Optimization of the Retrieval of Waste from Hanford Tank S-109 through Numerical Modeling- 9459

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ABSTRACT

This report covers 10 different retrieval scenarios to support the U.S. Department of Energy's Office of River Protection in its mission to facilitate the retrieval and treatment of high-level radioactive waste stored in underground tanks at the Hanford site by investigating the transport properties of the saltcake. Saltcake consists of salts precipitated out of the brines during evaporation and storage. The main objective of this study is to gain a better understanding of the dissolution process that will occur in Tank 241-S-109 as it is retrieved to provide waste for Vitrification at the Demonstration Bulk Vitrification System Facility (DBVS). Double Shell Tank (DST) space is extremely limited and will continue to be until the Waste Treatment Plant becomes operational. Maximizing the utilization of DST space is the goal of the S-109 Partial Waste Retrieval Project that will provide waste feed to the Demonstration Bulk Vitrification System (DBVS). Florida International University, FIU has developed a 2-D axisymmetric numerical model which will assist the Department of Energy (DOE) and Savannah River Site (SRS) in evaluating the potential of selective saltcake retrieval for schedule acceleration and significant cost savings by analyzing the performance of different retrieval scenarios with the prediction of Cs breakthrough curves in the resulting saltcake brine and to determine the displacement patterns of Cs. This predictive information is critical for scheduling and operational purposes. Ten retrieval scenarios which include addition of flushing liquid at the entire surface of the tank or at a side peripheral channel were simulated. All retrieval scenarios were analyzed for incremental retrieval (saturation of the tank with flushing liquid followed by complete drainage at the central well) versus continuous retrieval (water is continuously added at the top and retrieved at a central well). Furthermore, the specifics of the tank hydrology were approximated using a multilayer model (S-109 has 2 layers of considerably lower hydraulic conductivity compared to the remaining of the tank) versus a single layer model (uniform hydraulic conductivity throughout the tank). The results of the study showed that incremental retrieval has markedly better performance in terms of volume of waste generated and time for retrieval. In order to remove 0.65 fractions of the total cesium, the continuous retrieval of a single layer system will use approximately 2.98 pore volumes of washing fluid, while the incremental retrieval will need 0.69 pore volumes of fluid to remove 0.65 fractions of the total cesium whereas in the multi layer system (two layers of low permeability compared to the rest of the tank), the retrieval rates are much slower due to low permeability layers. Addition of displacement fluid at the peripheral side channel demonstrates best performance for a homogeneous porous media, however for a multilayer system with considerably lower permeability of some of the layers, the retrieval rates are slower compared to uniform addition at the top of the tank.

INTRODUCTION

The Hanford Tank Farms contain 53 million gallon of radioactive waste accumulated during over 50 years of operation and stored in 177 single (SST) and double shell tanks (DST). The high level waste (HLW) in the waste tanks are separated into layers: supernate (on top) containing soluble fission products, and saltcake and sludge (on the bottom of the tank) containing insoluble actinides. Salt waste can be further characterized as "supernate" (in normal solution), "concentrated supernate" (after evaporation has removed some of the liquid) or "saltcake" (previously dissolved salts, such as sodium nitrate and sodium nitrite, that have now crystallized out of solution). Hanford waste is vertically heterogeneous. At the bottom lies a layer of crusty solids, or salt cake. Usually sludge is on the bottom or mixed with saltcake with greater amounts of sludge nearer the bottom. Sludge and salt cake contain the most radioactive substances and are classified as HLW. Above the sludge is a viscous liquid supernatant which can be classified as LAW after the cesium is removed. The S-109 Partial Waste Retrieval Project (PWRS) will provide waste feed to the Demonstration Bulk Vitrification System (DBVS) as a supplemental treatment technology for low-activity waste (LAW) at the Hanford Site, and will be used to segregate the low curie salt waste from the high curie salt supernate by draining the supernate and interstitial salt solution from the saltcake while fresh water is continuously being added at the top of the tank. The DBVS is a full-scale research and development facility intended to demonstrate the effectiveness of the bulk vitrification process as a method for treatment and immobilizing LAW fractions from tank waste for onsite disposal. The S-109 PWRS will be capable of pumping brine solution either to a DST or to the DBVS facility depending on the concentration of cesium in the drained fluid. The liquid in S-109 currently contains significant amounts of cesium (0.32 Ci/L), enough so that the S-109 retrieved waste must be pretreated prior to supplying feed to the DBVS to ensure compliance with the DBVS waste feed specification of less than 0.006 Ci/L. Pretreatment will be accomplished via selective washing and dissolution of the saltcake and concurrent displacement and removal of cesium.

A plan for pretreatment of S-109 is to add water to the top of the salt cake and pump liquid from the bottom pump until the liquid concentration approaches the feed specification, then switch to the upper pump and begin withdrawing liquid for the DBVS. The S-109 PWRS contains a pump assembly that has three individual pumps. Two of the pumps (P1 and P2) are located 12 inches from the bottom of the tank and the third assembly is located 70 inches from the bottom of the tank as shown in Figure 1 below. The uncertainties in this method include the drainage parameters of the saltcake and more specifically, the hydraulic properties of the interstitial fluid in the saltcake. The hydraulic parameters of the saltcake have significance with respect to kinetics of the process and equilibrium conditions of the drainage.

