Used Fuel Disposition Campaign

Building the Crystalline Reference Case Performance Assessment

Emily Stein, Jenn Frederick, Glenn Hammond,
Paul Mariner, Dave Sevougian
Sandia National Laboratories

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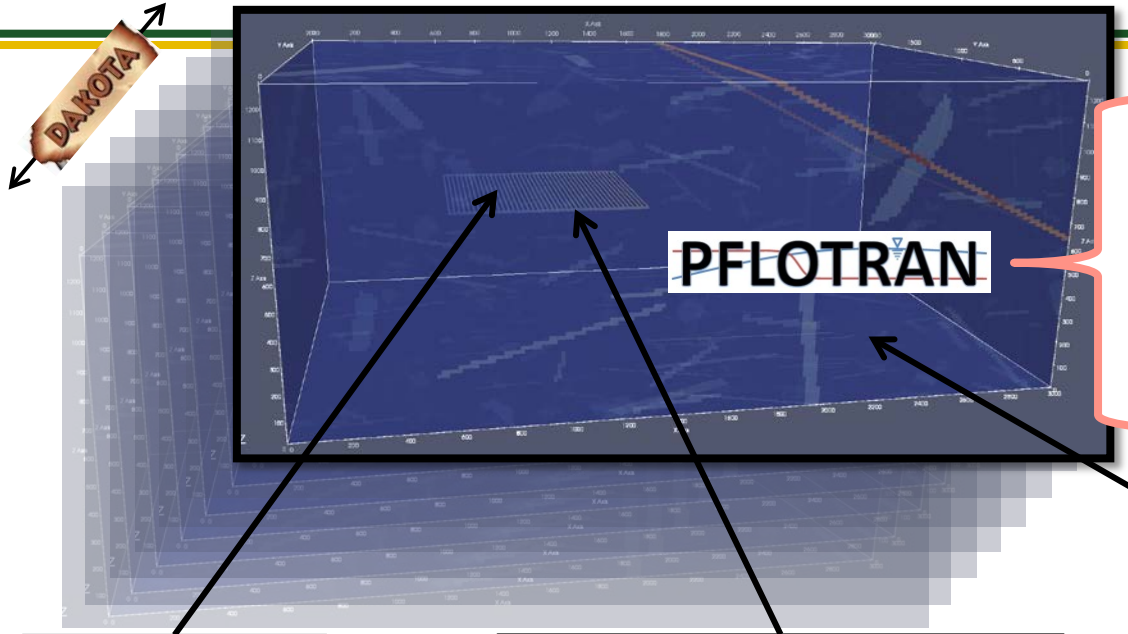
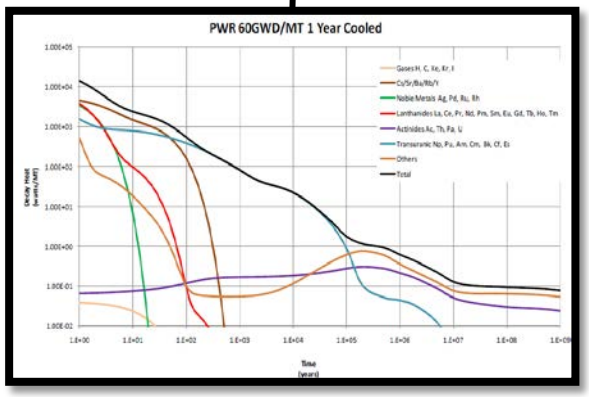
Performance Assessment



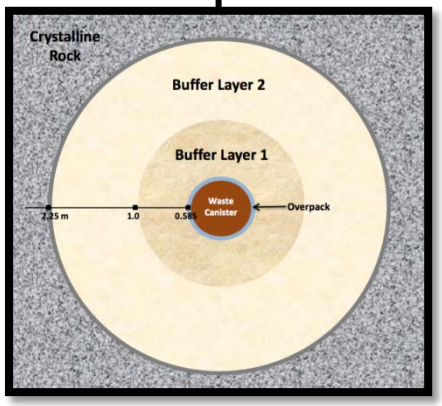
- Coupled heat and fluid flow
- Waste package degradation
- Waste form dissolution
- Radioactive decay and ingrowth
- Solubility, sorption
- Advection, dispersion, diffusion

Waste Forms



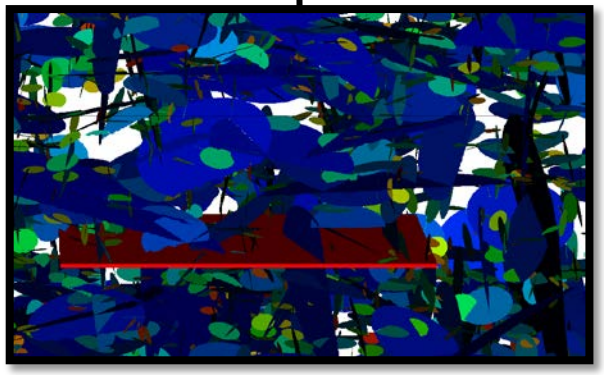
SRNL Inventory

Engineered Barrier System



SNL EBS Concepts

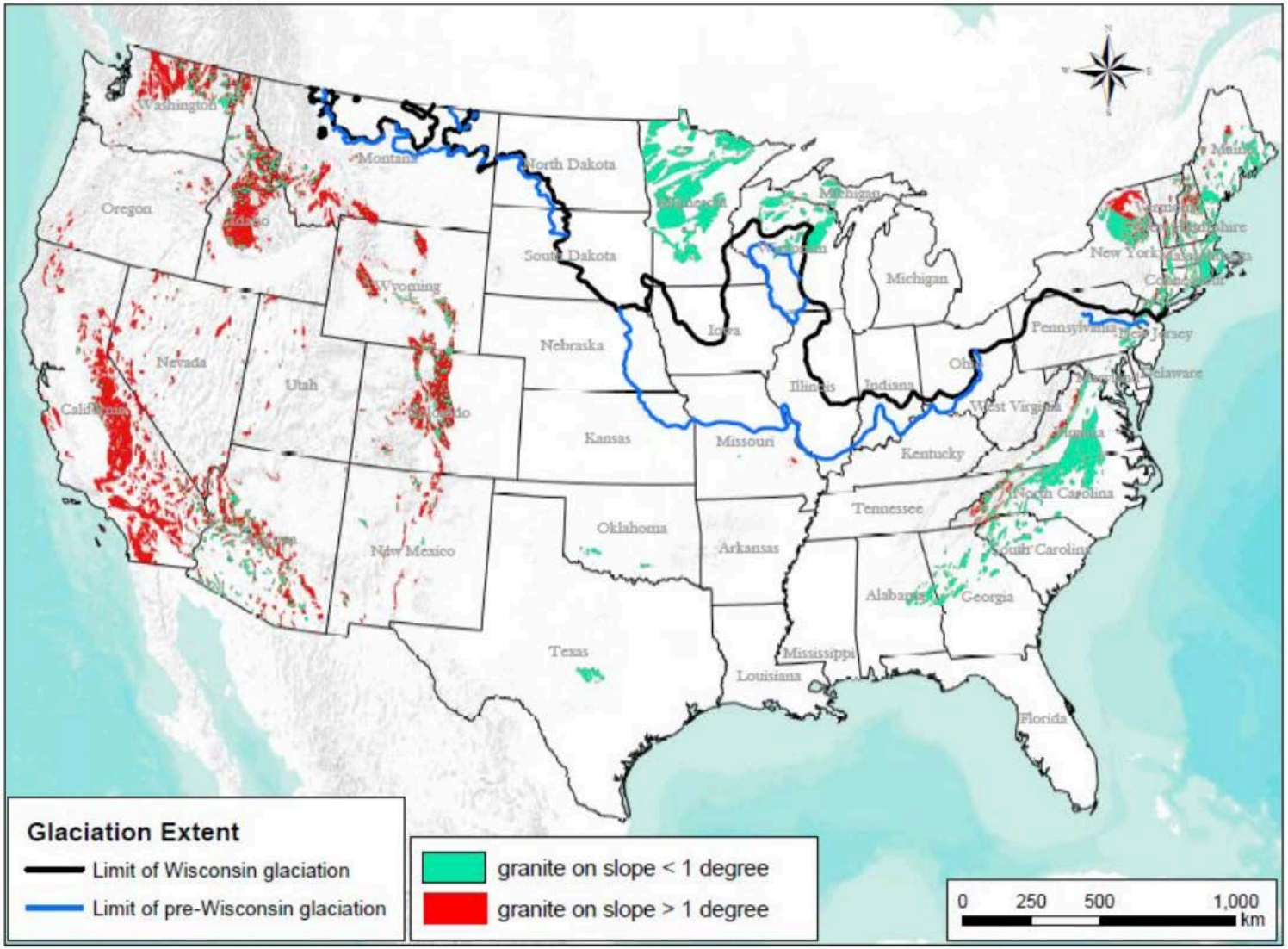
Natural Barrier System



LANL Discrete Fracture Network

Natural Barrier System

- Exposed crystalline basement
- Slope < 1 degree
- Topographically controlled water table
- Consistent with international concepts.



