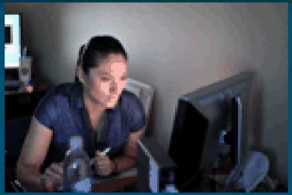
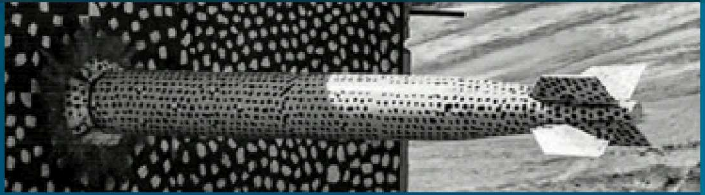
SAND2020-3043C

Generic Post-Closure Performance Assessment for Deep Borehole Disposal of Heat-Generating Waste





PRESENTED BY

Emily Stein and Geoff Freeze

WM2020 Symposia
Phoenix, Arizona
March 12, 2020

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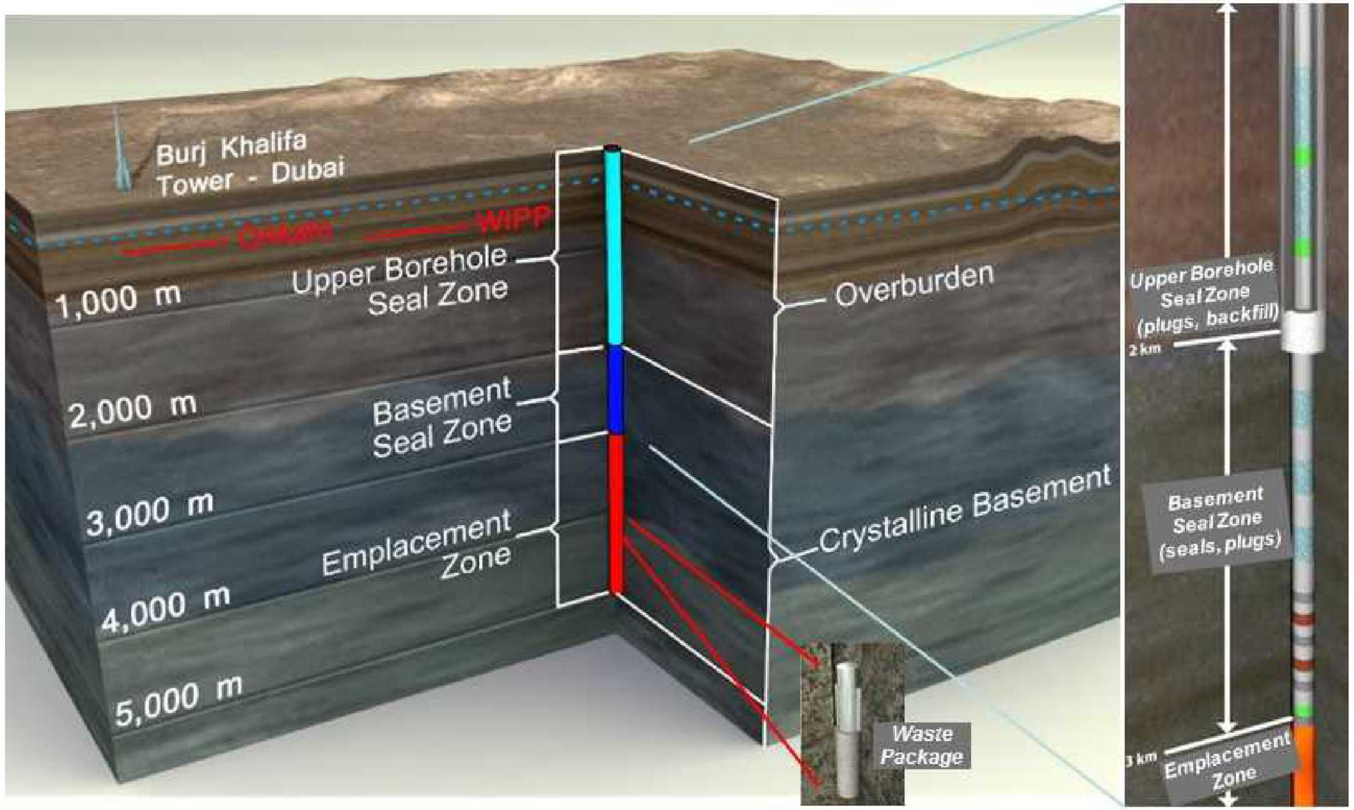
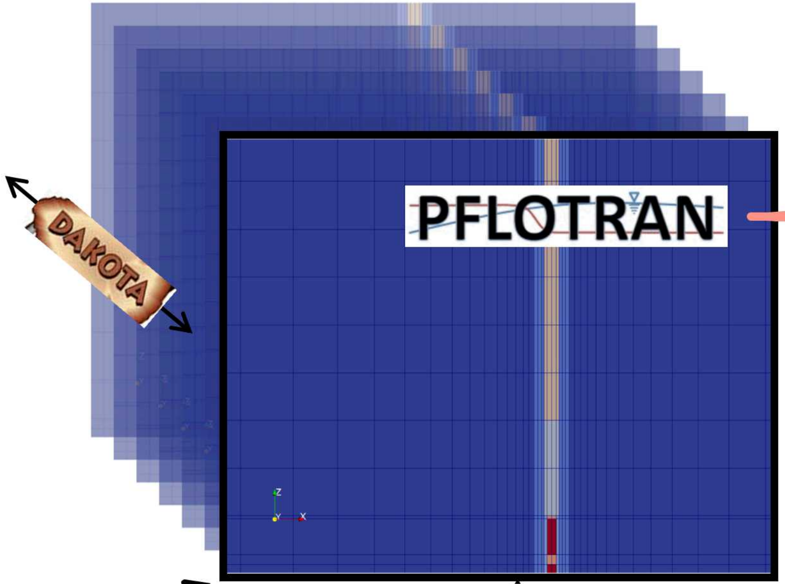
Deep Borehole Disposal

- Waste is emplaced deep in competent rock
- Hydrologically isolated, with density stratification, and geochemically reducing conditions
- Minimal reliance on engineered barriers (waste package, seals)



Performance Assessment

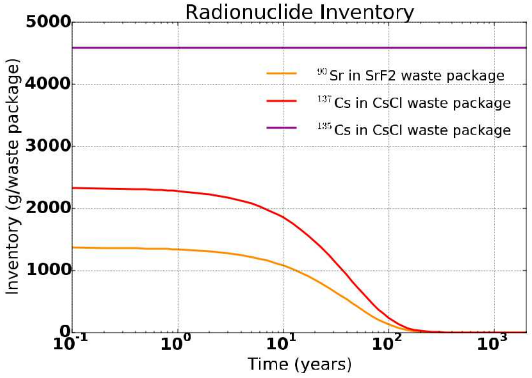


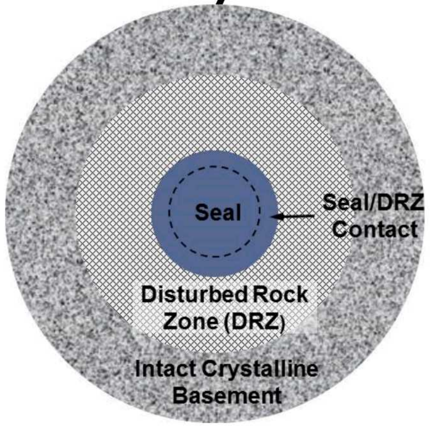
- Coupled heat and fluid flow
- Waste package degradation
- Waste form dissolution
- Radioactive decay and ingrowth
- Solubility, sorption
- Advection, dispersion, diffusion