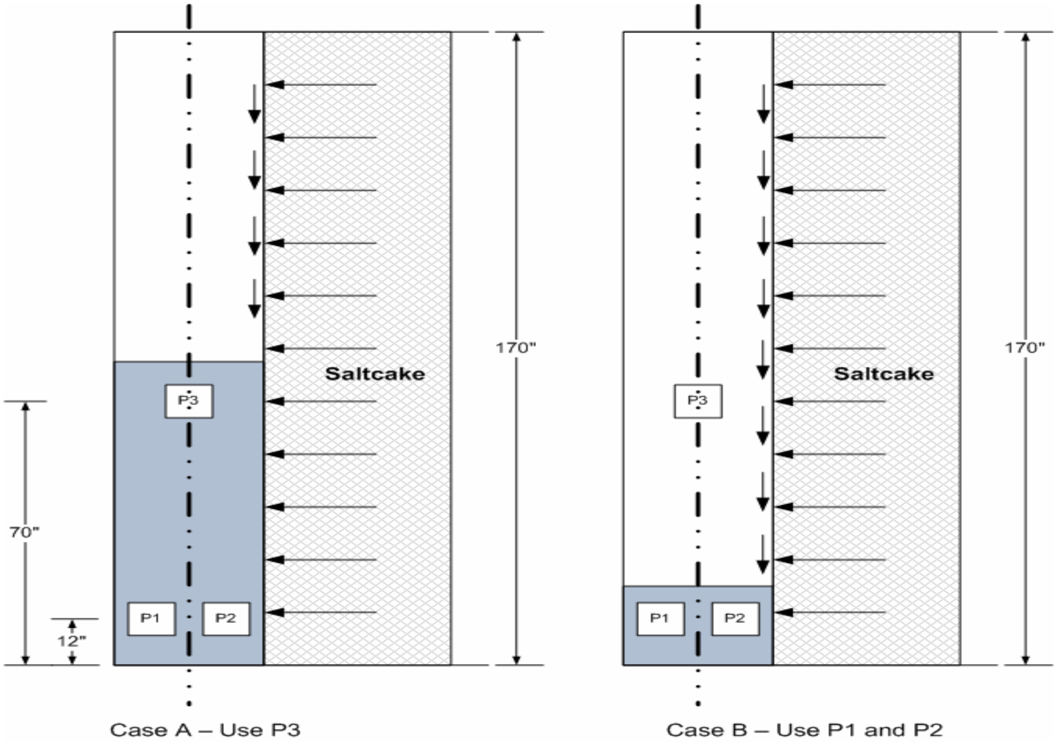

Figure 1 Pump Assemble of S-109

A 2D axisymmetric finite element model of the tank was created to determine the effect of addition of flushing fluid at the top of the tank, combined with drainage, and the displacement of the interstitial fluid and the resulting dilution of Cs, with emphasis on the volumes drained and the concentrations of Cs within the tank. The numerical model implements flow through porous media using Darcy's Law coupled with transport (Advection/Dispersion equations) through saturated and/or variably saturated porous media (Richard's Equation). By solving the coupled models of transport phenomena and the flow through porous media (saturated and/or unsaturated flow) the tank was analyzed to determine the concentration distribution as a function of time and location within the tank. The model was used to determine the retrieval parameters using continuous and incremental retrieval (series of saturation and drainages). The objective was to determine the following operating parameters:

1. How much liquid would be pumped when the concentration at the upper pump was down to <0.006 Ci/L (6 Ci/m^3)?
2. What would be the concentration of cesium in the liquid being pumped from lower pump when the concentration had dropped to <0.006 Ci/L at the location of the upper pump?

NUMERICAL MODELING OF CESIUM DISPLACEMENT

The movement of Cs requires modeling of transport in porous media, fluids, and diffusion/dispersion. The following phenomena affect the transport: 1) Advection with moving fluids, 2) Dispersion, 3) Molecular diffusion, 4) Sorption/recrystallization to solids, and 5) Chemical reactions between liquids and solids. Cs is a strong electrolyte and it can be assumed that advection and dispersion are the main two processes that will affect its movement through the tank while recrystallization and chemical reactions are negligible. The problem of selective dissolution requires numerical modeling and estimates of the transport and flow parameters. The hydraulic parameters of the saltcake (hydraulic conductivity and van Genuchten parameters) have significance with respect to tank drainage and resaturation. While the saturated hydraulic properties of the salt waste (hydraulic conductivity in the vertical and horizontal direction) can be used to determine the kinetics of the flow through the salt waste, the unsaturated properties are needed in order to assess not only the timeframe of tank drainage but also the equilibrium conditions. Draining of the fluid, if no other external forces/pressure is applied, is caused by gravity (i.e., weight of the fluid). For that case, only a fraction of the interstitial fluid can be drained and a considerable amount of fluid will remain within the saltcake pores, being held by surface tension forces. The hydraulic parameters determine how much fluid can be ultimately drained at given initial and boundary conditions (atmospheric pressure and temperature). The numerical simulation must include a 2-D axisymmetric numerical model which implements flow through porous media using Darcy's Law coupled with transport (Advection/Dispersion equations) through saturated and/or variably saturated porous media (Richard's Equation). The hydraulic properties define the performance of the retrieval process:

- The kinetics of the drainage process, i.e. how fast is the flow through the media
- The equilibrium conditions of the drainage, i.e., when the drainage is completed, what is the fraction of interstitial fluid remaining in the pores.
- The performance of the drainage process for different retrieval scenarios, including 1) incremental and continuous retrieval, 2) addition of washing fluid at the top and at peripheral channel, 3) homogenous and non-homogeneous saltcake with multiple layers of variable conductivity.

Governing Equations for Flow in Porous Media

One of the most important parameters for determining the transport properties of the porous media is the hydrodynamic dispersion tensor. The hydrodynamic dispersion can be applied to describe the spreading of cesium mass spatially and temporally. It combines effects from local variations in pore fluid velocity dispersion and molecular diffusion. In this study, the hydrodynamic dispersion parameters, the Peclet number for molecular diffusion, and the resulting uncertainties have been estimated from pilot scale column experiments using S-109 saltcake stimulant. The movement of Cs requires modeling of transport in porous media, fluids, and diffusion/dispersion. Cs is a strong electrolyte and it can be assumed that advection and dispersion are the main two processes that will affect its movement through the tank. The 2-D axisymmetric numerical model implements flow through porous media using Darcy's Law coupled with transport (Advection/Dispersion equations) through saturated and/or variably saturated porous media (Richard's Equation). The hydraulic properties are required to determine the kinetics of drainage process and equilibrium conditions of the drainage.

