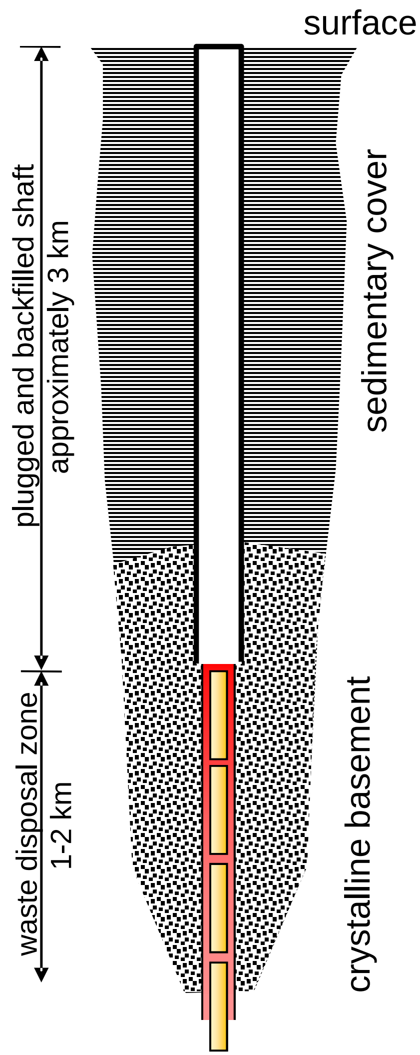
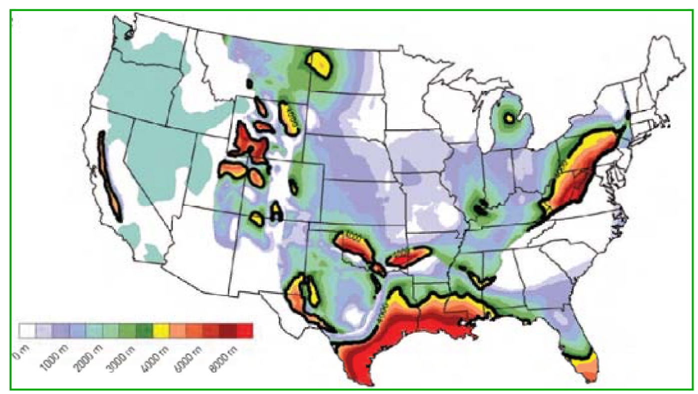
Preliminary Performance Assessment of Deep Borehole Disposal

Pat Brady, Bill Arnold, Geoff Freeze, Steve Bauer, and Peter Swift
Sandia National Laboratories



(not to scale)



Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Geochemical Constraints over the Source Term

Solubilities; T = 200^{o}C, pH 8.5,
E_H = -300 mV, 2M NaCl solution

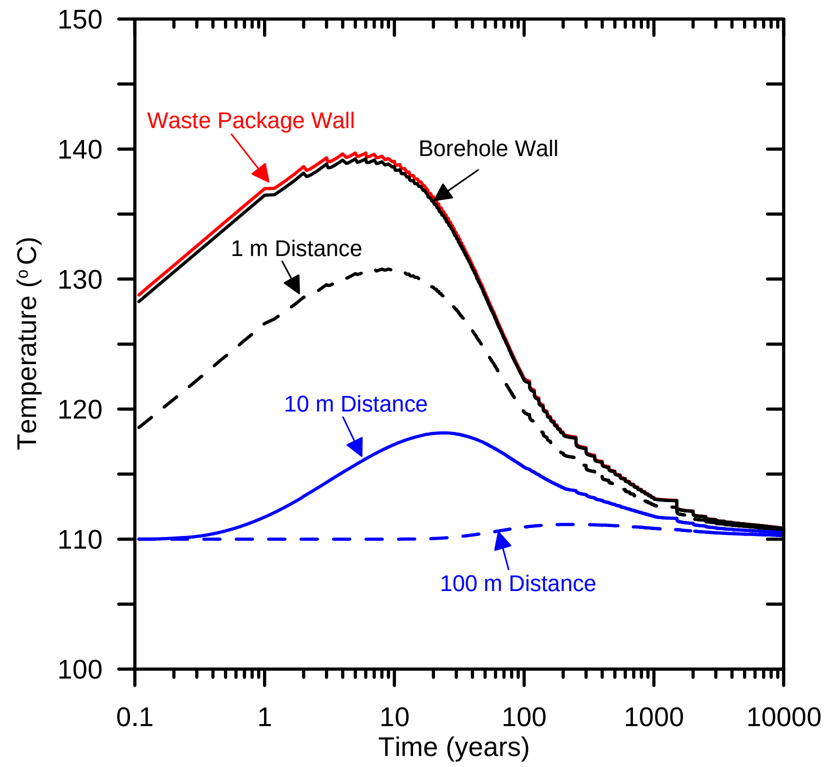
Radioelement	Solubility-limiting phase	Dissolved concentration (moles/L)
Am	Am_2O_3	1×10^{-9}
Ac	Ac_2O_3	1×10^{-9}
C	*	*
Cm	Cm_2O_3	1×10^{-9}
Cs	*	*
I	Metal iodides ?	*
Np	NpO_2	1.1×10^{-18}
Pa	PaO_2	1.1×10^{-18}
Pu	PuO_2	9.1×10^{-12}
Ra	$RaSO_4$	*
Sr	$SrCO_3$, $SrSO_4$?	*
Tc	TcO_2	4.3×10^{-38}
Th	ThO_2	6.0×10^{-15}
U	UO_2	1.0×10^{-8}

