# Used Fuel Disposition Campaign

## D-Repo Performance Assessment: Crystalline Reference Case

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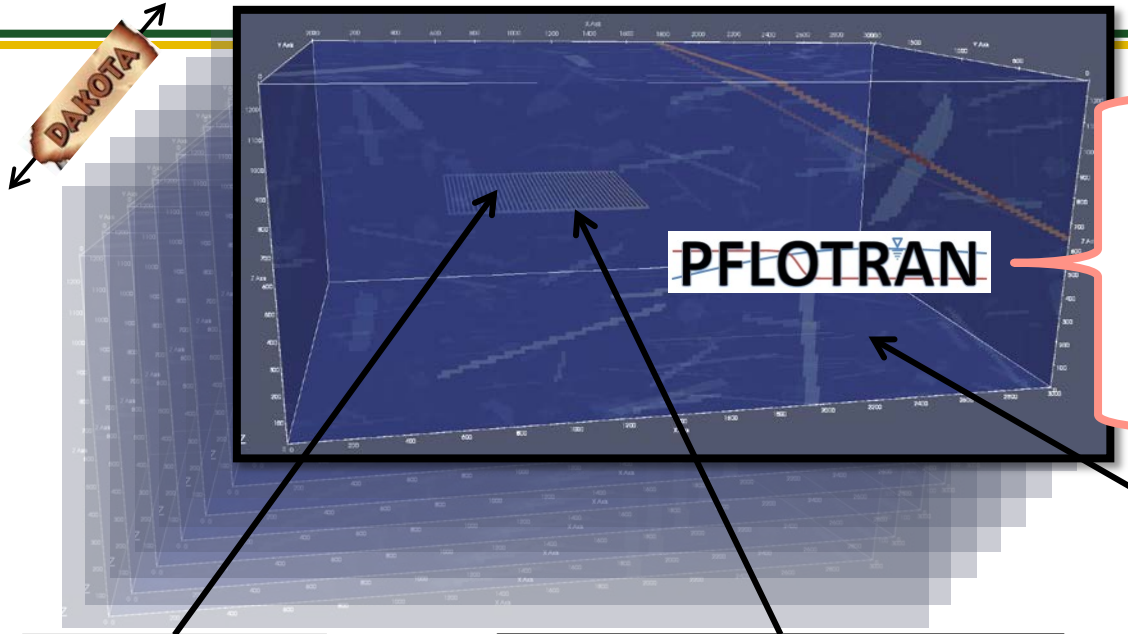
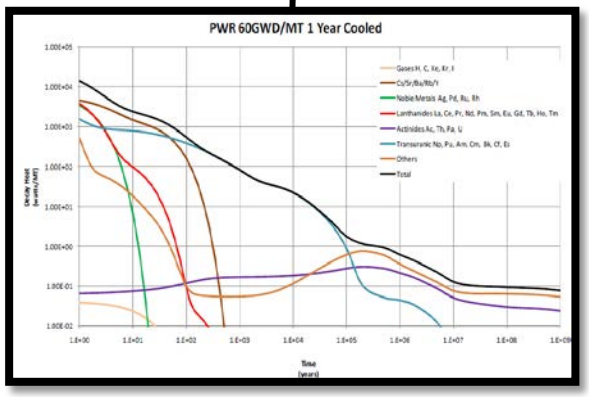
# Performance Assessment



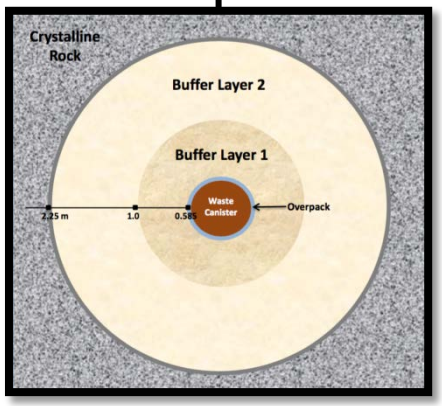

- Coupled heat and fluid flow
- Waste package degradation
- Waste form dissolution
- Radioactive decay and ingrowth
- Solubility, sorption
- Advection, dispersion, diffusion

*Waste Forms*



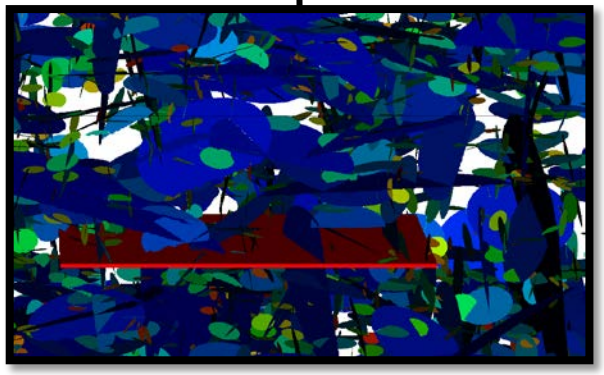

**SRNL Inventory**

*Engineered Barrier System*




**SNL EBS Concepts**

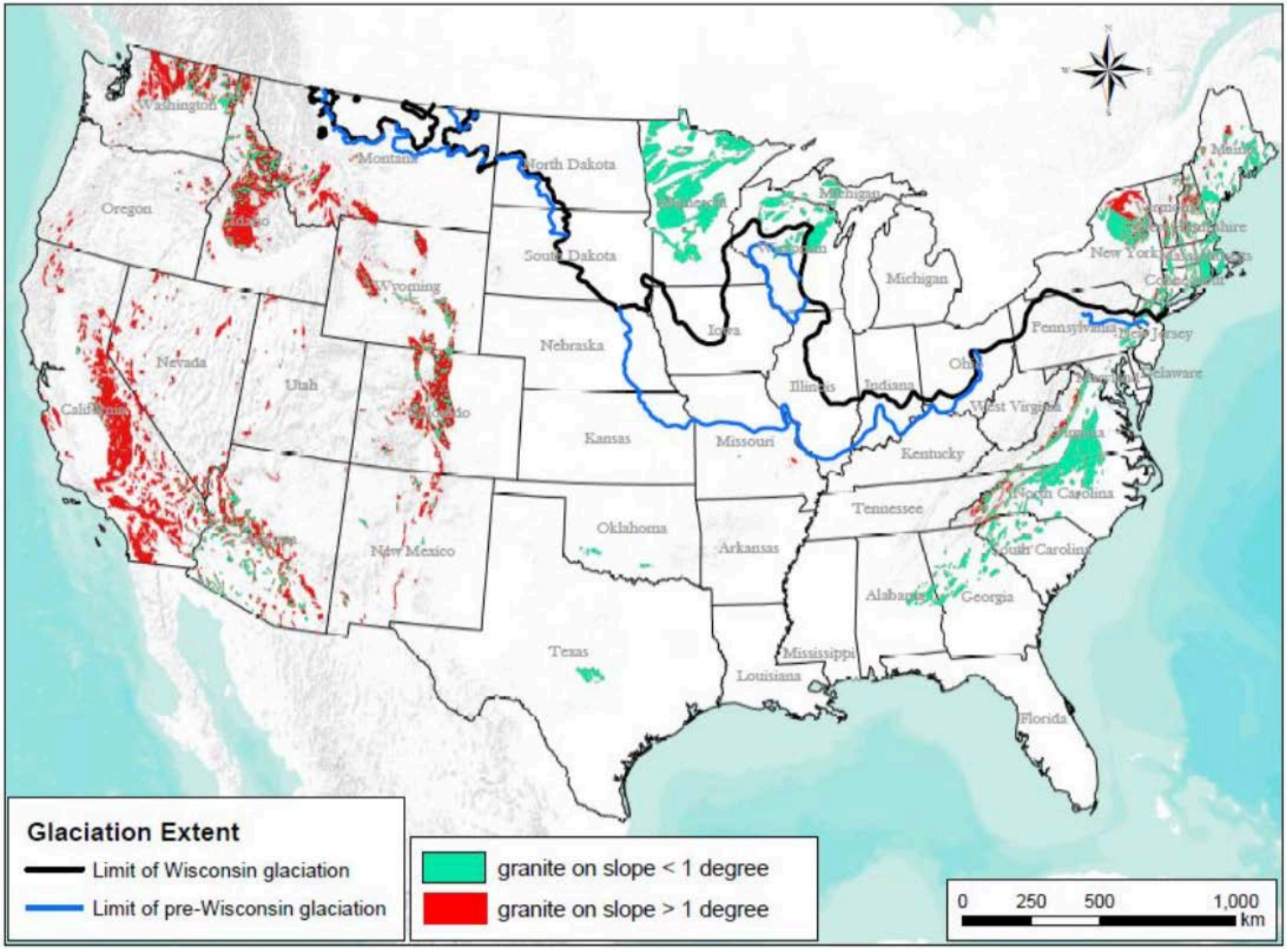
*Natural Barrier System*



**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

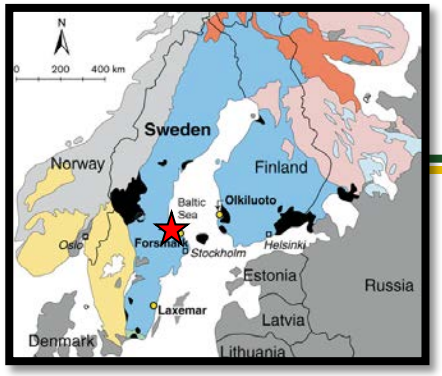
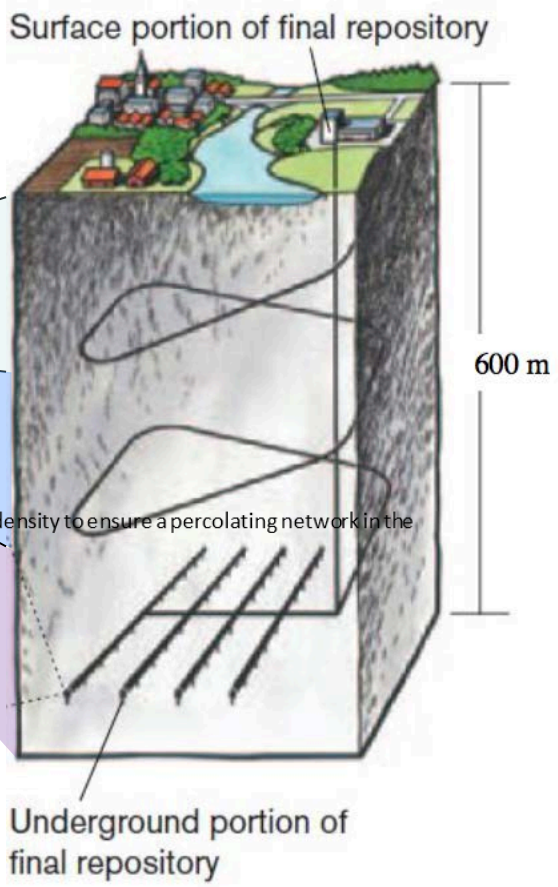



**Table 2** Hydrogeological DFN parameters for each fracture domain, fracture set and depth zone

| 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 ($a$,$b$,$\sigma$) | Correlated ($a$,$b$) | Uncorrelated ($\mu$,$\sigma$) |
|---|---|---|---|---|---|---|---|
| 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.

