly, the effective permeability of gas at residual water saturation to water permeability at trapped gas saturation was 157 times higher. The explanation that the results can be explained by drying of the saltstone during the gas injection, or the presence of a trapped gas saturation in the original preparation of the material is confusing. If the presence of trapped gas can explain the results, then the presence of trapped gas may have influenced the absolute permeability measurements.

Path Forward: Provide additional explanation for the observed behavior of effective permeability to liquid and gas for saltstone samples in the summarized Core Laboratories Report in Reference 2.

SRS Response: The Core Laboratories conducted tests on a series of samples that were representative of materials employed in the low-level waste disposal facilities at SRS. These samples were both unconsolidated (soil type) materials as well as consolidated (concrete or saltstone) materials. With respect to hydraulic characteristics, all of the samples were tested for saturated water (or brine) conditions and for permeability to water and gas under partially saturated conditions. The three consolidated materials tested in this program include samples of concrete representative of a Savannah River Site E-Area low level waste disposal vault (not included in the scope of this 3116 Determination), concrete from the Saltstone vault, and saltstone grout material itself. For each of the consolidated materials, three samples were tested for their saturated permeability to liquid, after which one of the samples was selected for testing to determine gas-water and water-gas effective (unsaturated) permeability. The values determined for water-saturated hydraulic conductivity are summarized in the Core Lab report in Section 1 (Project Summary) on page 1-6 and are shown in Table 34-1 below.

Table 34-1

	Sample No.	Saturated Hydraulic Conductivity (cm/s)	Porosity (%)
Saltstone	1	3.40E-12	44.6
	3A	2.80E-12	41.6
	4	1.90E-12	40.6
Concrete	1B	1.10E-10	17.4
(Saltstone)	5B	2.30E-09	18.9
	7B	1.30E-09	16.8
Concrete	2E	7.20E-13	18.1
(E-Area)	4E	1.20E-12	19.3
	7E	1.20E-12	18.6

These values appear to be within the range of hydraulic conductivity values reported in the literature for various unfractured crystalline rocks. On page 65 of Domenico and Schwartz 1990, Table 3-2 contains a listing of representative values for the hydraulic conductivity of various rock types. Table 34-2 below contains hydraulic conductivity values extracted from that reference for different crystalline rocks, the type of rocks most analogous to concrete and saltstone grout. (Note that units are converted from m/s in reference to cm/s.)

Table 34-2

Crystalline Rocks	Hydraulic conductivity range (cm/s)	
	From	To
Permeable basalt	4.0E-09	2.0E-04
Fractured ingneous and metamorphic rock	8.0E-11	3.0E-06
Weathered granite	3.3E-08	5.2E-07
Weathered gabbro	5.5E-09	3.8E-08
Basalt	2.0E-13	4.2E-09
Unfractured igneous and metamorphic rock	3.0E-16	2.0E-12

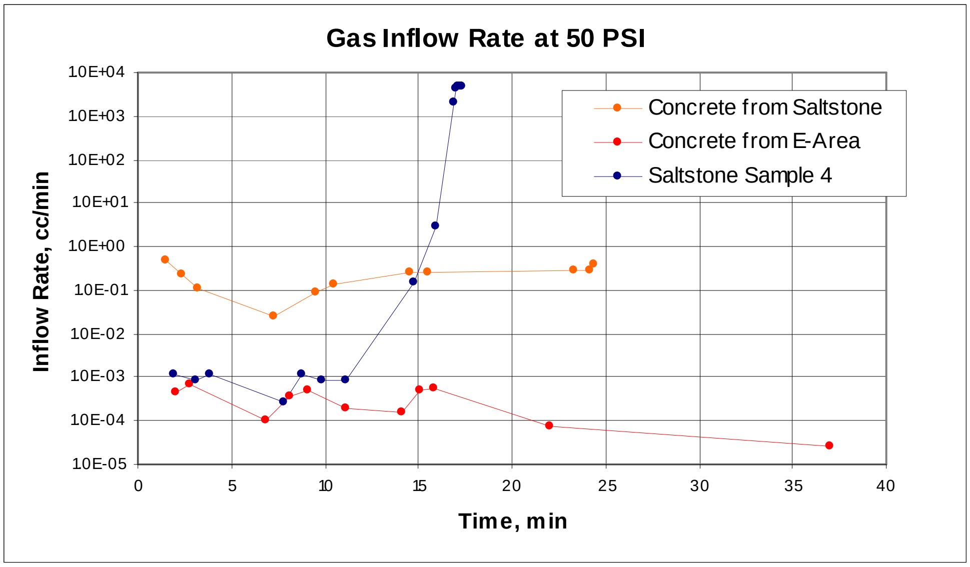
While three samples of each consolidated material were tested to determine saturated hydraulic conductivity, only one sample of each material was selected for unsaturated permeability measurements. The laboratory procedures used to conduct these tests and the results are presented in the Core Laboratories Report, Section 3 (Gas-Water, Water-Gas Relative Permeability). The results of these tests are summarized in the table of information on page 3-2 of the Core Lab report. Table 34-3 below contains information extracted from that table, including the water (or brine) saturated permeability, the unsaturated (or effective) permeability, the residual saturation at which the effective permeability was determined and the relative permeability (water or brine).

Table 34-3

Sample	Saturated permeability (milli-darcies)	Unsaturated permeability (milli-darcies)	Saturation (percent)	Relative (unsat./sat) permeability (dimension-less)
Saltstone	3.70E-06	5.80E-04	99.3	1.57E+02
Concrete	1.30E-03	2.00E-04	87.0	1.54E-01
(saltstone)				
Concrete	1.30E-06	5.40E-07	98.7	4.15E-01
(E-Area)				

The values of relative permeability to liquid (water) for the two concrete samples, 1.54E-01 and 4.15E-01, are in the expected range; however, the value of 1.57E+02 reported for the saltstone sample is anomalous. The cause of this can be traced to an anomalous value for unsaturated permeability that was calculated from the testing data. A close examination of the laboratory data on page 3-103 of the Core Lab report (Gas Displacing Water experiment) for Saltstone #4 indicates that a sudden change in conditions during the experiment led to a much higher gas injection rate. This change occurred between 11.1 and 14.8 minutes following the beginning of injection of nitrogen gas. Figure 34-1 below was created using the "gas displacing water" data reported in the Core Lab report on pages 3-83, 3-93 and 3-103 and indicates the rate of gas injection for all three consolidated samples.

Figure 34-1



The rate of gas injection for the Saltstone #4 sample tracks along with the gas injection rate for the concrete sample from E-Area for the first 11 minutes, after which a drastic increase of nearly 7 orders of magnitude occurred over a period of 8 minutes. As a result, the high flow rates realized during the gas-water and water-gas experiments on this sample contributed to calculation of anomalously high effective permeabilities for gas and water, these being 1.2E-01 and 5.8E-04 millidarcies, respectively. These anomalous values, in turn, result in the calculation of anomalously high relative permeabilities for this sample.

Considering that the water-saturated permeability falls within the expected range for Saltstone sample #4, but its unsaturated water permeability is much higher than the saturated water permeability (5.8E-04 millidarcies compared to 3.7E-06 millidarcies), it appears that the saltstone sample or its testing configuration was damaged during the gas-water experiment. Consequently, the effective permeability test results from the Saltstone #4 sample are not regarded as reliable. Given that the work was conducted nearly 13 years ago, it is not now known why the Core Lab did not re-test one of the other saltstone samples for effective liquid and gas permeability.

References:

Core Laboratories Report, contained in: WSRC, "*Addendum to the Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility at the Savannah River Site*." WSRC-RP-98-00156, Rev. 0, Aiken, South Carolina: Westinghouse Savannah River Company. April 1998.

Domenico, P.A, and F.W. Schwartz, 1990. *Physical and Chemical Hydrogeology*, John Wiley and Sons, Inc. New York, NY.

NRC Comment 35: Measurements of the degree of saturation of slag saltstone in field-emplaced conditions have not been provided.

Basis: Field measurements of the degree of saturation of slag saltstone over time were recommended in Section 5.3 of Reference 1 to reduce the uncertainties related to the long-term performance of the saltstone disposal facility. As pointed out in the report, the release rate of saltstone is very sensitive to the degree of saturation because the unsaturated hydraulic conductivity is orders of magnitude less than the saturated conductivity.

Path Forward: Provide the basis for the degree of saturation of slag saltstone in field-emplaced conditions.

SRS Response: The Vault 4 Special Analysis (SA) (Cook et al 2005) supplements the analyses in the 1992 Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) and supersedes the 2002 SA (reference 3 in the NRC RAI).

The recommendation in the third paragraph of Section 5.3 of the Saltstone PA for field measurement is focused on initial saturation at the time of closure. The initial saturation of saltstone grout is uncertain under field-emplaced conditions and would impact a transient flow model, which requires specification of initial conditions. However, near-field (vadose zone) contaminant transport simulations in the 2005 SA (Cook et al. 2005) use a sequence of steady-state flow fields to approximate changing hydrologic conditions with time. In each period, saturations in saltstone grout take on the long-term equilibrium values that would result from indefinite exposure to the assumed boundary conditions, most notably infiltration. Over the first 10,000 years, saturations in Saltstone range from 97.8% to 99.6% in numerical simulations. No credit is taken for the likelihood that the initial saturation of saltstone grout at closure will be significantly lower due to curing, and exposure to the atmosphere under protection from rainfall for decades during the operational and institutional control periods. Because initial saturation is not an input to the current steady-state flow model, uncertainty in field-emplaced saturation is no longer considered to be an important contributor to performance assessment uncertainty. Rather, this uncertainty is handled by the conservative assumption of equilibrium saturation values.

Reference:

Cook, J.R., Wilhite, E.L., Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC Comment 36: Additional information is needed to provide confidence that there will be no significant cracks or separation at the grout/vault interfaces along the inner surfaces of the vault.

Basis: The saltstone grout will be poured into the vaults in the SDF [1]. A loss of integrity or separation of the materials at the cured grout/vault interface could create a pathway for water infiltration and adversely impact the isolation of the waste from the environment.

Path Forward: Provide information to demonstrate that the cured grout/vault interfaces would not be hydrologically favorable pathways or that they have been studied and found to have no significant impact on waste isolation at the SDF.

SRS Response: The Vault 4 Special Analysis (Cook et al. 2005) supplements the analyses in the 1992 Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) and supersedes the 2002 Special Analysis (SA) (reference 3 in the NRC RAI).

Small-scale shrinkage cracks due to initial curing of saltstone grout will be filled when the next layer of saltstone grout is emplaced.

Section A.4 in Cook et al. 2005 provides an analysis of the effect of macroscopic cracks on the performance of the Vault 4 disposal system. The conclusion of the analysis is "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 pressure conditions, crack flow may be significant". The cracks analyzed were both within the saltstone grout and at the saltstone grout/vault interfaces.

Section 7.5.5 of Cook et al. 2005 presents a sensitivity study designed to assess the effect of system degradation leading to low suction pressure or saturated conditions. When the degradation mechanisms are extended beyond 10,000 years, the drainage layer overlying the vault becomes "plugged" by fines to the extent that water becomes perched on top of it. If there are macroscopic cracks present, they will become preferential paths for water flow under these conditions. The study demonstrates the importance of the drainage layer in meeting the performance objectives over long periods of time.

Reference:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC Comment 38: Table 2.3-1 in Reference 1 indicates a range of saltstone compositions over which acceptable saltstone can be produced. Toxicity Characteristic Leaching Procedure (TCLP) tests were performed on a range of samples, with acceptable results over the range but fairly significant differences in the magnitude of results between samples. It is not clear over what range of compositions the physical properties of saltstone was characterized.

Basis: The performance of the saltstone system can be sensitive to the hydraulic conductivity of the bulk material (unfractured) of the vault and saltstone as well as the effective diffusion coefficients of radionuclides. The pore structure of the material, in turn, is a primary determinant of these physical properties. The pore structure of a cementitious material can be greatly influenced by the proportions of major phases.

Path Forward: The compositions of the saltstone for which physical properties were determined should be provided. The justification that the physical properties of saltstone obtained are appropriate for the range of saltstone components shown in Table 2.3-1 should be provided.

Response: The ranges of ingredient proportions in Table 2.3-1 in the 1992 Saltstone Performance Assessment (PA) (MMES, 1992) are much broader than the ranges of proportions actually used in the Saltstone Facility to date. The wider ranges were developed in support of the state-approved operating permit for the facility. These wider ranges were provided for run-in of the facility and to allow responses to unexpected situations within the operating permit.

Although leaching is expected to be affected by the amount of water that contacts the waste form and therefore by the hydraulic conductivity of the waste form, the saltstone grout TCLP results are not a function of hydraulic conductivity because the samples are crushed to a powder prior to extraction.

The ranges of ingredients used for saltstone grout processing to date have been very narrow, are close to the nominal composition in Table 2.3-1 of the 1992 Saltstone PA, and are expected to remain very narrow. The ranges only varied by 1 to 2 wt% cement and fly ash in the premix and were tested to improve slurry processing properties. The range of compositions and the nominal composition from Table 2.3-1 are provided below.

The ranges of proportions listed in Table 2.3-1 are as follows:

Portland cement Type II	0 to 10 wt%
Fly Ash	10 to 40 wt%
Slag	10 to 40 wt%
Salt Solution	40 to 55 wt%

The nominal composition for saltstone in Table 2.3-1 is as follows:

Portland cement Type II	3 wt%
Fly Ash	25 wt%
Slag	25 wt%
Salt Solution	47 wt%

[MMES, 1992, p. 2-38].

The ranges listed in Table 2.3-1 are not used in the Saltstone Facility to process waste on a daily or batch basis. They were based on passing the TCLP test and for setting composition limits for RCRA metals on waste sent to the Saltstone Facility for processing. These limits were intended to accommodate the following potential issues within the state-approved operating permit for the facility:

1. Processing salt solutions with a wide range of water contents relative to salt contents.
2. Variability in chemical and physical properties of cement, slag and fly ash reagents which are manufactured for the construction industry and procured in bulk (minor adjustments).
3. Range of ambient conditions (winter/summer, wet/dry) which can affect the stored reagents, processing and pumping characteristics and flow in the cells (minor adjustments). (Hydration of the reagents takes place at ambient temperatures.)
4. Changes in the full-scale production facility over twenty plus years (equipment upgrades, modifications etc.).

The actual proportions of the cement, slag, and fly ash (premix) have been essentially constant during operation of the Saltstone Facility. The premix composition used in the facility is 10/45/45 cement/slag/fly ash by weight. Based on a review of the Saltstone Facility operating logs, this premix composition was varied during actual processing by reducing or increasing the cement content in the premix by only 1 to 2 wt% and making a corresponding adjustment in the Class F fly ash content of the premix in an attempt to optimize the processing properties of the mix. Type I/II Portland cement is used in the Saltstone process. Type I/II cement meets the requirements for both Type I and Type II cement.

The premix is batched and then metered into the mixer along with the salt solution. Based on Saltstone operating history, the premix to water ratio (water is a component of the salt solution) is maintained between 0.60 and 0.66 to maintain uniform physical properties, regardless of the salt content of the waste solution.

(This range is required to address the range of ambient conditions and properties of the premix reagents and salt solution.)

The water-to-cementitious solids ratio of concrete and cement waste forms has a significant impact on the porosity, hydraulic conductivity, leachability of soluble constituents, and durability of the porous material. Therefore, proportioning the saltstone waste form on the basis of water to premix (cementitious solids) ratio has been an important element of the quality control program.

Hydraulic conductivity of waste forms impacts the results of the TCLP test to some extent but not to the extent that the reviewer may have anticipated. This is because the requirement for the TCLP test is to size reduce the sample to –9.5 mm (-3/8 inch). The saltstone samples are size-reduced even more, typically to a powder with particles less than 1 mm. Consequently, the reported TCLP measurements are not dependent on the hydraulic conductivity of a monolithic sample.

In addition, the objective of stabilizing the RCRA contaminants in saltstone is to chemically precipitate insoluble/low solubility phases within the saltstone matrix rather than to physically encapsulate soluble RCRA contaminants in the saltstone matrix. Although hydraulic conductivity cannot be completely eliminated as an issue in dissolution of insoluble/low solubility phases exposed to infiltrating water over long times, it is not an issue in the TCLP test results.

Property data for slag saltstone were generated for several purposes including: formulation development, SCDHEC compliance, processibility, radiological performance assessment calculations. Most of the physical property data were generated during formulation development. At that time, the physical property testing included slurry characterization (gel time, set time, standing water), and cured waste form characterization (compressive strength, hydraulic conductivity, porosity, mineralogy, pore solution composition, and TCLP leaching). Per the Solid Waste Landfill Operating Permit, the state-approved operating permit for the Saltstone Disposal Facility, the saltstone product was required to result in a Low-Level (Class A) Radioactive, Non Hazardous Waste Form.

Several independent laboratories were hired to measure the hydraulic conductivity of slag saltstone including: the Pennsylvania State University, Materials Research Laboratory [Malek, et al, 1985, DP-MS-85-9], Western Company [Langton, 1985, DPST-85-982], and Core Laboratories [Yu, et al, 1993, WSRC-93-894]. All of the subcontractors acknowledged the following issues and attempted to modify methods to provide results.

1. The pore structure of the material is much smaller than that of soils and porous rock formations, and therefore performing the measurement is difficult. The mean pore radius of a slag saltstone tested at the Pennsylvania State University by Hg intrusion was 16nm [Langton, 1985, DPST-85-528]. Also detection and

quantification of small amounts of permeating liquid collected over long run times is difficult.

2. The pore structure can be compressed if high pressure is applied or expanded if the composition of the pore solution is rapidly changed or plugged if changes in the pore solution chemistry result in precipitation or hydration of the cementitious components and reaction products [Langton, 1985, DPST-85-982].

3. The chemistry of the permeating liquid effects the results and interpretation of the results. The pore solution contains dissolved salts. Infiltrating water will have a range of compositions as the contact time with the Saltstone increases.

In conclusion, hydraulic conductivity measurements on slag saltstone are difficult to make for the reasons explained above and therefore, were not attempted on radioactive saltstone. A hydraulic conductivity value of 1E-11cm/sec was used in the 1992 PA [MMES, 1992, WSRC-RP-92-1360, Table 3.33-1, p. 3-60]; the 1998 PA Addendum [WSRC-RP-98-00156, Table 3, p. 11 of May 17, 1993 response] the 2002 SA [Cook, et al. 2002, WSRC-TR-2002-00456]; and the 2005 SA [Cook, et al, 2005, WSRC-TR-2005-00074, Table A-4, p. A-9] for non-degraded slag saltstone. This value is consistent with measurements from Core Laboratories, 3.4E-12 cm/sec [Yu, et al. 1993, WSRC-RP-93-894, Section 2, p. 2-2] and the Pennsylvania State University, 1E-08 darcies (1E-11cm/sec) for slag saltstone [Malek et al. 1985, DP-MS-85-9]. Physical property data generated during formulation development studies for cured slag saltstone are summarized in the referenced table below.

As the PA work matured between 1992 and the 2005 SA, the approaches used to characterize and model a degraded waste form also changed. However, conceptualization of a degraded waste form has remained the same, i.e., a waste form that has a higher hydraulic conductivity than the original non-degraded material. (Degraded Saltstone was assumed to not result in landfill/cap collapse, i.e., loss of the ability of the waste form to support the overburden of the landfill.)

The approach used to model an increase in the hydraulic conductivity of the Saltstone in the 1992 PA was to model flow through parallel fractures on a 3-meter spacing across the width of the vaults. In the 1998 PA Addendum two computer simulations were run assuming Saltstone was already degraded at the time the landfill was closed to a hydraulic conductivity of 1E-08 cm/sec.

In the 2005 SA, eight specific times were identified during the 10,000 year period of performance at which significant changes (degradation) in the landfill cap/drain system were expected to occur [Phifer, 2004]. These time intervals were used to generate a base case for modeling the effects of progressive Saltstone degradation (increase in hydraulic conductivity). The hydraulic conductivity of Saltstone was increased from 1E-11 to 1E-09 over this 10,000 year period through eight steady-state stages [Cook, et al. 2005, Appendix A, Table A-4, p. A-9].

In addition, sensitivity analyses have been performed. (See the response to NRC Comment 19.) The relevant degradation mechanisms result in a greater hydraulic conductivity. Consequently the cumulative effect of these mechanisms (increases in hydraulic conductivity) has been addressed in the modeling to date.

Reference	Slag Saltstone Mix	Curing Time	Physical Property Data
DP-MS-85-9	Pennsylvania State University Mix 84-45 Type I cement = 7.5 wt% Slag = 7.5 wt% Class F Fly ash = 45.0 wt% Salt solution (29 wt% salt) = 40 wt%	Days 7 28 56 90 180 360	Compressive strength (MPa) 8.91 18.30 21.40 22.82 24.12 24.46
		Days 7 28 56 90 180 360	Bulk Porosity Hg Intrusion Porosity 40 not measured 43 42.5 43 45.4 43 44.4 44 42.5 45 43.7
		Days 7 28 56 90 180 360	Permeability (darcy) 2.46E-03, 5.30E-07 <10E-8 <10E-08, 1.6E-06 1.49E-05 6.42E-08 3.28E-06 2.4E-05
	Pennsylvania State University Mix 84-48 Cement = 15 wt% Slag = 18 wt% Class F Fly Ash = 27 wt% Salt solution (29%salt) = 40 wt%	Days 7 28 56 90 180	Permeability (darcy) No flow, No flow 1.47E-06 1.78E-07 No flow Sample failure Sample failure 5.74E-07 1.68E-04
DPST-85-528	Pennsylvania State University Mix 84-45 Type I cement = 7.5 wt% Slag = 7.5 wt% Class F Fly ash = 45.0 wt% Salt solution (29 wt% salt) = 40 wt%	Days 28	Mean pore radius = 16 nm, per Hg intrusion porosimetry data Porosity = 42.5 vol.%
DPST-87-530	Pennsylvania State University Mix 84-48 Slag = 25 wt% Class F Fly ash = 30 wt % Salt solution = 45 wt %		Pore solution chemistry after curing 7, 28, 56, 90, and 180 days.
DPST-87 673	SRS Type II cement = 5 wt% Slag = 24 wt% Class F Fly ash = 24 wt% Salt solution (29 wt% salt) = 47 wt%	Days 28	Physical properties of saltstone
DPST-87-869	SRS		Proportions of ingredients and RCRA

	Range of slag Saltstone compositions		D-code contaminants were varied.
WSRC-RP-93-894	Core Laboratory Nominal Saltstone Type I cement = 3 wt% Slag = 25 wt% Class F Fly ash = 25 wt% Salt solution (29 wt% salt) = 47 wt%	Cured at least 28 days before initiating test protocols	Porosity (volume %) Sample 1 Sample 3A Sample 4 44.6 41.6 40.6 Hydraulic Conductivity (cm/sec) 3.4E-12 2.8E-12 1.9E-12 Bulk Density (g/cc) Not measured 1.78 1.78 Poisson's Ratio Not measured 0.313 0.318 Young's Modulus Not measured 1.61E+06 1.64E+06
WSRC-TR-98-00337	SRS Mixes Type I cement = 4 wt% Slag = 25 wt% Class F Fly ash = 25 wt% Salt solution (29 wt% salt) = 46 wt% Type I cement = 3 wt% Slag = 25 wt% Class F Fly ash = 25 wt% Salt solution (29 wt% salt) = 48 wt% Spiked with 1.65E-04M (1.5 Ci/gallon waste solution) non radioactive cesium and cured as a function of temperature up to 90°C.	Samples cured for 28 days at 24, 45,70, and 90°C.	Samples cured at all temperatures passed TCLP for Cr and Hg. Cs leaching decreased as temperature increased relative to samples cured at 24°C. Compressive strength data provided. In general strength increased from about 2,200 psi at 24°C curing to about 4,000 psi at 90C curing. 90°C samples were cracked. 90°C Mineralogy: poorly crystallized hydrocalcite and gypsum.
Review of Saltstone facility Operating Logs [Chandler, 2005]	Type II cement = 3 (-1 to + 2) wt% Slag = 25 (± 1) wt% Class F Fly Ash = 25 (± 2) wt% Salt solution = 47 (± 2) wt%	Cured 28 days	Compressive strength of all samples greater than 200 psi which is the minimum required in the SCDHEC operating permit.

References:

Chandler, T. E., 2005, *E-mail from T. E. Chandler to C. A. Langton*, Westinghouse Savannah River Company, Aiken, South Carolina.

Cook, J., Kocher, D., McDowell-Boyer, L., and Wilhite, E., 2002, *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility*, WSRC-TR-2002-00456, Rev. 0, Westinghouse Savannah River Company, Aiken, South Carolina.

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revisions of Saltstone Vault 4 Disposal Limits (U)*, WSRC-TR-2005-0004, Westinghouse Savannah River Company, Aiken, South Carolina.

Langton, C. A., 1985, *Saltstone Durability – PSU Progress Report Part III – Diffusion Coefficients*, DPST-85-528, E. I. du Pont de Nemours and Company, Aiken, South Carolina.

Langton, C. A., 1985, *Saltstone Permeability (Hydraulic Conductivity)*, DPST-85-982, E. I. du Pont de Nemours and Company, Aiken, South Carolina.

Langton, C. A., 1987, *Physical Properties of Slag Saltstone*, DPST 87-673, E. I. du Pont de Nemours and Company, Aiken, South Carolina, Aiken, South Carolina.

Langton, C. A., 1987, *Analysis of Saltstone Pore Solutions - PSU Progress Report IV*, DPST-87-530, E. I. du Pont de Nemours and Company, Aiken, South Carolina.

Langton, C. A., 1987, *EP and TCLP Test Results for Slag Saltstone*, DPST-87-869, E. I. du Pont de Nemours and Company, Aiken, South Carolina.

Langton, C. A., 1998, Direct *Grout Stabilization of High Cesium Salt Waste: Salt Waste Alternative Phase III Feasibility Study (U)*, WSRC-TR-98-00337, Westinghouse Savannah River Company, Aiken, South Carolina.

MMES, 1992, *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, Martin Marietta Energy Systems, Inc., EG&G Idaho, Westinghouse Hanford Company and Westinghouse Savannah River Company, 1992, Westinghouse Savannah River Company, Aiken, South Carolina.

Malek, R., Roy, D. M., Barnes, M. W., and Langton, C. A., 1985, *Slag Cement – Low-Level Waste Forms at the Savannah River Plant*, DP-MS-85-9, E. I. du Pont de Nemours and Company, Aiken, South Carolina.

Phifer, M. A., 2004, *Interoffice Memorandum to J. R. Cook, et al, Vault 4 Infiltration and Hydraulic Conductivity Input for the Vadose Zone PORFLOW Modeling*, SRT-EST-2004-00068, Westinghouse Savannah River Company, Aiken, South Carolina.

Yu, A. D., Langton, C. A., Serrato, M., G., 1993, *Physical Properties Measurement Program (U)*, WSRC-RP-93-894, Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC, 2002, *Addendum to the Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility at the Savannah River Site*, WSRC-RP-98-00156, Rev. 0, Aiken, South Carolina.

NRC Comment 39 The credit taken for the vaults must consider the high concentrations of sulfate expected in the pore fluids of the saltstone.

Basis: The vaults have been assumed to be a diffusive and flow barrier. The basis for the conclusion that the concrete vault will last for 10,000 years is unclear. Although analyses of concrete degradation (section 3.1.3 of [1]) are presented, sulfate attack from the waste is not addressed. On page 3-9 of Reference 1 it is stated "Measured concentrations of sulfate in the saltstone pore-fluid are about 25,000 mg/L (Malek et al. 1987). Such levels are high enough to cause sulfate attack from inside the vault. ... The task of predicting concrete degradation for this case is very complex, and has not been attempted here." Such high levels of sulfate may be expected to result in significant attack.

Path Forward: Provide the basis for the credit taken for the concrete vaults, considering the potential sulfate attack from the waste. The task of predicting the concrete degradation in this case may be challenging, but amenable to experimental evaluation.

SRS Response: The 1992 Performance Assessment (PA) modeling cases that considered a degraded vault and saltstone did not take credit for the vaults. The 1992 PA modeling performed for a degraded vault and saltstone was based upon cracking as the predominant degradation mechanism. The modeling was based upon diffusion through the intact saltstone to the cracks where advective transport occurred. The following conservative assumptions were made for the cracking degradation mechanism (see Sections 3.1.3.5, 3.3.1.2, and A.1.3 of the 1992 PA):

- The saltstone was assumed to crack all the way through every 3 meters immediately upon installation of the closure cap.
- The cracks in the saltstone were assumed to remain saturated once they opened, to remain open, and to not fill with soils or precipitates.
- The flow and transport through the cracks in the saltstone were modeled ignoring the vault structure (i.e., the degraded vault and saltstone modeling assumed that the vault structure did not exist around the saltstone).

These 1992 PA assumptions, particularly that the vault structure does not exist, made potential sulfate attack of the vault concrete irrelevant to the 1992 PA degraded vault and saltstone modeling effort.

Beyond the fact that the 1992 PA did not take credit for the vault in the degraded vault and saltstone modeling cases, there are several factors associated with the saltstone vaults that make them very resistant to sulfate attack. The modes of sulfate attack on concrete will be described followed by the factors that make the saltstone vaults very resistant to sulfate attack.

Sulfate attack involves the diffusion of sulfate into the concrete matrix followed by the reaction of sulfate with two components of typical concrete. These components of typical concrete are tri-calcium aluminate (C3A) and calcium hydroxide (portlandite ($Ca(OH)3$), both of which are derived from the Portland cement utilized in the concrete mix. The sulfate reacts with tri-calcium aluminate to form monosulphoaluminate or ettringite and reacts with calcium hydroxide to form gypsum. All of these reaction products have greater volumes than the reactants, meaning the reaction products expand within the concrete matrix. In instances where the sulfate attack occurs on unconfined concrete surfaces, the reactions lead to expansion and spalling of the concrete, itself. (Clifton and Knab, 1989; Walton et al. 1990)

Concrete is made resistant to sulfate attack in one of two ways (ACI 2000; Clifton and Knab, 1989; Ramachandran 2001):

- Reducing the ability of sulfate to diffuse into the concrete matrix, and

- Reducing the amount of tri-calcium aluminate and calcium hydroxide within the concrete.

The resistance of the saltstone vaults to sulfate attack will be addressed by considering how the vault concrete mix and the physical nature of the saltstone/vault interface reduce sulfate diffusion into the concrete and reduce the presence of the concrete compounds which react with sulfate.

Vault Concrete Mix

The following concrete mix properties can be utilized to reduce the ability of sulfate to diffuse into the concrete matrix (ACI 2000; Clifton and Knab, 1989; Ramachandran 2001):

- A low water-to-cementitious material ratio results in a more dense concrete with a lower porosity, which produces a concrete with a lower permeability and diffusivity (i.e., reduces the rate of diffusion).

- The use of a water reducer admixture allows the concrete to remain workable while utilizing less water. This permits a lower water-to-cementitious material ratio and the associated lower permeability and diffusivity.

- The use of air entrainment admixture results in a more dense concrete with fewer interconnected pore spaces, which again produces a concrete with a lower permeability and diffusivity.

- The use of blast furnace slag produces a concrete with a lower permeability and diffusivity.

The following concrete mix properties can be utilized to reduce tri-calcium aluminate and calcium hydroxide within the concrete (ACI 2000; Clifton and Knab, 1989; Ramachandran 2001):

- The use of Type II or Type V Portland cement, which contains approximately 5 and 4 percent tri-calcium aluminate, respectively, can be utilized. Typical Type I Portland cement contains 11 percent tri-calcium aluminate.

- Blast furnace slag eliminates both tri-calcium aluminate and calcium hydroxide by replacing a portion of the Portland cement in the concrete mix. Additionally blast furnance slag reacts with calcium hydroxide to produce a calcium silicate hydrate which does not react with sulfate.

The concrete utilized for the floor slab and walls of the saltstone vaults has the general concrete mix formulation shown in Table 39-1. This concrete mix design is resistant to sulfate. The mix design features, which make this concrete durable to chemical attack in general, and sulfate attack in particular, include the use of a low water-to-cementitious material (i.e., Type II Portland cement plus blast furnace slag) ratio, the use of a water reducer admixture, the use of an air entrainment admixture, the inclusion of blast furnace slag, and the use of Type II Portland cement. Additionally this concrete mix formulation conforms to the recommendations for Class 3 sulfate exposure (SO4-2 >10,000 ppm) made by the American Concrete Institute (ACI) in the Guide to Durable Concrete (ACI 2000). ACI (2000) states that blast furnace slag can be effective at improving the sulfate resistance of concrete made with Type II Portland cement. ACI (2000) recommends that if blast furnace slag is the sole blending material with Type II Portland cement (i.e. no fly ash, natural pozzolan, or silica fume) that the slag "be in the range of 40 to 70% by mass of the total cementitious material" (i.e., Type II Portland cement plus blast furnace slag). As can be seen in Table 39-1, 40% blast furnace slag was utilized in the saltstone vault concrete. ACI (2000) recommends that the concrete have a water-to-cementitious material ratio less than 0.40. As can be seen in Table 39-1, the concrete utilized in the saltstone vault had a water-to-cementitious material ratio of 0.36.

Table 39-1. Saltstone Vaults Floor Slab and Walls Concrete Mix Formulation (Dixon 2005)

Material [1]	Amount
Type II cement (moderate sulfate resistant-moderate heat of hydration)	419 lbs/yd3
Blast furnace slag [2]	278 lbs/yd3
#67 aggregate (dry weight)	1798 lbs/yd3
Sand (dry weight)	1133 lbs/yd3
Water	254 lbs/yd3
Water/cementitious material ratio	0.36
Percentage of slag to total cementitious material (i.e. Portland cement plus blast furnace slag)	40%

1 The mix also contained an air entrainment and a water reducer admixture
2 The blast furnace slag is a product called NewCem produced by Lafarge North America, Inc. that conforms to ASTM C-989 Grade 120

Physical Nature of the Saltstone/Vault Interface

The interface between the Saltstone and vault exists in one of the following two configurations:

- The saltstone and vault may be in direct contact, or
- A sheet drain may exist between the saltstone and vault.

In the case of direct contact, potential sulfate reduction will occur from the inside out. That is diffusion of sulfate from the saltstone into the concrete will occur at this interface, which is confined by the intact concrete/soil on one side and the saltstone on the other. Under these confined conditions the potential formation of these expansive reaction products (i.e., monosulphoaluminate, ettringite and/or gypsum) would result in a reduction in the available total porosity and increasing internal pressures. It is likely that this would produce the following two results: 1) a reduction in saturated hydraulic conductivity due to the reduction in porosity; 2) a reduction in the rate of sulfate reactions due to the increased pressures (sufficient pressure can actually cause a reverse in the direction of reactions) (Langmuir 1997).

The sheet drains utilized on walls within Vault 4 consists of a polystyrene sheet with 7/16 inch dimples over which a non-woven, needle-punched polypropylene filter fabric is attached (American Wick Drain Corporation AmerDrain 500 sheet drain). The sheet drain provides a void space between the saltstone and vault wall into which excess saltstone cure water (i.e., bleed water) can enter and be removed out the bottom of the vault. The filter fabric does not allow the saltstone itself to enter the sheet drain. Prior to installation of the closure cap, bleed water which enters this

drainage system will be removed. The response to NRC Comment 42 states the following:

> For macroscopic cracks in Vault 4 at a 30 ft spacing and a saltstone saturated conductivity of 1.E-11 cm/s, the analysis concludes that fracture flow is the dominant transport mechanism under saturated and low suction conditions, but negligible for matric suctions exceeding about 200 cm. In the 0 to 10,000 year period, vadose zone simulations indicate saltstone will experience a suction of roughly 1200 cm. Thus, cracks are not expected to appreciably influence advective flow, and contaminant release from saltstone is diffusion controlled.

This means that during the time period when the saltstone experiences a suction of 1200 cm, the gap between the saltstone and vault wall, produced by the sheet drain, will be air filled. Under air filled conditions diffusion of sulfate from saltstone into the vault concrete cannot occur. Once the closure system degrades to the point that significant standing water forms on top of the vault, this gap should become water filled and sulfate diffusion into the vault concrete can occur. However the polystyrene sheet will continue to provide resistance to sulfate diffusion as long as it has not entirely degraded away. Oxidative degradation of the polystyrene is the most likely degradation mechanism. Such degradation will be extremely slow due to oxygen scavenging by the blast furnace slag contained in both the vaults and saltstone (see the response to NRC Comment 55).