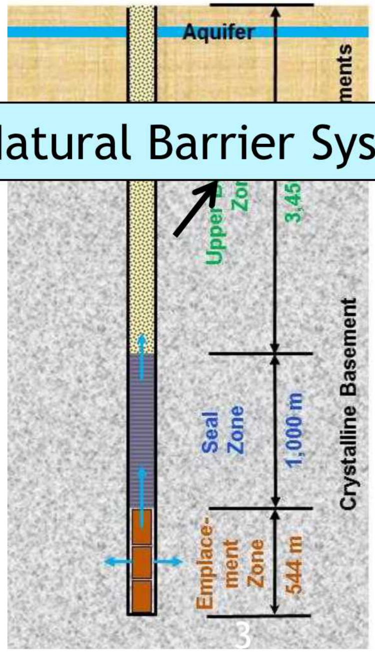
Waste Forms

Engineered Barrier System

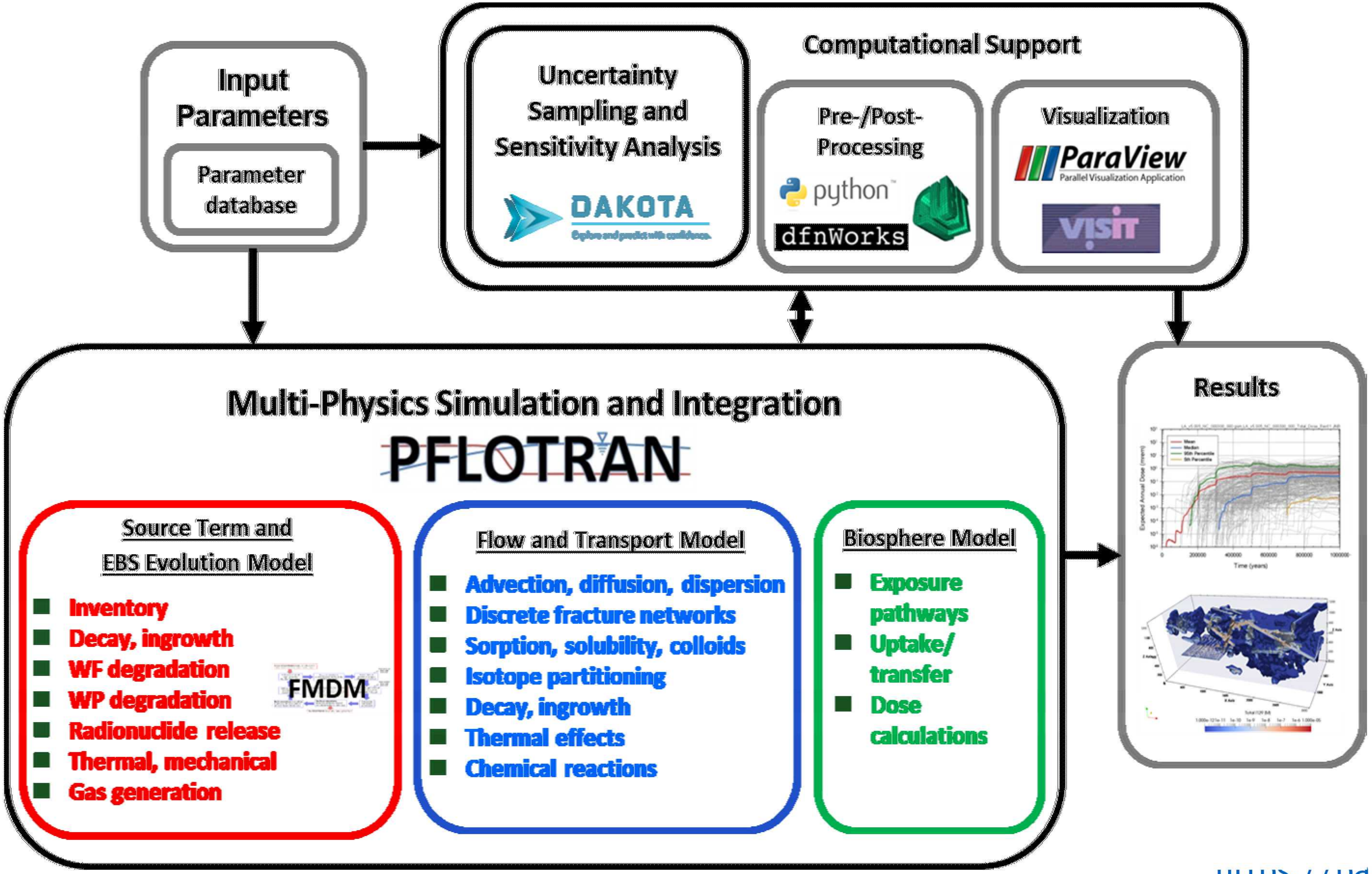
Natural Barrier System







Geologic Disposal Safety Assessment (GDSA) Framework



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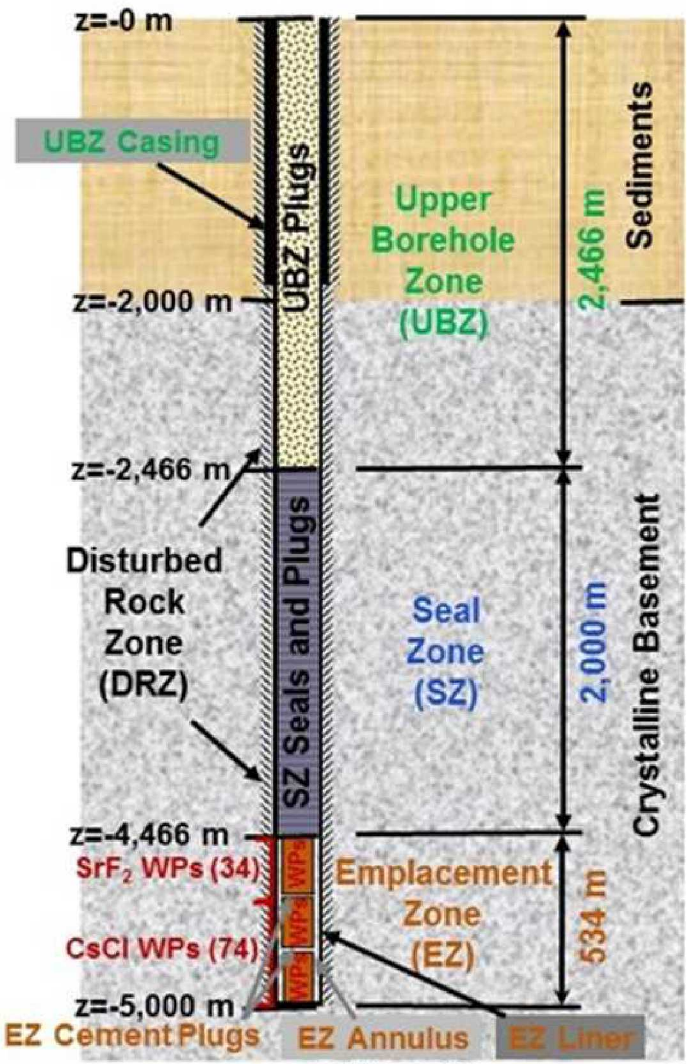
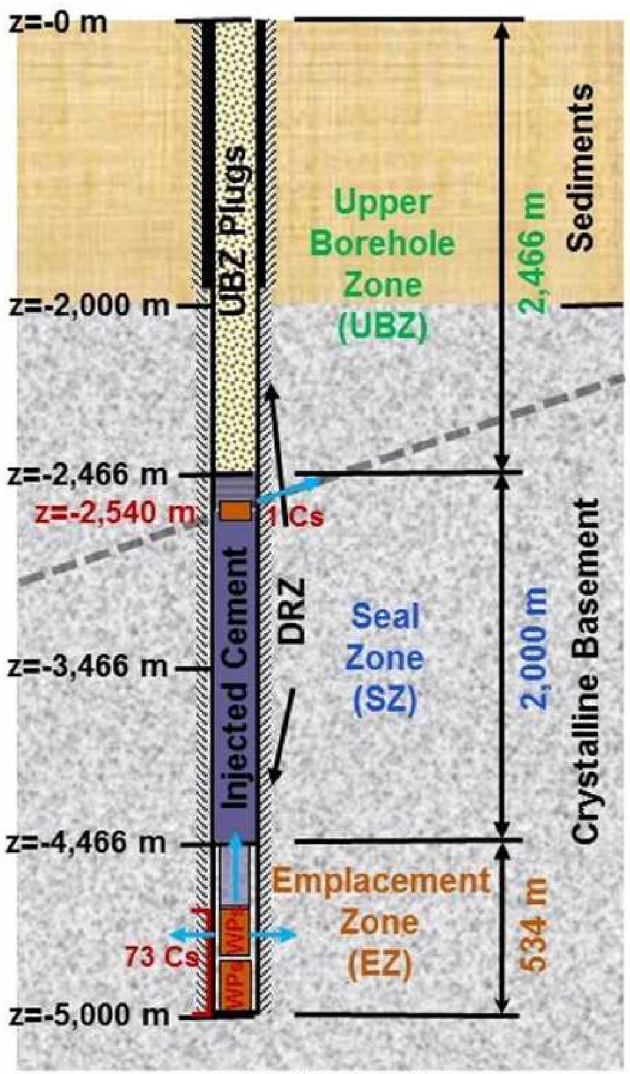
Generic DBD Concept – Two Scenarios