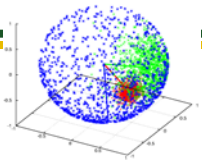
*Joyce et al., Hydrogeology Journal (2014) 22:1233-1249*

Used Fuel Disposition

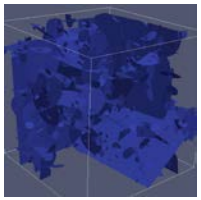
# Natural Barrier System

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

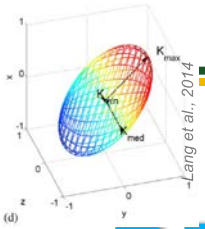
$b=(12T\mu/\rho g)^{1/3}$



**DFNWorks**

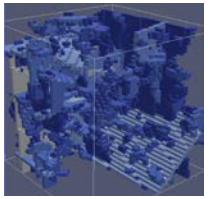


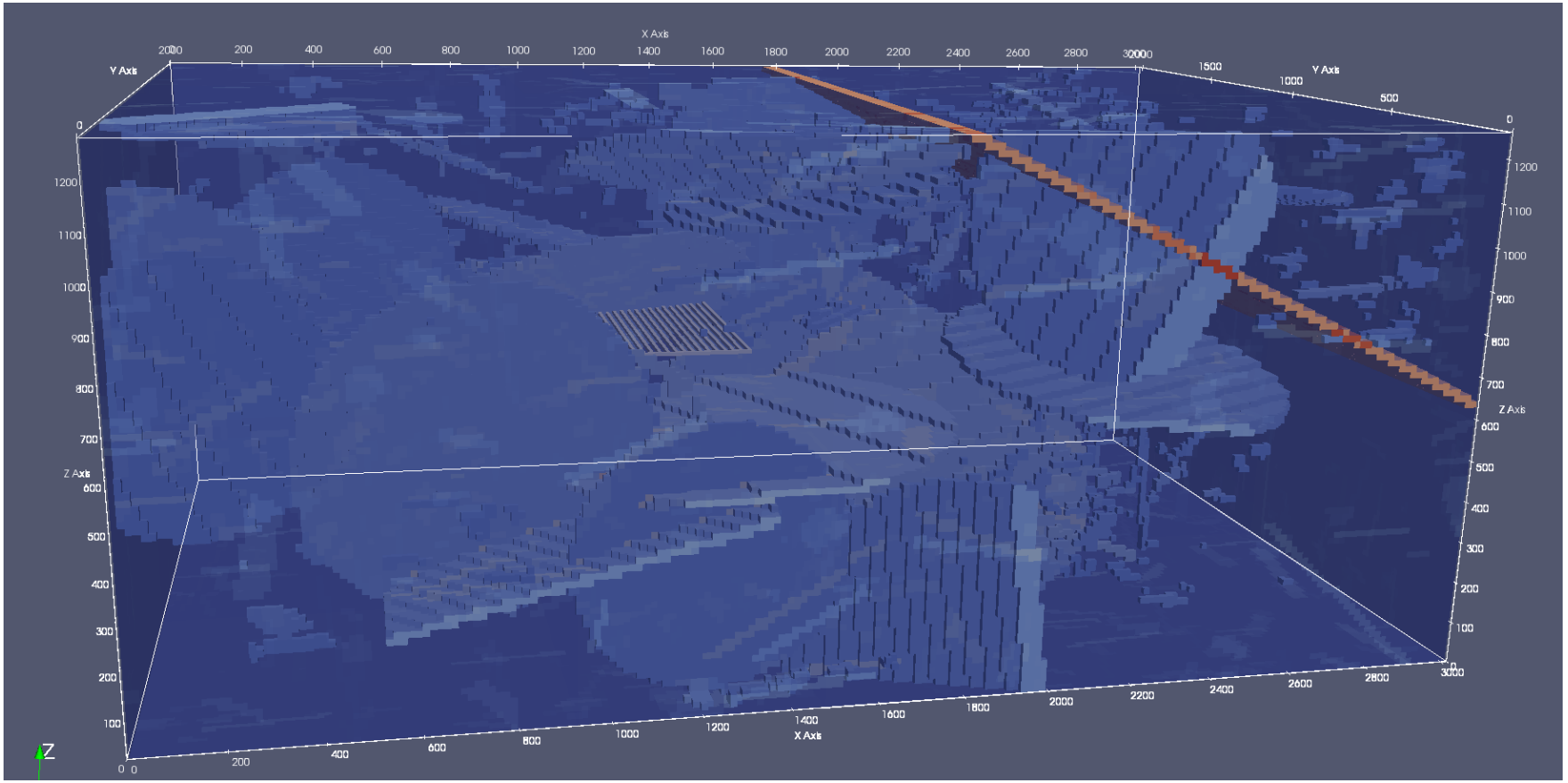
$\phi = V_f/V_{cell}$



