Performance Assessment of a Generic Repository in Bedded Salt

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U.S. DEPARTMENT OF ENERGY

Abstract

A mined repository in salt is one of the concepts under consideration for disposal of DOE-managed defense-related spent nuclear fuel (SNF) and high level waste (HLW). Bedded salt is a favorable medium for disposal of nuclear waste due to its low permeability, high thermal conductivity, and ability to self-heal. Sandia's Generic Disposal System Analysis framework[1] is used to assess the ability of a generic repository in bedded salt to isolate radionuclides from the biosphere. The performance assessment (PA) considers multiple waste types of varying thermal load and radionuclide inventory[2,3], the engineered barrier system comprising the waste packages, backfill, and emplacement drifts[4], and the natural barrier system formed by a bedded salt deposit and the overlying sedimentary sequence (including an aquifer)[5]. The model simulates disposal of nearly the entire inventory of DOE-managed, defense-related SNF (excluding Naval SNF) and HLW in a half-symmetry domain containing approximately 6 million grid cells. Grid refinement captures the detail of 21,126 individual waste packages in 152 disposal panels, associated access halls, and 4 shafts connecting the land surface to the repository. Equations describing coupled heat and fluid flow and reactive transport are solved numerically with PFLOTRAN[6], a massively parallel flow and transport code. Simulated processes include heat conduction and convection, waste package failure, waste form dissolution, radioactive decay and ingrowth, sorption, solubility limits, advection, dispersion, and diffusion. Simulations are run to 1 million years, and radionuclide concentrations are observed within an aquifer at a point approximately 5 kilometers downgradient of the repository. The software package DAKOTA[7] is used to sample likely ranges of input parameters including waste form dissolution rates and properties of engineered and natural materials in order to quantify uncertainty in predicted concentrations and sensitivity to input parameters.

