From: "Suttora, Linda" <Linda.Suttora@em.doe.gov>
To: "Xiaosong Yin" <XXY@nrc.gov>
Date: 06/29/2006 12:42:21 PM
Subject: Response to additional questions

Xiaosong-
Attached is the responses to additional questions from the 6/1 and 6/20 meeting that I mentioned in my earlier email.

<<DOE Responses to Additional_questions_DOE_ID_final_6-29-06.pdf>>

Linda Suttora
Office of Waste Processing, EM-21
Office of Engineering and Technology
Office of Environmental Management
(phone) 301-903-7921
(fax) 301-903-4307

CC: "Lockie, Keith A (NE-ID)" <lockieka@id.doe.gov>

Mail Envelope Properties (44A402DC.0F4 : 13 : 37108)

Subject:	Response to additional questions
Creation Date	06/29/2006 12:41:21 PM
From:	"Suttora, Linda" <Linda.Suttora@em.doe.gov>
Created By:	Linda.Suttora@em.doe.gov

Recipients
nrc.gov
TWGWPO04.HQGWDO01
XXY (Xiaosong Yin)

id.doe.gov
lockieka CC (Keith A (NE-ID) Lockie)

Post Office	**Route**
TWGWPO04.HQGWDO01	nrc.gov
	id.doe.gov

Files	**Size**	**Date & Time**
MESSAGE	362	06/29/2006 12:41:21 PM
TEXT.htm	1558	
DOE Responses to Additional_questions_DOE_ID_final_6-29-06.pdf	1371130	
Mime.822	1881063	

Options

Expiration Date:	None
Priority:	Standard
ReplyRequested:	No
Return Notification:	None
Concealed Subject:	No
Security:	Standard

Follow-up Items from June 1, 2006, Meeting with DOE on INL TFF Waste Determination

As committed by NRC staff at the conclusion of the June 1, 2006, meeting, the following list of follow-up items that require a response from DOE was provided. Information requested is based on the questions provided to DOE for this meeting as well as NRC's Request for Additional Information (RAI). DOE has provided responses following each request for information.

1. **Based on information provided in clarifying RAI #3 and as a follow-up to RAI #6, NRC requests the following information.**

DOE-ID should provide specifications or standards that will be imposed on the slag to ensure its suitability for cement blending and to ensure that it will release its content of reducing agents.

Response:

Attachment 1 provides the details of the vendor slag specification to be used in the Tank Farm Facility encapsulation pours. The vendor is contractually required to meet ASTM C-989 and the applicable quality assurance requirements have been specified. The slag will be stored in silos at the site of the batch plant and will remain dry at all times.

DOE-ID should provide additional justification regarding why the effect of stresses imposed by the large mass of grout and concrete to be emplaced in the tank and vault on the physical degradation of the concrete base mat can be neglected.

Response:

Load Capacity of the High-Level Waste Tank Base Slabs

Per Drawing Number 5773-CPP-WM-185-S-5, the base slab consists of 2.5-ft-thick, steel-reinforced concrete. General Note 3 states the base slab shall be at a 3,000-lb strength at 28 days. Because a sub-base slab is poured between the base slab and the bedrock, there is no opportunity for any shear load on the base slab, so strength calculations are based solely on compressive strength. No credit is taken for the additional strength provided by the steel reinforcing present in the base slab(s) or the sub-base.

Tank WM-185 was used for the example. Tank information from Table A-1 of the *Idaho Hazardous Waste Management Act/Resource Conservation and Recovery Act Closure Plan for Idaho Nuclear Technology and Engineering Center Tanks WM-184, WM-185, and WM-186* (DOE/ID-11067).

Tank diameter	50 ft
Tank height to springline	21 ft
Lower tank thickness	0.3125 in.
Upper tank thickness	0.25 in.
Dome height	8.5 ft
Approx. total tank volume	1,825 yd^3
Approx. total dome volume	300 yd^3

For conservative weight estimate, assume the tank is considered to be a cylinder with flat ends, 29.5 ft in height with a wall thickness of 0.3125 in., which is filled with hardened concrete (density of 150 lb/ft^3 – *Encyclopedia of Science and Technology*). The density of stainless steel is assumed to be 7.9 g/cm^3 (493 lb/ft^3) (*The Physics Factbook)*.

Based on the calculations that follow, filling the waste tanks with grout will not provide a compressive load on the base slab that approaches the strength requirements of the concrete used in pouring the high-level waste tank base slabs.

Calculations:

Area of tank base

$A = \pi r^2$ $\quad A = \pi (25')^2$ $\quad A = 1963.5 \text{ ft}^2$ (282,744 in.^{2})

Volume of cylinder

$V = \pi r^2 h$ $\quad V = \pi (25')^2 (29.5')$ $\quad V = 57{,}923 \text{ ft}^3$ (2,145 yd^3)

Weight of concrete = (vol. of cylinder) (density of concrete)

Weight of concrete = (57,923 ft^3) (150 lb/ft^3) = 8,688,450 lb

Weight of stainless steel = (vol. of outer cylinder – vol. of inner cylinder) (density of stainless steel) + (2) (vol of end) (density of stainless steel)

vol of outer cylinder = $\pi r^2 h = \pi (25')^2 (29.5') = 57{,}923 \text{ ft}^2$

vol of inner cylinder = $\pi r^2 h = \pi (25' - 0.026')^2 (29.5') = 57{,}802 \text{ ft}^3$

vol of end(s) = $\pi r^2 h = \pi (25')^2 (0.026') = 51.05 \text{ ft}^3$

Weight of stainless steel = [(57,923 ft^3 – 57,802 ft^3) + (2) (51.05 ft^3)] (493 lb/ft^3) = 109,988 lb

Total weight on slab = weight of concrete + weight of tank

= 8,688,450 lb + 109,988 lb = 8,798,438 lb

Weight per square inch of slab = 8,798,438 lb/282744 in^2 = 31.12 lb/in.^{2}

Compressive strength of base slab concrete = 3,000 lb/in.^{2}

Loading factor = 31.12 lb/in.^{2} / 3000 lb/in.^{2} = 0.0104

Tank and concrete will provide a nominal load of 1.04% of slab compressive strength, which allows for a very conservative load/strength safety factor (96).

2. **Based on information provided in response to RAIs #1 and #4, the following information is needed to determine if the uncertainty in the Np-237 inventory in the sand pad will have a significant impact on the modeling results and to help explain inconsistent modeling results for Sr-90 in response to RAI #4.**

DOE-ID should provide the K_ds used for Np-237 in the screening analysis, since DOE did not perform additional modeling of release and transport of Np-237, although the uncertainty in the inventory of Np-237 was much greater than it was for other modeled constituents in response to RAI #4.

Response:

The K_d values used for the screening analysis are provided in Table 3-1 of the performance assessment (PA) (DOE/ID-10966). Table 1 summarizes the K_d values used for ^{241}Pu, ^{241}Am, and ^{237}Np in the screening analysis.

Table 1. Sorption coefficients used in the screening analysis.

Radionuclide	Grout K_d (m^3/kg)	Sand K_d (m^3/kg)
^{241}Pu	5	0.55
^{241}Am	5	1.9
^{237}Np	5	0.005

The screening values for the tanks, provided in Table 3-2 of the PA were based on the grout K_d. The screening values for the sandpads, provided in Table 3-3 of the PA, were based on the sand K_d. The screening results provided in Tables 3-2 and 3-3 of the PA show that these radionuclides were not excluded during the first screening iteration. Therefore, contaminant release modeling was conducted using DUST-MS to evaluate the release from the tank/vault system. The results of this screening are provided in Figures F-28, F-29, and F-30 of the PA (shown below).

The controlling factor in the release of ^{241}Pu, ^{241}Am, and ^{237}Np from the tank/vault system is the grout K_d. The concrete K_d values for both oxidizing and reducing conditions are the same for ^{241}Pu, ^{241}Am, and ^{237}Np (i.e., 5 m^3/kg). The sandpad contaminants must pass through approximately 2 ft of the concrete vault floor. Figures F-28, F-29, and F-30 show the releases are delayed to approximately 10,000 years post-closure. Since the release of these contaminants was beyond the compliance period, no further modeling was conducted.

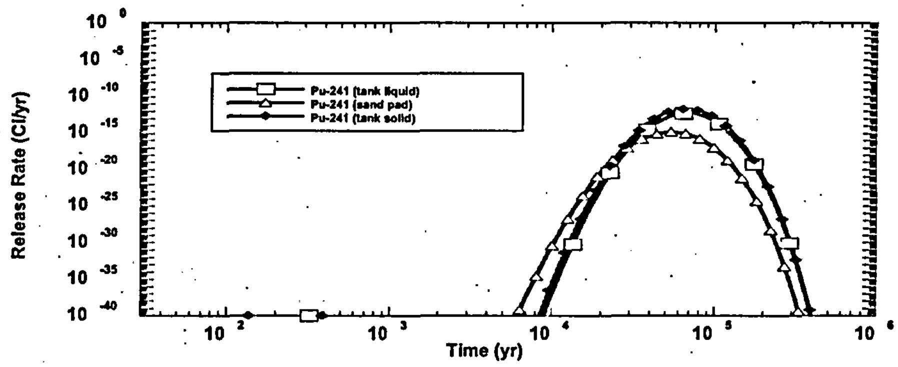

Figure F-28. Releases of ^{241}Pu from the sandpad and tanks (DOE/ID-10966).

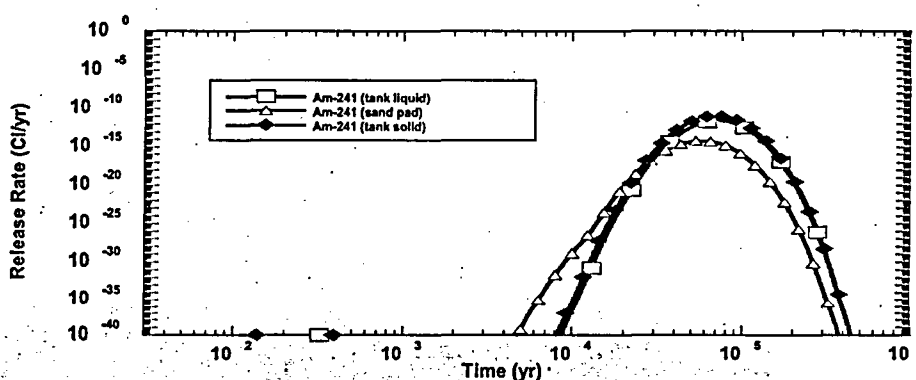

Figure F-29. Releases of ^{241}Am from the sandpad and tanks (DOE/ID-10966).

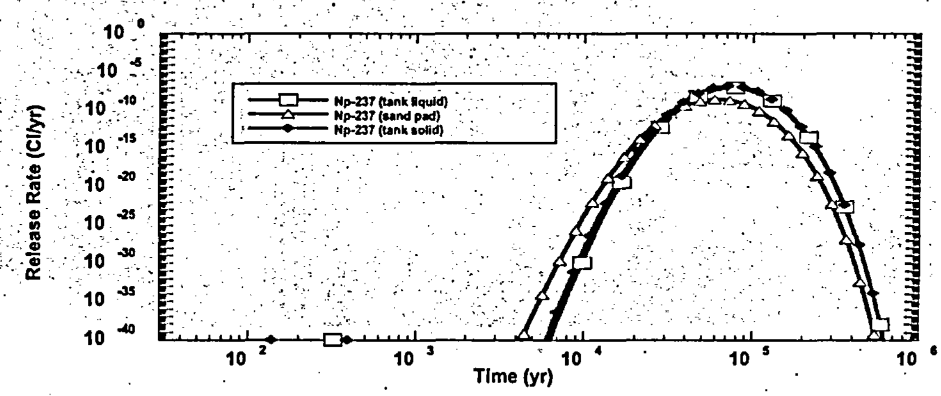

Figure F-30. Releases of ^{237}Np from the sandpad and tanks (DOE/ID-10966).

