Used Fuel Disposition Campaign

D-Repo Performance Assessment: Crystalline Reference Case

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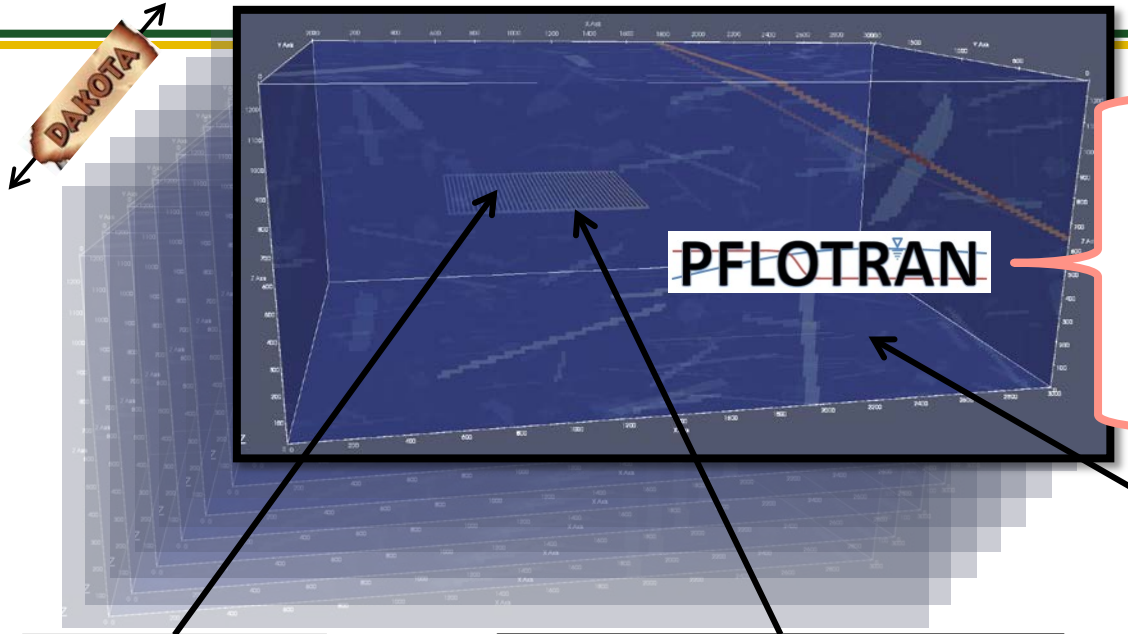
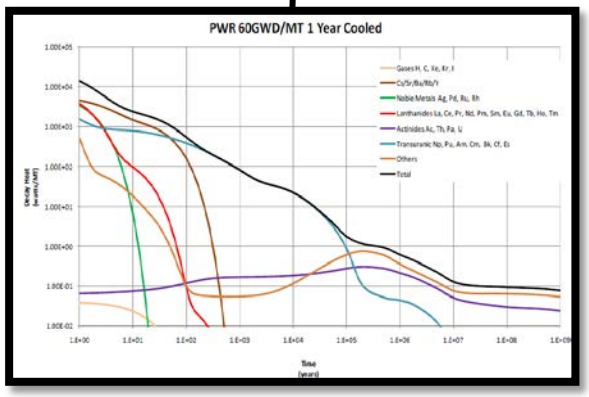
Performance Assessment



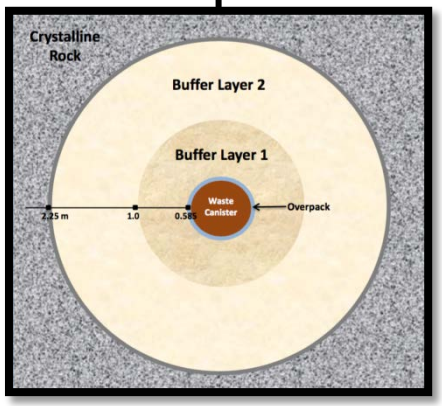
- Coupled heat and fluid flow
- Waste package degradation
- Waste form dissolution
- Radioactive decay and ingrowth
- Solubility, sorption
- Advection, dispersion, diffusion

Waste Forms



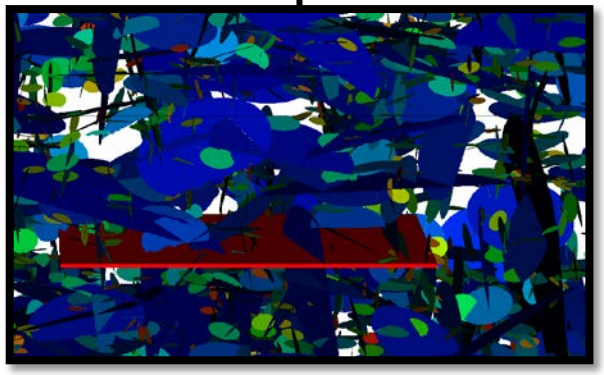
SRNL Inventory

Engineered Barrier System



SNL EBS Concepts

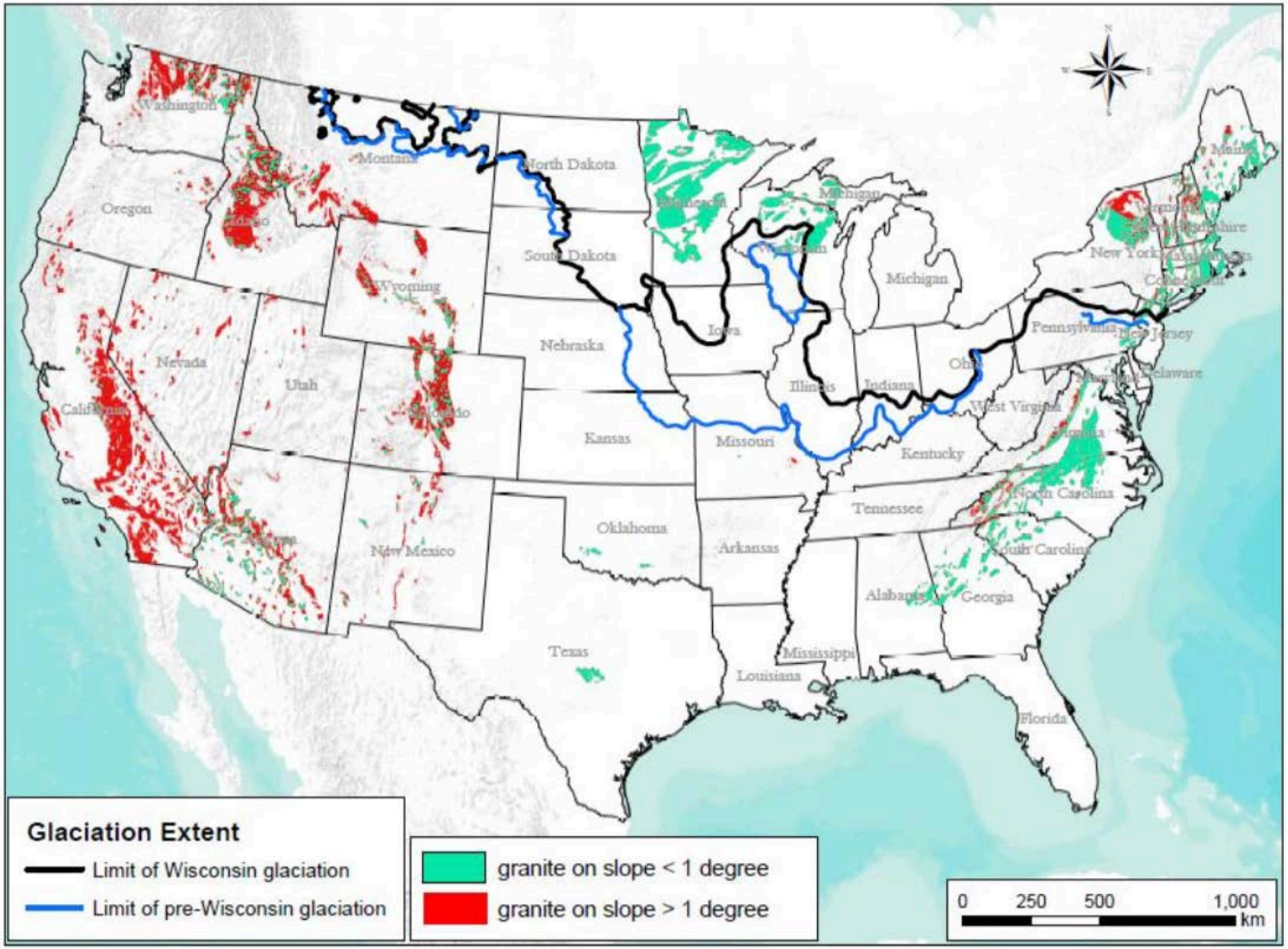
Natural Barrier System



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

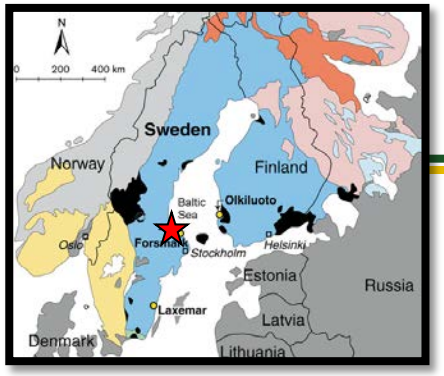
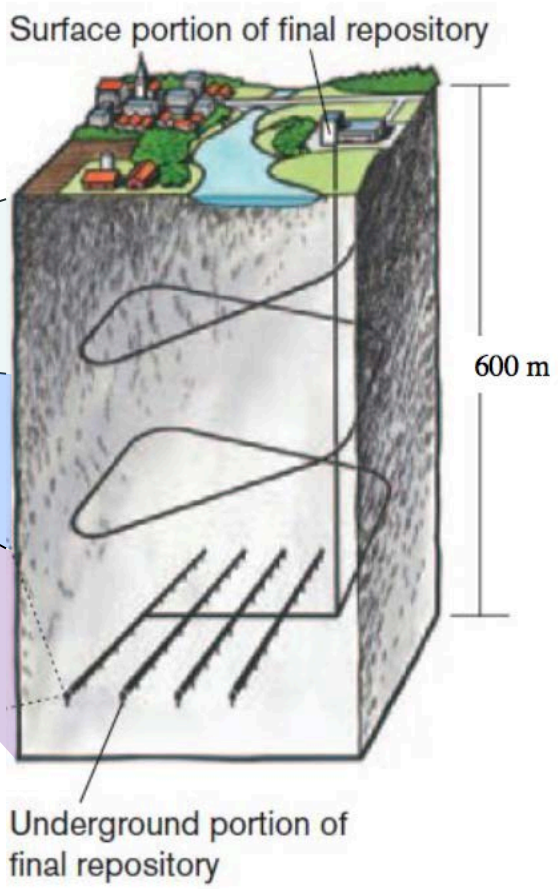