1. Generic Disposal System Analysis Framework

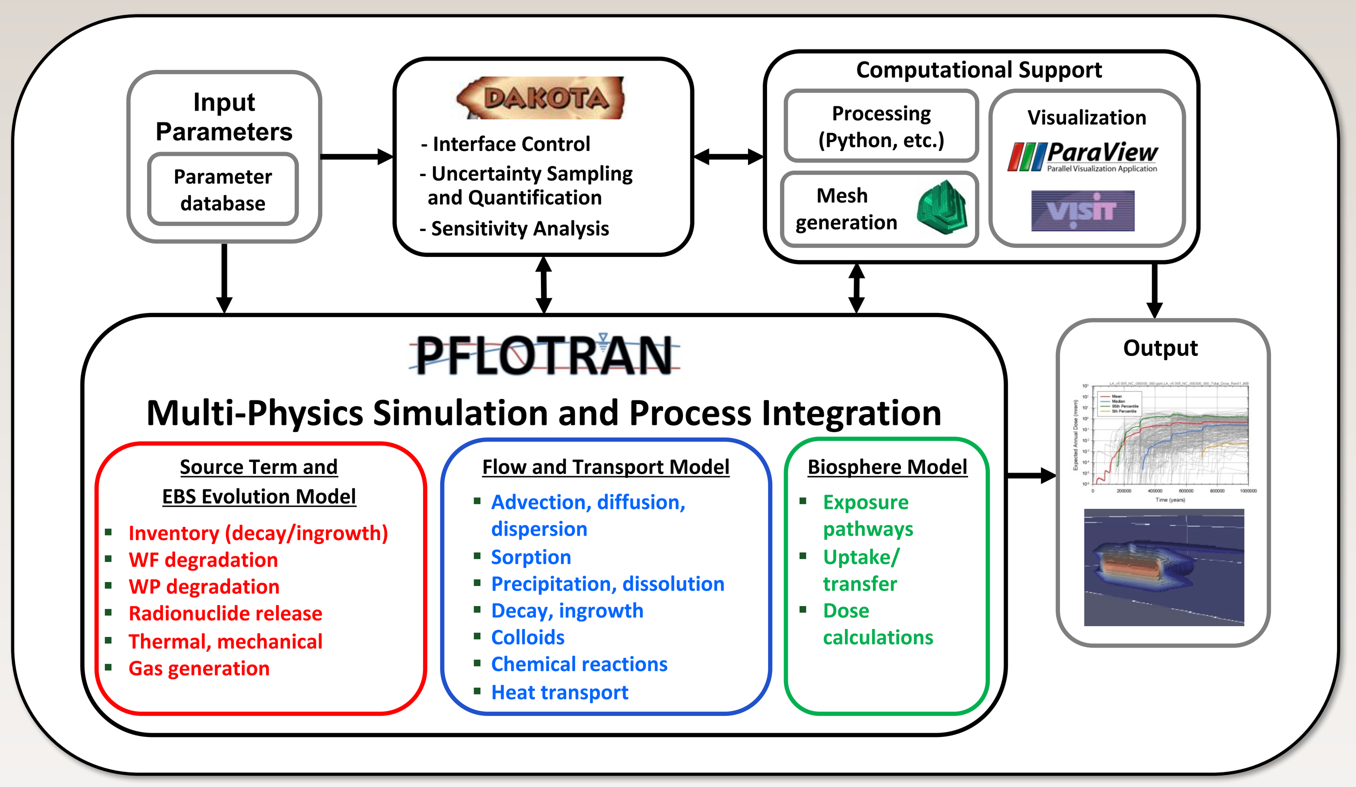

Figure 1. Generic Disposal System Analysis Computational Framework.

2. Inventory

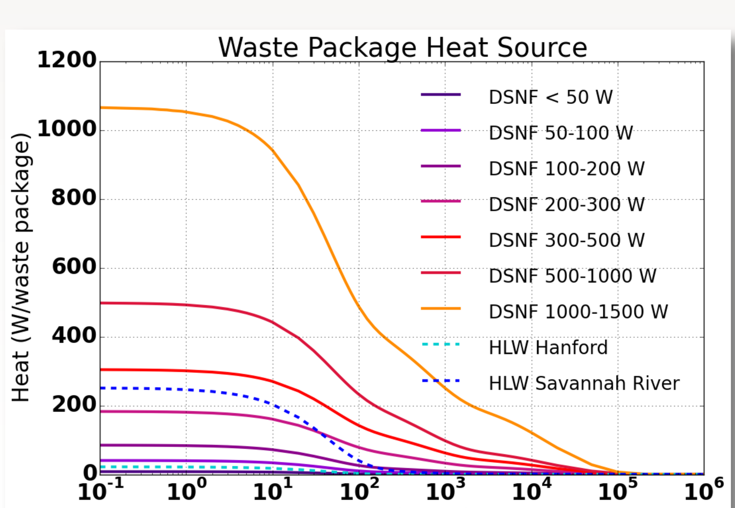

Figure 2. Heat of decay versus time for HLW and DSNF bins included in PA simulations. Time zero is the year 2038.