Nominal (undisturbed)

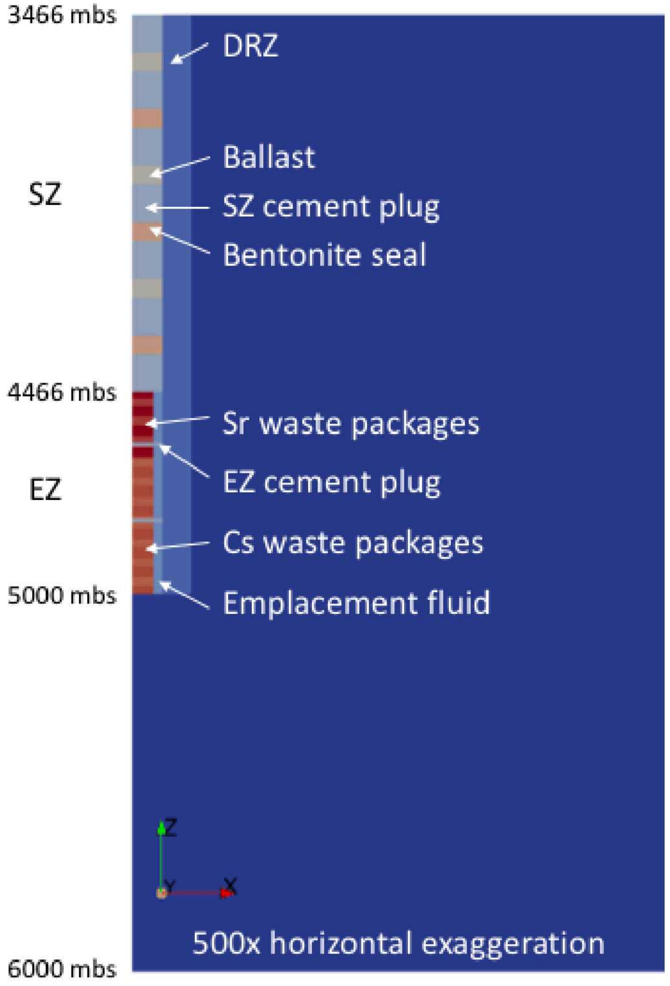


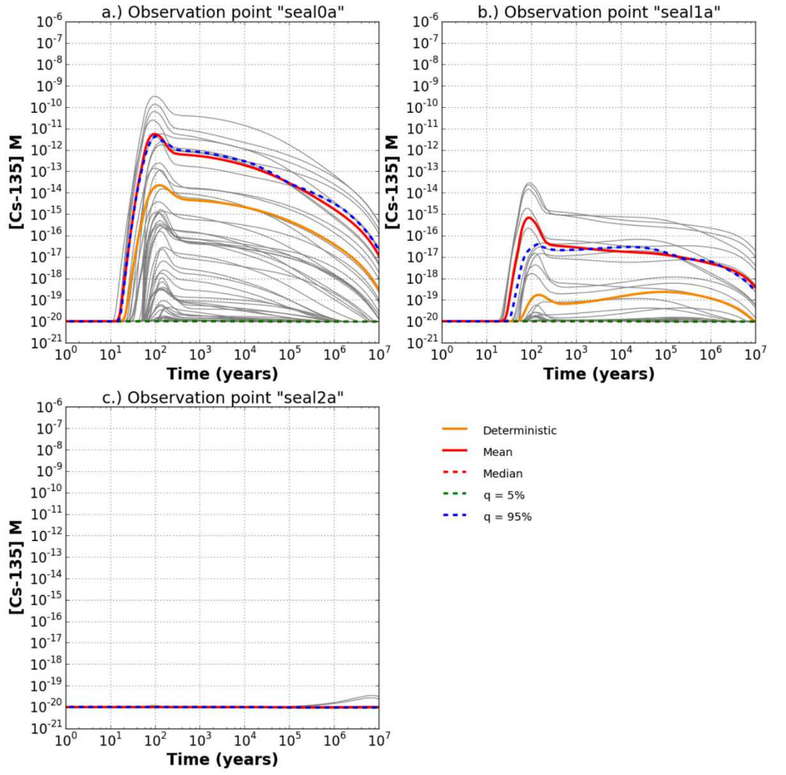
Stuck waste package

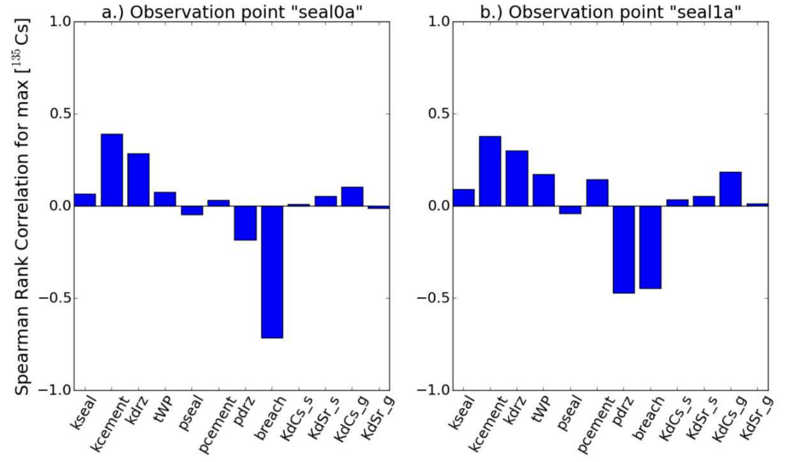


Previous Work: Nominal Scenario

- Simulate to 10 My
- 100 realizations
- 30 m above emplacement zone, essentially no increase above initial concentration
- Max [Cs-135] in the Seal Zone is sensitive to
  - Breach Time (↑↓)
  - Permeability (↑↑)
  - Porosity (↑↓)

