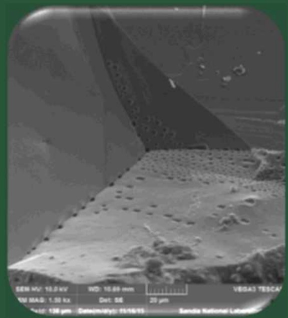
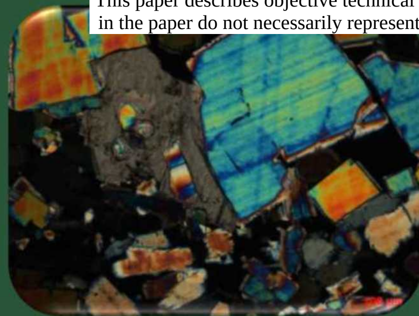
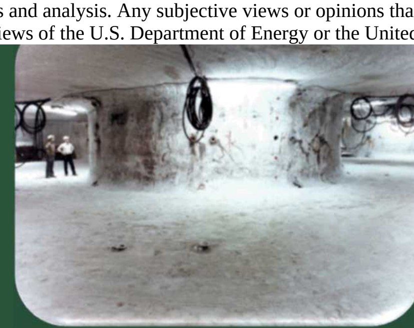
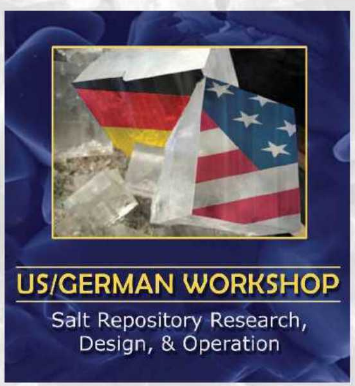





SAND2018-9828C

Simulations of Canister Compaction at the WIPP



PTKA Project Management Agency Karlsruhe
Karlsruhe Institute of Technology

U.S. DEPARTMENT OF ENERGY

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Federal Ministry for Economic Affairs and Energy

Benjamin Reedlunn and James Bean
Sandia National Laboratories

Hanover, Germany
September 10-11, 2018

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Outline

- Background
- Model Setup
  - Numerical Approach
- Results
  - Sensitivity to Canister Behavior
  - Sensitivity to Clay Seam Behavior
- Summary and Potential Future Work

Background

Standard Canisters

Schematic

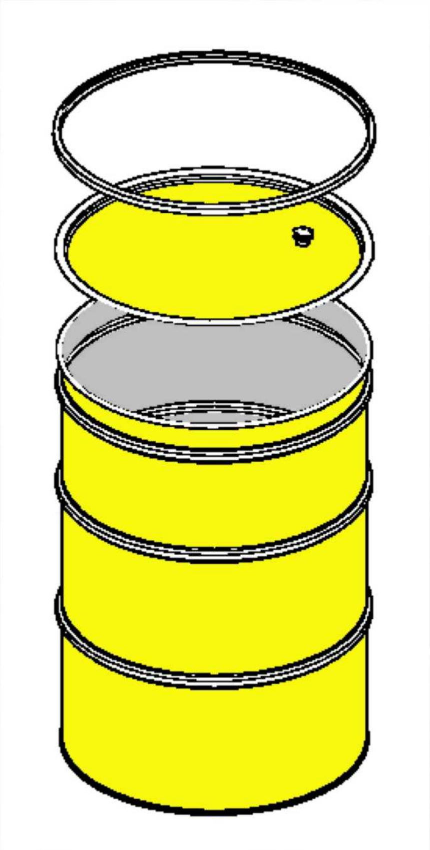
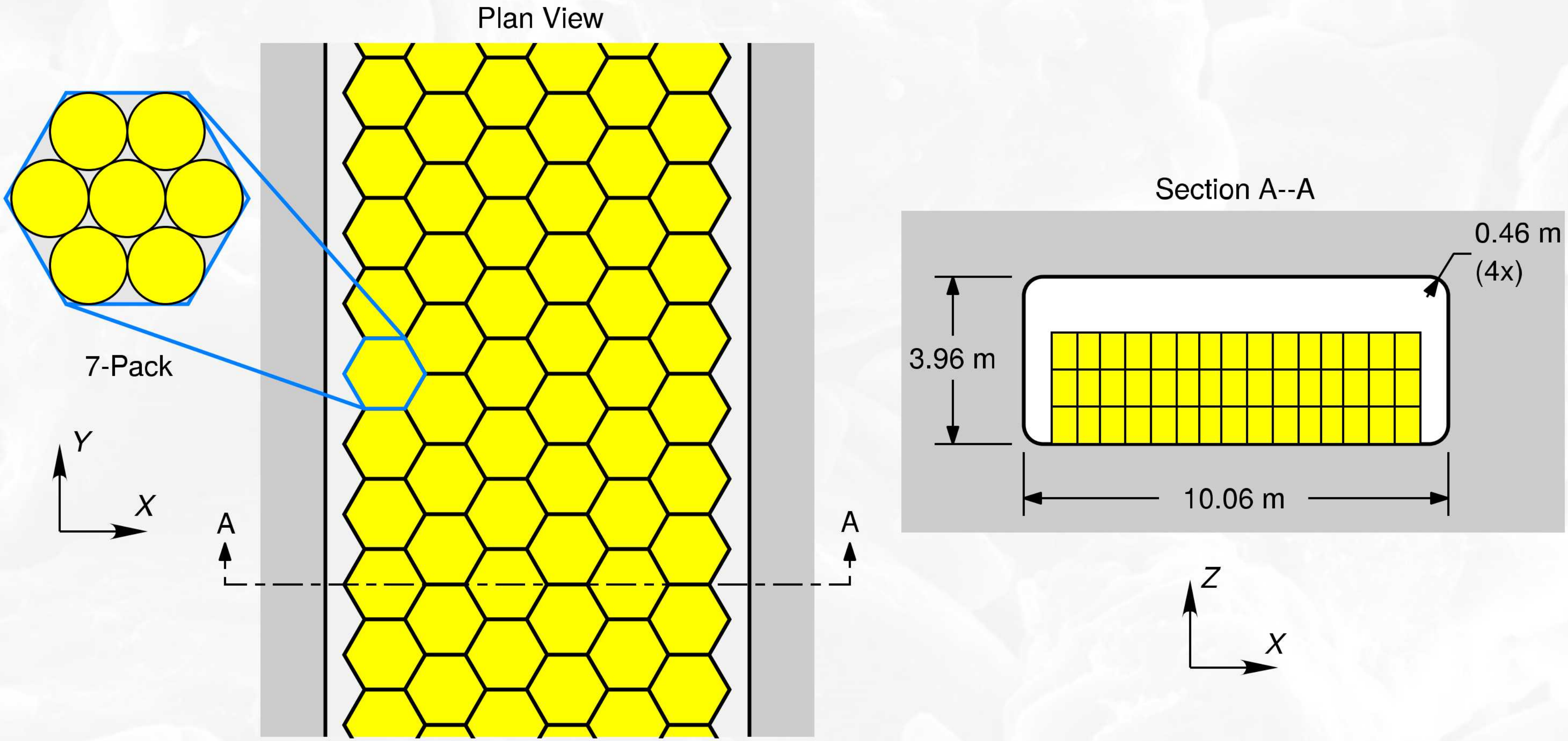