DOE-ID should explain the inconsistent and unexpected high sand pad inventory values for most of the low pH K_d sensitivity runs for Sr-90 contained within response to RAI #4.

Response:

During the creation of the tables in Word from Excel spreadsheets, selected cells were not tagged throughout the entire workbook, which resulted in incorrect numbers appearing in the low pH columns. Tables RAI-4-4 through RAI-4-6 provided in RAI #4 were impacted by these errors. The referenced engineering design file (PEI-EDF-1029) has been revised (specifically, Tables 6 through 8) and is included as Attachment 2.

3. **Based on new characterization data (ICP/EXT-04-00244) that show inconsistencies with DOE-IDs hydrogeologic conceptual model (HCM), NRC needs additional information to determine the implications of this new information on DOE-ID's modeling results. As a follow-up to information provided in response to RAIs 10, 11, 12, and 13, that addressed controlling hydrogeologic features and model support, NRC is requesting the following information:**

DOE-ID should provide the reference that contains a new west/east geologic cross-section B-B' that is illustrated in Figure 3-4 of "Evaluation of Tc-99 in Groundwater at INTEC: Summary of Phase I Results" (ICP/EXT-04-00244). The reference from ICP/EXT-04-00244 that contains this cross-section is "Phase 1 Monitoring Well and Tracer Study Report for Operable Unit 3-13, Group 4, Perched Water," DOE/ID-10967, Revision 1, 2003. DOE-ID did not provide the most recent geologic cross-sections for the study area in response to NRC RAI 12.

Response:

Revision 1 of DOE/ID-10967 (2003) is classified as "Official Use Only," which restricts its release to the public. A more recent revision, Revision 2, of this document is also classified as "Official Use Only." The requested cross-section (Figure B-12) has been cleared for release and is provided below. The cross-sections in DOE/ID-10967 are not considered to be more accurate than the Anderson cross-section used in the PA; the cross-sections are considered to be an additional interpretation of the geologic profile at INTEC.

The authors of the DOE/ID-10967 cross-sections note the following: "The cross-section correlations are interpretations based on individual well/borehole stratigraphic columns. Correlation of basalt flows and sedimentary interbeds between well locations without paleomagnetic, geochemical, K-Ar age dates, or petrographic data is possible but lacks a large degree of confidence." The authors also note that a detailed and accurate stratigraphic correlation beneath INTEC may not be possible given the currently available data. Collection of sufficient data to enable this accurate correlation would be cost-prohibitive.

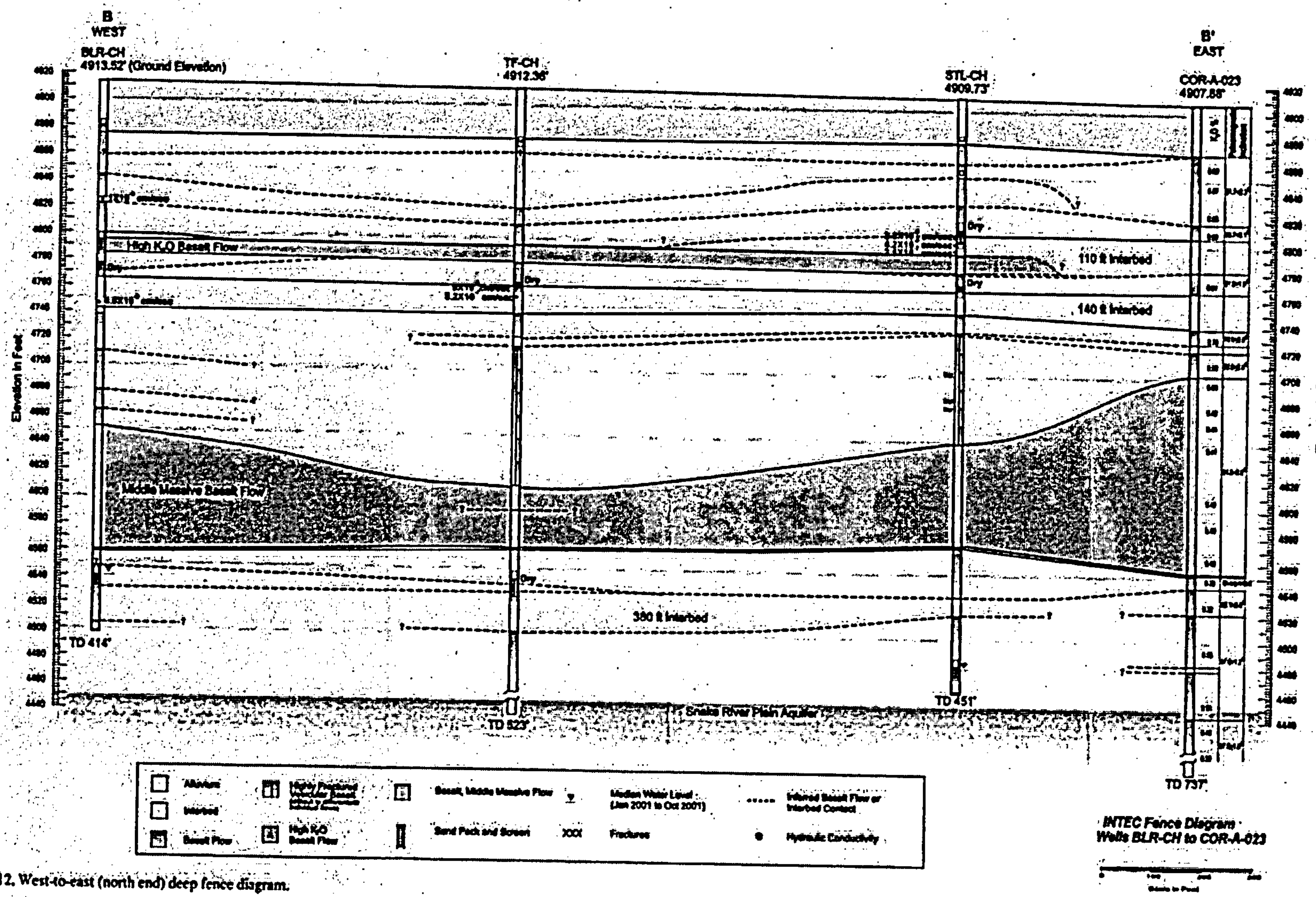

Figure B-12. West-to-east (north end) deep fence diagram.

5

DOE-ID should provide any additional reports documenting recent characterization activities related to the elevated Tc-99 monitoring well data that may provide additional information regarding the updated HCM for vadose zone flow at TFF.

Response:

Additional reports can be found on the INL website at: http://ar.inel.gov. Select the "Select All for Operable Unit (OU)" link and then select the "3-14" link. This database includes all of the recent OU 3-14 information.

DOE-ID should provide the approximate thickness and extent of perched zones in the final calibrated model in plan view along the cross-section, final calibrated heads at nearby monitoring well locations, and the hydrostratigraphic location of the top of the perched zones. Based on new information that shows the HCM for vadose zone flow at TFF has evolved based on collection of additional characterization data (ICP/EXT-04-0244), NRC needs additional information to determine the goodness of fit of the modeled versus observed heads, to determine the amount of dilution in the perched zones, and to estimate the magnitude of attenuation during lateral transport along the perched zone.

Response:

The data requested are not currently available. Development of these data requires another setup of the model to provide the specified parameters and several runs of the model. This is planned to be completed by July 15, 2006.

DOE-ID should provide center-line plume concentrations (as depicted in Figure 4-2 of the PA) as a function of time for modeled radionuclides at key locations in table format and a figure showing these locations. Locations should include the following grid cells: 1.) directly underneath the TFF in the perched water, 2.) near the "spillway" in the perched water, and 3.) in the saturated zone. DOE-ID revised the time of peak release for Tc-99 in Table 4-1 of the PA in response to RAI #13. The source of the error described in the RAI response is not clear. Furthermore, the travel time to saturated groundwater is difficult to determine with the use of scientific notation which truncates the year of maximum concentration in groundwater for Tc-99 (DOE-ID should provide the travel time in years). The information requested above is also needed to clarify to what extent Sr-90 concentrations are reduced due to attenuation in the 600 meters of lateral transport in the unsaturated zone, which cannot be determined easily from the currently available information.

Response:

The data requested are not currently available. Development of these data requires another setup of the model to provide the specified parameters and several runs of the model. This is planned to be completed by July 15, 2006.

DOE-ID should provide a new figure that shows an accurate depiction of the locations of sedimentary interbeds as shown in Figure 4-2 in the PA (the location of the sedimentary interbeds depicted on this figure is not consistent with Figure 2-12 in the PA).

Response:

A new figure is presented below as Figure 1, which shows the correct interbed location in Figure 4-2 of the PA.

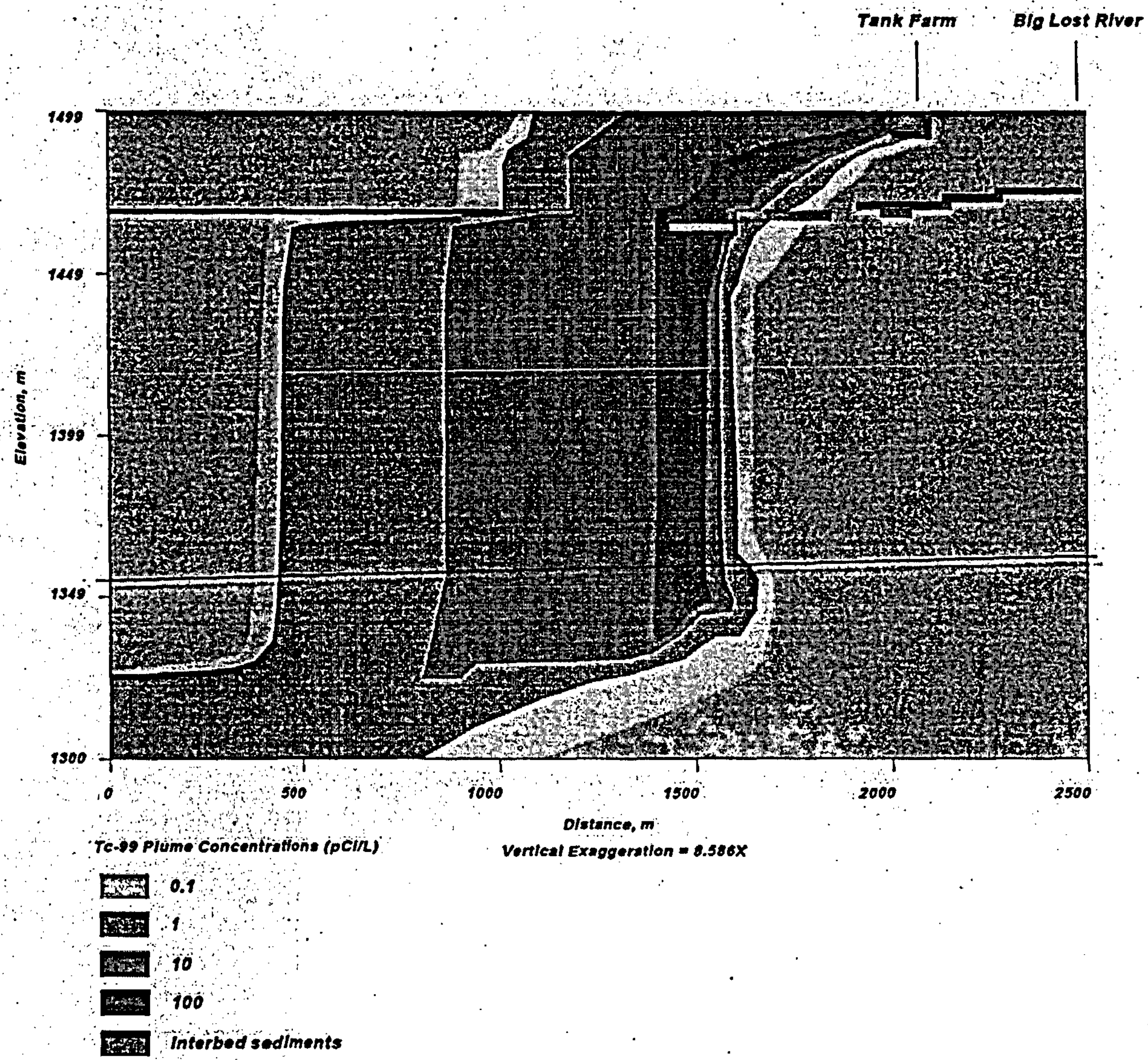

Figure 1. Depiction of the locations of sedimentary interbeds at the INTEC Tank Farm Facility.