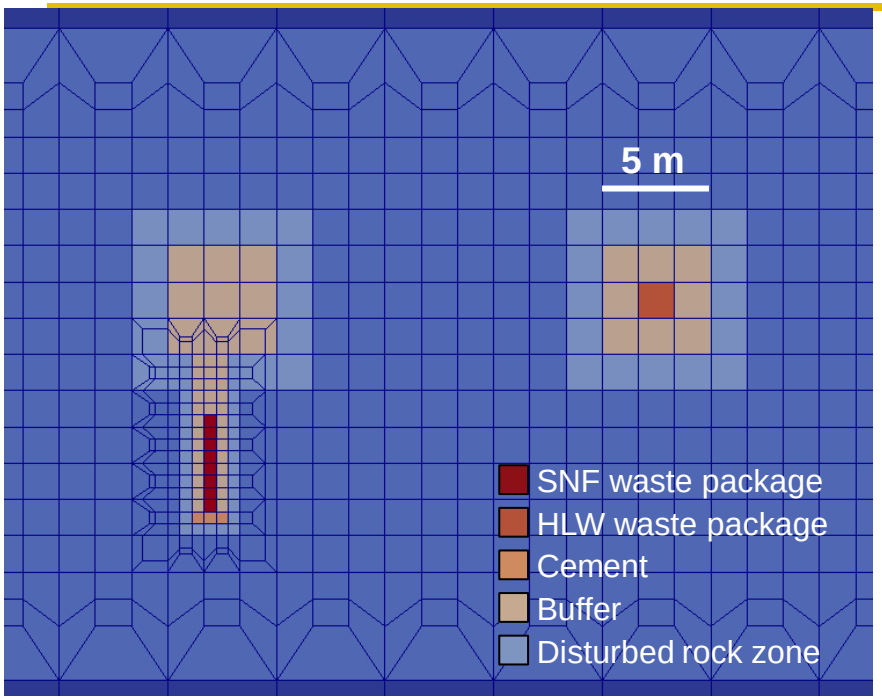

$k = T\rho g/\mu b$

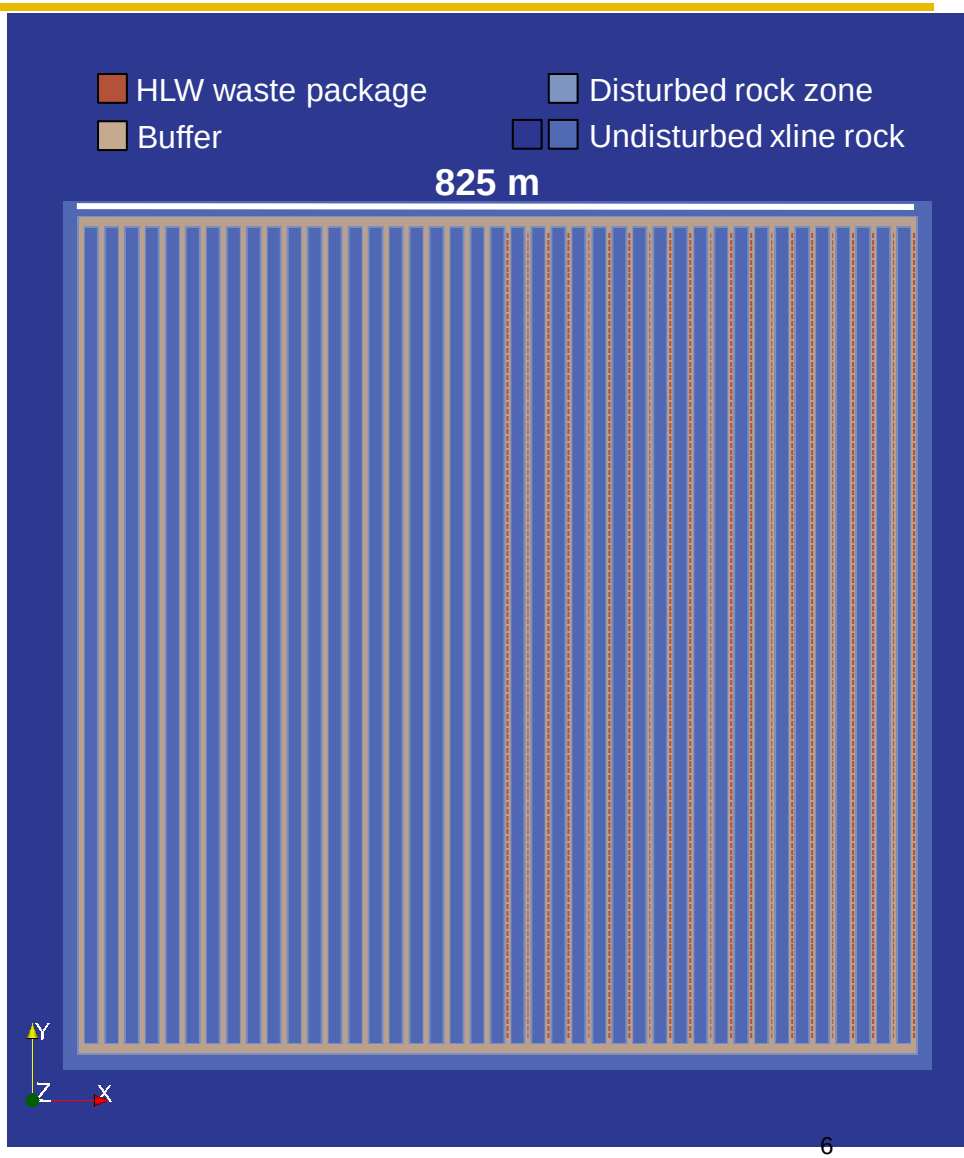
**mapDFN**





# 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.*

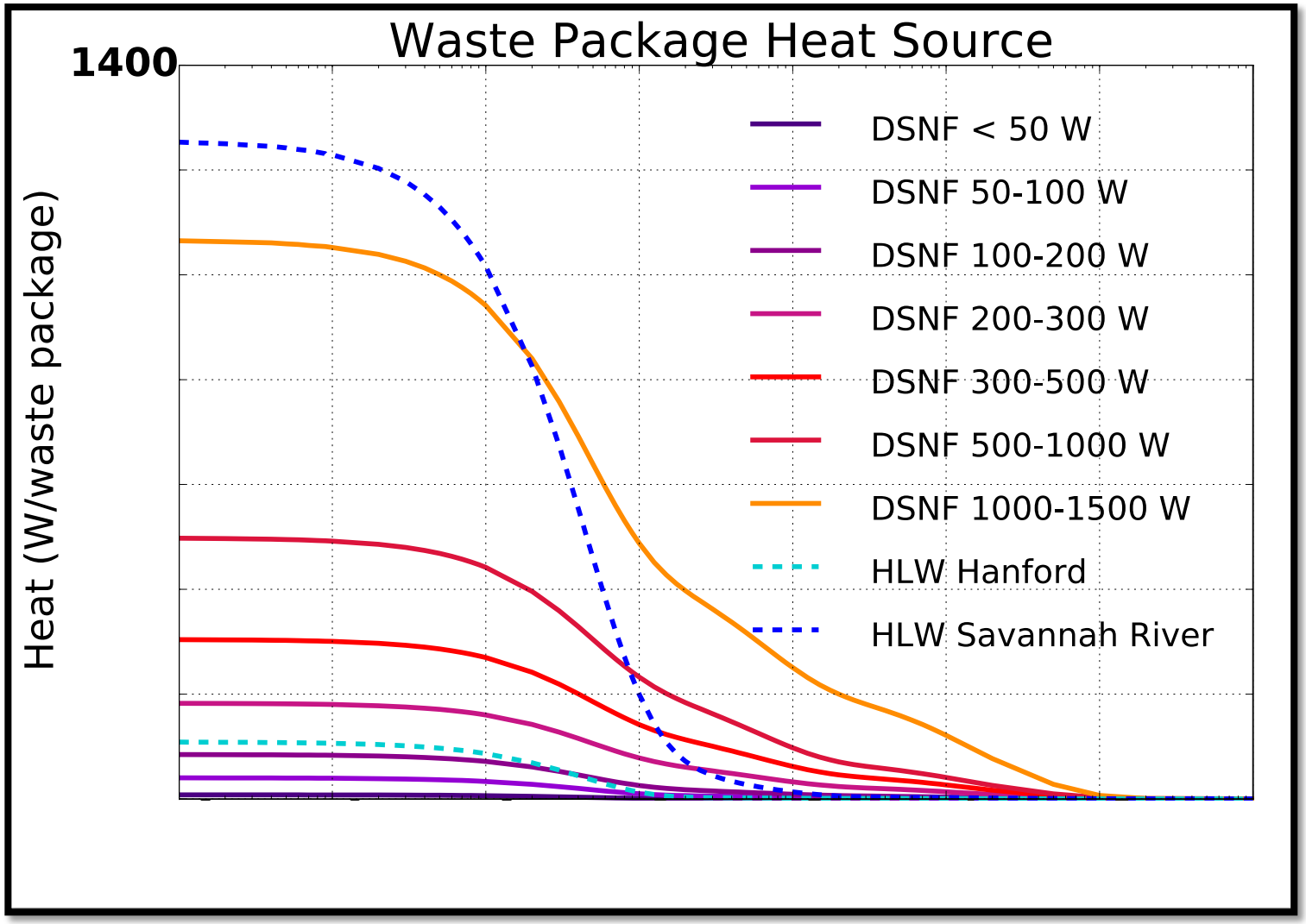
## Selected glass HLW

| | **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.**

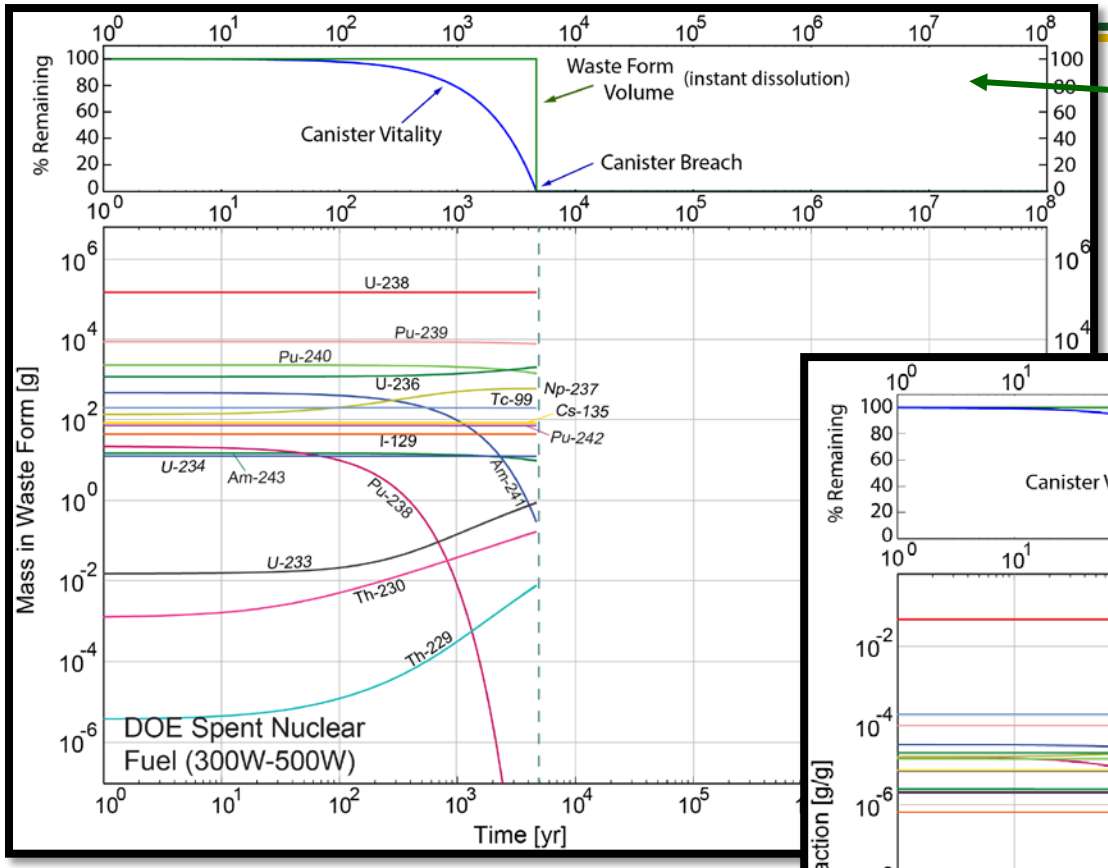
*Projected Inventories from Carter et al., 2013 and Wilson, 2016.*