Source term and Borehole K_ds.

Element	$k_{d\ basement}$	$k_{d\ sediment}$	$k_{d\ bentonite}$
Am, Ac, Cm	50-5000	100-100,000	300-29,400
C	0-6	0-2000	5
Cs	50-400	10-10,000	120-1000
Np, Pa	10-5000	10-1000	30-1000
Pu	10-5000	300-100,000	150-16,800
[c]Ra	4-30	5-3000	50-3000
Sr	4-30	5-3000	50-3000
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

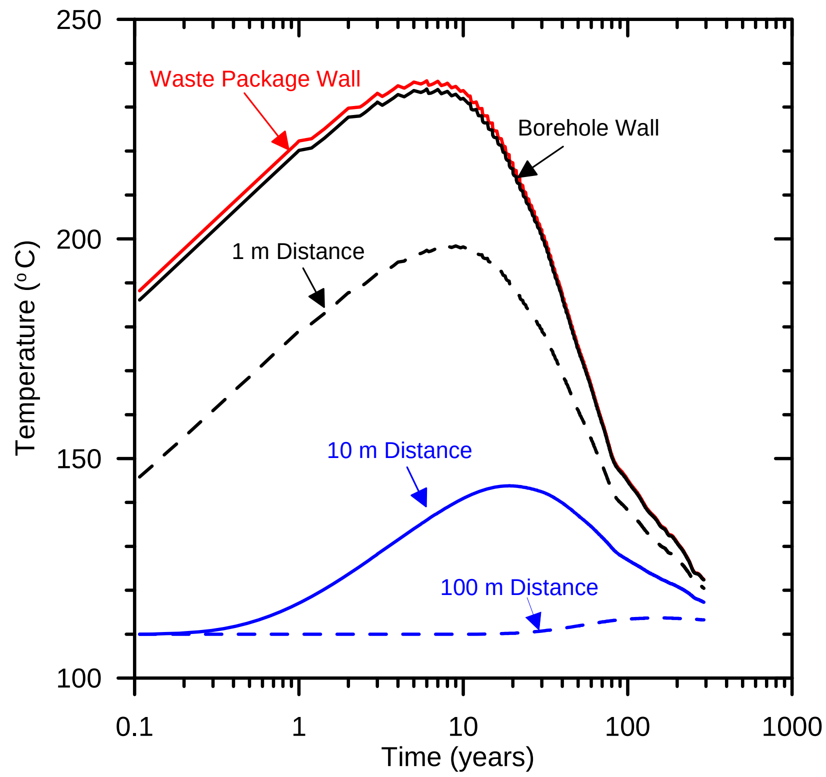
Thermal Conduction

- **Assumed disposal of a single PWR fuel assembly per waste package**
- **Thermal output for an average fuel assembly that has been aged for 25 years**
- **Results indicate a maximum temperature increase of about 30ºC at the borehole wall, similar to the results in the draft report of Sapiie and Driscoll (2009)**
- **Significant temperature increases do not persist beyond 100 to 200 years**