The transport properties are required in order to determine:

- The total amount of fluid and the timeframe which will be needed to remove Cs in interstitial fluid
- The displacement of the interstitial fluid with fresh fluid
- Concentration of solute as a function of location within the porous media (Tanks).

A coupled solution of the transport and flow equations provides spatial and temporal distribution of Cs during drainage. In addition, the flow rates and volume drained can be accurately determined. The flow through porous media is modeled in terms of pressure, p, as an independent variable. In addition, the following independent variables are used instead of pressure: hydraulic head, H, and pressure head, H_p. The relation between these three is given below:

$$H = H_p + z = \frac{p + \rho_f g \nabla z}{\rho_f g} \tag{1}$$

In the relation above p is the fluid's pressure and ρ_f is its density; g is the magnitude of gravitational acceleration; and z is the direction over which g acts. Darcy's law describes fluid movement through interstices in a porous medium. The net flux across an area of porous surface is:

$$u = -\frac{k}{\eta}\left(\nabla p + \rho_f g \nabla z\right) \tag{2}$$

In the equation, u is the Darcy velocity or specific discharge vector; k is the permeability of the porous media; η is the fluid's dynamic viscosity. Here the permeability, k, represents the resistance to flow over a representative volume consisting of many solid grains and pores. According to Bear [2] the continuity equation for incompressible fluid expressed using the net flux is:

$$S\frac{\partial p}{\partial t} + \nabla \bullet \left[-\frac{k}{\eta}\left(\nabla p + \rho_f g \nabla z\right)\right] = Q_s \tag{3}$$

where Q_s is the strength of a fluid source and S is a specific storage coefficient. Dirichlet's boundary conditions can be applied when the primary variable is known. $p=p_0$ where p_0 is a known pressure given as a number, a distribution, or an expression involving time, t, for example. At a free surface, pressure is atmospheric. This boundary condition can be used at central well, and it simulates porous media exposed to atmospheric pressure, or to simulate a constant head from the addition of fresh water on the top of the porous media. Neumann boundary conditions refers to known flux and it is applied at boundaries with known flux, e.g. during drainage flux at the top of the porous media is equal to zero.

The Richards' equation analyzes flow in variably saturated porous media. With variably saturated flow, hydraulic properties θ, S_e, C, and k_r vary for unsaturated conditions (for example, negative pressure) and reach a constant value at saturation (for example, pressure of zero or above).The general form of Richard's equation is shown below:

$$\delta_{ts}\left[C+S_eS\right]\frac{\partial p}{\partial t}+\nabla\bullet\left[-\frac{k_s}{\eta}k_r\nabla\left(p+\rho_f g\nabla z\right)\right]=Q_s \tag{4}$$

where pressure, p, is the dependent variable. In the equation, δ_{ts} is an optional coefficient, C represents the specific capacity, S_e denotes the effective saturation, S is the storage coefficient, κ_s gives the intrinsic permeability, η is the fluid viscosity, k_r denotes the relative permeability, ρ_f is the fluid density, g is gravitational acceleration, z represents the vertical coordinate, and Q_s is the fluid source (positive) or sink (negative). The volume of liquid per porous medium volume, θ, ranges from a small residual value θ_r to the total porosity θ_s. Its value is given in a constitutive relation in the model. The effective saturation, S_e, amounts to θ normalized to a maximum value of 1. The specific capacity, C, describes the change in θ as the solution progresses, the slope on a plot of θ versus pressure (or pressure head). The relative permeability, k_r, increases with moisture content and varies from a nominal value to 1. k_r attains maximum value at saturation which reveals that fluid moves more readily when the porous medium is fully wet. The fluid velocity across the faces of an infinitesimally small surface is:

$$u=-\frac{k_s}{\eta}k_r\nabla\left(p+\rho_f g\nabla z\right) \tag{5}$$

where u is the flux vector. The equation above describes the flux as distributed across a representative surface. This interstitial or average linear velocity is $u_a = u/\theta$, where θ is the liquid fraction. For modeling purposes, the van Genuchten equations are commonly used to describe the water retention characteristic with four adjustable parameters. The van Genuchten equations for water retention in dimensionless form and for hydraulic conductivity are:

$$\theta(H_p)=\begin{cases}\theta_r+S_e(\theta_s-\theta_r) & H_p<0\\ \theta_s & H_p\geq 0\end{cases} \tag{6}$$

$$S_e(H_p)=\begin{cases}\dfrac{1}{\left[1+\left|\alpha H_p\right|^n\right]^m} & H_p<0\\ 1 & H_p\geq 0\end{cases} \tag{7}$$

$$C(H_p)=\begin{cases}\dfrac{\alpha m}{1-m}(\theta_s-\theta_r)S_e^{\frac{1}{m}}\left(1-S_e^{\frac{1}{m}}\right)^m & H_p<0\\ 0 & H_p\geq 0\end{cases} \tag{8}$$

$$k(H_p)=\begin{cases}S_e^{\,L}\left[1-\left(1-S_e^{\frac{1}{m}}\right)^m\right]^2 & H_p<0\\ 1 & H_p\geq 0\end{cases} \tag{9}$$

where m=1-1/n, n > 1, S_e is the normalized relative saturation, θr is the residual liquid content, θ_s is the saturated liquid content, θ is the liquid content, K_0 is defined as the matching point at saturation and, in general, has a lower value than the saturated hydraulic conductivity; α is a shape parameter, with higher values implying larger pores. α is interpreted as the inverse of the air–entry pressure. The term *n* is a pore size distribution parameter and *L* is the pore connectivity parameter equal to an average of 0.5 for many soils (van Genuchten).

