Deep Borehole Disposal of Nuclear Waste

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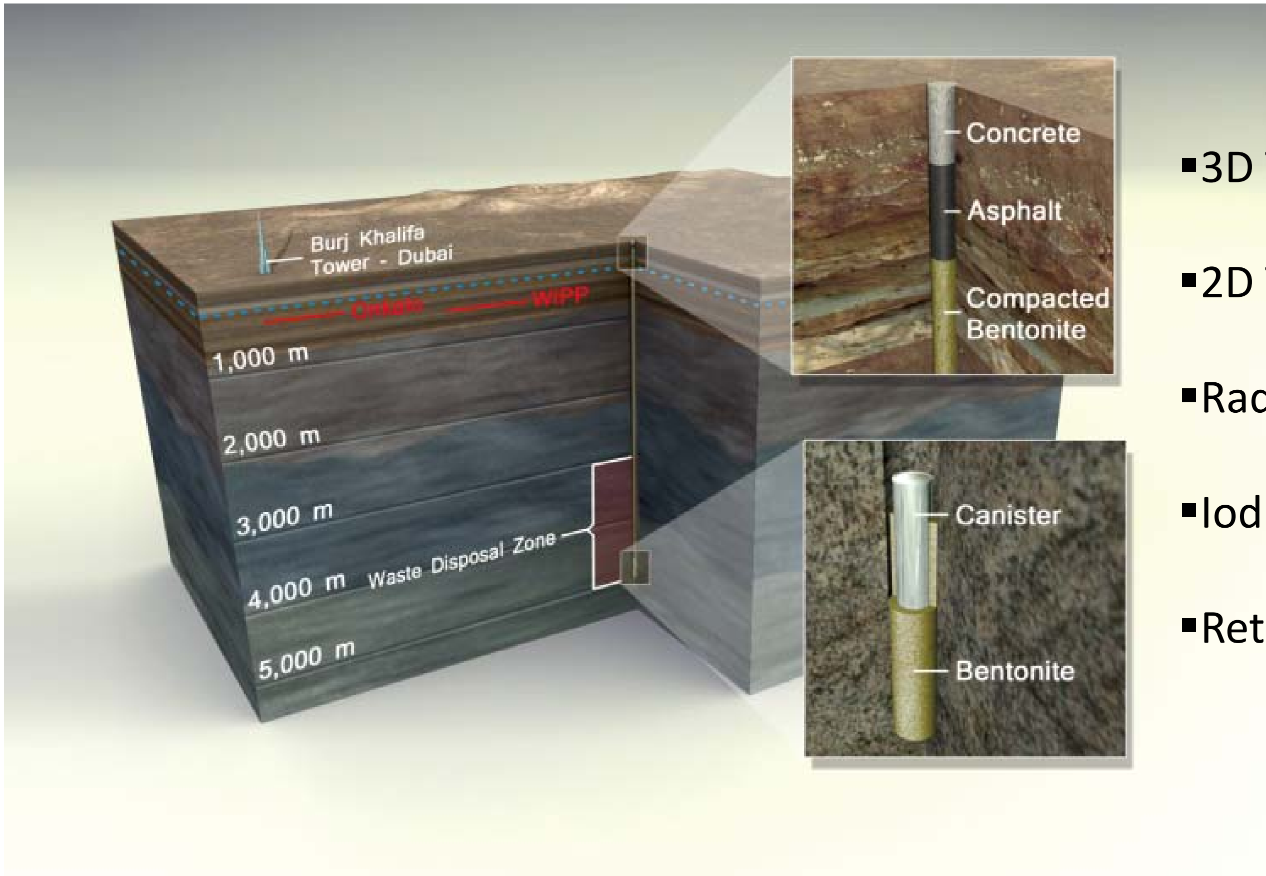

- 3D Thermal-hydrologic modeling
- 2D Thermal-mechanical modeling
- Radionuclide solubilities/sorption
- Iodide sorbents
- Retrievability concept