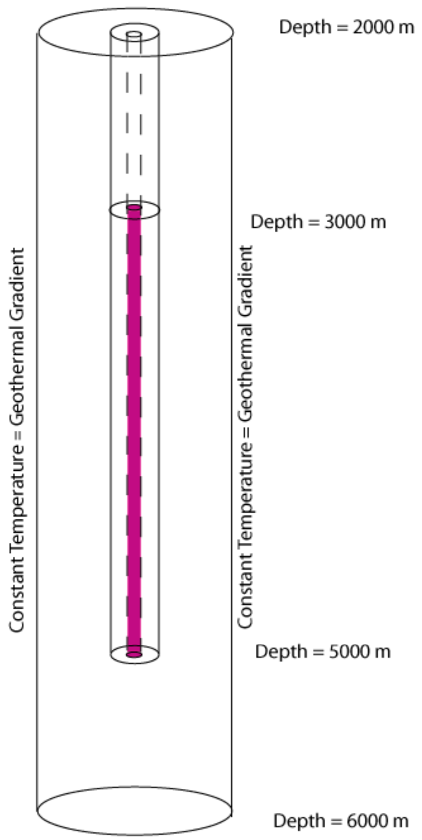


Thermal Conduction

- **Similar analysis performed for vitrified high-level waste**
- **Heat output curves are for the current vitrified waste from reprocessing of commercial spent nuclear fuel in France, aged for 10 years**
- **Results indicate a temperature increase of about 125 ºC at the borehole wall, which is significantly higher than the for disposal of PWR spent nuclear fuel assemblies**



Coupled Thermal-Hydrologic Model

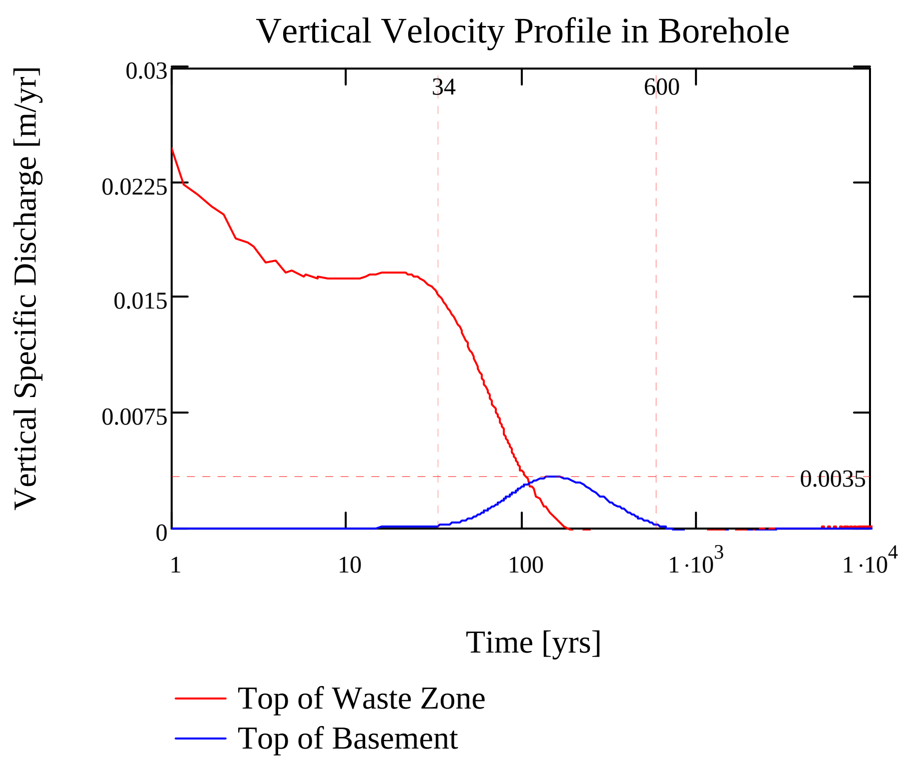


Not to Scale: Domain Radius is 100 m, height is 4 km
Borehole (radius 0.15 m) + Disturbed Zone has a cross-sectional area of 1 square meter