Isotope	Bulk inventory (g)									Decay Constant (1/s)[c]
	Hanford HLW[a]	Savannah HLW[a]	<50 W DSNF[b]	50-100 W DSNF[b]	100-200 W DSNF[b]	200-300 W DSNF[b]	300-500 W DSNF[b]	500-1000 W DSNF[b]	1000-1500 W DSNF[b]	
(canister count)	(11800)	(7824)	(1163)	(234)	(940)	(12)	(41)	(88)	(4)	
^{241}Am	4.1E+04	6.5E+05	3.0E+03	8.0E+03	1.0E+05	4.4E+03	2.7E+04	1.0E+05	7.6E+03	5.08E-11
^{243}Am	7.5E+01	4.6E+04	1.9E+02	1.0E+02	3.1E+03	1.5E+02	8.2E+02	3.5E+03	1.4E+01	2.98E-12
^{238}Pu	2.5E+02	3.6E+05	8.1E+02	3.8E+02	6.3E+03	2.2E+02	1.2E+03	4.9E+03	1.7E+02	2.56E-10
^{239}Pu	1.1E+06	1.9E+06	6.0E+04	1.9E+05	1.7E+06	7.9E+04	5.3E+05	1.7E+06	2.4E+05	9.01E-13
^{240}Pu	5.4E+04	2.6E+05	1.5E+04	4.2E+04	4.3E+05	2.1E+04	1.4E+05	4.4E+05	5.7E+04	3.34E-12
^{242}Pu	2.6E+02	3.8E+04	1.9E+03	8.2E+02	1.9E+04	8.3E+02	4.1E+03	1.2E+04	8.2E+01	5.80E-14
^{237}Np	2.0E+05	2.9E+05	3.9E+03	4.2E+03	4.9E+04	1.5E+03	7.8E+03	3.1E+04	1.5E+03	1.03E-14
^{233}U	5.3E+04	3.9E+04	4.8E+02	5.5E-01	2.0E+02	1.3E-01	7.7E-01	2.7E+00	1.5E-02	1.38E-13
^{234}U	3.5E+04	7.8E+04	1.1E+04	2.8E+03	1.9E+04	1.3E+02	7.0E+02	4.6E+04	9.1E+01	8.90E-14
^{236}U	9.3E+04	3.8E+05	1.9E+05	1.1E+05	8.5E+05	1.2E+04	6.9E+04	4.9E+05	2.2E+03	9.20E-16
^{238}U	5.9E+08	9.6E+08	1.2E+07	2.5E+07	1.7E+08	2.0E+06	9.2E+06	2.7E+07	2.9E+05	4.87E-18
^{229}Th	1.1E+01	4.4E+00	1.1E-01	8.6E-05	4.8E-02	3.0E-05	1.7E-04	5.3E-04	1.3E-06	2.78E-12
^{230}Th	7.0E-01	4.5E+00	1.1E+00	2.4E-01	1.8E+00	1.1E-02	6.1E-02	4.2E+00	7.8E-03	2.75E-13
^{129}I	2.7E+05	1.2E+04	2.8E+03	2.5E+03	2.0E+04	6.4E+02	2.5E+03	9.6E+03	1.3E+03	1.29E-15
^{135}Cs	1.3E+06	1.4E+05	1.1E+04	7.1E+03	3.9E+04	2.1E+03	4.8E+03	1.7E+04	7.8E+03	9.55E-15
^{99}Tc	1.8E+06	3.7E+06	1.5E+04	1.4E+04	1.0E+05	2.8E+03	1.1E+04	4.3E+04	5.4E+03	1.04E-13

[a]Bulk inventory in 2038 calculated on the basis of bulk inventory in 2017 as reported in Carter et al. (2013)
[b]Bulk inventory in 2038 calculated on the basis of average canister inventories in 2010 and canister counts reported in Wilson (2016)
[c]Decay constants from ORIGEN[8]

Table 1. Bulk radionuclide inventories (in 2038) for HLW and DSNF bins included in PA simulations.