Governing Equations for Transport in Porous Media

The governing equation for saturated porous media assuming no re-crystallization and no reaction of the solute is given as:

$$\theta_s \frac{\partial C_i}{\partial t} + \nabla \bullet \left[-\theta_s D_{Li} \nabla C_i + u C_i \right] = 0 \tag{10}$$

Here, C_i denotes the solute concentration in the liquid (mass per liquid volume for species *i*). In the equation, θ_s (porosity) is the volume of fluid divided by the total fluid-solid volume; and $\rho_b = (1 - \theta_s)\rho_p$ is the bulk density of the porous medium when ρ_p is the particle density. D_{Li} represents the hydrodynamic dispersion tensor, *u* is the vector of directional velocities and S_{ci} denotes a solute source. The most important parameter for studying the transport properties of the porous media is the hydrodynamic dispersion tensor. Hydrodynamic dispersion describes the spreading of contaminant mass. It combines effects from local variations in pore fluid velocity "dispersion" and molecular diffusion. The dispersion occurs because fluids in pore spaces navigate around solid particles, so velocities vary within pore channels. The spreading in the direction parallel to flow or "longitudinal dispersion" typically exceeds transverse dispersion from 3 to 10 times. Being driven by the concentration gradient alone, molecular diffusion is small relative to the mechanical mixing, except at very low fluid velocities. For 2-Dimensional geometry, the following defines the dispersion tensor:

$$\theta_s D_{xx} = \alpha_1 \frac{u^2}{|u|} + \alpha_2 \frac{v^2}{|u|} + \theta_s \tau_L D_m \tag{11}$$

$$\theta_s D_{yy} = \alpha_1 \frac{v^2}{|u|} + \alpha_2 \frac{u^2}{|u|} + \theta_s \tau_L D_m \tag{12}$$

$$\theta_s D_{xy} = \theta_s D_{yx} = (\alpha_1 - \alpha_2) \frac{uv}{|u|} \tag{13}$$

where D_{Lii} are the principal components of the hydrodynamic dispersion tensor, D_{Lji} and D_{Lji} are the cross terms; and α_1 is the dispersivity parallel to the directional velocity. If *z* is vertical, α_2 and α_3, are the dispersivities in the transverse horizontal and transverse vertical directions, respectively, Bear [1, 2]. The tensor entries also define molecular diffusion. Here D_m is the molecular diffusion coefficient, and τ_L is the tortuosity factor (less than 1). Multiplication by τ_L, to account for the solids, returns a diffusive flux that is less than that predicted for a strictly liquid system because the solid grains impede the Brownian motion. The tortuosity factor can be defined as: $\tau_L = \theta^{7/3}\theta_s^{-2}$. Dirichlet's boundary conditions can be applied when the primary variable is known. C_i=C_{i0} where C_{i0} is a known concentration given as a number, a distribution, or an expression involving time, *t*. For fresh water, the concentration is zero (top of the tank). Neumann boundary conditions are applied when flux (secondary variable) is known. Secondary variable is known. Zero flux across impervious boundaries (walls) is represented with: $\vec{n} \bullet \left(-\theta_s D_{Li} \nabla_{Ci} + \vec{u} C_i \right) = 0$.

MODEL DEVELOPMENT

To determine the effect of washing fluid addition at the top of the tank, combined with drainage, and the displacement of the interstitial fluid and the resulting dilution of Cs, numerical model was created with emphasis on the volumes drained and the concentrations of Cs within the tank. By solving the coupled models of transport phenomena and the flow through porous media (saturated and/or unsaturated flow) the tank was analyzed to determine the concentration distribution as a function of time and location within the tank. The modeling of Cs displacement simulates two scenarios. Scenario 1 simulates continuous water addition to the top of the tank and concurrent drainage through the central well. Scenario 2 simulates initial drainage of the tank, followed by water addition until resaturation, and subsequent second drainage. The objective of the simulations was to determine the best scenario for water addition and to compare the different alternatives to get maximum retrieval of cesium.

The properties of the domain were selected based on experimental data from tests performed at FIU in 2003-2006 and literature survey of available data for HLW tanks at Hanford and SRS. The water flow parameters used in this simulation were obtained from experimental data. The porous media flow parameters, θ_s and θ_r were respectively 0.4 and 0.20, K_s = 6e-6 m/s (saturated conductivity) for the entire domain, ρ_f= 1400 kg/m^3 (density liquid), α = 3.2, n=2.5 and l = 0.5 (van Genuchten shape parameters). The initial conditions were fully saturated saltcake. Transport parameters: α_r and α_z = 0.06 m (dispersivity parameters), D_{ml} = 1e-7 m^2/s (coefficient of molecular diffusion, ρ_b = 1700 kg/m^3 (bulk density of saltcake).

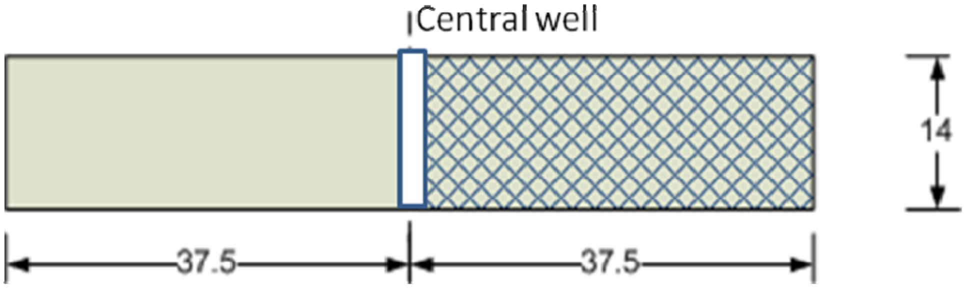

Figure 2 Dimensions of Tank S-109 used in the model (feet)

A 2D finite element tank model with dimensions of 37.5 ft (11.45 meters) by 14 ft (4.3 meters) with a central well of 3.3 ft (1.0 meters) by 14 ft (4.3 meters) was created in COMSOL. Schematic of the tank is shown in Figure 2. A list of the volumetric properties of the tank used for simulations is shown in Table 1

Table 1 Tank geometry

Tank Geometry	Volume m^3	Volume, gallon
V_tank	1770.146	467318
V_liquid	708.058	186927
porosity	0.4	
Diameter	11.45 m	
Height	4.30 m	

The initial model simulated washing fluid addition at the top of the tank combined with drainage at the bottom is shown on Figure 3. The initial model was modified as seen in Figure 3 to include a boundary condition of zero pressure at the central well (or seepage) which will direct the flux towards the center of the well (previous boundary condition was zero pressure at the bottom of the central well and implied drainage through the bottom focusing on drainage through the bottom of the central well).