Perry et al., 2014

Used

Natural Barrier System

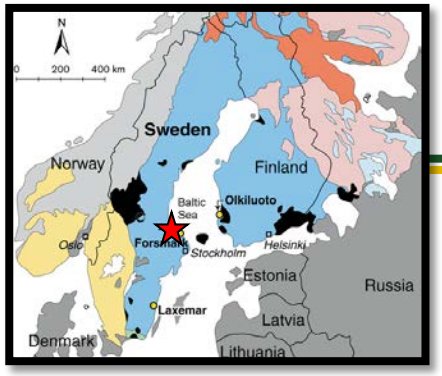
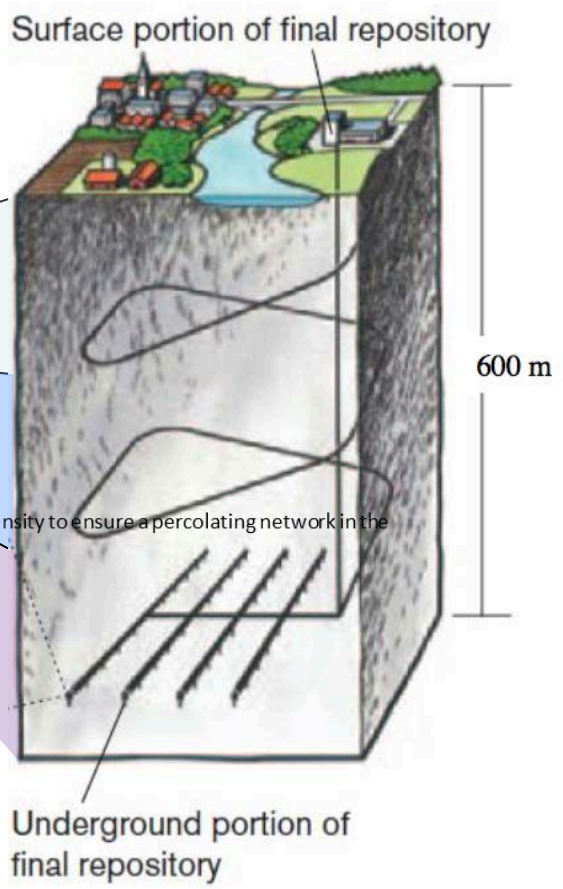


Table 2 Hydrogeological DFN parameters for each fracture domain, fracture set and depth zone

Fracture domain/elevation (m.a.s.l)[a]	Fracture set name	Orientation set pole: (trend, plunge), conc.	Size model, power-law (r_0, k_r) (m, −)	Intensity, (P_{32}), valid size interval: r_0 to 564 m (m^2/m^3)	Parameter values for the transmissivity models: Semi-correlated (a,b,σ)	Correlated (a,b)	Uncorrelated (μ,σ)
FFM01 and FFM06>−200	NS	(292, 1) 17.8	(0.038, 2.50)	0.073	$6.3 \cdot 10^{-9}$, 1.3, 1.0	$6.7 \cdot 10^{-9}$, 1.4	−6.7, 1.2
	NE	(326, 2) 14.3	(0.038, 2.70)	0.319			
	NW	(60, 6) 12.9	(0.038, 3.10)	0.107			
	EW	(15, 2) 14.0	(0.038, 3.10)	0.088			
	HZ	(5, 86) 15.2	(0.038, 2.38)	0.543			
FFM01 and FFM06 −200 to −400	NS	(292, 1) 17.8	(0.038, 2.50)	0.142	$1.3 \cdot 10^{-9}$, 0.5, 1.0	$1.6 \cdot 10^{-9}$, 0.8	−7.5, 0.8
	NE	(326, 2) 14.3	(0.038, 2.70)	0.345			
	NW	(60, 6) 12.9	(0.038, 3.10)	0.133			
	EW	(15, 2) 14.0	(0.038, 3.10)	0.081			
	HZ	(5, 86) 15.2	(0.038, 2.38)	0.316			
FFM01 and FFM06<−400	NS	(292, 1) 17.8	(0.038, 2.50)	0.094	$5.3 \cdot 10^{-11}$, 0.5, 1.0	$1.8 \cdot 10^{-10}$, 1.0	−8.8, 1.0
	NE	(326, 2) 14.3	(0.038, 2.70)	0.163			
	NW	(60, 6) 12.9	(0.038, 3.10)	0.098			
	EW	(15, 2) 14.0	(0.038, 3.10)	0.039			
	HZ	(5, 86) 15.2	(0.038, 2.38)	0.141			
FFM02>−200	NS	(83, 10) 16.9	(0.038, 2.75)	0.342	$9.0 \cdot 10^{-9}$, 0.7, 1.0	$5.0 \cdot 10^{-9}$, 1.2	−7.1, 1.1
	NE	(143, 9) 11.7	(0.038, 2.62)	0.752			
	NW	(51, 15) 12.1	(0.038, 3.20)	0.335			
	EW	(12, 0) 13.3	(0.038, 3.40)	0.156			
	HZ	(71, 87) 20.4	(0.038, 2.58)	1.582			
FFM03, FFM04 and FFM05>−400	NS	(292, 1) 17.8	(0.038, 2.60)	0.091	$1.3 \cdot 10^{-8}$, 0.4, 0.8	$1.4 \cdot 10^{-8}$, 0.6	−7.2, 0.8
	NE	(326, 2) 14.3	(0.038, 2.50)	0.253			
	NW	(60, 6) 12.9	(0.038, 2.55)	0.258			
	EW	(15, 2) 14.0	(0.038, 2.40)	0.097			
	HZ	(5, 86) 15.2	(0.038, 2.55)	0.397			
FFM03, FFM04 and FFM05<−400	NS	(292, 1) 17.8	(0.038, 2.60)	0.102	$1.8 \cdot 10^{-8}$, 0.3, 0.5	$7.1 \cdot 10^{-9}$, 0.6	−7.2, 0.8
	NE	(326, 2) 14.3	(0.038, 2.50)	0.247			
	NW	(60, 6) 12.9	(0.038, 2.55)	0.103			
	EW	(15, 2) 14.0	(0.038, 2.40)	0.068			
	HZ	(5, 86) 15.2	(0.038, 2.55)	0.250			

[a] Meters above sea level



*The crystalline reference case uses an increased fracture density to ensure a percolating network in the multi-kilometer model domain.

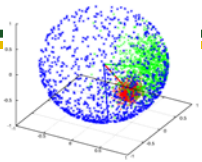
Joyce et al., Hydrogeology Journal (2014) 22:1233-1249