3. Model Domain

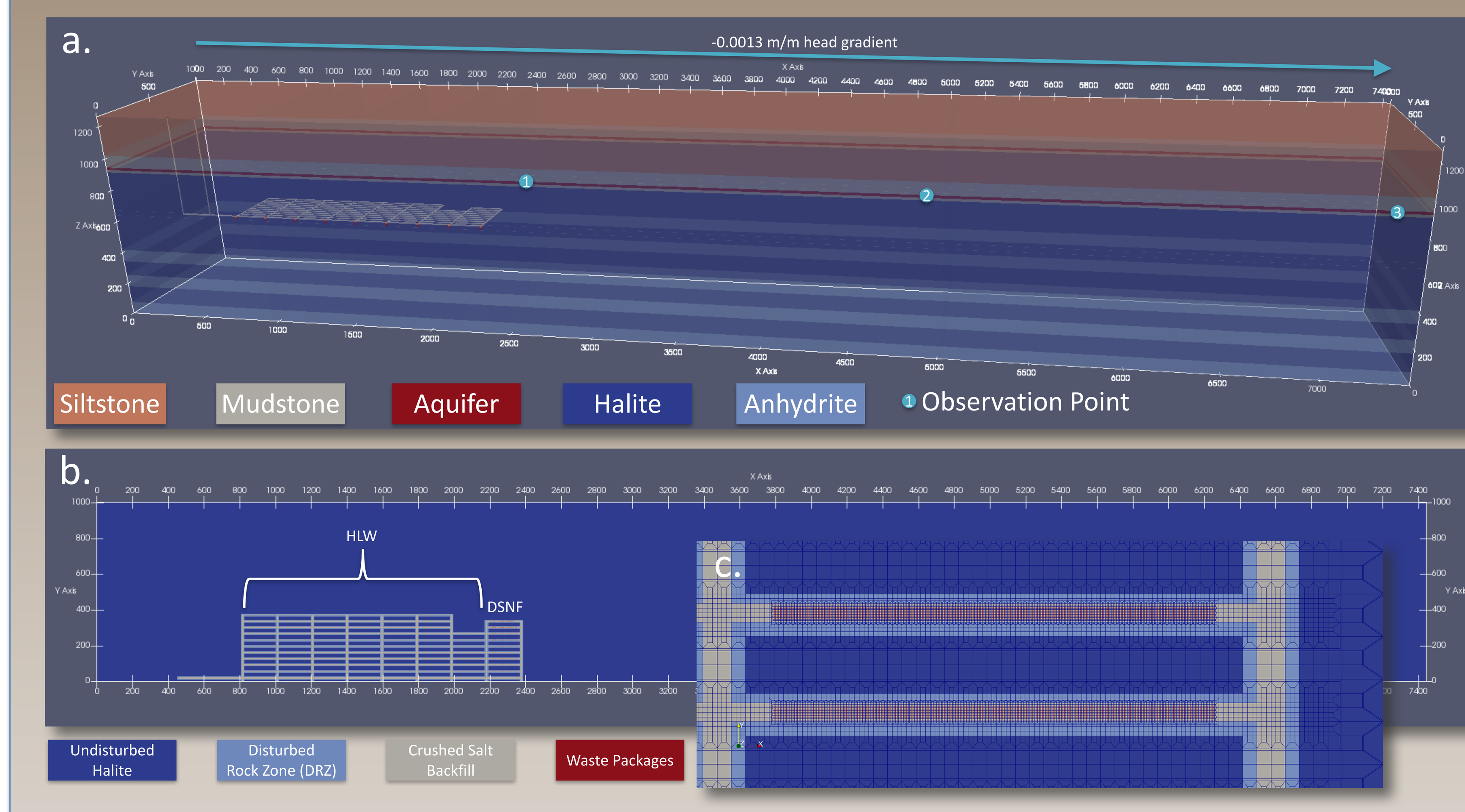

Figure 3. a.) Transparent view of the model domain. b.) *X-Y* slice of model domain (a reflection boundary lies at $y = 0$), and c.) close-up of two DSNF disposal rooms showing details of the discretization. Smallest cells are 5/9 m on a side; largest (at far right) transition to 15 m on a side.