Table 2 Hydrogeological DFN parameters for each fracture domain, fracture set and depth zone

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



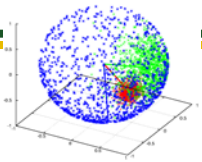
Joyce et al., Hydrogeology Journal (2014) 22:1233-1249

Used Fuel Disposition

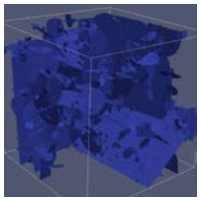
Natural Barrier System

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

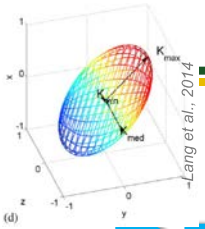
$b=(12T\mu/\rho g)^{1/3}$



DFNWorks

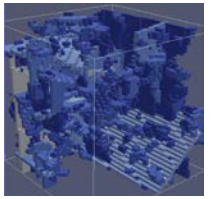


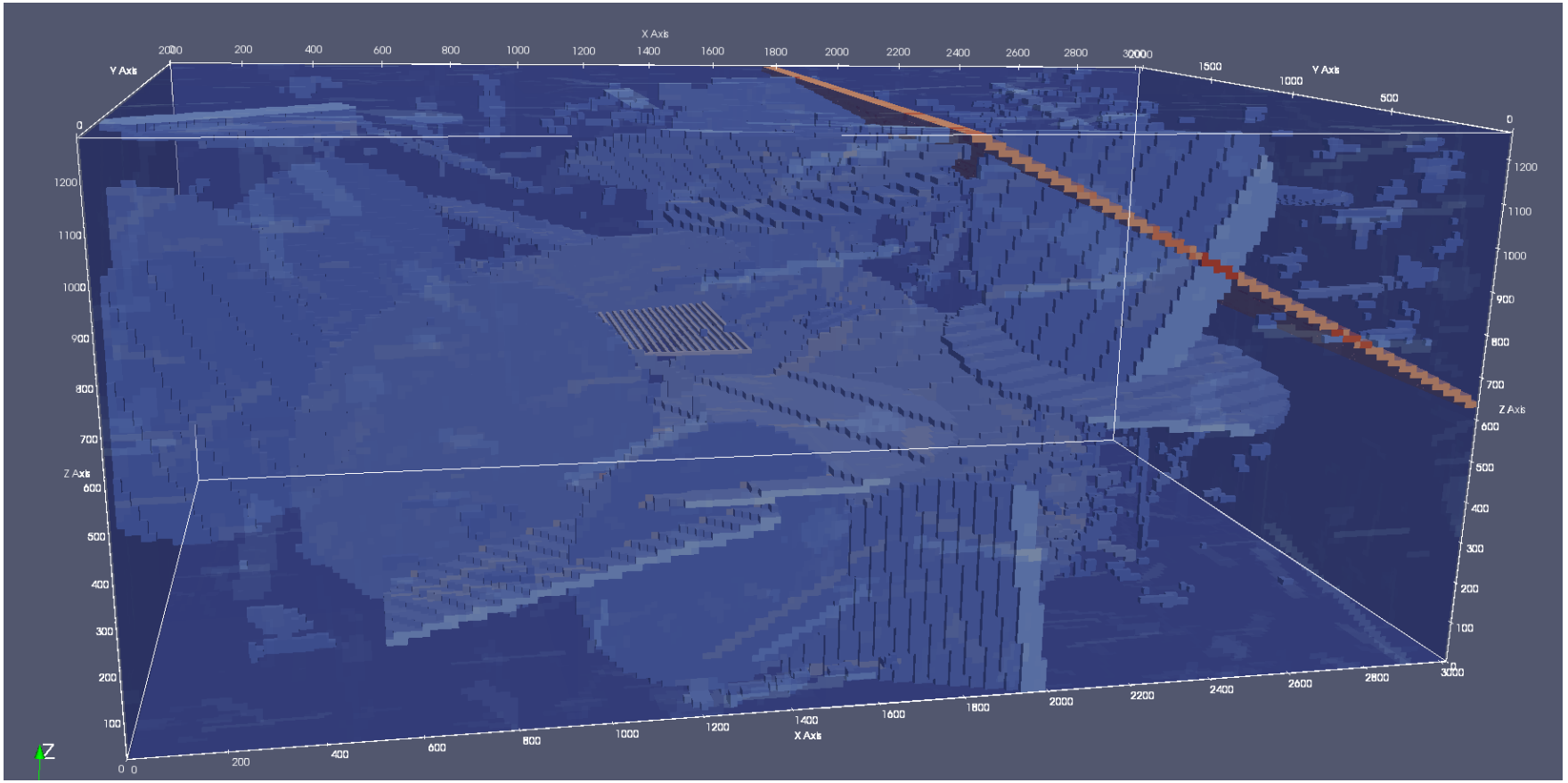
$\phi = V_f/V_{cell}$



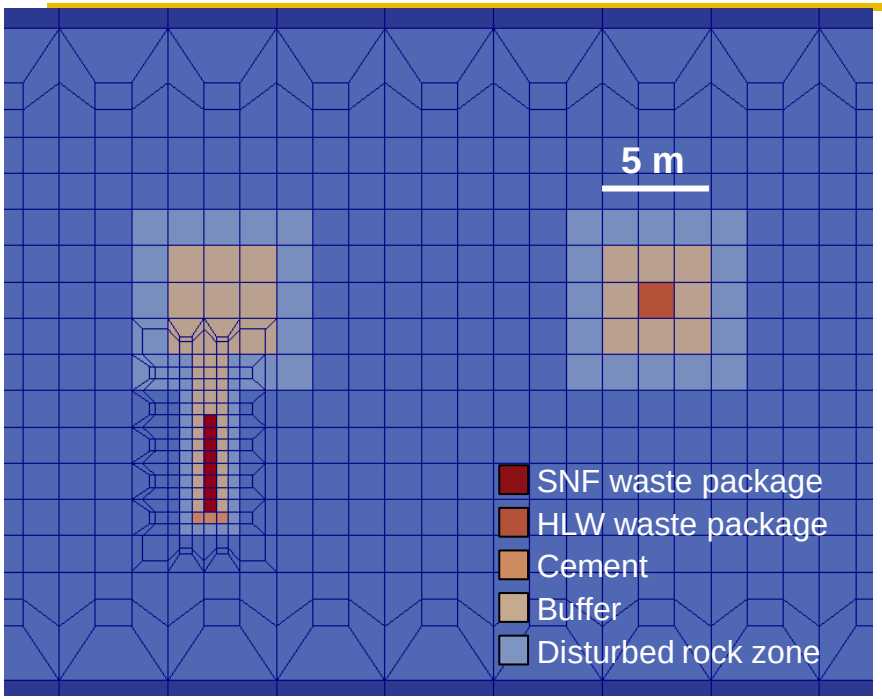
$k = T\rho g/\mu b$

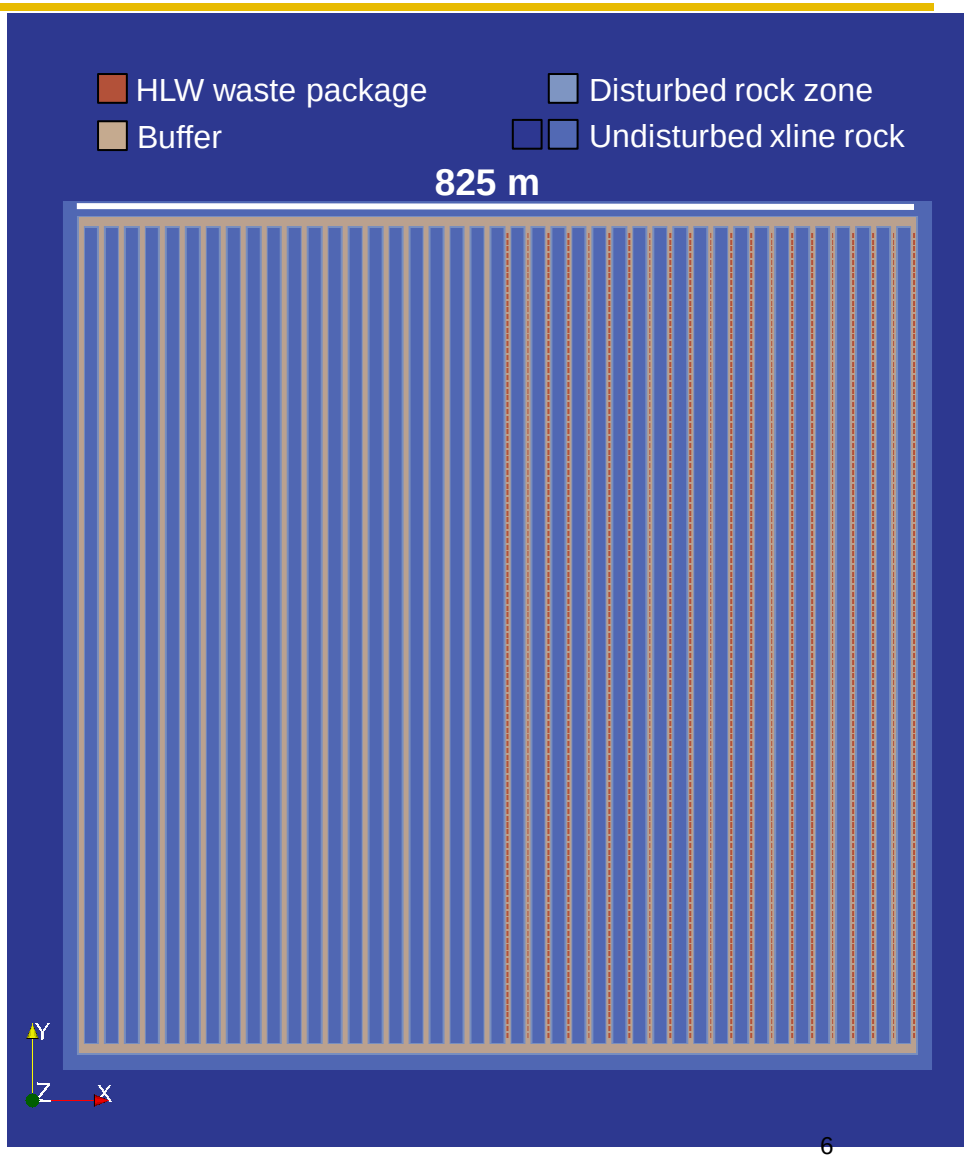
mapDFN





Engineered Barrier System





- Stainless steel waste packages
- Log normal distribution on waste package degradation rate
- Bentonite buffer
- 21 drifts w/ 80 SNF WP/drift
- 21 drifts w/ 119 HLW WP/drift
- 5 glass HLW logs/WP