DOE-ID should try to provide a better explanation regarding the large lateral extent (0.5-1 mile) of the contaminant plume near-surface and as it enters the saturated zone. For example, is the large lateral extent near-surface indicative of perched water in the alluvium? DOE-ID should also explain why the contaminant plume is depicted at the surface of the model domain in Figure 4-2 of the PA when the tanks are located at approximately 45 feet below grade.

Response:

The data requested are not currently available. Development of these data requires another setup of the model to provide the specified parameters and several runs of the model. This is planned to be completed by July 15, 2006.

Attachment 1

Vendor Slag Specification Details

LAFARGE
NORTH AMERICA

Cement

CEMENT TEST REPORT

September 14, 2005

Seattle Cement Plant–Type NewCem ASTM Mill Runs
Average of Mill Run Analysis from August 1 to August 31, 2005
Test Report No.: S-NewCem-05-08

Name:
Company:
Address:
City, State:
Zip Code:

Reference Cement
Fineness Blaine:
385 m^2/Kg
#325 Sieve:
3.6 % Retained

ASTM C989 Test Results
Fineness Blaine:
465 m^2/Kg
#325 Sieve:
5.3 % Retained

Compressive Strength

Reference Cement

	Actual	Limit
7 Day, psi	4,180	N/A
28 Day, psi	5,162	5,000

NewCem

	Actual
7 Day	3,549
28 Day	6,282

Reference Cement Chemical

	Actual	Limit
Na2O Equiv	0.83	0.9

Slag Activity Index %

	Actual	Limit
7 Day	85	75
28 Day	122	95

	Actual	Limit
Air Content %	5.3	12.0
Specific Gravity	2.89	NA

Chemical

	Actual	Limit
Sulfied Sulfur (S) %	0.79	2.50
Sulfate Ion (as SO3%)	1.84	4.0

The ground granulated blast furnace slag complies with the current specification of the chemical physical requirement of ASTM C-989, AASHTO M-302 for grade 100 Ground Granulated Blast Furnace Slag (GGBFS).

Certified:

Daniel Waldron
Quality Control Laboratory Supervisor

CEMENT GROUP / PACIFIC NORTHWEST DISTRICT
5400 W. Marginal Way, SW, Seattle, WA 98106-1517
Office: (206) 937-8025 Fax: (206) 932-4430

Attachment 2

Engineering Design File
Supplemental Sandpad Inventory Modeling

Document ID:PEI-EDF-1029
Revision ID:1
Effective Date:6/27/06

Engineering Design File

Supplemental Sandpad Inventory Modeling

Portage Project No.: 2121.01
Project Title:

Portage

TEM-0104
04/03/2006
Rev. 0

ENGINEERING DESIGN FILE

1. Portage Project No.: 2121.01 2. Project/Task: ____________

3. Subtask: ____________

4. Title: Supplemental Sandpad Inventory Modeling

5. Summary:

This report presents supplemental modeling conducted to evaluate the radionuclide inventory in the sandpads contained in WM-185 and WM-187 at the Tank Farm Facility. A two-dimensional, advective flow model was developed in PORFLOW (ACRi 2000) to evaluate the flow of the contaminated vault waters into the sandpad. The results of the analysis are compared to the sandpad inventories predicted using the performance assessment (DOE-ID 2003) one-dimensional, diffusion model.

6. Distribution: (Portage Environmental, Inc.)

Tracy Leatham, PEI Document Control (Original)

Kerry Martin

E. Kirk Roemer

Nick Stanisich, CIH

Dave Thorne, CHP

7. Review (R) and Approval (A) Signatures:
(Identify minimum reviews and approvals. Additional reviews/approvals may be added.)

	R/A	Printed Name/ Organization	Signature	Date
Author	A	Dave Thorne, CHP	[signature]	6/27/06
Author	A	Peter Kearl	[signature]	6/27/06
Independent Review	R	E. Kirk Roemer	[signature]	6/27/06
Project Manager	R/A	Kerry Martin	[signature]	6/27/06

CONTENTS

FIGURES

TABLES

1. INTRODUCTION AND PURPOSE

This report presents supplemental modeling conducted to evaluate the radionuclide inventory in the sandpads contained in WM-185 and WM-187 at the Tank Farm Facility (TFF). A two-dimensional, advective flow model was developed in PORFLOW (ACRi 2000) to evaluate the flow of the contaminated vault waters into the sandpad. The results of the analysis are compared to the sandpad inventories predicted using the TFF performance assessment (PA) (DOE-ID 2003) one-dimensional, diffusion model.

2. CONTAMINATION EVENT

A leakage of 31,700 gal of radioactive first-cycle aluminum nitrate-nitric acid raffinate waste from Tank WM-187 to the vault occurred between 1530 hours on March 16, 1962, and 1300 hours on March 17, 1962. Instrument charts indicated that the siphon event began at 1530 hours on March 16, 1962. Jetting back to the tank was started at 1300 hours on March 17, 1962, and completed at 0230 hours on March 18, 1962. Therefore, the waste was in the WM-187 vault for a period of 35 hours, 21.5 hours of which material was siphoning into the vault, and 13.5 hours of which the vault contents were being jetted back into Tank WM-187 (Latchum et al. 1962).

On March 19–20, 1962, a similar event occurred with regard to WM-185 and 33,500 gal were released to the vault. The mechanism of the transfers of the liquid radioactive wastes was determined to be the result of a siphon established through the vault sump jet piping to the tanks. At 0730 hours on March 20, 1962, jetting of the vault contents back to Tank WM-185 was started. Jetting was completed at 1730 hours on March 20, 1962. Therefore, there was waste solution in the WM-185 vault for a total of 21.25 hours, 11.25 hours of which material was siphoning into the vault and 10 hours of which material was being transferred back to the Tank WM-185 (Latchum et al. 1962).

The TFF design concept was based on the requirement of secondary waste storage confinement and the belief that the secondary barrier, the vault, would remain in a static (dry) condition as long as the integrity of the tank was maintained. A tank failure was considered highly improbable. However, due to the serious consequences of a release of radioactive wastes to the environment, the double containment concept was considered necessary. Commensurate with the probability of tank failure, only minimum transfer equipment and instrumentation were provided (Latchum et al. 1962).

Operating experience, up to 1962, had proven that the vault sumps would not always remain dry due to spring thaw. During the two months prior to the incident, heavy precipitation and warm weather caused considerable flooding at the Idaho National Laboratory (INL) and the incidence of vault seepage was occurring. One of the consequences of this seepage was to nullify the original intent of a high sump level alarm by the more or less "routine" explanation of water flooding (Latchum et al. 1962).

The initial amount of each radionuclide in the tanks at the time of the accidental spills was evaluated with limited sampling of Tanks WM-185 and WM-187 on February 14, 1962. Due to the limited number of radionuclides provided by this sampling analysis, an alternative method using information from a release from Tank WM-181 was used to determine the source term. This release occurred in 1972 when raffinate was released into the soil (Wenzel 1997). Using an aluminum-clad fuel with an initial ^{235}U enrichment of 93% and a burnup of the processed fuel of 18%, Wenzel (1997) evaluated the expected radionuclide content of the tank. The fuel from MTR Cycle No. 198 (Dykes 1963) was taken as typical for the fuel processed. The reactor contained 4,842 g of ^{235}U and had 684 megawatts per day of operation over a 417-day period. For calculational purposes, inventories were normalized to

the activity in a typical 200-g element. Table 1 presents the initial (i.e., 1962) inventories of the liquid in Ci/mL for all radionuclides and associated half-lives. The ORIGEN2 data were corrected to the concentration of ^{137}Cs in Tank WM-185 1 month before the incident. Data for Tanks WM-185 and WM-187 were shown in the record of the incident (Latchum et al. 1962). Tank WM-185 was used because of the slightly higher ^{137}Cs concentration of 1.71 Ci/L.

Table 1. Radionuclide half-lives and concentrations in the liquid released into the tanks in 1962.

Nuclide	T1/2 (yr)	Ci/mL	Nuclide	T1/2 (yr)	Ci/mL	Nuclide	T1/2 (yr)	Ci/mL
^{225}Ac	2.74E−02	1.48E−15	^{115}In	4.60E+15	3.18E−19	^{225}Ra	4.05E−02	1.48E−15
^{227}Ac	2.18E+01	4.37E−13	^{138}La	1.12E+11	4.57E−18	^{226}Ra	1.60E+03	1.08E−13
^{228}Ac	6.99E−04	3.09E−18	^{93m}Nb	1.46E+01	2.08E−08	^{228}Ra	5.75E+00	3.09E−18
^{108}Ag	4.51E−06	2.06E−16	^{94}Nb	2.03E+04	1.01E−08	^{87}Rb	4.73E+10	6.13E−13
^{108m}Ag	1.27E+02	2.32E−15	^{63}Ni	1.00E+02	6.54E−17	^{219}Rn	1.25E−07	4.38E−13
^{241}Am	4.32E+02	1.56E−07	^{235}Np	1.08E+00	1.13E−14	^{220}Rn	1.76E−06	3.26E−11
^{242}Am	1.83E−03	2.60E−12	^{237}Np	2.14E+06	2.39E−09	^{222}Rn	1.05E−02	1.08E−13
^{242m}Am	1.52E+02	2.62E−12	^{238}Np	5.80E−03	1.31E−14	^{126}Sb	3.40E−02	1.14E−09
^{243}Am	7.38E+03	1.84E−11	^{239}Np	6.45E−03	1.84E−11	^{126m}Sb	3.62E−05	8.12E−09
^{217}At	1.02E−09	1.48E−15	^{240m}Np	1.24E−04	0.00E+00	^{79}Se	6.50E+04	9.13E−09
^{137m}Ba	4.86E−06	1.62E−03	^{240m}Np	1.41E−05	1.39E−18	^{146}Sm	7.00E+07	1.33E−16
^{10}Be	1.60E+06	6.29E−14	^{231}Pa	3.28E+04	2.37E−12	^{147}Sm	6.90E+09	2.14E−13
^{210}Bi	1.37E−02	1.44E−14	^{233}Pa	7.39E−02	2.39E−09	^{151}Sm	9.00E+01	2.01E−05
^{211}Bi	4.05E−06	4.38E−13	^{234}Pa	7.64E−04	1.22E−13	^{121m}Sn	7.60E+01	1.66E−09
^{212}Bi	1.15E−04	3.26E−11	^{234m}Pa	2.22E−06	9.42E−11	^{126}Sn	1.00E+05	8.12E−09
^{213}Bi	8.68E−05	1.48E−15	^{209}Pb	3.71E−04	1.48E−15	^{90}Sr	2.86E+01	1.63E−03
^{214}Bi	3.78E−05	1.08E−13	^{210}Pb	2.23E+01	1.44E−14	^{98}Tc	4.20E+06	9.71E−15
^{14}C	5.73E+03	2.53E−12	^{211}Pb	6.86E−05	4.38E−13	^{99}Tc	2.13E+05	3.17E−07
^{113m}Cd	1.37E+01	1.59E−07	^{212}Pb	1.21E−03	3.26E−11	^{123}Te	1.00E+13	2.49E−22
^{249}Cf	3.51E+02	2.32E−23	^{214}Pb	5.10E−05	1.08E−13	^{227}Th	5.12E−02	4.32E−13
^{250}Cf	1.31E+01	2.04E−23	^{107}Pd	6.50E+06	3.36E−10	^{228}Th	1.91E+00	3.25E−11
^{251}Cf	9.00E+02	5.31E−26	^{146}Pm	5.53E+00	1.27E−09	^{229}Th	7.34E+03	1.48E−15
^{252}Cf	2.64E+00	3.45E−26	^{147}Pm	2.62E+00	4.43E−04	^{230}Th	7.70E+04	3.72E−11
^{242}Cm	4.47E−01	2.18E−12	^{210}Po	3.79E−01	1.28E−14	^{231}Th	2.91E−03	8.84E−09
^{243}Cm	2.85E+01	2.53E−13	^{211}Po	1.64E−08	1.23E−15	^{232}Th	1.41E+10	6.87E−18
^{244}Cm	1.81E+01	1.50E−10	^{212}Po	9.44E−15	2.09E−11	^{234}Th	6.60E−02	9.42E−11
^{245}Cm	8.50E+03	4.40E−15	^{213}Po	1.33E−13	1.45E−15	^{207}Tl	9.07E−06	4.37E−13
^{246}Cm	4.75E+03	9.85E−17	^{214}Po	2.02E−12	1.08E−13	^{208}Tl	5.81E−06	1.17E−11
^{247}Cm	1.56E+07	3.52E−23	^{215}Po	2.47E−11	4.38E−13	^{209}Tl	4.18E−06	3.20E−17
^{248}Cm	3.39E+05	1.08E−23	^{216}Po	4.63E−09	3.26E−11	^{232}U	2.47E−06	0.00E+00