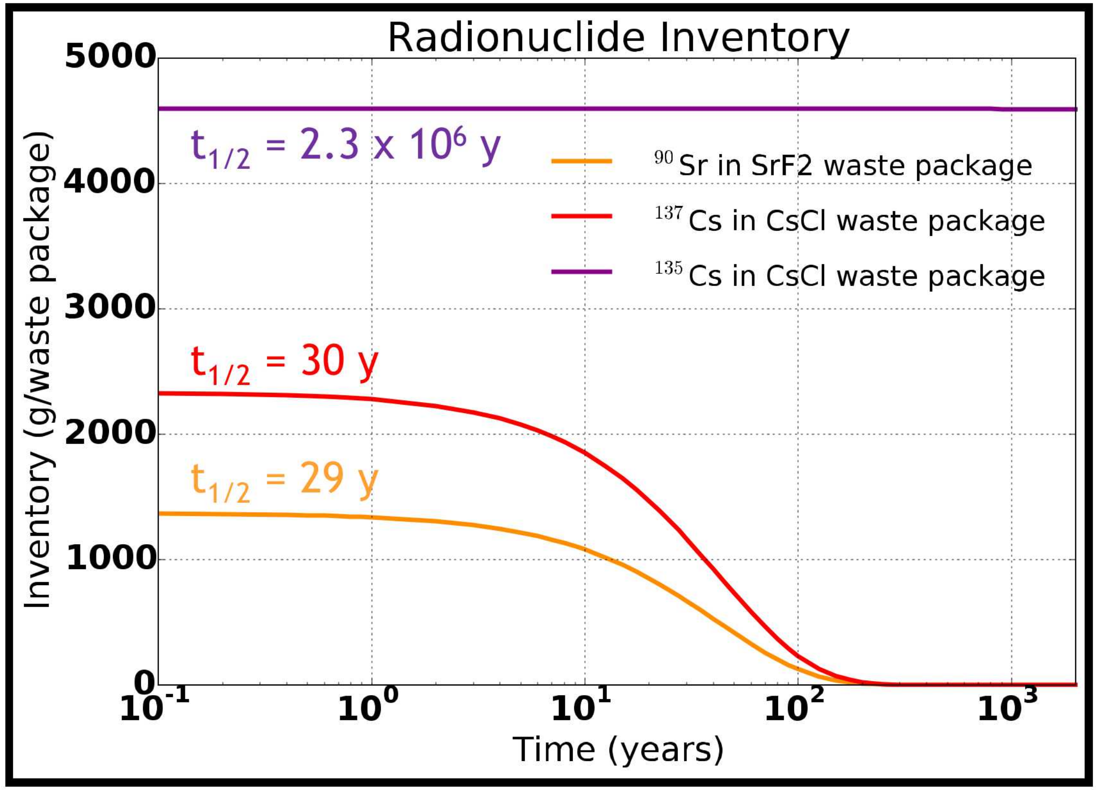




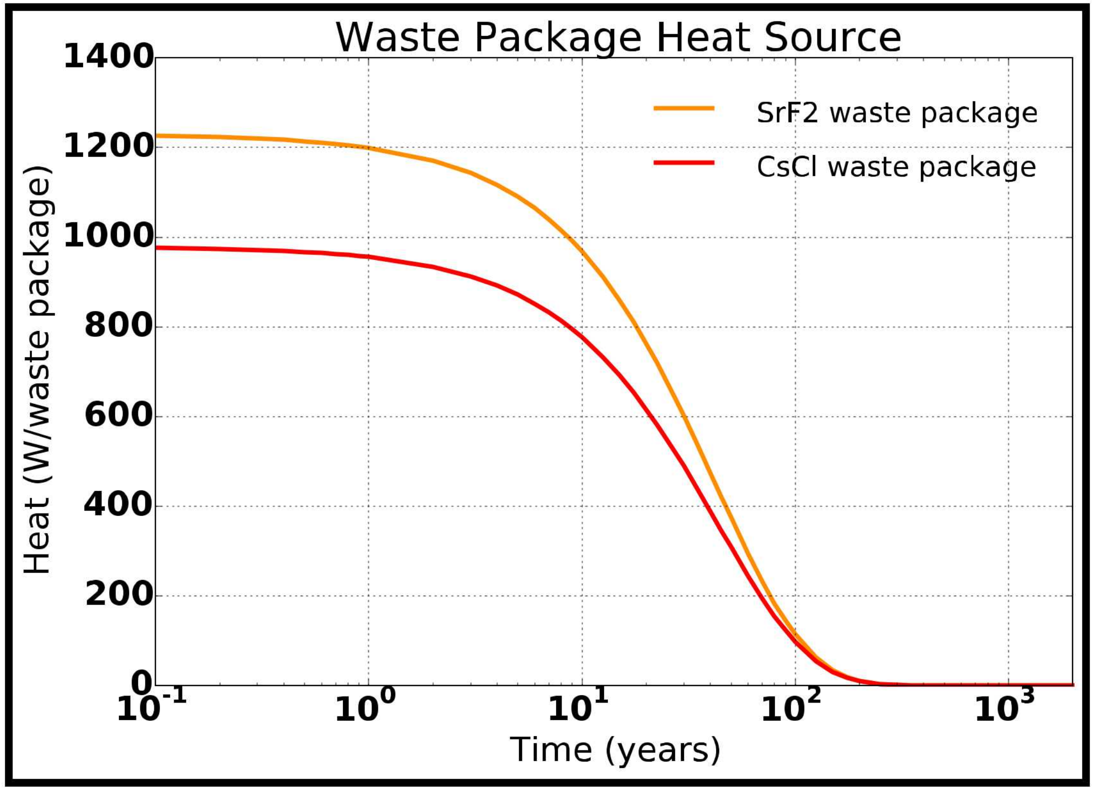


G. FREEZE, E. STEIN, L. PRICE, R. MACKINNON, and J. TILLMAN (2016). *Deep Borehole Disposal Safety Analysis*. SAND2016-10949. Sandia National Laboratories, Albuquerque, NM.

Inventory and Waste Form



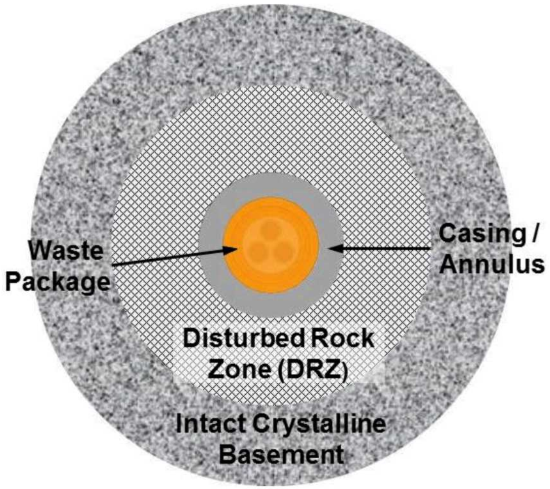
- 1335 CsCl capsules
- 601 SrF_2 capsules (Nominal Scenario)
- 18 capsules per waste package