Waste Inventory in 2038

DOE-managed defense-related SNF

Decay heat per canister (W)	Cumulative % in 2010	Number of canisters projected in 2035	Number of canisters in simulation
<50	46.8%	1163	787
50-100	56.2%	234	158
100-200	94.1%	940	636
200-300	94.5%	12	8
300-500	96.2%	41	28
500-1000	99.7%	88	60
1000-1500	99.9%	4	3
1500 - 2000	99.9%	0	0
>2000	100.0%	3	0
Total		**2485**	**1680**

Excludes Savannah River Site SRE fuel, commercial fuel in DOE possession, and Naval fuel.

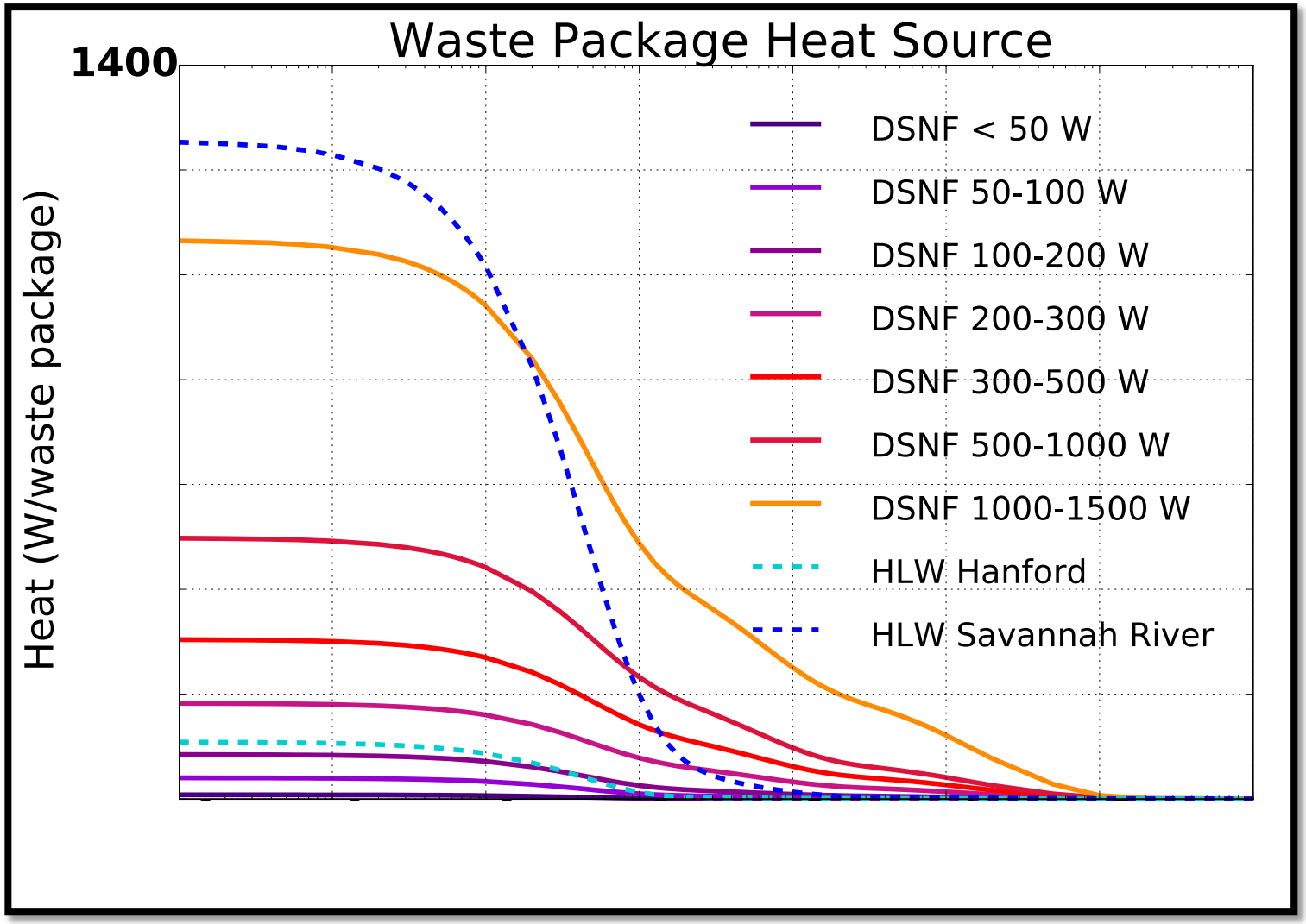
Selected glass HLW

	Average decay heat per canister in 2038 (W)	Number of canisters projected	Number of canisters in simulation
Hanford	22	11079	7425
Savannah River	251	7562	5070
Total		**18641**	**12495**

Simulating ~2/3 of selected inventory.

Projected Inventories from Carter et al., 2013 and Wilson, 2016.

Waste Inventory in 2038



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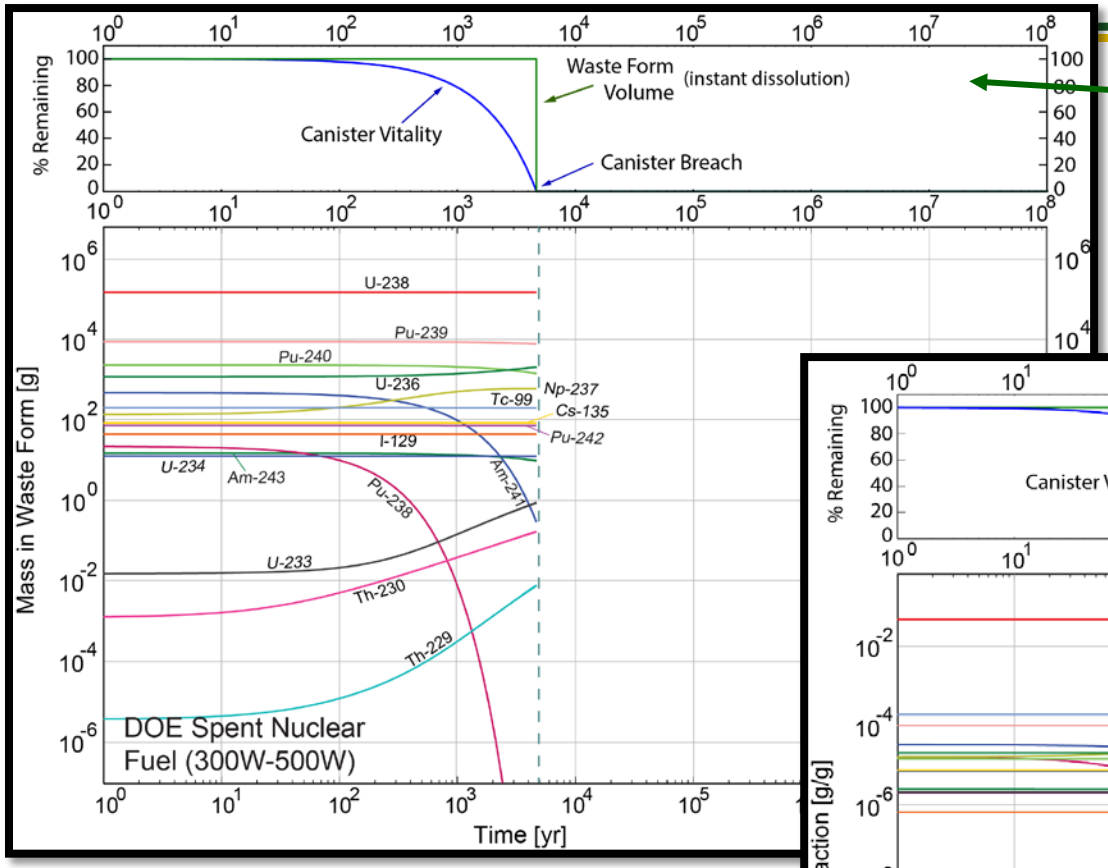
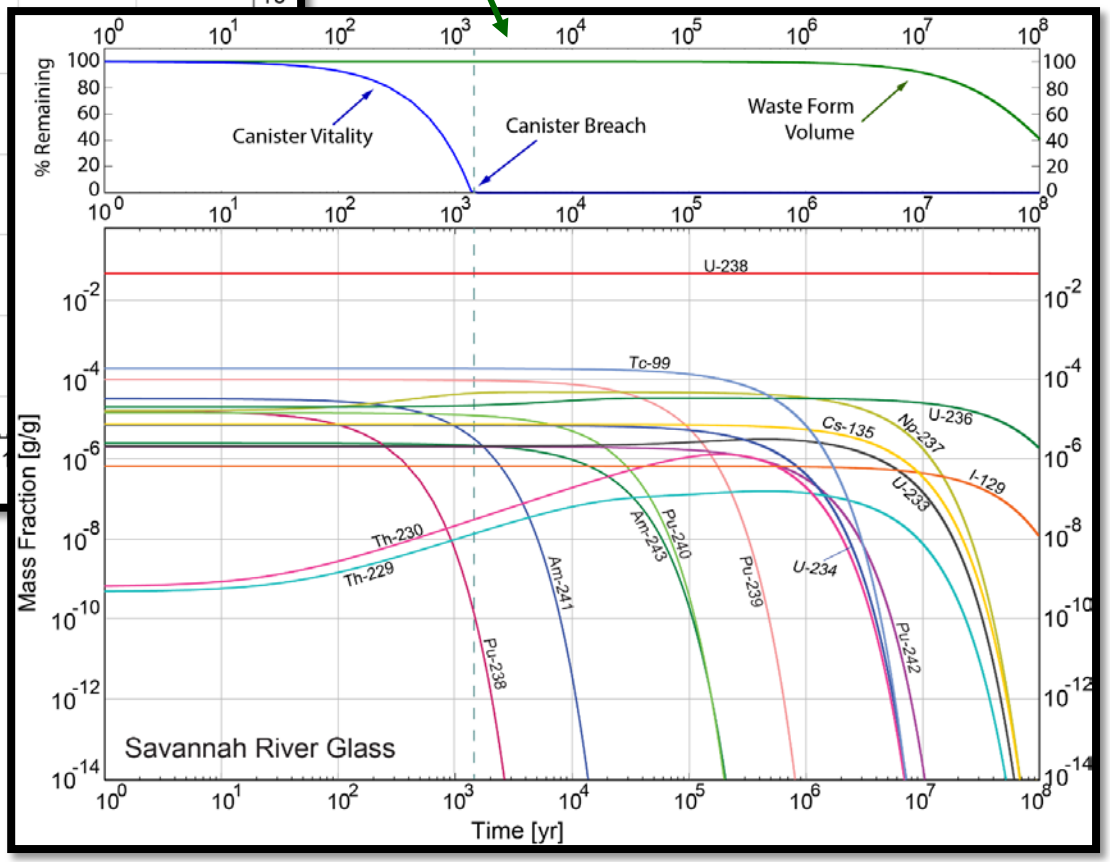
Waste Inventory in 2038