Table 1. (continued).

Nuclide	T1/2 (yr)	Ci/mL	Nuclide	T1/2 (yr)	Ci/mL	Nuclide	T1/2 (yr)	Ci/mL
^{60}Co	5.27E+00	1.47E–06	^{218}Po	5.80E–06	1.08E–13	^{233}U	7.20E+01	3.25E–11
^{135}Cs	2.30E+06	1.97E–09	^{236}Pu	2.85E+00	4.95E–12	^{234}U	1.59E+05	1.30E–12
^{137}Cs	3.02E+01	1.71E–03	^{146}Pm	8.78E+01	7.14E–07	^{235}U	2.45E+05	3.30E–07
^{152}Eu	1.36E+01	1.25E–08	^{147}Pm	2.41E+04	3.66E–07	^{236}U	7.04E+08	8.84E–09
^{154}Eu	8.80E+00	7.77E–06	^{240}Pu	6.54E+03	8.27E–08	^{237}U	3.42E+06	1.11E–08
^{221}Fr	9.13E–06	1.48E–15	^{241}Pu	1.44E+01	5.89E–06	^{238}U	1.85E–02	1.45E–10
^{223}Fr	4.14E–05	6.03E–15	^{242}Pu	3.76E+05	1.32E–11	^{240}U	4.47E+09	9.42E–11
^{152}Gd	1.10E+14	1.32E–21	^{243}Pu	5.65E–04	3.52E–23	^{232}U	1.61E–03	1.39E–18
^{3}H	1.23E+01	5.02E–06	^{244}Pu	8.26E+07	1.39E–18	^{90}Y	7.32E–03	1.64E–03
^{166m}Ho	1.20E+03	1.50E–13	^{223}Ra	3.13E–02	4.38E–13	^{93}Zr	1.53E+06	4.71E–08
^{129}I	1.57E+07	5.09E–10	^{224}Ra	3.62E+00	3.26E–11			

Radionuclides that were found to contribute the majority of the dose in the PA and for the Class C calculations were evaluated using the new two-dimensional advective model. These radionuclides include ^{14}C, ^{137}Cs, ^{129}I, ^{94}Nb, ^{63}Ni, ^{90}Sr, ^{99}Tc, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{241}Am.

3. MODEL DESCRIPTION

A two-dimensional model was constructed for the sandpad. The model consisted of a 1-m slice from the center of the tank to the inner edge of the 6-in. concrete curb containing the sandpad. All model boundaries were set as no-flow conditions with the exception of the outer edge of the sandpad that is exposed. This area was set as a P=0 boundary condition (i.e., saturated condition at boundary). The model domain was 8 by 0.15 by 1 m consisted of 100 by 100 by 1 nodes with a spacing of 0.08 m in the x-direction (i.e., 8 m from the center of the sandpad to the concrete curb) and 0.0015 m in the z-direction (i.e., 0.15-m-thick sandpad). The model was developed using the PORFLOW groundwater flow and transport model (ACRi 2000). The model input files are provided in Attachment 1.

4. HYDRAULIC PARAMETERS

There are no detailed specifications for the sand size distribution under the tanks. However, sand size distributions used as concrete aggregate in vault construction was available from the same source used for the sandpads. *Standard Specification for Concrete Aggregates* (ASTM C 33-01) provides a distribution for fine aggregate listed below in Table 2.

Table 2. Fine aggregate grading specifications.

Sieve Specification (mm)	Percent Passing
9.5	100
4.75	95–100
2.36	80–100
1.18	50–85
0.600	25–60
0.300	5–30
0.150	0–10

Figure 1 was used and compared to the ASTM size distribution in which three of the soil clarification systems defined the material under the tanks as coarse sand. Moisture characteristic curves from Taylor and Ashcroft (1972) for coarse sand (see Figure 2) provide an estimate of capillary forces. Saturated hydraulic conductivity was estimated using Figure 3 (Freeze and Cherry 1979). Assuming that the aggregate is clean sand with an upper size boundary of approximately 4–5 mm (i.e., below the gravel range), provides an estimate for the saturated hydraulic conductivity of 0.1 cm/s.

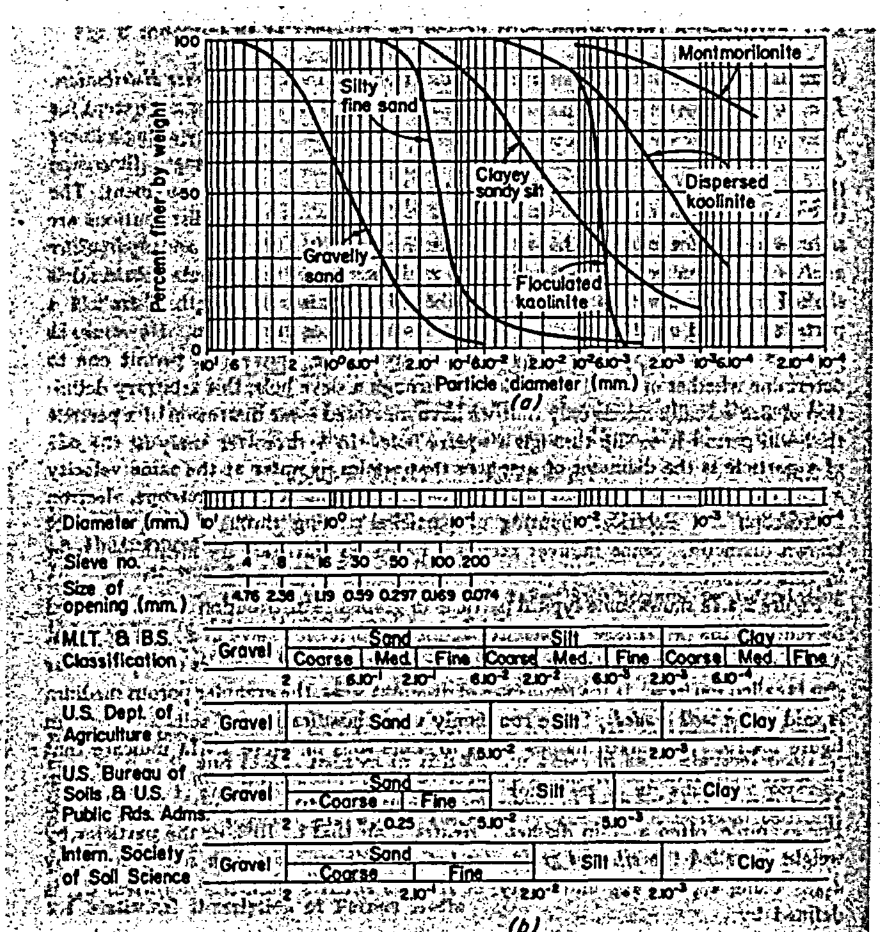

Figure 1. Typical grain size distribution curves for various soils by classification (Bear 1972).

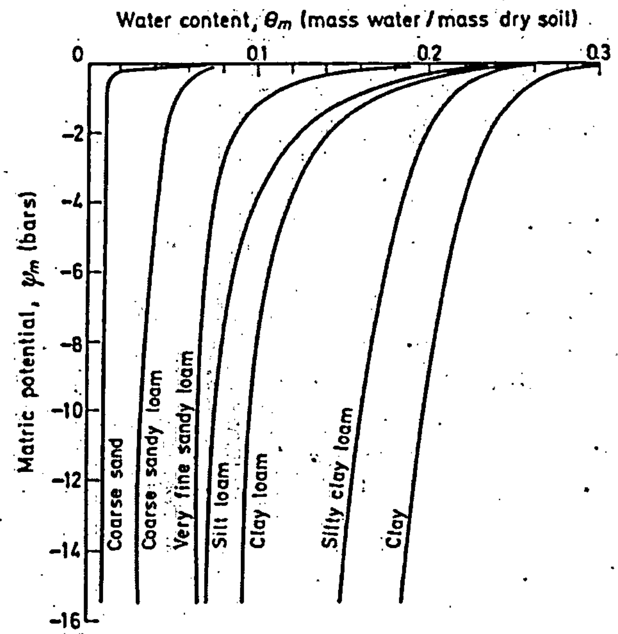

Figure 2. Soil water characteristic curves for several soils (Taylor and Ashcroft 1972).

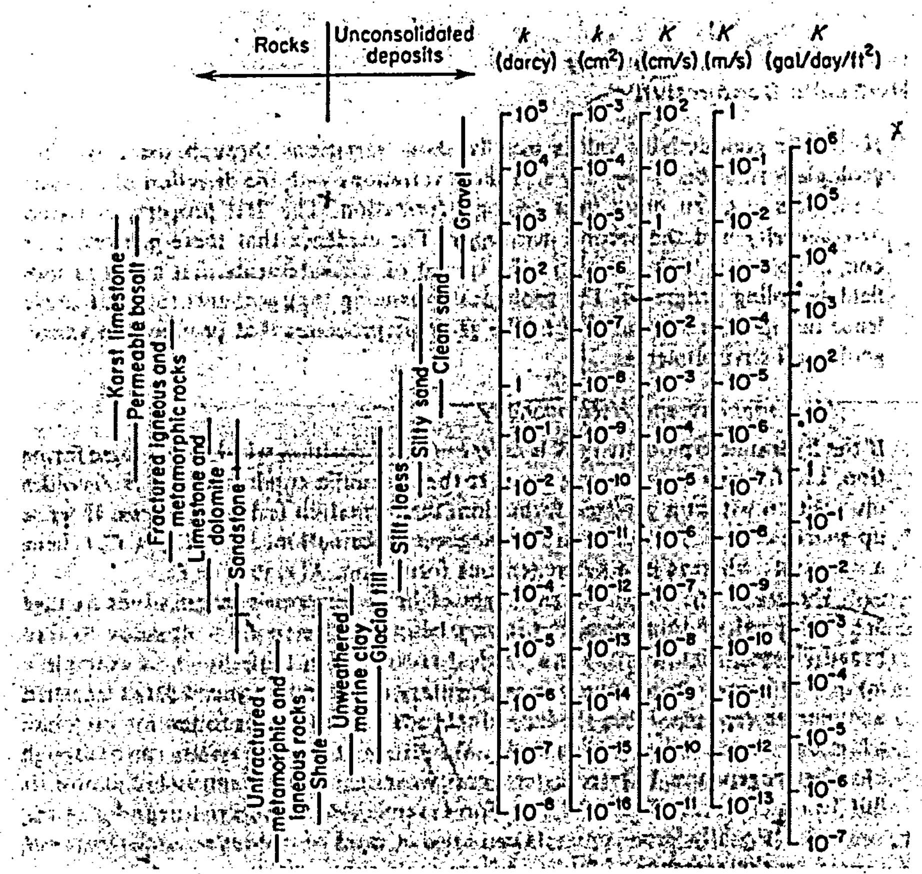

Figure 3. Range of values for hydraulic conductivity and permeability (Freeze and Cherry 1979).