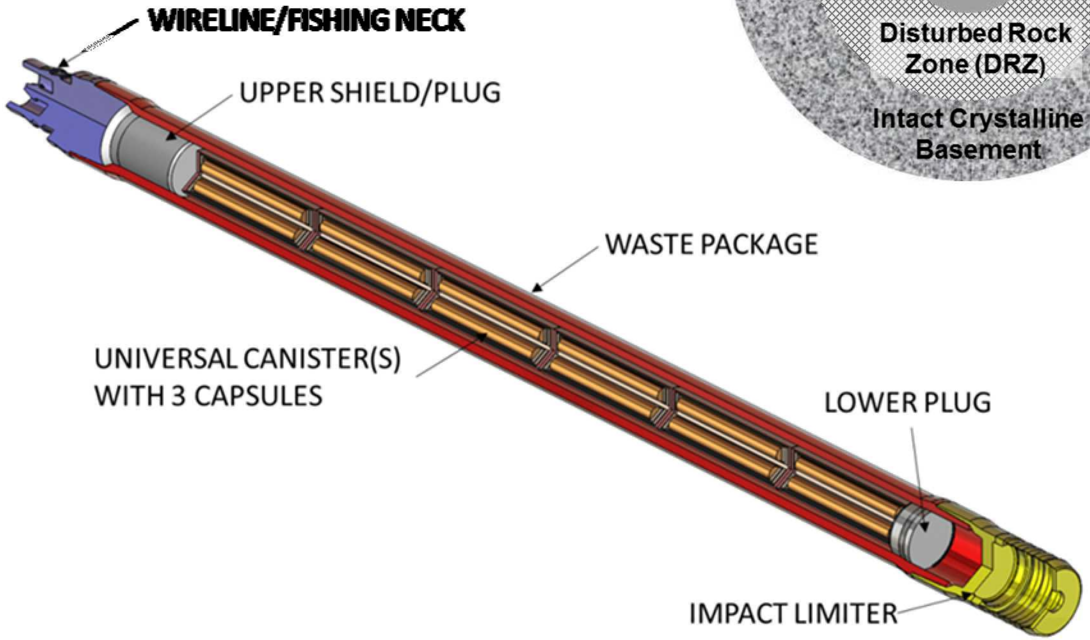


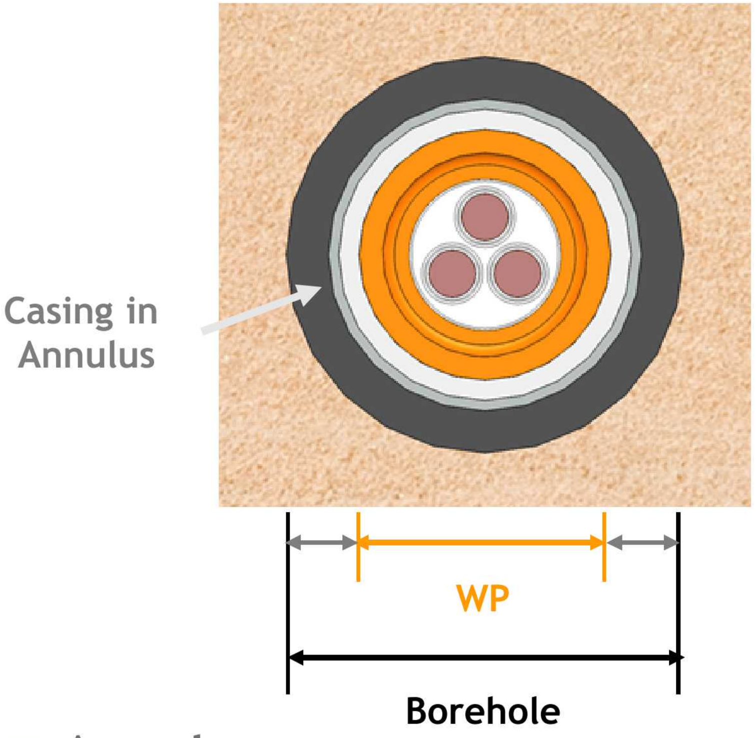
- Instantaneous degradation
- Unlimited solubility

Engineered Barrier System: Emplacement Zone

- **73 of 74 CsCl waste packages**
  - Diameter = 19.1 cm (7.5 in)
  - Length = 4.76 m
  - Breach time = 1–100 y
  - $k = 10^{-16}$ m^2, $\phi = 0.5$
  - No sorption ($K_d = 0$)





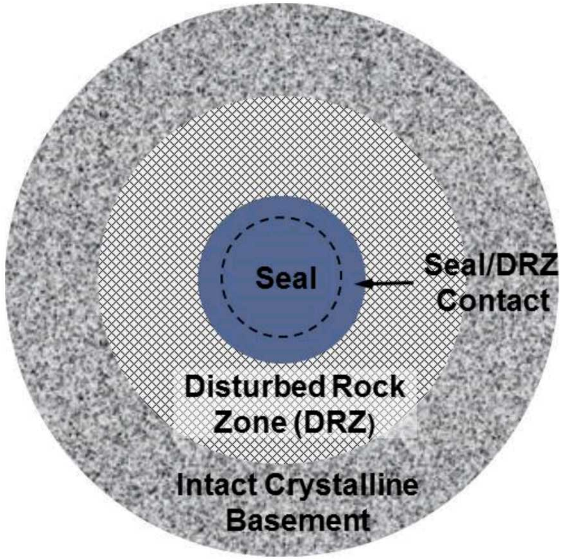


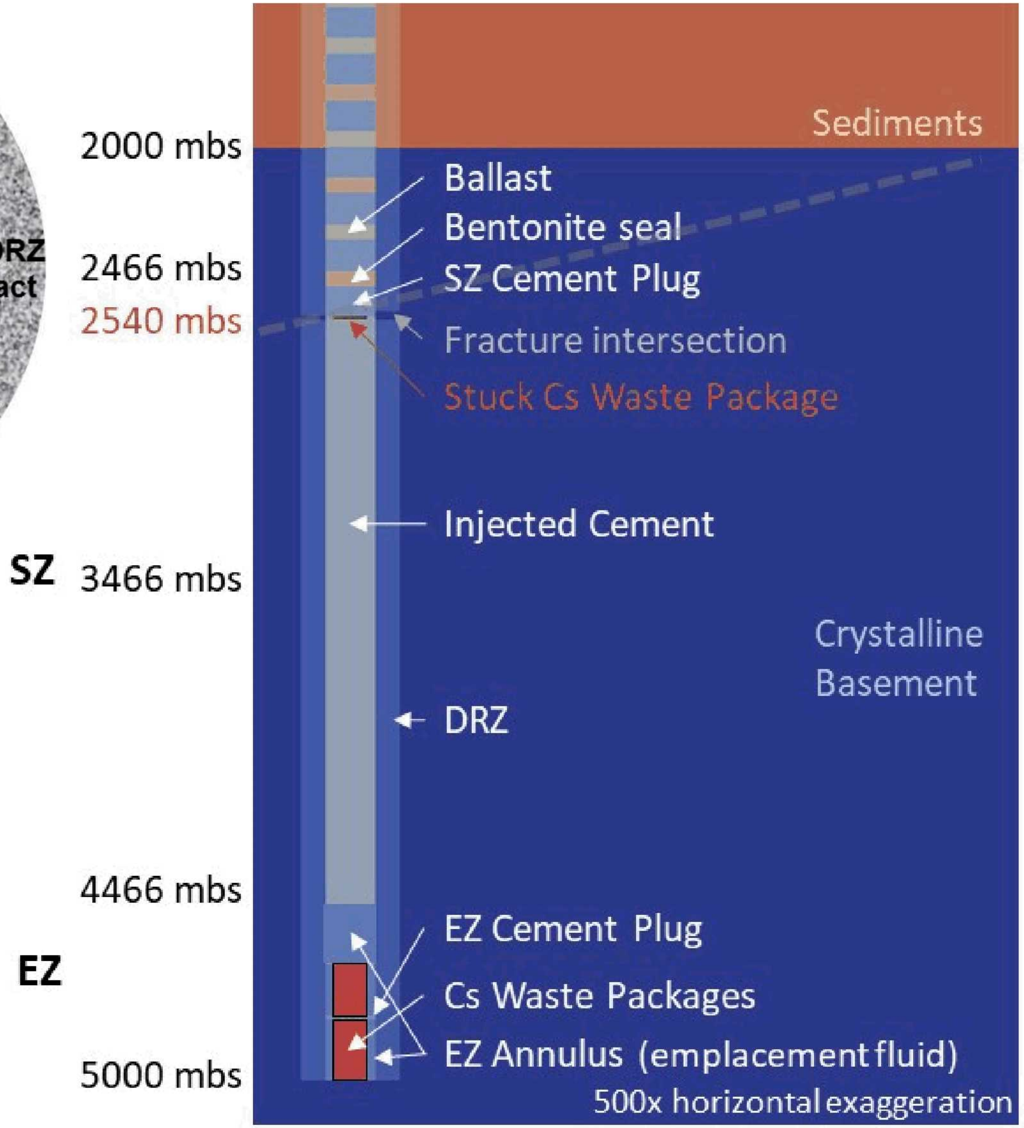
- **Annulus**
  - Diameter = 31.1 cm (12.25 in)
  - Contains:
    - *Perforated steel casing (not simulated)*
    - *Brine ($k = 10^{-14}$ m^2, $\phi = 0.99$)*
    - *Cement plug above 40th waste package*
  - No sorption ($K_d = 0$)

Engineered Barrier System: Seal Zone

- **Injected Cement**
  - 1900 m long
  - $k = 10^{-16} - 10^{-14}$ m^2
  - $\phi = 0.25$
  - No sorption ($K_d = 0$)