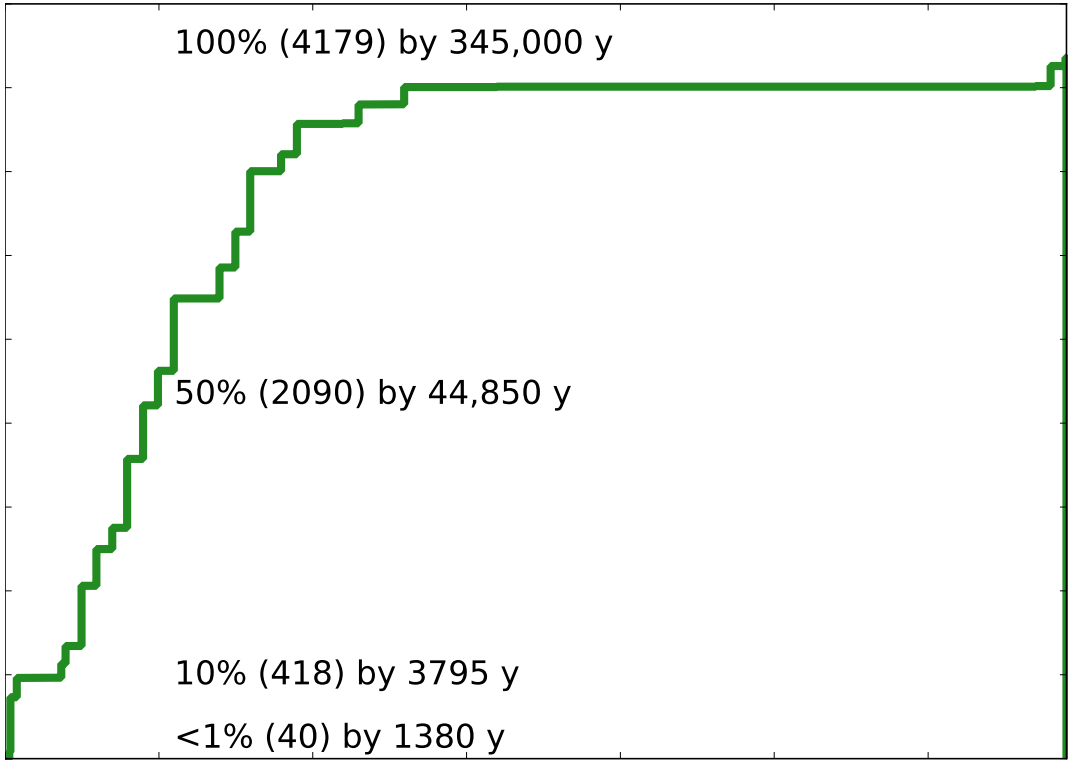


- Instantaneous DSNF dissolution
- Triangular distribution on HLW dissolution rate; f(T)

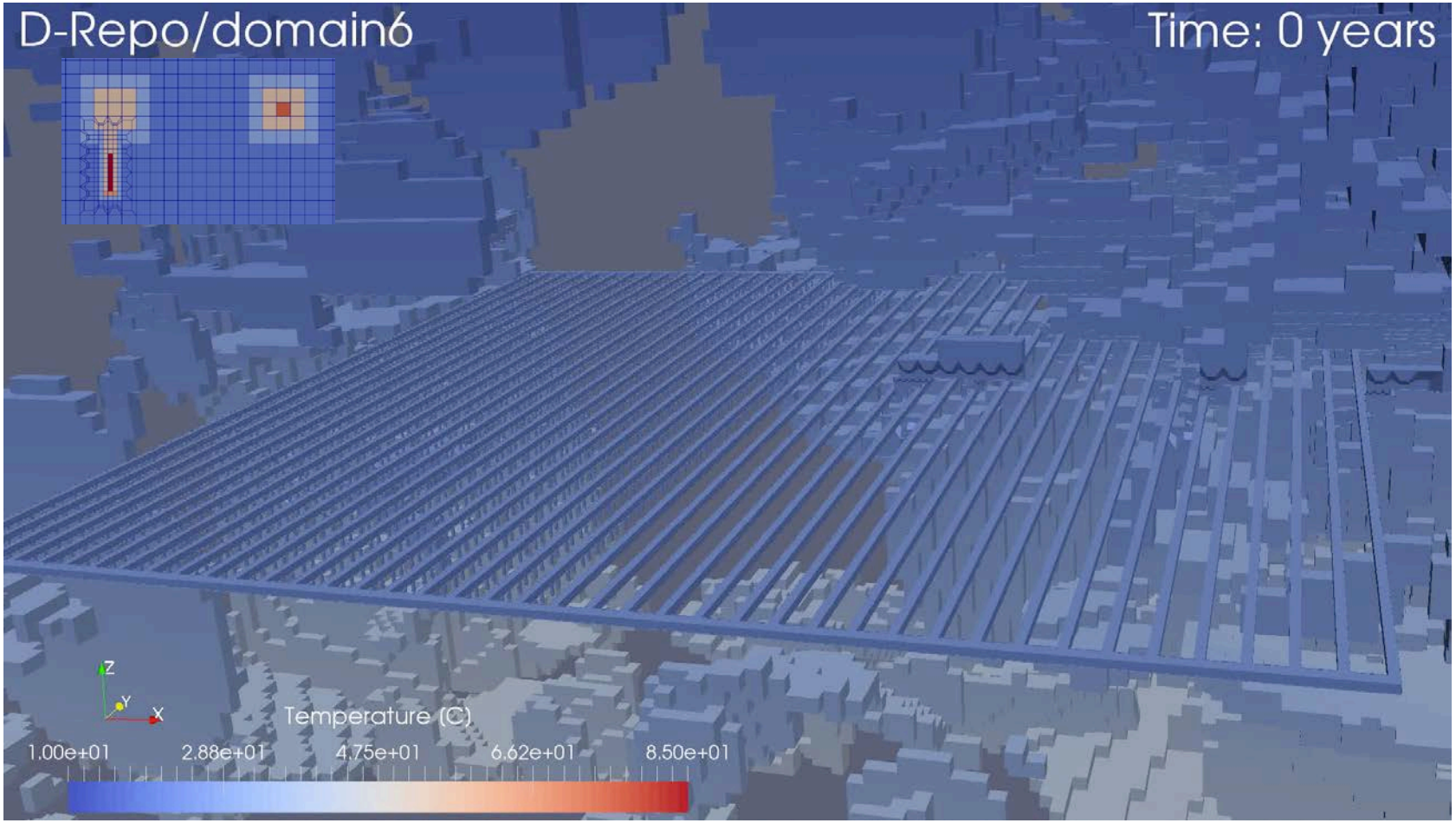


- Log normal distribution on canister degradation rate; f(T)