Used Fuel Disposition

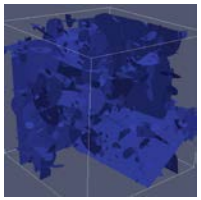
Natural Barrier System

$T=\log(1.6*10^{-9}*r^{0.8})$

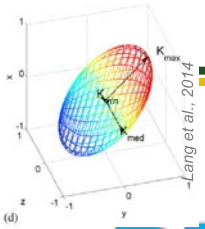
$b=(12T\mu/\rho g)^{1/3}$



DFNWorks

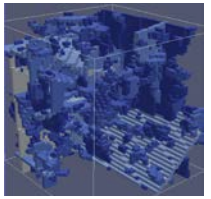


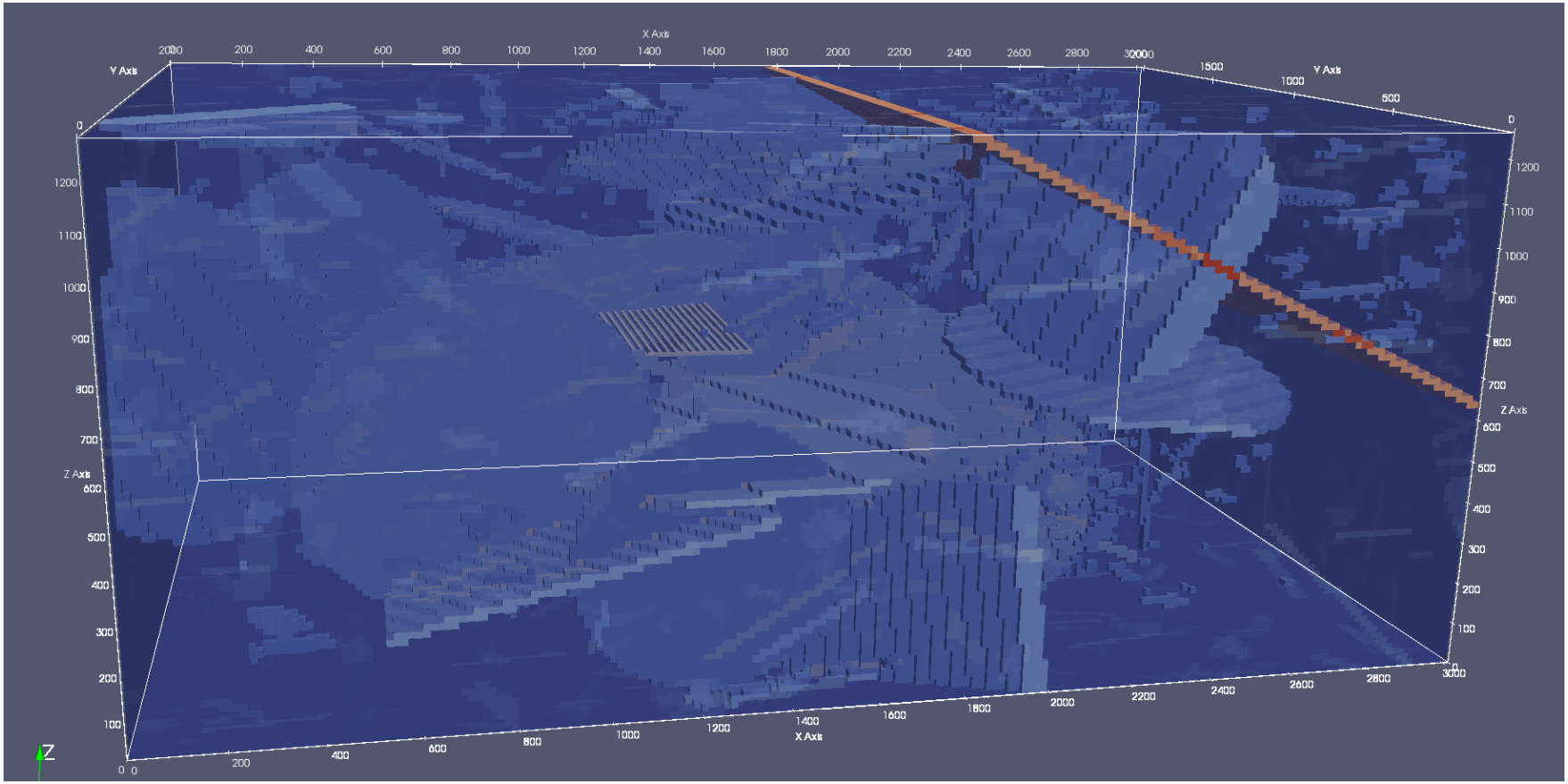
$\phi = V_f/V_{cell}$



$k = T\rho g/\mu b$

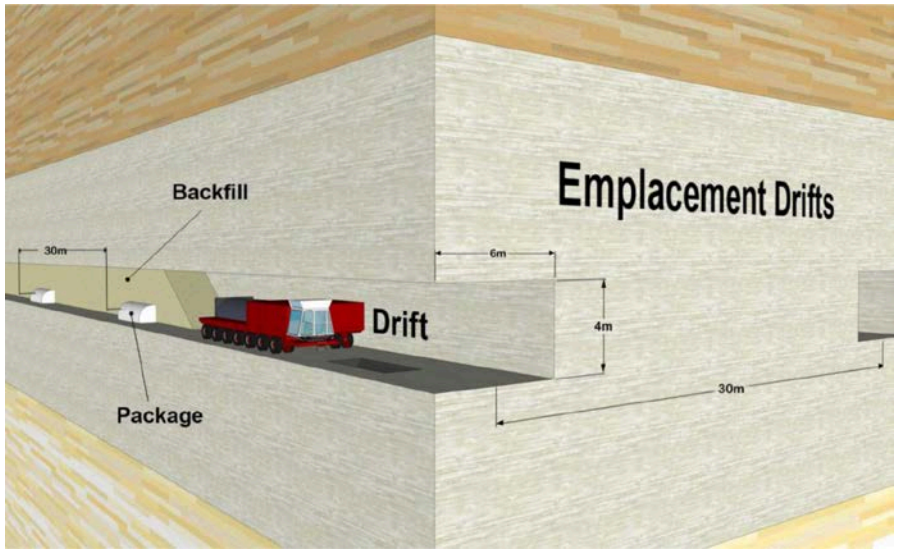
mapDFN

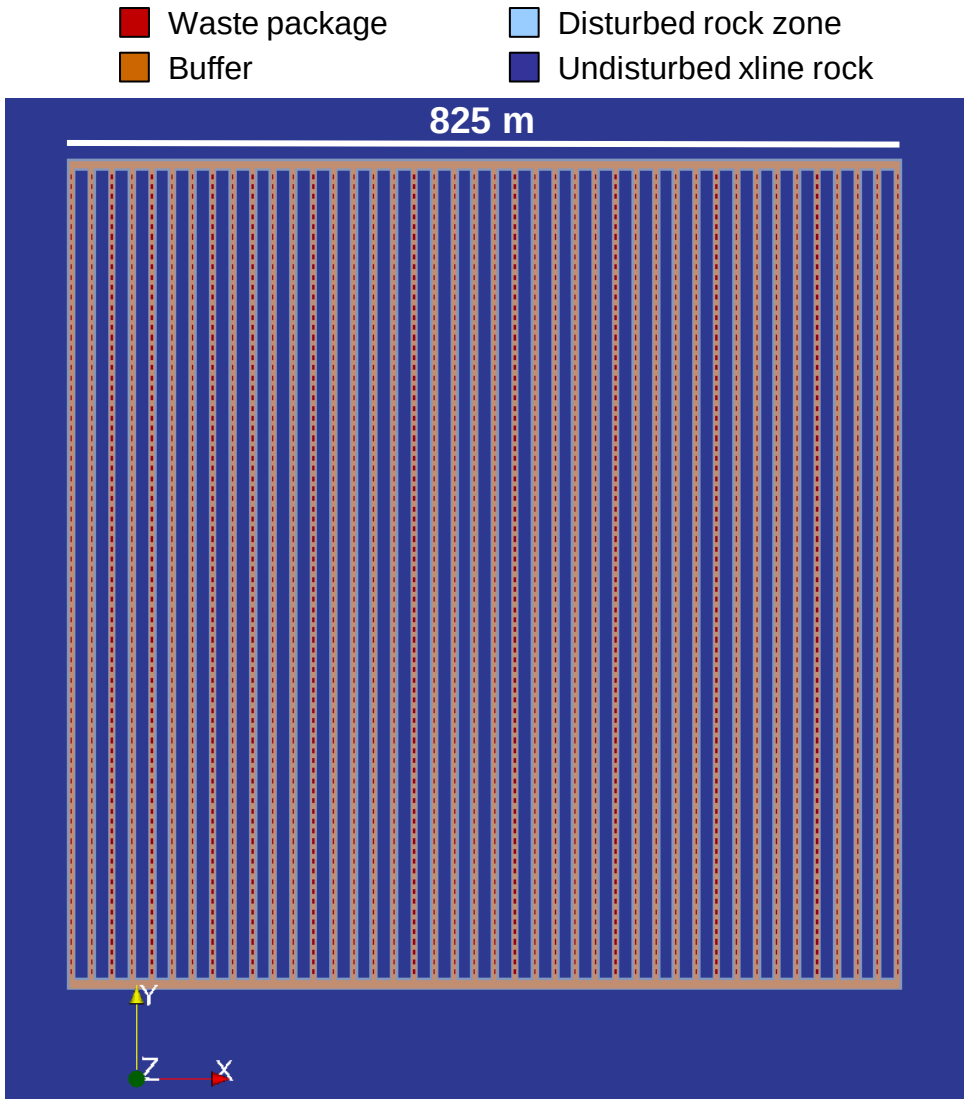




Used Fuel Disposition

Engineered Barrier System





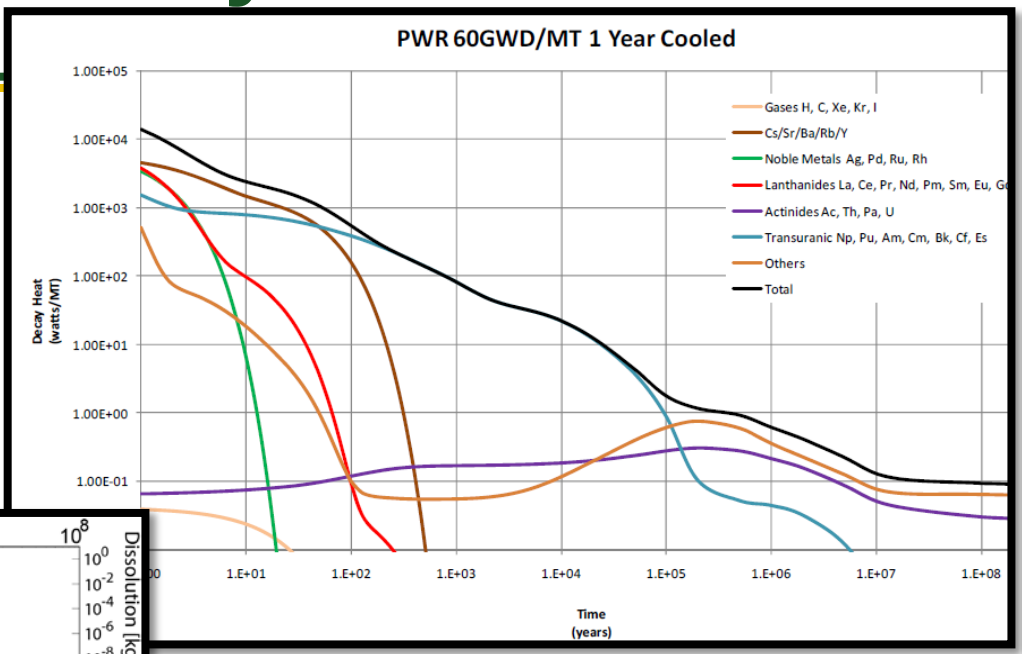
- Stainless steel waste packages
- Bentonite buffer
- Horizontal, in-drift emplacement
- Access halls, ramp, shafts

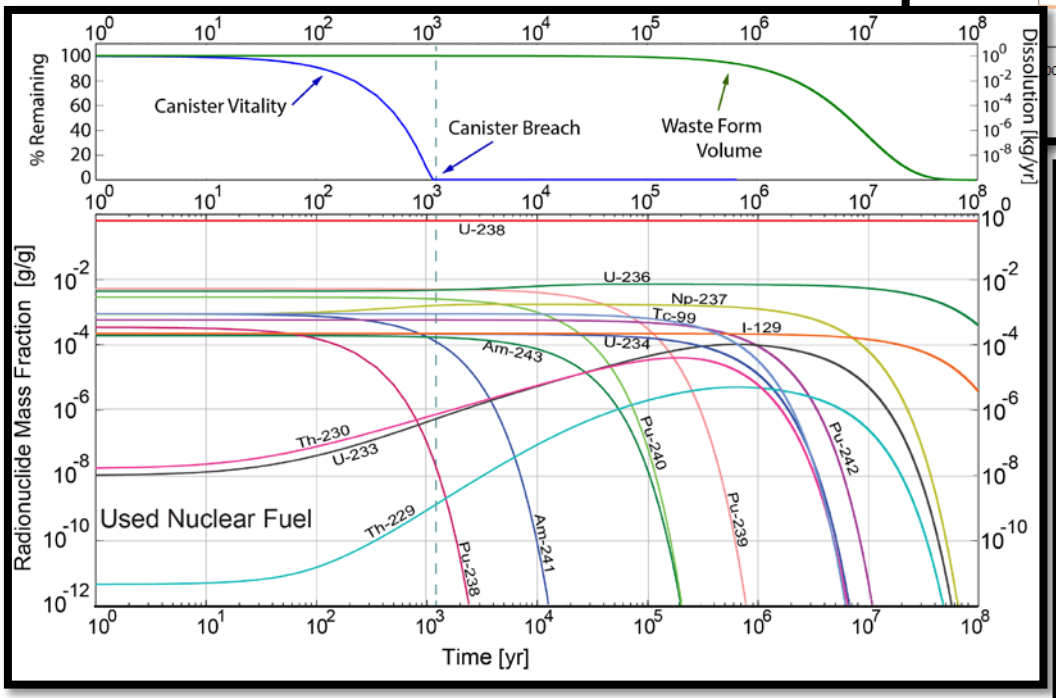
- 42 800-m drifts (80 WP/drift)
- ¼ of a 70,000 MTHM repository