The porosity for coarse sand is reported to range from 25 to 50% (Freeze and Cherry 1979). Since size grading directly affects the porosity and the sandpad consists of well-graded material (ASTM C 33-01), a lower range value of 30% was chosen as a realistic estimate. The moisture characteristic curve for coarse sand shows a residual saturation of 0.01. This value was doubled for the model-based grading considerations described in Bear (1979) (see Figure 4). Using the moisture characteristic curve for coarse gravel and modifying it for well-graded sand, the resulting moisture characteristic curve provided in Figure 5 was developed for the model.

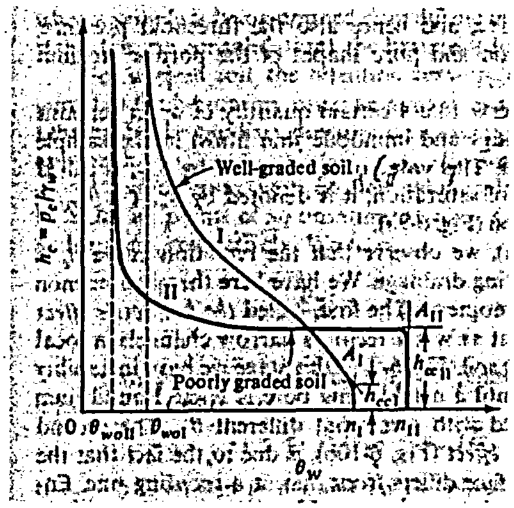

Figure 4. Schematic curves for water during drainage (Bear 1979).

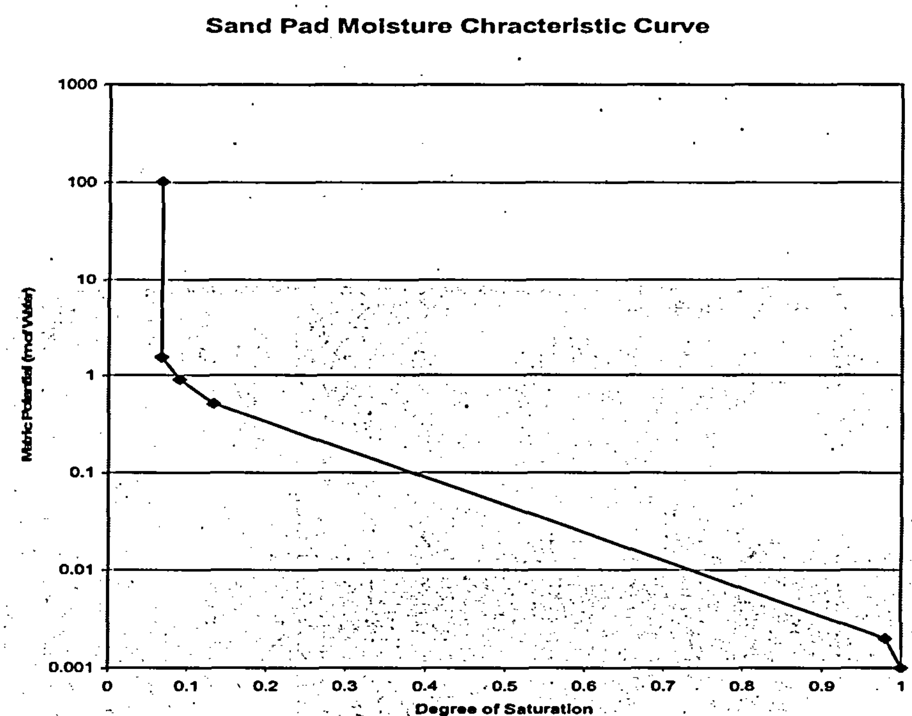

Figure 5. Moisture characteristic curve used in the sandpad model.

Applying Van Genuchten's closed form analytical model (Van Genuchten 1978), the relative hydraulic conductivity (K_r) can be calculated using the moisture characteristic curve. Relative hydraulic conductivity is used to predict the affect on convective transport at various moisture contents in the sand pores. Figure 6 illustrates the dependency of hydraulic conductivity on moisture content for unsaturated flow predictions in the sandpad modeling effort.

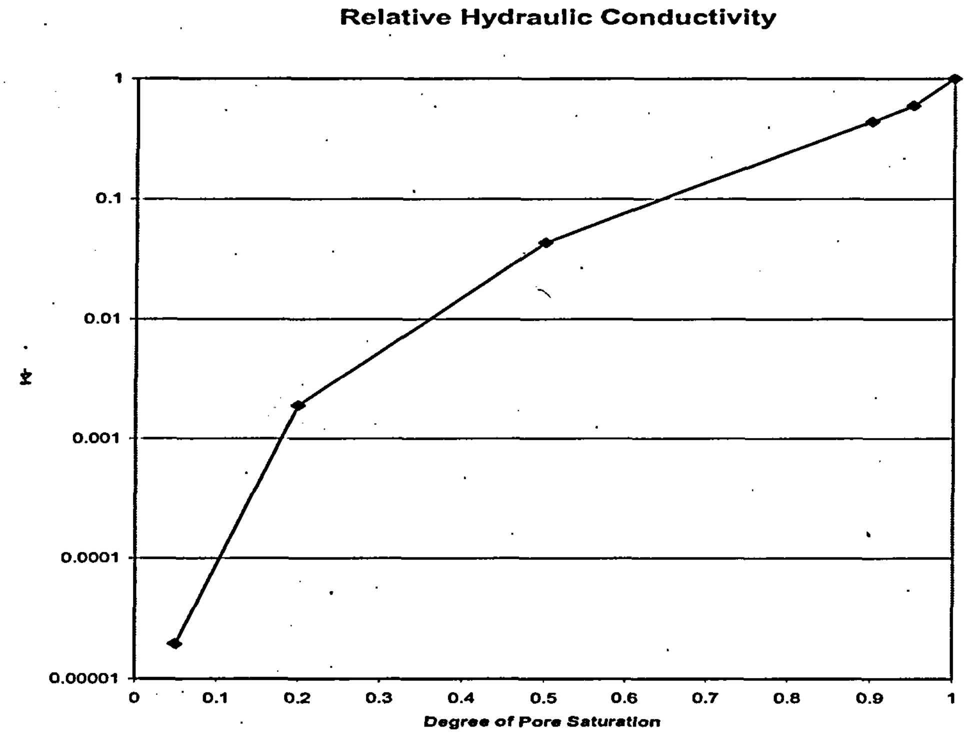

Figure 6. Hydraulic conductivity versus degree of saturation used in the model.

5. CONTAMINANT TRANSPORT PARAMETERS

As noted earlier, radionuclides that were found to contribute the majority of the dose in the PA and for the class C calculations were evaluated using the new two-dimensional advective sandpad model. These radionuclides include ^{14}C, ^{137}Cs, ^{129}I, ^{94}Nb, ^{63}Ni, ^{90}Sr, ^{99}Tc, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, and ^{241}Am.

Sandy soil sorption coefficients from Sheppard and Thibault (1990) were used in the PA (DOE-ID 2003) analyses for the sandpad. As noted by Sheppard and Thibault (1990), soils containing greater than 70% sand-sized particles were classified as sand soils. Therefore, these sand soils did contain silt- and clay-sized particles. In addition, the initial event released highly acidic waste to the vaults and the pH was less than 1. Also, the sandpad is considered to be well-graded, coarse sand with little to no fine and clay particles. Additional sorption coefficients were located for quartz and granite mineral phases in the Japan Nuclear Cycle Development Institute (Shibutani et al. 1999; Suyama and Sasamoto 2004). In addition, EPA (1999) provides a summary of radionuclide sorption coefficients for low clay and low pH conditions. These sorption coefficients are shown in Table 3.

Table 3. Sorption coefficient ranges.

Nuclide	PA K_d (mL/g)[a]	EPA K_d (mL/g)[b]	Quartz K_d (mL/g)[c]	Granite K_d (mL/g)[d]
Am	1,900		10–100	0–66
C	5			
Cm	4,000			
Cs	280	10–200		
I	1			
Nb	160			
Ni	400			
Np	5		4–30	5–50
Pu	550	5–420	4–30	10–100
Sr	15	1–40		
Tc	0.1			

a. Values for sand soil from Sheppard and Thibault (1990).
b. Values from EPA (1999) for low clay and low pH.
c. Shibutani et al. 1999; Suyama and Sasamoto 2004.
d. Shibutani et al. 1999; Suyama and Sasamoto 2004.

The sorption coefficients in Table 4 were used in the sandpad modeling. Three transport cases were assessed during the two-dimensional advective modeling: (1) PA sandpad sorption coefficients; (2) moderate pH, low clay sorption coefficients; and (3) low pH, low clay sorption coefficients. The PA sorption coefficients are considered to be bounding. The moderate pH, low clay sorption coefficients were used for the reasonable case. The low pH, low clay sorption coefficients were used in a third case for the initial acidic siphoning event, with the moderate pH, low clay sorption coefficients used for the washing events from snow melt and rainwater entering the vaults after the event.

The moderate pH, low clay sorption coefficients were chosen from the midpoint of the sorption coefficient ranges reported by EPA (1999) for low clay soils, or from the sorption coefficients reported for quartz and granite, whichever was more conservative. The low pH, low clay sorption coefficients were chosen from the low end of the sorption coefficient ranges reported from EPA (1999) or from the quartz and granite values, whichever was lower.

Table 4. Sorption coefficients used in the modeling analysis.

Nuclide	PA K_d (mL/g)	Moderate pH Low Clay K_d (mL/g)	Low pH Low Clay K_d (mL/g)
Am	1,900	50	10
C	5	5	5
Cm	4,000	4,000	4,000
Cs	280	100	10
I	1	1	1
Nb	160	160	160
Ni	400	400	400
Np	5	25	4
Pu	550	210	5
Sr	15	20	1
Tc	0.1	0.1	0.1

6. FLOW MODELING RESULTS

The coarse sand hydraulic characteristics used in the sandpad modeling resulted in the entire modeling domain being saturated at the end of the 24-hour period. Four initial saturation cases were evaluated in the sandpad modeling to evaluate the impact of the wet conditions that preceded the contamination event. The initial saturation values were 0.06, 0.3, 0.5, and 0.68. The initial saturation value of 0.68 corresponds to the mass balance calculations presented in Latchum et al. (1962), which indicated that 600 gal of liquid were input to the sandpads.

7. SANDPAD INVENTORY RESULTS

The initial mass of radionuclides input into the model domain were based on the initial contaminant concentrations in the vault (Table 1) and the volume of water input into the model domain based on the initial saturation values. The volume of water input into the model domain for initial saturation levels of 0.06, 0.3, 0.5, and 0.68 was 6.61 m^3 (1,746 gal), 4.93 m^3 (1,302 gal), 3.52 m^3 (930 gal), and 2.27 m^3 (600 gal), respectively. This volume of water was then multiplied by the values in Table 1 to determine the initial activity of each radionuclide in the sandpad after the initial event.