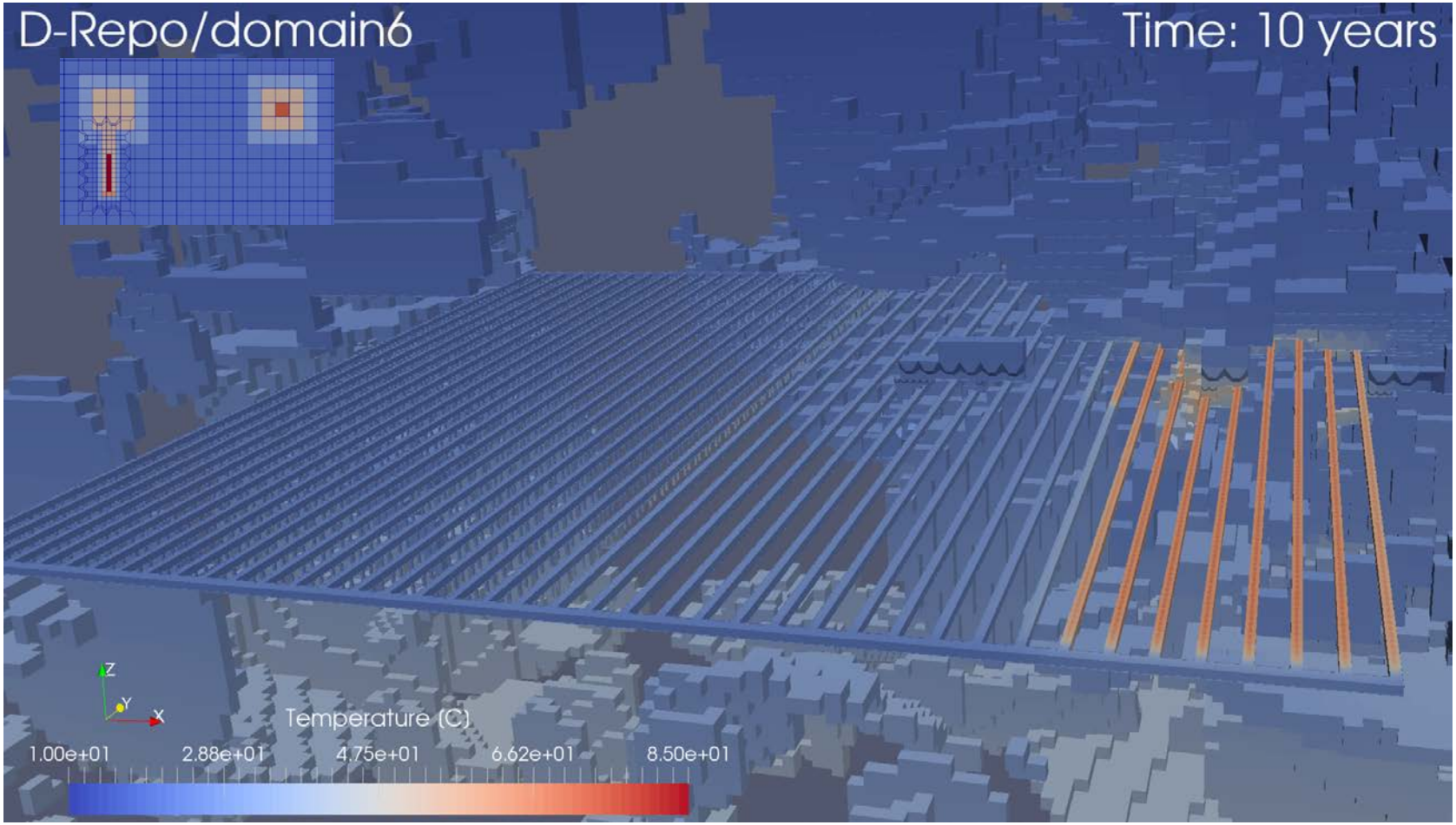
Deterministic Results: Waste Package Breach