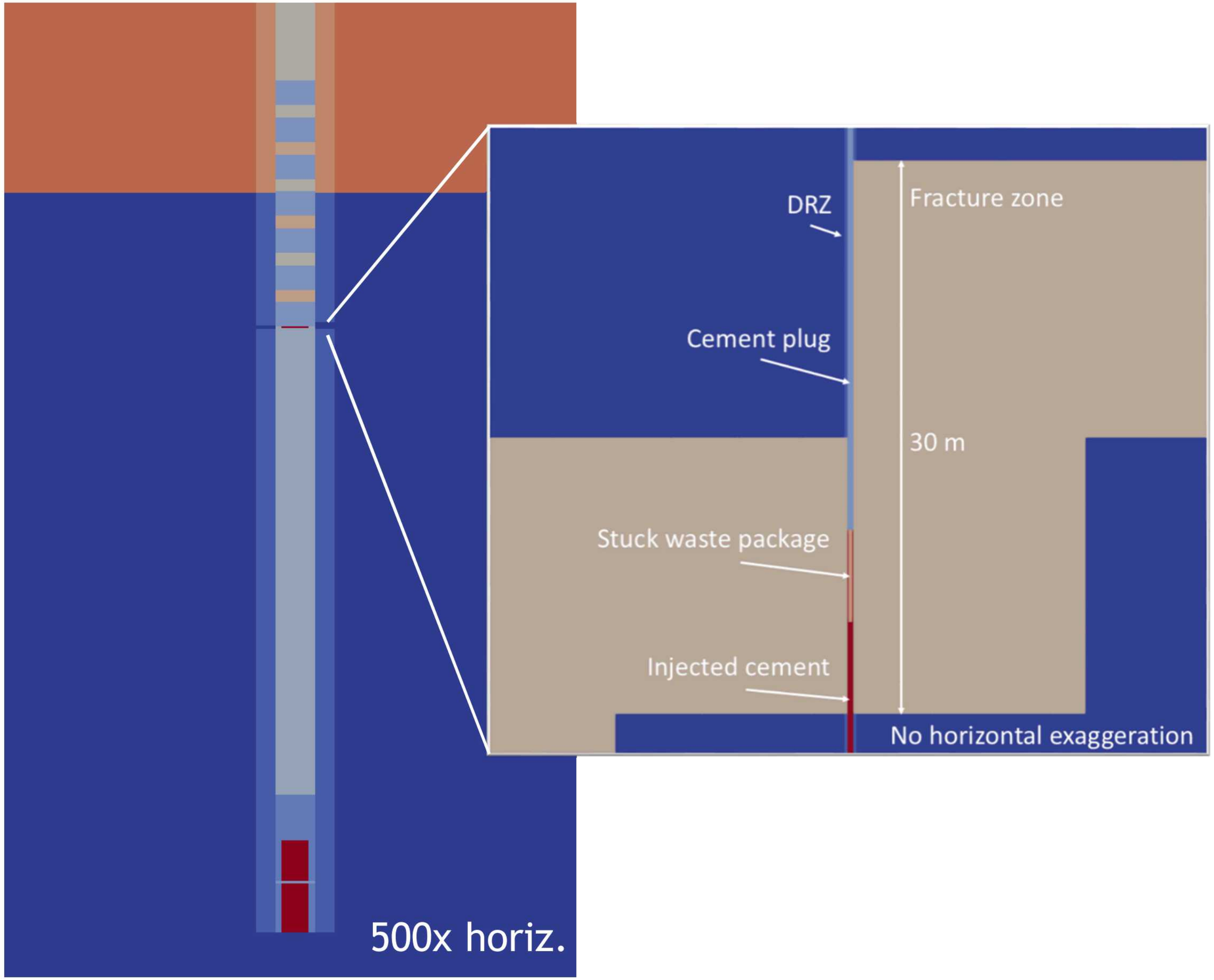
- **Seal System**
  - 1000 m long
  - 7 x 100-m cement plugs
  - 3 x 50-m bentonite seals
  - 3 x 50-m lengths of ballast ($k = 10^{-14}$ m^2 , $\phi = 0.20$)
  - Sorption in bentonite





Natural Barrier System

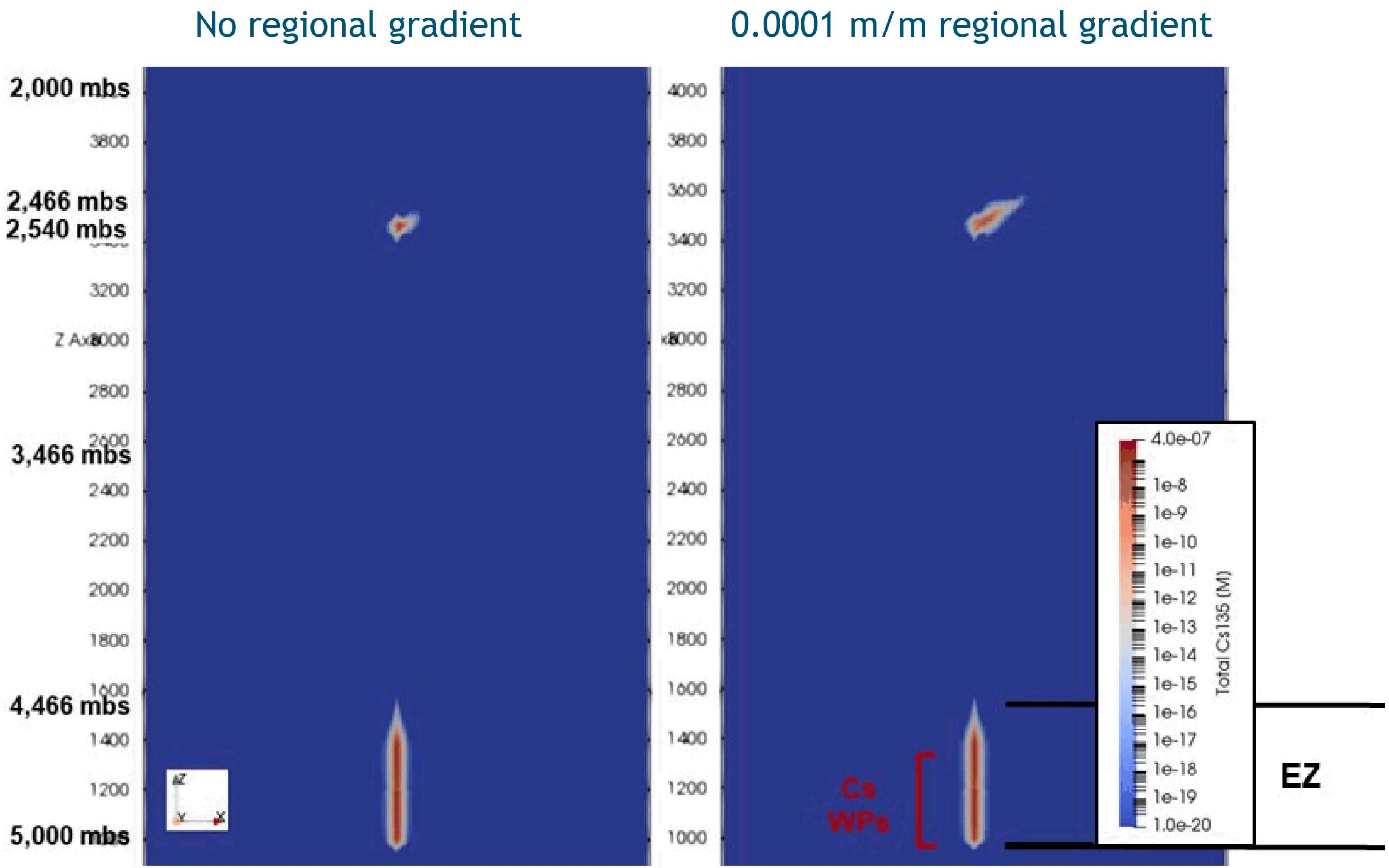
- **Undifferentiated Sediments**
  - $k = 10^{-15}$ m^2, $\phi = 0.20$
- **Crystalline Host Rock**
  - Sparsely fractured
  - Bulk $k = 10^{-18}$ m^2, $\phi = 0.005$
- **Disturbed Rock Zone (DRZ)**
  - Thickness = borehole radius
  - Bulk $k = 10^{-18}$ – 10^{-15} m^2
- **Fracture Zone**
  - 15 m thick
  - 30º dip
  - Bulk $k = 10^{-17}$ – 10^{-14} m^2
- **Regional Head Gradient**
  - 0.0001 m/m