References:

ACI (American Concrete Institute), 2000, Guide to Durable Concrete, ACI 201.2R-01, Farmington Hills, Michigan, Sections 2.1 and 2.2.

Clifton, J. R. and Knab, L. I., 1989, Service Life of Concrete, NUREG/CR-5466, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC.

Dixon, K. L., 2005, Re: Concrete Mixes for Saltstone Vault 4, SRNL-EST-2005-00105, Westinghouse Savannah River Company, Aiken, South Carolina. June 21, 2005.

Langmuir, D., 1997, Aqueous Environmental Geochemistry, Prentice-Hall, Inc. Upper Saddle River, New Jersey. 600 pp.

Ramachandran, V. S., 2001. Chapter 1 Concrete Science In Handbook of Analytical Techniques in Concrete Science and Technology – Principles, Techniques, and Applications, Ramachandran, V. S. and Beaudoin, J. J. (editors), Noyes Publications, Park Ridge, New Jersey, Page 4.

Walton, J. C., Plansky, L. E., and Smith, R. W., 1990. Models for Estimation of Service Life of Concrete Barriers in Low-Level Radioactive Waste Disposal, NUREG/CR-5542, Office of Nuclear Regulatory Research, U.S. Nuclear Regulatory Commission, Washington, DC.

NRC Comment 40 The calculations of the various degradation mechanisms do not provide sufficient detail (e.g., the parameters used) to allow independent verification [1].

Basis: Pages 3-9 to 3-18 and B-6 to B-11 of Reference 1 provide a summary of degradation calculations and results and theoretical framework for the modeling, but do not provide the parameter values used to perform the calculations.

Path Forward: Provide the details of the degradation calculations that allow independent verification of the results.

SRS Response: The 1992 Performance Assessment (PA) (reference 1 in the NRC RAI) evaluated the following chemical degradation mechanisms of the concrete vault: sulfate and magnesium attack, carbonation, calcium hydroxide leaching, and rebar corrosion. Based upon this analysis, however, physical and mechanical cracking of the vault and Saltstone was deemed to be the primary degradation mechanism which would impact contaminant release. Therefore the 1992 PA degraded vault and Saltstone modeling was based upon cracking as the predominant degradation mechanism. The modeling was based upon diffusion through the intact Saltstone to the cracks where advective transport occurred. The following conservative assumptions were made for the cracking degradation mechanism (see Sections 3.1.3.5, 3.3.1.2, and A.1.3):

- The Saltstone was assumed to crack all the way through every 3 meters immediately upon installation of the closure cap.
- The cracks in the Saltstone were assumed to remain saturated once they opened, to remain open, and to not fill with soils or precipitates.
- The flow and transport through the cracks in the Saltstone were modeled ignoring the vault shell (i.e., the degraded vault and Saltstone modeling assumed that the vault structure did not exist around the Saltstone).

These 1992 PA assumptions, particularly that the vault does not exist, made potential chemical degradation mechanism of the vault concrete irrelevant to the 1992 PA degraded vault and Saltstone modeling effort.

However the Engineering Design File, which provides the input parameter data associated with the 1992 PA Appendix B.3 Vault Degradation Computer Code, has been included as a reference.

Reference:

Dicke, C. A., 1992, *Engineering Design File: Concrete Degradation Calculation for Z-Area Vaults*, SALT-92-002,

NRC Comment 41: The conceptual model for degradation of the saltstone is not clearly described.

Basis: The various degradation mechanisms assessed for the vaults suggest that some fraction of the saltstone can be degraded, and that a shrinking core model may be most appropriate to represent this type of process. The degraded portion of the saltstone would likely have oxidizing chemical conditions and allow much greater radionuclide mobility than intact saltstone would (e.g., both chemical and hydrological properties would be degraded). Model results are likely to be sensitive to small fractions of the saltstone being in a degraded state. Reference 14 suggests that Tc in a slag cement may be oxidized at a significant rate even if the bulk material does not experience significant degradation, due to diffusion of oxygen. Therefore, cracking and the evolution of cracking over time could have a significant effect on model results. The model of release from saltstone assumes that reducing conditions will be maintained over the 10,000 year analysis period. Smith and Walton [16] provides a conceptual model to estimate oxidation of a cementitious wasteform.

Path Forward: Provide the conceptual model for degradation of saltstone and radionuclide release. Provide any experimental or other evidence that saltstone will maintain a reducing environment considering that degradation (e.g., chemical and physical) is likely to be represented as a shrinking core type of process at exposed surfaces, and that oxidation may be significant even if the bulk material does not degrade significantly.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

A discussion of the conceptual model of the physical degradation of the saltstone is presented elsewhere in this document, in part in response to NRC Comment 32. Attention will be directed in this response to discussing the conceptual model used to describe the oxidation of the slag-containing saltstone. Recently, Kaplan and Hang (2003) made laboratory measurements of the reduction capacity of the saltstone slag and then conducted two-dimensional simulations of the saltstone disposal facility to estimate the duration that the saltstone would maintain its reducing conditions. The slag was assumed to be evenly distributed throughout the saltstone because the slag is evenly mixed in the Saltstone extruder and the reductant was consumed by dissolved oxygen in the infiltrating porewater (and to a lesser extent by the oxidizing agents in the waste itself). The dissolved oxygen was continuously replenished (was in equilibrium with) air in the unsaturated soil surrounding the saltstone. The porewater diffuses in from all sides and has a limited amount of advection in the downward direction through the saltstone. No cracks in the saltstone were assumed to be present. As a conservative approach, it was also assumed that once the oxygen reached the reductant in the saltstone that the oxidation reaction occurred immediately. An example of the results from these calculations is presented below

showing the spatial distribution of the reduction capacity in the saltstone after 250,000 years.

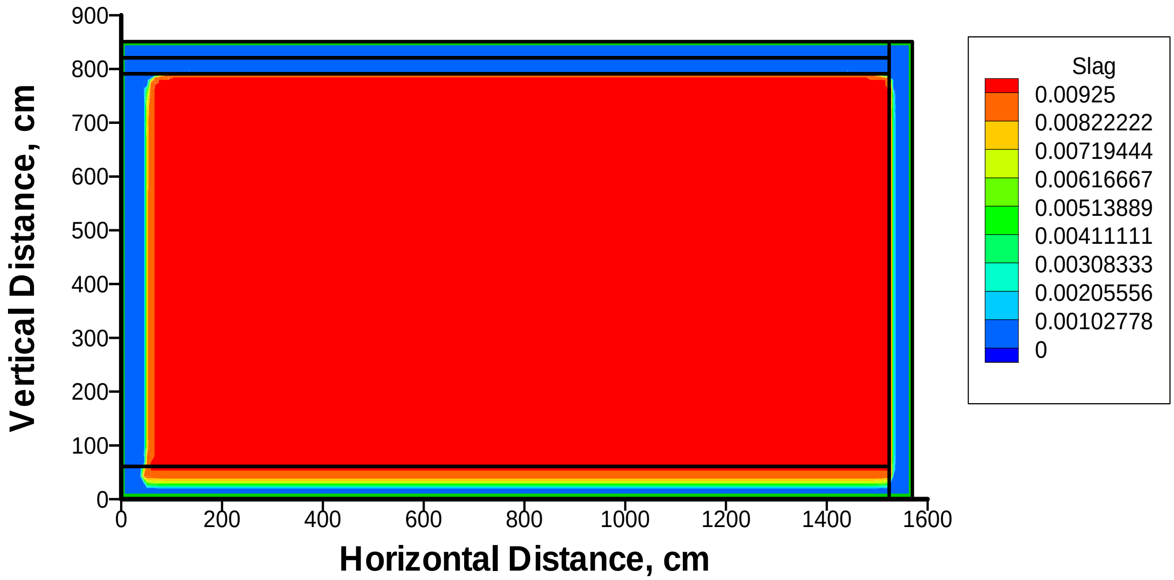


Figure 41-1. *Simulation Result at 250,000 Years (Units in meq e^-/g_{solid}). Red Indicates no Oxidation of Saltstone Occurred and Blue Indicates that Full Oxidation of the Saltstone Occurred (Kaplan and Hang 2003).*

Based on these calculations, after 50,000 years, only 8% (3% after 10,000 years) of the slag reduction potential was consumed by the dissolved oxygen in infiltrating groundwater (Figure 41-2). In the simulations, a rather sharp oxidized front moved slowly through the saltstone vault. Presumably, Tc residing in the oxidizing region would become oxidized and be released into the mobile aqueous phase, whereas Tc ahead of this front would remain immobilized in the saltstone. (After 50,000 years, 92% of Tc would remain immobilized in the saltstone.)

Authors from both references mentioned in the Basis of this comment worked with SRS on this technical issue. Robert Smith conducted the MINTEQ calculations described in Appendix D in the PA (WSRC-RP-92-1360) and is also the lead author in RAI reference [16]. RAI reference [14] by Lukens et al. describes measurements using SRS slag and SRS saltstone. SRS has provided Dr. Lukens with samples and keeps abreast of his research. A recent manuscript, Lukens et al. 2005, included much of the work presented in reference [14]) using spectroscopic and diffusional considerations and reported that ~4% of the reduction capacity of the SRS saltstone would be consumed in 213,000 years. To adjust the calculation to a two-dimensional (4-side diffusion) calculation, this percentage was multiplied by four (an approximation), yielding 16% of the total saltstone reduction capacity would be consumed in 213,000 years. This value is 15.8%, calculated using the SRS measurements of the reduction capacity of the slag and modeling the consumption of this reduction capacity by groundwater oxygen (see figure below Kaplan and Hang 2003).

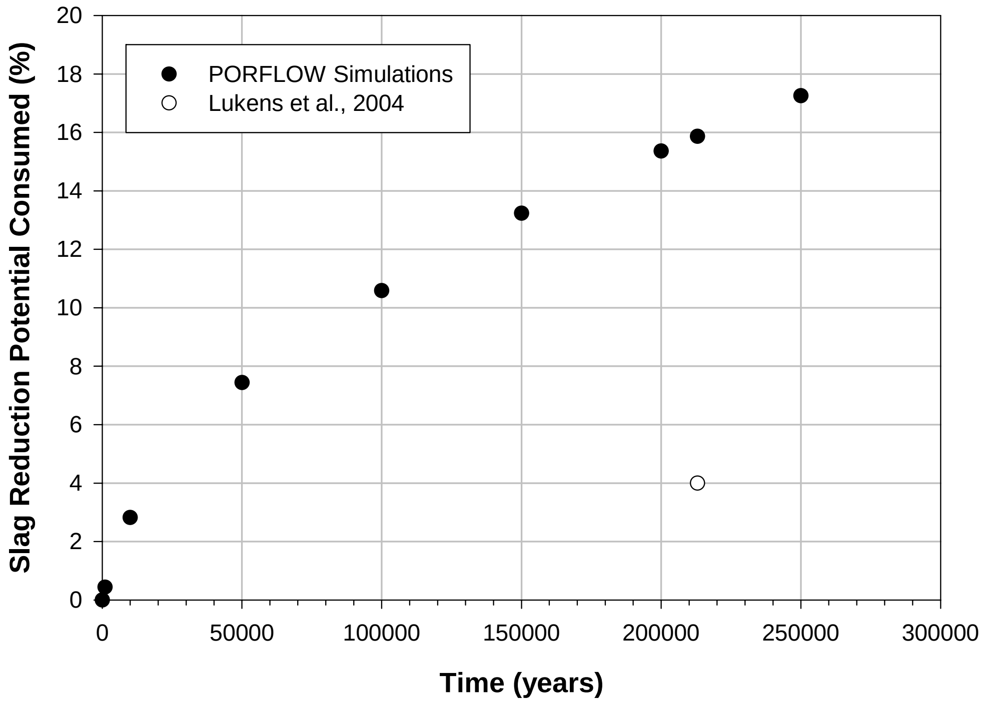


Figure 41-2. *Consumption of Slag Reduction Potential by Oxygen in Infiltrating Water. PORFLOW Data Based on 2-Dimension and Lukens Data Based on 1-Dimension (Kaplan and Hang 2003).*

The method used by Kaplan and Hang (2003) to measure the reduction capacity of the slag was designed to purposely underestimate the total reduction capacity in an attempt to introduce conservatism into the model. This method measured the reduction capacity primarily on the surface site of the slag particles, not within the interior of the slag particles. More recently, Lukens et al. (2005) measured the total reduction capacity of the slag, that of the surface and interior. Kaplan and Hang (2003) reported a reduction capacity of 9.5 meq/kg concrete (38 meq/kg slag) and Lukens et al. (2005) reported 800 meq/kg concrete. Lukens' value is the more accurate value in that it includes the total reduction capacity of the sulfur, whereas the method used by Kaplan and Hang (2003) includes mostly the Fe(II) and some sulfur. Work is presently underway to substantiate these values and will be used in future calculations. The new larger reduction capacity values will increase the estimates of the duration of the estimated longevity of the saltstone's reducing environment by anywhere from one to three orders of magnitude if it is substantiated that the total measured reduction capacity from Lukens et al. (2005) is correct.

The "Path Forward" refers to the "shrinking core" process. The modeling used by Kaplan and Hang (2003) was a shrinking core type of modeling. They used a transient unsaturated flow model that ran in two dimensions. It built upon the

original models proposed by Smith and Walton's (1993) spreadsheet calculations for one-dimensional flow. Figure 41-2 above shows how shrinking core model compares to the results of Lukens et al. 2005.

Given the expected slow oxidation rates of the saltstone, the 2005 SA assumed that the saltstone would remain reduced over this entire duration and assumed conservative K_d values taken from Bradbury and Sarott (1995) to describe the interaction between the radionuclides and the reducing saltstone.

References:

Bradbury, M. H., and F. Sarott. 1995. Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment. Nr. 95-06. Paul Scherrer Institut, Wurenlingen and Villigen, Switzerland.

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Kaplan, D. I., and T. Hang. 2003. Estimated Duration of the Subsurface Reducing Environment Produced by the Z-Area Saltstone Disposal Facility. WSRC-RP-2003-00362, Rev. 2. Westinghouse Savannah River Co., Aiken, SC.

Lukens, W. W., J. J. Bucher, D. K. Shuh, and N. M. Edelstein. 2005. Evolution of Technetium Speciation in Reducing Grout. Environ. Sci. Technol. (In Press).

Smith, R. W., and J. C. Walton. 1993. The Role of Oxygen Diffusion in the Release of Technetium from Reducing Cementitious Waste Forms. Mat. Res. Soc. Symp. Proc. 294:247-253.

NRC
Comment 42: Provide the characterization information of the as-emplaced saltstone and vaults.

Basis: The presence of the slag in the saltstone can result in shrinkage and cracking during curing. Cracking can have a significant influence on transport from the wasteform and degradation of the wasteform. On page 3-18 of Reference 1 it is stated that the assumptions about crack frequency for the "degraded case" are based on observations from vault #1; however, saltstone has a different composition than the vaults.

Assumptions used in the calculations of flow through fractured vaults and saltstone include the occurrence of vertical fractures that fully penetrate the vault and saltstone, with a fracture width of 0.005 cm and a fracture spacing of 300 cm. The authors considered the assumptions to be conservative because the presence of fully penetrating cracks has not been established, and the new design incorporates measures to minimize cracking. However, the assumption that the cracks are fully penetrating and vertical is not necessarily conservative because a fully penetrating, vertical geometry limits the residence time of infiltrating groundwater and reduces the interaction of the water with the saltstone wasteform. It is likely that cracks with frequent branching, commonly observed in the fracture of ceramics and concrete, would occur in the saltstone. These branching cracks, along with microcracks that result from mechanical and chemical (e.g., sulfate attack) effects, could lead to higher radionuclide releases compared to vertical fractures.

Higher releases also would occur if the fractures were more closely spaced than the 300 cm assumed in the model. For example, the sensitivity of nitrate release to crack spacing is discussed in Reference 1 (Section 4.2.1.2). Furthermore, information to support the statement that the new design incorporates measures to minimize cracking is not provided.

Path Forward: Provide characterization information, including photographs (if available), of the vaults and saltstone. If the basis for the assumed degree of cracking in saltstone is observations of cracking of vault # 1, differences between the chemical and physical properties of saltstone and the concrete used in vault # 1 should be addressed. In addition, the ability to observe small cracks should be discussed. The possible implications of the existence of cracks that are too small to be observed should be addressed with respect to the hydraulic properties of saltstone as well as saltstone oxidation as described in Comment 41. The technical basis for the assumption of fully-penetrating fractures with a fracture spacing of 300 cm should be provided, or it should be demonstrated that the selected approach is conservative considering the reasonably conservative alternatives mentioned in this comment that could lead to higher releases.

SRS Response: Cracks played a prominent role in the 1992 PA because saturated flow was anticipated due to water ponding over an intact vault at early times (MMES 1992, p. 3-61 last full paragraph). Since then, a more effective cover system has been conceptually designed (Phifer and Nelson 2003; see response to NRC Comment 24 for summary), such that ponding and subsequent saturated (or near saturated) flow are not expected from 0 to 10,000 years for Saltstone Vault 4. This change in hydrologic conditions greatly reduces the importance of fracture flow to the performance of Vault 4.

An extensive structural analysis was performed for Vault 4 to assess the potential for large-scale cracking in response to forecast static settlement and earthquakes (Peregoy 2003). Approximately vertical cracks or fractures spanning the entire vault width and height are predicted to form at multiple construction joints, which occur at 30 ft intervals. Cracks form within the first 100 years and gradually open with time (Figure 42-1). The hydraulic characteristics of generic fractures under a range of saturated and unsaturated conditions is investigated in the 2005 SA (Cook et al. 2005, Appendix A.4). For macroscopic cracks in Vault 4 at a 30 ft spacing and a saltstone saturated conductivity of 1.E-11 cm/s, the analysis concludes that fracture flow is the dominant transport mechanism under saturated and low suction conditions, but negligible for matric suctions exceeding about 200 cm. In the 0 to 10,000 year period, vadose zone simulations indicate saltstone will experience a suction of roughly 1200 cm. Thus, cracks are not expected to appreciably influence advective flow, and contaminant release from saltstone is diffusion controlled.

From 10,000 to about 12,000 years, the gravel drainage layer overlying the vault roof is predicted to completely silt up with fines (Phifer 2004), drastically reducing the ability of the layer to drain water off the top of the vault. The hydraulic conductivity of the gravel layer takes on a value for native soil or 1.E-4 cm/s, as shown under “Lower Drainage Layer” in Figure 42-2, an excerpt from Phifer (2004). Without consideration of macroscopic cracks, water ponds over the vault roof from 10,000 to 50,000 years in vadose zone flow simulations. Therefore macroscopic cracks were also explicitly simulated for this period as part of an overall sensitivity study, as described in the 2005 SA (Cook et al. 2005, Section 7.5.5).

The influence of small-scale cracking, together with other phenomena degrading the hydraulic performance of saltstone, is implicitly addressed by an increasing saturated hydraulic conductivity with time (Cook et al. 2005, Section A.2.3.1), starting from an initial estimate based on laboratory measurements from 3 saltstone samples (WSRC 1998, Core Laboratories report under Item A7. att. iv.). The long-term hydraulic conductivity of saltstone is likely to increase with time. The assumed degradation rate in modeling was judged to be reasonable. Additional sensitivity analyses using alternative initial conductivities and rates of degradation have been performed and are

discussed in response to NRC Comment 19. See responses to related NRC comments 32, 33, 38, 40, 41 and 43 for more extensive discussion of saltstone properties.

References:

Cook, J.R., Wilhite, E.L., Hiergesell, R.A., and Flach, G.P., Special Analysis: Revision of Saltstone Vault 4 Disposal Limits, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Peregoy, W. 2003. *Saltstone Vault Structural Degradation Prediction*, T-CLC-Z-00006, July 2003. Westinghouse Savannah River Company, Aiken, South Carolina.

Phifer, M. A., and E. A. Nelson. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest Scenario (U). WSRC-TR-2003-00436, Rev. 0. September 2003.

Phifer, M. A. 2004. Interoffice Memorandum to J. R. Cook, et al, *Vault #4 Closure Cap Estimated Infiltration for Years 50,000 to 1,000,000*, SRNL-EST-2004-00103, December 17, 2004. Westinghouse Savannah River Company, Aiken, South Carolina.

WSRC. Addendum to the Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility at the Savannah River Site, WSRC-RP-98-00156. April 1998.

Calculation No.	Sheet No.	Rev.
T-CLC-Z-00006	20	0

Table 2. Summary of crack areas and sizes for specific time intervals.

Cracks Open at Bottom

			Mean Crack Size		+1 sigma Crack Size	
			Length	Width	Length	Width
Time	Mean	+1 sigma	ft.	in.	ft.	in.
100	8.48	33.02	24.30	0.06	25.74	0.21
500	27.39	75.60	25.42	0.18	27.00	0.47
1000	47.87	116.88	26.54	0.30	27.00	0.72
2500	101.50	211.98	27.00	0.63	27.00	1.31
5000	186.53	347.05	27.00	1.15	27.00	2.14
10000	353.26	588.72	27.00	2.18	27.00	3.63

Cracks Open at Top

			Mean Crack Size		+1 sigma Crack Size	
			Length	Width	Length	Width
Time	Mean	+1 sigma	ft.	in.	ft.	in.
100	1.14	14.02	27	0.01	27	0.09
500	4.70	28.80	27	0.03	27	0.18
1000	10.00	43.86	27	0.06	27	0.27
2500	25.21	79.94	27	0.16	27	0.49
5000	50.78	133.98	27	0.31	27	0.83
10000	100.55	227.80	27	0.62	27	1.41

Figure 42-1. Excerpt from Peregoy (2003) showing timing for crack formation and aperture.

January 6, 2005 SRNL-EST-2004-00103

Summary (Vault 4 PORFLOW Input)

The following is the summary information for Vault 4 PORFLOW input. It also provides the previous estimates made for years 0 to 10,000 by Phifer (2004):

Year	Infiltration through Upper GCL [1] (in/yr)	Lower Drainage Layer K_s [1] (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

Data for years 0 through 10,000 was previously provided in Phifer 2004.

GCL = geosynthetic clay liner

K_s = saturated hydraulic conductivity

[1] Infiltration through the upper GCL and saturated hydraulic conductivity of the lower drainage layer of a 450-foot slope length closure cap for the base case scenario (i.e. institutional control to pine forest scenario) (Phifer 2003)

Figure 42-2 Excerpt from Phifer (2004) showing reduction in Lower Drainage Layer saturated conductivity to 1.E-4 cm/s after 10,000 years.

NRC Comment 43: The assessment of saltstone degradation is not sufficient. Justification is needed for the assumption that the saltstone degradation rate will be similar to the degradation rate of limestone.

Basis: Very limited basis is provided to support the conclusion that saltstone degradation will be minimal over 10,000 years. Three potentially important issues that were not discussed are the impact of radiation, the potential for ettringite formation, and the potential for chemical dissolution. Experience with a slag wasteform found that it did not survive irradiation [17]. Sulphate ions reacted with Al2O3 to form the ettringite expansive phase with solid volume increases that imposed large internal tensile forces on the wasteform which resulted in a dramatic failure mode, reducing the wasteform to powder over a period of weeks.

For the intruder scenarios, the degradation of the vault and saltstone are modeled by assuming they degrade at the same rate as carbonate rock (pg. 3-44 of [1]). The basis for this assumption is not discussed, although the composition of saltstone is different than the composition of limestone and these differences (e.g., in radiological properties, Na+ concentration, and sulfate concentration) may lead to different degradation rates. A number of leaching tests have been conducted, but the time frames were relatively short (< 90 days). Experience by Allan and Kukacka [18] suggests that some mechanisms can result in noticeable impacts that may not be fully-captured in short-term leaching tests. It is acknowledged that many cementitious materials do not respond well to accelerated tests for a variety of reasons, which is why sufficient understanding is needed of the potential mechanisms.

No technical basis is provided to support the assumption that the saltstone does not degrade by chemical dissolution, which could enhance the flow of water and the release and transport of radionuclides and chemical contaminants. The release of radionuclides from the saltstone is dependent on assumptions regarding the mechanisms of degradation, in addition to the characteristics of the fractures through which flow and transport occur. In Reference 1 (Section 3.1.2), it is recognized that contaminants bound in the solid matrix of the wasteform are released into the pore fluid through the process of dissolution. The release rate model for a fractured vault and saltstone wasteform, however, does not account for the potential effect of dissolution of the saltstone matrix by advecting groundwater. Dissolution of the saltstone matrix would release more radionuclides and chemical contaminants to the saltstone pore fluid and also would increase the fracture-width processes that would enhance the release and transport of contaminants from the SDF. Depending on the chemistry and flow rate of advecting water, the contribution of dissolution reactions to the release rate can be significant.

Path Forward: An assessment of saltstone degradation should be provided, including direct evidence of the resistance to radiation damage, other processes that may result in ettringite

formation, and chemical dissolution. The basis that saltstone will degrade to an insignificant degree or at a rate similar to carbonate rock should be provided.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The weathering properties of Saltstone and the concrete vault used in the 2005 SA intruder scenario calculations are not the same as those used in the 1992 PA. The use of limestone weathering to soil-equivalent material as an analog for vault concrete and saltstone grout degradation was used in the 1992 PA in the intruder analysis as a way to estimate the time at which radionuclides in the Saltstone Disposal Facility (SDF) could become available to hypothetical intruders (MMES, 1992, Section 3.2.4.1, page 3-44). In the 2005 SA, the vault concrete and saltstone grout are assumed to erode at the same rate as the overlying cover material, excluding the erosion barrier, starting at year 1,000 (Cook et al. 2005, Table B-2, page B-13).

Saltstone grout degradation in the SRS disposal environment was evaluated with respect to cause and effect. Saltstone grout degradation was ultimately defined as an increase in hydraulic conductivity of the waste form. Increases in hydraulic conductivity can be traced to an increase in porosity of the bulk material due to leaching, phase changes and/or cracking.

The following chemical and physical degradation mechanisms/causes and corresponding increases in hydraulic conductivity were considered:

Degradation Mechanism	**Analysis Summary**
Dissolution of salts and low solubility matrix phases.	The bulk of the slag saltstone matrix consists of insoluble/low solubility amorphous material, sodium substituted calcium aluminum silicate non crystalline solids (NCS). Leaching out of soluble components such as nitrate salts, which make up as much as 13.5 wt% of the initial weight of the material can potentially result in an increase in porosity. However, porosity may also be reduced over the long term by precipitation of carbonates and further hydration of matrix phases.
Cracking due to formation of new or expansive matrix phases due to hydration, precipitation and recrystallization reactions of the matrix	Expansive phases were not detected in x-ray diffraction analyses of saltstone test specimens. Phase changes as a function of curing time were detected. Mineralogy of saltstone was evaluated as a function of time: 1. No ettringite or other expansive phases were detected in samples cured up to 180 days at 38°C [Malek, et al. 1985, p. 13 and 20]. The matrix phases consisted of substituted amorphous hydrated calcium silicate. Calcium

Degradation Mechanism	Analysis Summary
	aluminium/iron hydrogarnet, calcite, and calcium nitrate hydrate increased with curing time. 2. Archive sample cured for 18 years at ambient temperature in a closed container. In addition to a large amount of non-crystalline sodium and aluminum, substituted calcium silicate hydrate material, gypsum, iron hydroxide sulfate, sodium nitrate, a hydrated sodium calcium aluminum sulfate and a hydrated calcium aluminum carbonate and possibly a substituted sodalite phase were detected by x-ray diffraction in the aged waste form [sample analyzed June, 2005, for this response by C. Langton]. 3. Curing temperature and temperature up to 90°C. Cracks were not observed in samples cured at 70º, but were very apparent in samples cured at 90ºC [Langton, 1998]. Cracking was attributed to drying and possibly to crystallization or dehydration of the matrix phases. Physical integrity of bars cast for expansion measurements were recorded for: 1. Up to 180 days [Langton, 1985, Memorandum from Langton to Wright]. 2. Archive sample of slag saltstone displays not cracking after aging 18 years in a closed container at ambient temperature.
Formation of new phases as the result of introduction of additional chemical species from the environment.	The potential for formation of new phases, beneficial and/or deleterious, to the durability of the saltstone waste form can not be ruled out over the long time period modeled in the Performance assessment. Water, carbon dioxide and bicarbonate ion were considered as contributing to rebar corrosion in the vault but introduction of carbonate ion into saltstone was considered to result in precipitation of calcium carbonate, calcium aluminum carbonate hydrate phases. Ettringite, a low-density hydrated calcium aluminate sulfate phase has not been detected in cured slag saltstone at any age up to 18 years. Ettringinte has not been detected in samples cured for 28 days at temperatures between ambient and 90ºC.
Radiation damage	Effects of radiation were assessed for slag Saltstone containing a Cs-137 concentration that would result in 24E-04 Watts/kg or about 1 Ci/gallon or a dose rate of 261 rad/hr. The testing was performed on non-radioactive Saltstone exposed to 4.2E+05 rad/hr for 185 hr with a Co-60 source which is approximately equivalent to a 34-year dose received from a nominal Cs-137 loading of 250 Ci/m^3. For a nominal moisture of 25 wt%, a

Degradation Mechanism	Analysis Summary
	G(H2) based on water alone was calculated to be in the range of 0.08 to 0.12. These G values are significantly lower than the maximum value obtained for pure water, 0.45. No degradation or cracking was observed in the irradiated samples [Langton, 1998, WSRC-TR-98-00337, p. 7].
Settling and/or seismic forces.	The structural analysis showed that the cracks will open either at the top or at the bottom and will be pinched closed at the opposite end [Peregoy, 2003]. The 2005 Special Analysis Section A.4 concluded that cracks of any geometry have very little effect on contaminant transport rate. Based on this finding, large-scale cracks [from seismic events and settlement] were not explicitly modeled in the 2005 SA [Cook, et al, 2005 SA, Section A.4].
Freeze-thaw cycling	Not considered to be applicable to the disposal environment.
Erosion of material exposed to the environment	In the 2005 SA, saltstone was assumed to erode at the same rate as the overlying cover material, excluding the erosion barrier, starting at year 1,000 (Cook, et al. 2005, Table B-2, page B-13).
Excavation, drilling, and other intruder scenarios.	Saltstone was assumed to be recognizable as different than the surrounding soil in Aiken County for the duration of the Performance Assessment analysis. At this point the intruder is assumed to move to another location [Cook, et al. 2005].

Saltstone degradation mechanisms were studied and samples were analyzed as a function of curing time up to 18 years. However, due to the long time-periods required in the PA modeling effort, a mechanistic approach was not used to predict long-term durability. Instead, in the 2005 SA, eight specific times were identified during the 10,000 year period of performance at which significant changes (degradation) in the landfill cap/drain system were expected to occur [Phifer, 2004]. These time intervals were used to generate a base case for modeling the effects of progressive saltstone grout degradation (increase in hydraulic conductivity). The hydraulic conductivity of saltstone was increased from 1E-11 to 1E-09 over this 10,000 year period through the eight steady-state stages [Cook, et al. 2005, Appendix A, Table A-4, p. A-9].

In addition, sensitivity analyses have been performed and are discussed in the response to NRC Comment 19. The relevant degradation mechanisms result in a greater hydraulic conductivity. Consequently the cumulative effect of these mechanisms (increases in hydraulic conductivity) has been addressed in the modeling to date.

References:

Cook, J. R., Wilhite, E. L., Hiergesell, R. A., and Flach, G. P., 2005. Special Analysis: Revisions of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-0004, Westinghouse Savannah River Company, Aiken, South Carolina. May 26, 2005.

Langton, C. A., 1998. Direct Grout Stabilization of High Cesium Salt Waste: Salt Waste Alternative Phase III Feasibility Study (U), WSRC-TR-98-00337, Westinghouse Savannah River Company, Aiken, South Carolina. September 30, 1998.

MMES, 1992. Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility, WSRC-RP-92-1360, Martin Marietta Energy Systems, Inc., EG&G Idaho, Westinghouse Hanford Company and Westinghouse Savannah River Company, 1992, Westinghouse Savannah River Company, Aiken, South Carolina, 1992.

Malek, R., Roy, D. M., Barnes, M. W., and Langton, C. A., 1985, Slag Cement – Low-Level Waste Forms at the Savannah River Plant, DP-MS-85-9, E. I. du Pont de Nemours and Company, Aiken, South Carolina, 1985.

Peregoy, W., 2003. Saltstone Vault Structural Degradation Prediction, 2003, T-CLC-Z-00006, Westinghouse Savannah River Company, Aiken, South Carolina. July 2003.

NRC
Comment 44: It is not clear that the saturated zone model has been appropriately calibrated.

Basis: The text on page 4-41 of Reference 1 indicates that the model is relatively insensitive to recharge; however, observations at the site suggest that water levels fluctuate primarily in response to changes in recharge [19]. The text suggests the model is very sensitive to hydraulic conductivity. However, the observations of water level fluctuations are driven primarily by recharge fluctuations not changes in hydraulic conductivity which is essentially a static parameter.

Path Forward: Based on the limited calibration performed, explain whether the modelpredicted insensitivity to recharge is consistent with the observations of water level fluctuations. If necessary, recalibrate the model to be able to reasonably predict water table fluctuations in response to changes in recharge. Model calibration uncertainty should be addressed considering the results presented on page A-44 of Reference 1.

SRS Response: The first paragraph on page 4-41 of the 1992 PA states that a recharge rate of 40 cm/yr was specified over the entire model domain, except over the footprint of the Saltstone Disposal Facility (SDF) where recharge was set to 0.175 cm/yr for the nominal case. Additional simulations were performed with recharge set to 2 cm/yr and 40 cm/yr over the SDF footprint, while maintaining 40 cm/yr elsewhere. Model results were found to be relatively insensitive to recharge variations only over the localized SDF area, which represents a small fraction of the overall surface area encompassed by the model domain.

Results indicate that groundwater level fluctuates in the field because of transient recharge, and that a representative steady-state groundwater model should be sensitive to recharge averaged over the entire model domain. This is the case with the 1992 PA model (e.g. line 4 of Table A.2-3 on page A-44 in 1992 PA) and the current model described in the 2005 SA (Cook et al. 2005). The response to NRC Comment 47 describes two sensitivity runs using the 2005 SA model and varying recharge. To maintain model calibration to measured well water levels in these sensitivity runs, adjustments to hydraulic conductivity in proportion to changes in recharge (and leakage through the underlying confining unit) were required, thus indicating model sensitivity to recharge applied over the entire model domain.

Reference:

Cook, J.R., Wilhite, E.L., Hiergesell, R.A., and Flach, G.P., 2005, Special Analysis: Revision of Saltstone Vault 4 Disposal Limits, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

NRC Comment 45: Sufficient information for the development of the multiplier of 9.5E-9 yr/L found in Reference 2 ("Sensitivity/Uncertainty of Z-Area Radiological Performance Results with Respect to Kd") is not provided.

Basis: Comparison of values in Table 1 and the resulting values in Table 2 of the "Sensitivity/Uncertainty of Z-Area Radiological Performance Results with Respect to Kd" in Reference 2 suggest that the effective dilution area is much larger than the vault dimensions multiplied by the aquifer thickness for a conservative tracer.

Path Forward: Provide a description of the hydrological parameters and their values that are used to generate the multiplier of 9.5E-9 yr/L.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al 2005). The Vault 4 SA did not use the multiplier discussed in the comment above because the groundwater sensitivity analyses presented did not need to estimate concentrations from the calculated flux. The response to NRC Comment 19 provides a discussion of additional sensitivity analyses performed on the Vault 4 SA. The multiplier was also not used because concentrations were calculated directly instead of being estimated from fluxes.

In response to the specific request for additional information above, the following information is provided. The subject multiplier (9.5E-9 yr/L) was developed for the purpose of estimating peak groundwater concentrations at the compliance point in the 1992 PA (MMES 1992) from the calculated peak flux. The multiplier was developed using the maximum groundwater concentration of nitrate of 5.2 mg/L for the intact vaults and saltstone grout (from Table 4.1-5 in MMES 1992) and the maximum nitrate flux of 5.5E8 mg/year for the intact vaults and saltstone grout case with 40 cm/year of infiltration (from Table 4.1-3 of MMES 1992). The multiplier was calculated by dividing the maximum groundwater concentration by the maximum flux.

The hydraulic properties assumed in the simulation are shown in Table 3.3-1 of MMES 1992. Tables 3.3-1, 4.1-3, and 4.1-5 of MMES 1992 are appended.