4. Numerical Model and Computational Requirements

- Domain Size: 7440 × 1005 × 1262 m^3
- Number of Grid Cells: 5,811,350
- Grid Resolution: 15 m to 5/9 m
- Number of Gridded Waste Packages: 10,563
- Processor Cores Employed: 512
- Run Time to 10^6 y: 1.8 hrs

5. Simulation Results

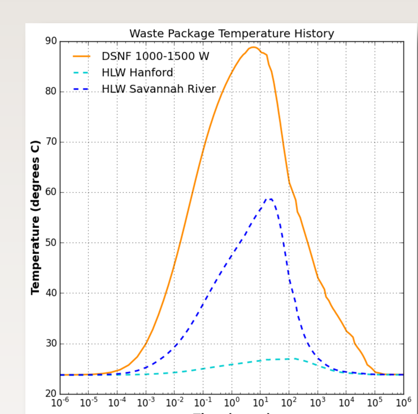

Figure 4. Waste package temperature histories for Hanford HLW, Savannah River HLW, and the hottest DSNF bin.

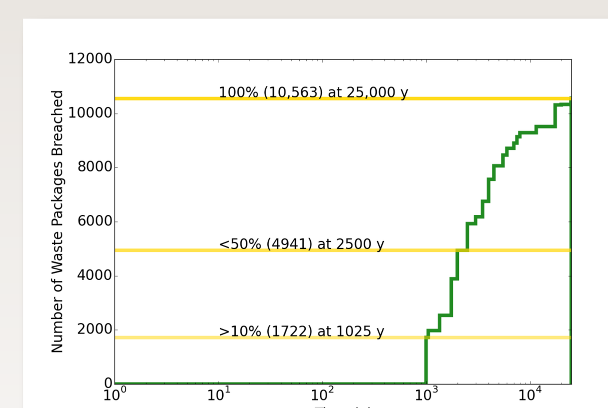

Figure 5. Cumulative number of waste packages breached versus time. Rate of degradation for each waste package is sampled from a truncated log-normal distribution.