- **Radial 2-D simulations conducted using the FEHM code**
- **Thermal properties were consistent with the thermal conduction modeling**
- **Granite was assigned a permeability of 1 X 10^{-19} m^2**
- **Sealed borehole and disturbed bedrock surrounding the borehole were assigned a value of 1 X 10^{-16} m^2**
- **Hydrostatic fluid pressures were assumed to exist under ambient conditions**

Coupled Thermal-Hydrologic Model

- **Results indicate upward vertical flow in the borehole driven primarily by thermal expansion, and not by free convection**
- **Significant upward flow persists for about 200 years at the top of the waste disposal zone**
- **Lesser upward flow occurs for about 600 years in the borehole at a location 1000 m above the waste**

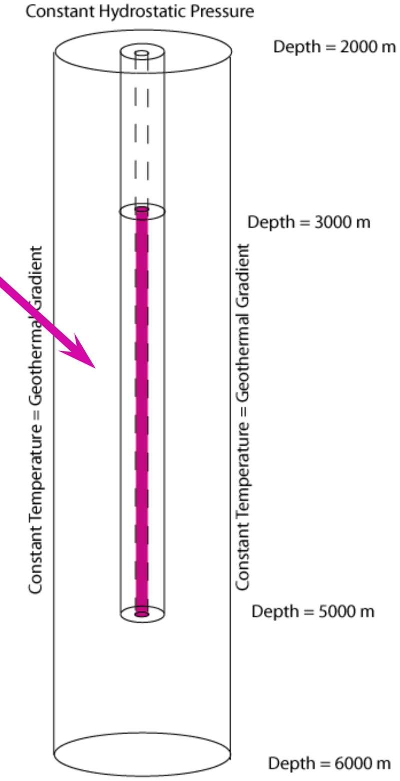


Scenario Selection

- Evaluated comprehensive list of FEPs from Yucca Mountain Project (YMP) and geologic disposal programs in other countries
- Formed three scenarios from retained (screened in) FEPs
  - Transport up borehole
  - Transport up DRZ/annulus around the borehole
  - Transport away from borehole in surrounding rock

Scenario Description - Source

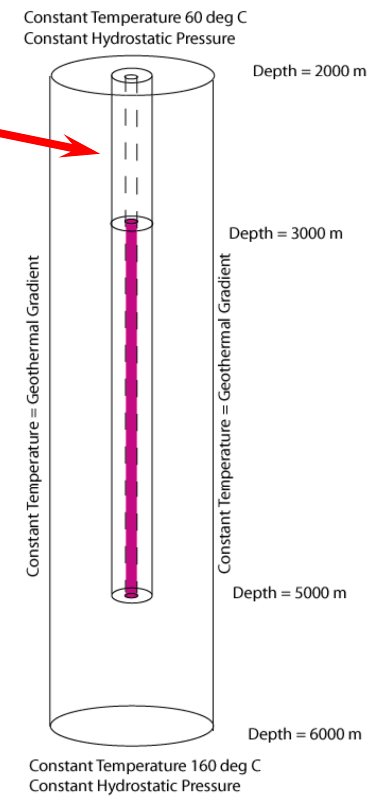
- **Waste Disposal Zone**
  - Single borehole with 400 PWRs vertically stacked down a 2000 m disposal zone
  - No credit for waste package or waste form degradation
  - Inventory (31 radionuclides with decay and ingrowth) consistent with YMP PWR assemblies aged to 2117
  - Dissolved concentrations subject to solubility limits



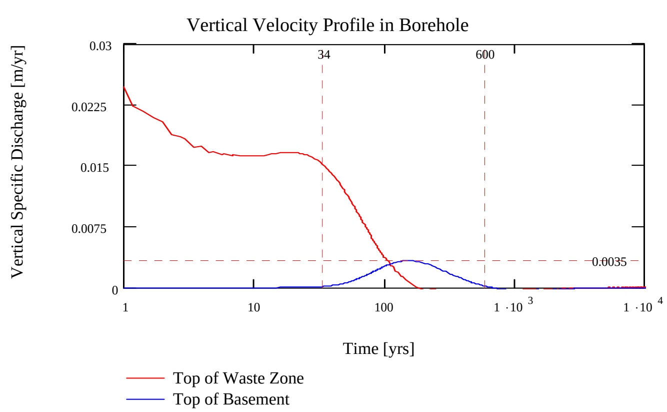
Not to Scale: Domain Radius is 100 m, height is 4 km
Borehole (radius 0.15 m) + Disturbed Zone has a cross-sectional area of 1 square meter