# Waste Inventory in 2038

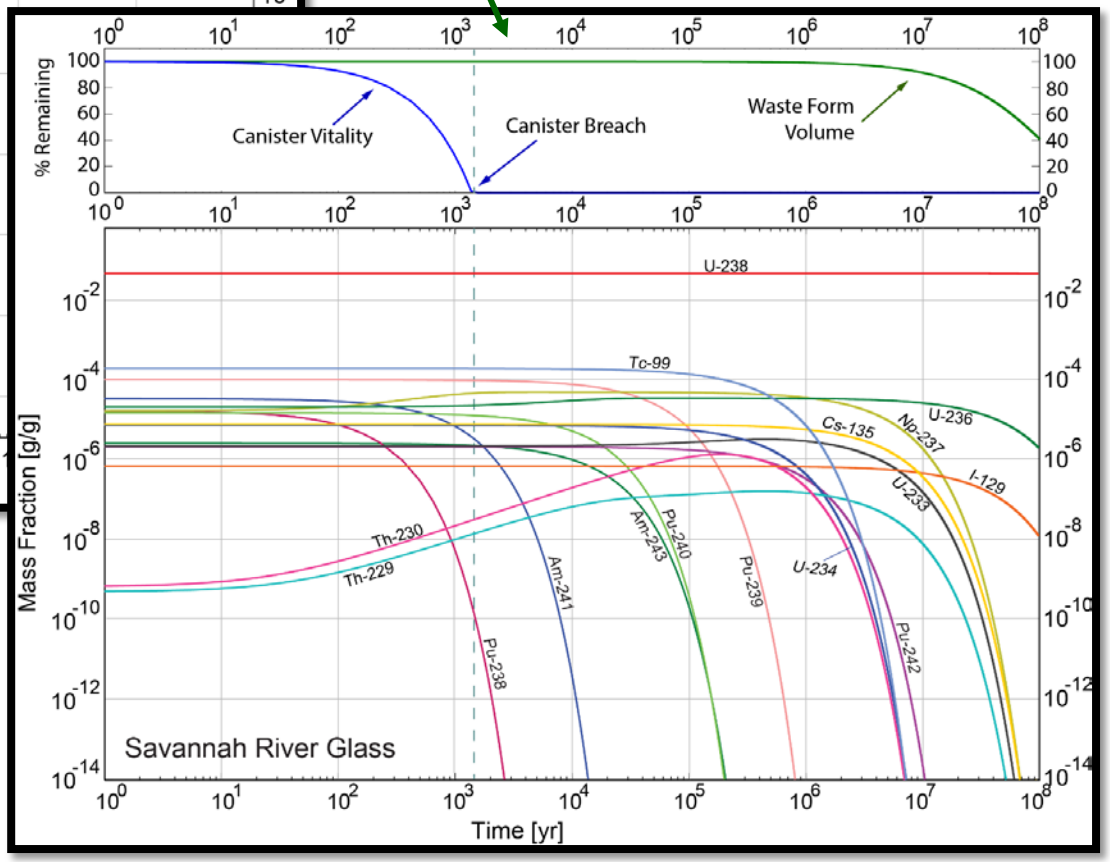


Used Fuel Disposition

# Waste Inventory in 2038

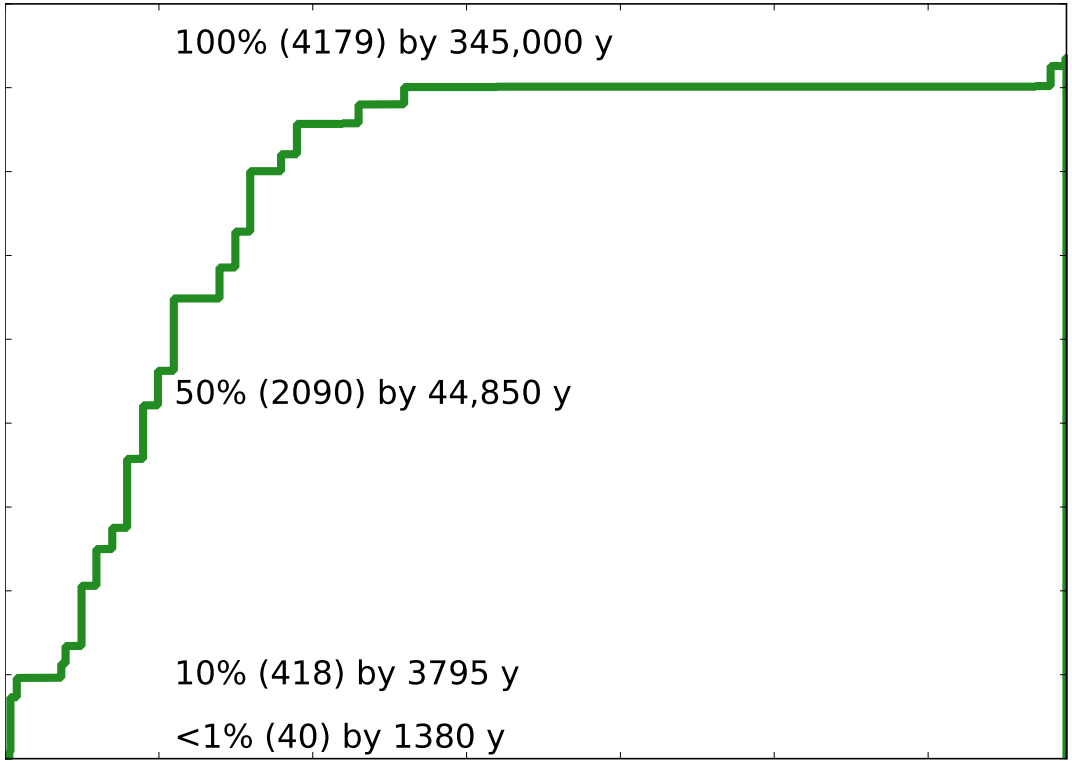



- Instantaneous DSNF dissolution
- Triangular distribution on HLW dissolution rate; f(T)

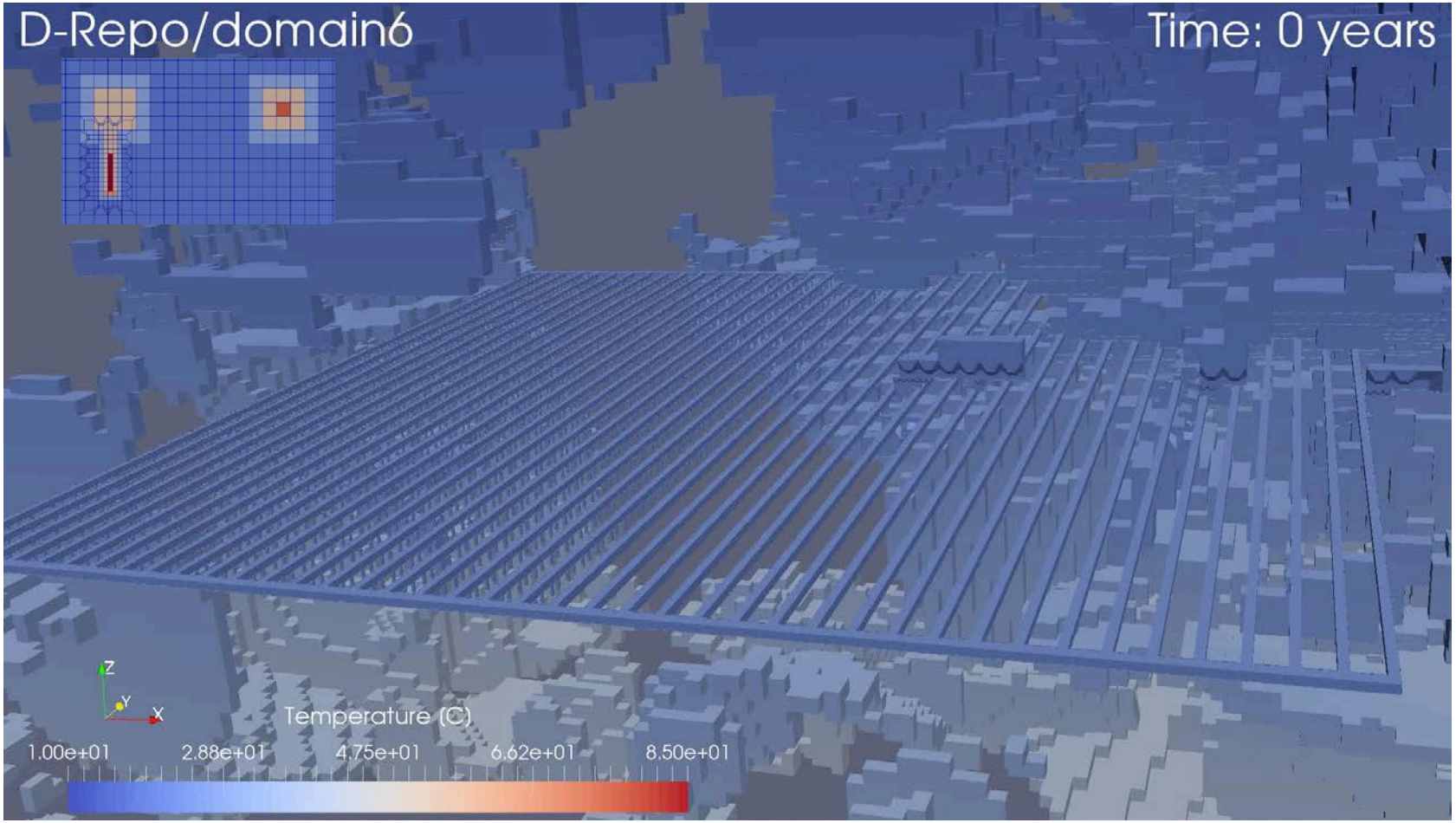



- Log normal distribution on canister degradation rate; f(T)