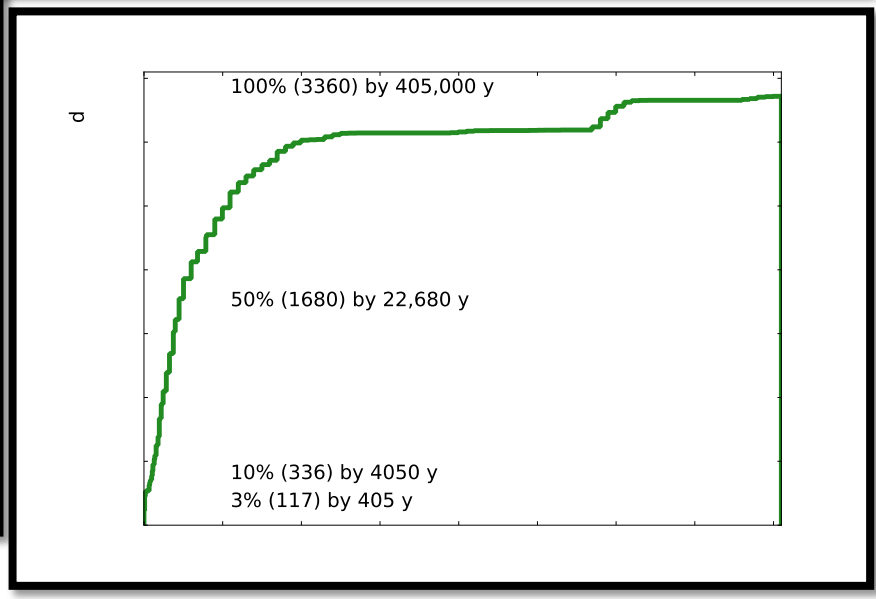
Used Fuel Disposition

Waste Inventory

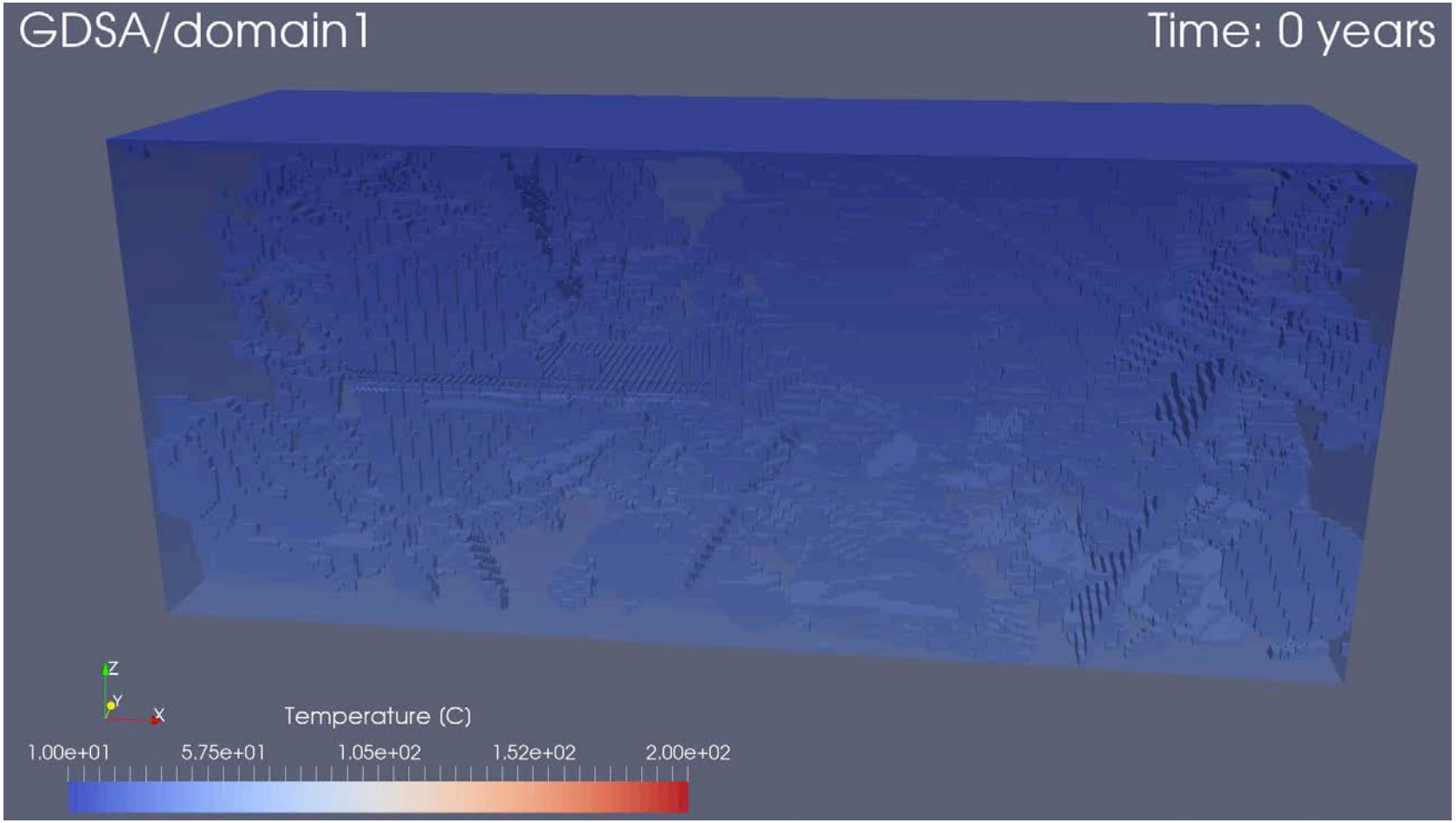
- 12-PWR waste packages
- 60 GWD/MT burn-up
- 4.73 wt% ^{235}U enrichment
- 100 yrs OoR
- Uniform WF diss. rate (10^{-7}/y)
- Heterogeneous WP deg. rate