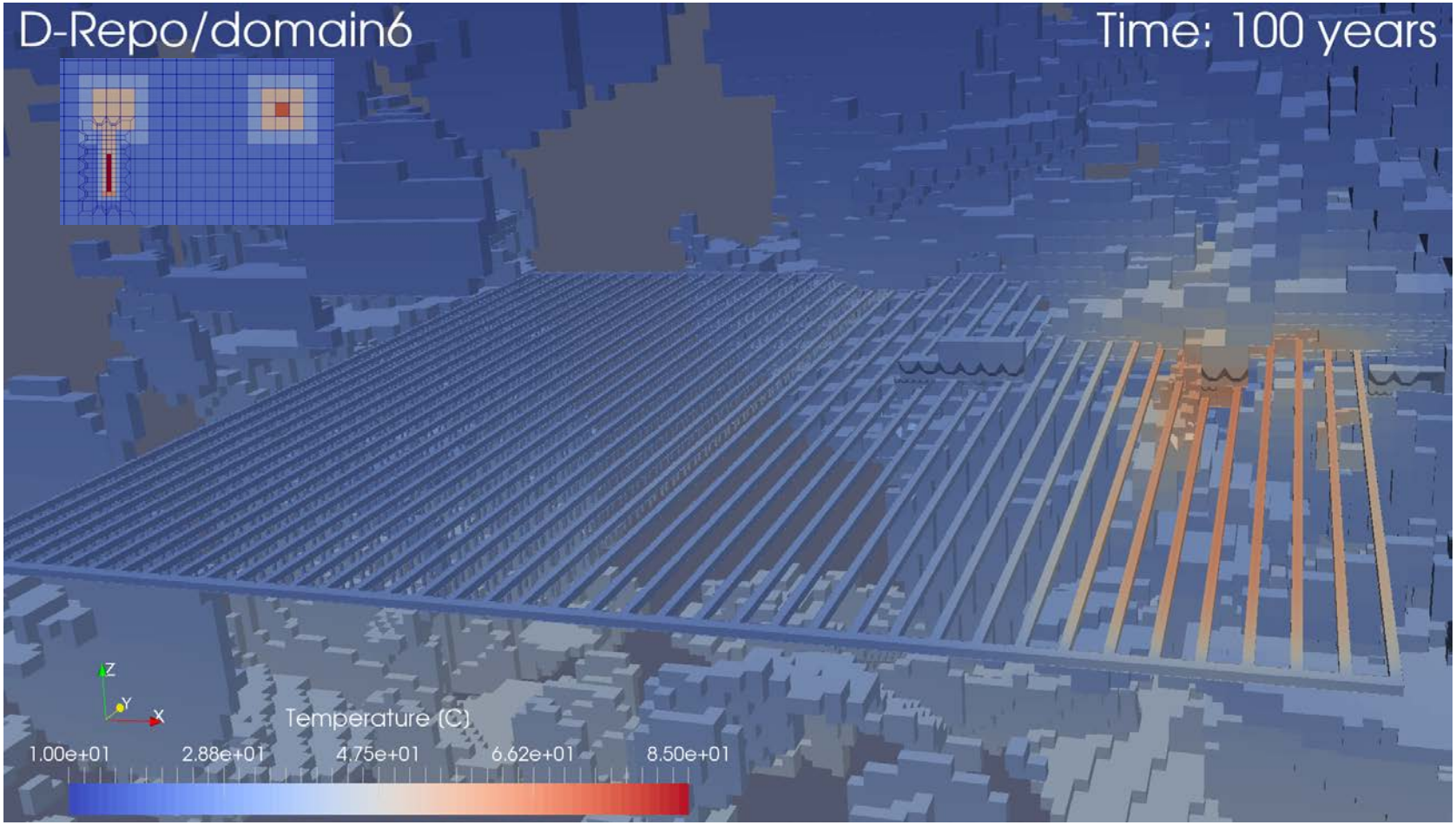
Deterministic Results: Temperature



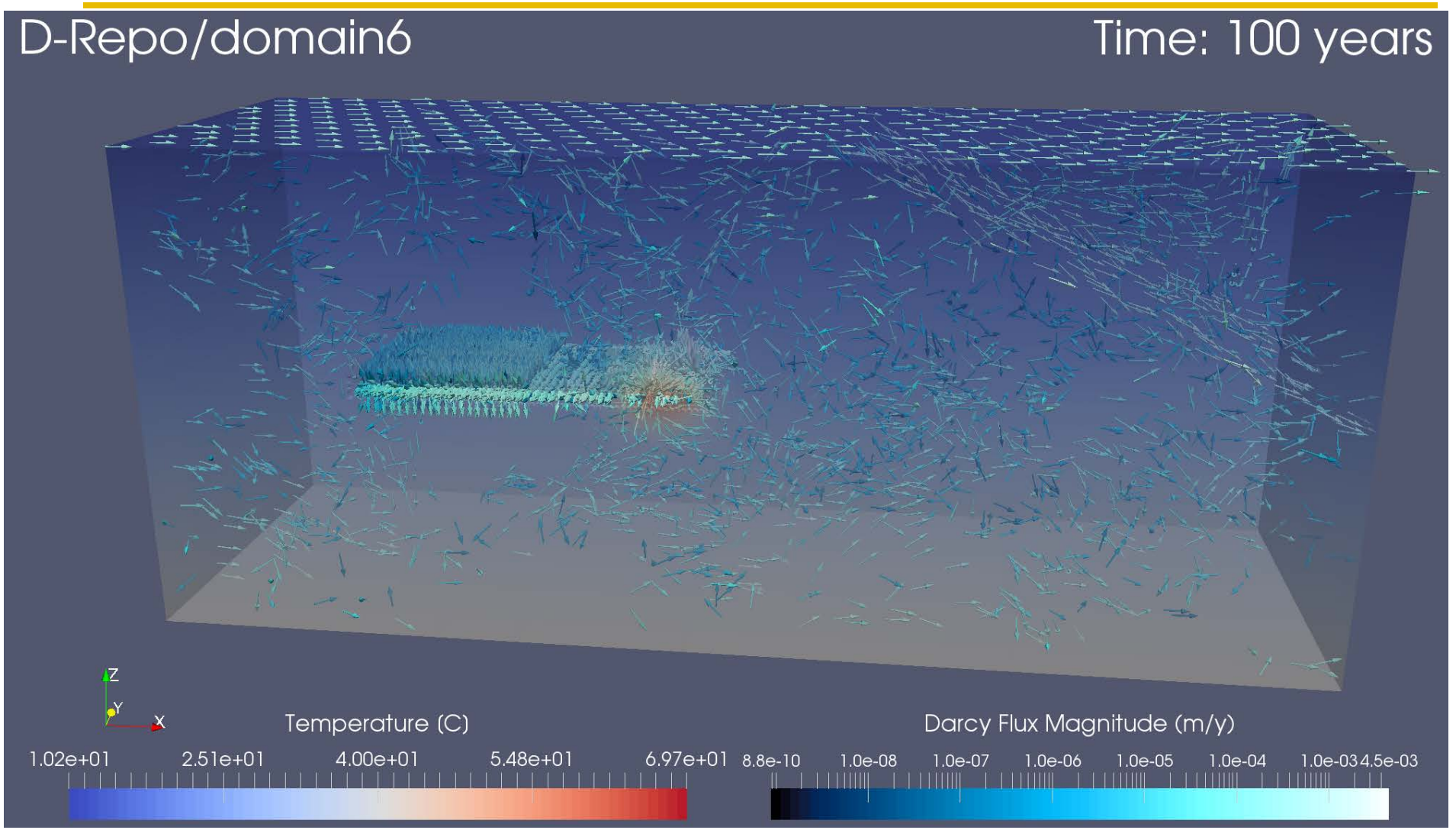
Deterministic Results: Temperature



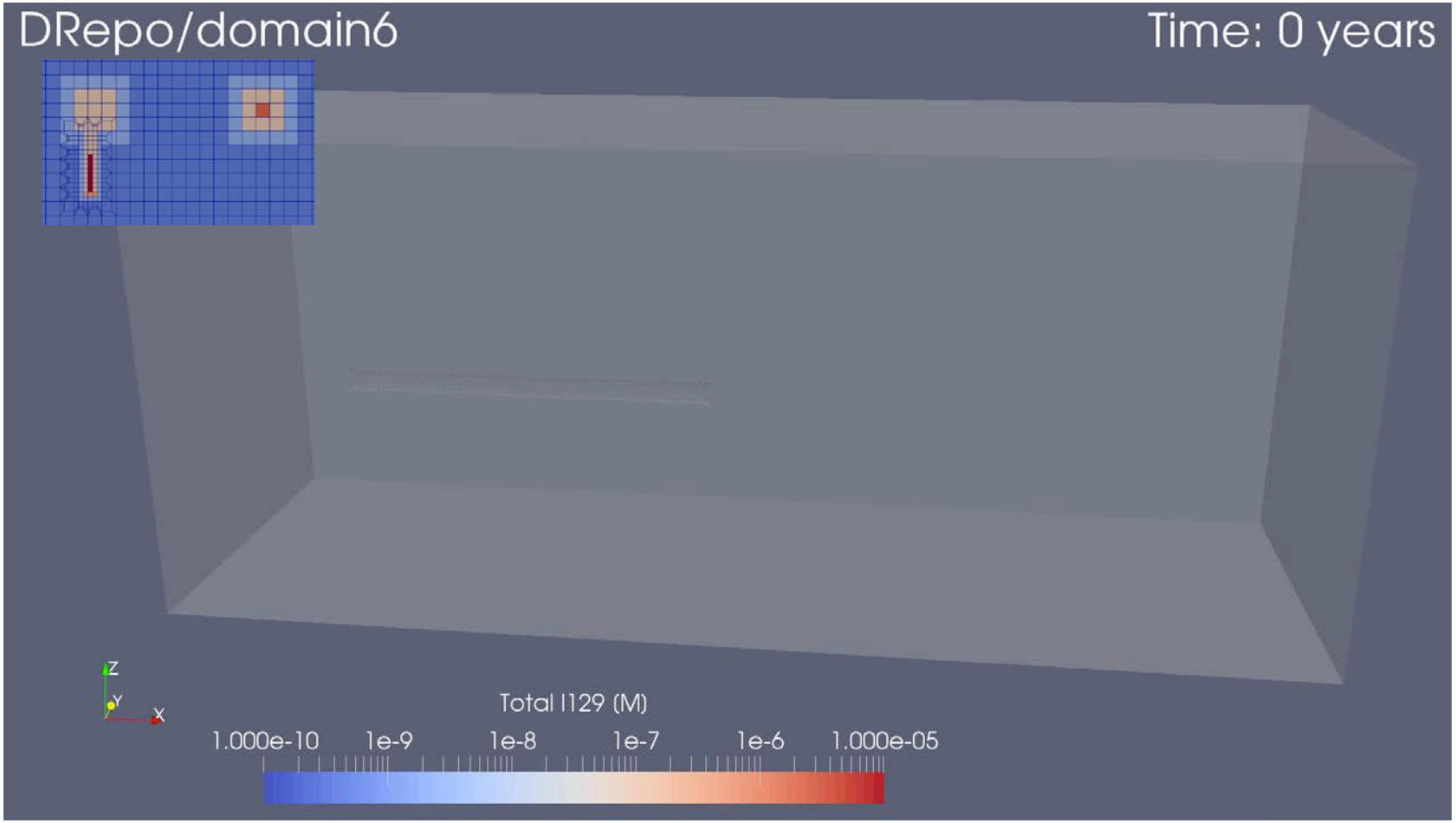
Deterministic Results: Temperature



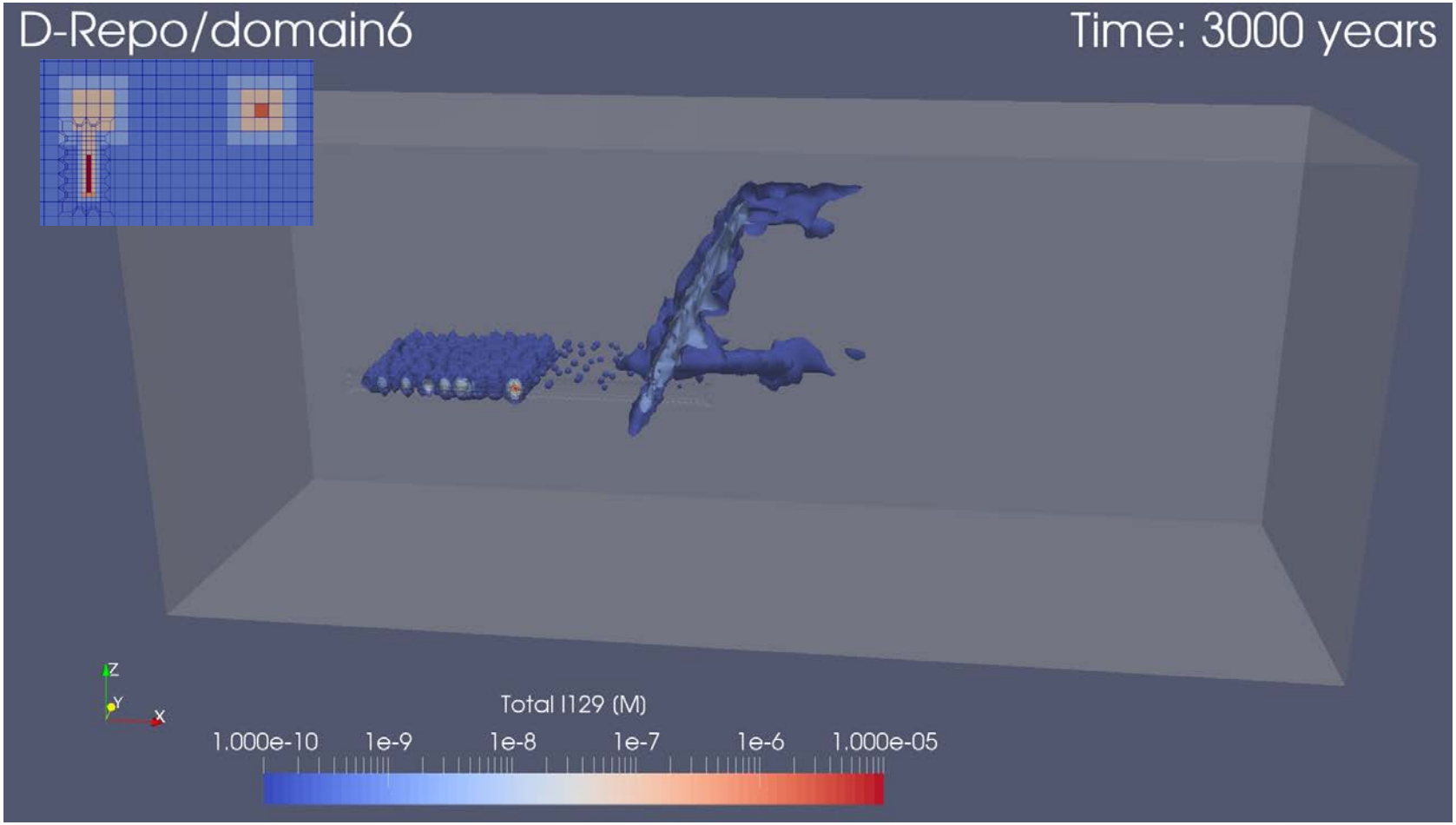
Deterministic Results: Darcy Flux



Deterministic Results: ^{129}I Concentration



Deterministic Results: ^{129}I Concentration



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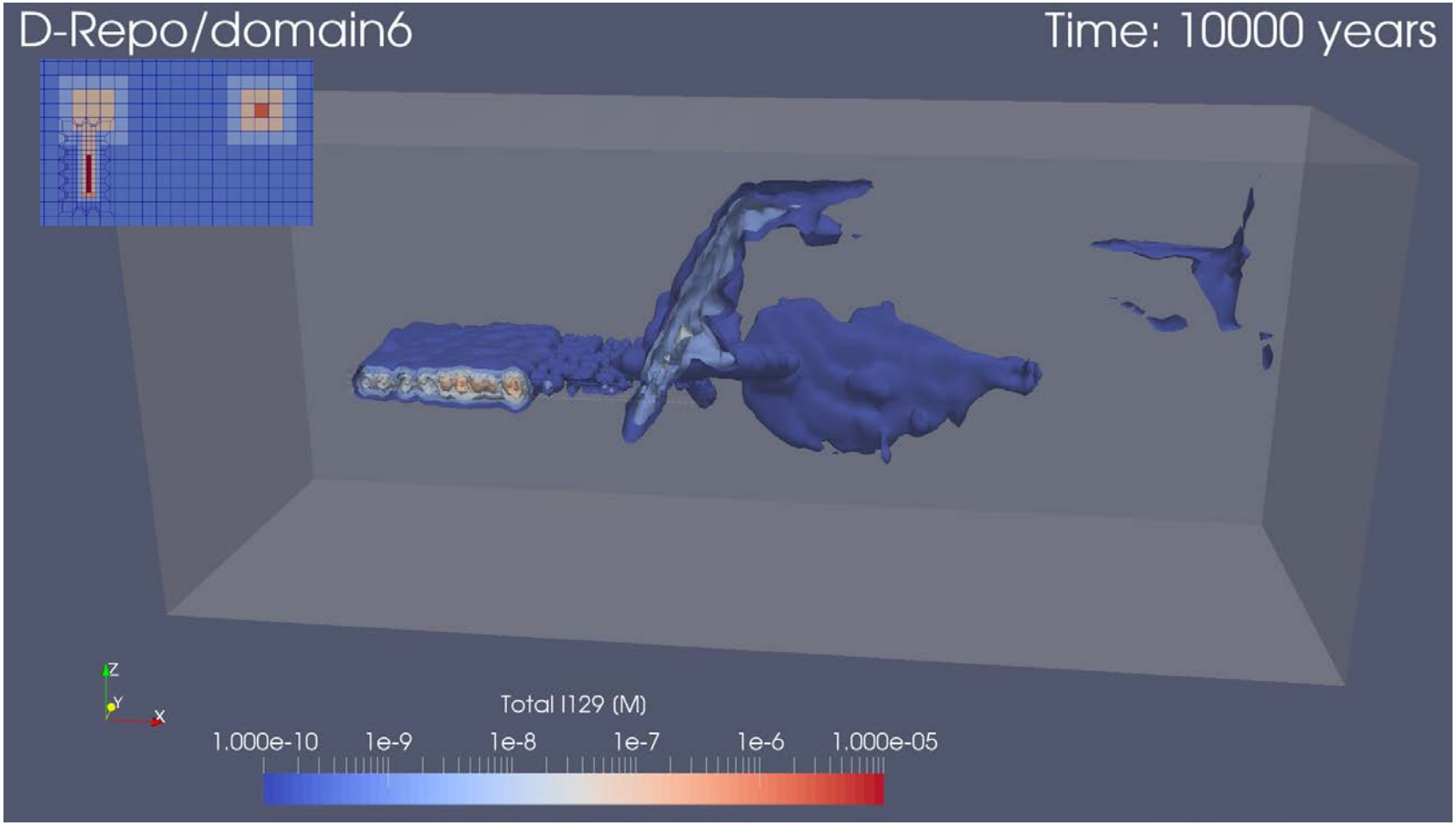
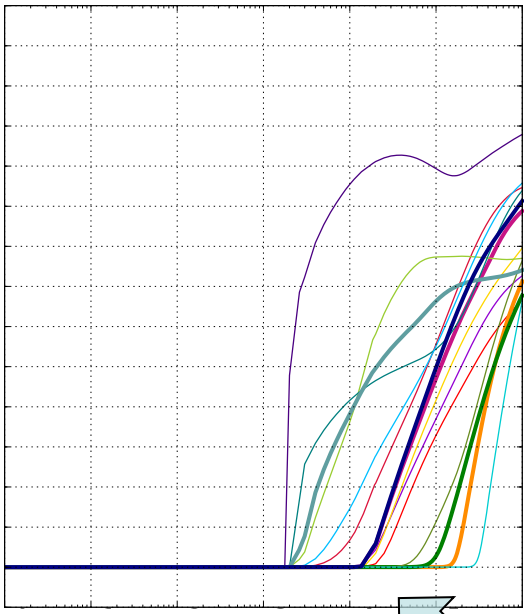
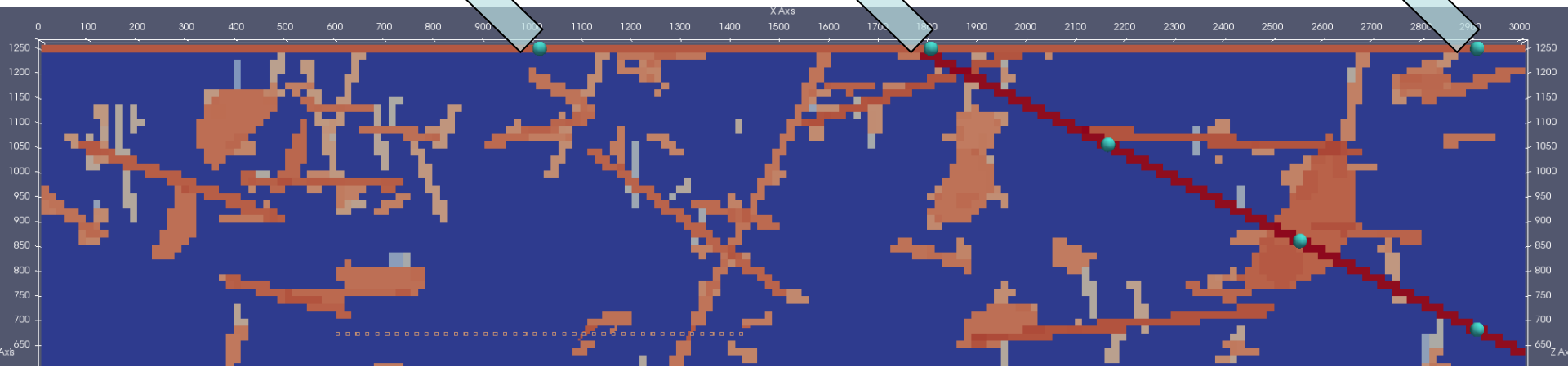


Uncertainty due to fracture realization





Probabilistic: Sampled Parameters