# Deterministic Results: Waste Package Breach



# Deterministic Results: Temperature



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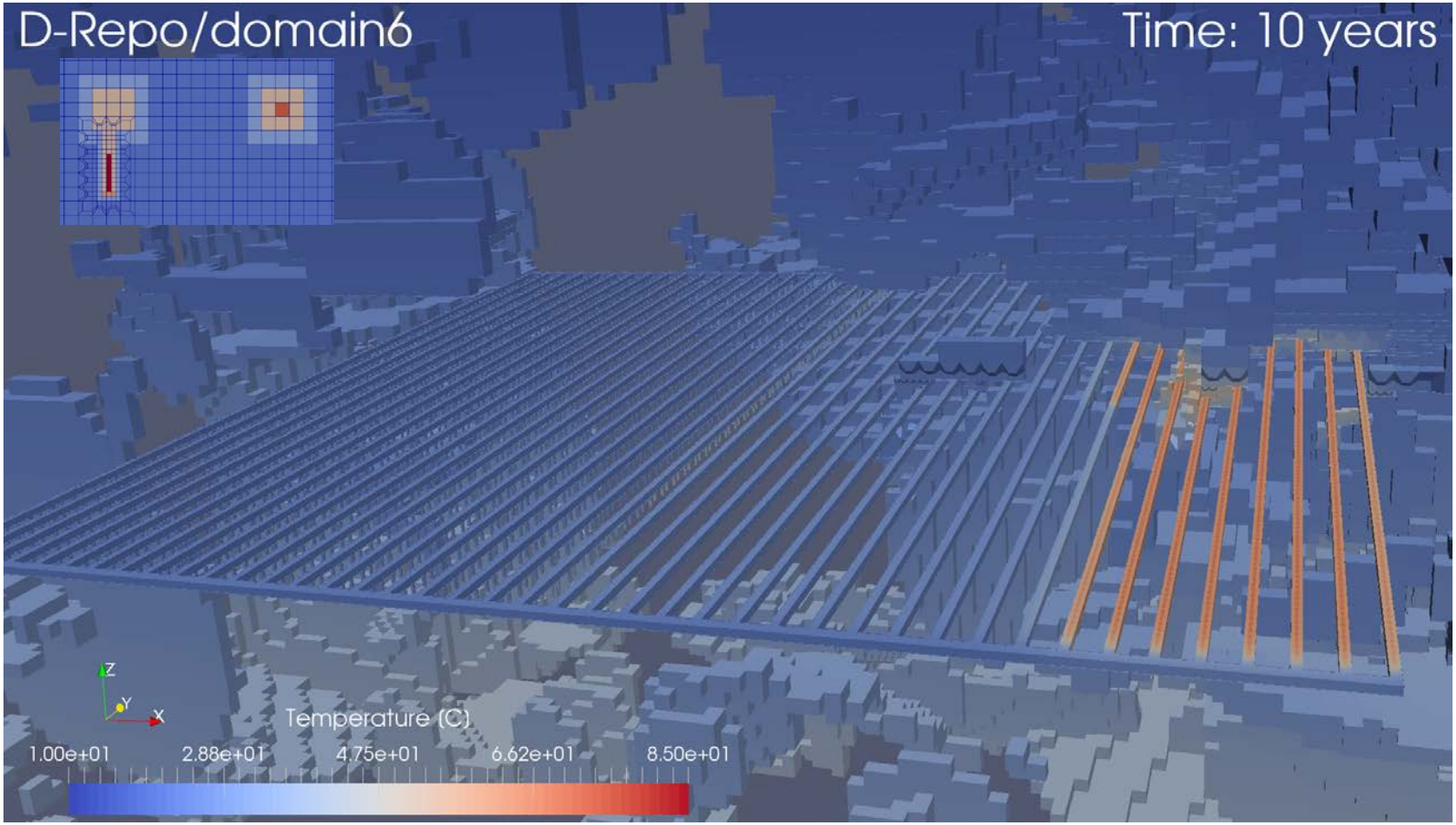
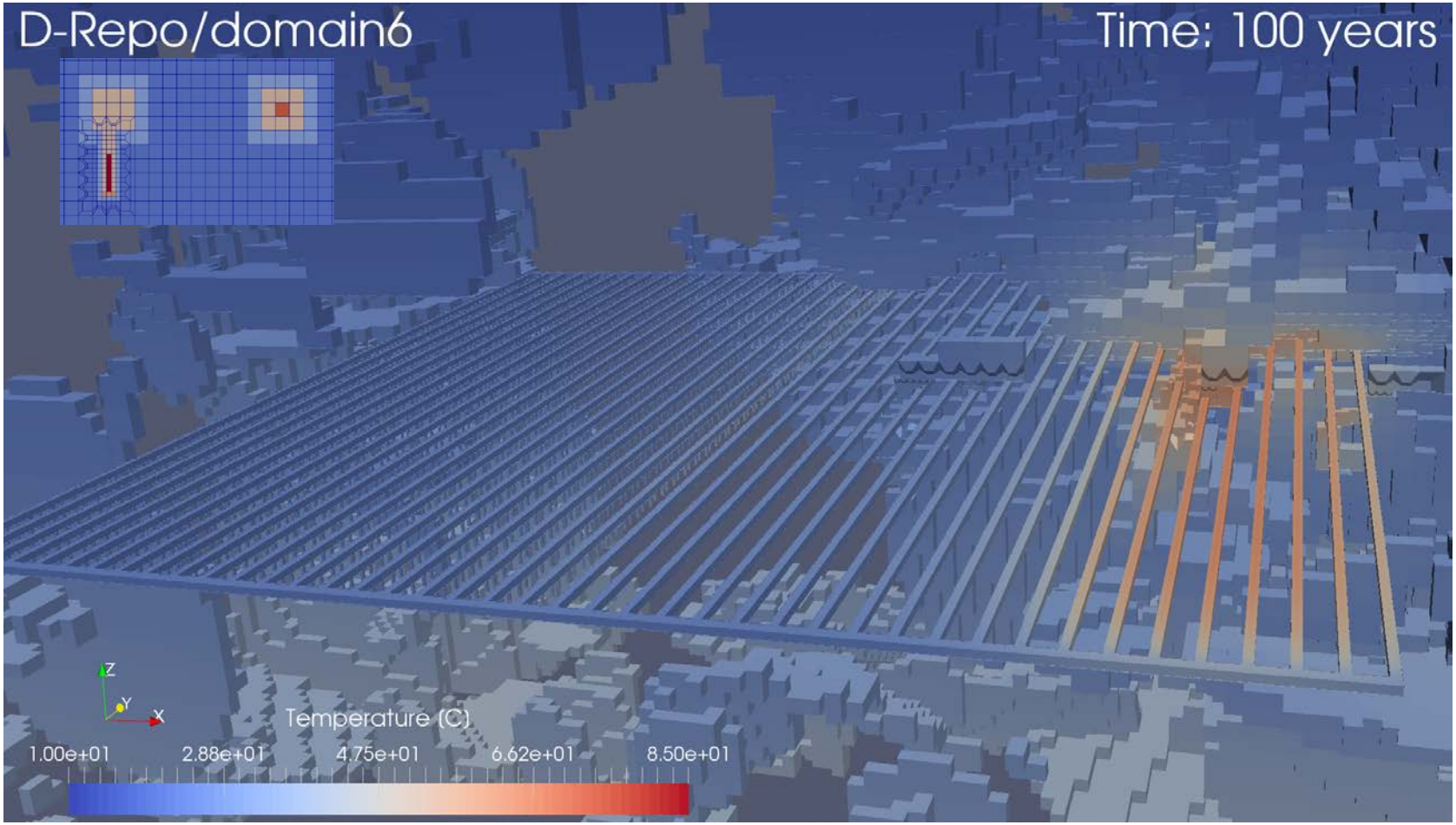
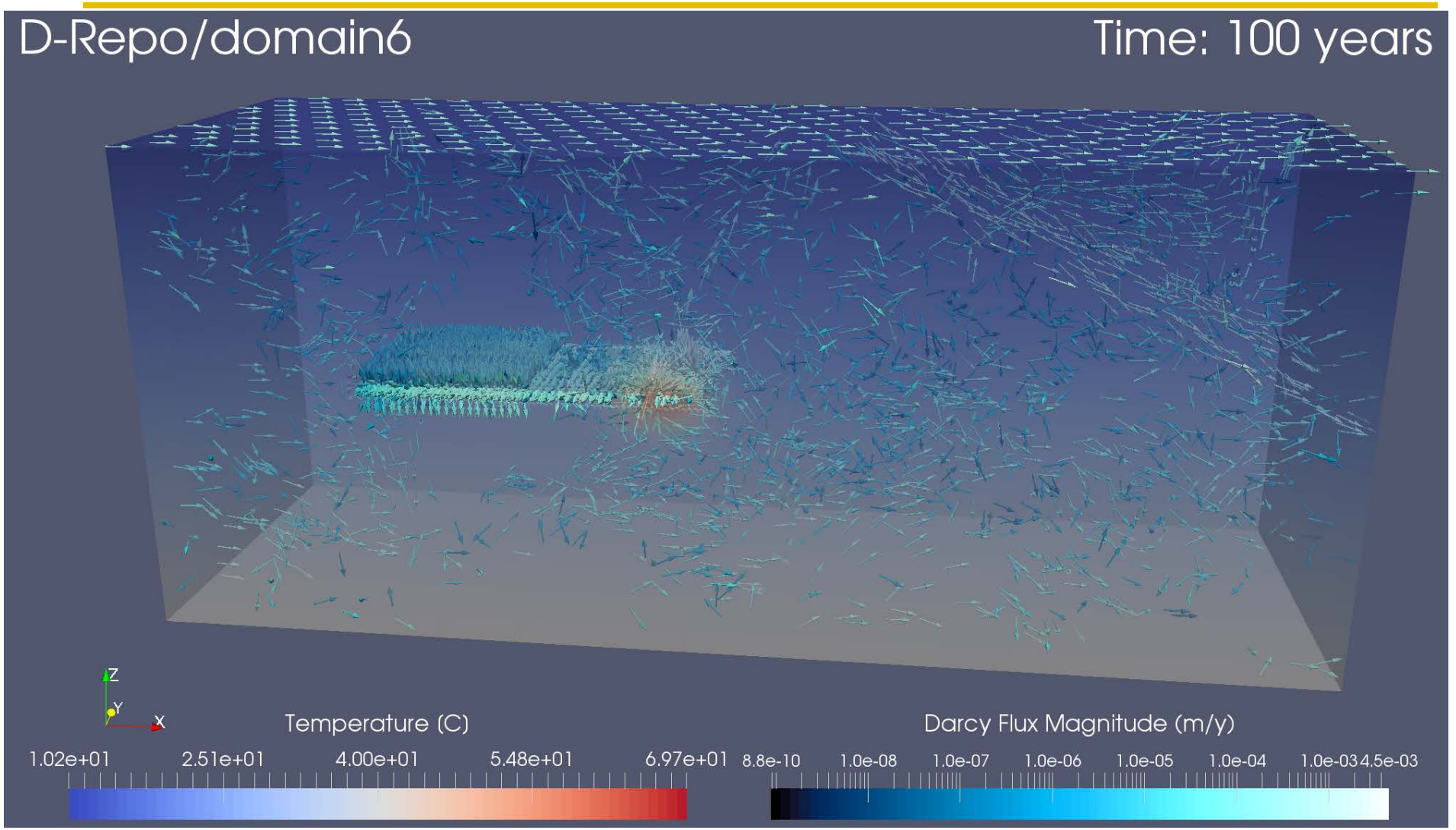