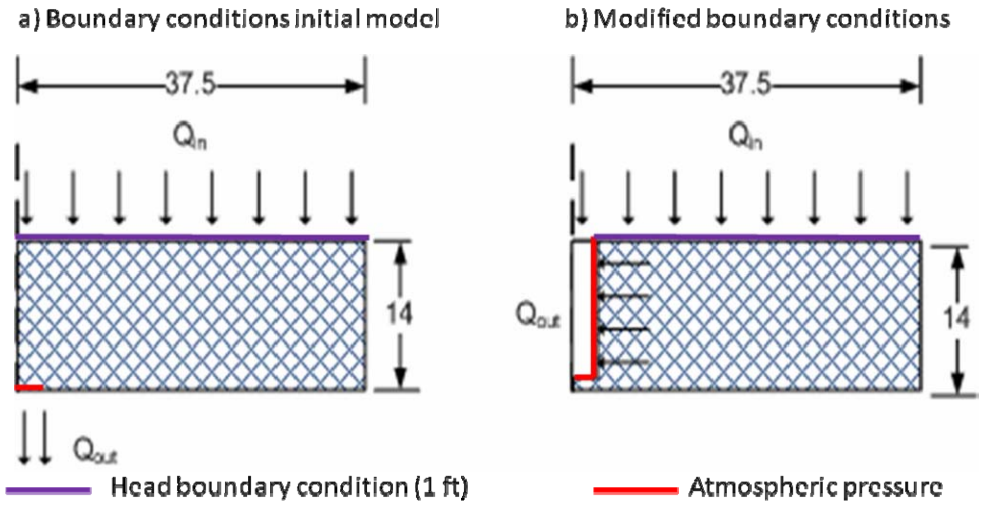

Figure 3 Model boundary conditions at the central well (continuous retrieval)

Figure 4 gives an overview of the different cases simulated, the boundary conditions used and the hydraulic conductivities of the domain. A model simulating washing fluid addition at the top & side of the tank and subsequent drainage toward the central well while maintaining a zero pressure condition at the central well and having uniform conductivity throughout the entire domain (homogenous system) can be seen in Figure 4a and Figure 4b and having non-uniform conductivity (multi-layer system) can be see in Figure 4c and Figure 4d respectively. The main objective was to compare the retrieval in terms of time, waste retrieved and fraction of Cs retrieved.

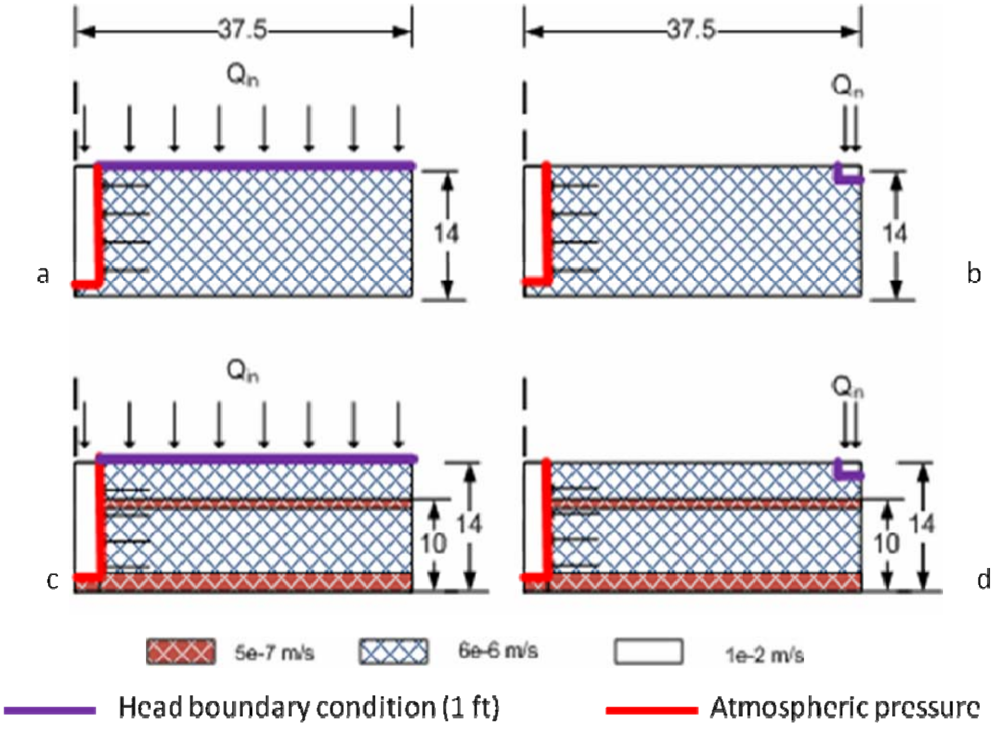

Figure 4 Boundary conditions for incremental and side channel addition

A layer with lower permeability is normally observed in HLW tanks. In order to characterize the regions with different permeability as suggested by the site representatives, the initial model was modified and two layers of low permeability in the domain was created as shown above in Figure 4c and Figure 4d respectively. A constant pressure head at the top of the tank where water is added was maintained and water was drained out of the tank through the central well at atmospheric pressure and temperature. This multi-layer model was simulated for both displacement fluid addition at the top and at the side of the tan and the retrieval in terms of time, waste retrieved and fraction of Cs retrieved was compared.

Simulation Scenarios

The modeling of Cs displacement simulated two operational scenarios.

- **Scenario 1** simulated continuous water addition to the top of the tank and concurrent drainage through the central well.
- **Scenario 2** simulated initial drainage of the tank, followed by water addition until resaturation, and subsequent second drainage.