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

MMES 1992. *Radiological Performance Assessment for the Z-Area Saltstone Disposal Facility*, WSRC-RP-92-1360, Martin Marietta Energy Systems, Inc., EG&G Idaho, Westinghouse Hanford Company and Westinghouse Savannah River Company, 1992, Westinghouse Savannah River Company, Aiken, South Carolina.

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.

Table 4.1-3. Maximum predicted contaminant flux to water table and corresponding times for Z-Area vaults - intact vaults and saltstone

Contaminant	40 cm/year[a] infiltration through upper cap		2 cm/year[b] infiltration through upper cap	
	Peak flux (pCi/year)	Time (years)	Peak flux (pCi/year)	Time (years)
NO_3	5.5×10^{8} [c]	7.5×10^{3}	4.9×10^{8} [c]	7.1×10^{3}
H-3	4.0×10^{4}	8.9×10^{1}	4.0×10^{4}	9.1×10^{-1}
C-14	$<10^{-6}$	N/A[d]	$<10^{-6}$	N/A[d]
Se-79	1.4×10^{6}	2.1×10^{5}	1.2×10^{6}	2.0×10^{5}
Sr-90	$<10^{-6}$	N/A[d]	$<10^{-6}$	N/A[d]
Tc-99	6.4×10^{1}	1.6×10^{6}	6.3×10^{1}	1.6×10^{6}
Sn-126	4.8×10^{-3}	8.9×10^{5}	4.6×10^{-3}	8.8×10^{5}
I-129	9.0×10^{5}	$>2.0 \times 10^{6}$	9.0×10^{5}	$>2.0 \times 10^{6}$
Cs-137	$<10^{-6}$	N/A[d]	$<10^{-6}$	N/A[d]
Pu-238	$<10^{-6}$	N/A[d]	$<10^{-6}$	N/A[d]
Am-241	$<10^{-6}$	N/A[d]	$<10^{-6}$	N/A[d]

[a] Degraded cover scenario (Sect. 3.1.3.5).
[b] Intact scenario (Sect. 3.1.3.5).
[c] Units for nitrate concentration are in mg/year.
[d] N/A = (same as footnote *c* in Table 4.1-4).

Table 4.1-5. Peak predicted groundwater concentration at compliance point for Z-Area vaults - intact vaults and saltstone[a]

Contaminant	Peak Conc. (pCi/L)	Time of Peak GW Conc. (years)
NO_3	5.2 [b]	7.1×10^3
H-3	3.5×10^{-5}	1.2×10^2
C-14	$<10^{-12}$	N/A[c]
Se-79	1.2×10^{-2}	2.1×10^5
Sr-90	$<10^{-12}$	N/A[c]
Tc-99	6.7×10^{-7}	1.6×10^6
Sn-126	4.0×10^{-11}	9.2×10^5
I-129	7.2×10^{-3}	$\geq 2.5 \times 10^6$ [d]
Cs-137	$<10^{-12}$	N/A[c]
Pu-238	$<10^{-12}$	N/A[c]
Am-241	$<10^{-12}$	N/A[c]

[a] Intact and degraded cover scenarios (Sect. 3.1.3.5); both cover scenarios give the same groundwater recharge due to presence of clay/gravel drain on top of vaults which is assumed to remain intact.

[b] Units for nitrate concentration in mg/L.

[c] N/A =not applicable; compliance point concentration not calculated because estimated groundwater concentration directly under the facility is less than 10^{-12} pCi/L, which is orders of magnitude below relevant drinking water standards.

[d] Peak concentration for I-129 may occur sometime after given time.

NCR Comment 46: Given the fractional release rates from the vaults, it is extremely difficult to reconcile the low predicted groundwater concentrations at 100 m given in the figures in Appendix C of Reference 1, especially for the fractured cases.

Basis: Assuming complete mixing of radionuclides released from the vaults into the aquifer given the reported fractional release rates, the saturated zone units would need to be many hundreds of meters thick in order to result in the dilution that would result in the reported groundwater concentrations at 100 m (Appendix C of [1]). However, Appendix E [1] indicates the units are approximately 10 to 30 m thick. For a conservative species like nitrate, the main processes affecting groundwater concentrations at the compliance point should only be dispersion and dilution.

Path Forward: Provide plots of the fractional release rates leaving the vaults, entering the water table, and arriving at the receptor location. Provide information that reconciles the numerical modeling results with basic physical parameters governing transport in the saturated zone.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (SA) (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al 2005).

In the Vault 4 SA, the peak fractional flux to the water table for nitrate is 3.24E-5 mole/year/mole at year 9800, which is depicted in Figure A-26 on page A-39 of the Vault 4 SA reproduced below. The figure also shows that about 16% of the total nitrate inventory is released to the water table in 10,000 years. The peak nitrate concentration in the groundwater arriving at the receptor location is 2.8 pmole/L/mole at 9800 years as depicted in Figure A-46 on page A-57 of the Vault 4 SA reproduced below. In the modeling process, releases from the Saltstone vault are not captured. However, because the distance from the vault bottom and the water table is relatively small, the flux to the water table is approximately the same as the flux leaving the vault. The Vault 4 SA peak fractional release rate results for nitrate are about an order of magnitude greater than the intact case results in the 1992 PA (3E-5 vs 4E-6) and about the same as the "cracked vault" case (3E-5 vs 2.6E-5).

The response to NRC Comment 31 provides a discussion of the apparent discrepancy between hand calculations of release and flux and concentration model outputs. This apparent discrepancy arises from the inclusion of the clean concrete diffusion barrier in the modeling outputs and its exclusion in the hand calculations.

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

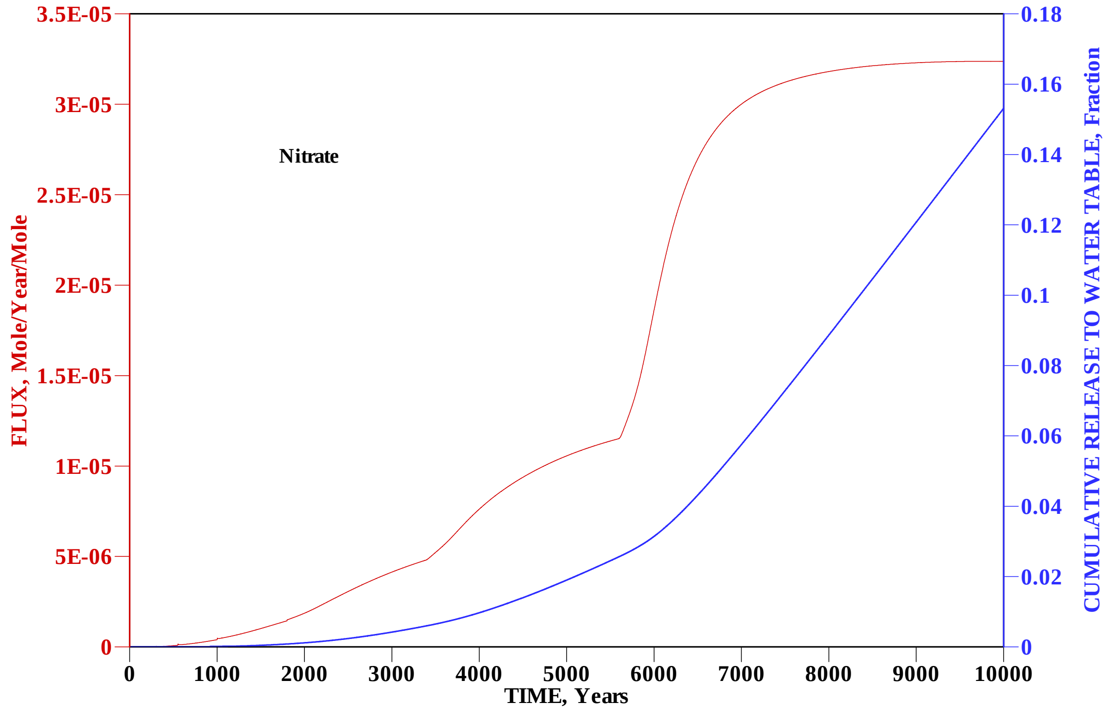


Figure A-26. Predicted Peak Flux and Cumulative Release for Nitrate in 10,000 Years

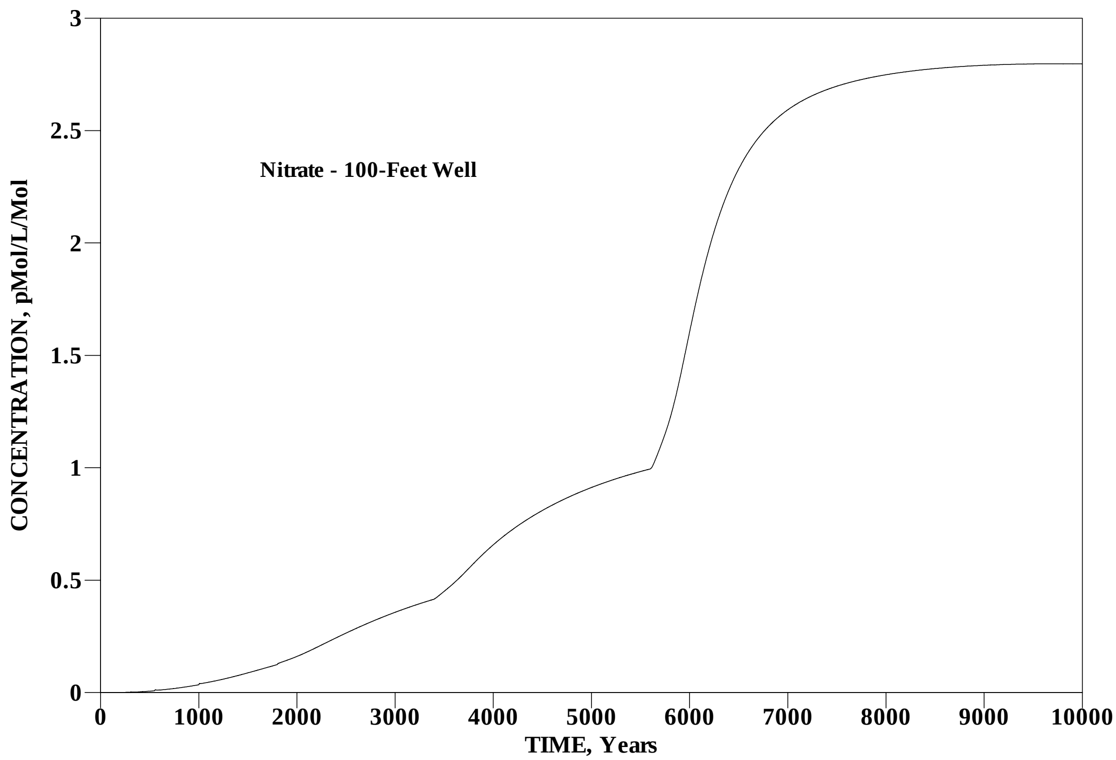


Figure A-46. Nitrate concentration history at node 15, 15, 11 in 10,000 years.

NRC Comment 47: The process for addressing heterogeneity in geologic properties in the PA, considering resultant horizontal aquifer velocity directly impacts dilution and transport of radionuclides, is not adequately described.

Basis: Table 3.3-2 of the 1992 PA provides point values that were selected from much broader ranges provided in Table 2.2-1. However, limited discussion is provided as to why the point values were selected and how they were reasonably conservative. Increases in hydraulic conductivity will result in decreases in contaminant concentrations at the compliance point from dilution but will decrease transport times.

Path Forward: Provide the projected variability in horizontal aquifer velocity. The uncertainty in hydraulic conductivities and gradients given on pages 2-28 and 2-29 of Reference 1 should be provided and addressed in the performance assessment.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005). In particular, the groundwater model in the 1992 PA has been superseded in the 2005 SA for Saltstone Vault 4 (Cook et al. 2005, pp. 1-1 and 2-4). The current model spanning the General Separations Area, in which the Saltstone Vaults are located, has a heterogeneous model conductivity field derived from extensive characterization data including 85 pumping and 481 slug tests, 258 laboratory permeability measurements, and nearly 37,500 lithology data records (Flach and Harris 1999, p. 5). The latter are based on foot-by-foot visual descriptions of drill core, and geophysical logs. Model development and attributes are primarily discussed by Flach and Harris (1999, entire document) and Flach (2004, entire document). The latter describes porting of an earlier FACT code model to the PORFLOW numerical code.

Average horizontal Darcy velocity in the Upper Three Runs (water table) aquifer (zones 6/7/8 in the 1992 PA) is primarily controlled by local recharge and leakage through the Gordon confining unit (zone 5b) to the Gordon Aquifer (zone 5a). As part of a probabilistic uncertainty analysis focusing on E-Area trench disposal performance (Cook et al. 2002, p. 16-17), uncertainty in recharge was estimated to be ±5 in/yr about an estimated nominal value of 14.5 in/yr with 95% confidence, based on multiple lysimeter studies, a water budget analysis, and calibration of a regional flow model to baseflow in major site streams. The thickness of, and hydraulic head difference across, the Gordon confining unit are relatively well known from numerous borings and monitoring wells in the area. Therefore, uncertainty in leakage is predominantly a result of uncertainty in vertical conductivity, which was estimated in the same study to be three orders of magnitude about the nominal value of 1E-5 ft/d at 95% confidence. Pore velocity is also affected by effective porosity. A nominal value of effective porosity is 0.25 with an 95% uncertainty level of ±0.10.

To help quantify the impact of uncertainty in these three parameters on groundwater flow paths, travel times and contaminant migration, two flow sensitivity runs were performed in response to this RAI comment using the current groundwater model. Horizontal Darcy velocity in the water table aquifer is maximized by high recharge and low leakage to the underlying unit. Conversely, horizontal flow is minimized when recharge is low and leakage is high. For the "Fast" sensitivity case, recharge was set to 19.5 in/yr and the Gordon confining unit vertical conductivity to 3.2E-07 ft/d. For the "Slow" sensitivity run, the settings were 9.7 in/yr and 3.2E-04 ft/d, respectively. In both cases, conductivities in the Upper Three Runs (water table) aquifer were re-adjusted to maintain agreement with measured water levels. In general, horizontal conductivities in the water table aquifer were increased for the "Fast" scenario, and decreased for the "Slow" scenario. For particle tracking and transport using the Darcy flow field simulations, the Fast, Nominal and Slow effective porosity settings were selected as 0.15, 0.25 and 0.35, respectively. The Fast and Slow cases are believed to reasonably bracket the potential velocity range.

Figures 47-1 through 47-3 show the resulting groundwater flow paths and 5-year timing markers for seeds placed beneath the 4 corners of Vaults 1 and 4. Within the footprint of the mesh refinement shown in these figures and the lower aquifer zone through which transport primarily occurs, horizontal Darcy and pore velocities range as indicated in Table 47-1. Figure 47-4 shows predicted nitrate/tracer concentration for the Nominal, Fast and Slow aquifer flow fields, using the same (nominal) water table flux source term. At 1000 years, nitrate concentration for the Fast case is 23% lower than the Nominal, and 73% higher for the Slow case. Therefore, varying the horizontal aquifer velocity over a reasonable range of values produces groundwater concentrations varying from 1.7 times higher to 0.77 times lower than the base case.

References:

Cook, J. R., L. B. Collard, G. P. Flach and P. L. Lee, 2002, Development of Probabilistic Uncertainty Analysis Methodology for SRS Performance Assessments Maintenance Plan Activities, WSRC-TR-2002-00121, Rev. 0.

Cook, J. R., E. L. Wilhite, R. A. Hiergesell and G. P. Flach, 2005, Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U), WSRC-TR-2005-00074 Rev. 0.

Flach, G. P. and M. K. Harris, 1999, Integrated Hydrogeological Modeling of the General Separations Area; Volume 2, Groundwater Flow Model (U), WSRC-TR-96-0399, Rev. 1.

Flach, G. P., 2004, Groundwater Flow Model of the General Separations Area Using PORFLOW (U), WSRC-TR-2004-00106, Rev. 0.

Table 47-1. Horizontal Darcy and pore velocities observed in the Nominal, Fast and Slow sensitivity aquifer runs.

Velocity (ft/d)	Slow	Nominal	Fast
Darcy min	0.000	0.000	0.000
Darcy avg	0.030	0.057	0.079
Darcy max	0.113	0.228	0.317
Pore min	0.000	0.000	0.001
Pore avg	0.087	0.227	0.524
Pore max	0.324	0.910	2.114

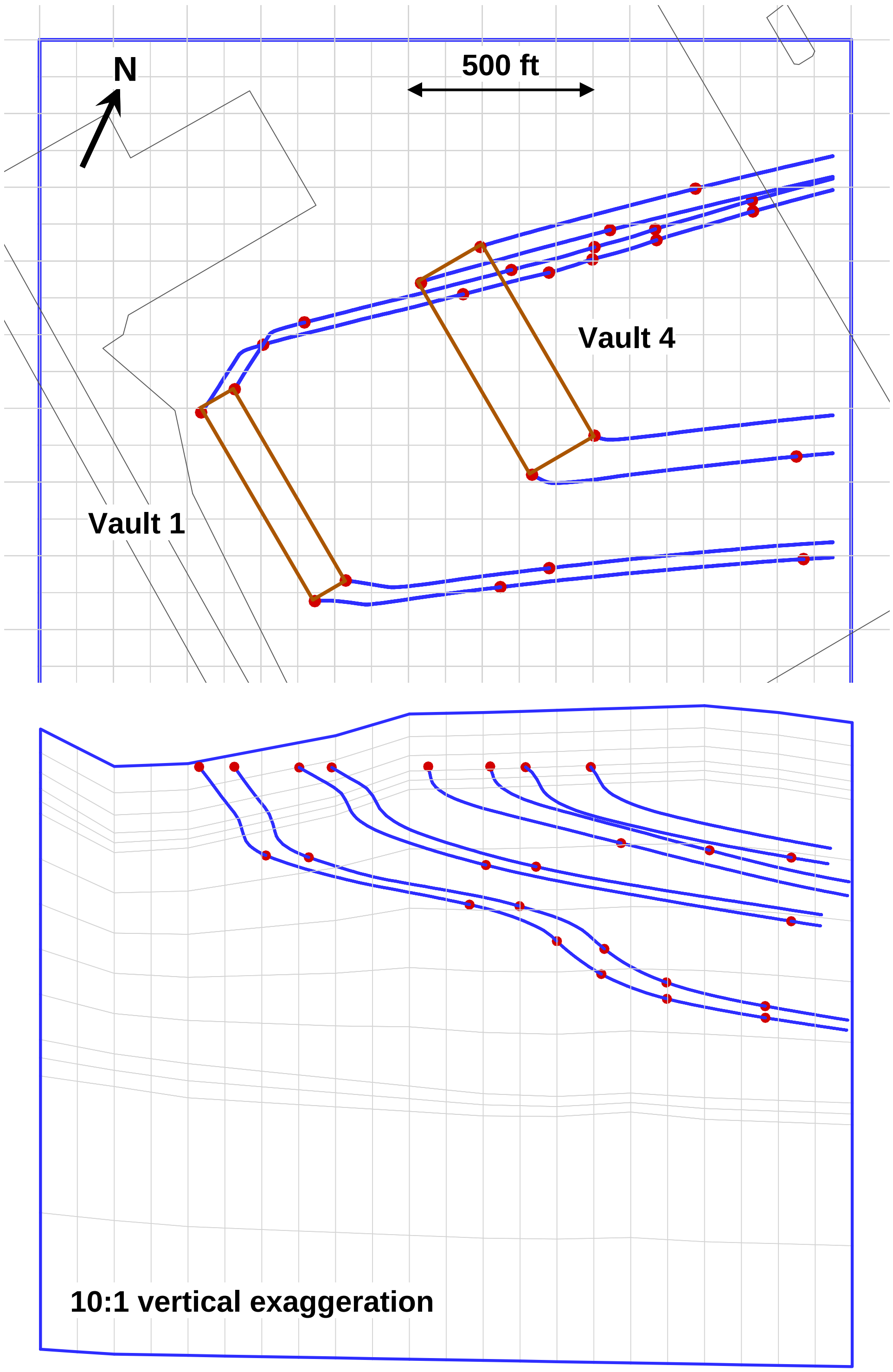


Figure 47-1. Plan and cross-sectional views of groundwater flow paths emanating from Vaults 1 and 4 for the Nominal case.

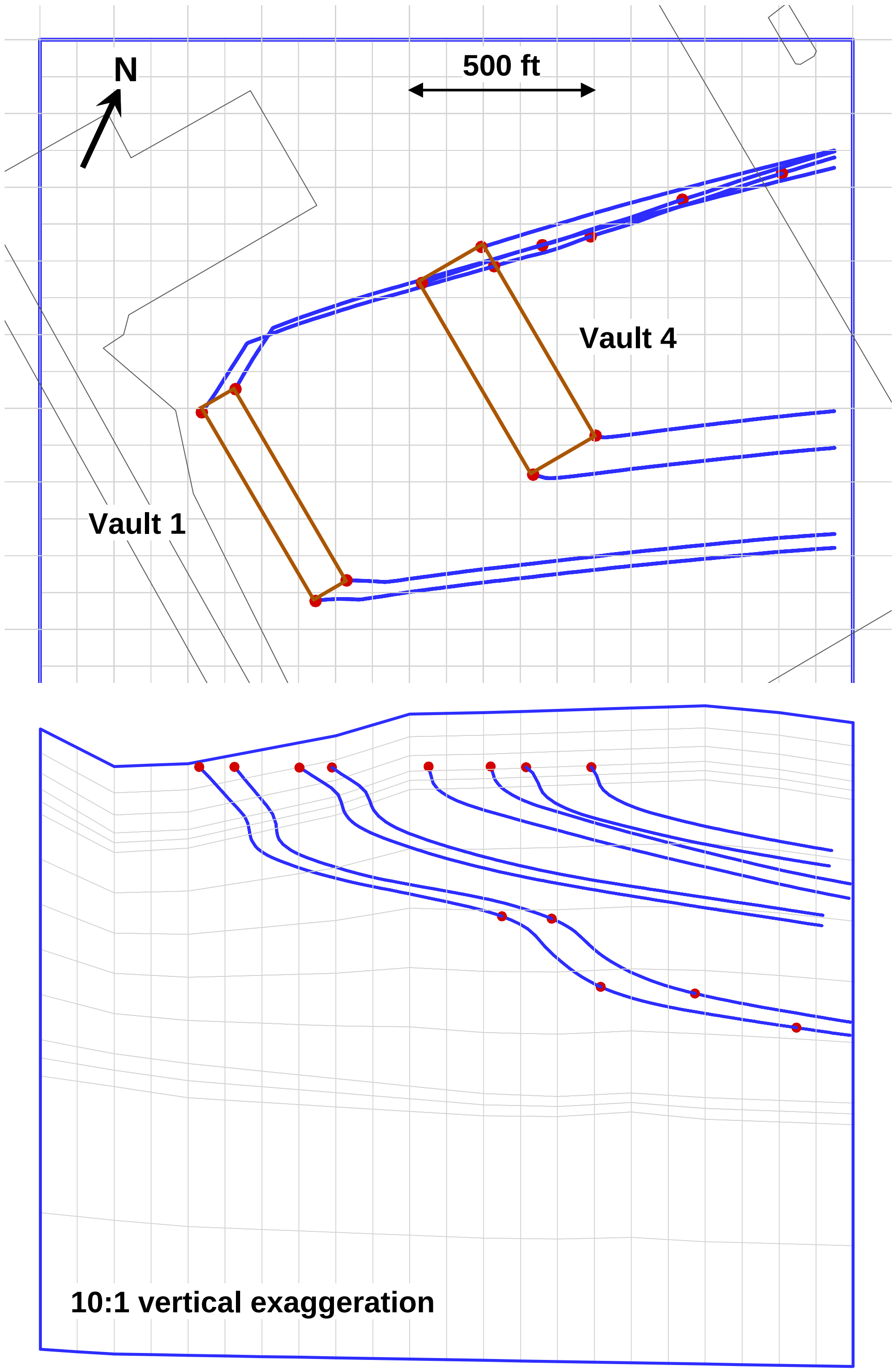


Figure 47-2. Plan and cross-sectional views of groundwater flow paths emanating from Vaults 1 and 4 for the Fast case.

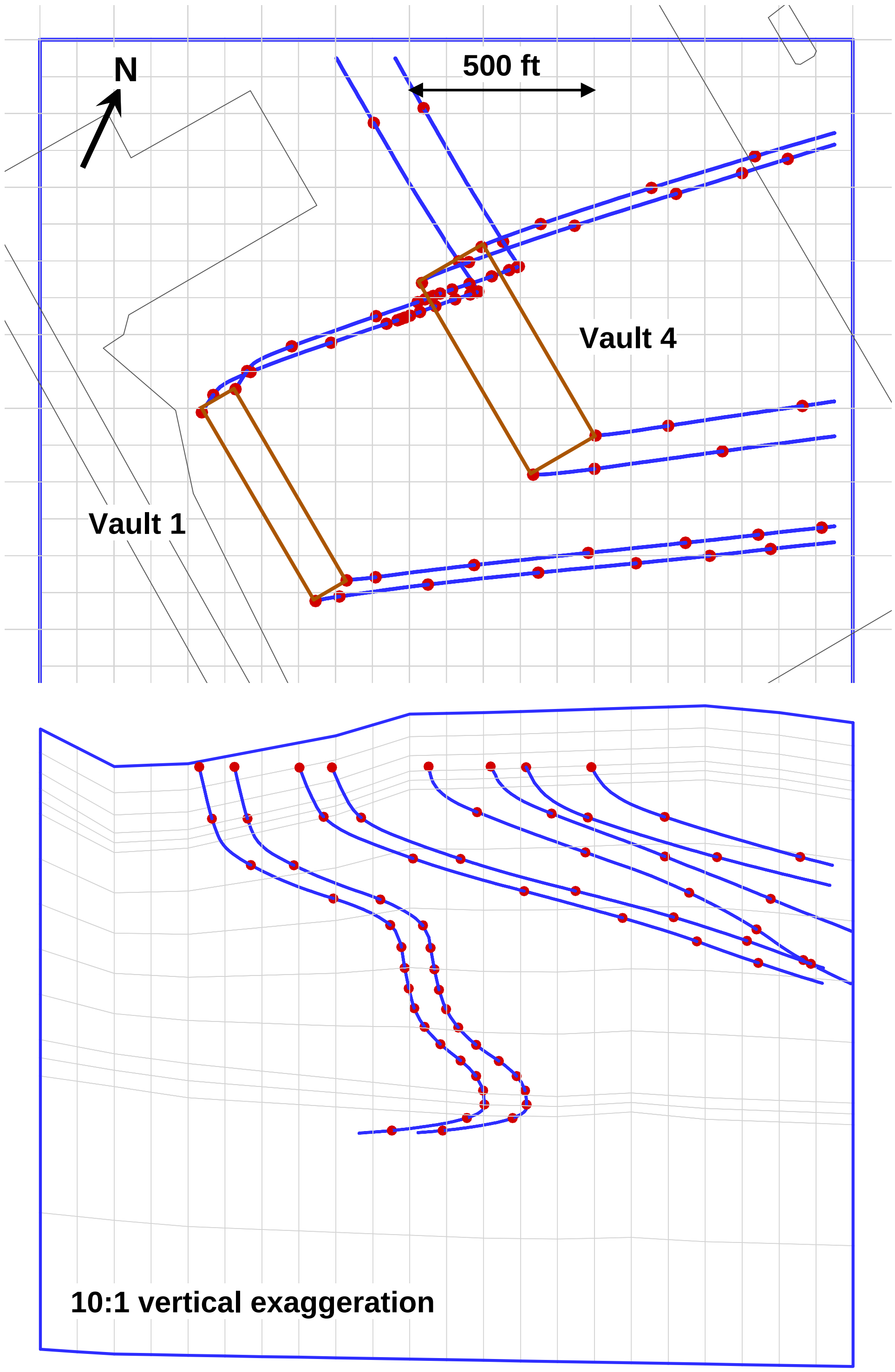


Figure 47-3. Plan and cross-sectional views of groundwater flow paths emanating from Vaults 1 and 4 for the Slow case.

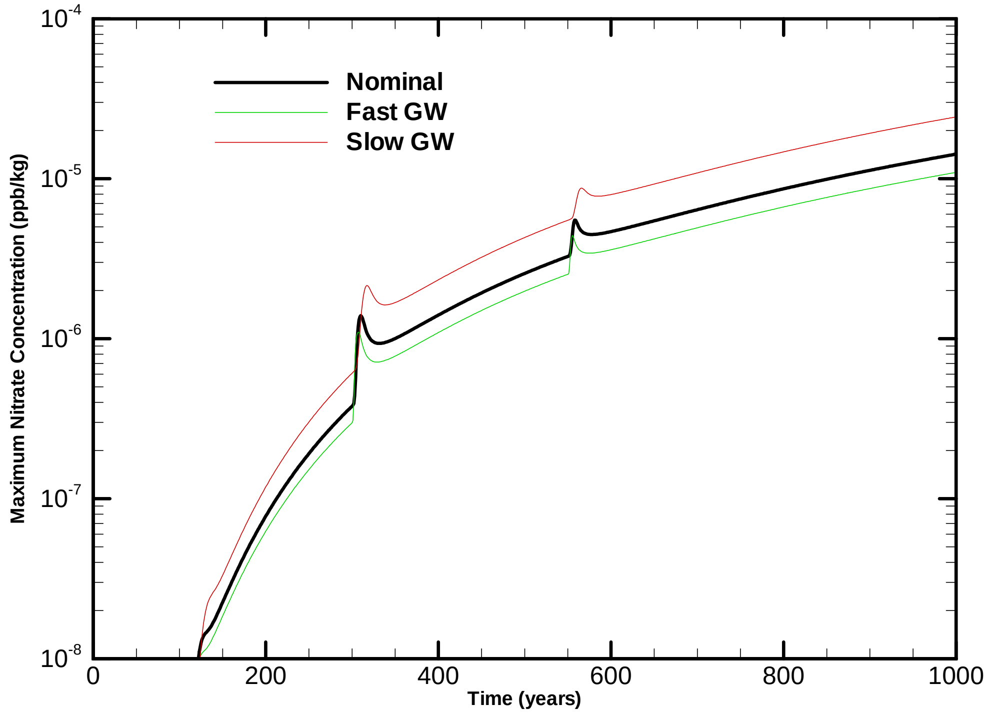


Figure 47-4. Maximum nitrate/tracer concentration beyond 100-m perimeter of Vault 4; Nominal curve is also shown in Figure 7-7 of Cook et al. (2005).

NRC Comment 48: Parameter values and supporting data are not available for some of the distribution coefficients used for groundwater pathway modeling [1].

Basis: Although K_d values were used in the groundwater pathway screening analysis, K_d values were provided only for radionuclides that were included in the groundwater analysis (Table A.1-2 of [1]). To evaluate the appropriateness of the screening process, it is necessary to evaluate K_d values for radionuclides that were screened from the groundwater pathway as well as those that were included in the groundwater pathway.

Furthermore, selection of distribution coefficients for groundwater transport modeling is an exercise typically subject to uncertainty and to which model results can be quite sensitive. It is, therefore, important to understand how well-constrained the choices of K_d values are to have confidence that the model will not underestimate contaminant mobility. Table A.1-2 of Cook and Fowler (1992) [1] contains a number of K_d values based on site-specific data. NRC staff needs to review the reports from which the K_d values were obtained because conditions under which the data were obtained will affect how applicable they are to a given transport model.

Path Forward: Provide all of the K_d values that were used in the groundwater pathway screening analysis, including those for radionuclides that were excluded from further analysis based on the results of the screening analysis.

Provide the following references:

Hoeffner, S.L. "Radionuclide Sorption on SRP Burial Ground Soil: A Summary and Interpretation of Laboratory Data." Internal Report DPST–84–799. Aiken, South Carolina: E.I. du Pont de Nemours and Company, Inc., Savannah River Laboratory. 1984.

Looney, B.B., M.W. Grant, and C.M. King. "Estimation of Geochemical Parameters for Assessing Subsurface Transport at the Savannah River Site—Environmental Information Document." DPST–85–904. Aiken, South Carolina: E.I. du Pont de Nemours and Company, Inc., Savannah River Laboratory. 1987.

McIntyre, P.F. "Sorption Properties of Carbon-14 on Savannah River Plant Soil." Internal Report DPST–88–900. Aiken, South Carolina: E.I. du Pont de Nemours and Company, Inc., Savannah River Laboratory. 1988.

SRS Response: The Vault 4 Special Analysis (SA) (Cook et al. 2005) supplements the analyses in the Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) and supersedes the 2002 Special Analysis (reference 3 in the NRC RAI). The information below describes the source of K_d values used in both the screening and final groundwater analyses for the new SA.

Screening K_ds

SRNL has adopted the screening methodology developed by the National Council on Radiation Protection and Measurements (NCRP 1996). The results for groundwater pathway screening for trench disposal units at SRS (E-Area Low-Level Waste Disposal Facility) (Cook and Wilhite 2004) were used to determine the radionuclides considered in the Vault 4 Special Analysis (Cook et al. 2005). In this process the K_d values given in the NCRP report were used for each radionuclide These are given in Table 4-1 of Volume I of the NCRP report (attached). Please note that the units shown on the table are in error. The units should be mL/g. This was verified by direct communication with Kennedy, the cited source. SRNL made appropriate corrections to the table before using it in the screening analysis.

Special Analysis K_ds

Table A-8 in Cook et al. 2005 provides the K_ds used in the Vault 4 Special Analysis but does not include the references for the source of the K_d values. The following table provides that information. Extracts from the cited references are attached, and a complete copy of each SRS-specific reference is being provided with the full RAI response document to support the NRC review of site-specific data used in establishing K_ds.

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 & 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 III/IV	370	f			6500	f	5000	f
Pu V/VI	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_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 & Vault K_d (mL/g)	ref
k	Assumed to be the same as for Pb							
l	Assumed to be the same as for Am							
m	Serkiz & Johnson, 1994, Figure 4-12, page 69							

The retardation coefficient is defined:

$$R = 1 + \frac{\rho k_d}{n} \tag{4.4}$$

where

ρ = density of soil, kg m^{-3}
k_d = the soil partition coefficient, m^3 kg^{-1}

Soil partition coefficients used in this Report are presented in Table 4.1, and were derived from the values suggested in Kennedy and Strenge (1992). The infiltration rate is chosen to be 0.18 m y^{-1}, which is based on the high end of the range of infiltration rates determined for low-level radioactive waste sites in the southeast United States (Oztunali *et al.*, 1981). Default values for porosity of 0.3 and waste thickness, H, of 0.5 m are also chosen for the present screening model. The leach rate of all progeny in a chain decay are assumed to be the same as the first member of the chain.

All radionuclides released from the buried waste are assumed to be diluted in a volume of water, V, equal to the annual average per

TABLE 4.1—*Soil partition coefficients (Kennedy and Strenge, 1992).*

Element	K_d m^3 kg^{-1}	Element	K_d m^3 kg^{-1}	Element	K_d m^3 kg^{-1}
Ac	420	H	0	Ra	500
Ag	90	Hg	19	Rb	52
Am	1,900	Ho	240	Re	14
As	110	I	1	Rh	52
Au	30	In	390	Rn	0
Ba	52	Ir	91	Ru	55
Be	240	K	18	S	14
Bi	120	Kr	0	Sb	45
Br	14	La	1,200	Sc	310
C	6.7	Mn	50	Se	140
Ca	8.9	Mo	10	Sm	240
Cd	40	Na	76	Sn	130
Ce	500	Nb	160	Sr	15
Cf	510	Nd	240	Tb	240
Cl	1.7	Ni	400	Tc	0.1
Cm	4,000	Np	5	Te	140
Co	60	Os	190	Th	3,200
Cr	30	P	8.9	Tl	390
Cs	270	Pa	510	U	15
Cu	30	Pb	270	W	100
Eu	240	Pd	52	Xe	0
F	87	Pm	240	Y	190
Fe	160	Po	150	Zn	200
Gd	240	Pr	240	Zr	580
		Pu	550		

NRCP 1996

Bradbury & Sarott 1995

Table 4: Sorption Database.