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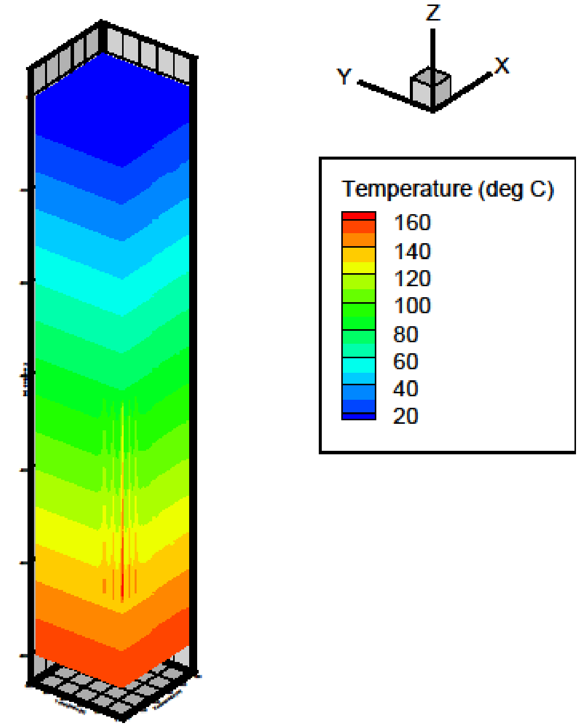
3D Thermal-Hydrologic Model: Multiple Boreholes

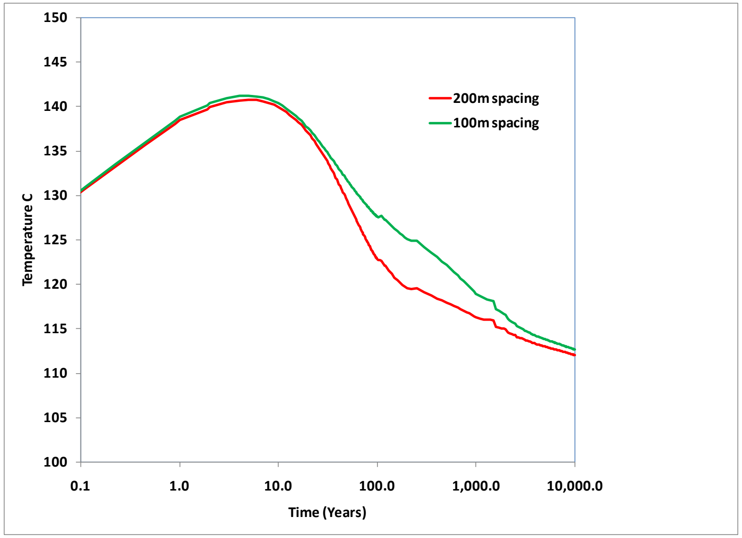
- 3D coupled thermal – hydrologic model simulates waste heat in the disposal zones of multiple boreholes
- The model uses a variable resolution mesh and quarter symmetry boundaries
- Simulations are run using the FEHM software code
- Objectives are: (1) evaluate sensitivity to borehole spacing, (2) evaluate sensitivity to number of boreholes, and (3) provide simulated groundwater flow rates as functions of time and depth for use in the performance assessment model