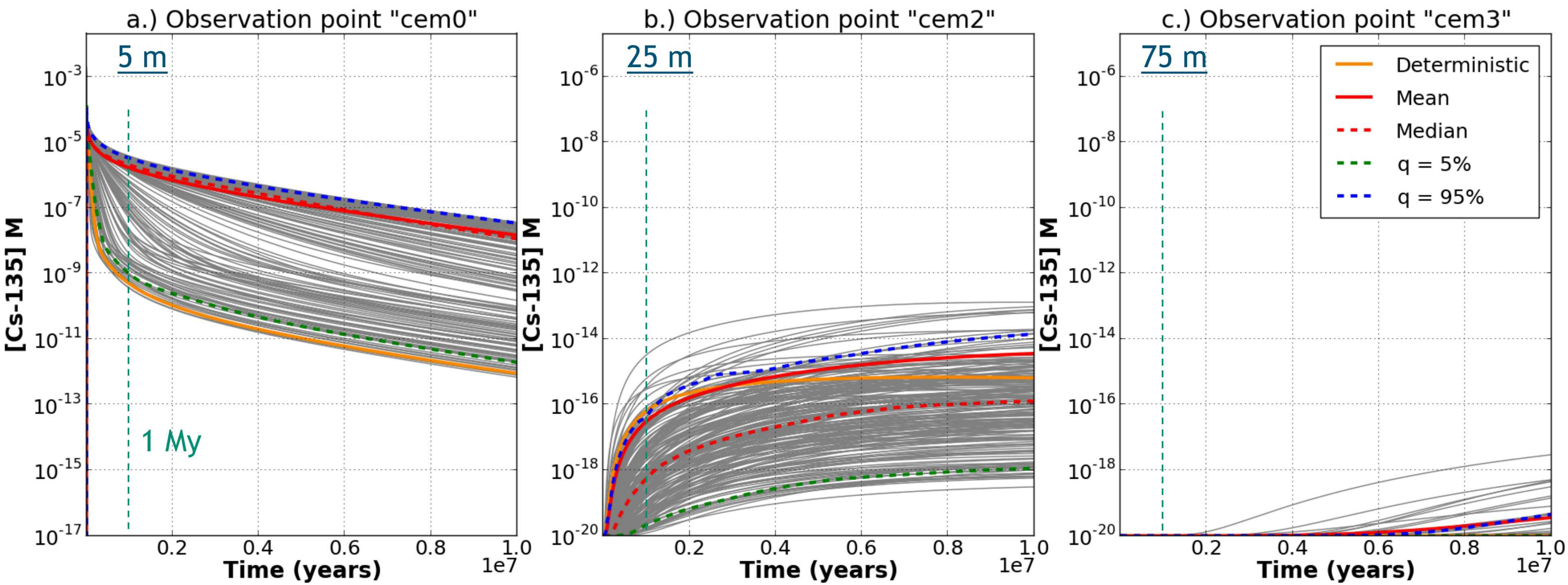
Sampled Variable Distributions

Variable	Description	Min	Max	Units	Distribution
kSeal	Bentonite k	10^{-20}	10^{-16}	m^2	log uniform
kPlug	Cement plug k	10^{-20}	10^{-16}	m^2	log uniform
kInj	Injected cement k	10^{-16}	10^{-14}	m^2	log uniform
kDRZ	DRZ k	10^{-18}	10^{-15}	m^2	log uniform
kFrac	Fracture zone k	10^{-17}	10^{-14}	m^2	log uniform
pSeal	Bentonite ϕ	0.40	0.50	-	uniform
pPlug	Cement plug ϕ	0.15	0.20	-	uniform
pDRZ	DRZ ϕ	0.005	0.01	-	uniform
bTime	Breach time	1	100	y	uniform
KdSeal	Cs K_d in bentonite	120	1000	L/kg	uniform
KdGran	Cs K_d in granite host rock	5	40	L/kg	uniform
KdDRZ	Cs K_d in DRZ	5	40	L/kg	uniform
KdFrac	Cs K_d in fracture	5	40	L/kg	uniform

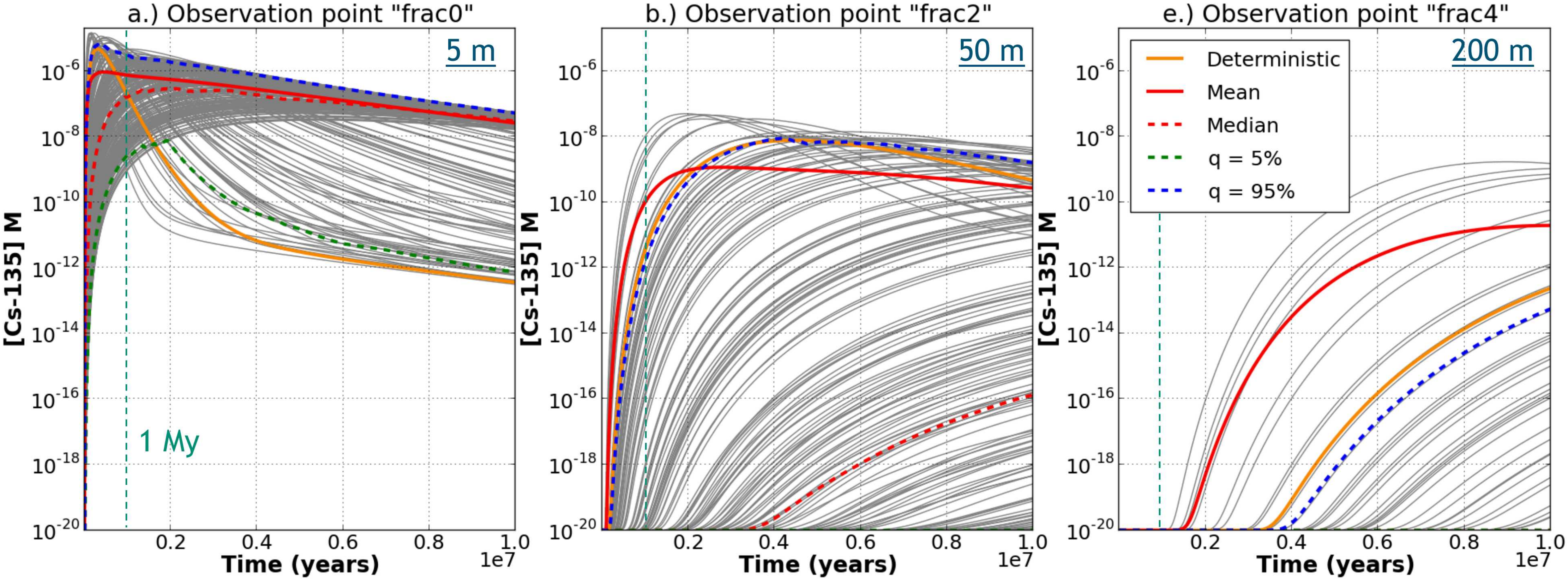
[Cs-135] at 10 My – Two Deterministic Simulations