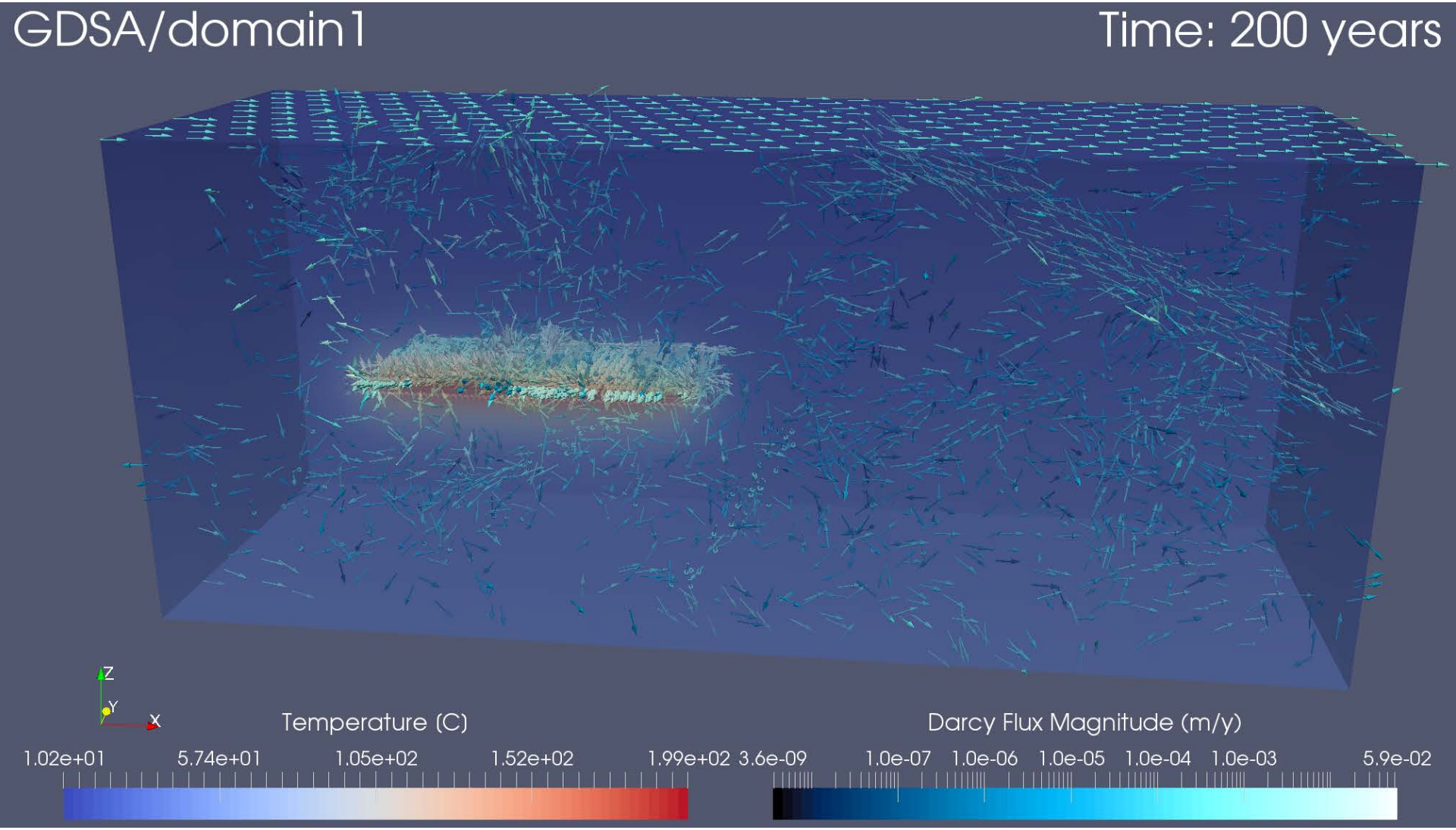




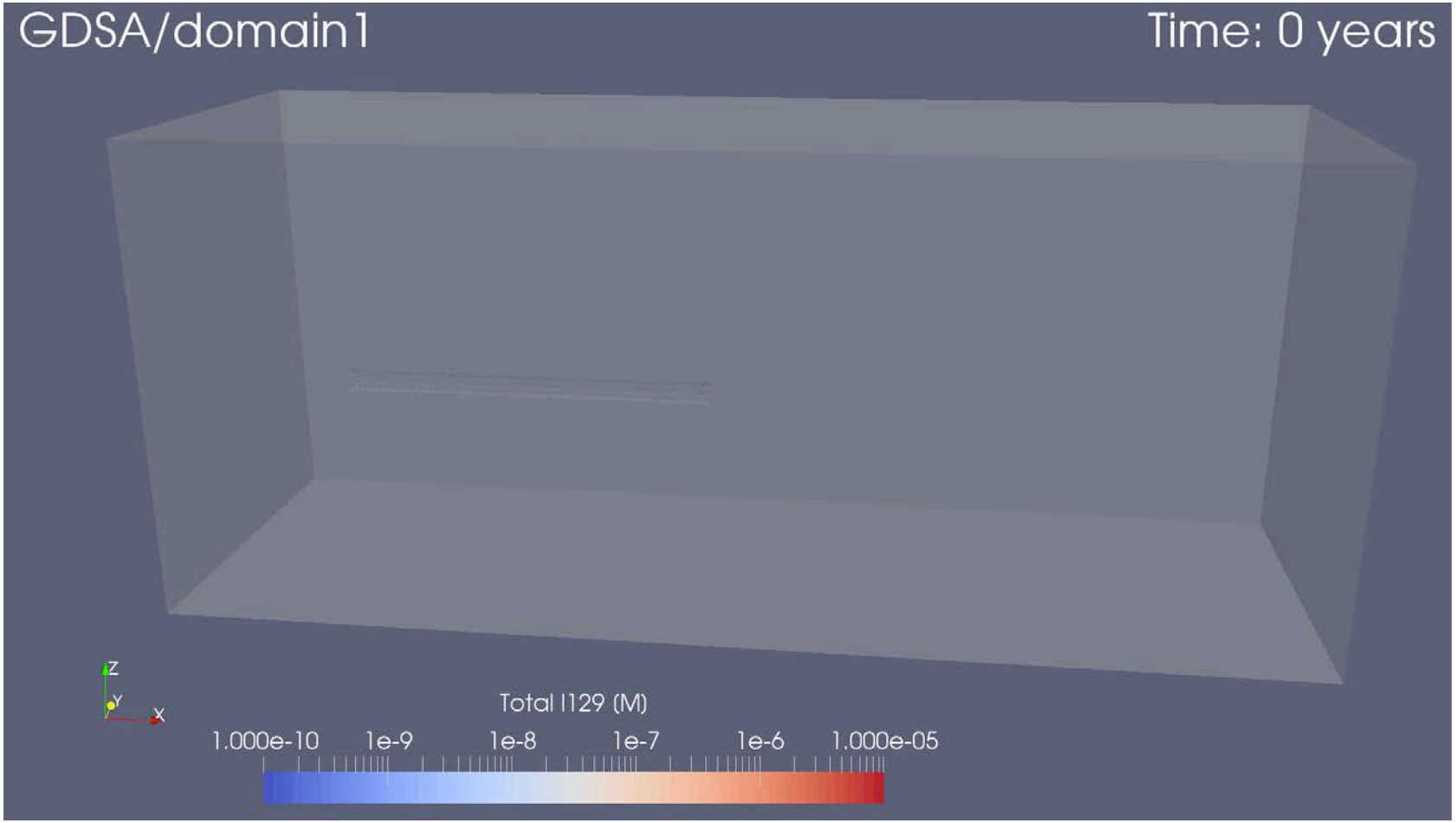
Deterministic Results: Temperature



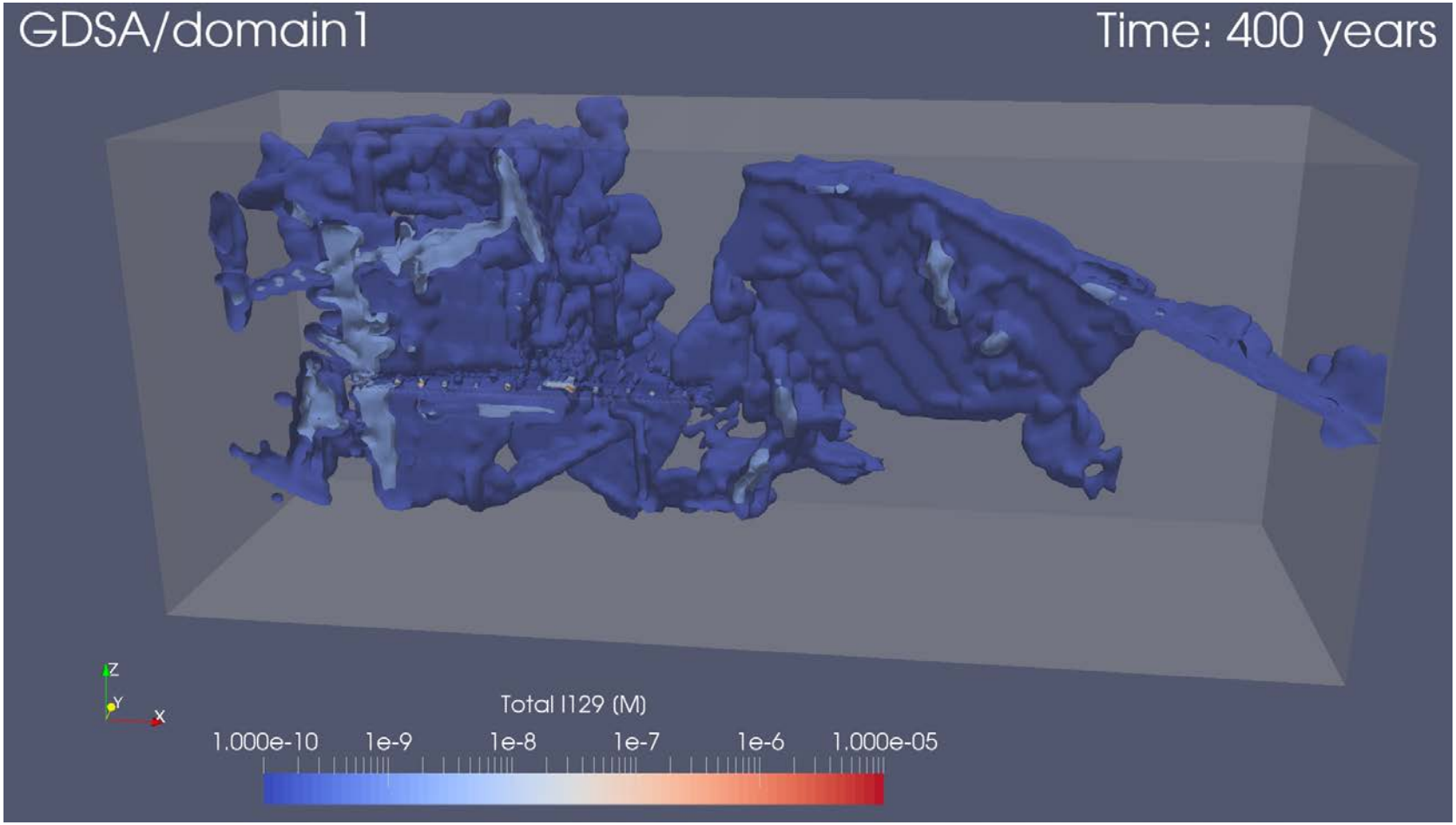
Deterministic Results: Darcy Flux



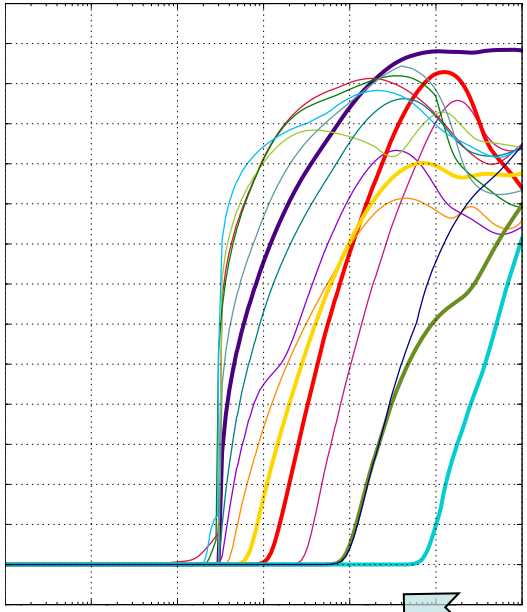
Deterministic Results: ^{129}I Concentration