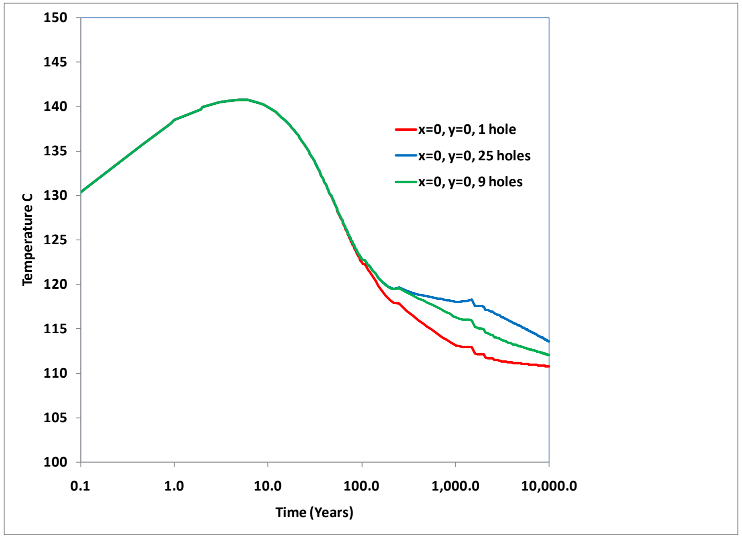


25 boreholes, 100 m well spacing, Time = 10 years

3D Thermal-Hydrologic Model: Multiple Boreholes

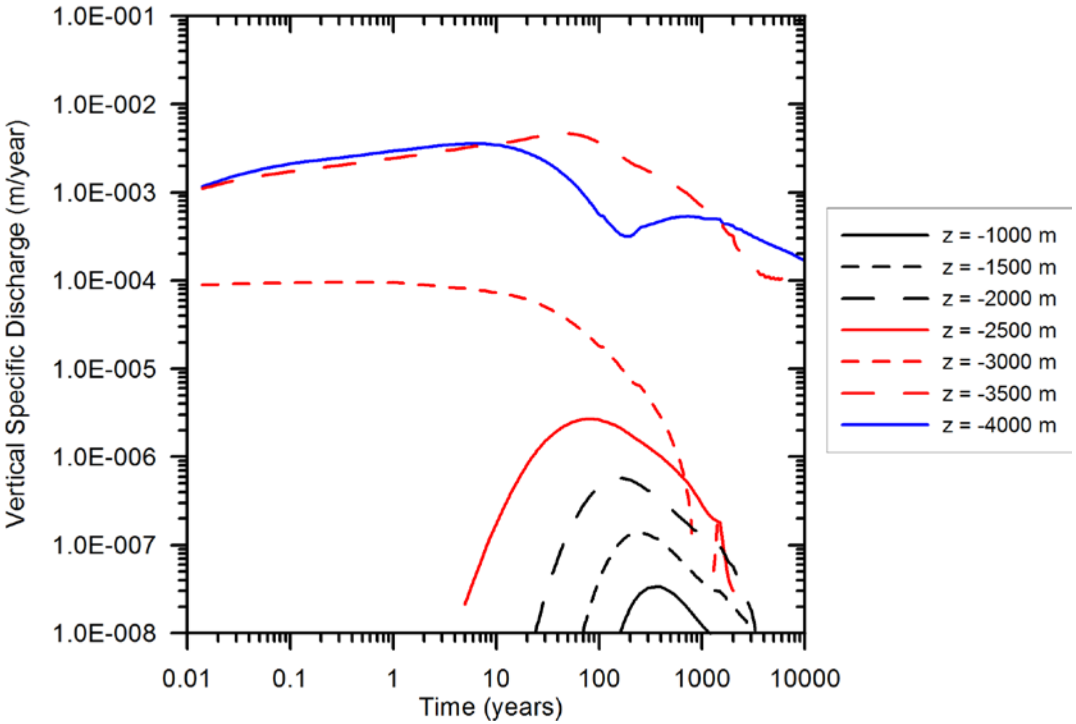
- Simulated peak temperature occurs relatively soon after waste emplacement and is insensitive to borehole spacing and number of boreholes
- Differences in temperature histories for multiple boreholes and closer borehole spacing are generally small
- Pressure and temperature conditions are below boiling for disposal of used fuel assemblies and high heat output vitrified waste from reprocessing
- Temperature perturbations are generally limited to the waste disposal zone (no significant vertical heat transport)