Element	State of Cement Degradation (see Fig. 2)					
	Region I		Region II		Region III	
	Oxid.	Red.	Oxid.	Red.	Oxid.	Red.
H (HTO)	0	0	0	0	0	0
CO_3^{2-}	see section 5.2.7					
Cl	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
Mn	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Ni	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Se	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0	0
Sr	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Zr	5	5	5	5	1	1
Nb	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Mo	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0	0
Tc	10^{-3}	1	10^{-3}	1	0	10^{-1}
Pd	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Ag	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Sn	1	1	1	1	10^{-1}	10^{-1}
I	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	0	0
Cs	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$
Pb	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Ra	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Th	5	5	5	5	1	1
Pa	5	5	5	5	10^{-1}	1
U	2	5	2	5	10^{-1}	1
Np	5	5	5	5	10^{-1}	1
Pu	5	5	5	5	1	1
Am	5	5	5	5	1	1
Cm	5	5	5	5	1	1

The elements are listed according to increasing atomic number. All distribution ratios are in units of $m^3 \, kg^{-1}$. Data selection procedures are described in the text.

TECHNICAL DIVISION
SAVANNAH RIVER LABORATORY

Keywords: Carbon-14
Soil Sorption
Burial Ground

Retention Period: Permanent

DPST-88-900

MEMORANDUM

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SRL Records (4)

October 18, 1988

To: H.F. Sturm, Jr, 773-43A

From: P.F. McIntyre

SORPTION PROPERTIES OF CARBON-14 ON SAVANNAH RIVER PLANT SOIL

SUMMARY

Batch experiments performed using ^{14}C, Savannah River Plant (SRP) soil, and SRP burial ground groundwater indicate that the distribution coefficient, or K_d, for ^{14}C in the form of carbonates is typically 2 ml/g after 7 hours of equilibration and 55 ml/g after 72 hours. These results were obtained for samples containing ^{14}C concentrations ranging from 4.2 nCi/ml up to 40.9 nCi/ml. For comparison the concentration of ^{14}C in the sump leachate of the defense waste lysimeters [1] have ranged from 0.06 nCi/ml to 0.9 nCi/ml.

McIntyre 1988

Table 1. Summary of GM K_d values ($L\ kg^{-1}$) for each element by soil type.[a,b]

Element	Sand	Loam	Clay	Organic
Ac	450[a]	1 500	2 400	5 400
Ag	***90***[b]	***120***	***180***	***15 000***
Am	***1 900***	***9 600***	***8 400***	***112 000***
Be	250	800	1 300	3 000
Bi	100	450	600	1 500
Br	15	50	75	180
C	***5***	20	1	70
Ca	5	30	50	90
Cd	***80***	***40***	***560***	***800***
Ce	***500***	***8 100***	***20 000***	***3 300***
Cm	***4 000***	***18 000***	6 000	***6 000***
Co	***60***	***1 300***	***550***	***1 000***
Cr	***70***	***30***	1 500	***270***
Cs	***280***	***4 600***	***1 900***	***270***
Fe	***220***	***800***	***165***	***600***
Hf	450	1 500	2 400	5 400
Ho	250	800	1 300	3 000
I	***1***	***5***	***1***	***25***
K	15	55	75	200
Mn	***50***	***750***	***180***	***150***
Mo	***10***	125	***90***	***25***
Nb	160	550	900	2 000
Ni	***400***	300	***650***	***1 100***
Np	***5***	***25***	***55***	***1 200***
P	5	25	35	90
Pa	550	1 800	2 700	6 600
Pb	***270***	***16 000***	550	***22 000***
Pd	55	180	270	670
Po	***150***	***400***	3 000	7 300
Pu	***550***	***1 200***	***5 100***	***1 900***
Ra	***500***	***36 000***	***9 100***	2 400
Rb	55	180	270	670
Re	10	40	60	150
Ru	***55***	***1 000***	***800***	***66 000***
Sb	***45***	150	250	550
Se	150	500	740	1 800
Si	35	110	180	400
Sm	245	800	1 300	3 000
Sn	130	450	670	1 600
Sr	***15***	***20***	***110***	***150***
Ta	220	900	1 200	3 300
Tc	***0.1***	***0.1***	***1***	***1***
Te	125	500	720	1 900
Th	***3 200***	3 300	***5 800***	***89 000***
U	***35***	***15***	***1 600***	***410***
Y	170	720	1 000	2 600
Zn	***200***	***1 300***	***2 400***	***1 600***
Zr	600	2 200	3 300	7 300

[a] Values with regular numbering are default values predicted using CRs.
[b] Values with italic bold numbering come from the *literature*.

matter and were either classic peat or muck soils, or the litter horizon of a mineral soil.

If a time series of K_d values was reported, we used only the K_d values for the longest time since these values would most closely approximate equilibrium conditions. Only one value was entered for each soil reported in the literature. For example, where K_d values were reported for the same soil for a range of soil:solution ratios, competing cations, contact solution concentrations, or pH values, the results were ln-transformed and averaged to provide a single geometric mean (GM) value. The transformation was justified because soil K_d values are lognormally distributed (Sheppard et al. 1984; Sheppard and Evenden 1989). The single values for each soil were also ln-transformed, and GMs and geometric standard deviations (GSDs) were determined for each element by soil texture for the mineral soils and also for organic soils.

If no data existed in the literature for a given element, the soil-to-plant concentration ratio (CR) was used as an indicator of the element's mobility and to predict a default K_d value (Baes et al. 1984; Sheppard 1985). The CR values used were taken from Baes et al. (1984). This technique is successful because of the strong negative correlation between CR and K_d (Sheppard and Sheppard 1989). The model used had the following form:

$$\ln K_d = a + \mathrm{STEX} + b\,(\ln \mathrm{CR}), \qquad (2)$$

where a, b, and STEX are constants. The values for the coefficients were $a = 4.62$, and $b = -0.5$. The following

Sheppard & Thibault 1990

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.)

Kaplan 2004

Table 6. Average K_d Values Measured in Sediments Collected from Borehole 299-E17-21[a]

Formation	pH	Cation-Exchange Capacity (meq/100)	K_d Cs (mL/g)	I (mL/g)	Se (mL/g)	Sr (mL/g)	Tc (mL/g)	U (mL/g)
Layer 3	8.54	5.07	2044.8	0.00	7.77	14.09	-0.01	0.94
Layer 2	8.69 ± 0.15	4.66 ± 1.57	1994.9 ± 441.2	0.01 ± 0.05	7.13 ± 0.95	14.05 ± 1.04	-0.01 ± 0.00	0.63 ± 0.07
Layer 1	8.84 ± 0.11	8.00 ± 1.57	2123.2 ± 793	0.08 ± 0.07	6.17 ± 2.64	15.57 ± 1.93	-0.01 ± 0.01	0.56 ± 0.11
P value[b]	0.02	1E-5	0.66	0.03	0.29	0.04	0.68	0.15

(a) The data used to generate the statistics in this table are presented in Table 3. Layer 3 had 1 observation; layer 2 had 10 observations; layer 1 had 9 observations.

(b) The P value is the probability that the pH, CEC, and K_d values in layers 2 and 1 are different. For the purposes of this study, a P value greater than 0.05, 5% probability, indicated that the means for each layer are not significantly different.

9

Kaplan et al. 1998

Table 1. Summary of Column Conditions and Data

Column	Void Volume, mL	Total Volume of Water, mL*	I^- Break-through, mL	Flow Rate mL/hr
1a	7.0	10.7	37.5	32.6
1b	7.0	10.7	36.0	32.6
2	7.8	11.9	36.6	15.2

* The sum of the amount of water contained in the initial moist soil plus the amount of water required to saturate the soil in the column.

Table 2. Summary of Iodide Batch and Column Distribution Coefficients

	Average Iodide K_d, mL/g		
I^-, ppm	Batch[a]	Batch[b]	Column
5	6.6	4.0	–
25	–	–	0.60
50	5.3	0.5	–
250	–	–	0.60
500	3.6	2.0	–

[a]Plastic centrifuge cones
[b]Glass centrifuge cones

SLH:ske
Disc 5

Hoeffner 1984a

TABLE I

Range of K_d's Expected in the Burial Ground for Various Radionuclides

	K_d, mL/g			
	Groundwater*			
Radionuclide	Low	High	Typical Groundwater**	Trench Water***
Co-60	3.5	>10,000	10	30-100
Sr-90	1.5	3,000	7.5	7-600
Ru-106	65	-	175	160-580
Sb-125	180	>4,000	3,800	190->4000
Cs-137	330	1,800	500	100-400
Pu-238/239				
Pu (VI)	7	250	9	-
Pu (IV)	120	7,100	150	-
Pu(III)	800	>10,000	8,000	-
Tc-99	-	-	0.5	-
I-129	3	10	5	-

* Groundwater K_d for all radionuclides except Tc-99 and I-129 determined from the 2σ groundwater pH range of 3.4 to 7.3. The low K_d values for Co, Sr, Ru, Cs, and Pu occur at pH 3.4, the high K_d values at pH 7.3. The low K_d value for Sb occurs at pH 7.3, the high K_d value at pH 4.3. Iodine K_d range determined from iodine concentration range of 5 to 500 ppb iodine.

** Measured K_d with a groundwater of typical composition; pH 4.7.

*** K_d range observed for seven trench waters.

Hoeffner 1984b

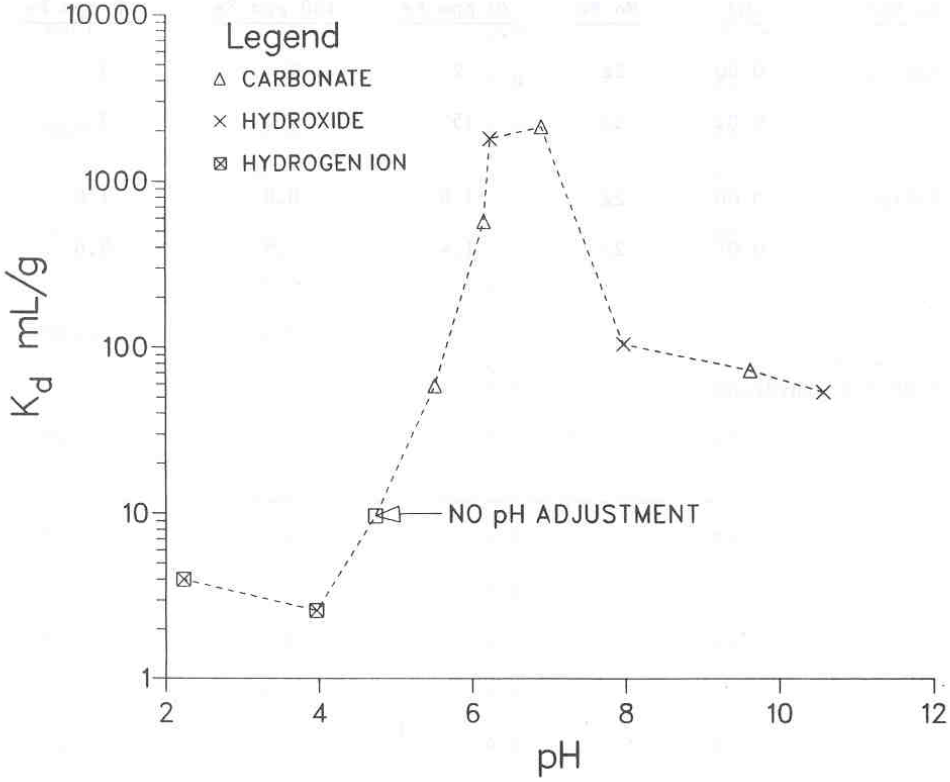
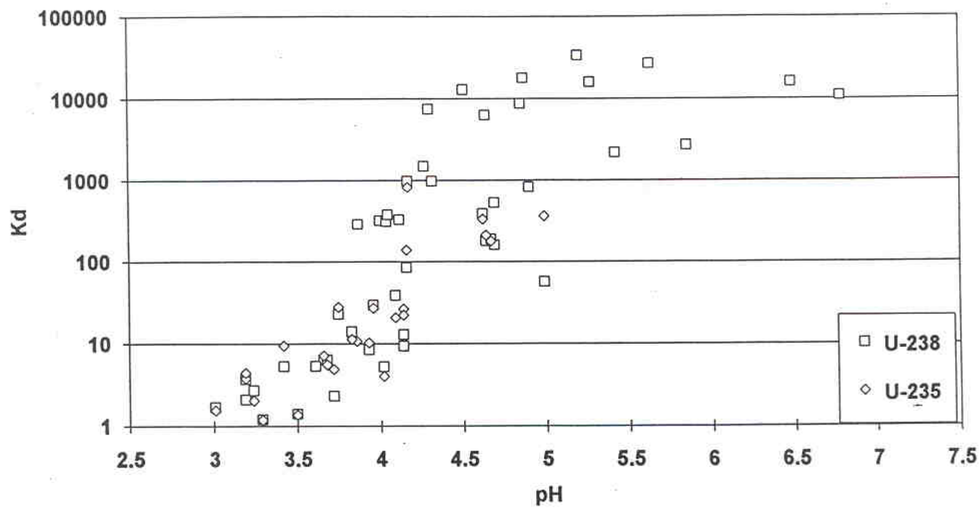


FIGURE 4. Effect of pH on Strontium K_d

- 30 -

Hoeffner 1985

Figure 4-12. Field-derived distribution coefficients versus pH.



Serkiz & Johnson 1994

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Hoeffner, S. L. 1984a. Additional Laboratory Studies on Radionuclide Sorption at the SRP Burial Ground. DPST-84-797. E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.

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Kaplan, D. I., K. E. Parker, and I. V. Kutynakov. 1998. Radionuclide Distribution Coefficients for Sediments Collected from Borehole 299-E17-21: Final Report for Subtask 1a, PNNL-11966. Pacific Northwest National Laboratory, Richland, Washington.

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McIntyre, P. F. 1988. Sorption Properties of Carbon-14 on Savannah River Plant Soil. DPST-88-900. E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, SC.

NCRP. 1996. Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground, Vol. I and II, NCRP Report No. 123, National council on Radiation Protection and Measurements, Bethesda, MD.

Serkiz, Steven M and Johnson, William H. 1994. Uranium Geochemistry in Soil and Groundwater at the F and H Seepage Basins. EPD-SGS-94-307, Revision 0. Westinghouse Savannah River Company, Aiken, South Carolina.

Sheppard, M. I., and D. H. Thibault. 1990. Default Soil Solid/Liquid Partition Coefficients, Kds, for Four Major Soil Types: A Compendium. Health Physics, **59**:471-482.

NRC Comment 49: The basis for the Se-79 distribution coefficient for concrete and saltstone in the performance assessment is not clear [1].

Basis: Se-79 is a potentially mobile contaminant in cementitious materials [20]. Selenium solubility and sorption properties are strongly dependent on oxidation-reduction conditions. A footnote to Table A.1-2 of Reference 1 states that the Kd value of 7 mL/g used for Se-79 in concrete and saltstone was "based on apparent diffusion coefficient for sulfate." NRC staff could not find text explaining this derivation.

Path Forward: Provide the technical basis for the concrete and saltstone Kd value for Se-79 used in the 1992 performance assessment.

SRS Response: The Vault 4 Special Analysis (SA) (Cook et al. 2005) supplements the analyses in the Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) and supersedes the 2002 Special Analysis (reference 3 in the NRC RAI).

The Se-79 K_d values for Saltstone and the concrete vault in the Vault 4 Special Analysis (Cook et al. 2005) were taken from Bradbury and Sarott 1995, Table 4, page 42, Region II, Reducing, rather than being derived as stated in the 1992 PA. The new K_d value is 10^{-4} m^3/kg, or 0.1 mL/g.

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, Special Analysis: Revision of Saltstone Vault 4 Disposal Limits, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Bradbury, M. H. and F. A. Sarott. 1995. Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment, Paul Scherrer Institut, Villigen, March 1995.

Table 4: Sorption Database.

Element	State of Cement Degradation (see Fig. 2)					
	Region I		Region II		Region III	
	Oxid.	Red.	Oxid.	Red.	Oxid.	Red.
H (HTO)	0	0	0	0	0	0
CO_3^{2-}	see section 5.2.7					
Cl	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
Mn	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Ni	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Se	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0	0
Sr	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Zr	5	5	5	5	1	1
Nb	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Mo	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0	0
Tc	10^{-3}	1	10^{-3}	1	0	10^{-1}
Pd	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Ag	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Sn	1	1	1	1	10^{-1}	10^{-1}
I	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	0	0
Cs	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$
Pb	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Ra	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Th	5	5	5	5	1	1
Pa	5	5	5	5	10^{-1}	1
U	2	5	2	5	10^{-1}	1
Np	5	5	5	5	10^{-1}	1
Pu	5	5	5	5	1	1
Am	5	5	5	5	1	1
Cm	5	5	5	5	1	1

The elements are listed according to increasing atomic number. All distribution ratios are in units of $m^3\,kg^{-1}$. Data selection procedures are described in the

Bradbury & Sarott 1995

NRC Comment 50: Use of literature K_d values for ordinary concrete mixtures to represent radionuclide mobility in saltstone requires further justification.

Basis: Saltstone does not have the composition of ordinary concrete. For example, saltstone pore water is expected to have much higher Na+ and NO3 - concentrations than the pore water of ordinary concrete [15, 21]. However, the potential effects of this difference on the mobility of radionuclides for which adsorption is sensitive to ionic strength, including Cs, have not been discussed. Similarly, differences in the solid composition of concrete and saltstone may cause differences in radionuclide sorption. Justification is needed to support the use of the same K_d to represent radionuclide mobility in both in saltstone and concrete (Table A-3 of [1]).

Path Forward: Provide a technical basis for the use of literature K_d values applicable to standard cement environments to predict radionuclide mobility in saltstone. The response should address potential effects of differences between the composition of solid phases and pore water in saltstone and the composition of solid phases and pore water in the concrete studied in the cited literature. If it is found that literature values for K_d in concrete cannot be used to represent radionuclide partitioning in saltstone, alternative K_d values for radionuclides in saltstone should be provided, and the expected doses from groundwater pathways should be recalculated.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The reactive surface sites for the solid phases of both the saltstone and concrete, are similar and, given their high pH environments, would be expected to have similar functionalities and number of surface exchange sites. As the comment above indicates, the saltstone would be expected to have a higher ionic strength pore water solution than the concrete. This would tend to promote competition for sorption sites, thereby decreasing the tendency of radionuclides to sorb to the saltstone. This attribute was considered in the selection of the K_d values used in the 2005 SA as described below.

The K_d values for radionuclides in contact with saltstone used in the 1992 PA were primarily derived from the literature (Table A1-1; Page A-13; [1] are presented below in Table 50-1). The Allard (1985) source was among the resources used by Bradbury and Sarott (1995) in their later critical compilation of K_d values that is the bases of the K_d values used in the 2005 SA. The Bradbury and Sarott (1995) K_d values are presented in Table 50-2.

A-13 WSRC-RP-92-1360

Table A.1-2. Kd's (mL/g) assumed in the near-field model

Radionuclide	Backfill[a,b]	Clay[a]	Gravel	Concrete[c]	Saltstone[c]
H-3	0.	0.	0.	0.	0.2[d]
C-14	2.4[e]	0.	0.	5000.	5000.
Se-79	47.	20.	0.	7[f]	7[f]
Sr-90 + d	10.[g]	10.	0.	10.	10.
Tc-99	0.36[g]	2.2	0.	700.[d]	700.[d]
Sn-126 + d	100.[h]	0.	0.	500.	500.
I-129	0.6[g]	3.	0.	30.	30.
Cs-137 + d	100.[g]	100.	0.	2.	2.
Pu-238	100.[g]	1000.	0.	5000.	5000.
Am-241	150.	1800.	0.	5000.	5000.
Nitrate	0.			0.	0.

[a] NEA Sorption Data Base 1989.
[b] Values apply to native soils also.
[c] Allard (1985).
[d] MINTEQ calculations.
[e] McIntyre 1988.
[f] Based on apparent diffusion coefficient for sulfate.
[g] Hoeffner 1984.
[h] Looney et al. 1987.

Table 50-1. K_d values used in the 92 PA (WSRC-RP-92-1360).

42

Table 4: Sorption Database.

Element	State of Cement Degradation (see Fig. 2)					
	Region I		Region II		Region III	
	Oxid.	Red.	Oxid.	Red.	Oxid.	Red.
H (HTO)	0	0	0	0	0	0
CO_3^{2-}	see section 5.2.7					
Cl	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$
Mn	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Ni	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Se	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0	0
Sr	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Zr	5	5	5	5	1	1
Nb	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Mo	10^{-4}	10^{-4}	10^{-4}	10^{-4}	0	0
Tc	10^{-3}	1	10^{-3}	1	0	10^{-1}
Pd	10^{-1}	10^{-1}	10^{-1}	10^{-1}	10^{-2}	10^{-2}
Ag	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}	10^{-3}
Sn	1	1	1	1	10^{-1}	10^{-1}
I	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	0	0
Cs	$2 \cdot 10^{-3}$	$2 \cdot 10^{-3}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$	$2 \cdot 10^{-2}$
Pb	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-1}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Ra	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$	$5 \cdot 10^{-2}$
Th	5	5	5	5	1	1
Pa	5	5	5	5	10^{-1}	1
U	2	5	2	5	10^{-1}	1
Np	5	5	5	5	10^{-1}	1
Pu	5	5	5	5	1	1
Am	5	5	5	5	1	1
Cm	5	5	5	5	1	1

The elements are listed according to increasing atomic number. All distribution ratios are in units of $m^3\ kg^{-1}$. Data selection procedures are described in the text.

Table 50-2. The "Region II, Reducing" K_d Values from Bradbury and Sarott (1995) were used in the 2005 SA.

The 2005 SA adopted the Bradbury and Sarott (1995; Table 4; Page 42) "Region II Reducing Concrete K_d values, Region II" because they are meant to reflect conservative estimates, and as the authors indicate, often reflect very conservative estimates, especially for the actinides. Region II was selected versus Region III because it covers the duration of interest most applicable to the SA (i.e., hundreds to thousands of years versus hundreds of thousands of years).

The uncertainty associated with the influence of ionic strength on K_d values was included in the selection of K_d values by Bradbury and Sarott. In their discussion of each element and the justification for the selection of their K_d values they present data of the impact of ionic strength on radionuclide K_d values. For example, on page 31 they discuss the impact of ionic strength on Cs K_d values:

> In region II, the concentrations of (Na, K) OH have decreased by orders of magnitude and their competitive effect on Cs sorption has been correspondingly diminished.

Bradbury and Sarott (1995) took into consideration numerous environmental conditions, including different waste loadings, concrete ages, and concrete formulations when they produced the above table (Table 50-2) of conservative K_d values. The effect of ionic strength was also considered.

References:

Bradbury, M. H., and F. Sarott. 1995. Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment. Nr. 95-06. Paul Scherrer Institut, Wurenlingen and Villigen, Switzerland.

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC Comment 51: Additional information is needed to support the predicted solubility of Tc in saltstone pore water.

Basis: An effective Kd for Tc was derived based on the solubility of Tc2S7 as calculated with the MINTEQ code (Appendix D of [1]). The MINTEQ calculations are based on the assumption that the concentration of Tc in saltstone pore water is constrained by equilibrium with the solid Tc2S7; however, no experimental evidence is presented to demonstrate that Tc2S7 is present in the slag saltstone. The calculated concentration of Tc in the pore fluid is very sensitive to the presence of aqueous sulfide, but no direct measurement of aqueous sulfide in saltstone pore fluids is presented. In addition, the MINTEQ calculations of Tc concentration are uncertain because of uncertainty in the thermodynamic data for Tc2S7 [22].

Furthermore, because the default MINTEQ thermodynamic database does not include Tc species, values used to calculate Tc solubility must be provided to allow evaluation of the geochemical model. Specifically, reactions used to model the formation of aqueous Tc species, stability constants for those reactions, and the thermodynamic solubility constant for Tc2S7 should be provided.

Path Forward: Provide evidence to support the assumption that a sufficient concentration of sulfide is present in the saltstone pore fluid and that solid Tc2S7 is present in the saltstone to constrain Tc concentrations to low values. An alternative approach is to assume equilibrium with the solid TcO2, which is reasonably characterized [22]. Provide the reactions used to model the formation of aqueous Tc species, stability constants for those reactions, and the thermodynamic solubility constant used to model Tc2S7 solubility. Provide a justification for the aqueous species of Tc included in the chemical modeling. If no aqueous complexes of Tc were included, explain why the choice is justified and does not lead to an underestimate of Tc solubility.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The MINTEQ calculations were used for the 1992 PA to help develop a conceptual model regarding how Tc interacts with slag and to demonstrate that Tc aqueous concentrations as lower in the presence of slag. They were used to provide some generalized guidance for selecting the Tc K_d value (700 mL/g) for the 1992 PA, as shown in response to NRC Comment 50 in Table 50-1.

There have not been any measurements of saltstone porewater sulfide concentrations at SRS. However, we have spectroscopic evidence of the existence of Tc_3S_{10} in SRS saltstone, which is generally referred to in the literature as Tc_2S_7 (Lukens et al. 2005). Further discussion of the related reducing capacity can be found in the response to NRC Comment 41. Reducing capacity is a measure of the capacity of the sulfide within the saltstone to immobilize the Tc-99.

In the 2005 SA, Tc was modeled using a constant K_d value of 1000 mL/g, taken from Bradbury and Sarott (1995). The K_d values of Bradbury and Sarott (1995) were selected for the 2005 SA because they represent the best available conservative values in the literature. Tc concentrations that will be encountered in the saltstone will fall in what is referred to as "the linear range of the sorption isotherm," meaning that the Kd value will not change as a function of Tc concentrations.

Although no longer used in the 2005 SA, the following information associated with the 1992 PA is included in response to the suggested path forward. The MINTEQ calculations in the 1992 PA were conducted using the constants provided by Rard (1982; UCRL-53440, LLNL, Livermore, CA). These calculations were conducted prior to the publication of Rard et al. (1999) (reference [22] in comment), the present source for Tc thermodynamic constants, was published. Rard (1982) was the original report that was later turned into the book, Rard et al. (1999).

References:

Bradbury, M. H., and F. Sarott. 1995. Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment. Nr. 95-06. Paul Scherrer Institut, Wurenlingen and Villigen, Switzerland.

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Rard, J. A. 1999. Chemical Thermodynamics of Technetium. Elsevier. Amsterdam

Rard, J. A. 1983. Critical Review of Chemistry and Thermodynamics of Technetium and some of its Inorganic Compounds and Aqueous Species. UCRL-53440. Lawrence Livermore National Laboratory. Livermore, California.

Lukens, W. W., J. J. Bucher, D. K. Shuh, and N. M. Edelstein. 2005. Evolution of Technetium Speciation in Reducing Grout. Environ. Sci. Technol. (In Press).

NCR Comment 52: It is unclear whether the saltstone pore fluid concentrations calculated using MINTEQ in Appendix D of Reference 1 are appropriate, because the activity coefficient model used is not valid at high ionic strengths.

Basis: The methods used by MINTEQ to calculate activity coefficients of electrically charged aqueous species are most applicable to dilute solutions and are only valid for solutions with ionic strengths of less than approximately 1 mole/kgH2O [23]. The saltstone pore fluids, however, have much higher ionic strengths. Solubilities and solution concentrations calculated with geochemical codes, such as MINTEQ, are dependent on the activity coefficient model used by those codes. Incorrect results may result if the activity coefficient model is used outside its valid range of concentration. In Appendix D of Reference 1, for example, it was noted that the MINTEQ results, which indicated that all nitrate and nitrite in saltstone occurs within the pore fluids, differed from identified by the x-ray diffraction (XRD) analysis of Malek, et al. [15]. The difference was attributed to the method used by Malek, et al. [15] for preparing saltstone samples for XRD analysis. An alternative explanation for the difference in calculated and measured concentrations is the extrapolation of the activity coefficient model and the thermodynamic parameters used by MINTEQ beyond their applicable ranges.

Path Forward: Use an activity coefficient model valid to high concentrations to calculate saltstone pore fluid concentrations. Computer codes that use activity coefficient models valid to high concentrations include the EQ3 code (Pitzer model option), PHRQPITZ, and the Environmental Simulation Program developed by OLI Systems, Inc. (Morris Plains, New Jersey).

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The MINTEQ code used in the 1992 Performance Assessment is no longer used for high ionic strength speciation calculations. OLI software is now utilized to conduct high ionic strength speciation calculations. In the 1992 PA, the Tc K_d value used in the saltstone was based on MINTEQ calculations which takes into consideration saltstone pore fluid concentration (Appendix D of WSRC-RP-92-1360); it was 700 mL/g (see Table 50-1 in the response to NRC Comment 50 and 51). In the 2005 SA, the Tc K_d value used in the saltstone was based on the conservative estimates of Bradbury and Sarott (1995; see Table 50-2 in the response to NRC Comment 50). These K_d estimates were based on laboratory leach experiments; the conservative Tc K_d value for a reducing concrete suggested by Bradbury and Sarott (1995) is 1000 mL/g.

References:

Bradbury, M. H., and F. Sarott. 1995. Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment. Nr. 95-06. Paul Scherrer Institut, Wurenlingen and Villigen, Switzerland.

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina.

NRC Comment 53: The concentration of Tc in saltstone pore water and the effective distribution coefficient for Tc should be recalculated to reflect current conditions.

Basis: Because the effective K_d for Tc is calculated based on the solubility of Tc2S7 (Appendix D of [1]), the effective K_d is sensitive to the concentration of Tc in the saltstone. However, the effective K_d value was not updated to reflect the Tc concentrations currently predicted to occur in saltstone made from DDA, ARP/MCU, and SWPF wastes. Thus it appears that the effective K_d derived based on concentrations of Tc predicted to be in saltstone in 1992 (Appendix D of [1]) may be inapplicable to saltstone made with DDA, ARP/MCU, and SWPF wastes.

In addition, it is unclear whether differences between the expected salt feed composition and the salt feed composition used in the MINTEQ analyses (Appendix D of [1]) will have a significant effect on the predicted partitioning of Tc.

Path Forward: Calculate effective distribution coefficients for Tc in saltstone made from DDA, ARP/MCU, and SWPF wastes and the current feed composition, or explain why the distribution coefficient calculated in the 1992 PA (Appendix D) is appropriate to predict Tc leaching from each type of waste. If new values of effective K_d values for each type of saltstone are calculated, the expected doses due to groundwater contamination with Tc should be recalculated.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The MINTEQ calculations in Appendix D of [1] were not used to provide quantitative input values for the 2005 SA. Instead, they provided information used to develop the chemical conceptual model for Tc in the reducing cementitious environment. The Tc K_d value (1000 mL/g) used in the 2005 SA was taken from Bradbury and Sarott (1995; see Table 50-2 in NRC Comment 50), who compiled a table of conservative K_d values in various cementitious environments. As such, these are generic K_d values that are not waste-specific and are applicable to numerous waste streams, including DDA, ARP/MCU, and SWPF wastes, which are similar in their bulk composition. The K_d values described and utilized in the Vault 4 SA are appropriate for all of the proposed salt processing waste streams that will be disposed of in the SDF. The concentration of Tc in these waste streams will not influence the K_d value. The Tc concentration is within the linear range of the sorption isotherm, meaning that the K_d parameter does not change as a function of Tc concentration.

References:

Bradbury, M. H., and F. Sarott. 1995. Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment. Nr. 95-06. Paul Scherrer Institut, Wurenlingen and Villigen, Switzerland.

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

NRC Comment 54: Information about the uncertainty of the effective K_d used to model Tc partitioning in saltstone is needed to evaluate the predicted release of Tc in saltstone and the resulting uncertainty in doses from the groundwater pathways.

Basis: The predicted Tc solubility is sensitive to the thermodynamic solubility constant assumed for Tc2S7 and the concentration of sulfide in the saltstone pore water (pg. D-11 of [1]). Because these values are both very uncertain (pg. D-11 of [1]), and because precipitation of Tc as Tc2S7 is a key factor in determining the potential concentrations of Tc in groundwater, the uncertainty in the effective K_d of Tc in saltstone is needed to assess the uncertainty in potential groundwater contamination with Tc.

Path Forward: Provide an estimate of the uncertainty in the value of the effective K_d for Tc used in the performance assessment modeling. The response should address uncertainty in the solubility constant for Tc2S7 as well as the sulfide concentration in saltstone.

SRS Response: The analyses in the 1992 Saltstone Performance Assessment (PA) (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (SA) (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

As the comment indicates, there is a great deal of uncertainty associated with the concentration of Tc in the aqueous phase in contact with Saltstone.

The Tc K_d value used in the 1992 PA was 700 ml/g. The calculated K_d value based on the solubility calculation in Appendix D on Page D-10 of the 1992 Saltstone PA was 800 ml/g. The Tc K_d value used in the 2005 Vault 4 SA was 1000 ml/g and was taken from Bradbury and Sarott (1995). Bradbury and Sarott's data were selected for the 2005 SA because it was supported by the most recent laboratory measurements.

Tc_2S_7 solubility and the associated uncertainty of this solubility is largely unknown. Our estimate of its solubility is based on theoretical considerations (the Linear-Free-Energy method, a common method for estimating solubility values based on Gibbs Free Energy). Our best estimate of Tc K_d values derived from these theoretical considerations is orders of magnitude greater than 1000 ml/g. The 2005 SA is quite sensitive to this value, and for this reason the conservative value of 1000 ml/g was used.

There have not been any measurements of saltstone grout pore water sulfide concentration values. However, we have indirect evidence that sulfides exist in the pore water, through the spectroscopic detection of Tc_2S_7. The response to NRC Comment 51 provides further discussion of this topic.

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Bradbury, M. H., and F. Sarott. 1995. Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment. Nr. 95-06. Paul Scherrer Institut, Wurenlingen and Villigen, Switzerland.

NRC Comment 55: The assumption that chemical conditions in the wasteform will remain reducing throughout the model period is not supported.

Basis: The saltstone formulation includes blast furnace slag in order to impose reducing conditions in the wasteform (pg. 2–52 and D–8 of [1]). The chief benefit of this additive is to immobilize Tc-99, which is characterized by low solubility and high sorption coefficients under reducing conditions. In the current assessment [1], it is assumed that reducing conditions are maintained for the entire performance period, and an effective K_d derived for Tc under reducing conditions is used to represent Tc release from saltstone. However, measurements of the redox conditions of experimentally simulated saltstone indicate that the pore water in saltstone is actually oxidizing, perhaps because of the high NO3 – content [15]. Furthermore, the Tc (IV) species in reducing grout waste forms are not stable towards oxidation under aerobic conditions. As saltstone in the shallow vadose zone degrades, its reducing capacity could potentially diminish over time. Oxidation of the saltstone that could occur near surfaces and cracks could result in oxidation and release of Tc [14, 16].

Path Forward: Provide a technical basis for the assumption that reducing conditions will persist in saltstone throughout the period of performance. Provide any experimental evidence that the saltstone will be reducing and address the results of Malek et al. [15]. The response should address the potential effects of oxidation near cracked surfaces of the waste on Tc oxidation and mobility. The response also should address the potential effects of oxygen in soil gas on the saltstone and as a source of oxygen for water contacting the saltstone. Alternately, if it is determined that the effects of oxidation near waste surfaces exposed to subsurface gas or infiltrating water cannot be neglected, the model should be revised to incorporate the effects of oxidation on Tc release from saltstone and the performance assessment should be updated.

SRS Response: The analyses in the 1992 PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The 2005 Vault 4 SA does not assume that the saltstone grout will remain reducing for the entire time of compliance. Kaplan and Hang (2003) conducted laboratory and numerical calculations that demonstrated that a vast majority, ~97%, of the saltstone grout will remain in a reduced state for more than 10,000 years. Section A.4 of the Vault 4 SA evaluated the potential effect of cracks in the saltstone grout and vault structure and concluded that, under the infiltration conditions expected during the 0 to 10,000-year period, cracks would not be a pathway for water migration.

Kaplan and Hang (2003) measured the reduction capacity of the slag and then conducted two-dimensional simulations of the Saltstone Disposal Facility in an effort to estimate the duration that the saltstone grout would maintain a reducing environment.

The slag was assumed to be evenly distributed throughout the saltstone grout and the reductant, as measured in the laboratory study, was consumed by dissolved oxygen in the infiltrating pore water (and to a lesser extent by the oxidizing agents in the waste itself). The dissolved oxygen was continuously replenished (was in equilibrium with) with oxygen in the vadose zone air surrounding the Saltstone Facility. The pore water was assumed to diffuse in from all sides and to have a limited amount of advection in the downward direction through the saltstone grout. No cracks in the saltstone grout were assumed to be present. It was also assumed that once the oxygen reached the reductant in the saltstone, then the oxidation reaction occurred immediately.

An example of the output from these calculations is presented in Figure 41-1, in response to NRC Comment 41.

After 50,000 years, only 8% of the slag reduction potential was consumed by the infiltrating dissolved groundwater. In the simulations, a sharp oxidized front moved slowly through the vault. Technicium residing in the oxidizing region would become oxidized and released into the environment, whereas Technicium residing in the grout ahead of the front would remain immobilized.