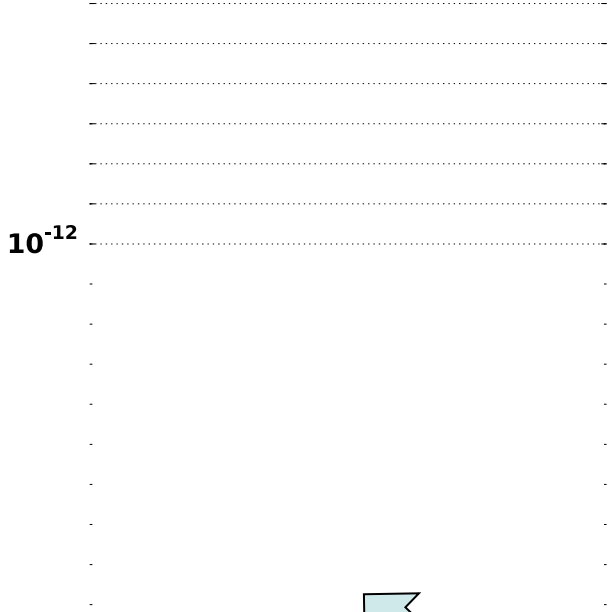


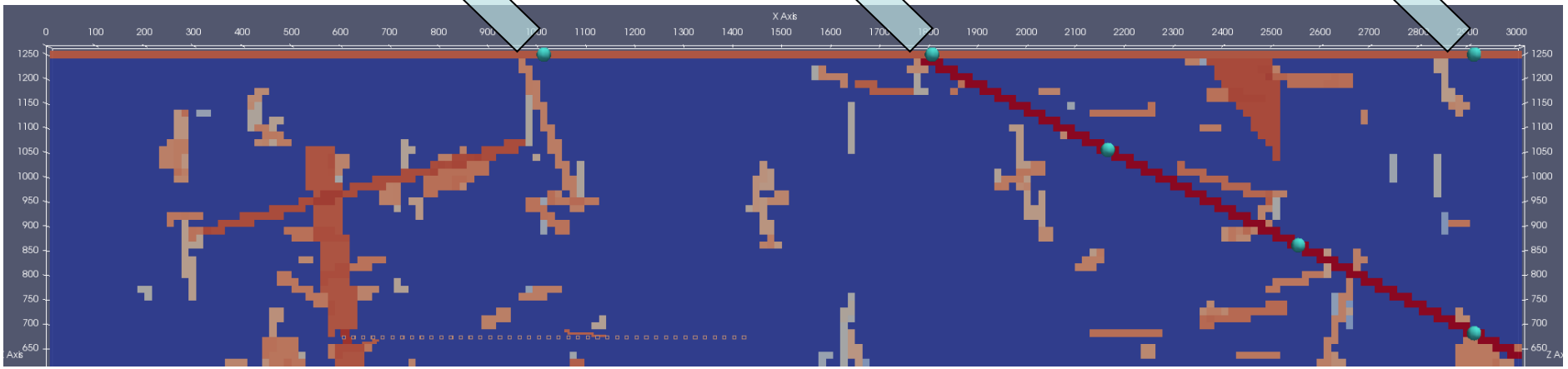
Deterministic Results: ^{129}I Concentration



Uncertainty due to fracture realization







Probabilistic: Sampled Parameters

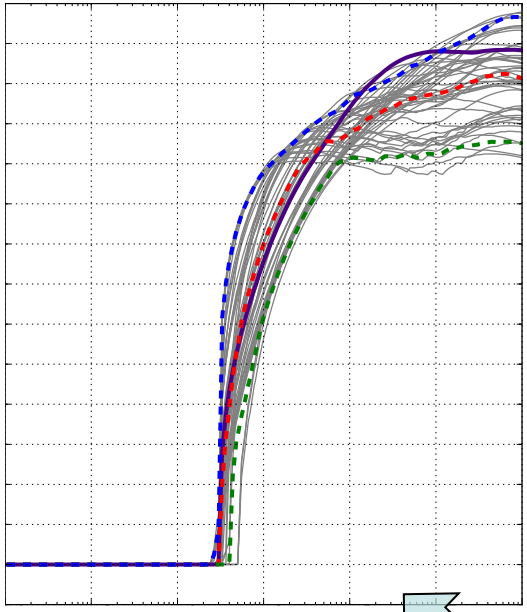
Parameter	Distribution	Lower Bound	Upper Bound
Glacial k (m^2)	Log uniform	10^{-16}	10^{-13}
Waste package tortuosity	Log uniform	0.01	1.0
Mean waste package degradation rate (1/yr)	Log uniform	$10^{-5.5}$	$10^{-4.5}$
UNF dissolution rate (1/yr)	Log uniform	10^{-8}	10^{-6}
DRZ porosity	Uniform	0.005	0.05
Buffer porosity	Uniform	0.1	0.4

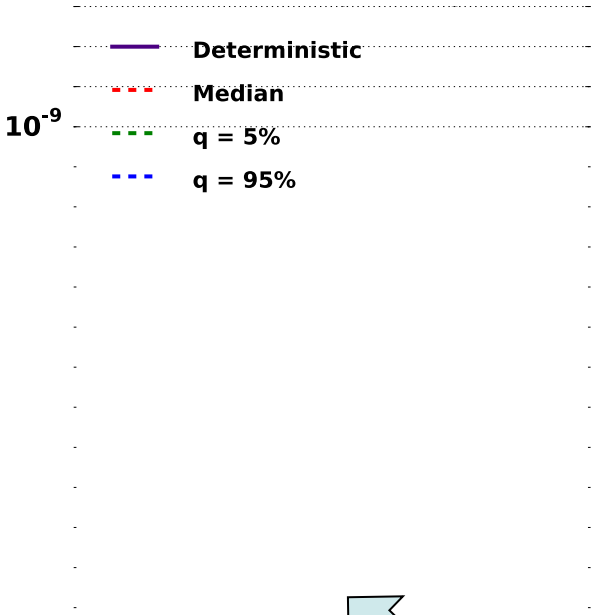
Example of capability only!

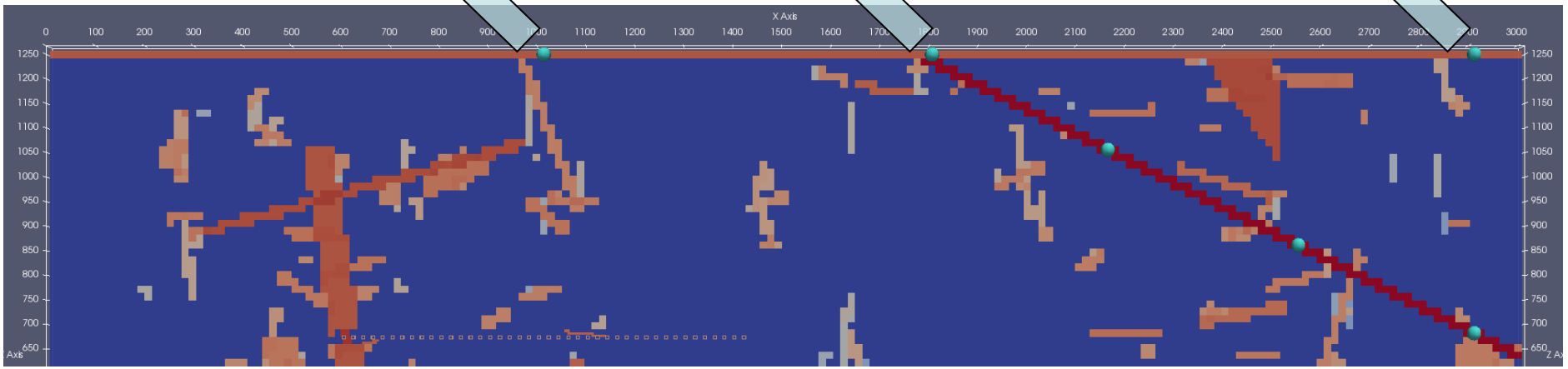
Have yet to explore:

- **Sensitivity to sampled range**
- **Sensitivity to Kd, etc.**
- **Most appropriate metric in fractured rock**