Furthermore, the numerical model was used to determine the effect of different initial conditions, including a homogeneous media, (uniform conductivity throughout the domain) and a multi layer media (two layers with low permeability in the domain). Several cases were investigated as mentioned below.

- **Case 1 -** Continuous water addition to the top of the tank and concurrent drainage through the central well for a Single Layer System
- **Case 2** – Incremental retrieval: Initial drainage of the tank, followed by water addition to the top of the tank until resaturation, and subsequent second drainages and resaturation for a Single Layer System
- **Case 3 -** Continuous water addition to the side of the tank and concurrent drainage through the central well for a Single Layer System
- **Case 4 -** Incremental retrieval: Initial drainage of the tank, followed by water addition to the top of the tank until resaturation, and subsequent second drainages and resaturation for a Single Layer System
- **Case 5 -** Continuous water addition to the top of the tank and concurrent drainage through the central well for a Multi Layer System
- **Case 6 -** Incremental retrieval: Initial drainage of the tank, followed by water addition to the top of the tank until resaturation, and subsequent second drainages and resaturation for a Multi Layer System
- **Case 7 -** Continuous water addition to the side of the tank and concurrent drainage through the central well for a Multi Layer System
- **Case 8 -** Incremental retrieval: Initial drainage of the tank, followed by water addition to the top of the tank until resaturation, and subsequent second drainages and resaturation –for a Multi Layer System

Additionally, the numerical model was also investigated for a multi layer system having two times the difference in magnitude of permeability. The model was simulated for both continuous water addition as well as for incremental water drainage and resaturation cases.

- **Case 9-** Continuous water addition to the top of the tank and concurrent drainage through the central well for a Multi Layer System (2 times the difference in magnitude of permeability).

- **Case 10-** Incremental retrieval: Initial drainage of the tank, followed by water addition to the top of the tank until resaturation, and subsequent second drainages and resaturation for a Multi Layer System (2 times the difference in magnitude of permeability).

RESULTS & DISCUSSION

A total of 10 different retrieval scenarios including addition of flushing liquid at the top of the tank or at a side peripheral channel were simulated. All retrieval scenarios were analyzed for incremental retrieval (saturation of the tank with flushing liquid followed by complete drainage) as seen in Figure 6 and for continuous retrieval (water is continuously added at the top and retrieved at a central well) as seen in **Error! Not a valid bookmark self-reference.**.

Continuous Retrieval

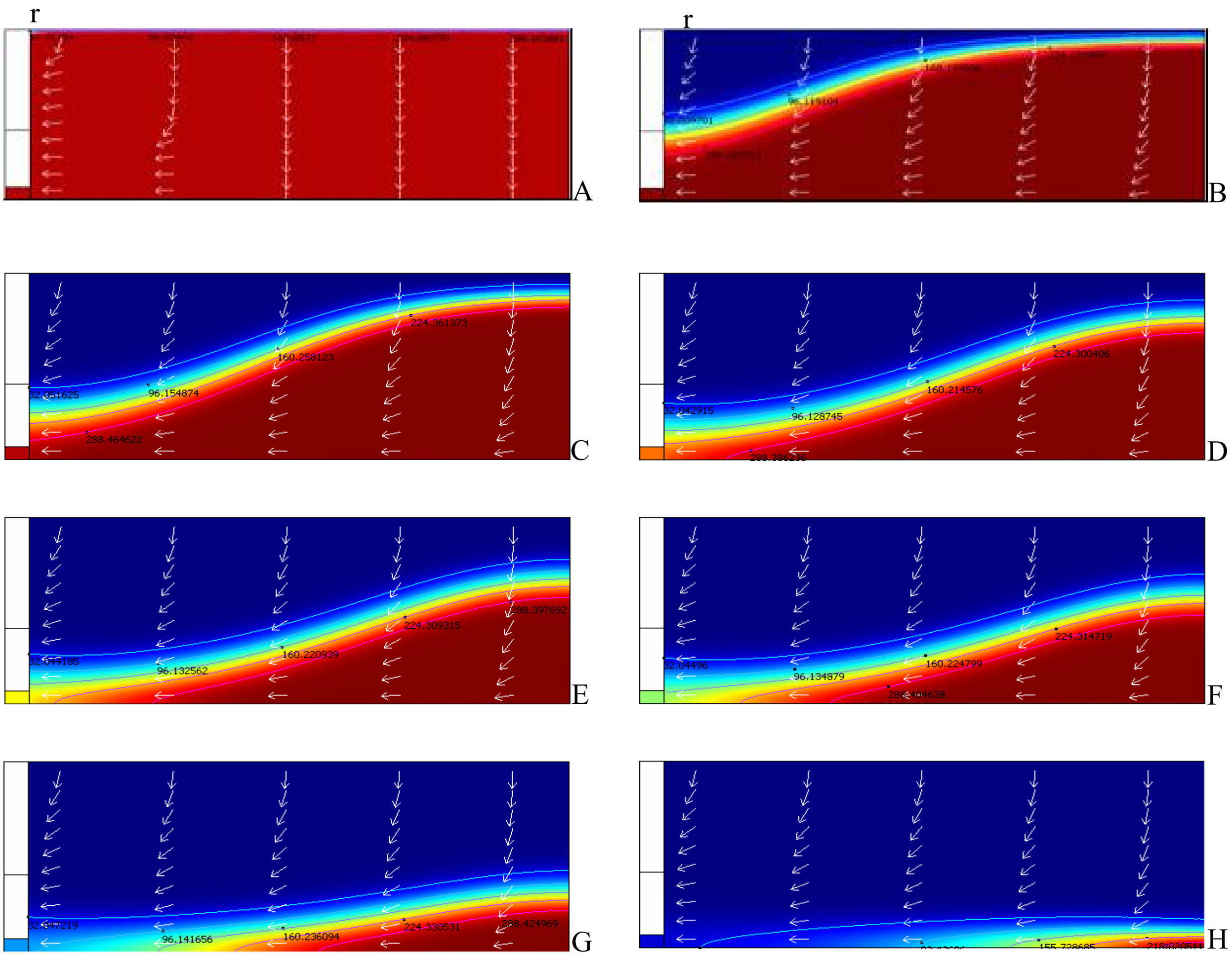

Figure 5 Distribution of Cs concentration within the tank after continuous retrieval at A) T=0 days and B) T=7 days and C) T=20 days and D) T=45 days and E) T=60 days and F) T=90 days and G) T=180 days and H) T=365 days arrows show the velocity vectors (normalized). The center of symmetry is on the left hand side