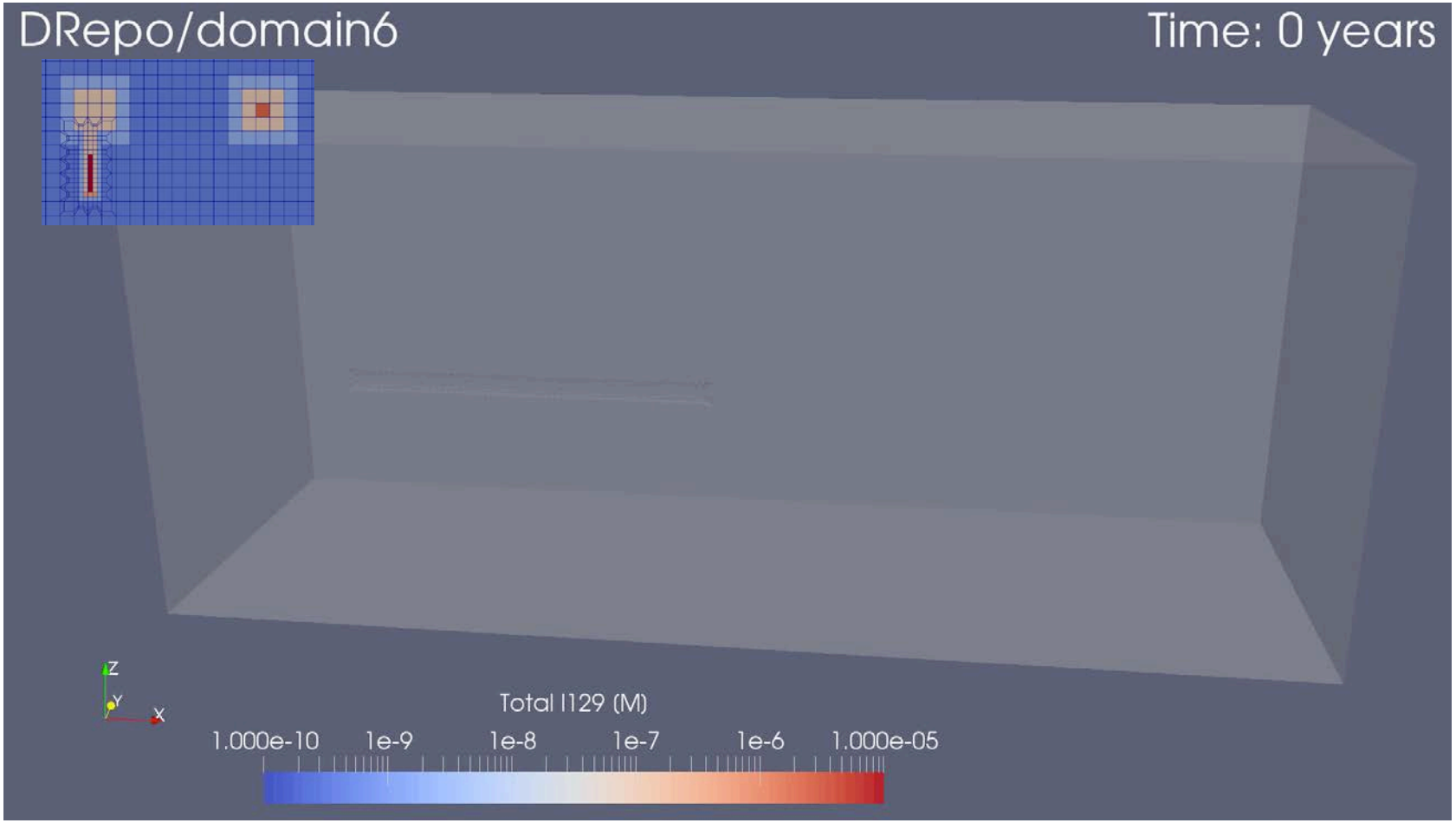
# Deterministic Results: Temperature



# Deterministic Results: Darcy Flux



# Deterministic Results: $^{129}I$ Concentration



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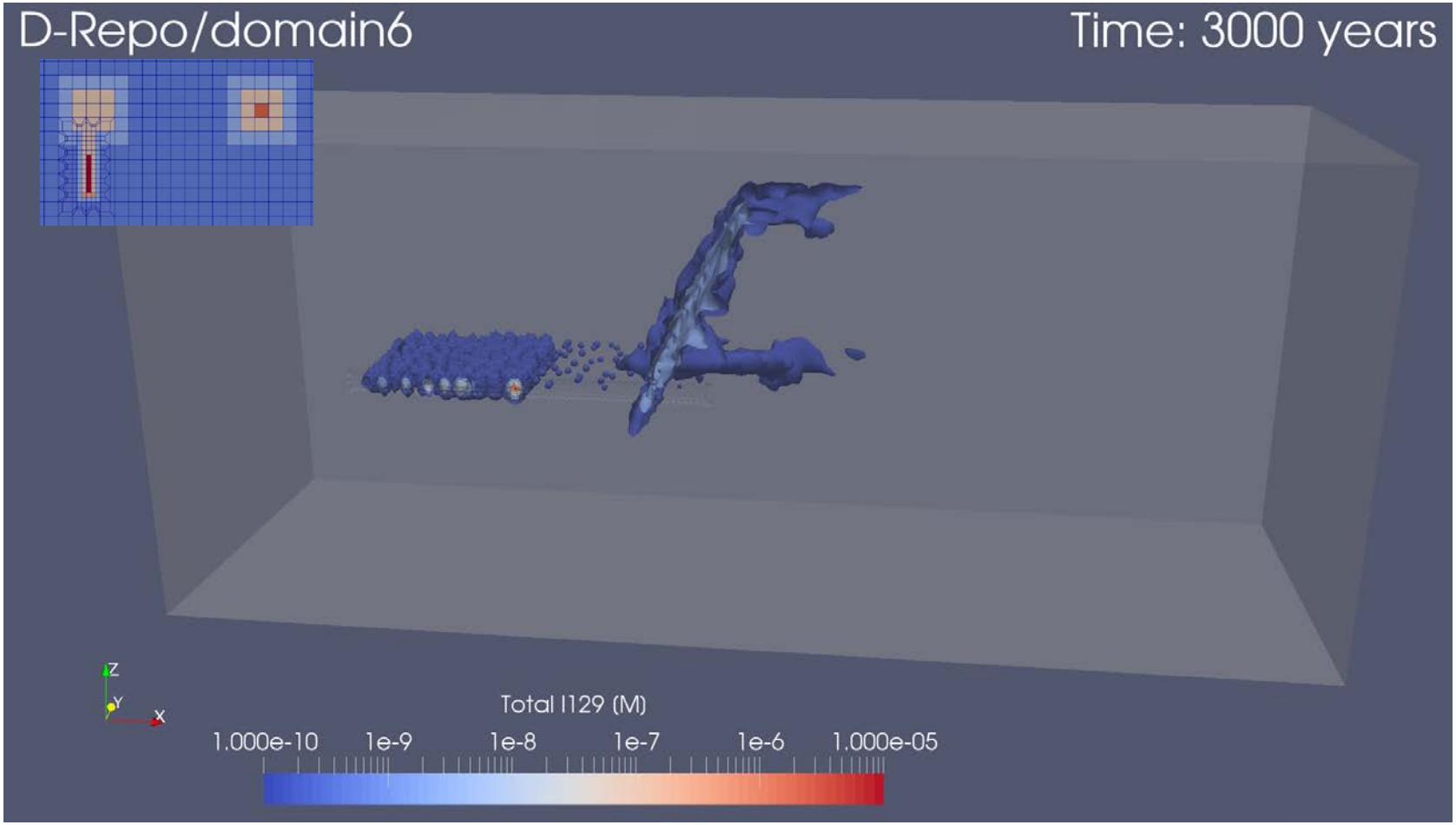