The contaminant concentrations in the sandpad after the initial contamination event were then flushed (i.e., rainfall and snowmelt water entering vaults) one time per year for 38 years, to the year 2000. The final sandpad inventories were then decayed from 2000 to 2012 without additional flushing events in the vault.

The results of the sensitivity/uncertainty analysis for the varying initial saturations and sorption coefficients are provided in Tables 5–8 along with a comparison to the results presented in the draft 3116 Determination (DOE-ID 2005) based on the diffusion model originally used in the PA analysis for the sandpad inventory.

Table 5. Sandpad inventory (Ci) at 2012 for an initial saturation of 0.06 and varying K_d values.

	Two-Dimensional Advective Model with 0.06 Initial Saturation			Draft 3116 Determination[a] Values Based on PA One-Dimensional Diffusion Model
Nuclide	PA K_d	Moderate K_d	Low pH and Moderate K_ds	
^{241}Am	2.06	1.87	1.83	1.89
^{14}C	4.95E–06	4.95E–06	4.95E–06	3.90E–07
^{242}Cm	1.11E–05	9.88E–06	9.75E–06	1.38E–05
^{137}Cs	3,511	3,375	3,326	1,650
^{129}I	1.13E–05	1.13E–05	1.13E–05	1.08E–06
^{94}Nb	6.41E–02	6.41E–02	6.41E–02	2.29E–02
^{63}Ni	3.01E–10	3.01E–10	3.01E–10	1.69E–10
^{237}Np	4.73E–03	1.24E–02	1.20E–02	3.71E–04
^{238}Pu	3.43	3.37	3.27	2.06
^{239}Pu	2.39	2.35	2.27	1.57
^{240}Pu	0.54	0.53	0.51	0.35
^{241}Pu	3.47	3.41	3.30	2.28
^{242}Pu	8.63E–05	8.47E–05	8.21E–05	5.68E–05
^{90}Sr	2,134	2,362	2,049	249
^{99}Tc	2.73E–16	2.73E–16	2.73E–16	2.02E–12

a. DOE-ID 2005.

Table 6. Sandpad inventory (Ci) at 2012 for an initial saturation of 0.3 and varying K_d values.

Nuclide	Two-Dimensional Advective Model with 0.06 Initial Saturation: PA K_d	Two-Dimensional Advective Model with 0.06 Initial Saturation: Moderate K_d	Two-Dimensional Advective Model with 0.06 Initial Saturation: Low pH and Moderate K_ds	3116 Determination[a] Values Based on PA One-Dimensional Diffusion Model
^{241}Am	1.54	1.40	1.36	1.89
^{14}C	3.70E–06	3.70E–06	3.70E–06	3.90E–07
^{242}Cm	8.30E–06	7.37E–06	7.27E–06	1.38E–05
^{137}Cs	2,618	2,517	2,480	1,650
^{129}I	8.39E–06	8.39E–06	8.39E–06	1.08E–06
^{94}Nb	4.78E–02	4.78E–02	4.78E–02	2.29E–02
^{63}Ni	2.25E–10	2.25E–10	2.25E–10	1.69E–10
^{237}Np	3.53E–03	9.24E–03	8.94E–03	3.71E–04
^{238}Pu	2.56	2.51	2.44	2.06
^{239}Pu	1.78	1.75	1.70	1.57
^{240}Pu	0.40	0.39	0.38	0.35
^{241}Pu	2.59	2.54	2.46	2.28
^{242}Pu	6.43E–05	6.32E–05	6.13E–05	5.68E–05
^{90}Sr	1,591	1,761	1,530	249
^{99}Tc	2.03E–16	2.03E–16	2.03E–16	2.02E–12

a. DOE-ID 2005.

Table 7. Sandpad inventory (Ci) at 2012 for an initial saturation of 0.5 and varying K_d values.

	Two-Dimensional Advective Model with 0.5 Initial Saturation			3116 Determination[a] Values Based on PA One-Dimensional Diffusion Model
Nuclide	PA K_d	Moderate K_d	Low pH and Moderate K_ds	
^{241}Am	1.10	1.00	0.97	1.89
^{14}C	2.64E–06	2.64E–06	2.64E–06	3.90E–07
^{242}Cm	5.93E–06	5.26E–06	5.19E–06	1.38E–05
^{137}Cs	1,869	1,797	1,770	1,650
^{129}I	5.99E–06	5.99E–06	5.99E–06	1.08E–06
^{94}Nb	3.42E–02	3.42E–02	3.42E–02	2.29E–02
^{63}Ni	1.60E–10	1.60E–10	1.60E–10	1.69E–10
^{237}Np	2.52E–03	6.60E–03	6.38E–03	3.71E–04
^{238}Pu	1.83	1.79	1.74	2.06
^{239}Pu	1.27	1.25	1.21	1.57
^{240}Pu	0.29	0.28	0.27	0.35
^{241}Pu	1.85	1.82	1.76	2.28
^{242}Pu	4.59E–05	4.51E–05	4.37E–05	5.68E–05
^{90}Sr	1,136	1,258	1,090	249
^{99}Tc	1.45E–16	1.45E–16	1.45E-16	2.02E–12

a. DOE-ID 2005.

Table 8. Sandpad inventory (Ci) at 2012 for an initial saturation of 0.68 and varying K_d values.

Nuclide	Two-Dimensional Advective Model with 0.68 Initial Saturation			3116 Determination[a] Values Based on PA One-Dimensional Diffusion Model
	PA K_d	Moderate K_d	Low pH and Moderate K_ds	
^{241}Am	0.70	0.64	0.62	1.89
^{14}C	1.69E–06	1.69E–06	1.69E–06	3.90E–07
^{242}Cm	3.79E–06	3.36E–06	3.32E–06	1.38E–05
^{137}Cs	1,195	1,149	1,130	1,650
^{129}I	3.83E–06	3.83E–06	3.83E–06	1.08E–06
^{94}Nb	2.18E–02	2.18E–02	2.18E–02	2.29E–02
^{63}Ni	1.02E–10	1.02E–10	1.02E–10	1.69E–10
^{237}Np	1.61E–03	4.22E–03	4.08E–03	3.71E–04
^{238}Pu	1.17	1.15	1.11	2.06
^{239}Pu	0.81	0.80	0.77	1.57
^{240}Pu	0.18	0.18	0.17	0.35
^{241}Pu	1.18	1.16	1.12	2.28
^{242}Pu	2.94E–05	2.88E–05	2.80E–05	5.68E–05
^{90}Sr	726	804	698	249
^{99}Tc	9.29E–17	9.29E–17	9.29E–17	2.02E–12

a. DOE-ID 2005.

8. CONCLUSION

A two-dimensional advective model was developed to assess the potential sandpad inventory based on varying initial saturation conditions and varying sorption coefficients. The results indicate that for most radionuclides of concern, the inventories do not increase significantly. Radionuclides such as ^{137}Cs and ^{90}Sr increase by a factor of 2.1 and 8.6, respectively. However, the increases in the sandpad inventories will not result in the exceedance of the performance objectives presented in the PA.

The water levels in the Tank WM-185 and WM-187 vaults prior to the incidents are not completely known. The incident report does not describe the conditions in WM-187 prior to the incident (Latchum et al. 1962). There are some descriptions of the water levels in WM-185 prior to the incident but it is known water continued to enter the vaults as the steam jets were being used to empty the vaults. It is also mentioned in the incident report that the water level instrumentation was not working to specifications due to leaks in instrumentation lines and because operators had turned off alarms because of the continued water influx in the weeks prior to the incidents.

The incident report states:

> *During the two months prior to the incident, heavy precipitation and warm weather caused considerable flooding in the area and the incidence of vault seepage was incurred again. One of the consequences of Seepage has been to nullify the original intent of a high sump level alarm by more or less "routine" explanation of water flooding.* (Latchum et al. 1962)

Since during this period of time, influx of water into the vaults was fairly routine, and it was assumed that some level of residual sand saturation was evident. Water infiltrates through the tank roof and leaks down on the tank, vault walls and directly into the vault. Since the tank occupies a large area of the vault it is likely the water leaks onto the tank and enters the vault floor by moving down the tank walls. There is no direct information to determine the amount of saturation before, during, or after the incident. However, the vaults are not ventilated (the relative humidity in the vault was likely near 100%) and this time period was one of greater-than-average precipitation at the INL. A residual saturation of 30–90% prior to the incident could be inferred but not measured because of the short time between the vault steam jetting and the incidents (approximately 1–2 hours) and the recognized vault filling events, which were common in the weeks preceding the incident.

Therefore, the sandpad inventories for the higher initial saturation values are likely a better indicator of the potential sandpad inventory. The sandpad inventory at an initial saturation value of 0.5 indicates that the sandpad inventory is not significantly greater than that predicted in the PA using a one-dimensional diffusion model.

9. REFERENCES

ACRi, 2000, *PORFLOW User's Manual*, Version 4.0, Rev. 4, Bel Air, California.

ASTM C 33-01, *Standard Specification for Concrete Aggregates*, as amended.

Bear, Jacob, 1972, *Dynamics of Fluids in Porous Media*, American Elsevier Publishing Company, New York.

Bear, Jacob, 1979, *Hydraulic of Groundwater*, McGraw Hill Series in Water Resources and Environmental Engineering, New York.

DOE-ID, 2003, *Performance Assessment for the Tank Farm Facility at the Idaho National Engineering and Environmental Laboratory*, DOE/ID-10966, Rev. 1, April 2003 (Errata December 2, 2003).

DOE-ID, 2005, *Draft Section 3116 Determination Idaho Nuclear Technology and Engineering Center Tank Farm Facility*. DOE/NE-ID-11226, Rev. 0 Draft, September 7, 2005.

Dykes, J. W., (ed.) 1963, *MTR Progress Report, Cycle No. 198, September 30, 1962–October 21, 1963*, IDO-16952, Phillips Petroleum Company, INEEL.

EPA, 1999, *Understanding Variation in Partition Coefficient, Kd, Values: Volume II – Review of Geochemistry and Available Kd Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (3H), and Uranium*, EPA 402-R-99-004B, U.S. Environmental Protection Agency, Washington, D.C., August 1999.

Grove Engineering, Inc., 1990, "RadDecay," *MicroShield User's Manual*, Rockville, Maryland.

Latchum, J. W., A. L. Biladeau, E. S. Brown, D. D. Deming, B. L. Schmalz, F. M. Warzel, and L. J. Weber, 1962, *Report of the Investigating Committee, CPP Waste Tank WM-187 Leakage of March 17, 1962*, La-53-62A, Phillips Petroleum Company, April 17, 1962.

Shibutani, T., et al., 1999, "Sorption Database for Radionuclides on Bentonite and Rocks," JNC Technical Report (in Japanese with English abstract), TN8410 99-050, available at http://migrationdb.jaea.go.jp/english.html, 1999.

Suyama, T., and H. Sasamoto, 2004, "A Renewal of the JNC-Sorption Database (JNC-SDB) Addition of Literature Data Published from 1998 to 2003," JNC Technical Report (in Japanese with English abstract), TN8410 2003-018, available at http://migrationdb.jaea.go.jp/english.html, 2004.

Taylor, S. A., and G. L. Ashcroft, 1972, *Physical Edaphology: The Physics of Irrigated and Non-irrigated Soils,* William H. Freeman: San Francisco, California.

Van Genuchten, Rien, 1978, *Calculating the Unsaturated Hydraulic Conductivity with a New Closed-Form Analytical Model.* Department of Civil Engineering, Princeton Univ., 78-WR-08, Princeton, New Jersey.