Incremental Retrieval

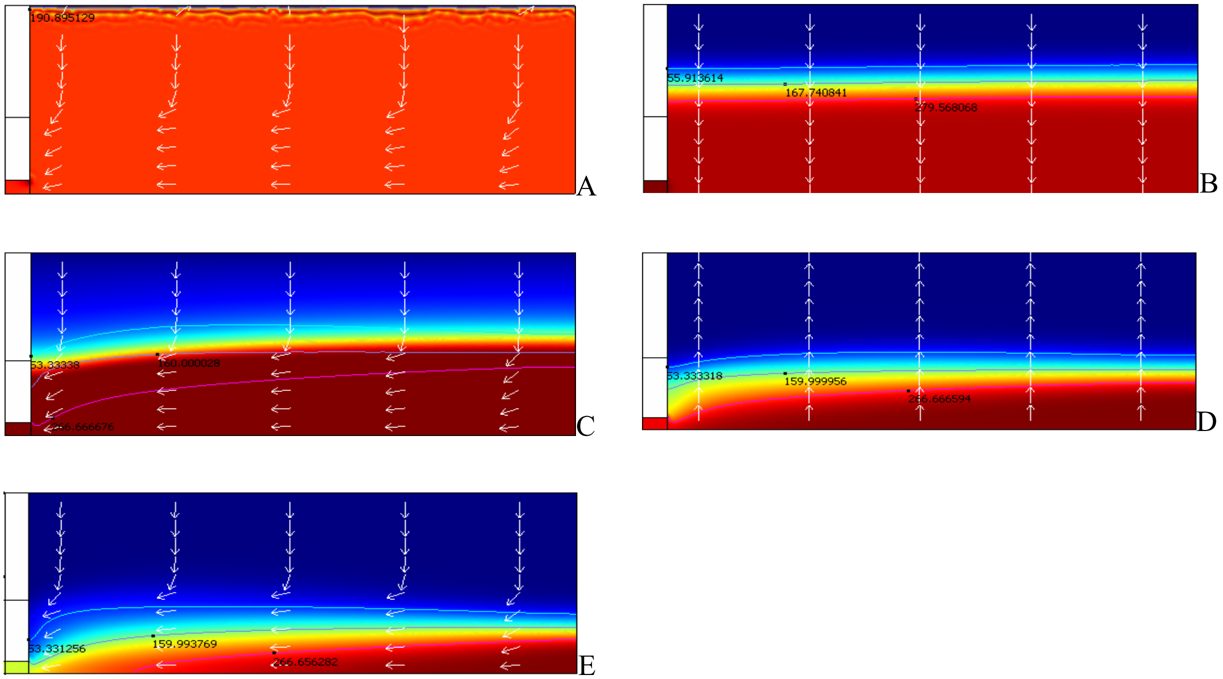

Figure 6 Distribution of Cs concentration within the tank after incremental retrieval at A) Drainage T=70 days B) Resaturation T=7 days & C) Drainage, T= 70 days, D) Resaturation T=7 days & E) Drainage, T= 70 days. Arrows show the velocity vectors (normalized). The center of symmetry is on the left hand side

Furthermore, the specifics of the tank hydrology were approximated using a multilayer model (S-109 has 2 layers of considerably lower hydraulic conductivity compared to the remaining of the tank). Figure 7 and Figure 8 below shows the comparison of all 10 cases.