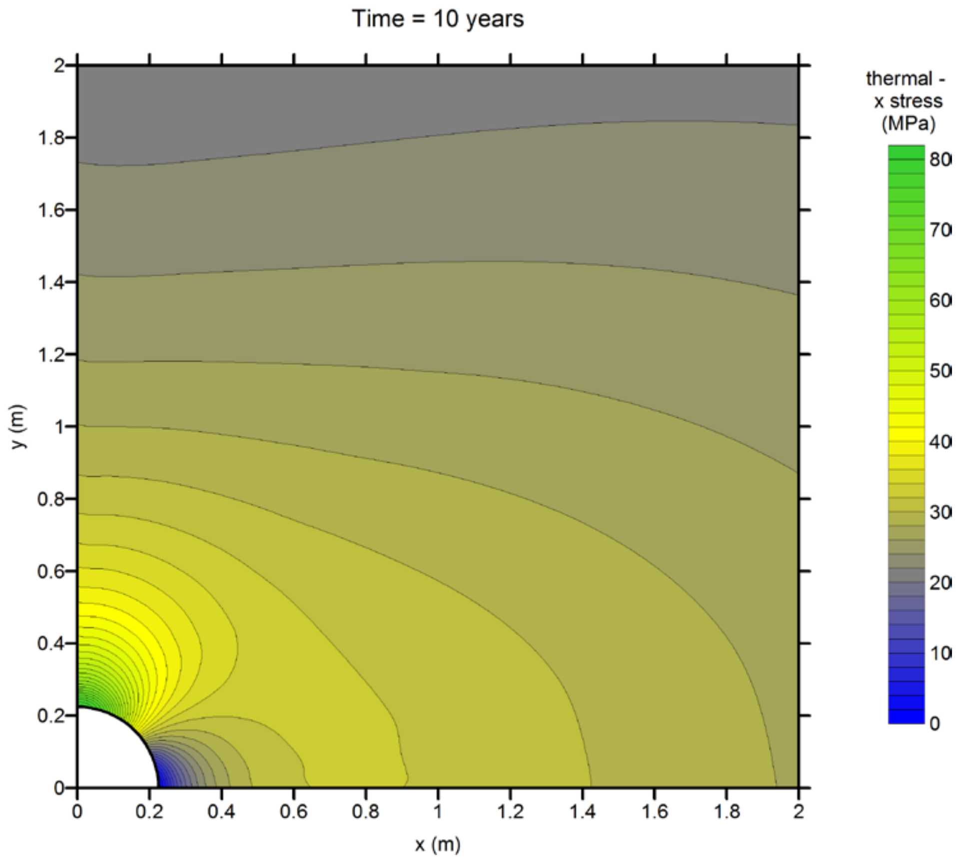
3D Thermal-Hydrologic Model: Multiple Boreholes

- Simulated vertical upward groundwater flow rates in the borehole/disturbed zone are shown in the plot
- The borehole/disturbed zone is assumed to have a permeability 3 orders of magnitude higher than the host rock
- The waste disposal zone is at z = -3000 to -5000 m
- Flow is driven primarily by thermal expansion of groundwater within and near the borehole, with only minor large-scale free convection