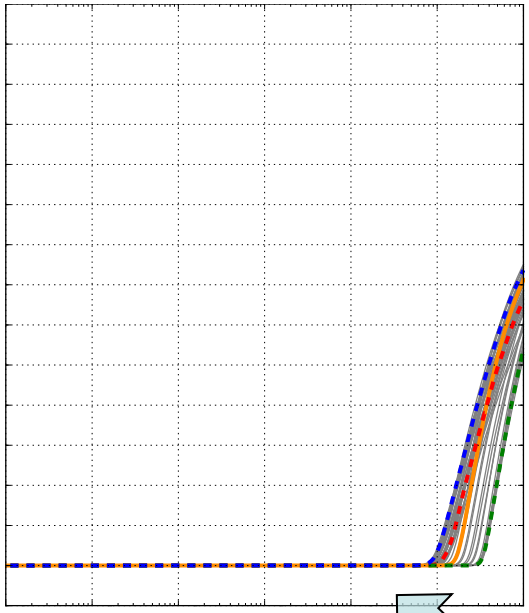
Parameter	Distribution	Lower Bound	Upper Bound
Glacial k (m^2)	Log uniform	10^{-16}	10^{-13}
Waste package tortuosity	Log uniform	0.01	1.0
Mean waste package degradation rate (1/yr)	Log uniform	$10^{-5.5}$	$10^{-4.5}$
DRZ porosity	Uniform	0.005	0.05
Buffer porosity	Uniform	0.1	0.4

Example of capability only!

Have yet to explore:

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

Probabilistic Results: Uncertainty due to sampled parameters



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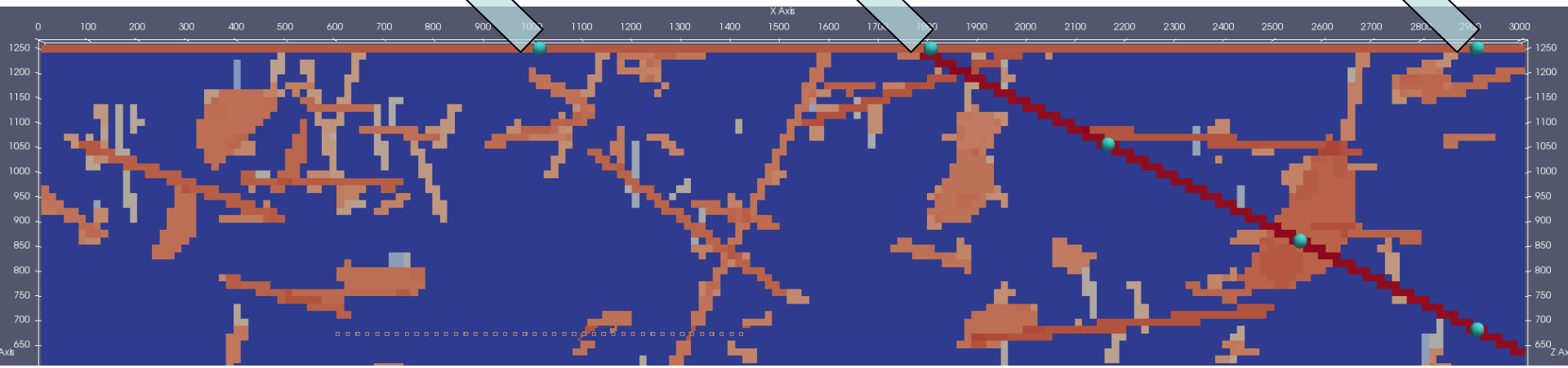
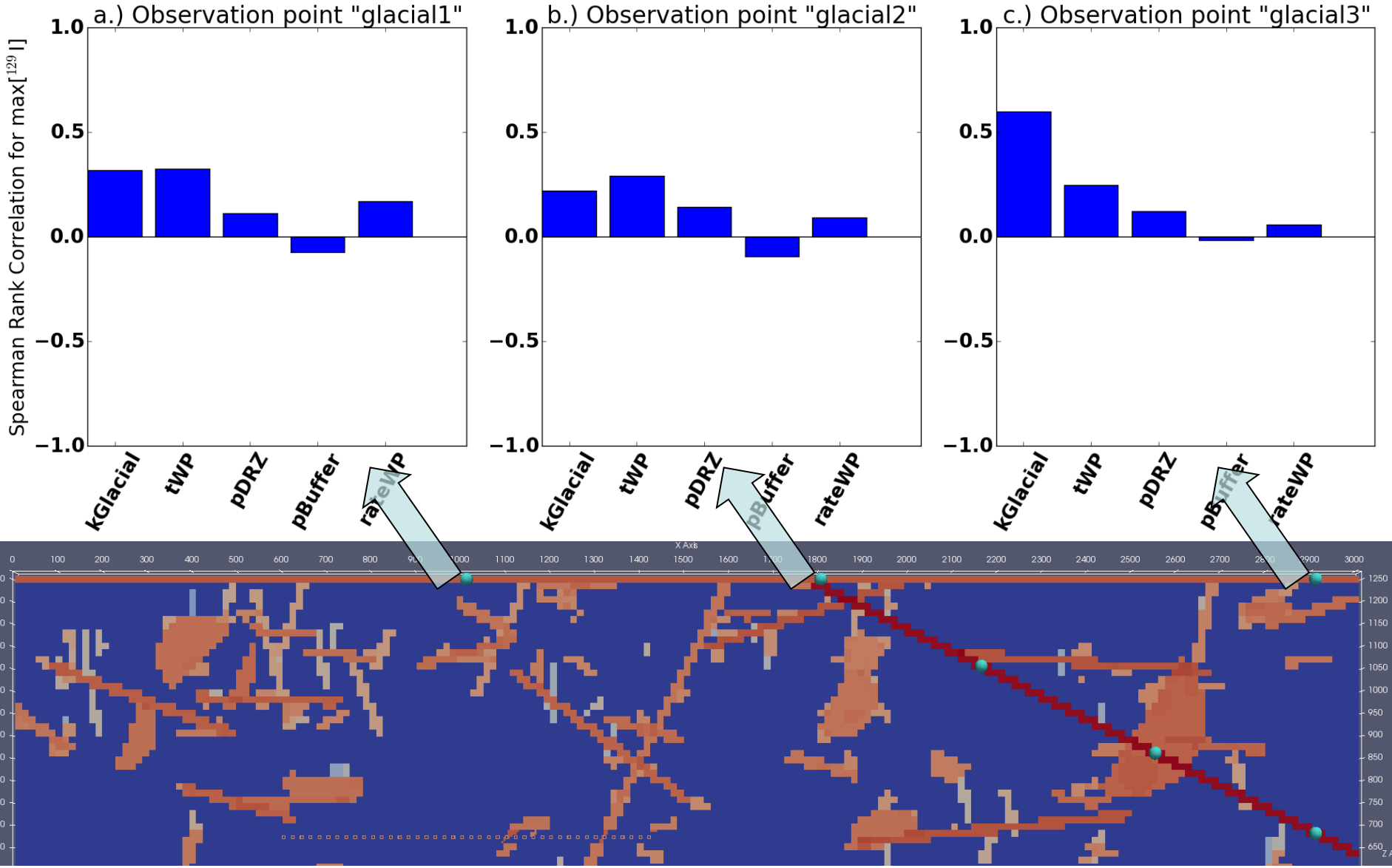
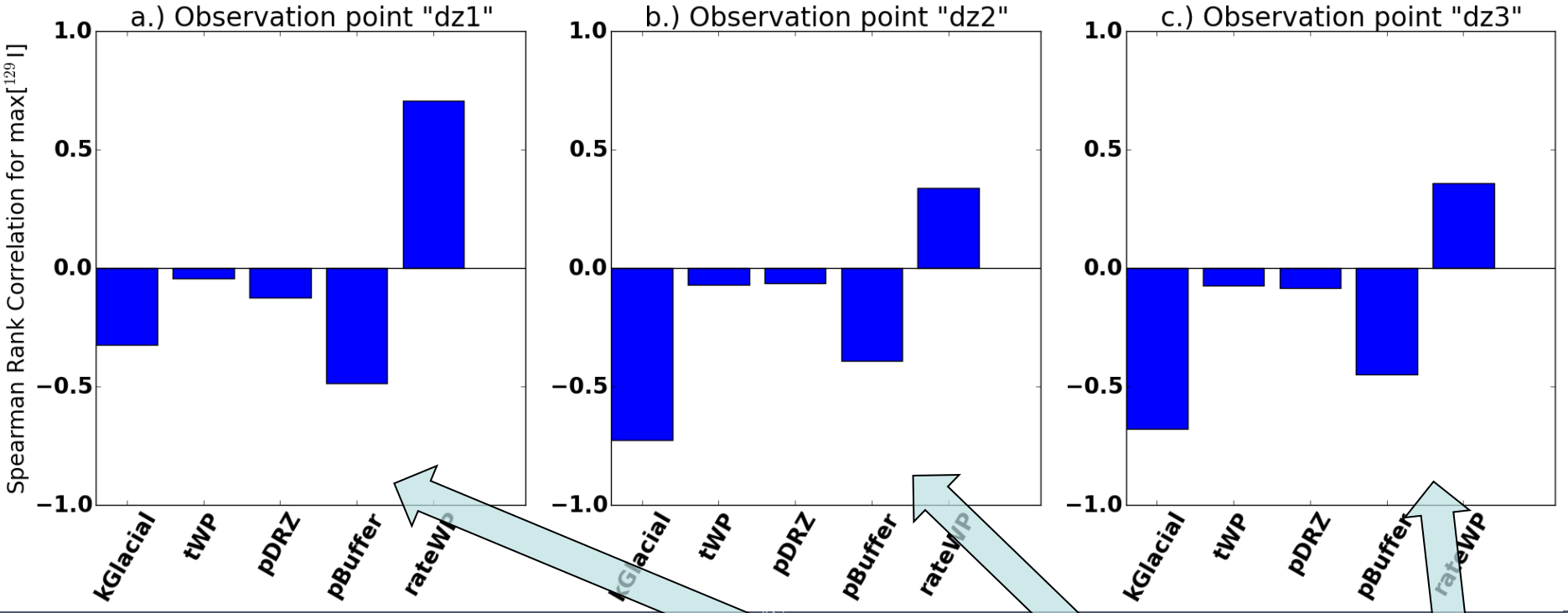