Wenzel, D. R., 1997, "Evaluation of Contaminated Soil Site CPP-31 Activity," EDF-CPP-058, Functional File Number 1000-50, Idaho National Engineering and Environmental Laboratory, 1997.

Attachment 1

PORFLOW Input Files

```
/==== PROBLEM IDENTIFICATION ====/
/----------------------------------------------------------------------/
/ PROBLEM IDENTIFICATION:
TITLe Sand Pad Two dimensional pressure run
USER Peter Kearl Dave Thorne
/File sandpad_twoD.inp
/Date: March 24, 2006
/----------------------------------------------------------------------/
/ GEOMETRY SPECIFICATIONS:
TIME = 0.0
GRID 102 x 102
COORdinates X -0.08 0.08 0.16 0.24 0.32 0.40 0.48 0.56 0.64 0.72
0.80 0.88 0.96 1.04 1.12 1.20 1.28 1.36 1.44 1.52
1.60 1.68 1.76 1.84 1.92 2.00 2.08 2.16 2.24 2.32
2.40 2.48 2.56 2.64 2.72 2.80 2.88 2.96 3.04 3.12
3.20 3.28 3.36 3.44 3.52 3.60 3.68 3.76 3.84 3.92
4.00 4.08 4.16 4.24 4.32 4.40 4.48 4.56 4.64 4.72
4.80 4.88 4.96 5.04 5.12 5.20 5.28 5.36 5.44 5.52
5.60 5.68 5.76 5.84 5.92 6.00 6.08 6.16 6.24 6.32
6.40 6.48 6.56 6.64 6.72 6.80 6.88 6.96 7.04 7.12
7.20 7.28 7.36 7.44 7.52 7.60 7.68 7.76 7.84 7.92
7.96 8.04
     NODEs
COORdinates Y -0.0015 0.0015 0.003 0.0045 0.006 0.0075 0.009 0.0105 0.012 0.0135
0.015 0.0165 0.018 0.0195 0.021 0.0225 0.024 0.0255 0.027 0.0285
0.03 0.0315 0.033 0.0345 0.036 0.0375 0.039 0.0405 0.042 0.0435
0.045 0.0465 0.048 0.0495 0.051 0.0525 0.054 0.0555 0.057 0.0585
0.06 0.0615 0.063 0.0645 0.066 0.0675 0.069 0.0705 0.072 0.0735
0.075 0.0765 0.078 0.0795 0.081 0.0825 0.084 0.0855 0.087 0.0885
0.09 0.0915 0.093 0.0945 0.096 0.0975 0.099 0.1005 0.102 0.1035
0.105 0.1065 0.108 0.1095 0.111 0.1125 0.114 0.1155 0.117 0.1185
0.12 0.1215 0.123 0.1245 0.126 0.1275 0.129 0.1305 0.132 0.1335
0.135 0.1365 0.138 0.1395 0.141 0.1425 0.144 0.1455 0.147 0.1485
0.14925 0.15075
          NODEs
/----------------------------------------------------------------------/
/ ALLOCATE NEW SPACE:
/
ZONE 1 from (1 1) to ( 102 102 ) $Coarse Sand
!ANS
/----------------------------------------------------------------------/
GRAVity 0, -9.81
DATUm coordinates: (0 0)
!IBC
/----------------------------------------------------------------------/
/ FLUID PROPERTIES & CONSTANTS:
/DENSity of FIRSt phase = 1000 $kg/m3
!FPC
/----------------------------------------------------------------------/
/ SOLID MATRIX PROPERTIES:
FOR ZONE 1 $Coarse Sand
HYDRaulic 1.0E-2 44.9 44.9 $0.1 cm/s after Freeze and Cherry (1979)
ROCK DENSity 2650.0 POROsity 0.28 0.30 $
MULTiphase properties:TABLe of 6
/ moisture characteristic curve, theta sub s vs. pressure ()
/data detailed in scientific notebook
```

```
1.0000      0.001
0.98        0.002
0.133       0.508
0.09        0.9
0.067       1.52
0.066       101.6
/Developed using Van Genuchten (1978)
MULTiphase CONDuctivity TABLe of 6
/unsaturated hydraulic conductivity, theta sub s vs. relative k(0)
1.0000      1.00000
0.95        0.60
0.90        0.44
0.50        0.043
0.20        0.00189
0.05        0.0000195
/----------------------------------------------------------------/
/ SOLUTION OPTIONS:          !SOP
/ INITIAL & BOUNDARY CONDITIONS:
INITial for S is 0.06 EVERywhere
BOUNdary condition P FLUX X- 0.0 EVERywhere
BOUNdary condition P FLUX X+ 0.0 EVERywhere
BOUNdary condition P FLUX Y- 0.0 EVERywhere
BOUNdary condition P Y+ 0.0 EVERywhere
SELEct subdomain (1 102)(95 102)) ID=tank
SELEct subdomain (96 102)) (102 102)) ID=sand
BOUNdary condition P FLUX Y+ 0.0 for ID=tank
BOUNdary condition P Y+ 0.0 for ID=sand
/----------------------------------------------------------------/
/ OUTPUT CONTROL:
SAVE 'sandpad_twoD.sav' FORMatted
DIAGnostic node at: (90 20) frequency: 10  TIME S P
CONVergence P  GLOBal 0.0001 10 10
CONVergence FLOW 0.0001 10 10
/----------------------------------------------------------------/
/ OPERATIONAL CONTROL:
SOLVe  for 0.000000001 in step of 0.0000000001
SOLVe  for 0.00000001 in step of 0.0000000001
SOLVe  for 0.0000001 in step of 0.000000001
SOLVe  for 0.000001 in step of 0.00000001
SOLVe  for 0.00001 in step of 0.0000001
SOLVe  for 0.0001 in step of 0.000001
SOLVe  for 0.001 in step of 0.000001
SOLVe  for 0.01 in step of 0.000001
SOLVe  for 0.23888 in step of 0.000001
SOLVe for 0.75 in steps of 0.000001
/OUTPut C C2 C3 C4 in XY NARRow format  everywhere
----------------------------------------------------------------/
/ APPEND TO THE END:          !APPENDEND
END
```

```
/==== PROBLEM IDENTIFICATION ====/
/------------------------------------------------------------------/
/ PROBLEM IDENTIFICATION:
TITLe Sand Pad Two dimensional pressure run 30% saturation
USER Peter Kearl Dave Thorne
/File sandpad_twoD30.inp
/Date: March 24, 2006
/------------------------------------------------------------------/
/ GEOMETRY SPECIFICATIONS:
TIME = 0.0
GRID 102 x 102
COORdinates X -0.08 0.08 0.16 0.24 0.32 0.40 0.48 0.56 0.64 0.72
0.80 0.88 0.96 1.04 1.12 1.20 1.28 1.36 1.44 1.52
1.60 1.68 1.76 1.84 1.92 2.00 2.08 2.16 2.24 2.32
2.40 2.48 2.56 2.64 2.72 2.80 2.88 2.96 3.04 3.12
3.20 3.28 3.36 3.44 3.52 3.60 3.68 3.76 3.84 3.92
4.00 4.08 4.16 4.24 4.32 4.40 4.48 4.56 4.64 4.72
4.80 4.88 4.96 5.04 5.12 5.20 5.28 5.36 5.44 5.52
5.60 5.68 5.76 5.84 5.92 6.00 6.08 6.16 6.24 6.32
6.40 6.48 6.56 6.64 6.72 6.80 6.88 6.96 7.04 7.12
7.20 7.28 7.36 7.44 7.52 7.60 7.68 7.76 7.84 7.92
7.96 8.04
NODEs
COORdinates Y -0.0015 0.0015 0.003 0.0045 0.006 0.0075 0.009 0.0105 0.012 0.0135
0.015 0.0165 0.018 0.0195 0.021 0.0225 0.024 0.0255 0.027 0.0285
0.03 0.0315 0.033 0.0345 0.036 0.0375 0.039 0.0405 0.042 0.0435
0.045 0.0465 0.048 0.0495 0.051 0.0525 0.054 0.0555 0.057 0.0585
0.06 0.0615 0.063 0.0645 0.066 0.0675 0.069 0.0705 0.072 0.0735
0.075 0.0765 0.078 0.0795 0.081 0.0825 0.084 0.0855 0.087 0.0885
0.09 0.0915 0.093 0.0945 0.096 0.0975 0.099 0.1005 0.102 0.1035
0.105 0.1065 0.108 0.1095 0.111 0.1125 0.114 0.1155 0.117 0.1185
0.12 0.1215 0.123 0.1245 0.126 0.1275 0.129 0.1305 0.132 0.1335
0.135 0.1365 0.138 0.1395 0.141 0.1425 0.144 0.1455 0.147 0.1485
0.14925 0.15075
NODEs
/------------------------------------------------------------------/
/ ALLOCATE NEW SPACE:
/
ZONE 1 from (1 1) to ( 102 102 ) $Coarse Sand
!ANS
/------------------------------------------------------------------/
GRAVity 0, -9.81
DATUm coordinates: (0 0)
!IBC
/------------------------------------------------------------------/
/ FLUID PROPERTIES & CONSTANTS:
/DENSity of FIRSt phase = 1000 $kg/m3
!FPC
/------------------------------------------------------------------/
/ SOLID MATRIX PROPERTIES:
FOR ZONE 1 $Coarse Sand
HYDRaulic 1.0E-2 44.9 44.9 $0.1 cm/s after Freeze and Cherry (1979)
ROCK DENSity 2650.0 POROsity 0.28 0.30 $
MULTiphase properties:TABLe of 6
/ moisture characteristic curve, theta sub s vs. pressure ()
/data detailed in scientific notebook
```

```
1.0000     0.001
0.98       0.002
0.133      0.508
0.09       0.9
0.067      1.52
0.066      101.6
/Developed using Van Genuchten (1978)
MULTiphase CONDuctivity TABLe of 6
/unsaturated hydraulic conductivity, theta sub s vs. relative k(0)
1.0000     1.00000
0.95       0.60
0.90       0.44
0.50       0.043
0.20       0.00189
0.05       0.0000195
/-----------------------------------------------------------------/
/ SOLUTION OPTIONS:              !SOP
/ INITIAL & BOUNDARY CONDITIONS:
INITial for S is 0.30 EVERywhere
BOUNdary condition P FLUX X- 0.0 EVERywhere
BOUNdary condition P FLUX X+ 0.0 EVERywhere
BOUNdary condition P FLUX Y- 0.0 EVERywhere
BOUNdary condition P Y+ 0.0 EVERywhere
SELEct subdomain (1 102)(95 102)) ID=tank
SELEct subdomain (96 102)) (102 102)) ID=sand
BOUNdary condition P FLUX Y+ 0.0 for ID=tank
BOUNdary condition P Y+ 0.0 for ID=sand
/-----------------------------------------------------------------/
/ OUTPUT CONTROL:
SAVE 'sandpad_twoD30.sav' FORMatted
DIAGnostic node at: (90 20) frequency: 10  TIME S P
CONVergence P  GLOBal 0.0001 10 10
CONVergence FLOW 0.0001 10 10
/-----------------------------------------------------------------/
/ OPERATIONAL CONTROL:
SOLVe  for 0.000000001 in step of 0.0000000001
SOLVe  for 0.00000001 in step of 0.0000000001
SOLVe  for 0.0000001 in step of 0.000000001
SOLVe  for 0.000001 in step of 0.00000001
SOLVe  for 0.00001 in step of 0.0000001
SOLVe  for 0.0001 in step of 0.000001
SOLVe  for 0.001 in step of 0.00001
SOLVe  for 0.01 in step of 0.00001
SOLVe  for 0.23888 in step of 0.00001
SOLVe for 0.75 in steps of 0.00001
/OUTPut C C2 C3 C4 in XY NARRow format everywhere