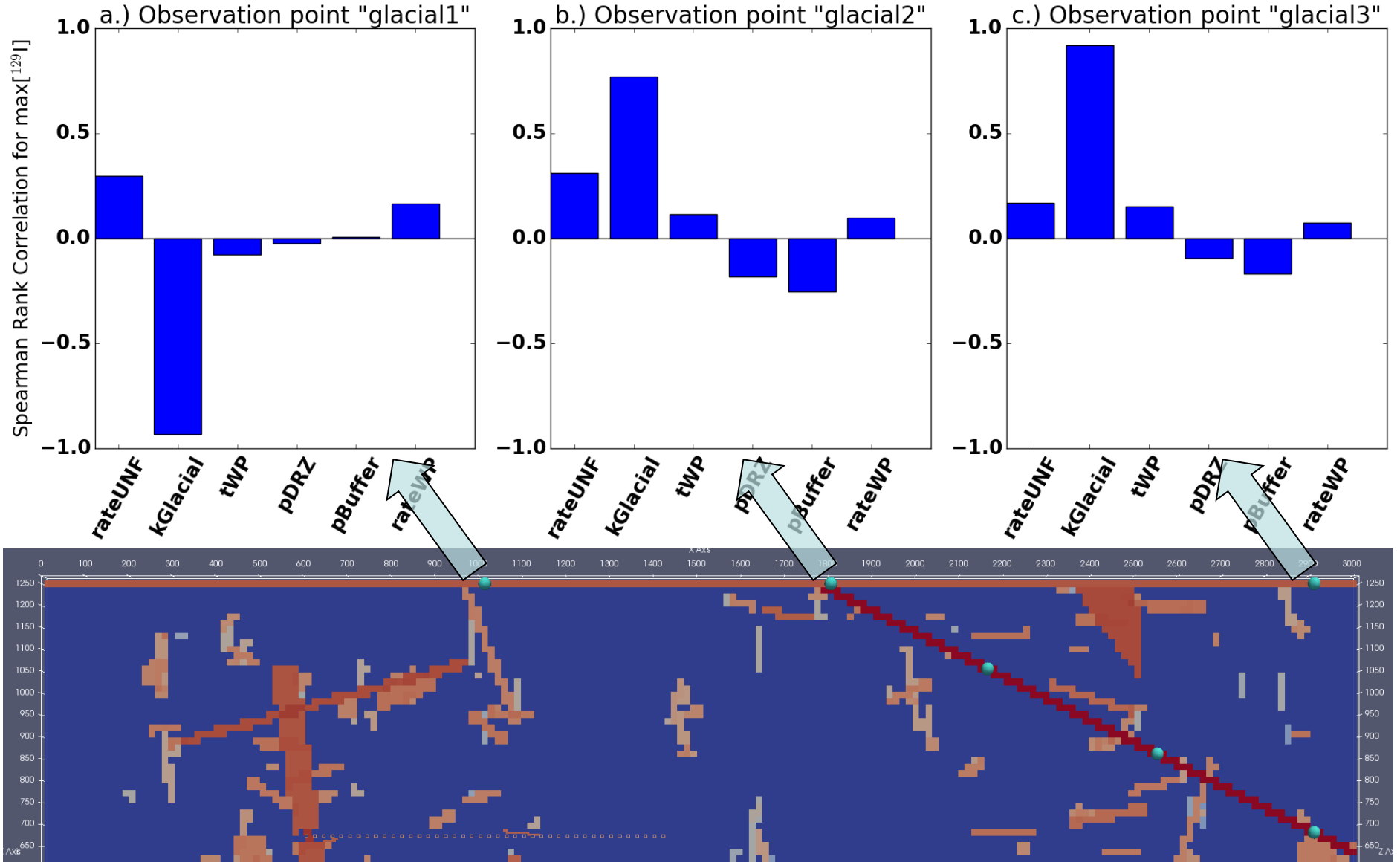
Probabilistic Results: Uncertainty due to sampled parameters





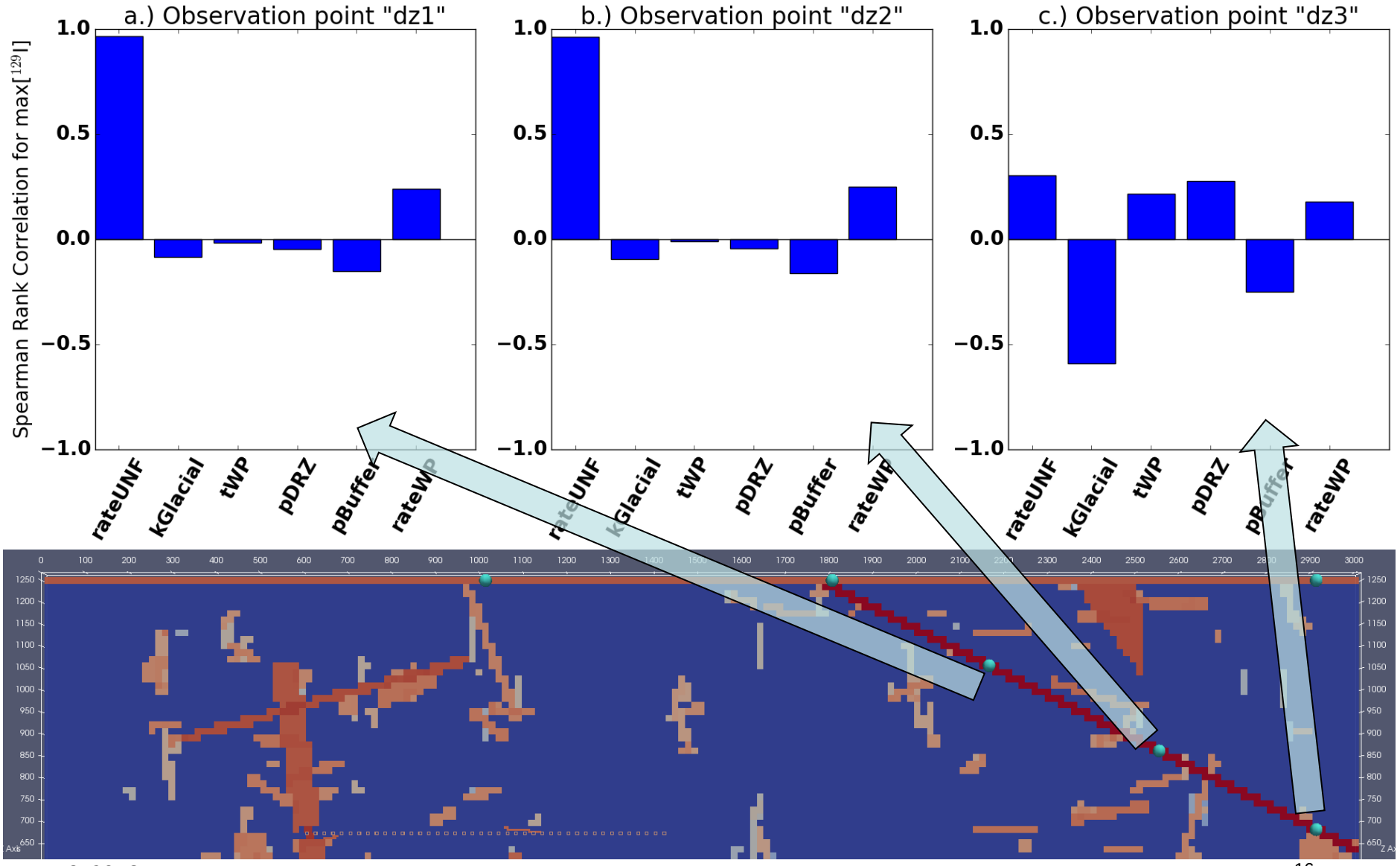


Probabilistic Results: Sensitivity



Used Fuel Disposition

Probabilistic Results: Sensitivity



Crystalline PA: R&D Future

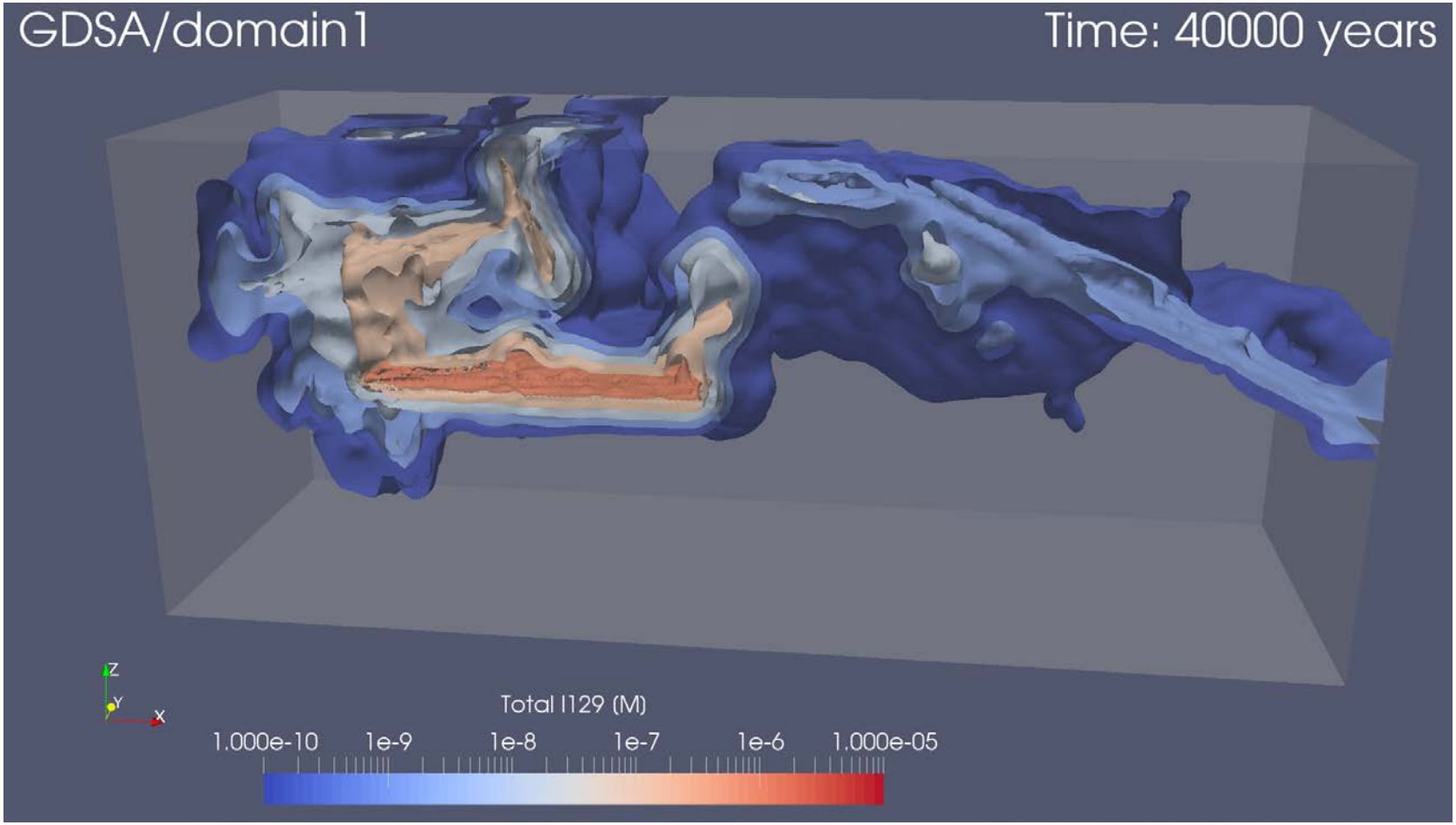
How to ensure isolation in a fractured host rock?