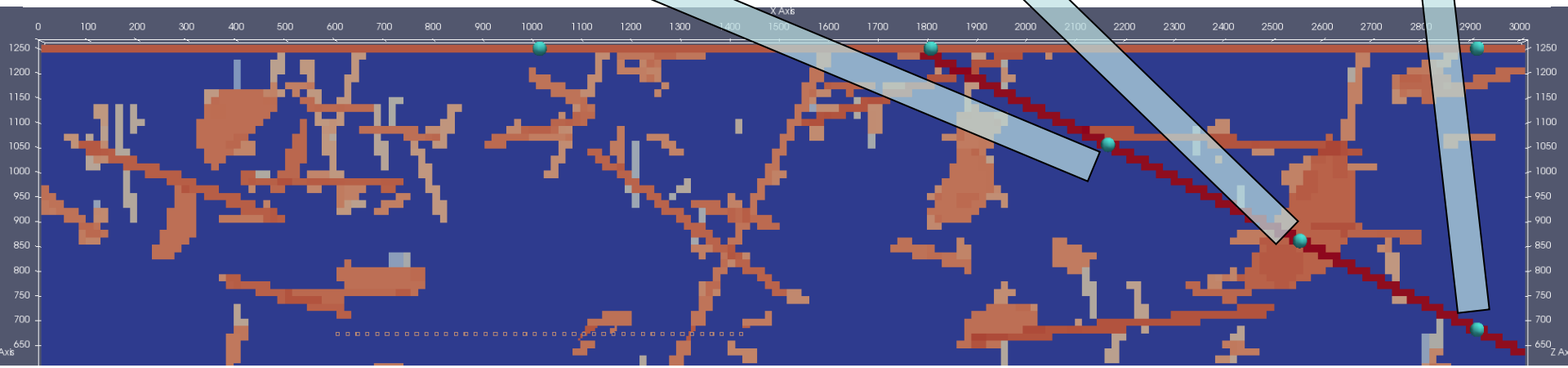
Probabilistic Results: Sensitivity



Used Fuel Disposition

Probabilistic Results: Sensitivity





Crystalline PA: R&D Future

How to ensure isolation in a fractured host rock?

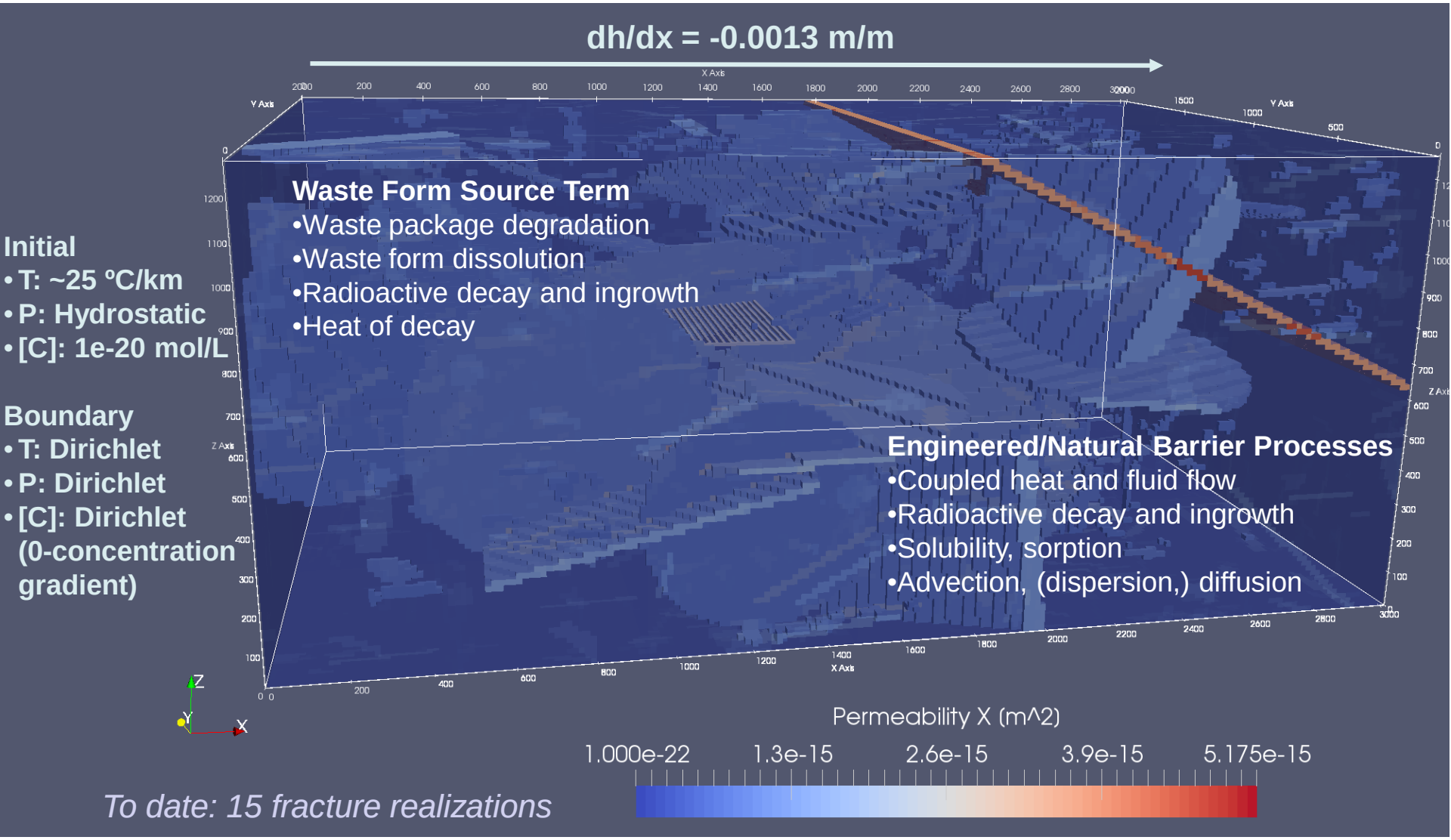
Generic Performance Assessment can identify:

- **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

Used Fuel Disposition

Setting up a simulation



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

Uncertainty due to fracture realization: Comparison to CSNF