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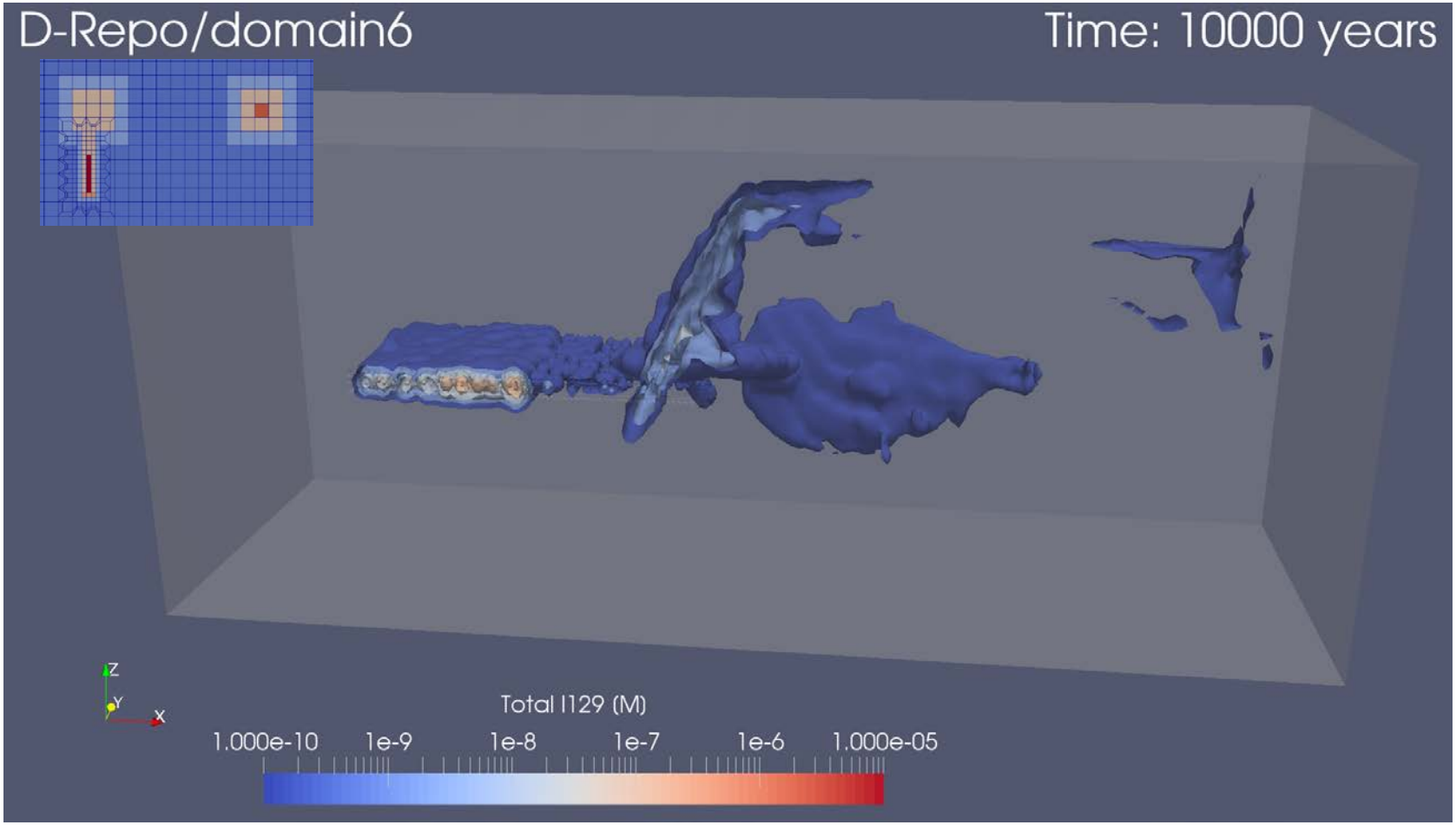
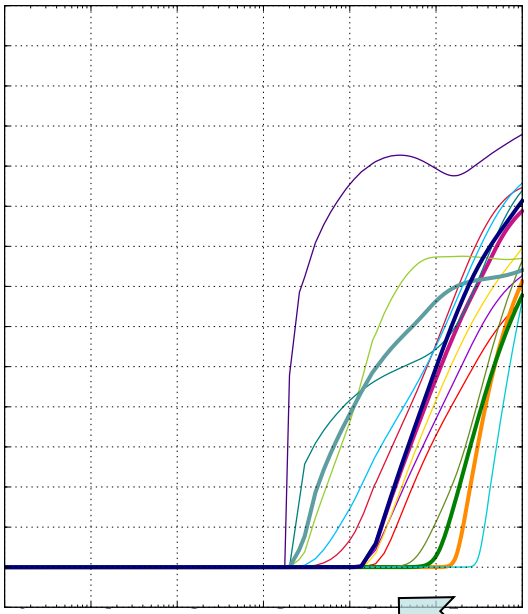
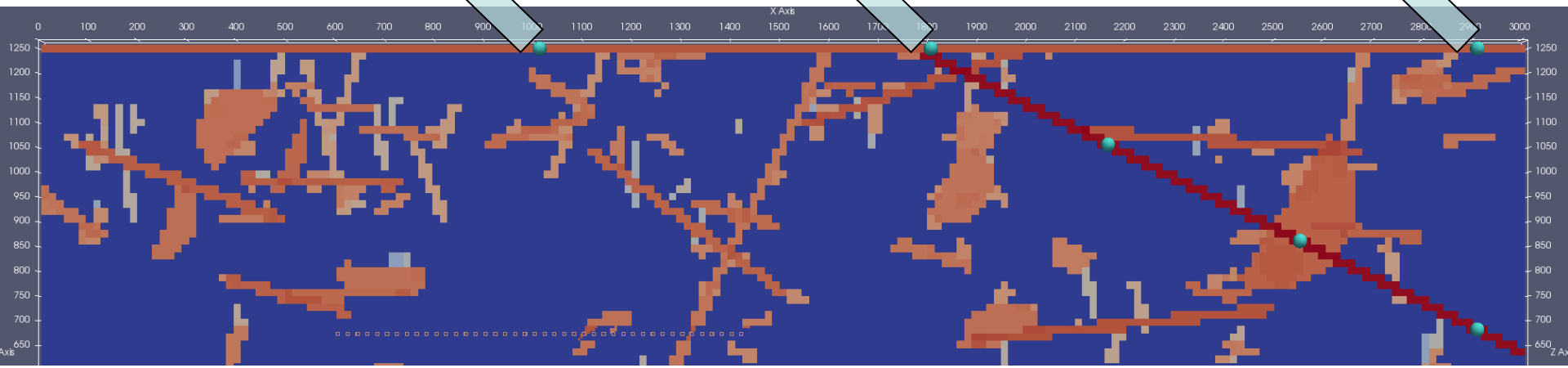


# Uncertainty due to fracture realization





# Probabilistic: Sampled Parameters

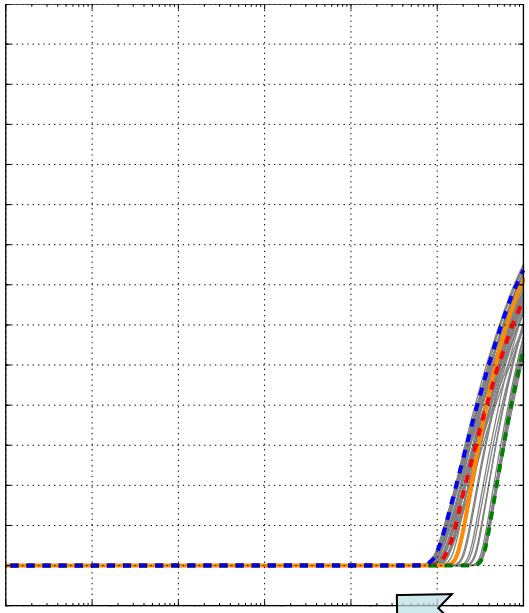
| Parameter | Distribution | Lower Bound | Upper Bound |
|---|---|---|---|
| Glacial k ($m^2$) | Log uniform | $10^{-16}$ | $10^{-13}$ |
| Waste package tortuosity | Log uniform | 0.01 | 1.0 |
| Mean waste package degradation rate (1/yr) | Log uniform | $10^{-5.5}$ | $10^{-4.5}$ |
| DRZ porosity | Uniform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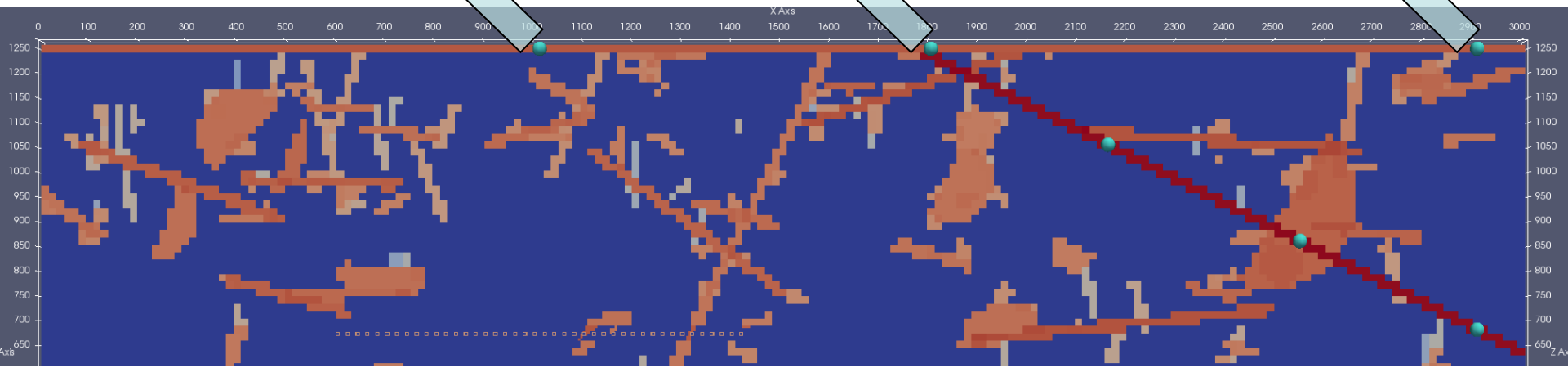
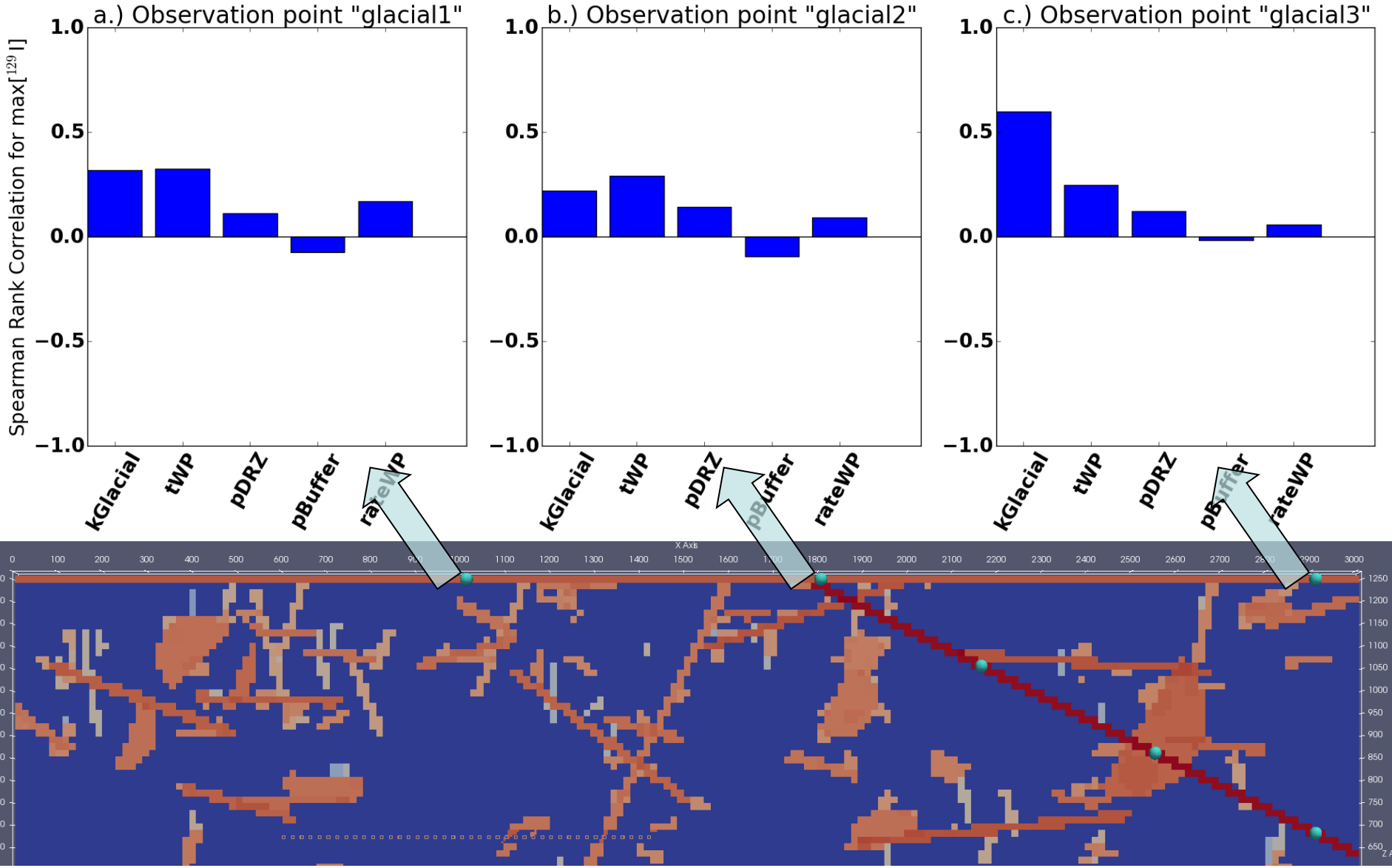
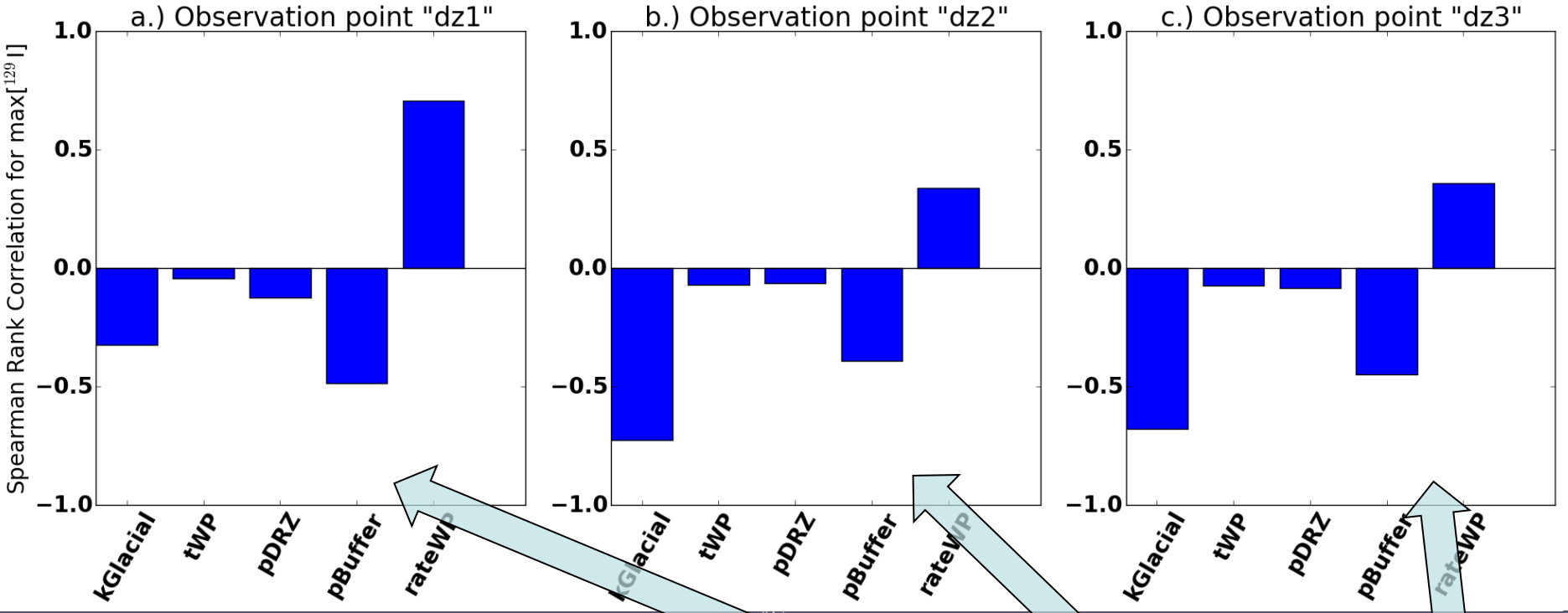