Lukens et al. (2005; this manuscript includes much of the work presented in the report cited in the Basis section of this comment [14; Shuh et al. 2003]), using spectroscopic and diffusional considerations, reported that ~4% of the reduction capacity of the SRS saltstone grout would be consumed in 213,000 years. To adjust Lukens et al. (2005) one-dimensional calculation to a two-dimensional (4-side diffusion) calculation, the percentage (~4%) is increased by four (an approximation), yielding 16% of the total saltstone reduction capacity would be consumed in 213,000 years. This value aligns well with the value of 15.8% shown in Figure 41-2 in the response to NRC Comment 41.

The method used by Kaplan and Hang (2003) to measure the reduction capacity of the slag was designed to intentionally underestimate the total reduction capacity in an attempt to introduce conservatism into the model. This method measured the reduction capacity primarily on the surface site of the slag particles, not within the interior of the slag particles. More recently, Lukens et al. (2005) measured the total reduction capacity of the slag, including both the surface and interior. Kaplan and Hang (2003) reported a reduction capacity of 3.8E-4 meq/g slag and Lukens et al. (2005) reported 0.821 meq/g slag. Lukens' value is the more accurate value in that it includes the total reduction capacity of the sulfur, whereas the method used by Kaplan and Hang (2003) includes predominantly the Fe(II) and some sulfur. The slag is thermodynamically unstable in concrete and is expected to be releasing electrons, primarily from sulfur for a extended duration. SRNL recently measured the "total" reduction capacity of the slag and came up with a value essentially identical to that of Lukens, 0.817 meq/g slag (see recent personal communication in Figure 55-1). By

repeating the calculations that created Figures 41-1 and 41-2 and substituting this larger, more realistic reduction capacity, it is anticipated that the calculated durations over which the saltstone grout would maintain its reducing condition would be extended three orders-of-magnitude.

Daniel Kaplan/SRNL/Srs	To	Thong Hang/SRNL/Srs@srs
06/14/2005 05:25 PM	cc	Bruce Martin/WSRC/Srs@Srs, Ed Stevens/SRNL/Srs@Srs, Tom Butcher/SRNL/Srs@Srs, Jim Cook/SRNL/Srs@srs, Christine Langton/SRNL/Srs@Srs, David Best/SRNL/Srs@srs, John Harbour/SRNL/Srs@Srs, wwlukens@lbl.gov
	bcc	
	Subject	New reduction capacity value for the Slag used in the Saltstone

Thong: The new slag reduction capacity is 0.817 +/- 0.001 meq/g. This is essentially identical to that measured by Wayne Lukens group at Lawrence Berkeley National Laboratory 0.821 meq/g. This value is also 3 orders of magnitude greater than that measured by our other method (that measured mostly surface reductant (Fe2+) and little internal reductant capacity of the slag particles), 3.8e-4 meq/g. Let me know if you have any questions. Dan

Figure 55-1.

E-mail message from Dan Kaplan of Savannah River National Laboratory (June 15, 2005) reporting that latest slag reduction capacity is appreciably higher than previous measured by another method but nearly identical to that reported by LLNL.

The results in Malek et al. (1987; reference contained within Langton 1987) indicate that the slag-containing concrete does not maintain a reducing environment. Specifically they reported that slag concrete pore water has a positive Eh value (reduction potential), an indication that the pore water was oxidizing. It is important to note that these studies were not conducted in an oxygen-free environment, and no precautions were taken to maintain samples free of oxygen contamination. Contamination of the samples with air-borne oxygen would compromise the data. Finally, these results contradict those of Kaplan and Hang (2003), who measured an Eh of -247 ± 1 mV. The results of Malek et al. (1987) also indirectly conflict with the results of SRNL and Lawrence Berkeley National Laboratory showing that the slag has a measurable reduction capacity (Figure 55-1). Eh and reduction capacity are related, but not identical parameters. (The former is an intensity term whereas the latter is a capacity term, analogous to the comparison of pH to the buffering capacity of a material.) Therefore, the results of Malek et al. (1987) are not used in the Vault 4 SA (Cook et al. 2005).

References:

Bradbury, M. H., and F. Sarott. 1995. *Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment*. Nr. 95-06. Paul Scherrer Institut, Wurenlingen and Villigen, Switzerland.

Cook, J. R., Wilhite, E. L, Hiergesell, R. A., and Flach, G. P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Kaplan, D. I., and T. Hang. 2003. *Estimated Duration of the Subsurface Reducing Environment Produced by the Z-Area Saltstone Disposal Facility*. WSRC-RP-2003-00362, Rev. 2. Westinghouse Savannah River Co., Aiken, SC.

Langton, C. A. 1987. *Analysis of Saltstone Pore Solutions PSU Progress Report IV. DPST-87-530*. WSRC, Aiken SC.[5]

Lukens, W. W., J. J. Bucher, D. K. Shuh, and N. M. Edelstein. 2005. *Evolution of Technetium Speciation in Reducing Grout.* Environmental Science Technology (In Press).

[5] Malek et al. (1987) is a report contained within Langton 1987. This NRC RAI Path Forward refers to Malek et al. (1987).

NRC Comment 56: The soil-to-plant concentration ratio for Tc requires additional justification.

Basis: The soil-to-plant concentration ratio for Tc used in the agricultural inadvertent intruder scenario is based on the assumption that Tc in excavated waste spread on the land surface will be insoluble (pg. 4-47 and A-69 of [1]). However, excavated waste is expected to be present in small pieces. Once waste is excavated and spread on the land surface, Tc would be expected to oxidize and dissolve rapidly [16]. Therefore the modification of the soil-to-plant concentration ratio based on the assumption that the Tc is in an insoluble form appears to be inappropriate.

Furthermore, a generic literature value of 5 (pCi/g vegetation / pCi/g soil) was used as the basis for the soil-to-plant concentration factor [1]. However, the results of site-specific plant uptake experiments conducted with saltstone samples indicate that a higher soil-to-plant concentration factor may be appropriate [24]. It is unclear why a generic literature value has been used instead a value based on existing site-specific data. Because ingestion of contaminated plants is an important route for Tc uptake in the agricultural intruder scenario, the value for the soil-to-plant ratio requires further justification.

In addition, the interpretation of literature values for plant uptake factors in Reference 2 may not be consistent with the information in the original reports. In Reference 2, the results of Baes et al. [27] are represented by using the plant categories “forage” and “food” instead of “leafy” and “reproductive”. Baes uses the latter classifications, while in Reference 2 the former is used. The value for the reproductive component of plant intake is used in the calculations and is labeled the “food” component. However, approximately 10% of the plant intake would be expected to be in the form of “leafy” plants. Because the plant uptake factor is almost an order of magnitude greater for the leafy component than the reproductive component, the leafy component should not be excluded from the analysis if the results of Baes et al. are used as a basis for the soil-to-plant concentration ratio.

Path Forward: Explain whether Tc in waste that is excavated and spread on the land surface can be expected to remain in an insoluble form. The response should address the predicted rate of oxidation of small particles of waste that are exposed to the atmosphere and the consequent rate of Tc oxidation. Provide a comparison of the results of site-specific plant uptake experiments [24] with the generic literature value of the soil-to-plant concentration factor that was used in PA modeling [1]. The response should include the value of K_d that is used to convert the results of Murphy et al. [24] to a soil-mass basis. If it is determined that Tc in waste that is excavated and spread on the land surface would be expected to oxidize and dissolve rapidly, or that the results of site-specific plant uptake experiments should be used instead of a generic value, a new value of the soil-to-plant concentration ratio for Tc should be provided.

SRS Response: The Vault 4 Special Analysis (Cook et al 2005) supplements the analysis in the Saltstone PA (reference 1 in the NRC RAI) and supersedes the 2002 Special Analysis (reference 3 in the NRC RAI).

In the Vault 4 Special Analysis (Cook et al. 2005) the plant-to-soil ratios for all elements except H and C are taken from Baes et al. 1984 and the assumption that the Tc is not available for uptake by plant is no longer made. This is documented in Lee 2004 in Section 2.2 and Table 2.2-1 (attached).

The adopted values of plant uptake factors for all elements are based entirely on published evaluations and compilations which are generic in nature. The adopted values for almost all elements were obtained from the evaluation of published data by Baes et al. (1984). The use of data from this single source was based on scientific judgment and ensures consistency among the adopted values for the different elements.

Baes et al. (1984) give concentration ratios for vegetative portions of food crops, which would apply to leafy vegetables, and for nonvegetative (reproductive) portions, which would apply to nonleafy vegetables. The values for nonvegetative portions of food crops were adopted for use in this analysis, because consumption of nonleafy vegetables is expected to be considerably greater than consumption of leafy vegetables (Baes et al. 1984; Hamby 1992). The reported concentration ratios on a dry-weight basis for nonleafy vegetation were converted to a fresh-weight basis by multiplying by a factor of 0.43, which represents the average conversion factor for all types of nonleafy vegetables (Baes et al. 1984).

The base case analysis presented in the Vault 4 Special Analysis (Cook et al. 2005) used the presence of the Erosion Barrier layer and the contrast in properties between the vault structure and the near-surface materials in the vicinity of SRS to preclude either excavation or drilling activities and thus eliminate the scenarios where Saltstone could be brought to the surface.

Sensitivity cases were run where excavation and drilling were each allowed to occur over a 10,000 year time frame. By using the plant-to-soil factor from Baes 1984 (0.645), the assumption is that the Tc is readily available to the plant roots. If the post-drilling scenario were credible, the sum of fractions for Vault 4 would increase from 0.22 to 0.31 (Section 7.5.3). The sensitivity case that allows excavation has to postulate that the Erosion Barrier fails to work. In this case, the sum of fraction is 1.49 (Section 7.5.4). However, as shown in Appendix K of Phifer and Nelson 2003,

the Erosion Barrier has been designed to survive a 10,000 year event of 3.3 inches of rain in a 15 minute period, which makes the scenario not credible.

References:

Baes III, C. F., Sharp, R. D., Sjoreen, A. L. and Shor, R. W. 1984. A Review and Analysis of Parameters for Assessing Transport of Environmentally Released Radionuclides through Agriculture. ORNL-5786. Oak Ridge National Laboratory. September 1984.

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, Special Analysis: Revision of Saltstone Vault 4 Disposal Limits, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Hamby, D. M. 1992. Site Specific Parameter Values for the Nuclear Regulatory Commission Food Pathway Dose Model. Health Physics, Volume 62, Number 2 pp 136-143. February 1992.

Lee, Patricia L. 2004. Inadvertent Intruder Analysis Input for Radiological Performance Assessments. WSRC-TR-2004-00295, Revision 0. Westinghouse Savannah River Company, Aiken, South Carolina. July 22, 2004.

Phifer, Mark A. and Nelson, Eric A. 2003. Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest. WSRC-TR-2003-00436. Westinghouse Savannah River Company, Savannah River Site, Aiken, SC.

2.2 Plant-to-Soil Ratio

Element plant-to-soil ratios are taken from Baes et al (1984) unless noted below. These are contaminant specific ratios of fresh weight in vegetation (μCi/kg) per dry weight in soil (μCi/kg). Values taken from Baes et al. (1984) are reported in dry weight of vegetation and are multiplied by 0.43 to get fresh weight. Select plant-to-soil ratios in the "IntruderInput" file are listed in Table 2.2-1.

Table 2.2-1. Element plant-to-soil ratios in vegetables

Element	Soil Ratio	Element	Soil Ratio
Ac	1.51E-04	Np	4.30E-03
Am	1.08E-04	Pa	1.08E-04
At	6.45E-02	Pb	3.87E-03
Ba	6.45E-03	Pd	1.72E-02
Bi	2.15E-03	Po	1.72E-04
Bk	6.60E-06	Pu	1.94E-05
C*	5.60E-01	Ra	6.45E-03
Ca	1.51E-01	S	6.45E-01
Cd	6.50E-02	Sb	1.29E-02
Cf	6.60E-06	Sc	4.30E-04
Cl	3.01E+01	Se	1.08E-02
Cm	6.45E-06	Sm	1.72E-03
Co	3.01E-03	Sn	2.58E-03
Cs	1.29E-02	Sr	1.08E-01
Eu	1.72E-03	Tc	6.45E-01
Fr	1.29E-02	Th	3.66E-05
Gd	1.72E-03	Tl	1.72E-04
H**	4.80E+00	U	1.72E-03
I	2.15E-02	W	4.30E-03
K	2.37E-01	Y	2.58E-03
Mo	2.20E-03	Zr	2.15E-04
Nb	2.15E-03		

*C is based on Sheppard et al. (1991)
**H obtained from USNRC (1977)

NRC Comment 58: Distribution coefficients used in the PATHRAE analysis have not been presented.

Basis: DOE updated the groundwater transport pathway analysis in Reference 3 using the PATHRAE code. DOE argued that, with the exception of Np-237, the new analysis confirmed the radionuclide screening and groundwater concentration results of Reference 1. However, values for contaminant distribution coefficients used for release and transport modeling in PATHRAE were not provided [3]. Model results cannot be evaluated without this information. It is important to note that the newer analysis indicated Np-237 was significant to performance. In addition, Reference 1 used K_d values for concrete and saltstone that, in light of later studies, may need to be reevaluated. In many cases, the concrete and saltstone K_d values used in Reference 1 were higher than the recommended values for cementitious wasteforms from the later literature review of Reference 20. NRC staff needs to be able to determine which, if any, values were changed for the 2002 analysis and what values were used in 2002 for radionuclides not analyzed in 1992. In addition, the NRC staff needs to be able to evaluate how values differ between intact and degraded cases.

Path Forward: Provide the values and technical bases for distribution coefficients used for PATHRAE release and transport modeling and address how values were reevaluated in the light of post-1992 literature or site-specific studies. The response should indicate which values are based on site-specific information and which are from other sources. The response also should address how parameter selection ensured that contaminant mobility was not underestimated.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005). The Vault 4 SA does not use the PATHRAE code. Groundwater modeling in this new SA is discussed in detail in Appendix A, Section A.2.5 and the K_d values (Cook et al. 2005) used for different media are shown in Table A-8. The K_d values used in the 2005 SA are either based on site-specific studies or are reasonably conservative values from the literature thus ensuring that contaminant mobility was not underestimated. This section of the Appendix, including the table of K_d's, is reproduced below. The basis of selection of these K_d's is discussed further in the response to NRC Comment 48.

A.2.5 Distribution Coefficient

The distribution coefficients (K_d) of all contaminants and daughters used for this study are summarized in Table A-8. The values for clay are used for the saturated-zone models. Various plutonium isotopes of different oxidation states are lumped into two pseudo components: Pu- for Pu (III, IV) and Pu5- for Pu (V,VI). For soil, drain and clay, K_d in Pu (III, IV) is significantly higher than Pu (V,VI).

Table A-8. Distribution Coefficients (K_d in cm^3/g)

Nuclides	Soil	Drain	Clay	Saltstone	Concrete
NO3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Al-26	4.00E+01	4.00E+01	0.00E+00	2.00E+01	2.00E+01
Am-243	1.90E+03	1.90E+03	8.40E+03	5.00E+03	5.00E+03
Np-239	5.00E+00	5.00E+00	5.50E+01	5.00E+03	5.00E+03
Pu-239	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-239	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
Bi-210	4.50E+02	4.50E+02	1.20E+04	5.00E+03	5.00E+03
Po-210	1.50E+02	1.50E+02	3.00E+03	5.00E+02	5.00E+02
C-14	2.00E+00	2.00E+00	1.00E+00	5.00E+03	5.00E+03
Cf-249	5.10E+02	5.10E+02	8.40E+03	5.00E+03	5.00E+03
Cm-245	4.00E+03	4.00E+03	6.00E+03	5.00E+03	5.00E+03
Pu-241	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-241	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
Am-241	1.90E+03	1.90E+03	8.40E+03	5.00E+03	5.00E+03
Np-237	5.00E+00	5.00E+00	5.50E+01	5.00E+03	5.00E+03
Cl-36	0.00E+00	0.00E+00	0.00E+00	5.00E+03	5.00E+03
Cm-245	4.00E+03	4.00E+03	6.00E+03	5.00E+03	5.00E+03
Pu-241	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-241	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
Am-241	1.90E+03	1.90E+03	8.40E+03	5.00E+03	5.00E+03
Np-237	5.00E+00	5.00E+00	5.50E+01	5.00E+03	5.00E+03
Cm-246	4.00E+03	4.00E+03	6.00E+03	5.00E+03	5.00E+03
Cm-247	4.00E+03	4.00E+03	6.00E+03	5.00E+03	5.00E+03
Am-243	1.90E+03	1.90E+03	8.40E+03	5.00E+03	5.00E+03
Np-239	5.00E+00	5.00E+00	5.50E+01	5.00E+03	5.00E+03
Pu-239	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-239	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
Cm-248	4.00E+03	4.00E+03	6.00E+03	5.00E+03	5.00E+03
Pu-244	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-244	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
Cs-135	3.30E+02	3.30E+02	1.90E+03	2.00E+01	2.00E+01
Cs-137	3.30E+02	3.30E+02	1.90E+03	2.00E+01	2.00E+01
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
I-129	6.00E-01	6.00E-01	1.00E+00	2.00E+00	2.00E+00
K-40	3.00E+00	3.00E+00	5.00E+00	2.00E+00	2.00E+00
Mo-93	3.00E+00	3.00E+00	1.30E+01	1.00E+00	1.00E+00
Nb-93m	1.60E+02	1.60E+02	9.00E+02	5.00E+02	5.00E+02
Nb-94	1.60E+02	1.60E+02	9.00E+02	5.00E+02	5.00E+02
Nb-95m	1.60E+02	1.60E+02	9.00E+02	5.00E+02	5.00E+02
Nb-95	1.60E+02	1.60E+02	9.00E+02	5.00E+02	5.00E+02
Ni-59	4.00E+02	4.00E+02	6.50E+02	1.00E+02	1.00E+02
Np-237	5.00E+00	5.00E+00	5.50E+01	5.00E+03	5.00E+03
Pd-107	5.50E+01	5.50E+01	2.70E+02	1.00E+02	1.00E+02
Pu-238	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-238	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
U-234	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03

Pu-239	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-239	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
U-235	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Pu-240	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-240	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
U-236	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Pu-241	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-241	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
Am-241	1.90E+03	1.90E+03	8.40E+03	5.00E+03	5.00E+03
Np-237	5.00E+00	5.00E+00	5.50E+01	5.00E+03	5.00E+03
Pu-242	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-242	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
U-238	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Pu-244	3.70E+02	3.70E+02	6.50E+03	5.00E+03	5.00E+03
Pu5-244	1.50E+01	1.50E+01	5.00E+01	5.00E+03	5.00E+03
Ra-226	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
Rb-87	5.50E+01	5.50E+01	2.70E+02	5.50E+01	5.50E+01
Se-79	3.60E+01	3.60E+01	7.60E+01	1.00E-01	1.00E-01
Sn-126	1.30E+02	1.30E+02	6.70E+02	1.00E+03	1.00E+03
Sr-90	1.00E+01	1.00E+01	1.10E+02	1.00E+00	1.00E+00
Tc-99	1.00E-01	1.00E-01	1.00E-01	1.00E+03	1.00E+03
Th-228	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-224	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
Th-229	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-225	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
Ac-225	4.50E+02	4.50E+02	2.40E+03	5.00E+03	5.00E+03
Th-230	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-226	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
Pb-210	2.70E+02	2.70E+02	5.50E+02	5.00E+02	5.00E+02
Po-210	1.50E+02	1.50E+02	3.00E+03	5.00E+02	5.00E+02
Th-232	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-228	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
Th-228	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-224	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
U-232	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Th-228	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-224	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
U-233	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Th-229	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-225	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
U-234	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Th-230	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-226	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
Pb-210	2.70E+02	2.70E+02	5.50E+02	5.00E+02	5.00E+02
Po-210	1.50E+02	1.50E+02	3.00E+03	5.00E+02	5.00E+02
U-235	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Pa-231	5.50E+02	5.50E+02	2.70E+03	5.00E+03	5.00E+03
Ac-227	4.50E+02	4.50E+02	2.40E+03	5.00E+03	5.00E+03
Th-227	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
Ra-223	5.00E+02	5.00E+02	9.10E+03	5.00E+01	5.00E+01
U-236	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
U-238	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Th-234	3.20E+03	3.20E+03	5.80E+03	5.00E+03	5.00E+03
U-234	8.00E+02	8.00E+02	1.60E+03	2.00E+03	2.00E+03
Zr-93	6.00E+02	6.00E+02	3.30E+03	5.00E+03	5.00E+03
Nb-93m	1.60E+02	1.60E+02	9.00E+02	5.00E+02	5.00E+02
Zr-95	6.00E+02	6.00E+02	3.30E+03	5.00E+03	5.00E+03
Nb-95	1.60E+02	1.60E+02	9.00E+02	5.00E+02	5.00E+02

Source for K_d Values

The Vault 4 SA does not provide references for the sources of the K_d values. That information is provided below (see response to NRC Comment 48).

Table 58-1. 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 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

Table 58-1. 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 and Vault K_d (mL/g)	ref
*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 & Johnson 1994, Figure 4-12, page 69

*Site Specific

References:

Bradbury, M. H., and F. A. Sarott, 1995. *Sorption Databases for the Cementitious Near-Field of a L/ILW Repository for Performance Assessment*, Paul Scherrer Institut, Villigen,

Cook, J.R., Wilhite, E. L, Hiergesell, R. A., and Flach, G. P., *2005, Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*. WSRC-TR-2005-00074. Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Hoeffner, S. L., 1984a, *Additional Laboratory Studies on Radionuclide Sorption at the SRP Burial Ground*. DPST-84-797. E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Hoeffner, S. L., 1984b, *Radionuclide Sorption on Savannah River Plant Burial Ground Soil: A Summary and Interpretation of Laboratory Data*, DPST-84-799. E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Hoeffner, S. L., 1985, *Radionuclide Sorption on Savannah River Plant Burial Ground Soil: A Summary and Interpretation of Laboratory Data*, DP-1702, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

Kaplan, D. I., K. E. Parker, and I. V. Kutynakov. 1998. Radionuclide Distribution Coefficients for Sediments Collected from Borehole 299-E17-21: Final Report for Subtask 1a, PNNL-11966. Pacific Northwest National Laboratory, Richland, Washington.

Kaplan, D. I., 2004, *Recommended Geochemical Input Values for the Special Analysis of the Slit/Engineered Trenches and Intermediate Level Vault*, WSRC-RP-

2004-00267, Revision 0, Westinghouse Savannah River Company, Aiken, South Carolina.

McIntyre, P. F., 1988, *Sorption Properties of Carbon-14 on Savannah River Plant Soil*. DPST-88-900, E. I. du Pont de Nemours and Company, Savannah River Laboratory, Aiken, South Carolina.

NCRP. 1996. *Screening Models for Releases of Radionuclides to Atmosphere, Surface Water, and Ground*, Vol. I and II, NCRP Report No. 123, National Council on Radiation Protection and Measurements, Bethesda, Maryland.

Serkiz, S. M., and Johnson, W. H., 1994, *Uranium Geochemistry in Soil and Groundwater at the F and H Seepage Basins*, EPD-SGS-94-307, Revision 0. Westinghouse Savannah River Company, Aiken, South Carolina.

Sheppard, M. I., and D. H. Thibault, 1990, *Default Soil Solid/Liquid Partition Coefficients, Kds, for Four Major Soil Types: A Compendium*,,Health Physics, 59:471-482.

NRC
Comment 59: The composition of sediment interstitial fluids calculated using MINTEQ (Table D.4-1 of [1]) appears to be incorrect.

Basis: MINTEQ was used to calculate fluid compositions in sediments outside of SDF vaults to simulate reaction of the saltstone pore fluid with mineral phases (represented by quartz, kaolinite, gibbsite, and an iron oxide phase) in the unsaturated zone (Appendix D). The composition of the pore fluid, also calculated using MINTEQ, is tabulated in Table D.3-3, and the calculated composition of sediment interstitial fluid is tabulated in Table D.4-1. A comparison of Tables D.3-3 and D.4-1 indicates that the concentrations of all species are exactly the same in the two tables, with the exception of Al^{3+} and hydronium ion (pH). The text in Appendix D.4.2 states that the pore fluid changed very little after reacting with the soil minerals. Aluminum concentration was reduced because of a small amount of diaspore precipitation. The results tabulated in Table D.4-1 are inconsistent with the high degree of disequilibrium between the saltstone pore fluids and the soil minerals. In particular, SiO_2(aq) in the sediment fluid should be higher than the 1 mg/L listed in Table D.4-1 due to the dissolution of quartz and kaolinite. The OH! concentration should be lower than the value given in Table D.4-1 because the pH was reduced to 7.32. Also, if calcite had precipitated, as is commonly observed in systems where cement pore fluids were exposed to atmospheric CO_2(g), the Ca^{2+} concentration would be different from that given in Table D.4-1.

Path Forward: Confirm that the MINTEQ calculations of sediment interstitial fluid composition are correct.

SRS Response: The geochemical modeling study using MINTEQ was performed as part of the SDF performance assessment (PA) program as described below. However, for the reasons cited below, the results of this study were reported for completeness only and have not been used in any SRS PA analysis.

From the 1950's to through the 1980's SRS operated seepage basins as a method for dealing with large quantities of slightly radioactive, high-nitrate, high-pH water it was regularly observed that the bottom of the basins would "plug". The treatment of this problem was to add large quantities of nitric acid to the basin, which did increase the seepage rate for a time.

A study (Cook 1981) showed that the permeability of soil from the vicinity of the seepage basins would show a decrease in permeability of two orders of magnitude, from 5E-3 to 5E-5 m/sec as the pH of permeating water varied from 2 to 12, with the lowest permeability resulting from the highest pH (attached). One conclusion of the study was that is was likely that a reaction occurs among the quartz and kaolinite in the soil and the OH^- and NO^-_3 in the solution.

Since any leachate escaping from a Saltstone vault would be expected to be high in both pH and nitrate, a geochemical modeling study was commissioned as part of the Saltstone PA program to attempt to identify the reactions that could lead to the observed permeability decrease. This study was based on the premise that if the leachate could be shown to produce a low-permeability “shell” around the vault, it might be possible to estimate the distance from the vault that would be affected and some hydrologic credit might be taken.

The study results shown in Appendix D (Section D.4.2, pg D-12, Cook and Fowler 1992 PA) documenting the MINTEQ calculations clearly do not match the actual observations. As noted in the comment, the results presented on the calculated interactions with the sediment are not consistent with expectations. The study was terminated, and the work was reported in Appendix D for completeness. Although the study results were reported, this work has not been used in any SRS PA analysis.

References:

Cook, J. R. 1981. Study of the Relationship of pH and Permeability in the Separations Area Seepage Basins. DPST-81-935. E. I. DuPont de Nemours and Co. December 1981.

DPST-81-935

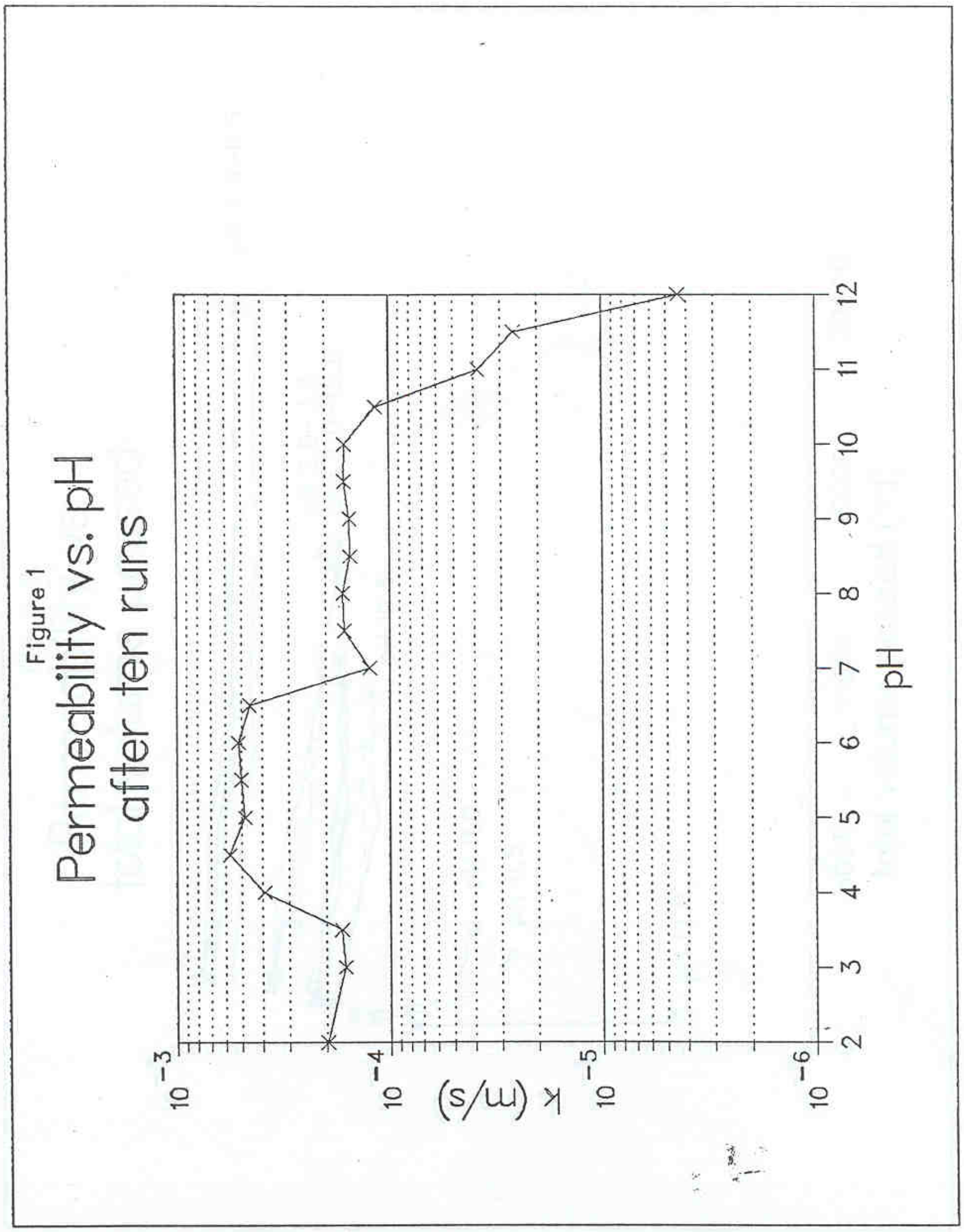


Figure 1
Permeability vs. pH
after ten runs
k (m/s)
pH
10^-3
10^-4
10^-5
10^-6
2
3
4
5
6
7
8
9
10
11
12

NRC
Comment 60: DOE has not established the appropriateness of a distribution coefficient approach to modeling radionuclide release from the saltstone wasteform.

Basis: While acknowledging that wasteform dissolution and radioelement solubility limits are important aspects of radionuclide release, the saltstone performance assessment models employ equilibrium distribution coefficients to model radionuclide concentrations in pore fluids in contact with the wasteform [1, 3]. The distribution coefficient, or K_d, represents dissolved contaminant equilibrium sorption on the surface of the wasteform and, therefore, does not reflect wasteform dissolution or contaminant concentration control by solid phase solubility. This modeling approach, therefore, will not accurately simulate radionuclide release. For instance, if solubility control is in effect, radionuclide concentration will not decrease as inventory is depleted, as would be modeled by using a K_d. There is no *a priori* reason to assume that, given a bulk waste radionuclide content, contaminants will partition between solid and liquid according to a partition coefficient. DOE needs to demonstrate that its model will not underestimate rates and quantities of radionuclide release.

Path Forward: Provide a technical basis for the appropriateness of the distribution coefficient approach to modeling saltstone contaminant release.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

DOE agrees that, in some applications, a solubility model is better suited for describing the interaction of many radionuclides with saltstone than the K_d model, e.g., reducing saltstone with Pu and Tc. Solubility models are presently being developed for future applications. Figure 60-1 below shows the difference between the two sorption models. One model is considered to be more conservative than the other if it estimates greater radionuclide aqueous concentrations. At very low solid radionuclide concentrations, the solubility model is more conservative than the K_d model. As the solids concentration increases, there is a critical point beyond which the K_d model is more conservative. The solubility model is a more accurate representation of the chemistry than the K_d model for such elements as Pu and Tc near the waste form, where solid phase concentrations are high.

The following is an illustration using Tc to compare the conservatism of the solubility versus the K_d model (see figure below). Again, a model is considered more conservative if it estimates a higher aqueous radionuclide concentration. Use the following values:

- Tc concentration in the saltstone = 25,000 pCi/g (see similar calculation on page D-10, in the 1992 PA; Appendix A);

- Tc concentration based on solubility calculations for reducing conditions: 2E-8 pCi/L (page D-9 in 1992 PA)[6]

- 2005 SA Tc-K_d = 1000 mL/g for reducing saltstone.

Then the aqueous Tc concentration = 25,000 pCi/g ÷ 1000 mL/g = 25 pCi/mL or (25,000 pCi/L). The aqueous Tc concentration based on the K_d calculation is orders if magnitude higher than that based on solubility calculations.

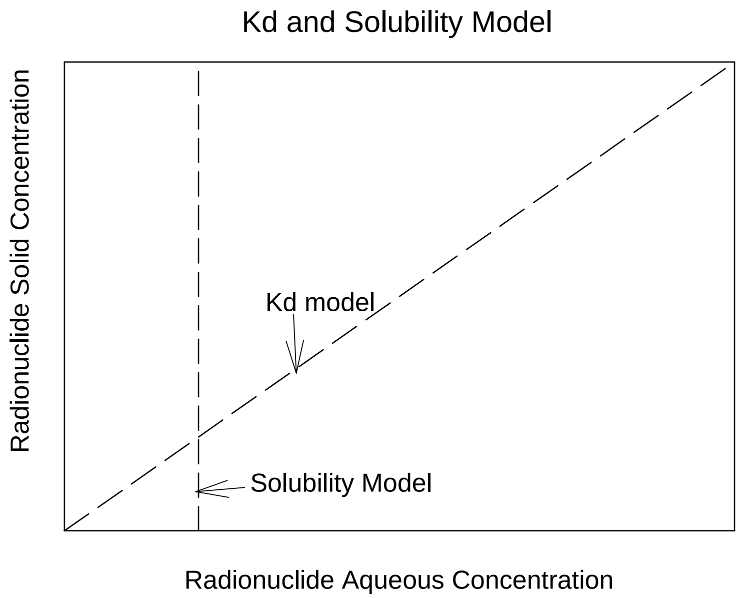


Figure 60-1. Generalized schematic comparing the K_d and the solubility models.

The Vault 4 Special Analysis (Cook et al. 2005) elected to use conservative K_d values to describe containment release because such values underestimate (are conservative) solubility controlled aqueous concentrations. The conservative K_d values used to describe containment release in the Vault 4 Special Analysis were taken from critical review of Bradbury and Sarott (1995).

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

[6] This 12 order-of-magnitude range of Tc concentrations is so large because of the rather unusually conservative assumptions made in the thermodynamic calculations regarding the sulfide concentrations in the saltstone porewater. By assuming sulfide concentrations were limiting (i.e., were held down to unrealistically low concentrations), aqueous TcO_4^- concentrations increased, thereby increasing the range of aqueous Tc concentrations.

NRC Comment 61: Leaching from concrete and saltstone would increase the pH of infiltrating groundwaters and could result in the migration of a hyperalkaline plume below the vault. The presence of a hyperalkaline plume could affect the flow of water and the transport of radionuclides and contaminants from the SDF. These effects were not considered in the performance assessment of the SDF.

Basis: The chemistry of pore fluids in contact with cementitious materials is characterized by alkaline pH (>10) that can persist for thousands of years [25, 26]. The high pH and the low silica concentration associated with cement pore fluids could strongly alter the aluminosilicate minerals (quartz, clays) present in the underlying native soil, possibly affecting its hydraulic conductivity and sorption properties and the solubility of radionuclides and chemical contaminants. These effects could influence the transport of contaminants from the SDF.

Path Forward: Evaluate the potential importance of alkaline plume migration on the release, flow, and transport of radionuclides and chemical contaminants from the SDF or explain why it is not important.