------------------------------------------------------------------/
/ APPEND TO THE END:             !APPENDEND
END
```

```
/==== PROBLEM IDENTIFICATION ====/
/--------------------------------------------------------------------/
/ PROBLEM IDENTIFICATION:
TITLe Sand Pad Two dimensional pressure run 50% saturation
USER Peter Kearl Dave Thorne
/File sandpad_twoD50.inp
/Date: March 24, 2006
/--------------------------------------------------------------------/
/ GEOMETRY SPECIFICATIONS:
TIME = 0.0
GRID 102 x 102
COORdinates X -0.08 0.08 0.16 0.24 0.32 0.40 0.48 0.56 0.64 0.72
0.80 0.88 0.96 1.04 1.12 1.20 1.28 1.36 1.44 1.52
1.60 1.68 1.76 1.84 1.92 2.00 2.08 2.16 2.24 2.32
2.40 2.48 2.56 2.64 2.72 2.80 2.88 2.96 3.04 3.12
3.20 3.28 3.36 3.44 3.52 3.60 3.68 3.76 3.84 3.92
4.00 4.08 4.16 4.24 4.32 4.40 4.48 4.56 4.64 4.72
4.80 4.88 4.96 5.04 5.12 5.20 5.28 5.36 5.44 5.52
5.60 5.68 5.76 5.84 5.92 6.00 6.08 6.16 6.24 6.32
6.40 6.48 6.56 6.64 6.72 6.80 6.88 6.96 7.04 7.12
7.20 7.28 7.36 7.44 7.52 7.60 7.68 7.76 7.84 7.92
7.96 8.04
        NODEs
COORdinates Y -0.0015 0.0015 0.003 0.0045 0.006 0.0075 0.009 0.0105 0.012 0.0135
 0.015 0.0165 0.018 0.0195 0.021 0.0225 0.024 0.0255 0.027 0.0285
 0.03 0.0315 0.033 0.0345 0.036 0.0375 0.039 0.0405 0.042 0.0435
 0.045 0.0465 0.048 0.0495 0.051 0.0525 0.054 0.0555 0.057 0.0585
 0.06 0.0615 0.063 0.0645 0.066 0.0675 0.069 0.0705 0.072 0.0735
 0.075 0.0765 0.078 0.0795 0.081 0.0825 0.084 0.0855 0.087 0.0885
 0.09 0.0915 0.093 0.0945 0.096 0.0975 0.099 0.1005 0.102 0.1035
 0.105 0.1065 0.108 0.1095 0.111 0.1125 0.114 0.1155 0.117 0.1185
 0.12 0.1215 0.123 0.1245 0.126 0.1275 0.129 0.1305 0.132 0.1335
 0.135 0.1365 0.138 0.1395 0.141 0.1425 0.144 0.1455 0.147 0.1485
 0.14925 0.15075
                NODEs
/--------------------------------------------------------------------/
/ ALLOCATE NEW SPACE:
/
ZONE   1 from (1 1) to ( 102 102 ) $Coarse Sand
!ANS
/--------------------------------------------------------------------/
GRAVity 0, -9.81
DATUm coordinates: (0 0)
!IBC
/--------------------------------------------------------------------/
/ FLUID PROPERTIES & CONSTANTS:
/DENSity of FIRSt phase = 1000 $kg/m3
!FPC
/--------------------------------------------------------------------/
/ SOLID MATRIX PROPERTIES:
FOR ZONE 1 $Coarse Sand
HYDRaulic 1.0E-2 44.9 44.9 $0.1 cm/s after Freeze and Cherry (1979)
ROCK DENSity 2650.0 POROsity 0.28 0.30 $
MULTiphase properties:TABLe of 6
/ moisture characteristic curve, theta sub s vs. pressure ()
/data detailed in scientific notebook
```

```
1.0000      0.001
0.98        0.002
0.133       0.508
0.09        0.9
0.067       1.52
0.066       101.6
/Developed using Van Genuchten (1978)
MULTiphase CONDuctivity TABLe of 6
/unsaturated hydraulic conductivity, theta sub s vs. relative k(0)
1.0000      1.00000
0.95        0.60
0.90        0.44
0.50        0.043
0.20        0.00189
0.05        0.0000195
/-----------------------------------------------------------------/
/ SOLUTION OPTIONS:          !SOP
/ INITIAL & BOUNDARY CONDITIONS:
INITial for S is 0.50 EVERywhere
BOUNdary condition P FLUX X- 0.0 EVERywhere
BOUNdary condition P FLUX X+ 0.0 EVERywhere
BOUNdary condition P FLUX Y- 0.0 EVERywhere
BOUNdary condition P Y+ 0.0 EVERywhere
SELEct subdomain (1 102)(95 102)) ID=tank
SELEct subdomain (96 102)) (102 102)) ID=sand
BOUNdary condition P FLUX Y+ 0.0 for ID=tank
BOUNdary condition P Y+ 0.0 for ID=sand
/-----------------------------------------------------------------/
/ OUTPUT CONTROL:
SAVE 'sandpad_twoD50.sav' FORMatted
DIAGnostic node at: (90 20) frequency: 10  TIME S P
CONVergence P  GLOBal 0.0001 10 10
CONVergence FLOW 0.0001 10 10
/-----------------------------------------------------------------/
/ OPERATIONAL CONTROL:
SOLVe  for 0.000000001 in step of 0.0000000001
SOLVe  for 0.00000001 in step of 0.0000000001
SOLVe  for 0.0000001 in step of 0.000000001
SOLVe  for 0.000001 in step of 0.00000001
SOLVe  for 0.00001 in step of 0.0000001
SOLVe  for 0.0001 in step of 0.000001
SOLVe  for 0.001 in step of 0.00001
SOLVe  for 0.01 in step of 0.00001
SOLVe  for 0.23888 in step of 0.00001
SOLVe for 0.75 in steps of 0.00001
/OUTPut C C2 C3 C4 in XY NARRow format everywhere
------------------------------------------------------------------/
/ APPEND TO THE END:          !APPENDEND
END
```

```
/==== PROBLEM IDENTIFICATION ====/
/-------------------------------------------------------------------/
/ PROBLEM IDENTIFICATION:
TITLe Sand Pad Two dimensional pressure run 68% saturation
USER Peter Kearl Dave Thorne
/File sandpad_twoD68.inp
/Date: March 24, 2006
/-------------------------------------------------------------------/
/ GEOMETRY SPECIFICATIONS:
TIME = 0.0
GRID 102 x 102
COORdinates X -0.08 0.08 0.16 0.24 0.32 0.40 0.48 0.56 0.64 0.72
0.80 0.88 0.96 1.04 1.12 1.20 1.28 1.36 1.44 1.52
1.60 1.68 1.76 1.84 1.92 2.00 2.08 2.16 2.24 2.32
2.40 2.48 2.56 2.64 2.72 2.80 2.88 2.96 3.04 3.12
3.20 3.28 3.36 3.44 3.52 3.60 3.68 3.76 3.84 3.92
4.00 4.08 4.16 4.24 4.32 4.40 4.48 4.56 4.64 4.72
4.80 4.88 4.96 5.04 5.12 5.20 5.28 5.36 5.44 5.52
5.60 5.68 5.76 5.84 5.92 6.00 6.08 6.16 6.24 6.32
6.40 6.48 6.56 6.64 6.72 6.80 6.88 6.96 7.04 7.12
7.20 7.28 7.36 7.44 7.52 7.60 7.68 7.76 7.84 7.92
7.96 8.04
      NODEs
COORdinates Y -0.0015 0.0015 0.003 0.0045 0.006 0.0075 0.009 0.0105 0.012 0.0135
 0.015 0.0165 0.018 0.0195 0.021 0.0225 0.024 0.0255 0.027 0.0285
 0.03 0.0315 0.033 0.0345 0.036 0.0375 0.039 0.0405 0.042 0.0435
 0.045 0.0465 0.048 0.0495 0.051 0.0525 0.054 0.0555 0.057 0.0585
 0.06 0.0615 0.063 0.0645 0.066 0.0675 0.069 0.0705 0.072 0.0735
 0.075 0.0765 0.078 0.0795 0.081 0.0825 0.084 0.0855 0.087 0.0885
 0.09 0.0915 0.093 0.0945 0.096 0.0975 0.099 0.1005 0.102 0.1035
 0.105 0.1065 0.108 0.1095 0.111 0.1125 0.114 0.1155 0.117 0.1185
 0.12 0.1215 0.123 0.1245 0.126 0.1275 0.129 0.1305 0.132 0.1335
 0.135 0.1365 0.138 0.1395 0.141 0.1425 0.144 0.1455 0.147 0.1485
 0.14925 0.15075
            NODEs
/-------------------------------------------------------------------/
/ ALLOCATE NEW SPACE:
/
ZONE 1 from (1 1) to ( 102 102 ) $Coarse Sand
!ANS
/-------------------------------------------------------------------/
GRAVity 0, -9.81
DATUm coordinates: (0 0)
!IBC
/-------------------------------------------------------------------/
/ FLUID PROPERTIES & CONSTANTS:
/DENSity of FIRSt phase = 1000 $kg/m3
!FPC
/-------------------------------------------------------------------/
/ SOLID MATRIX PROPERTIES:
FOR ZONE 1 $Coarse Sand
HYDRaulic 1.0E-2 44.9 44.9 $0.1 cm/s after Freeze and Cherry (1979)
ROCK DENsity 2650.0 POROsity 0.28 0.30 $
MULTiphase properties:TABLe of 6
/ moisture characteristic curve, theta sub s vs. pressure ()
/data detailed in scientific notebook
```

```
1.0000    0.001
0.98      0.002
0.133     0.508
0.09      0.9
0.067     1.52
0.066     101.6
/Developed using Van Genuchten (1978)
MULTiphase CONDuctivity TABLe of 6
/unsaturated hydraulic conductivity, theta sub s vs. relative k(0)
1.0000    1.00000
0.95      0.60
0.90      0.44
0.50      0.043
0.20      0.00189
0.05      0.0000195
/------------------------------------------------------------------/
/ SOLUTION OPTIONS:          !SOP
/ INITIAL & BOUNDARY CONDITIONS:
INITial for S is 0.68 EVERywhere
BOUNdary condition P FLUX X- 0.0 EVERywhere
BOUNdary condition P FLUX X+ 0.0 EVERywhere
BOUNdary condition P FLUX Y- 0.0 EVERywhere
BOUNdary condition P Y+ 0.0 EVERywhere
SELEct subdomain (1 102)(95 102)) ID=tank
SELEct subdomain (96 102)) (102 102)) ID=sand
BOUNdary condition P FLUX Y+ 0.0 for ID=tank
BOUNdary condition P Y+ 0.0 for ID=sand
/------------------------------------------------------------------/
/ OUTPUT CONTROL:
SAVE 'sandpad_twoD68.sav' FORMatted
DIAGnostic node at: (90 20) frequency: 10  TIME S P
CONVergence P  GLOBal 0.0001 10 10
CONVergence FLOW 0.0001 10 10
/------------------------------------------------------------------/
/ OPERATIONAL CONTROL:
SOLVe  for 0.000000001 in step of 0.0000000001
SOLVe  for 0.00000001 in step of 0.0000000001
SOLVe  for 0.0000001 in step of 0.000000001
SOLVe  for 0.000001 in step of 0.00000001
SOLVe  for 0.00001 in step of 0.0000001
SOLVe  for 0.0001 in step of 0.000001
SOLVe  for 0.001 in step of 0.00001
SOLVe  for 0.01 in step of 0.00001
SOLVe  for 0.23888 in step of 0.00001
SOLVe for 0.75 in steps of 0.00001
/OUTPut C C2 C3 C4 in XY NARRow format  everywhere
------------------------------------------------------------------/
/ APPEND TO THE END:          !APPENDEND
END
```