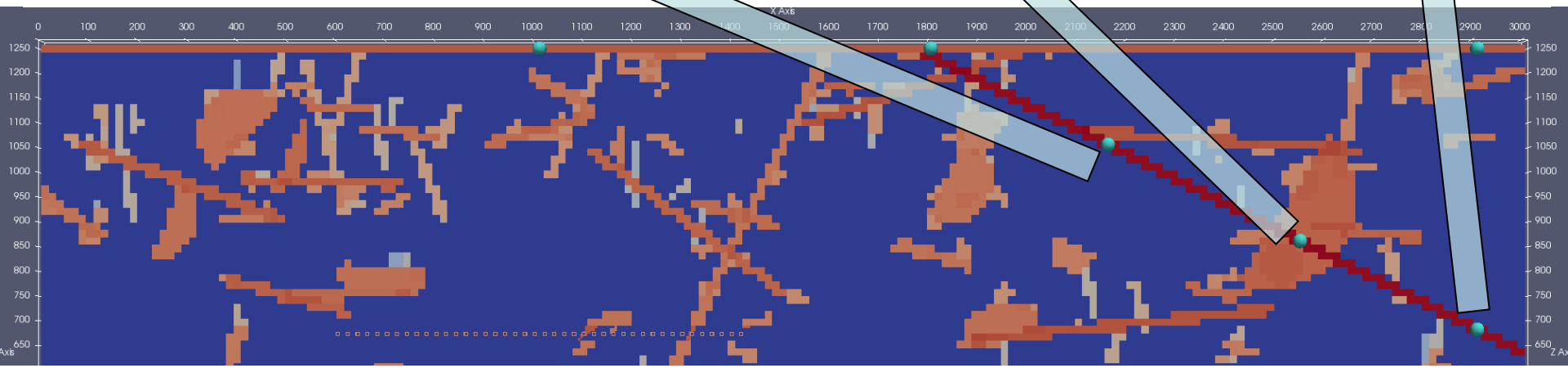
# Probabilistic Results: Sensitivity



# Used Fuel Disposition

# Probabilistic Results: Sensitivity



# Crystalline PA: R&D Future

## *How to ensure isolation in a fractured host rock?*

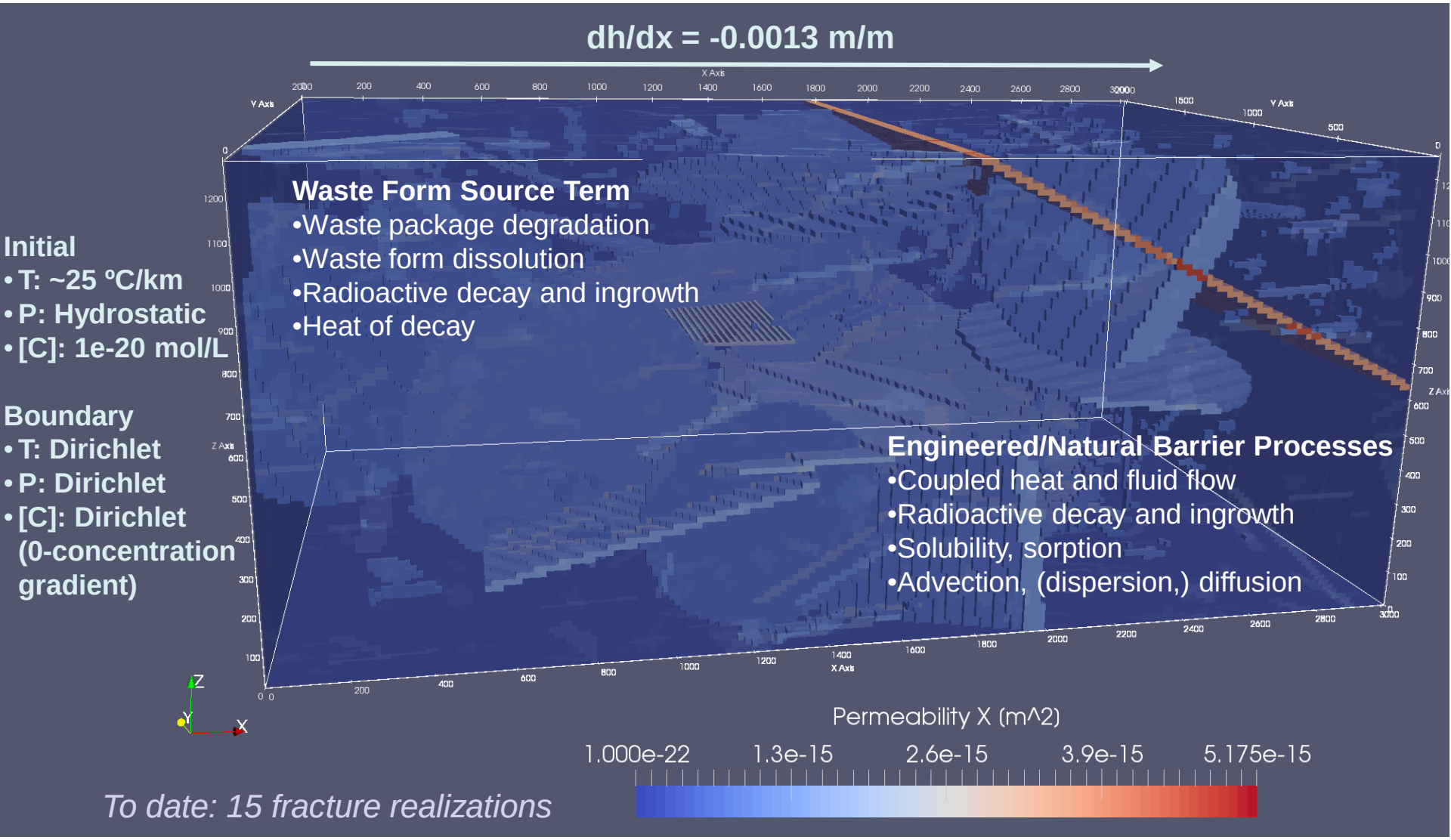
### *Generic Performance Assessment can identify:*

- **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