200 Realizations – [Cs-135] in Cement Plug



200 Realizations – [Cs-135] in Fracture



Scatter Plots – [Cs-135] vs. Influential Input Variables

Cement Plug

5 m

25 m

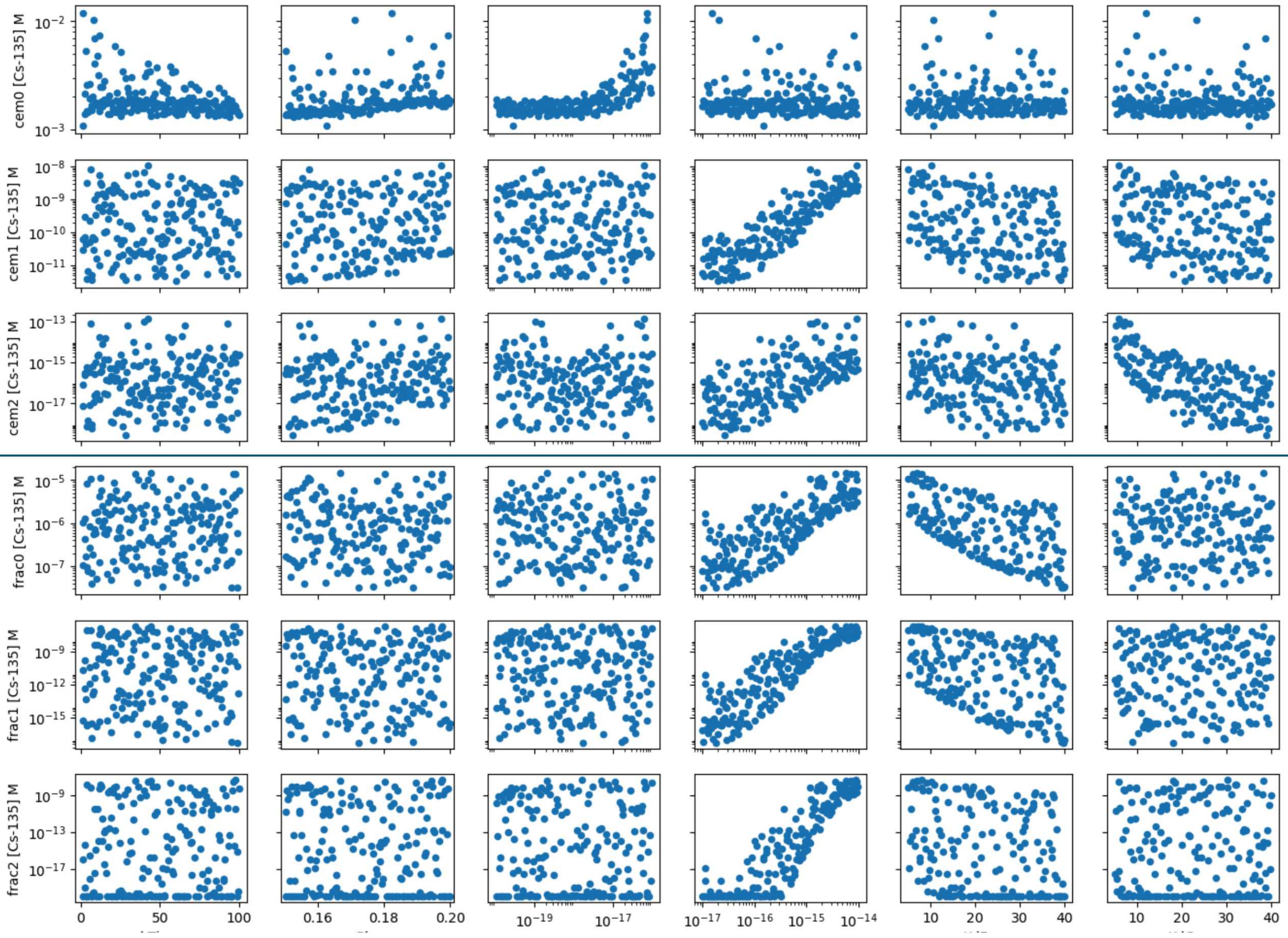
50 m

Fracture

5 m

25 m

50 m



Breach Time | Plug ϕ | Plug k | Frac. k | Frac. Kd | Granite Kd

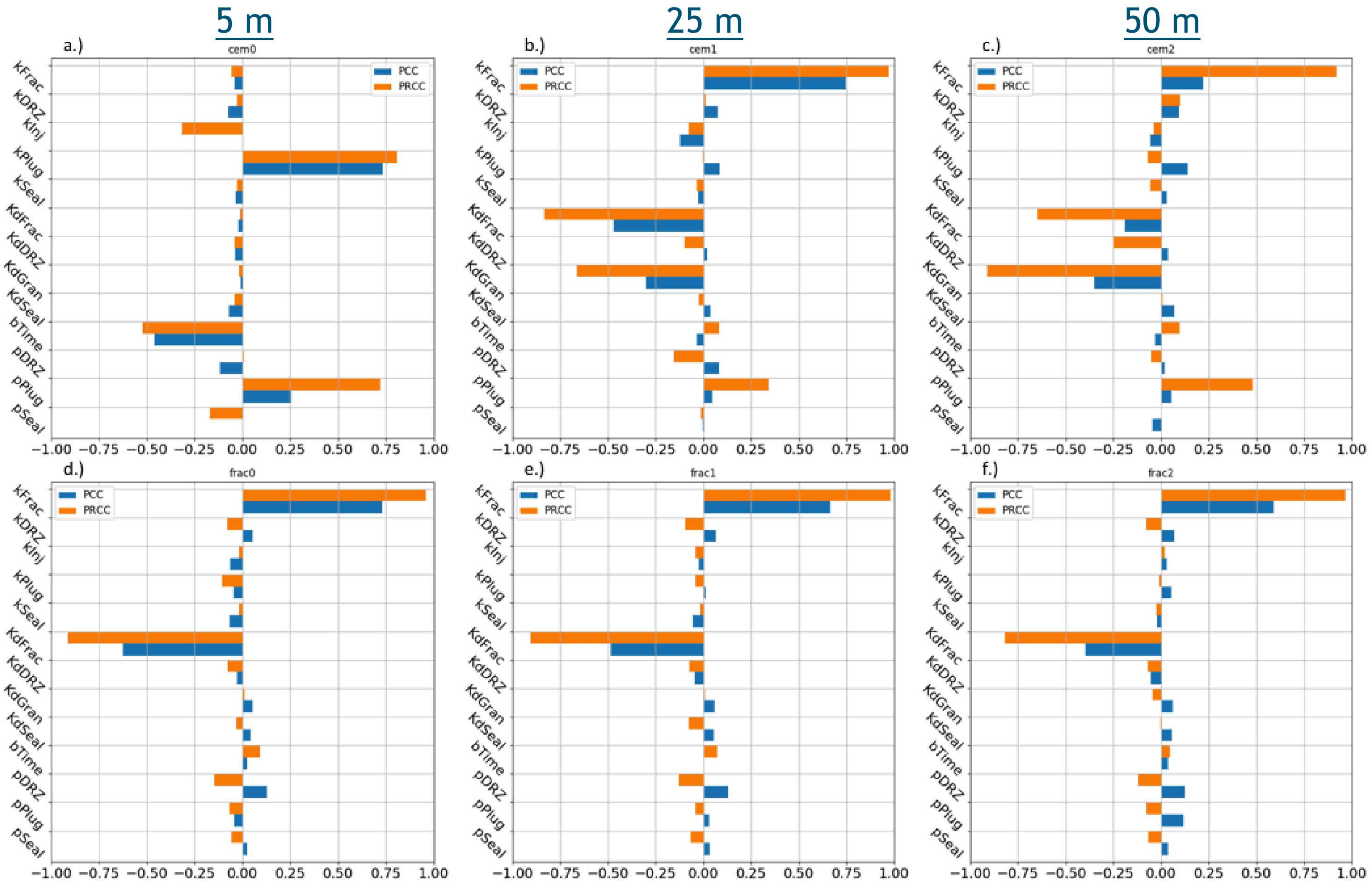
Partial and Partial Rank Correlation Coefficients

Cement Plug

- Plug k
- Fracture k
- Fracture K_d
- Granite K_d

Fracture

- Fracture k
- Fracture K_d



Conclusions

- Uncertainties affecting radionuclide mobilization and transport are propagated through **200 realizations** of a subsurface flow and transport model to quantify uncertainties in predicted radionuclide concentrations within the borehole and the fracture zone.
- Simulations predict **no radionuclide transport in the borehole at distances greater than 100 m** above the stuck waste package.
- The assumed lateral pressure gradient of 0.0001 m/m leads to **limited advective transport in the transmissive fracture zone**.
- None of the simulations predict radionuclide transport to a lateral distance of 200 m from the stuck waste package at times less than 10^6 y; fewer than half of the simulations predict radionuclide transport to this distance by 10^7 y.
- In both the borehole and the fracture, **peak concentrations are sensitive to fracture permeability and sorption coefficient**.
- These results complement previous results for the nominal scenario and contribute to the development of a generic safety case for DBD.

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