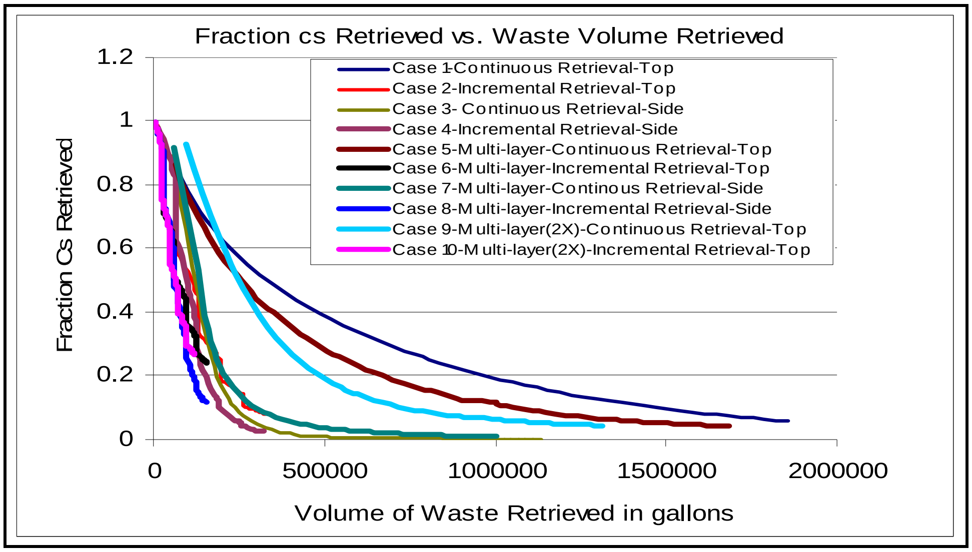

Figure 7 Fraction Cs Retrieved vs. waste volume for all 10 cases

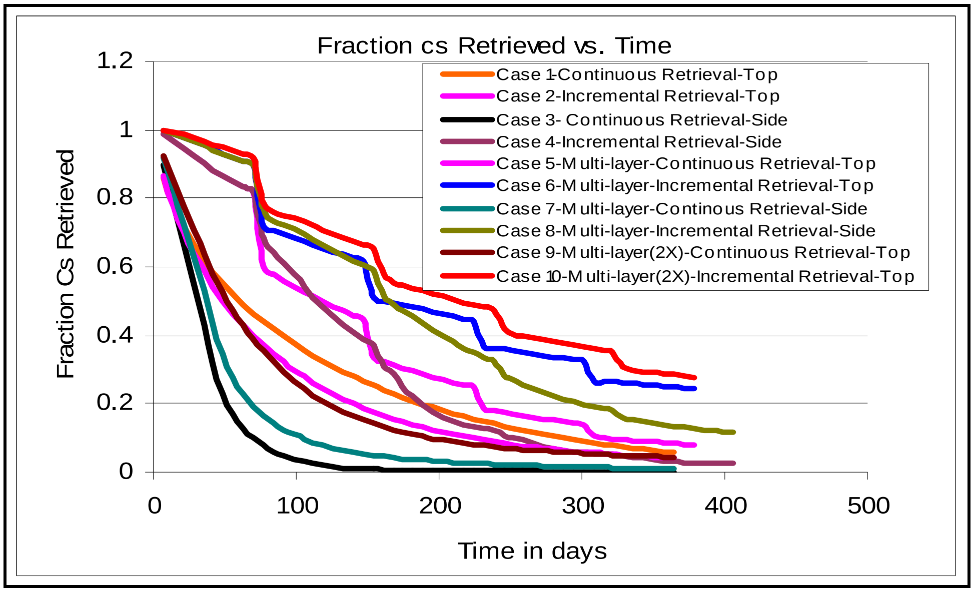

Figure 8 Fraction Cs Retrieved vs. Time for all 10 cases

The results of the study showed that incremental retrieval has markedly better performance in terms of volume of waste generated and time for retrieval. In order to remove 0.65 fractions of the total Cs, the continuous retrieval of a single layer system (uniform permeability throughout the domain) will use approximately 2.98 pore volumes of washing fluid, while the incremental retrieval will need 0.69 pore volumes of fluid to remove 0.65 fractions of the total Cs (Table 2) whereas in the multi layer system (two layers of low permeability compared to the rest of the tank), the retrieval rates are much slower due to low permeability layers. Addition of displacement fluid at the peripheral side channel demonstrates best performance for a homogeneous porous media, however for a multilayer system with considerably lower permeability of some of the layers, the retrieval rates are slower compared to uniform addition at the top of the tank.

Table 2 Comparison of Continuous and Incremental Retrieval

Type Retrieval	Time[d]	Fraction Cs Remaining s	Liquid in Tank	Water Retrieved	Retrieved Pore Fraction
Case 1 Continuous-Single Layer-Top					
	0	1	187,000	0	0
	14	0.77	187,000	100,230	0.53
	140	0.27	187,000	733,040	3.92
	365	0.057	187,000	185,8000	9.95
Case2 Incremental-Single Layer-Top					
1.Drainage	0	1	187,000	0	0
	70	0.81	153,000	63,000	0.33
2.Resaturation	70	0.81	153,000	63,000	0.33
	77	0.59	187,000	63,000	0.33
3.Drainage	78	0.59	187,000	63,000	0.33

	147	0.44	154,000	129,000	0.69
4.Resaturation	148	0.44	154,000	129,000	0.69
	155	0.33	187,000	129,000	0.69
5.Drainage	156	0.33	187,000	129,000	0.69
	225	0.24	154,000	195,000	1.04
6.Resaturation	225	0.24	154,000	195,000	1.04
	232	0.18	187,000	195,000	1.04
7.Drainage	233	0.18	187,000	195,000	1.04
	303	0.13	154,000	315,800	1.69
8.Resaturation	303	0.13	154,000	315,800	1.69
	310	0.10	187,000	315,800	1.69
9.Drainage	310	0.10	187,000	315,800	1.69
	378	0.07	154,000	327,300	1.75

CONCLUSION

A 2-D axisymmetric finite element model which couples flow through porous media and transport of solutes has been developed to simulated transport of non-reacting cesium. The model used unsaturated hydraulic properties as determined from previous experimental work. The simulation showed that incremental addition and drainage of the tank is more efficient compared to continuous addition of water and withdrawal of the salt solution. This method reduces the influence of dead zones in the tank. The results from the simulation show that experimental data can be used to better predict the partial retrieval operations. The hydraulic and hydrodynamic dispersion parameters showed high variability when obtained from column studies and more experiments may be needed to decrease the uncertainty of the data. Although the numerical methods shown here do not incorporate the effects of dissolution, the data provide insight in the flow and transport patterns and supports the retrieval operation by providing a tool for analysis of different retrieval scenarios. The model is being extended to include the effect of dissolution. The purpose of the model is to simulate addition of freshwater as washing fluid in the model. The following concepts are used to simulate saltcake dissolution.

- Bulk fraction of dissolved saltcake as function of fresh water added
- Fraction retrieved as function of water added and bulk saltcake dissolved

The model was used to determine the retrieval parameters simulating continuous and incremental retrieval (series of saturation and drainages). The model focused on the possibility to add chemically saturated fluid (8 M NaOH) which will result in Cs displacement. The displacement of Cs will allow separate processing of retrieved waste from S-109. Two alternatives were investigated: 1) Incremental retrieval (water addition, followed by complete drainage) and 2) Continuous addition (water is continuously added at the top and retrieved at the bottom). Simulations have been extended to characterize the regions with lower permeability on the retrieval efficiency. In terms of volume of waste generated and time for retrieval, the results showed considerably better performance when incremental addition of fluid was used. In order to remove 0.65 fractions of the total Cs, the continuous retrieval of a single layer system (uniform permeability throughout the domain) will use approximately 2.98 pore volumes of washing fluid, while the incremental retrieval will need 0.69 pore volumes of fluid to remove 0.65 fractions of the total Cs whereas in the multi layer system (two layers of low permeability compared to the rest of the tank), the retrieval rates are much slower due to low permeability layers.