Scenario Description – Borehole Transport

- **Borehole Sealed Zone**
  - **Radionuclide transport up borehole for 1000 m**
  - **Properties are composite of bentonite seal and excavation disturbed zone (EDZ)**
  - **Constant thermally driven flow (pore velocity = 0.5 m/yr) from top of waste disposal zone for 200 yrs**



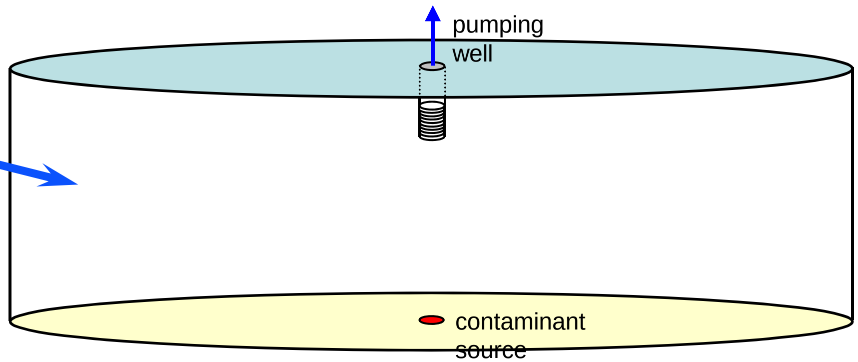
Not to Scale: Domain Radius is 100 m, height is 4 km
Borehole (radius 0.15 m) + Disturbed Zone has a cross-sectional area of 1 square meter



Sandia National Laboratories

Scenario Description – Geosphere Transport

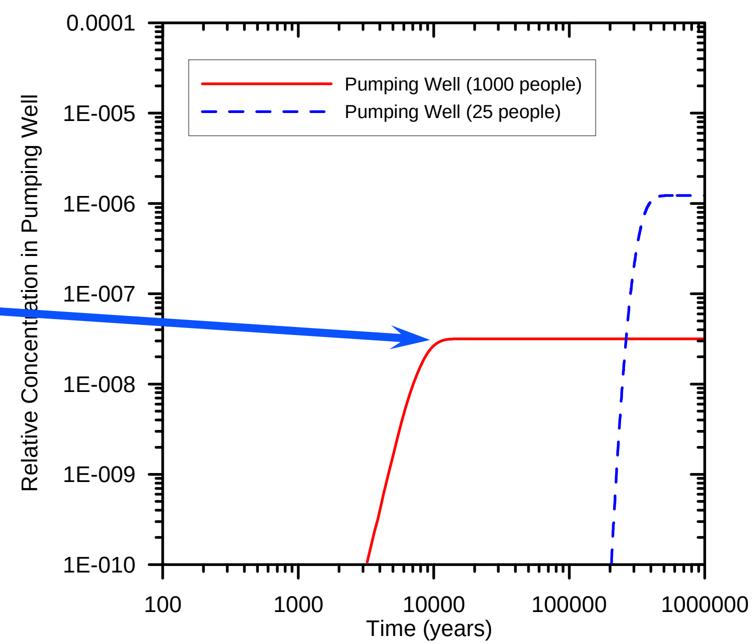
- **Geosphere**
  - **Capture of radionuclides from top of borehole sealed zone**



  - **Transport and dilution of radionuclides in geosphere (properties approximate fractured rock and/or sediments)**
  - **Withdrawal of radionuclides to surface/biosphere via pumping well**

Modeling Approach

- **Source Term**
  - **Continuous radionuclide source**
- **Sealed Borehole Transport**
  - **1-D analytic solution of advection-dispersion equation with sorption and decay through composite bentonite/EDZ**
  - **Transport ceases at 200 yrs**
- **Geosphere Transport**
  - **Assumed travel time (8000 yrs) and dilution factor (3.16×10^7)**
- **Dose**
  - **Assumed exposure pathways consistent with YMP**