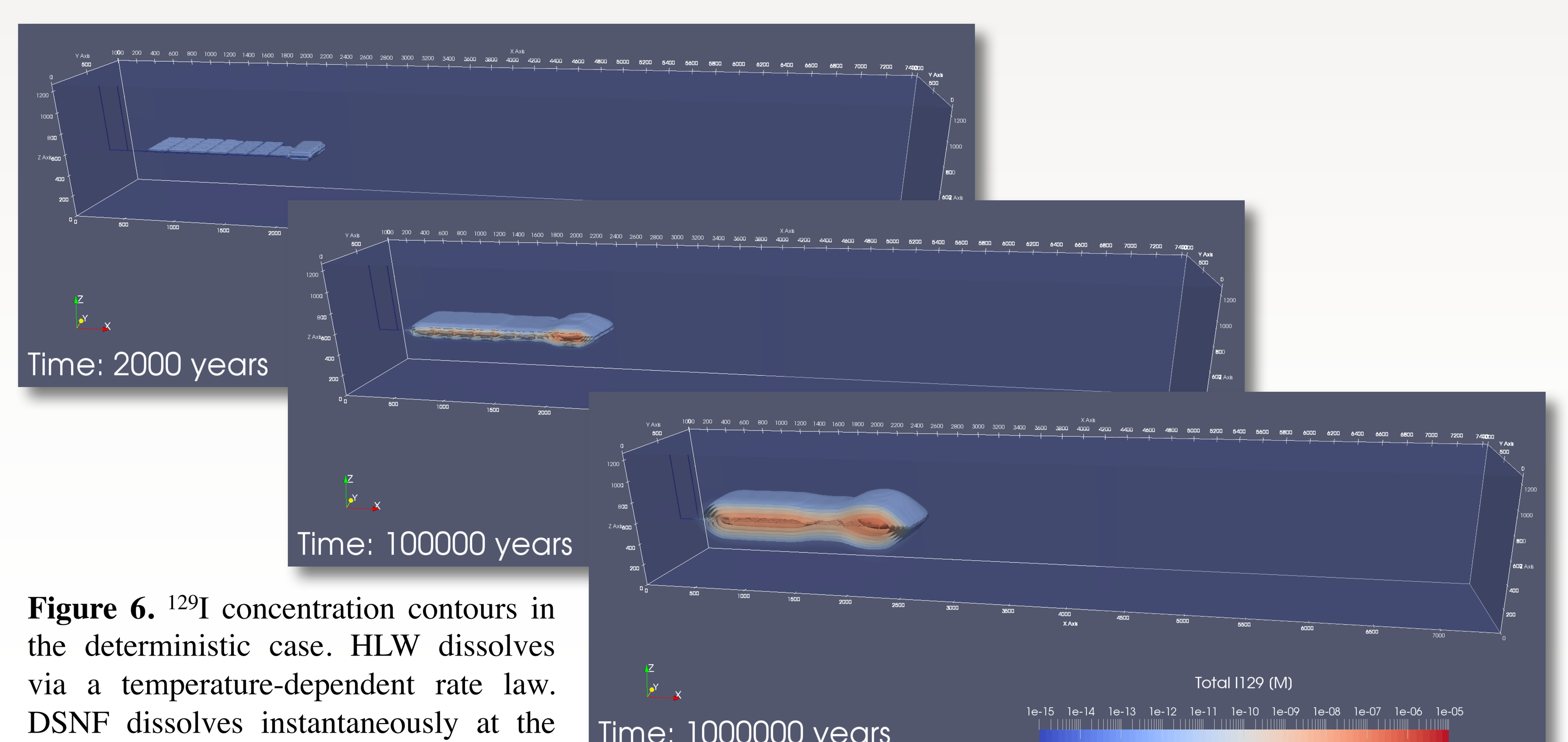

Figure 6. ^{129}I concentration contours in the deterministic case. HLW dissolves via a temperature-dependent rate law. DSNF dissolves instantaneously at the time of waste package breach.