SRS Response: As noted in the response to NRC Comment 59, it has been observed both in the field and the laboratory that, when near-surface material from the vicinity of Z-Area comes in contact with high-pH, high-nitrate solutions the permeability of the soil can decrease greatly. An attempt was made to identify the chemical reactions that occur using MINTEQ. The results did not match the observations, so no credit was taken for the decrease in permeability that will likely develop around the vault when high-pH, high-nitrate solutions begin to seep out of the Saltstone vaults. Since the effect would reduce movement, neglecting the effect results in higher, more conservative, transport rates.

NRC Comment 62: The recent intruder scenarios [3, 4] do not evaluate potential water usage inside the 100 m buffer zone, even though it is assumed that a house is built inside the buffer zone. The approach is inconsistent with the NRC regulatory approach if there is a viable water source.

Basis: Intruder scenarios should be designed to assess the impact to receptors who may disrupt waste or otherwise reside at the disposal site. A higher dose limit (500 mrem/yr compared to 25 mrem/yr) is applied in the NRC regulatory approach that takes into account the reduced likelihood that dwelling construction, well placement, or other activities are undertaken directly in the area of waste disposal (inside the buffer zone) after the institutional controls end. Contaminated well water usage by the intruder cannot be neglected on the basis that it is evaluated for the public (nonintruder) receptor, because the public receptor is at a different location and may not be exposed to more strongly-sorbing contaminants due to longer travel times. Although Reference 1 indicates that drinking water from an onsite well should be considered in the agricultural intruder scenario (pg 3-42 and A-57), the drinking water dose for onsite well was screened based on low expected doses from drinking water from a well located 100 m from the vaults.

Path Forward: Include the groundwater pathway and associated pathways in the analysis of the doses to hypothetical intruders. Specify where the intruder's well is assumed to be located. The response should address doses due to drinking water from an onsite well (i.e., a well within the 100 m buffer zone) or the response should demonstrate that doses from drinking water from a well outside of the buffer zone bound doses from drinking water from a well within the buffer zone.

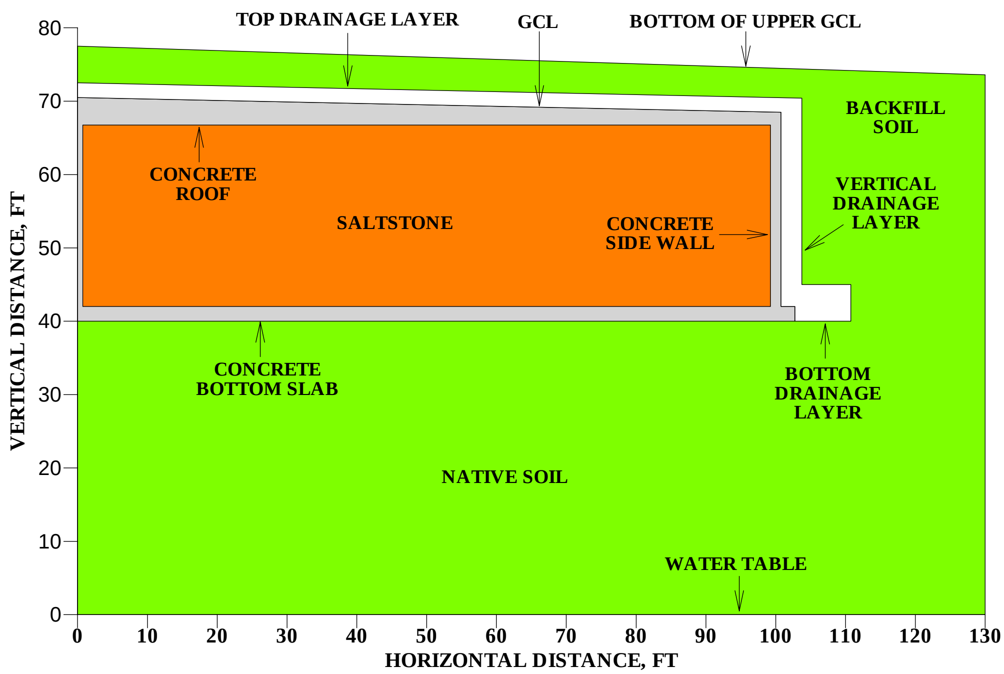
SRS Response: The analyses in the 1992 PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (SA) (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The intruder analyses in the 1992 PA (MMES 1992) and subsequent Special Analyses (Cook et al. 2002 and Cook et al. 2005) do not include dose from use of contaminated groundwater. Additionally, the intruder analyses argue that the physical integrity of a Saltstone vault would prevent drilling through it for 10,000 years. To determine the dose to a hypothetical inadvertent intruder who is presumed to drill a well near, but not through, a Saltstone vault, and use the water for a variety of purposes (e.g., drinking, irrigating a garden), the following analysis was conducted.

The groundwater modeling in the Vault 4 SA (Cook et al. 2005) did not monitor groundwater concentrations at points nearer than 100 m from a vault. Therefore, groundwater concentrations immediately under a vault were estimated by assuming that the maximum radionuclide flux leaving the vadose zone in a year was contained in the volume of water in the first layer of groundwater model nodes below the vault.

This is conservative because the groundwater concentrations are from the water directly below the vaults, does not account for concentration dilution within the water table and uses all of the activity released in a year in that volume of water. Figure 62-1 (Figure 2-1 of Cook et al. 2005) presents the upper portion of the model. The flux to the water table is the amount of contaminant crossing into the water table indicated at the 0 foot elevation in Figure 62-1. These groundwater concentrations were used to calculate, for each radionuclide, the all-pathways dose from use of the water. The total of the maximum doses from all radionuclides was only 0.27 mrem/year as described below; this dose is very conservative because it assumes that the peak fluxes from all radionuclides are coincident in time.

Figure 62-1 Vault 4 Model Configuration



<u>Groundwater Concentrations</u>

As noted above, groundwater concentrations are based upon maximum radionuclide flux leaving the vadose zone. The peak radionuclide flux over 10,000 years was obtained from Table A-11 of Cook et al. 2005. The volume of the first layer of groundwater model nodes below Vault 4 is 1.73E7 L (Section A.3.3.1 of Cook et al. 2005). Since the porosity of the soil is 0.42, the volume of water in the first layer of groundwater model nodes below Vault 4 is 7.27E6 L. The tables and pertinent text from Cook et al. 2005 are reproduced below.

The radionuclide composition of salt waste for disposal in the Saltstone Disposal Facility has recently been revised (d'Entremont & Drumm 2005). The revised projected inventory of radionuclides in Vault 4 is shown in Table 62-1.

Table 62-2 shows the peak fractional radionuclide flux from the vadose zone, the peak fractional radionuclide concentration, the revised projected inventory in Vault 4, and the estimated maximum concentration in groundwater under Vault 4 using the radionuclide inventory in Table 62-1.

Table 62-1 Projected Vault 4 Radionuclide Inventory

Radionuclide	Curies	Radionuclide	Curies	Radionuclide	Curies
H-3	2.43E+03	Cs-137	1.20E+06	Np-237	5.76E-01
C-14	6.88E+01	Ba-137m	1.13E+06	Pu-238	3.69E+03
Na-22	2.59E+02	Ce-144	3.46E-01	Pu-239	3.36E+01
Al-26	1.03E+00	Pr-144	3.46E-01	Pu-240	8.39E+00
Ni-59	3.46E-01	Pm-147	2.93E+02	Pu-241	1.72E+02
Co-60	4.46E+01	Sm-151	3.04E+02	Pu-242	9.32E-03
Ni-63	8.77E+01	Eu-152	1.48E+00	Am-241	1.44E+01
Se-79	1.96E+00	Eu-154	8.10E+01	Am-242m	7.52E-03
Sr-90	5.29E+03	Eu-155	1.72E+01	Pu-244	9.38E-06
Y-90	5.29E+03	Ra-226	2.44E-01	Am-243	6.22E-03
Nb-94	1.02E-03	Ra-228	6.41E-06	Cm-242	6.21E-03
Tc-99	7.16E+02	Ac-227	1.37E-06	Cm-243	2.88E-03
Ru-106	4.82E+01	Th-229	2.79E-03	Cm-244	3.16E+00
Rh-106	4.82E+01	Th-230	1.49E-03	Cm-245	3.03E-04
Sb-125	2.05E+02	Pa-231	3.80E-06	Cm-247	5.55E-13
Te-125m	4.98E+01	Th-232	6.41E-06	Cm-248	5.79E-13
Sn-126	9.56E+00	U-232	9.52E-03	Bk-249	4.23E-20
Sb-126	1.33E+00	U-233	9.82E-01	Cf-249	3.21E-12
Sb-126m	9.50E+00	U-234	6.59E+00	Cf-251	2.47E-01
I-129	4.40E-01	U-235	7.41E-02	Cf-252	3.56E-15
Cs-134	2.40E+03	U-236	1.42E-01		
Cs-135	4.14E+00	U-238	1.61E-01		

Table 62-2	Estimated Peak Radionuclide Concentrations below Saltstone Vault 4				
Nuclide	Daughter	Peak Fractional Flux Ci/yr/Ci[a]	Peak Fractional Concentration pCi/L/Ci	Inventory Ci/Vault 4	Estimated Peak Concentration, pCi/L
Am-243		1.43E-32	1.96E-27	6.22E-03	1.22E-29
	Np-239	4.53E-36	6.22E-31		3.87E-33
	Pu-239	4.53E-27	6.22E-22		3.87E-24
	Pu-5-239	1.65E-30	2.27E-25		1.41E-27
C-14		3.44E-24	4.73E-19	6.88E+01	3.25E-17
Cm-245		1.24E-38	1.70E-33	3.03E-04	5.15E-37
	Pu-241	4.48E-40	6.15E-35		1.86E-38
	Pu5-241	1.75E-43	2.40E-38		7.27E-42
	Am-241	2.32E-37	3.19E-32		9.67E-36
	Np-237	3.96E-24	5.44E-19		1.65E-22
Cs-135		1.10E-14	1.51E-09	4.14E+00	6.25E-09
Cs-137		1.42E-41	1.95E-36	1.20E+06	2.34E-30
H-3		4.03E-13	5.54E-08	2.43E+03	1.35E-04
I-129		1.29E-07	1.77E-02	4.40E-01	7.79E-03
Nb-94		3.33E-21	4.57E-16	1.02E-03	4.67E-19
Ni-59		2.37E-18	3.26E-13	3.46E-01	1.13E-13
Np-237		7.25E-24	9.96E-19	5.76E-01	5.74E-19
Pu-238		5.59E-42	7.68E-37	3.69E+03	2.83E-33
	Pu5-238	2.07E-45	2.84E-40		1.05E-36
	U-234	4.13E-26	5.67E-21		2.09E-17
Pu-239		7.75E-27	1.06E-21	3.36E+01	3.56E-20
	Pu5-239	2.81E-30	3.86E-25		1.30E-23
	U-235	1.83E-27	2.51E-22		8.43E-21
Pu-240		3.59E-27	4.93E-22	8.39E+00	4.14E-21
	Pu5-240	1.30E-30	1.79E-25		1.50E-24
	U-236	5.85E-27	8.04E-22		6.75E-21
Pu-241		3.93E-68	5.40E-63	1.72E+02	9.28E-61
	Pu5-241	1.64E-71	2.25E-66		3.87E-64
	Am-241	4.00E-39	5.49E-34		9.45E-32
	Np-237	7.25E-24	9.96E-19		1.71E-16
Pu-242		1.01E-26	1.39E-21	9.32E-03	1.29E-23
	Pu5-242	3.68E-30	5.05E-25		4.71E-27
	U-238	1.26E-28	1.73E-23		1.61E-25
Se-79		7.11E-07	9.77E-02	1.96E+00	1.91E-01
Sn-126		2.03E-22	2.79E-17	9.56E+00	2.67E-16
Sr-90		4.32E-19	5.93E-14	5.29E+03	3.14E-10
Tc-99		5.61E-20	7.71E-15	7.16E+02	5.52E-12
Th-232		3.13E-36	4.30E-31	6.41E-06	2.76E-36
	Ra-228	9.13E-45	1.25E-39		8.04E-45
	Th-228	4.74E-46	6.51E-41		4.17E-46
	Ra-224	1.59E-47	2.18E-42		1.40E-47
U-232		2.38E-48	3.27E-43	9.52E-03	3.11E-45

Table 62-2	Estimated Peak Radionuclide Concentrations below Saltstone Vault 4				
Nuclide	Daughter	Peak Fractional Flux Ci/yr/Ci[a]	Peak Fractional Concentration pCi/L/Ci	Inventory Ci/Vault 4	Estimated Peak Concentration, pCi/L
	Th-228	1.66E-50	2.28E-45		2.17E-47
	Ra-224	5.58E-52	7.66E-47		7.30E-49
U-233		4.45E-26	6.11E-21	9.82E-01	6.00E-21
	Th-229	5.04E-29	6.92E-24		6.80E-24
	Ra-225	1.79E-33	2.46E-28		2.42E-28
U-234		4.52E-26	6.21E-21	6.59E+00	4.09E-20
	Th-230	3.58E-29	4.92E-24		3.24E-23
	Ra-226	2.86E-23	3.93E-18		2.59E-17
	Pb-210	7.72E-25	1.06E-19		6.99E-19
	Po-210	2.36E-26	3.24E-21		2.14E-20
U-235		4.65E-26	6.39E-21	7.41E-02	4.73E-22
	Pa-321	1.09E-30	1.50E-25		1.11E-26
	Ac-227	8.86E-34	1.22E-28		9.02E-30
	Th-227	2.93E-37	4.02E-32		2.98E-33
	Ra-223	1.15E-36	1.58E-31		1.17E-32
U-236		4.65E-26	6.39E-21	1.42E-01	9.07E-22
U-238		4.65E-26	6.39E-21	1.61E-01	1.03E-21
	Th-234	1.72E-37	2.36E-32		3.80E-33
	U-234	7.12E-32	9.78E-27		1.57E-27

a. From Table A-11 of Cook et al. 2005

<u>All-Pathways Dose</u>

The dose from all-exposure pathways (e.g., drinking water, eating crops irrigated by groundwater) from the use of groundwater under Saltstone Vault 4 is shown in Table 62-3. The dose was calculated from the peak groundwater concentrations using the LADTAP XL program (Simpkins 2004), which is an SRS implementation of the NRC computer code. The total dose is calculated to be 0.27 mrem/year. This total dose is very conservative in that it assumes that the peak groundwater concentrations for each radionuclide are coincident in time. The results of this evaluation is included in the Saltstone Performance Objective Demonstration Document (PODD) (Rosenberger et al. 2005).

Table 62-3 Peak all-pathways dose from use of groundwater below Saltstone Vault 4

Nuclide	Peak All-Pathways Dose, mrem/year
H-3	1.17E-08
C-14	3.45E-17
Ni-59	1.50E-16
Se-79	2.56E-01
Sr-90	1.66E-10
Nb-94	1.43E-18
Tc-99	6.44E-13
Sn-126	2.86E-16
I-129	1.05E-02
Cs-135	2.73E-09
Cs-137	7.24E-30
Th-232	2.78E-35
U-232	2.84E-45
U-233	5.02E-21
U-234	1.92E-16
U-235	3.65E-22
U-236	6.90E-22
U-238	7.21E-22
Np-237	7.04E-18
Pu-238	1.66E-17
Pu-239	4.54E-19
Pu-240	5.72E-20
Pu-241	2.10E-15
Pu-242	1.55E-22
Am-243	4.88E-23
Cm-245	2.02E-21
Total	2.67E-01

References:

Cook, J. R., Kocher, D. C. McDowell-Boyer, L., and Wilhite, E. L. 2002. *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility,* WSRC-TR-2002-00456, October 23, 2002.

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Simpkins, A. A. 2004. *LADTAP XL©: A Spreadsheet for Estimating Dose Resulting from Aqueous Releases*, WSRC-TR-2004-00059, February 2004.

Table A-11. Predicted Peak Fluxes over 10,000 Years

Nuclides	Peak Flux mol/yr/mol	Peak Time years
NO3	3.24E-05	9.80E+03
Al-26	5.49E-13	1.00E+04
Am-243	1.43E-32	1.00E+04
Np-239	4.53E-36	1.00E+04
Pu-239	4.53E-27	1.00E+04
Pu5-239	1.65E-30	1.00E+04
Bi-210	0.00E+00	
Po-210	0.00E+00	
C-14	3.44E-24	1.00E+04
Cf-249	3.71E-34	5.76E+03
Cm-245	7.17E-34	1.00E+04
Pu-241	1.38E-35	1.00E+04
Pu5-241	5.06E-39	1.00E+04
Am-241	1.07E-34	1.00E+04
Np-237	3.82E-24	1.00E+04
Cl-36	1.88E-23	1.00E+04
Cm-245	1.24E-38	1.00E+04
Pu-241	4.48E-40	1.00E+04
Pu5-241	1.75E-43	1.00E+04
Am-241	2.32E-37	1.00E+04
Np-237	3.96E-24	1.00E+04
Cm-246	6.54E-39	1.00E+04
Cm-247	2.82E-38	1.00E+04
Am-243	2.40E-36	1.00E+04
Np-239	7.62E-40	1.00E+04
Pu-239	9.20E-31	1.00E+04
Pu5-239	3.34E-34	1.00E+04
Cm-248	2.76E-38	1.00E+04
Pu-244	1.58E-28	1.00E+04
Pu5-244	5.76E-32	1.00E+04
Cs-135	1.10E-14	1.00E+04
Cs-137	1.42E-41	1.46E+03
H-3	4.03E-13	1.20E+02
I-129	1.29E-07	1.00E+04
K-40	6.97E-08	1.00E+04
Mo-93	8.21E-08	1.00E+04
Nb-93m	6.72E-12	1.00E+04
Nb-94	3.33E-21	1.00E+04
Nb-95m	0.00E+00	
Nb-95	0.00E+00	
Ni-59	2.37E-18	1.00E+04
Np-237	7.25E-24	1.00E+04
Pd-107	1.25E-16	1.00E+04

Pu-238	5.59E-42	2.60E+03
Pu5-238	2.07E-45	2.60E+03
U-234	4.13E-26	1.00E+04
Pu-239	7.75E-27	1.00E+04
Pu5-239	2.81E-30	1.00E+04
U-235	1.83E-27	1.00E+04
Pu-240	3.59E-27	1.00E+04
Pu5-240	1.30E-30	1.00E+04
U-236	5.85E-27	1.00E+04
Pu-241	3.93E-68	1.06E+03
Pu5-241	1.64E-71	1.06E+03
Am-241	4.00E-39	1.00E+04
Np-237	7.25E-24	1.00E+04
Pu-242	1.01E-26	1.00E+04
Pu5-242	3.68E-30	1.00E+04
U-238	1.26E-28	1.00E+04
Pu-244	1.03E-26	1.00E+04
Pu5-244	3.75E-30	1.00E+04
Ra-226	5.55E-19	1.00E+04
Rb-87	2.38E-15	1.00E+04
Se-79	7.11E-07	1.00E+04
Sn-126	2.03E-22	1.00E+04
Sr-90	4.32E-19	5.62E+02
Tc-99	5.61E-20	1.00E+04
Th-228	0.00E+00	
Ra-224	0.00E+00	
Th-229	1.21E-36	1.00E+04
Ra-225	4.32E-41	1.00E+04
Ac-225	3.23E-41	1.00E+04
Th-230	2.85E-36	1.00E+04
Ra-226	8.04E-21	1.00E+04
Pb-210	2.16E-22	1.00E+04
Po-210	6.60E-24	1.00E+04
Th-232	3.13E-36	1.00E+04
Ra-228	9.13E-45	1.00E+04
Th-228	4.74E-46	1.00E+04
Ra-224	1.59E-47	1.00E+04
U-232	2.38E-48	2.79E+03
Th-228	1.66E-50	2.80E+03
Ra-224	5.58E-52	2.80E+03
U-233	4.45E-26	1.00E+04
Th-229	5.04E-29	1.00E+04
Ra-225	1.79E-33	1.00E+04
U-234	4.52E-26	1.00E+04
Th-230	3.58E-29	1.00E+04
Ra-226	2.86E-23	1.00E+04
Pb-210	7.72E-25	1.00E+04
Po-210	2.36E-26	1.00E+04

U-235	4.65E-26	1.00E+04
Pa-231	1.09E-30	1.00E+04
Ac-227	8.86E-34	1.00E+04
Th-227	2.93E-37	1.00E+04
Ra-223	1.15E-36	1.00E+04
U-236	4.65E-26	1.00E+04
U-238	4.65E-26	1.00E+04
Th-234	1.72E-37	1.00E+04
U-234	7.12E-32	1.00E+04
Zr-93	2.22E-27	1.00E+04
Nb-93m	9.19E-32	1.00E+04
Zr-95	0.00E+00	
Nb-95	0.00E+00	

A.3.3.1 Source Terms

For each of the contaminants and all daughters, the source terms are expressed as the fractional release to the water table calculated by the unsaturated-zone modeling. The fractional release has the unit of mole/year/mole of parent. The time history of each component is used as the source term. The amount released is assumed to be evenly distributed to the total volume of the 12 source cells listed in Table A-12. Based on the grid coordinates, the volumes of all these cells are calculated (Table A-13). The total volume is 6.1215×10^5 ft^3.

Table A-13
Source Node Locations and Volumes

I	J	K	XC	YC	ZC	VOL
13	13	14	21350.0	11750.0	230.110	5.1200E+04
13	14	14	21350.0	11850.0	230.650	5.0900E+04
13	15	14	21350.0	11950.0	231.306	5.0525E+04
14	12	14	21450.0	11650.0	229.997	5.1250E+04
14	13	14	21450.0	11750.0	230.353	5.1100E+04
14	14	14	21450.0	11850.0	230.822	5.0850E+04
14	15	14	21450.0	11950.0	231.405	5.0500E+04
15	10	14	21550.0	11450.0	229.486	5.1525E+04
15	11	14	21550.0	11550.0	229.935	5.1250E+04
15	12	14	21550.0	11650.0	230.340	5.1050E+04
15	13	14	21550.0	11750.0	230.699	5.0925E+04
16	11	14	21650.0	11550.0	230.306	5.1075E+04
					TOTAL	6.1215E+05

The fractional release is divided by the total volume to obtain the concentration increments in the source nodes in mole/ ft^3/mole parent. However, because fractional release is often a very small number, within PORFLOW we multiply it by $10^{12}/6.1215\times10^5$ ft^3 = 1.6336×10^6. The concentration unit in PORFLOW saturated-zone computation is, therefore, pico-mole/ft^3/mole parent. This multiplication factor is the same for every contaminant. PORFLOW has a “SCALE” command so that users can apply it to each fractional release time history. In PORFLOW 5.97.0, the scaling is performed by the code if a user enters “TOTAl VOLUme” in the SOURce command. The source terms are read by a PORFLOW input file.

The flux terms exiting the bottom of the unsaturated zone model was processed using a Fortran program to truncate the fluxes less than 10^{-20} times the peak flux such that only the significant part of the output flux profile was utilized to generate the input source terms for the saturated zone model.

NRC Comment 63: The intruder scenario does not evaluate potential disruption of the engineered barriers (e.g., the lower infiltration barrier of the engineered cap) and associated potential increases in grout degradation and groundwater pathway doses.

Basis: As noted in Reference 2, the low dose from the drinking water pathway was determined based on the assumption that the waste is undisturbed. In an intruder scenario, the waste may be directly disturbed or the engineered cap may be disturbed by near-surface activities. Since some of the degradation mechanisms of concrete and saltstone may be sensitive to the flux of water and deleterious species, a significant increase in infiltration to the surfaces of or through the system may result in degradation of the vault and wasteform, as well as accelerated transport through the unsaturated zone.

Path Forward: For the intruder scenarios, evaluate the potential disruption of the engineered barriers and the associated impacts on the groundwater pathway doses.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al 2005).

The groundwater pathway analyses in the Saltstone PA (MMES 1992) and subsequent Special Analyses (Cook et al. 2002 and Cook et al. 2005) did not consider disruption of engineered barriers or natural features of the disposal site by a hypothetical inadvertent intruder. This is consistent with NRC PA guidance (USNRC 2000). Section 3.2.1.2 of the NRC guidance states: "Finally, the disruptive actions of an inadvertent intruder do not need to be considered when assessing releases of radioactivity off-site." This statement is made in the context of a number of types of changes that will take place over long time periods (e.g., societal changes, human behaviors), and the guidance recommends against unnecessary speculation.

DOE guidance (Wood et al. 1994) is consistent with the NRC guidance. The rationale given in the DOE guidance is

1. Inadvertent intrusion has been used historically as a hypothetical device, originally as a tool for defining general categories or classes of radioactive waste, and later as a mechanism for deriving criteria for low-level waste acceptance and facility design and operation.

2. The recommendation is consistent with federal regulatory requirements for disposal of other kinds of waste.

3. Because intrusion scenarios stem from hypothesized projections of human activities (which may never occur), countless scenarios could be envisioned. However, natural processes should be expected to occur, and the kinds of natural processes that could affect the performance of the disposal facility can be reasonably bounded.

The Vault 4 SA did evaluate potential disruption of the closure cover due to natural phenomena (e.g., erosion, intrusion of pine trees) (Section 5.0 of Phifer and Nelson 2003) and the consequent effect on infiltration (Section 6.0 of Phifer and Nelson 2003). Infiltration increased from 0.29 inches per year immediately after closure to 14.1 inches per year after 10,000 years.

To help better understand the combined effects of cap degradation and vault/saltstone degradation, an analysis of the coupled effects of increased infiltration, which could be caused by cap degradation, and concrete and saltstone degradation was performed. The results of this sensitivity analysis is described in the response to NRC Comment 19 and in Rosenberger et al. 2005.

Sections 5.0 and 6.0 of Phifer and Nelson 2003 and Section 2.19 of Wood et al. 1994 are reproduced below.

In addition, the response to NRC Comment 62 provides an intruder all-pathways dose resulting from the uses of water from a well within the 100-meter buffer zone.

References:

Cook, J. R., Kocher, D. C. McDowell-Boyer, L., and Wilhite, E. L. 2002. *Special Analysis: Reevaluation of the Inadvertent Intruder, Groundwater, Air and Radon Analyses for the Saltstone Disposal Facility,* Westinghouse Savannah River Company, Aiken, South Carolina.

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Wood, D.E., Curl, R.U., Armstrong, D.R., Cook, J.R., Dolenc, M.R., Kocher, D.W., Owens, K.W., Regnier, E.P., Roles, G.W., Seitz, R.R., and Wood, M.I., *Performance Assessment Task Team Progress Report*, DOE/LLW-157, Rev. 1, May 1994.

5.0 CLOSURE CAP DEGRADATION

The following three primary closure cap degradation mechanism have been assumed to significantly impact the infiltration through the closure cap over time:

Pine forest succession

Erosion

Colloidal clay migration

Each of these degradation mechanisms is discussed in detail below.

5.1 Pine Forest Succession

According to the PA and Closure Plan the SDF closure cap will be vegetated with bamboo. Bamboo is a shallow-rooted species that quickly establishes a dense ground cover and evapotranspirates year-round in the SRS climate. Pine trees are the most deeply rooted naturally occurring plants at SRS. (MMES 1992; Cook et al. 2000). The institutional control to pine forest, land use scenario evaluated herein assumes a 100-year institutional control period following final SDF closure during which the closure cap is maintained. It is assumed that a pine forest begins to encroach upon the bamboo at the end of institutional control, when the approximately 43-acre closure cap (approximate area (~1300 foot by ~1450 foot) over vaults 1 through 12 in Figure 2.0-1) is no longer maintained.

The following discussion of the assumed successional transition from bamboo to pine trees is derived from the following references: Bohm (1979), Burns and Hondala (1990), Ludovici et al. (2002), Taylor (1974), Ulrich et al. (1981), Walkinshaw (1999), and Wilcox (1968).

After institutional control, it is assumed that it will take approximately 100 years for loblolly pine to be established around the closure cap perimeter and for some breakup of the bamboo to begin to occur. Within 10 years of pine tree establishment around the perimeter, the pines begin shading the bamboo located along the perimeter, which allows the establishment of pine tree seedlings 50 feet in from the perimeter of the closure cap. The process of pine tree growth and bamboo shading followed by further seedling encroachment in 50-foot increments toward the cap center continues to occur on a 10-year cycle until the entire closure cap is established with pine trees. 200 years after the end of institutional control it is assumed that the entire cap is covered with pine trees, with the oldest trees near the perimeter and the youngest in the center (i.e. an uneven age distribution).

Because of the age structure difference from edge to center, the second generation, and subsequent ones, will also probably be variable across the cap. Decline of loblolly will begin around 100 years of age. After the second establishment, the new seedlings will be established as “gaps” occur in the overstory, either through the decline or death of a dominant tree, or through abiotic occurrences (wind throw, lightning strikes, fire, insect outbreak, tornado, etc.). This will tend towards making the entire acreage an uneven age, constantly re-establishing forest. In this region, fire may be quite important in the long-term ecology of the cap. Fire will reduce the smaller understory individuals and seedlings, but will have minimal impact on the dominant individuals. It may affect the age structure over long periods of time and make the 43-acre cap closer in age distribution than the original establishment period would indicate.

It is anticipated that tree density will remain fairly constant. For a natural regeneration stand, the tree density is assumed to be approximately 550 dominant and co-dominant trees per acre with approximately 400 mature (i.e. 70 to 125 years old) trees per acre. Smaller trees will be suppressed and die.

It is assumed that mature pine will have 5 deep roots, mainly near the center of the tree spread (i.e., concentrated near main trunk). Of these 5 deep roots, four go to a depth of 6 feet and one to 12 feet. Deep roots have a diameter of 3 inches in the top foot of soil and taper with depth to 0.25 inches at depth. These roots will be maintained over the life of the tree and exhibit little turnover prior to death. They will enlarge with yearly growth, similar to branches, although anatomically different and at a slower rate. Smaller trees, which are suppressed and die, will not establish deep roots in excess of 4 to 5 feet, and primarily only 1 or 2 such roots. Hard layers and water-saturated layers will slow root penetration. A continuous water surface will stop elongation. Hard layers will eventually be penetrated.

Decomposition of roots near the ground surface should occur fairly quickly due to better microclimate for microbial populations than at depth. Decomposition of roots at depth will be fairly slow, depending on the soil environment and aeration. It is assumed that it will take 25 years for the decomposition of intermediate depth roots and 30 years at depth due to the soil environment. Some shrinkage of the deep roots may occur at depth and provide a channel for water or sediment movement along the surface. Very rapid yearly turnover of fine roots and feeder roots occurs in the soil, although these are primarily in the top 18 inches of soil and will not go vertically with any intensity or longevity.

Based upon this discussion the following assumptions are made relative to the succession of bamboo by a pine forest for this evaluation:

- 200 years after the end of institutional control it is assumed that the entire cap is dominated by pine.
- Complete turnover of the 400 mature trees per acre occurs every 100 years (in a staggered manner).
- There are 400 mature trees per acre with 4 roots to 6 feet and 1 root to 12 feet. The roots are 3 inches in diameter at a depth of 1 foot and 0.25 inches in diameter at either 6 or 12 feet, whichever is applicable.

5.2 Erosion

The topsoil and upper backfill layers, which are located above the erosion barrier, are subject to erosion. For the institutional control to pine forest land use scenario, it is assumed that the closure cap will be vegetated with bamboo during the institutional control period, with a combination of bamboo and pine trees for 200 years immediately following the institutional control period, and with a pine forest thereafter. The projected erosion rate for both the topsoil and upper backfill layers has been determined utilizing the Universal Soil Loss Equation (Horton and Wilhite 1978; Goldman et al. 1986). The Universal Soil Loss Equation is expressed as:

$$A = R \times K \times LS \times C \times P \qquad \text{(Eq. 5.2-1)}$$

where

A = soil loss (tons/acre/year)

R = rainfall erosion index (100 ft·ton/acre per in/hr)
K = soil erodibility factor, tons/acre per unit of R
LS = slope length and steepness factor, dimensionless
C = vegetative cover factor, dimensionless
P = erosion control practice factor, dimensionless

The erosion rate for the SRP Burial Grounds (i.e. current SRS E-Area) was previously estimated and documented by Horton and Wilhite (1978) as provided in Table 5.2-1.

Table 5.2-1. Previous SRP Burial Grounds Estimated Erosion Rate (Horton and Wilhite 1978)

Parameter	Value Utilized	Comment
R	260	-
K	0.28	Dothan subsoil
LS	0.67	1000 foot long 2% slope
C	0.001	Natural successional forest
P	1	No supporting practices
A (soil loss)	0.05 tons/acre/year	-
A (soil loss)	0.0007 cm/year	Assuming dry bulk density of 1.6 g/cm^3

The following are estimated parameter values based upon Horton and Wilhite 1978 and Goldman et al. 1986:

- From Figure 5.2 of Goldman et al. (1986), R is slightly greater than 250 but significantly less than 300 100 ft·ton/acre per in/hr. Therefore will utilize the Horton and Wilhite 1978 R value of 260 100 ft·ton/acre per in/hr
- From Figure 5.6 of Goldman et al. (1986):
  - If topsoil is assumed to consist of 70% sand, 25% silt, and 5% clay, K equals 0.28 tons/acre per unit of R.
  - If backfill is assumed to consist of 70% sand, 20% silt, and 10% clay, K equals 0.20 tons/acre per unit of R.
- With a slope length of 350 feet (see Figure 4.2-2) and a slope of 3% the LS value equals 0.40 as determined from Table 5.5 of Goldman et al. (1986).
- Will assume that both bamboo and a pine forest, have C values of a natural successional forest, therefore the C value equals 0.001 as utilized by Horton and Wilhite (1978).
- No supporting practices are associated with the closure cap therefore P equals 1.

Based upon the Universal Soil Loss Equation and the parameter values listed above the following are the estimated soil losses:

- Topsoil with a natural successional forest has an estimated soil loss of 0.0291 tons/acre/year ($A = 260 \times 0.28 \times 0.40 \times 0.001 \times 1$). Based upon the dry bulk density the estimated soil loss can be converted to a loss in terms of depth of loss per year. From Jones and Phifer (2002), the dry bulk density of topsoil was taken as 90 lbs/ft^3. Topsoil with a natural successional forest has an estimated depth of soil loss of approximately 1.8E-04 inches/year ($Loss = \frac{0.0291\ tons/acre/year \times 2000\ lbs/ton \times 12\ inches/foot}{43560\ ft^2/acre \times 90\ lbs/ft^3}$).
- Backfill with a natural successional forest has an estimated soil loss of 0.0208 tons/acre/year ($A = 260 \times 0.20 \times 0.40 \times 0.001 \times 1$). Based upon the dry bulk density the estimated soil loss can be converted to a loss in terms of depth of loss per year. From Jones and Phifer (2002), the dry bulk density of backfill was taken as 104 lbs/ft^3. Backfill with a natural successional forest has an estimated depth of soil loss of approximately 1.1E-04 inches/year ($Loss = \frac{0.0208\ tons/acre/year \times 2000\ lbs/ton \times 12\ inches/foot}{43560\ ft^2/acre \times 104\ lbs/ft^3}$).

The previous estimated erosion rate of 0.0007 cm/year (2.8E-04 inches/year) for the SRP Burial Grounds (Horton and Wilhite 1978) compares well with the current estimates for the SDF closure cap of 1.8E-04 and 1.1E-04 inches/year for topsoil and backfill, respectively. The primary difference in input between the two estimates is associated with the site-specific slopes and slope lengths.

5.3 Colloidal Clay Migration

It is assumed that colloidal clay migrates from overlying backfill layers and accumulates in the drainage layers reducing the saturated hydraulic conductivity of the drainage layers over time. The clay minerals (in order of predominance) at SRS are shown in Table 5.3-1 along with the percentage range of the clay mineral fraction and typical range in particle size for each. Colloids can be mineral grains such as clays, which have particle sizes between 0.01 and 10 μm (Looney and Falta 2000). Colloidal clay can exist in groundwater in concentrations up to 63 mg/L as measured by suspended solids (Puls and Powell 1991). Based upon this information and the previous assumption, it will be assumed that water flux driven colloidal clay migration at a concentration of 63 mg/L occurs from overlying backfill layers to the drainage layers. It will be further assumed that the colloidal clay accumulates in the drainage layer from the bottom up filling the void space of the drainage layer with clay at a density of 1.1 g/cm^3 (Hillel 1982). These assumptions are analogous to the formation of the B soil horizon as documented in the soil science literature. Clay translocation is a very slow process where discrete clay particles are washed out in slightly acidic conditions and deposited lower in the soil profile (McRae 1988). Evidence has been found that the B-horizon where the translocated clay is deposited may form at a rate of 10 inches per 5,000 years (Buol et al. 1973).