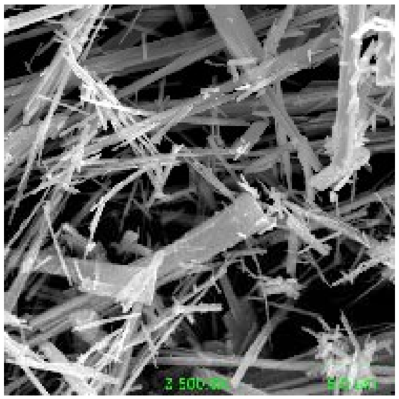


Preliminary PA Results

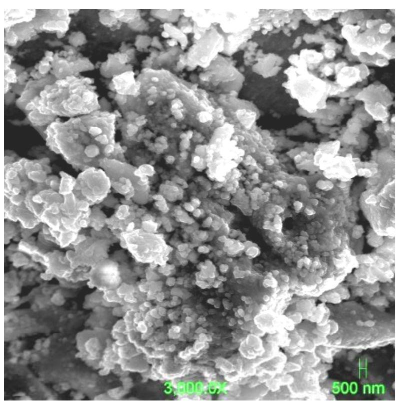
- Peak dose to exposed individual is 1.4×10^{-10} mrem/yr at 8200 yrs
- ^{129}I is sole contributor to peak dose
- Peak concentration at top of borehole sealed zone (^{129}I at 200 yrs) is 5.3×10^{-8} mg/L
- Peak is due to leading edge of dispersive front – center of mass of ^{129}I travels ~ 100 m in 200 yrs

Sandia National Laboratories

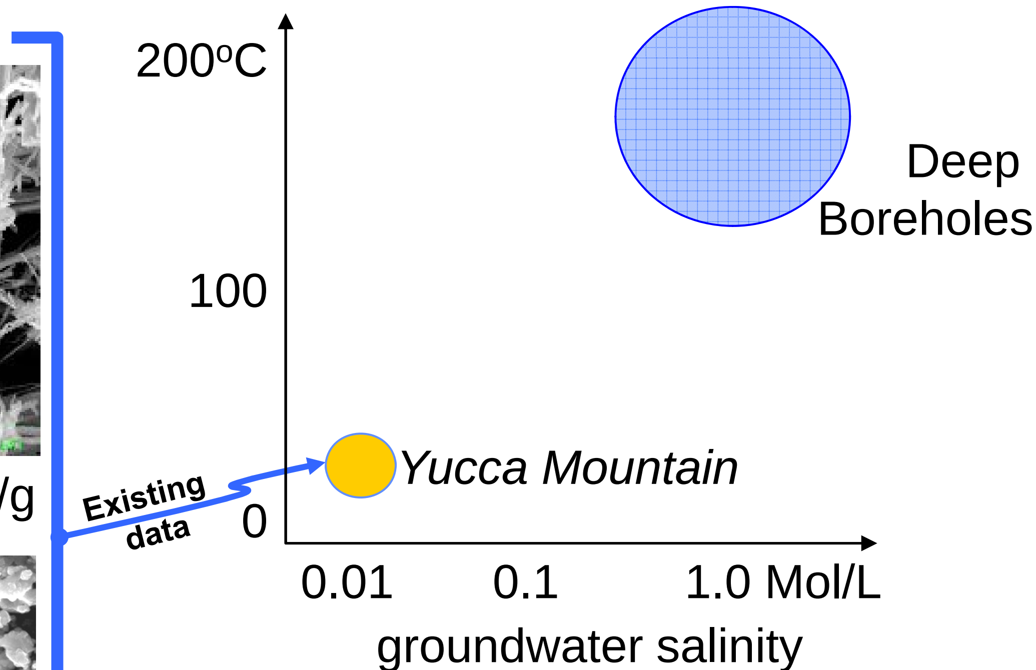
Bismuth-based ^{129}I sorbents



K_d = 720 ml/g



K_d = 2300 ml/g



- Thermal stability of Bi phases
- Effect of anion competition
- Reversibility
- Modification