Generic Performance Assessment can identify:

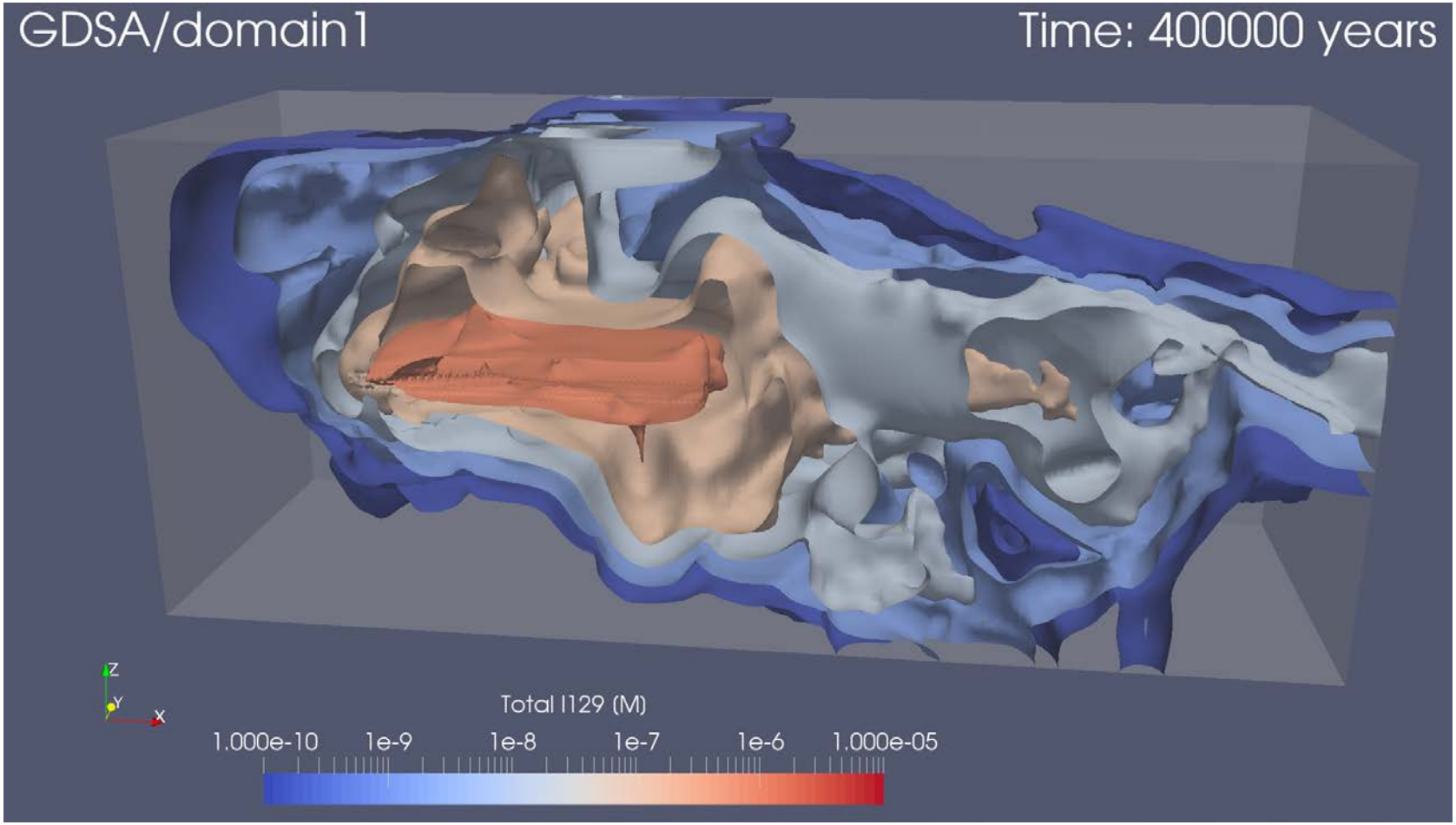
- **Components of the Engineered Barrier System capable of ensuring isolation, *e.g., long-lasting copper waste packages with compatible buffer material*.**
- **Features of the Natural Barrier System sufficient and/or necessary to ensure robust isolation from the biosphere, *e.g., lack of fracture connectivity, deep unsaturated zone, or thick sedimentary overburden*.**
- **Need-to-know aspects of fractured rock characterization, *e.g., spacing of deformation zones*.**
- **Appropriate performance metrics for uncertainty and sensitivity analyses in fractured rock.**
- **Overly conservative assumptions, *e.g. fully saturated system at t = 0.***

Backup slides

Deterministic Results: ^{129}I Concentration



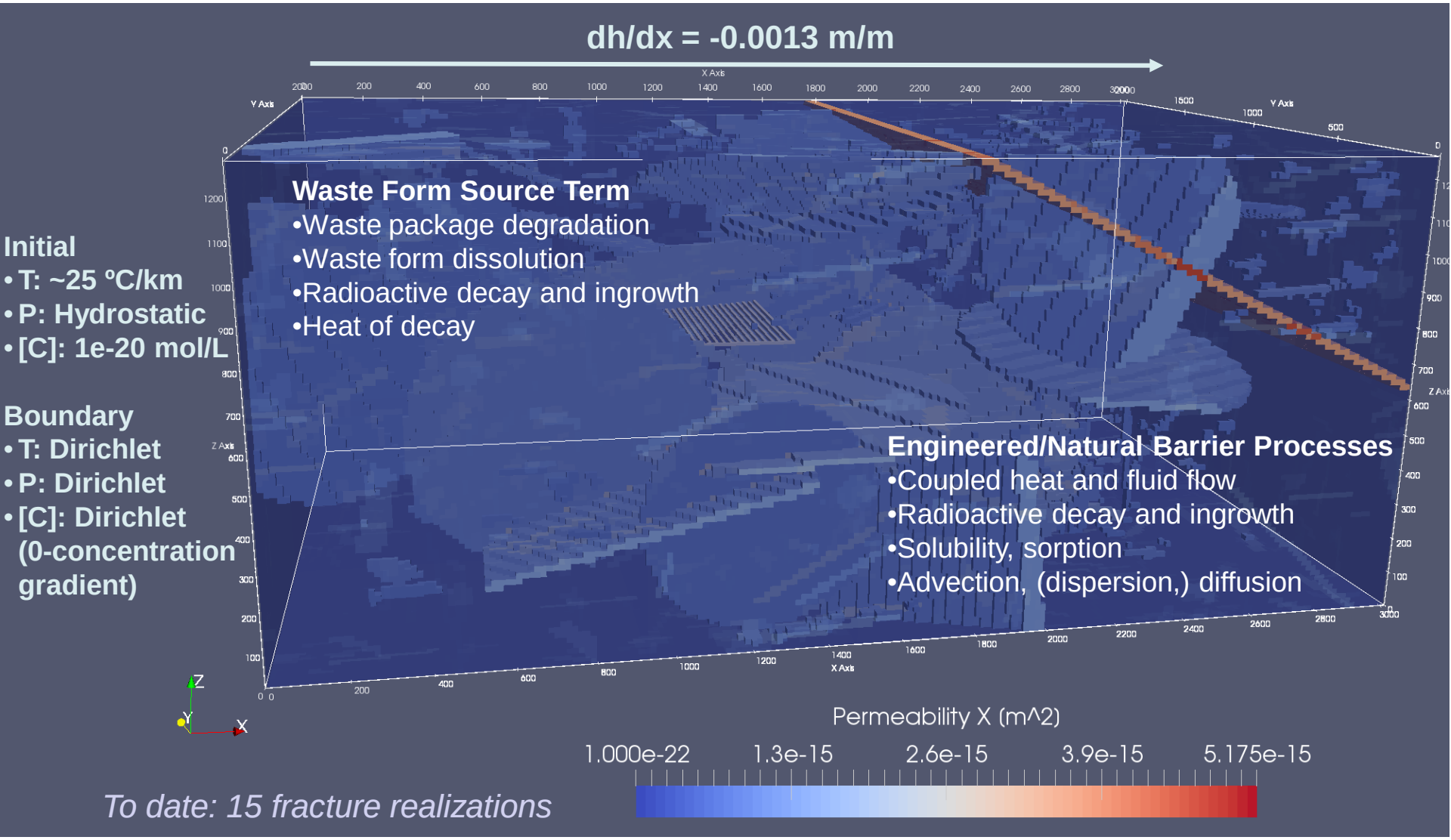
Deterministic Results: ^{129}I Concentration



Used Fuel Disposition

Setting up a simulation

This slide probably isn't necessary.
I can put dh/dx and IC/BC on slide 5.



Initial
- **T: ~25 ºC/km**
- **P: Hydrostatic**
- **[C]: 1e-20 mol/L**

Boundary
- **T: Dirichlet**
- **P: Dirichlet**
- **[C]: Dirichlet (0-concentration gradient)**

To date: 15 fracture realizations

Deterministic Results: Waste Package Breach