Table 5.3-1. SRS Clay Minerals

Clay Mineral	Percentage Range of the Clay Mineral Fraction [1] (%)	Typical Particle Size Range [2] (μm)
Kaolinite	62.6 to 98.8	0.1 to 4
Vermiculite	0.7 to 34.3	0.1 to 2
Illite	0 to 7.1	0.1 to 2

[1] Looney et al. (1990), Table 6.31
[2] Mitchell (1993)

5.4 Closure Cap Degradation Summary

Base upon the assumed closure cap degradation mechanisms, pine forest succession, erosion, and colloidal clay migration, an assumed degradation scenario has been assumed for each layer as outlined in Table 5.4-1. These degradation scenarios form the basis for modifying the thickness and hydraulic properties of each layer over time. This information will be utilized in section 6.0 to determine infiltration though the upper GCL over time.

Table 5.4-1. SDF GCL Closure Cap Layer Degradation Scenarios

Layer	Degradation Scenario
Vegetation	Bamboo is maintained during the 100-year institutional control period, pine trees begin to encroach upon the bamboo at the end of institutional control, and a pine forest covers the cap 200 years after the end of institutional control.
Topsoil	Topsoil erosion occurs at 1.8E-04 inches per year.
Upper Backfill	Backfill erosion occurs at 1.1E-04 inches per years, after the topsoil layer has been depleted.
Erosion Control Barrier	Maintenance during institutional control period prevents degradation of the erosion control barrier. However pine forest succession and associated root penetration results in holes through the erosion control barrier. This does not impact its ability to function as an erosion barrier, however it allows the overlying backfill to fill the holes left after the roots decompose.
Middle Backfill	Colloidal clay migration from the 1-foot-thick middle backfill to the underlying 1-foot-thick upper drainage layer causes the saturated hydraulic conductivity to increase over time.
Geotextile Filter Fabric	For purposes of colloidal clay migration into the underlying drainage layer the geotextile filter fabric is assumed to be ineffective over the time period under consideration.
Upper Drainage Layer	Colloidal clay migration from the overlying 1-foot-thick backfill into the 1-foot-thick upper drainage layer causes the saturated hydraulic conductivity to decrease over time.
Upper GCL	Maintenance during institutional control period prevents degradation of the upper GCL. However pine forest succession and associated root penetration results in holes through the GCL. This allows the overlying drainage layer to fill the holes after the roots decompose.
Lower Backfill	None. While it is assumed that colloidal clay migration from this layer to the underlying lower drainage layer occurs, it is also assumed that the thickness of the lower backfill layer (almost 5-foot) relative to the lower drainage layer (2-foot) prevents the quantity of clay loss necessary to change the hydraulic properties of the lower backfill.
Geotextile Filter Fabric	For purposes of colloidal clay migration into the underlying drainage layer the geotextile filter fabric is assumed to be ineffective over the time period under consideration.
Lower Drainage Layer	Colloidal clay migration from the overlying ~5-foot-thick lower backfill into the 1-foot-thick lower drainage layer reduces its saturated hydraulic conductivity over time.
Lower GCL	None. Pine tree roots do not penetration to a sufficient enough depth to impact this layer. Additionally the underlying concrete vault roof along with the GCL produces a hard layer and continuous water saturation within and above these layers so that root elongation is stopped.
Side Vertical Drainage Layer [1]	None, until the vault base drainage layer has been filled with colloidal clay.
Vault Base Drainage Layer [1]	Colloidal clay migrates from the overlying ~30-foot-thick backfill into the 5-foot-thick drainage layer reduces its saturated hydraulic conductivity over time.

[1] These layers are not included in the HELP model for determination of the infiltration through the upper GCL. However their degradation properties will be included in the subsequent PORFLOW vadose zone modeling.

6.0 CLOSURE CAP INFILTRATION

6.1 Degraded Layer Properties over Time

The SDF GCL closure cap initial (0 year) intact layer thickness and hydraulic property values from top to bottom are provided in Table 4.7-1. The degradation scenarios for each layer are provided in Table 5.4-1. Based upon the Table 5.4-1 degradation scenarios, the Table 4.7-1 initial SDF closure cap layer thickness and hydraulic property values have been modified to account for degradation at 100, 300, 550, 1,000, 1,800, 3,400, 5,600 and 10,000 years after closure of the SDF. The following discussions provide additional detail associated with determination of the degraded properties for the erosion barrier, upper GCL, middle backfill, upper drainage layer, lower drainage layer, and vault base drainage layer.

1.1.1 6.1.1 Erosion Barrier

Maintenance during the institutional control period prevents degradation of the erosion barrier. However pine forest succession and associated root penetration results in holes through the erosion control barrier. This does not impact its ability to function as an erosion barrier, however it allows the overlying backfill to fill the holes after the roots decompose. It is assumed that the hydraulic conductivity of the infiltrating backfill increases one order of magnitude (i.e. from 1.0E-04 to 1.0E-03 cm/s) when it fills the hole since it will not be mechanically compacted at that time. The equivalent hydraulic properties of the overall erosion barrier change as the area of holes filled with backfill material increases with time. The equivalent hydraulic properties have been estimated over time by area proportioning the properties between that of the intact erosion barrier and infiltrating backfill.

1.1.2 6.1.2 Upper GCL

Maintenance during the institutional control period prevents degradation of the upper GCL. However pine forest succession and associated root penetration results in holes through the erosion barrier. This allows the overlying drainage layer to fill the holes after the roots decompose. The holes in the GCL essentially act as direct conduits from the upper drainage layer to the lower backfill layer. When saturated conditions occur in the drainage layer after major precipitation events, cones of depression are created around the holes in the GCL with a radius of influence much greater than the radius of the hole. This means that a small area of GCL holes can greatly reduce the lateral flow of water in the drainage layer and increase the vertical flow into the lower backfill. Due to the significant influence of holes in the GCL to the quantity of infiltration, the use of equivalent hydraulic properties is not appropriate, since it does not consider the radius of influence associated with holes. Therefore, within the HELP model the degraded GCL has been modeled as a geomembrane liner with leakage through holes. The HELP model considers both water flux through intact portions of the geomembrane using an "equivalent geomembrane hydraulic conductivity" and water flux through holes in the geomembrane. The HELP model does not assign a porosity, field capacity, or wilting point to geomembranes, however this is not considered essential to the GCL, since it is assumed that the GCL will remain fully saturated and it is below the depth where evapotranspiration is assumed to occur. The HELP model allows the input of up to 999,999 one square centimeter installation defects for a geomembrane liner. Therefore the calculated area of holes created by root penetration has been converted into an equivalent number of one square centimeter installation defects for input to the HELP model. Excellent

contact is assumed between the GCL and underlying backfill layer as a HELP model input, since the GCL is put in dry and swells into the surrounding soil as it hydrates.

1.1.3 6.1.3 Middle Backfill and Upper Drainage Layer

It is assumed that water flux driven colloidal-clay migration from the 1-foot-thick middle backfill to the underlying 1-foot-thick upper drainage layer causes the middle backfill saturated hydraulic conductivity to increase over time and that of the upper drainage layer to decrease over time. It has been assumed that clay migration occurs out of the backfill into the drainage layer with the water flux containing 63 mg/L of colloidal clay. Since both layers are of the same thickness and the middle backfill layer has limited clay content, it has been assumed that half the clay content of the backfill will migrate into the drainage layer. At which point the two layers essentially become the same material and material property changes cease. Based upon this it will be assumed that the endpoint saturated hydraulic conductivity of the layers will become that of the log mid-point between the initial backfill and upper drainage layer conditions. It will also be assumed that the endpoint porosity, field capacity, and wilting point will become the arithmetic average of the backfill and upper drainage layer. The hydraulic properties at times prior to the endpoint have been proportioned between that of the endpoint properties and the initial properties based upon the fraction of clay that has migrated out of the backfill.

1.1.4 6.1.4 Lower Drainage Layer

It is assumed that colloidal clay migration from the approximately 5-foot-thick overlying backfill into the 2-foot-thick lower drainage layer is driven by the water flux through the upper GCL. This water flux driven clay migration enters into the lower drainage layer and fills the lower drainage layer from the bottom up. This reduces the saturated hydraulic conductivity of the clay-filled portion from 1.0E-01 to 1.0E-04 cm/s (i.e. to the saturated hydraulic conductivity of the overlying backfill), while the conductivity of the clean portion remains at 1.0E-01 cm/s. As the thickness of the lower drainage layer filled with clay increases, the equivalent hydraulic conductivity of the entire layer decreases. The equivalent horizontal hydraulic conductivity for this layer has been determined from the following equation (Freeze and Cherry 1979):

$$K_h = \sum_{i=1}^{n} \frac{K_i \, d_i}{d} \qquad \text{(Eq. 6.1-1)}$$

where

K_h = equivalent horizontal saturated hydraulic conductivity,
K_i = horizontal saturated hydraulic conductivity of i^{th} layer,
d_i = thickness of i^{th} layer,
d = total thickness

This is different from that assumed for the upper drainage layer, since the lower drainage layer has significantly more backfill overlying it.

1.1.5 6.1.5 Vault Base Drainage Layer

It is assumed that colloidal clay migration, from the overlying backfill (approximately 30 feet) into the 5-foot-thick vault base drainage layer, is driven by the water flux through the

upper GCL. This water-flux-driven clay migration enters into the vault base drainage layer and fills the lower drainage layer from the bottom up.

The saturated hydraulic conductivity of the clay-filled portion is reduced from 1.0E-01 to 1.0E-04 cm/s (i.e. the saturated hydraulic conductivity of the overlying backfill layer), while the conductivity of the clean portion remains at 1.0E-01 cm/s. The thickness of the clay-filled portion increases with time, while the thickness of the clean portion decreases with time. This is essentially the same process as that described above for the lower drainage layer.

The calculations associated with determination of the layer thicknesses and hydraulic property values over time are provided in Appendix P. Table 6.1-1 provides the primary Appendix P, material property results (thickness, saturated hydraulic conductivity, and holes in the upper GCL), for layers which change with time and were utilized in subsequent HELP modeling. The porosity, field capacity, and wilting points are not provided in Table 6.1-1. Values for these parameters are provided in Appendix P.

Table 6.1-1. Material Property Summary Results for HELP Modeling from Appendix P

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	5.982	3.97E-04	1.20E-04
300	Pine Forest	5.946	3.98E-04	1.60E-04
550	Pine Forest	5.901	3.99E-04	2.30E-04
1,000	Pine Forest	5.82	4.01E-04	4.60E-04
1,800	Pine Forest	5.676	4.06E-04	1.60E-03
3,400	Pine Forest	5.388	4.15E-04	3.20E-03
5,600	Pine Forest	4.992	4.27E-04	3.20E-03
10,000	Pine Forest	4.2	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	9.91E-02	
1,000	2.10E-02	59,458	9.64E-02	
1,800	6.30E-03	118,916	9.01E-02	
3,400	3.20E-03	237,832	7.62E-02	
5,600	3.20E-03	401,341	5.68E-02	
10,000	3.20E-03	728,360	1.81E-02	

[1] Number of HELP model installation defects

6.2 Degraded Closure Cap Infiltration over Time

Table 6.1-1 and Appendix P data were utilized as input to the HELP model (USEPA 1994a and USEPA 1994b) in order to determine infiltration through the upper GCL at each degraded time step. The following appendices provide the detailed HELP model, input data and output files for each time step:

Appendix Q, Degraded SDF GCL Closure Cap (100 Years): HELP Model Input Data and Output File (output file name: ZGCLD1ou.OUT)

Appendix R, Degraded SDF GCL Closure Cap (300 Years): HELP Model Input Data and Output File (output file name: ZGCLD2ou.OUT)

Appendix S, Degraded SDF GCL Closure Cap (550 Years): HELP Model Input Data and Output File (output file name: ZGCLD3ou.OUT)

Appendix T, Degraded SDF GCL Closure Cap (1,000 Years): HELP Model Input Data and Output File (output file name: ZGCLD4ou.OUT)

Appendix U, Degraded SDF GCL Closure Cap (1,800 Years): HELP Model Input Data and Output File (output file name: ZGCLD5ou.OUT)

Appendix V, Degraded SDF GCL Closure Cap (3,400 Years): HELP Model Input Data and Output File (output file name: ZGCLD6ou.OUT)

Appendix W, Degraded SDF GCL Closure Cap (5,600 Years): HELP Model Input Data and Output File (output file name: ZGCLD7ou.OUT)

Appendix X, Degraded SDF GCL Closure Cap (10,000 Years): HELP Model Input Data and Output File (output file name: ZGCLD8ou.OUT)

The following outputs from this evaluation are necessary inputs to the subsequent PORFLOW vadose zone modeling:

Infiltration through the upper GCL
Saturated hydraulic conductivity of the 2-foot-thick lower Drainage Layer
Saturated hydraulic conductivity of the 3-foot-thick Side Vertical Drainage Layer
Saturated hydraulic conductivity of the 5-foot-thick Vault Base Drainage Layer

Table 6.2-1 provides a summary of these parameter values. The 3-foot Side Vertical Drainage Layer is assumed to have no degradation within the 10,000-year time frame. Rather than denoting the degradation of the Vault Base Drainage Layer with a single saturated hydraulic conductivity value, its degradation has been denoted as an upper thickness with a saturated hydraulic conductivity of 0.1 cm/s and a lower thickness with a saturated hydraulic conductivity of 0.0001 cm/s. Figure 6.2-1 additionally provides the infiltration through the upper GCL over time in graphical format.

Table 6.2-1. Inputs for PORFLOW Vadose Zone Modeling

Year	Infiltration through Upper GCL (in/yr)	Lower Drainage Layer Saturated Hydraulic Conductivity (cm/s)	Side Vertical Drainage Layer Saturated Hydraulic Conductivity (cm/s)	Thickness of Upper Portion of the Vault Base Drainage Layer with a K of 0.1 cm/s (feet)	Thickness of Lower Portion of the Vault Base Drainage Layer with a K of 0.0001 cm/s (feet)
0	0.29165	1.00E-01	1.00E-01	5	0
100	0.33135	1.00E-01	1.00E-01	4.9996	0.0004
300	2.48161	9.98E-02	1.00E-01	4.996	0.004
550	7.01335	9.91E-02	1.00E-01	4.98	0.02
1,000	11.55066	9.64E-02	1.00E-01	4.93	0.07
1,800	13.65308	9.01E-02	1.00E-01	4.8	0.2
3,400	14.00566	7.62E-02	1.00E-01	4.52	0.48
5,600	14.05202	5.68E-02	1.00E-01	4.14	0.86
10,000	14.09426	1.81E-02	1.00E-01	3.36	1.64

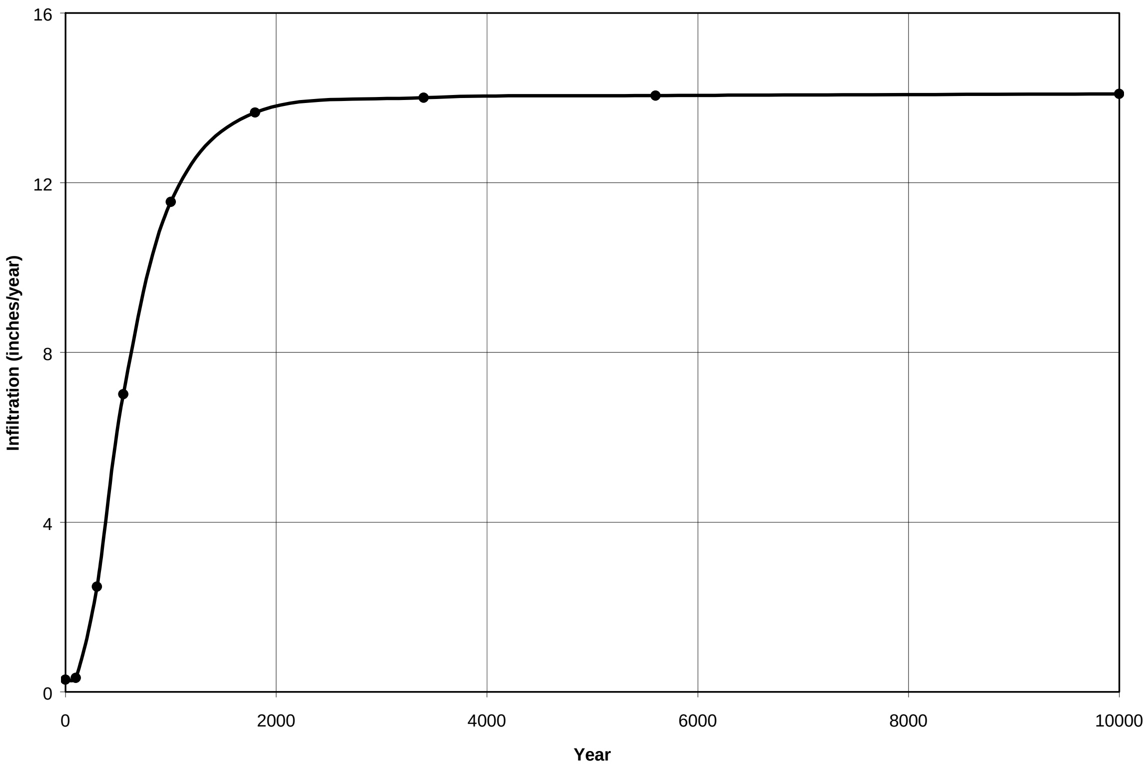

Figure 6.2-1. Infiltration through Upper GCL

2.19 The Intruder and the All-Pathways Analyses

2.19.1 Issue

Chapter 111 of DOE Order 5820.2A requires that performance assessments for LLW disposal facilities provide reasonable assurance of compliance with the performance objectives listed in Section IIL3.a. These performance objectives include a requirement to limit the annual dose to individuals assumed to inadvertently intrude into the disposal facility following an assumed end to an active institutional control period, and a requirement to limit possible release of radioactive material to the environment. Limits for release to the environment are specified in terms of an annual dose to members of the public based on consideration of all pathways of exposure.

For the intruder analysis, one assumes that the intruder performs a limited set of construction and homesteading activities. The issue is whether, when performing all-pathways analyses, one should consider the possible disruptive effects of these construction and homesteading activities on barriers to release and transport of radioactive material.

2.19.2 Recommendation

In performance assessments, pursuant to Chapter I11 of Order 5820.2A**,** the intruder protection analyses should be considered separately from the all-pathways analyses. The hypothetical effects of an intruder on barriers to release from disposal units need not be explicitly considered in all-pathways analyses. Rather, all-pathways analyses should consider reasonably foreseeable, naturally occurring processes (e.g., erosion, burrowing animals, plant roots) that also may have disruptive effects on barriers to release and transport of radioactive material.

2.19.3 Rationale

This recommendation derives from the following information:

1. Inadvertent intrusion has been used historically as a hypothetical device, originally as a tool for defining general categories or classes of radioactive waste, and later as a mechanism for deriving criteria for LLW acceptance and facility design and operation.

2. The recommendation is consistent with federal regulatory requirements for disposal of other kinds of waste.

3. Because intrusion scenarios stem from hypothesized projections of human activities (which may never occur), countless scenarios could be envisioned. However, natural processes should be expected to occur, and the kinds of natural processes that could affect the performance of the disposal facility can be reasonably bounded.

2.19.3.1 Use as a Hypothetical Device. There are no legal mandates to consider protection for an inadvertent intruder into a radioactive waste disposal facility-this is in contrast to legal mandates to protect the air and ground and surface waters, and in contrast with the charter of

the EPA to set generally applicable environmental standards. Intrusion was originally conceived for use in studies estimating the relative "hazard" of different categories of radioactive waste. Intrusion scenarios were later modified and used by the NRC to establish general waste acceptance and facility design and operating requirements for LLW disposal. Under DOE

Order 5820.24 intrusion must be considered in LLW performance assessments to set similar requirements on a site-specific basis.

Traditionally, the principal objective for achieving safe disposal of low-level waste has been to limit releases to the environment to some acceptably low level. This was the basis for the siting and original operation of all commercial LLW disposal sites, as well as the basis for siting and operating existing DOE disposal areas. The concept that one should limit radiation exposures to a potential inadvertent intruder arose during the late 1970s in the context of defining general categories or classes of radioactive waste.

At that time, different ways of estimating and comparing the relative hazard of different radioactive wastes, and thereby classifying the wastes according to a hierarchy, had been used or considered. Waste might be classified according to the generator or process that produced the waste, or according to operational considerations such as surface dose rates. Waste might be classified by the heat that was generated from decay. Waste might be classified by dividing radionuclide inventories by maximum permissible concentration limits from 10 CFR Part 20, thereby deriving a hypothetical measure of the volume of air or water required to dilute the waste to meet public dose limits.

Because these classification schemes seemed nebulous or incomplete, there arose an interest in categorizing different radioactive wastes in terms of disposal hazard. To this end, a number of "waste classification" studies were completed, including those by Leddicott,[67] Adam and Rogers,[68] Healy,[69] and Cohen.[70] These studies were generic rather than site-specific, and generally independent of regulatory requirements for disposal of the various categories of waste. These studies calculated human exposures by considering a limited number of scenarios involving direct intrusion into disposed waste (assuming that at the end of an institutional control period the disposal facility would be released for unrestricted use), as well as scenarios involving release into the environment. These assumptions and scenarios were then used to set concentration limits for categories of radioactive waste based on comparison to a limiting dose objective.

For the Part 61 rulemaking, NRC departed from previous waste classification studies. First, the NRC abandoned the notion of a general classification of radioactive waste, limiting its consideration to LLW as it had been defined by exclusion in the Low-Level Radioactive Waste Policy Act of 1980. Second, the NRC assumed that, although there may be some breakdowns in passive institutional control following the end of an active institutional control period, unconditional release of a LLW disposal facility was unlikely. Intrusion was envisioned as a hypothetical event-an accident, and very likely a temporary accident-triggered by bureaucratic bungling. Third, the NRC gave greater emphasis to waste form than had been the case for pervious waste classification studies and had previously been the practice for LLW disposal.

The NRC used the concept of inadvertent intrusion as a tool to establish a general waste classification system for commercial LLW disposal. Intrusion scenarios were used as a basis for the system because these scenarios were thought to be relatively independent of the disposal site environment, and because intrusion scenarios involving direct contact with disposed waste could be used directly to establish concentration limits. Given the hypothetical nature of intrusion, the NRC did not try to evaluate the almost boundless range of human actions that could be imagined, but limited the consideration to a few representative scenarios. In this way, a simple system was derived that could be used by potentially thousands of waste generators.

Despite the use of intrusion scenarios to derive concentration limits, the main emphasis in the Part 61 rulemaking was-and is-to minimize releases to the environment and to avoid situations requiring future remedial actions. The classification system was designed to ensure that most of the waste activity (in practice, greater than 90%) would be disposed of in a structurally stable form, which reduces the potential for release to the environment. Applicants for Part 61 licenses need not perform analyses to calculate hypothetical doses to hypothetical intruders. About the only times an applicant might consider intrusion in a performance assessment for a LLW disposal facility would be if the waste to be disposed of differed significantly from that assumed for the rulemaking, or if the disposal method differed radically from those considered in the rulemaking.

More recently, DOE published Order 5820.24, in which protection of an inadvertent intruder is considered on a site-specific rather than a generic basis. Analyses are to be used to establish waste acceptance and facility design and operating requirements.

2.19.3.2 Consistency. The recommendation is consistent with federal regulatory requirements for other types of waste. The only federal regulatory requirement to consider the effects of an intruder on the performance of a disposal facility is Section 191.13 of EPA's standard for disposal of high-level and transuranic waste, 40 CFR Part 191.

The intruder need not be considered in disposing of hazardous or municipal solid waste. An applicant for a disposal permit need not consider the possible health effects on a hypothetical intruder into a hazardous waste disposal facility or municipal landfill, nor the disruptive effects the intruder might have on the disposal facility or landfill.

For low-level radioactive waste, two regulatory citations of note include 10 CFR Part 66 and draft 40 CFR Part 193. The Part 61 regulation is silent about whether intrusion should be considered for compliance with 10 CFR 61.41, "Protection of the General Population from Release of Radioactivity." So is the NRC's standard format and content guide for a Part 61 app1ication.[l9]

In the draft[10] and final[35] environmental impact statements for the Part 61 rule, the NRC nominally considered the possible effects an intruder might have on a LLW disposal facility,

in that an assumption was made that an inadvertent intruder would disturb some of the trench caps at the disposal facility. However, no basis was given for the assumption, and the possible disruptive effects the intruder might have were lumped with those that could occur from natural processes such as erosion or plant and animal intrusion.

The April 1989 version of the EPA draft standard for LLW disposal, 40 CFR 193, contains a dose limit for release to the environment, plus a groundwater protection requirement7l In this draft standard, the EPA is not explicit about whether one should consider potential disruptions by the intruder when demonstrating compliance with the draft disposal standard. It does not appear that the EPA means that the intruder should be so considered, because they did not consider the effects of intrusion in the draft Background Information Document written to provide technical support to the draft standard.[72]

For disposal of uranium mill tailings, the EPA has indicated that intrusion need not be considered when demonstrating compliance with 40 CFR Part 192, "Health and Environmental Protection Standards for Uranium Mill tailings."[73] Promulgating these standards on January 5, 1983 (58 FR 590), the EPA set standards for control and remedial action at inactive uranium processing sites. These standards set criteria for stabilization and control of tailings, limits for release of radon from residual materials, concentration limits for radium in soil, and limits for radiation levels in buildings. As stated by EPA[73] (see 48 FR 597),

We consider the single most important goal of control to be effective isolation and stabilization of tailings for as long a period of time as is reasonably feasible, because tailings will remain hazardous for hundreds of thousands of years. The longevity of tailings control is governed chiefly by the possibility of intrusion by man and erosion by natural forces. Reasonable assurance of avoiding casual intrusion by man can be provided through the use of relatively thick and/or difficult-to-penetrate covers (such as soil, rock, or soil-cement). No standard can guarantee absolute protection against the purposeful works of man and these standards do not require such protection. . .

On September 24, 1987, the EPA proposed amendments to 40 CFR Part 192 to add groundwater protection requirements.[33] A final rulemaking has not been published, although the rule has been drafted in final form and submitted to the Office of Management and Budget.
Because the EPA does not address intrusion in the Federal Register Notice (FRN) for either the proposed or draft final rule, this suggests that their position on intrusion, as stated in their 1983 FRN, is still applicable. The EPA does indicate that a judgement about meeting the standard would "necessarily be based on site-specific analyses of the properties of the sites, candidate disposal systems, and the potential effects of natural processes over time."[33]

The existing EPA standard for high-level and transuranic waste disposal: 40 CFR Part 191, includes individual, groundwater protection, and containment requirements. For the individual and groundwater protection requirements (Sections 191.15 and 191.16), EPA indicated that compliance could be demonstrated, assuming that the disposal system was not disrupted by human intrusion or the occurrence of unlikely natural events. Similar to draft 40

CFR 193, these requirements prescribe limiting doses to individuals outside the disposal facility.

The containment requirements in Section 191.13 represent the only federal regulatory mandate to consider the possible impact of an intruder on a disposal facility. In Section 191.13, the EPA requires a probabilistic analysis for which intrusion is considered an event having a cumulative probability exceeding 0.1 over 10,000 years. But even in this case, consideration of intrusion is constrained: First, intrusion must be considered not for compliance with a dose limit to a small group of individuals, but for an abstracted release limit from a repository given as curies released per time per unit of nuclear fuel. The purpose of the containment requirements is to provide a level of protection for very large populations.[7]

Second, there are limits to the assumptions that need be made about the nature and extent of intrusion. For example, an implementing agency need not assume use of more exotic technology than that existing today-namely, use of standard well drilling techniques. Caps are specified for the number and frequency of well boreholes that need be assumed. In Appendix B of 40 CFR Part 191, the EPA states that "implementing agencies can assume that passive institutional controls or the intruders' own exploratory procedures are adequate for the intruders to soon detect, or be warned of, the incompatibility of the area with their activities." This suggests that as long as one can assume that the intruders are smart enough to quickly recognize that they are dealing with a radioactive waste disposal facility, one should also be able to assume that the intruders are smart enough to realize that any damage to the facility should be repaired.

In any event, the EPA's inclusion of the intruder requirement in 40 CFR 191 is controversial. In *Federal Register* Notices for the draft[74] and final[75] 10 CFR Part *60,* the NRC remarked that consideration of intrusion into a geological repository was of "no use" and "fanciful." Since that time, DOE, NRC, NRC's Advisory Committee on Nuclear Waste, and others have recommended that the EPA regard intrusion as a very unlikely event for purposes of compliance with the Part 191 standard. A National Research Council Symposium has also addressed the issue.[76]

Two recent actions of Congress have restricted the application of 40 CFR Part 191. In the Waste Isolation Pilot Plant (WIPP) Withdrawal Act, Congress has mandated that, except for certain sections of Part 191 (Sections 191.15 and 191.16, to be re-proposed by EPA), 40 CFR Part 191 is in effect for WIPP. Therefore, Section 191.13 is in effect for WIPP. However, the Act stipulates that 40 CFR Part 191 does not apply to the Yucca Mountain site under investigation for possible disposal of high-level waste and spent fuel.

For that site, under the National Energy Strategy Act, the EPA must promulgate regulations for release of radioactive material to the general environment in terms of "the maximum annual effective dose equivalent to individual members of the public." The regulations must be consistent with findings and recommendations of the National Academy of Science (NAS) on reasonable standards for protection of public health and safety. NAS is to specifically consider (1) whether a health-based standard based on dose to individuals represents a reasonable standard; (2) whether active institutional controls can preclude intrusion into the

disposal facility; and (3) whether the probability of intrusion can be predicted over 10,000 years.

2.19.3.3 Intrusion versus Natural Processes. Although it could be argued that inadvertent intrusion and natural processes both involve events that could degrade the effectiveness of infiltration barriers over LLW disposal units, or could enhance possible transport through environmental pathways, only the latter is reasonable for consideration in all-pathways analyses.

Because all inadvertent intruder scenarios involve assumptions about the actions of humans in the future, countless numbers of possible scenarios could be envisioned. There is no way to authoritatively predict the kinds of human actions that might occur in the future, nor the levels of technologies nor social structures. Thus, there is no way to authoritatively predict the effects an intruder might have on infiltration barriers and environmental pathways. If one did consider intrusion as part of the all-pathways analyses, a Catch-22 situation could result. No matter how favorable the site environment or how extensive the natural or engineered barriers, releases to the environment could be speculated merely by assuming that favorable site characteristics and barriers are bypassed. (It is in the nature of intrusion calculations to assume that barriers are bypassed.)

On the other hand, although intrusion events are hypothetical by nature, and may never occur, natural processes should be expected to occur. To be sure, there are large uncertainties in projecting natural processes into the distant future. However, it is believed that the kinds of natural processes that need to be considered can be reasonably bounded, as can their effects.

(For example, one can project typical activities and burrowing depths of animals such as gophers without having to consider whether the gophers will employ heavy construction equipment.) By considering possible degradation to the disposal system caused by natural processes, one is also effectively considering the kinds of possible degradation effects that can be hypothesized as resulting from inadvertent intrusion. However, one is on firmer footing for the performance assessment.

NRC Comment 64: Considering the uncertainties in long-term engineered cap performance and the long-term weathering rate of the grout, long-term intruder doses (>1000 years) from direct disruption of the waste should be evaluated.

Basis: Analysis presented in References 1 and 3 suggest that intruder doses may be sensitive to exposure pathways (agricultural) and the amount of shielding present at the time of the scenario. The exposure pathways evaluated and the amount of shielding present are in turn dependent on the performance of the gravel layer in the engineered cap (see Comment 22) and the integrity of the saltstone and vault (see Comment 43). Maintenance of the physical integrity of the saltstone is the basis for excluding the well-driller intruder scenario for the entire 10,000 year performance period (pg. 57 of [4]). The performance of the gravel layer for 10,000 years is the basis for eliminating the agricultural scenario and for the amount of shielding in the intruder resident scenario.

Path Forward: Provide analysis of the long-term intruder doses from direct disruption of the waste. It should be noted that this is an acceptable mechanism toaddress technical issues and uncertainties discussed in other comments.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and those in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

<u>Post Drilling Scenario after 1000 years Post Closure</u>

In the Vault 4 SA, a number of sensitivity cases were analyzed. In one of these (Section 7.5.3 of Cook et al. 2005) it was assumed that the Saltstone vault is no longer a deterrent to intrusion after 1000 years post-closure and that a well is drilled through the disposal vault at that time. The analysis of the post-drilling scenario was carried out over the time period of 1000 years to 10,000 years post-closure. Radionuclide disposal limits were developed from this case (Table B-5 of Cook et al 2005). The projected inventory of Vault 4 gives a sum-of-fractions of these limits of 0.31, which indicates the intruder post-drilling scenario produces a dose of 31 mrem/year. However, this use of the disposal limits to estimate doses is very conservative since it assumes that peak doses from all the radionuclides are coincident in time.

<u>Agriculture Scenario Following Failure of Erosion Barrier</u>

Another sensitivity case was run, which assumed that the erosion barrier eroded at the same rate as soil (Section 7.5.4 of Cook et al. 2005). This allows the intruder in the agriculture scenario, after sufficient depth of the closure cover has eroded away, to excavate into the disposed waste. Radionuclide disposal limits for this case were determined over a 10,000-year time frame and are listed in Table 7-9 of Cook et al. 2005. The projected inventory of Vault 4 gives a sum-of-fractions of these limits of 1.49, which indicates the intruder agriculture scenario produces a dose of 149

mrem/year. However, as noted above, this is a very conservative interpretation of the limits since it presumes that the peak doses from all the radionuclides are coincident in time.

Examination of the time at which the dose from each radionuclide in this scenario peaks in Table 7-9 of Cook et al. 2005 shows that the doses from the radionuclides contributing >98% of the sum-of-fractions occur at three widely-spaced time intervals. The results for these radionuclides are summarized in the table below.

Summary of Doses from Intruder Agriculture Scenario Following Failure of Erosion Barrier[a]			
Time of Limit, years[b]	Radionuclide	Inventory Fraction of Limit[c]	Total Dose per time period, mrem/year[d]
1132	Am-241	0.138	67.2
	Pu-241	0.0148	
	Sn-126	0.519	
3275	Pu-239	0.0943	31.9
	Pu-240	0.135	
	Tc-99	0.0898	
10,000	Np-237	0.0293	47.6
	Pu-238	0.0185	
	U-233	0.325	
	U-234	0.103	

a. From Section 7.5.4 of Cook et al 2005.
b. From Table 7-9 of Cook et al 2005.
c. From Table 7-10 of Cook et al 2005.
d. Sum-of-Fractions of limits for the time period multiplied by 100 mrem/year.

The analysis presented in the table shows that the agriculture intruder scenario would actually produce a maximum dose of 67.2 mrem/year. Note that the contribution from other radionuclides, including I-129 and Se-79, were considered but their contribution to the intruder dose were negligible compared to the nuclides cited in the table above.

This scenario is judged to be incredible because the erosion barrier is constructed of material sized to remain in place during a rainfall event with a 10,000-year recurrence interval calculated using an extreme-value distribution (i.e., 3.3 inches of rain in a 15 minute time span, [Weber 1998]).

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, SC. May 2005.

Weber, A. H. 1998. *Tornado, Maximum Wind Gust and Extreme Rainfall Event Recurrence Frequencies at the Savannah River Site*, WSRC-TR-98-00329. Westinghouse Savannah River Company, Aiken SC.

NRC Comment 65: Two types of averaging are applied in the direct exposure intruder analysis that may not be appropriate considering the volume of waste to be disposed of.

Basis: Page 4-26 of Reference 3 indicates that "the use of the average concentrations of radionuclides in a disposal vault, rather than the maximum concentrations at any location in a vault, is appropriate when an inadvertent intruder would access a vault at random locations". From a risk perspective, the statement is correct. However, the information provided in Reference 4 shows that each waste stream may in fact be different classes of waste (Class A, B, or C). Thus the risk from each type of vault should be provided, unless the waste streams are going to be mixed prior to emplacement in the vaults. The reduced likelihood of the scenario occurring is already accounted for in the application of a 500 mrem/yr limit to the intruder scenarios as compared to the application of a 25 mrem/yr limit to the nominal scenario. Use of the average concentration is not appropriately protective if the volume of more highly concentrated waste would fill an area that is consistent with the exposure scenario. If the volume of waste is considerably smaller than the area used in the exposure scenario, then averaging would be appropriate. In addition, a dilution factor of 0.6 is applied to account for the probability of putting a house down on an area between vaults. As indicated with respect to waste concentrations, the likelihood of the scenario occurring is accounted for in application of the higher limit.