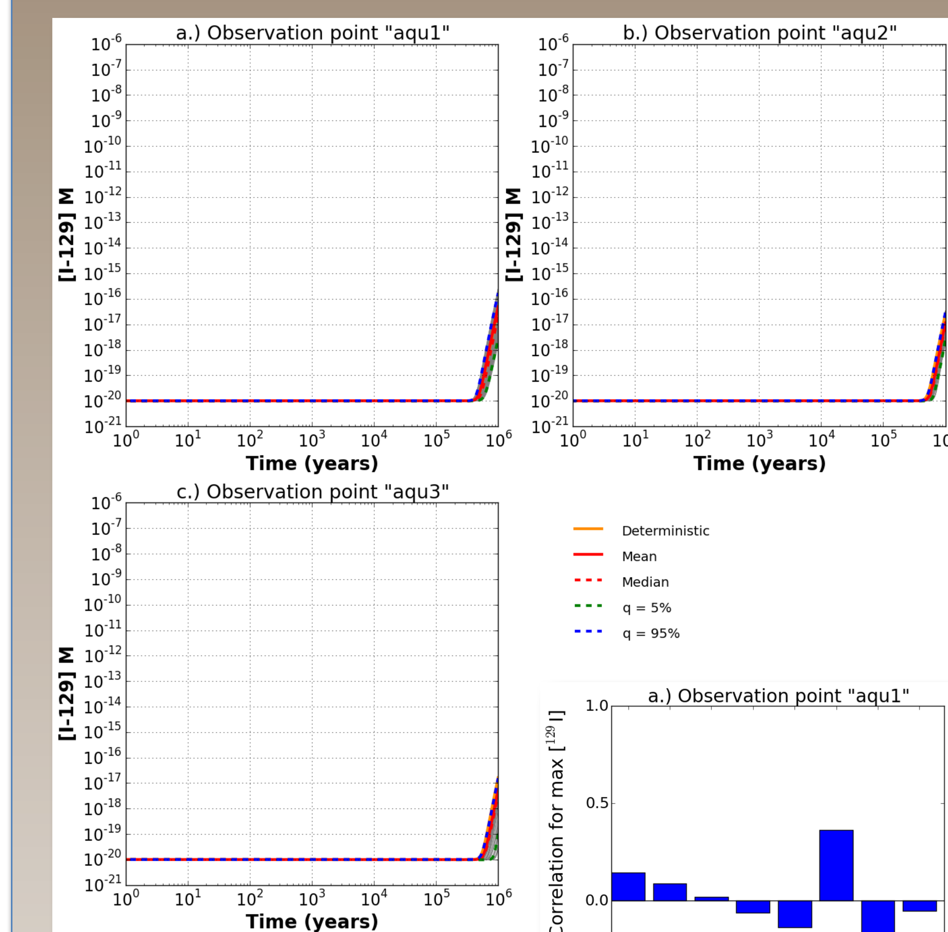

Figure 7. Predicted concentration of ^{129}I versus time for 50 probabilistic simulations. The orange line is the deterministic simulation.

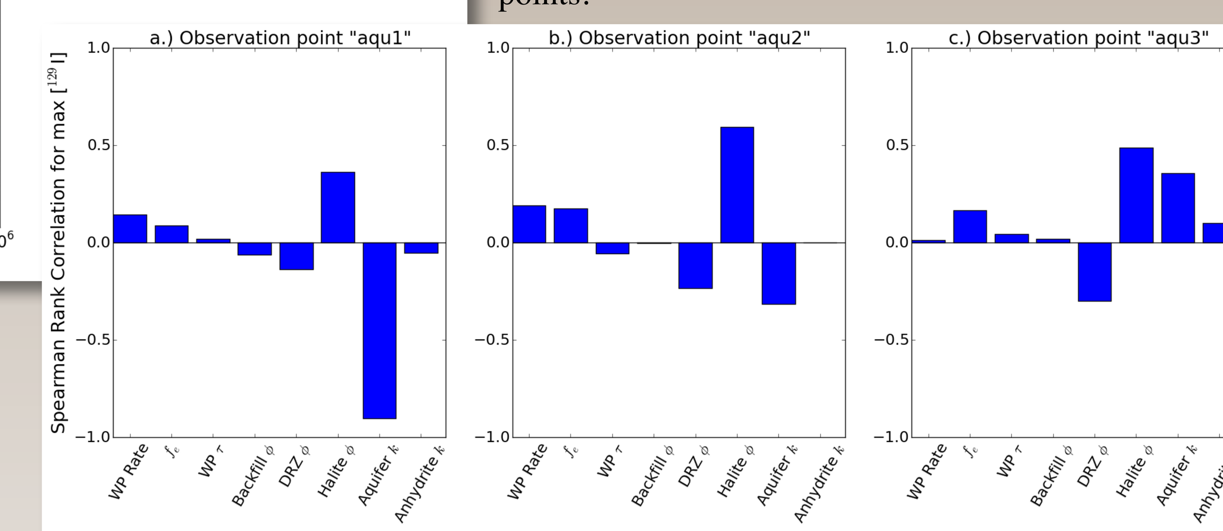

Figure 8. Spearman's rank correlation coefficients for maximum concentration of ^{129}I at aquifer observation points.

6. Conclusion

The bedded salt reference case and simulation results[9] are not dissimilar to earlier R&D for a commercial SNF repository in bedded salt[10], except the heat load is far lower for a Defense Waste Repository. The PA simulations show that because of the impermeable nature of the bedded salt host rock, radionuclide transport for this concept is minimal, i.e., isolation from the surface is ensured in bedded salt at all but extremely low radionuclide concentrations arising from the slow process of molecular diffusion.

Future simulations may examine different emplacement concepts and repository layouts, as well as the potential time-dependent effects on DRZ properties caused by salt creep. This latter investigation will help determine whether mechanical and coupled mechanical processes need to be explicitly represented in total system simulations.

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Acknowledgments

Thanks to Joe Carter and Jason Wilson at Savannah River National Laboratory for providing the waste inventory.

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