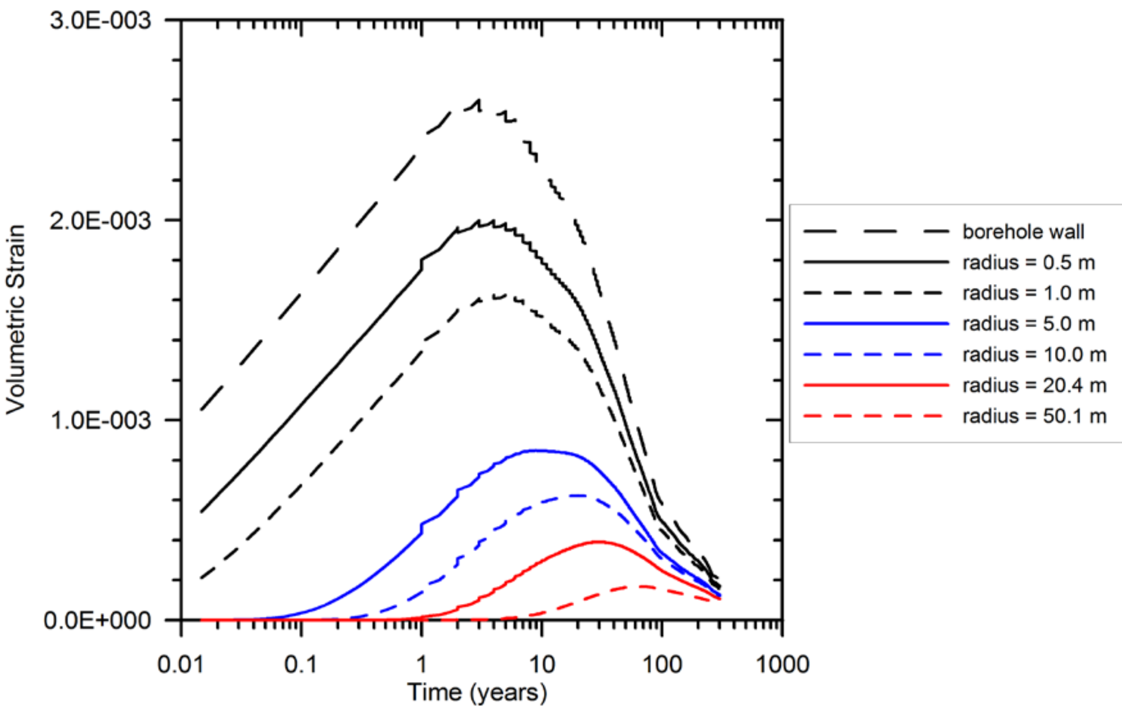
2D Thermal-Mechanical Model

- 2D coupled thermal-mechanical model simulates the impacts of waste heat on displacement, mechanical stress, and strain
- Model uses the FEHM software code, an unstructured mesh, quarter symmetry boundaries, and is oriented horizontally
- Objectives are: (1) evaluate thermally induced strain and impacts on host rock permeability, and (2) evaluate stress changes and impacts on borehole stability
- Plot shows the distribution of stress in the x-direction induced by heat from vitrified waste in an anisotropic ambient stress field



2D Thermal-Mechanical Model

- Simulated volumetric strain histories at various distances from the borehole for disposal of vitrified reprocessing waste are shown in the plot
- Significant compressive volumetric strain is induced for distances of several meters into the host rock for decades following waste emplacement
- This transient compressive strain would tend to close fractures and counteract the enhanced permeability in the borehole disturbed zone during the early post-emplacement period



Solubility and Sorption

Insoluble Radionuclides

Element	Solid Phase	Concentration (mol/L) [a]Borehole	[b]Low E_H Groundwater
Am	AmOCl	2×10^{-8}	2×10^{-9} to 10^{-5}
	Am_2O_3	3×10^{-7}	
	$Am(OH)_3$	1×10^{-5}	
Np	$Np(OH)_{4,am}$	1×10^{-8}	2×10^{-12} to 10^{-8}
	NpO_2	2×10^{-16}	
Pu	$Pu(OH)_{4,am}$	6×10^{-6}	10^{-11} to 10^{-6}
	PuO_2	2×10^{-13}	
Tc	$TcO_2 \cdot nH_2O_{am}$	3×10^{-8}	10^{-12} to 10^{-7}
	[c]TcO_2	9×10^{-13}	
	Tc_3O_4	2×10^{-15}	
	Tc sulfides	$< 10^{-20}$	
Th	$Th(OH)_{4,am}$	6×10^{-8}	10^{-10} to 10^{-9}
	ThO_2	4×10^{-15}	
U	[d]$UO_{2,am}$	4×10^{-4}	10^{-10} to 10^{-6}
	UO_2	6×10^{-9}	

[a]Borehole solubilities calculated for 150°C, 1M NaCl, C_{total} = 1 mM, S_{total} =100 µmol, redox set by FeO-Magnetite equilibria. [b]From McKinley and Savage (1996). [c]25°C value from data0.ymp.r5d. All other thermodynamic values are from thermo.com.V8.R6.230. [d]ΔH set to -77.9 (Uraninite value).

higher salinities will lower values

Soluble Radionuclides

	Potential Solids
^{14}C	$CaCO_3$
$^{135,137}Cs$	none
^{129}I	(Metal iodides)
$^{226,228}Ra$	(SS-$RaCO_3$, $RaSO_4$)
^{90}Sr	(SS-$SrCO_3$, $SrSO_4$)

long shots

Sorption k_ds

Element	$k_{d\ basement}$	$k_{d\ sediment}$	$k_{d\ bentonite}$
Am	50-5000	100-100,000	300-29,400
C	0-6	0-2000	5
Cs	50-400	10-10,000	120-1000
Np	10-5000	10-1000	30-1000
Pu	10-5000	300-100,000	150-16,800
[b]Ra	4-30	5-3000	50-3000
Sr	4-30	5-3000	50-3000
[c]Tc	0-250	0-1000	0-250
Th	30-5000	800-60,000	63-23,500
U	4-5000	20-1700	90-1000
I	0-1	0-100	0-13

[a]All values are from the review of McKinley and Scholtis (1993). Values less than one were rounded down to zero. [b]k_ds for Ra were set equal to those of somewhat chemically similar Sr. [c]Tc k_ds under reducing borehole conditions will likely be much greater than the zero values listed here which were measured under more oxidizing conditions.