Path Forward: The full range of results for waste type and receptor location should be provided that would allow for comparison with the performance objectives of 10 CFR 61, Subpart C.

SRS Response: The analyses in the 1992 PA (reference 1 in the NRC RAI) have been supplemented and the analyses in the 2002 Special Analysis (SA) (reference 3 in the NRC RAI) have been superseded by the Vault 4 SA (Cook et al. 2005).

The projected salt waste concentrations for salt batches into Fiscal Year 2014 (SWPF Batch #14) have been estimated (d'Entremont & Drumm 2005) versus average concentrations used previously. Table 65-1 presents the revised projected inventory for Vault 4. The intruder analysis dose is a result of the direct resident exposure scenario and therefore Cs-137 is the dominating radionuclide for the intruder dose.

The radionuclide disposal limits determined in the Vault 4 SA within the 10,000-year evaluation period are shown in Table 7-2 of Cook et al. 2005 (attached). Comparison of the projected Vault 4 inventory to the disposal limits indicates an intruder dose of approximately 22 mrem/year as shown in Table 5-4 of Rosenberger et al. (2005) Cesium-137 contributes approximately 95% of the intruder dose.

The data in Table 65-2 shown below for the individual batch Cs-137 concentrations indicates that the Cs-137 content of Vault 4 will be the highest of any of the Saltstone Vaults yet to be built due to the presence of the DDA waste stream. Cs-137 is the primary contributor to intruder dose. Since the Cs-137 inventory in Vault 4 will be

greater than any other Saltstone vault, the intruder analysis presented in the Vault 4 SA is bounding from the perspective of radionuclide inventory.

If the geometrical reduction factor (see Table B-2 of Cook et al. 2005), which is applied to account for the probability of putting a house on an area between vaults, was not applied, the dose from the resident intruder analysis would be approximately 36 mrem/year instead of 22 mrem/year. This larger dose is well below the NRC performance objective for intruder protection of 500 mrem/year.

References:

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P. 2005. *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, May 2005.

d'Entremont, P. D. & Drumm, M. D. 2005. *Radionuclide Concentrations in Saltstone*, CBU-PIT-2005-00013, Revision 3, June 2005.

Table 65-1 Projected Vault 4 Radionuclide Inventory

Radionuclide	Curies	Radionuclide	Curies	Radionuclide	Curies
H-3	2.43E+03	Cs-137	1.20E+06	Np-237	5.76E-01
C-14	6.88E+01	Ba-137m	1.13E+06	Pu-238	3.69E+03
Na-22	2.59E+02	Ce-144	3.46E-01	Pu-239	3.36E+01
Al-26	1.03E+00	Pr-144	3.46E-01	Pu-240	8.39E+00
Ni-59	3.46E-01	Pm-147	2.93E+02	Pu-241	1.72E+02
Co-60	4.46E+01	Sm-151	3.04E+02	Pu-242	9.32E-03
Ni-63	8.77E+01	Eu-152	1.48E+00	Am-241	1.44E+01
Se-79	1.96E+00	Eu-154	8.10E+01	Am-242m	7.52E-03
Sr-90	5.29E+03	Eu-155	1.72E+01	Pu-244	9.38E-06
Y-90	5.29E+03	Ra-226	2.44E-01	Am-243	6.22E-03
Nb-94	1.02E-03	Ra-228	6.41E-06	Cm-242	6.21E-03
Tc-99	7.16E+02	Ac-227	1.37E-06	Cm-243	2.88E-03
Ru-106	4.82E+01	Th-229	2.79E-03	Cm-244	3.16E+00
Rh-106	4.82E+01	Th-230	1.49E-03	Cm-245	3.03E-04
Sb-125	2.05E+02	Pa-231	3.80E-06	Cm-247	5.55E-13
Te-125m	4.98E+01	Th-232	6.41E-06	Cm-248	5.79E-13
Sn-126	9.56E+00	U-232	9.52E-03	Bk-249	4.23E-20
Sb-126	1.33E+00	U-233	9.82E-01	Cf-249	3.21E-12
Sb-126m	9.50E+00	U-234	6.59E+00	Cf-251	2.47E-01
I-129	4.40E-01	U-235	7.41E-02	Cf-252	3.56E-15
Cs-134	2.40E+03	U-236	1.42E-01		
Cs-135	4.14E+00	U-238	1.61E-01		

Based on the projected volume of salt waste batches (d'Entremont & Drumm 2005) and the volume remaining to be filled in Vault 4, Vault 4 will contain all of batches zero through 7 and about 50% of batch 8.

Table 65-2 Projected Salt Batches		
Batch Number	^{137}Cs, Ci/gal	Volume, gallons
0	2.54E-05	750,000
1	1.85E-01	1,250,000
2	2.01E-01	775,000
3	1.42E-01	1,800,000
4	1.88E-01	1,140,000
5	1.86E-01	1,135,000
6 (MCU)	5.83E-02	1,440,000
7 (MCU + DDA)	1.64E-02	1,225,000
8 (MCU)	3.30E-02	1,400,000
9 (MCU + DDA)	1.05E-01	1,230,000
SWPF Average	2.89E-05	95,800,000

From Tables A-9 and A-12 of d'Entremont & Drumm 2005

Table 7-2. Disposal Limits for Vault 4 Based on 10,000-Year Time of Compliance, Ci						
	Pathway					
Radionuclide	Groundwater	Resident Intruder	Atmospheric	Radon	All Pathways	Most Restrictive
Ac-227		8.8E+07				8.8E+07
Ag-108m		5.7E+03				5.7E+03
Al-26	6.5E+10	1.6E+02			2.3E+10	1.6E+02
Am-241		3.4E+08				3.4E+08
Am-242m		9.8E+06				9.8E+06
Am-243		3.0E+05				3.0E+05
Ba-133		1.2E+10				1.2E+10
Bi-207		3.1E+05				3.1E+05
Bk-249		4.9E+07				4.9E+07
C-14			4.4E+07		1.1E+08	4.4E+07
Cf-249		1.3E+05				1.3E+05
Cf-250		3.1E+15				3.1E+15
Cf-251		1.8E+06				1.8E+06
Cf-252		6.3E+12				6.3E+12
Cl-36			1.5E+19		5.2E+18	5.2E+18
Cm-242		2.5E+09				2.5E+09
Cm-243		7.0E+09				7.0E+09
Cm-244		1.1E+15				1.1E+15
Cm-245		8.4E+06				8.4E+06
Cm-246		8.3E+12				8.3E+12
Cm-247		2.5E+04				2.5E+04
Cm-248		4.6E+07				4.6E+07
Co-60		5.8E+09				5.8E+09
Cs-134		4.1E+19				4.1E+19
Cs-135	8.1E+13					8.1E+13
Cs-137		6.0E+06				6.0E+06
Eu-152		6.4E+06				6.4E+06
Eu-154		1.2E+08				1.2E+08
Eu-155		1.1E+19				1.1E+19
H-3	1.8E+12		5.5E+11		1.3E+12	5.5E+11
I-129	2.2E+02		1.7E+14		4.0E+03	2.2E+02
K-40	1.3E+05	3.2E+03			1.3E+04	3.2E+03
Kr-85		2.7E+11				2.7E+11
Mo-93	1.4E+06				6.2E+05	6.2E+05
Na-22		7.8E+15				7.8E+15
Nb-93m					1.5E+05	1.5E+05
Nb-94	8.6E+19	1.0E+03			7.0E+17	1.0E+03
Ni-59	2.5E+17				1.6E+19	2.5E+17
Np-237	6.6E+19	6.7E+04			8.9E+18	6.7E+04
Pa-231		2.2E+04				2.2E+04

Table 7-2. Disposal Limits for Vault 4 Based on 10,000-Year Time of Compliance, Ci						
	Pathway					
Radionuclide	Groundwater	Resident Intruder	Atmospheric	Radon	All Pathways	Most Restrictive
Pb-210		3.9E+11				3.9E+11
Pd-107	4.4E+16				1.8E+17	4.4E+16
Pu-238		1.3E+07				1.3E+07
Pu-239		1.4E+10				1.4E+10
Pu-240		3.0E+12				3.0E+12
Pu-241		1.0E+10				1.0E+10
Pu-242		4.9E+10				4.9E+10
Pu-244		3.7E+03				3.7E+03
Ra-226	4.8E+16	4.2E+02		1.1E+12	3.8E+16	4.2E+02
Ra-228		3.7E+08				3.7E+08
Rb-87	1.7E+13				5.1E+09	5.1E+09
Sb-125		1.4E+17	3.0E+47			1.4E+17
Se-79	3.8E+04		4.8E+06		1.0E+03	1.0E+03
Sn-126		1.2E+03	6.4E+62		2.9E+19	1.2E+03
Sr-90	2.4E+16				1.4E+17	2.4E+16
Tc-99	4.5E+17	3.7E+13			1.1E+17	3.7E+13
Th-228		1.9E+19				1.9E+19
Th-229		8.6E+03				8.6E+03
Th-230	1.1E+16	3.3E+02				3.3E+02
Th-232		1.6E+02				1.6E+02
U-232		9.0E+03				9.0E+03
U-233		1.4E+04				1.4E+04
U-234	1.5E+18	4.5E+03				4.5E+03
U-235		1.0E+05				1.0E+05
U-236		3.2E+08				3.2E+08
U-238		6.6E+04				6.6E+04

NRC Comment 66: The pathway screening procedure in Reference 1 was based on estimates of waste concentration in 1992. It is unclear that the pathway screening analysis was reevaluated in the more recent documents [3, 4] based on the updated waste concentrations.

Basis: The concentrations of many radionuclides in the projected waste composition in 1992 were significantly lower than projected concentrations in the Low Curie Salt evaluated in 2002 or the DDA waste evaluated in 2005. Pathways may have been eliminated based on the composition of waste in 1992 that would not have been eliminated based on the new waste composition.

Path Forward: Provide a revised pathway screening analysis based on current waste concentrations.

SRS Response: The pathway screening process used by SRNL is not based on radionuclide concentration; rather it considers the nature of the environment at SRS and the ways in which contaminants can get from the waste to members of the public. Therefore, the pathway screening analysis performed in 1992 is still applicable for DOE's current salt waste disposal plans. The implementation of the pathway screening process at SRS is described below.

The analysis shows that the significant exposure pathways involve transport by either groundwater or air. The actual exposure pathways involving water that were analyzed in the Vault 4 Special Analysis (Cook et al. 2005, Section 6) are those included in the LADTAP XL program (Simpkins 2004), i.e., ingestion of water, meat, milk and fish, shoreline exposure, swimming and boating. The exposure pathways involving atmospheric transport, analyzed using the CAP88 program (Beres, D. A. 1990), are inhalation, ingestion, plume shine and ground shine

SRNL Pathway Screening

In order to evaluate the potential sources of off-site contamination, numerous pathways to human exposure from buried LLW are considered. A generalized diagram of pathways to human receptors from a subsurface source of radionuclides is shown in Figure 66-1. Arrows (both broken and solid) represent pathways of radionuclide movement from the source, between compartments (represented by boxes), and eventually to a human receptor.

For a subsurface source, radionuclides may be leached by infiltrating water into underlying aquifers or isolated perched water zones, they may diffuse in the air-filled voids in the soil to the ground surface, or they may be moved to the surface (cover) soil by burrowing animals or deep tree roots. Radionuclides that are leached to groundwater may be ingested by humans directly, transported to the ground surface as a result of irrigation with groundwater, or they may eventually reach surface water at locations where there are seeps or streams.

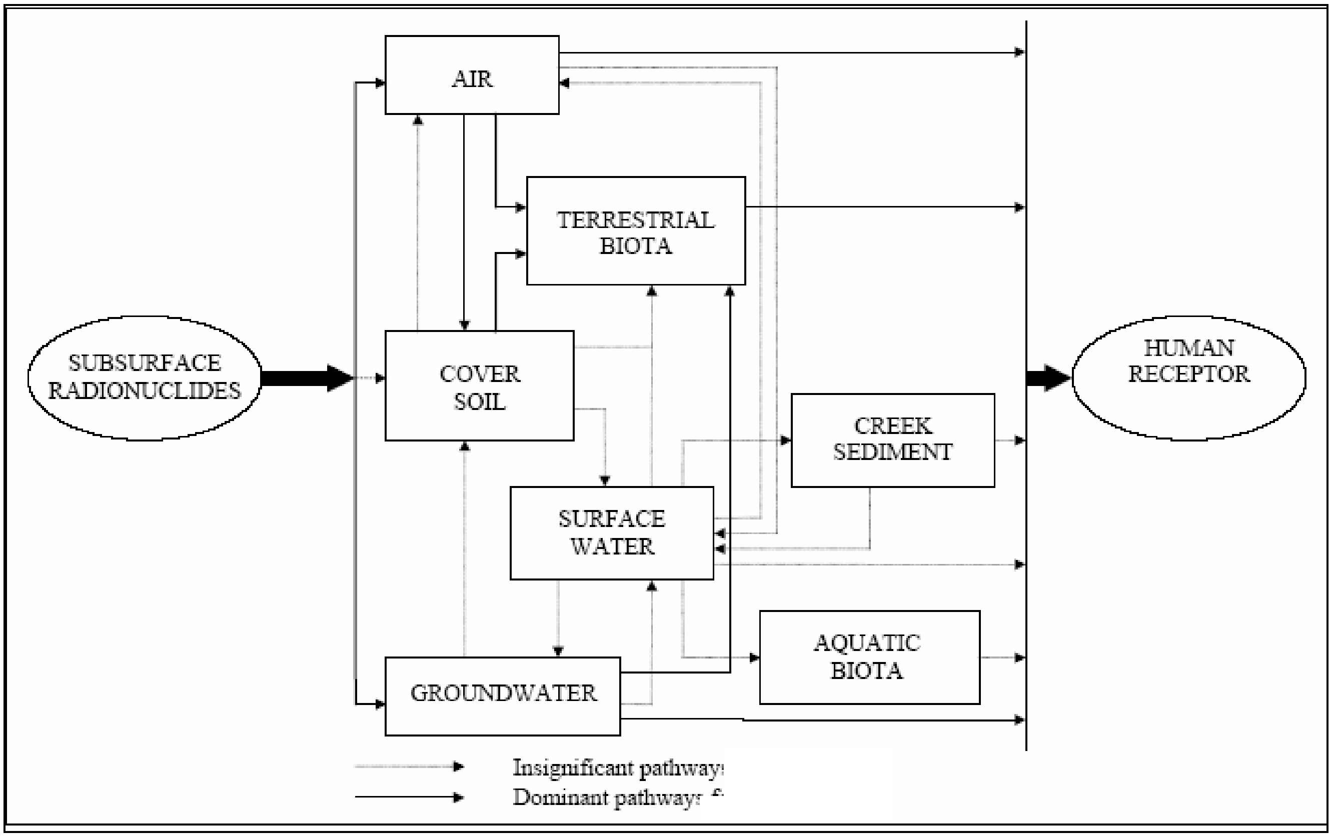

Figure 66-1 Pathways to Human Receptors from Subsurface Radionuclides

The arrow leading directly from the "Groundwater" box in Figure 66-1 to the human receptor is solid, indicating that this pathway is considered a potentially significant route of human exposure. Radionuclides may move through groundwater either as dissolved constituents or in a suspended colloidal form. Colloidal migration is a very dynamic process. As suspended colloids encounter slight changes in water chemistry or flow rate along a flow path, they may either deposit on the immobile soil surfaces, or become mobilized. Therefore, colloidal transport in natural aquifer media can be viewed as a process with attributes similar to those governing sorption and desorption of elements and compounds. Colloidal forms are not explicitly addressed for two reasons, discussed below.

First, colloidal forms are not directly addressed because reliable means of predicting site-specific colloidal influences on solute migration are not available. The types of colloids present are not readily measured, and thus the sorptive potential and stability of the colloids cannot be predicted. Second, colloids migrate according to complex physical and chemical immobilization and remobilization mechanisms. These mechanisms are not easily determined in non-idealized media such as natural aquifer materials. Because of these and other uncertainties, many conservative assumptions are used in the performance assessment to assure that these indeterminate effects attributable to colloids will not have a significant influence on the results.

For liquid transport, a sorption coefficient, normally referred to as a K_d, is used to partition a radionuclide between the solid and liquid phases. Coefficients for each

radionuclide are empirically determined, and are calculated from experimental tests that either measure "liquid phase" and solid phase concentrations of radionuclides, or measure the retardation that occurs as a result of reversible sorption processes when liquid constituents move through a porous medium. "Liquid phase" in both of these measurements is defined as that portion of the experimental media that passes through a filter of a specified pore size. Because of this definition, the "liquid phase" may actually contain some colloidal solid material that also passes through the filter. This colloidal material is very sorptive because the particles are small with a very high surface to volume ratio. Thus, an experimentally determined K_d may include the colloidal fraction passing through the filter, and may underestimate the true sorption potential of the porous media that is being tested. Because an experimental K_d may yield a liquid phase concentration that is greater than or equal to the true solubility of a radionuclide due to the presence of colloids, calculated doses from liquid pathways will always be conservative.

As depicted in Figure 66-1, radionuclides in groundwater may also exchange with surface water, via discharge and recharge, and with cover soil, via irrigation. These two pathways are considered relatively insignificant (as indicated by the broken arrows) for the following reasons.

The streams on the SRS are gaining streams; therefore, groundwater is not recharged by the streams and radionuclides discharged to the streams will not contaminate groundwater in locations downstream from Z-Area. This is indicated in Figure 66-1 by the broken line leaving the "Surface Water" compartment and entering the "Groundwater" compartment. Groundwater from beneath the GSA does discharge to local streams on the SRS (shown by a broken arrow leaving "Groundwater" and entering "Surface Water"); however, dilution is considerable in the nearby creeks. Groundwater in the vicinity of the disposal units is expected, therefore, to exceed surface water concentrations by orders of magnitude; thus, direct ingestion of groundwater will result in exposures exceeding those arising from less direct routes of exposure through aquatic food chains. For this reason, surface-water pathways (including those involving aquatic biota and creek sediment) were dropped from further consideration as potentially significant pathways to exposure.

Irrigation of cover soil by groundwater is practiced only occasionally in the SRS region, due to abundant precipitation during the growing season. Furthermore, groundwater under the SRS is intercepted by on-site surface water streams rather than flowing off-site, thus restricting the region of potential groundwater contamination. Therefore, groundwater irrigation, indicated in Figure 66-1 by a broken arrow between the "Groundwater" and "Cover Soil" compartments, is not an important pathway to cover soil, and ultimately to human exposure.

Volatile radionuclides that diffuse to the ground surface may be transported in air and eventually inhaled by humans. This pathway is shown in Figure 66-1 by a solid arrow from the subsurface radionuclide compartment to the air compartment. Volatile radionuclides may also exchange with the cover soil and terrestrial biota compartments. Deposition on cover soil and plant surfaces leads to exposure via ingestion of crops, milk or beef.

Based on the discussion above, only two sets of transport pathways are considered to be of significant consequence to exposures of off-site members of the public. These pathways, indicated by solid arrows in Figure 66-1, include: 1) leaching of the wasteform resulting in contamination of groundwater local to Z-Area, and both direct ingestion of that groundwater and ingestion of meat and milk arising from cattle that drink the contaminated groundwater; and 2) release of volatile radionuclides to air, subsequent contamination of agricultural soil, crops, and animals, inhalation of air and ingestion of food products contaminated by volatile radionuclides. The assessment of the release of volatile radionuclides to air is made using the CAP88 program (Beres, D.A. 1990). Therefore, the remaining pathway of concern in the all-pathways analysis is the pathway involving groundwater.

The nearest location from the disposal site for off-site members of the public depends on the time after disposal. During the period of active institutional control, i.e., for the first 100 years after facility closure, off-site members of the public are assumed to be located no closer to the disposal site than the present boundary of the SRS.

However, after active institutional control ceases, off-site members of the public could be located as close as 100 meters from the Z-Area disposal vaults. Because of such factors as 1) the design and closure concept for the disposal units that are intended to inhibit infiltration of precipitation, 2) the considerable distance from the disposal site to the present boundary of the SRS, and 3) the expected discharge of contaminated groundwater to surface streams within the SRS and the considerable dilution in radionuclide concentrations provided by such discharge, it is reasonable to conclude that the dose analysis for off-site members of the public can focus on exposure pathways resulting from use of contaminated groundwater at distances from the disposal units as close as 100 meters for the time period after active institutional control ceases. Thus, in the dose analysis for the groundwater pathway, an off-site member of the public is assumed to use water from a well for domestic purposes, and the well is assumed to be at the location at least 100 meters from the disposal units where the maximum concentrations of radionuclides in groundwater are predicted to occur after loss of active institutional control.

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References:

Beres, D. A. 1990. The Clean Air Act Assessment Package-1988 (CAPP88) A Dose and Risk Assessment Methodology for Radionuclide Emissions to Air. U.S. Environmental Protection Agency Contract No. 68-D9-0170. Washington DC

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., Special Analysis: Revision of Saltstone Vault 4 Disposal Limits, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Simpkins, A. A. 2004. LADTAP XL©: A Spreadsheet for Estimating Dose Resulting from Aqueous Releases. WSRC-TR-2004-00059. Westinghouse Savannah River Company, Aiken, South Carolina.

NRC Comment 67: The argument for eliminating the biointrusion pathway in Reference 1 may no longer be appropriate.

Basis: In Reference 1, one of the arguments for eliminating the biointrusion pathway as an exposure pathway was that the other pathways would have a more significant contribution due to the disruption of larger quantities of waste. However, in References 3 and 4 these other more significant pathways have been proposed to be eliminated with the revised design, whereas the biointrusion pathway may not have been eliminated in the revised design, depending on the depth of cover provided and the degradation rate of the waste.

Path Forward: Reevaluate the biointrusion pathway in the current analysis, or describe why it is still considered appropriate to screen out this pathway.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and the analyses in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (Cook et al. 2005).

The current Z-Area closure configuration (Section 4.0 of Phifer and Nelson 2003) calls for a geosynthetic cover system instead of a kaolin cap as assumed in the 1992 PA (see Figure 4.7-1 from Phifer and Nelson 2003, attached). 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., pine trees) and silting of drainage layers (see Table 5.4-1 from Phifer and Nelson 2003, attached). While it is assumed that tree root penetration will contribute to closure system degradation, tree roots will not penetrate into the saltstone grout 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, including pine 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 rather than penetrate.
- The pore fluid within the saltstone grout 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 grout due to the matrix potential (i.e., the force required to extract water from the saltstone grout pores).

Reference:

Phifer, Mark A. and Nelson, Eric A. 2003. *Saltstone Disposal Facility Closure Cap Configuration and Degradation Base Case: Institutional Control to Pine Forest*. WSRC-TR-2003-00436. Westinghouse Savannah River Company, Savannah River Site, Aiken, SC.

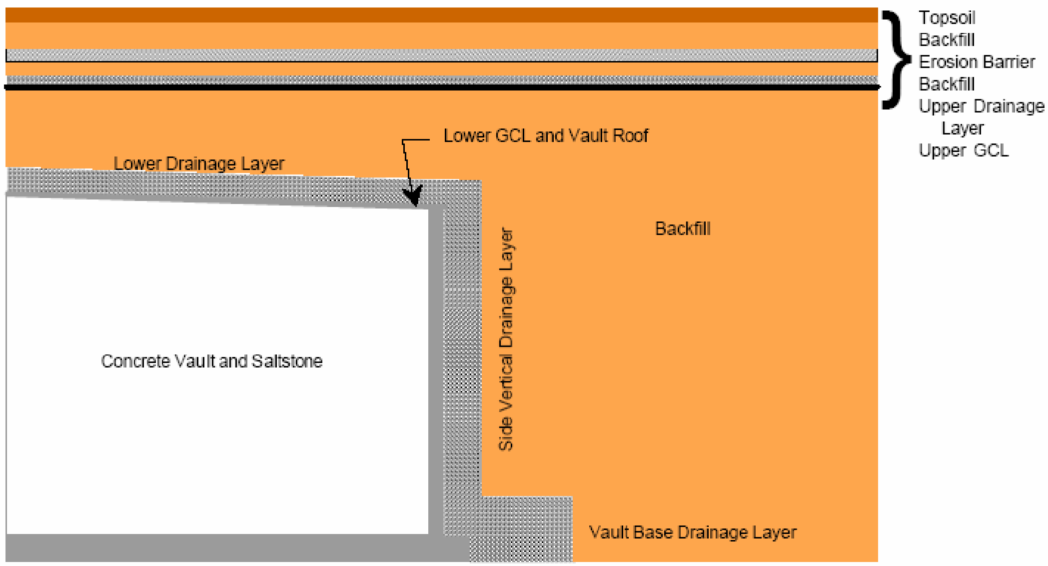

Figure 4.7-1. SDF GCL Closure Cap Configuration

Table 5.4-1. SDF GCL Closure Cap Layer Degradation Scenarios

Layer	Degradation Scenario
Vegetation	Bamboo is maintained during the 100-year institutional control period, pine trees begin to encroach upon the bamboo at the end of institutional control, and a pine forest covers the cap 200 years after the end of institutional control.
Topsoil	Topsoil erosion occurs at 1.8E-04 inches per year.
Upper Backfill	Backfill erosion occurs at 1.1E-04 inches per years, after the topsoil layer has been depleted.
Erosion Control Barrier	Maintenance during institutional control period prevents degradation of the erosion control barrier. However pine forest succession and associated root penetration results in holes through the erosion control barrier. This does not impact its ability to function as an erosion barrier, however it allows the overlying backfill to fill the holes left after the roots decompose.
Middle Backfill	Colloidal clay migration from the 1-foot-thick middle backfill to the underlying 1-foot-thick upper drainage layer causes the saturated hydraulic conductivity to increase over time.
Geotextile Filter Fabric	For purposes of colloidal clay migration into the underlying drainage layer the geotextile filter fabric is assumed to be ineffective over the time period under consideration.
Upper Drainage Layer	Colloidal clay migration from the overlying 1-foot-thick backfill into the 1-foot-thick upper drainage layer causes the saturated hydraulic conductivity to decrease over time.
Upper GCL	Maintenance during institutional control period prevents degradation of the upper GCL. However pine forest succession and associated root penetration results in holes through the GCL. This allows the overlying drainage layer to fill the holes after the roots decompose.
Lower Backfill	None. While it is assumed that colloidal clay migration from this layer to the underlying lower drainage layer occurs, it is also assumed that the thickness of the lower backfill layer (almost 5-foot) relative to the lower drainage layer (2-foot) prevents the quantity of clay loss necessary to change the hydraulic properties of the lower backfill.
Geotextile Filter Fabric	For purposes of colloidal clay migration into the underlying drainage layer the geotextile filter fabric is assumed to be ineffective over the time period under consideration.
Lower Drainage Layer	Colloidal clay migration from the overlying ~5-foot-thick lower backfill into the 1-foot-thick lower drainage layer reduces its saturated hydraulic conductivity over time.
Lower GCL	None. Pine tree roots do not penetration to a sufficient enough depth to impact this layer. Additionally the underlying concrete vault roof along with the GCL produces a hard layer and continuous water saturation within and above these layers so that root elongation is stopped.
Side Vertical Drainage Layer [1]	None, until the vault base drainage layer has been filled with colloidal clay.
Vault Base Drainage Layer [1]	Colloidal clay migrates from the overlying ~30-foot-thick backfill into the 5-foot-thick drainage layer reduces its saturated hydraulic conductivity over time.

[1] These layers are not included in the HELP model for determination of the infiltration through the upper GCL. However their degradation properties will be included in the subsequent PORFLOW vadose zone modeling.

NRC Comment 68: The approach to eliminate exposure pathways is based on deterministic values of parameters such as K_d values and B_v values (soil-to-plant transfer factor). This approach is not adequate unless the parameter values are sufficiently conservative or supported by site-specific data.

Basis: The relative importance of the exposure pathways can be very sensitive to the parameter values selected in the screening process. As an example, the calculated result that the Tc-99 water pathway exceeds the vegetable pathway by a factor of 4 can change to 1/10 based on the selection of K_d and B_v within the range of natural variability.

Path Forward: For screening of exposure pathways, use sufficiently conservative parameters or site-specific data.

SRS Response: The analyses in the Saltstone PA (reference 1 in the NRC RAI) have been supplemented and the analyses in the 2002 Special Analysis (reference 3 in the NRC RAI) have been superseded by the Vault 4 Special Analysis (SA) (Cook et al. 2005).

The exposure pathways involving transport by water that were analyzed in the Vault 4 SA (Cook et al. 2005) are those included in the LADTAP program (Simpkins 2004), i.e., water ingestion, fish ingestion, shoreline exposure, swimming and boating. The pathways involving atmospheric transport, analyzed using CAP88 (Chaki, S. 2002), are inhalation, ingestion, plume shine and ground shine.

In all SRS dose models, site-specific data are used where appropriate. A Land and Water Use Study was performed (Hamby 1991) and parameters for the adult individual are shown in Table 68-1. The SRS value is used for all parameters.

Table 68-1. SRS Adult Maximum Individual Usage Parameters

Land Usage	**Units**	**NRC Default**	**SRS Value**
Leafy Veg Consumption	kg/yr	64	43
Other Veg Consumption	kg/yr	520	276
Meat Consumption	kg/yr	110	81
Milk Consumption	L/yr	310	230
Water Usage			
Water consumption	L/yr	730	730
Fish consumption	kg/yr	21	19
Invertebrate consumption	kg/yr	5	8
Recreational shoreline usage	hr/yr	12	23

Other agricultural site-specific parameters are shown in Table 68-2. The SRS value is used for all parameters.

Table 68-2. SRS Site Specific Agricultural Parameters

Parameters	Units	NRC default	SRS Value
beef-cow forage consumption (wet)	kg/day	50	36
milk-cow forage consumption(wet)	kg/day	50	52
pasture-grass exposure time	days	30	30
crop exposure time	days	60	70
agricultural productivity (pasture grass)	kg/m^2	0.7	1.8
agricultural productivity (stored feed)	kg/m^2	2	0.7
vegetable garden productivity	kg/m^2	2	0.7
transport time (feed-milk-man)	days	4	3
holdup time (pasture grass, forage)	days	0	0
holdup time (stored feed	days	90	90
fraction of time milk-cow on pasture	-	0.75	1
fraction of time goats spend on pasture	-		0.79
fraction of time beef-cow on pasture	-	0.75	1
fraction of intake from pasture (milk cow)	-	1	0.56
fraction of intake from pasture (goat)	-		0.85
fraction of intake from pasture (beef cow)	-	1	0.75
time from slaughter to consumption	days	20	6
fraction of leafy veg from garden	-	1	1
fraction of other veg from garden	-	0.76	0.76
transport time (leafy veg, produce;pop)	days	14	14
transport time (leafty veg MI	days	1	1
transport time (produce; MI)	days	60	60

Radionuclide specific parameters for bioaccumulation in plants, meat, milk or fish are taken from Hamby 1991 with the exception of Cs-137 bioaccumulation in fish which is based on other site-specific data (Jannik 2003).

LADTAP, an NRC code, and CAP88, an EPA code, use parameters endorsed by the NRC and the EPA, and are part of the SRS regulatory reporting program. The non-SRS parameters are provided by the NRC and the EPA and are considered conservative.

References:

Chaki, S., 2002, CAP88-PC Version 3.0 User Guide, Draft Revision 1, Trinity Engineering Associates, Inc. Cincinnati, OH. August 2002.

Cook, J.R., Wilhite, E.L, Hiergesell, R.A., and Flach, G.P., 2005, *Special Analysis: Revision of Saltstone Vault 4 Disposal Limits*, WSRC-TR-2005-00074, Westinghouse Savannah River Company, Aiken, South Carolina. May 2005.

Hamby, D.M. 1991, Land and Water Use Characteristics in the Vicinity of the Savannah River Site, Westinghouse Savannah River Company Report: WSRC-RP-91-17, Aiken, SC March 1991.

Jannik, G.T. 2003, Cesium-137 Bioconcentration Factor For Freshwater Fish In The SRS Environment, Westinghouse Savannah River Company Interoffice Memorandum SRTC-EST-2003-00134, Aiken, SC 2003.

Simpkins, A. A. 2004. LADTAP XL©: A Spreadsheet for Estimating Dose Resulting from Aqueous Releases. WSRC-TR-2004-00059. Westinghouse Savannah River Company, Aiken, South Carolina.

<u>Response to NRC RAI Editorial Comments</u>:

EDITORIAL COMMENTS

1. Pg. 4-3 of [3]. Po-210 listed after Pb-210 should be Bi-210.

2. Pg. 6-2 of [3]. Is it the E-Area Disposal Facility?

3. Pg. 2-15 of [1]. The arithmetic mean for turbidity is outside of the range.

4. Pg. 2-43 of [1]. It is not clear that Tc-99 comprising 30.63% of the activity of the projected salt solution feed to saltstone is accurate considering its low specific activity.

5. Pg. A-10 of [1]. The scale on Figure A.1-5 has errors in the exponents.

6. Pg. A-40 of [1]. Table A.2-1 gives vertical hydraulic conductivities of 4E6 and 2E9 m/s. It appears the exponents are not correct.

7. Pg. A-40 of [1]. The effective diffusion in the saturated zone is estimated to be of 5E-6 cm/s. The units do not appear to be correct.

8. Pg. C-41 of [1]. Table C.4-3 lists a Kd for Se-79 of 5 cm3/g which is not consistent with the value given in Table A.1-2.

9. Pg. E-23 of [1]. The values given in Figure E.2-8 do not appear to be consistent with the text given on page E-21.

10. Pg. 10 of SRT-WED-93-203 [2]. Footnote d indicates that the result of 0.6 mrem/yr includes the effect of an increase in the hydraulic conductivity of the clay as well as increased hydraulic conductivity and effective diffusivity of the concrete and saltstone. However, the text seems to indicate that the 0.6 mrem/yr result is for an increase in the hydraulic conductivity of the clay and a cracked vault, not the scenario indicated.

11. Pg. 3 of the OPS-DTZ-94-0001 letter in Reference 2 indicates that even if the facility degrades sometime in the future, the results would still be two orders of magnitude below the 4 mrem/yr groundwater protection standard. This seems to conflict with the results found throughout the addendum.

12. Although a value of 880 mL/g for the effective Kd of Tc in saltstone is derived from chemical modeling (Appendix D of [1]), it is stated that a value of 700 mL/g was used in the performance assessment modeling (Table A-3).

REFERENCES

*[1] Cook, J. and J. Fowler. "**Radiological Performance Assessment** for the Z-Area Saltstone Disposal Facility (U)." WSRC–RP–92–1360. Rev. 0. Aiken, South Carolina: Westinghouse Savannah River Company. December 1992.*

*[2] WSRC, "**Addendum to the Radiological Performance Assessment** for the Z-Area Saltstone Disposal Facility at the Savannah River Site." WSRC-RP-98-00156, Rev. 0, Aiken, South Carolina: Westinghouse Savannah River Company. April 1998.*

*[3] Cook, J., D. Kocher, L. McDowell-Boyer, and E. Wilhite. "**Special Analysis**: Reevaluation of the Inadvertent Intruder, Groundwater, Air, and Radon Analyses for the Saltstone Disposal Facility." WSRC–TR–2002–00456. Rev. 0. Aiken, South Carolina: Westinghouse Savannah River Company. October 2002.*

SRS RESPONSE:

The editorial comments regarding clarity, accuracy, and consistency are on portions of documents referred to in the "Draft Section 3116 Determination [for] Salt Waste Disposal [at the] Savannah River Site." The items do not impact the accuracy of any of the analyses on which the waste determination is based. These items will be corrected or will be obviated by the publication of updated documents.

The "Special Analysis: Revision of Saltstone Vault 4 Disposal Limits," which was approved for use on June 17, 2005, supersedes RAI Reference 3 and obviates the comments on [3].

Since the comments are editorial in nature and do not impact the analyses nor the results of those analyses, the comments regarding the Radiological Performance Assessment (PA) of the Saltstone Disposal Facility [1] & [2] will be addressed in the next update of the Saltstone Disposal Facility Performance Assessment. This next update is being performed in accordance with the DOE PA maintenance process and is currently scheduled to be issued in November 2006.

REFERENCE:

Cook, J. R., et al. "Special Analysis: Revision of Saltstone Vault 4 Disposal Limits (U)." WSRC-TR-2005-00074. Westinghouse Savannah River Company, Aiken, South Carolina. March 26, 2005.