Photo
(with surrogate waste)

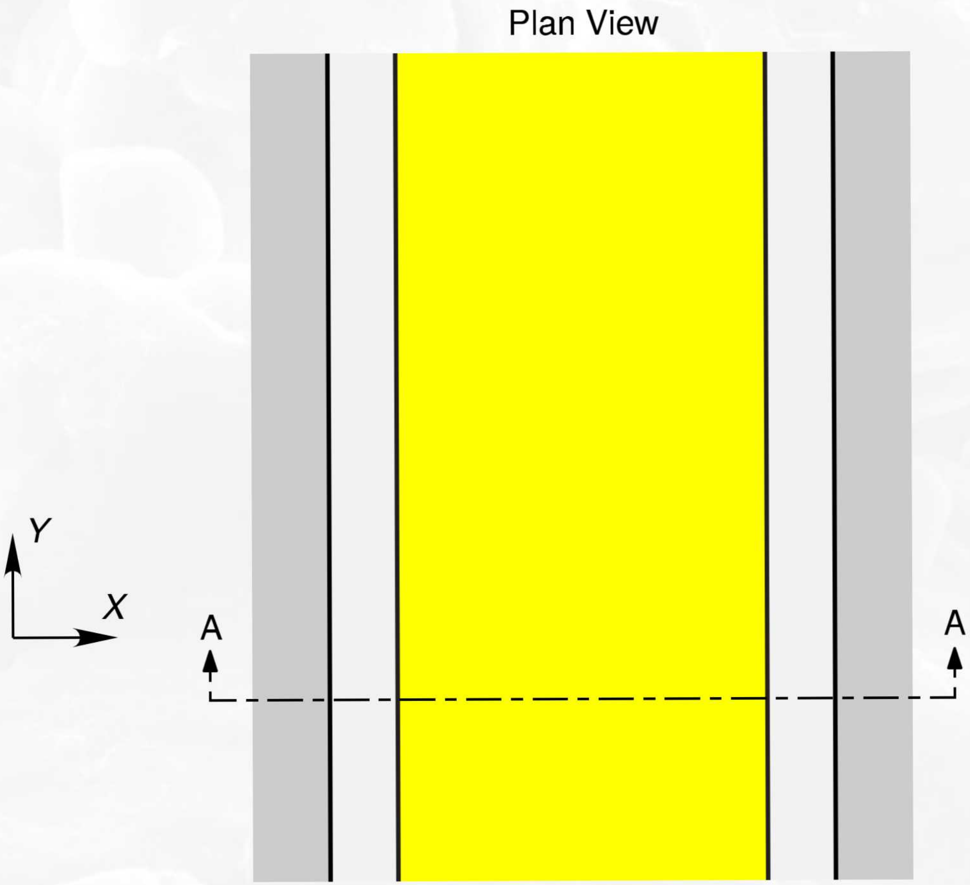
Park, B.Y. and Hansen, F. D., “Determination of the Porosity Surfaces of the Disposal Room Containing Various Waste Inventories for WIPP PA”, 2005, SAND2005-4236

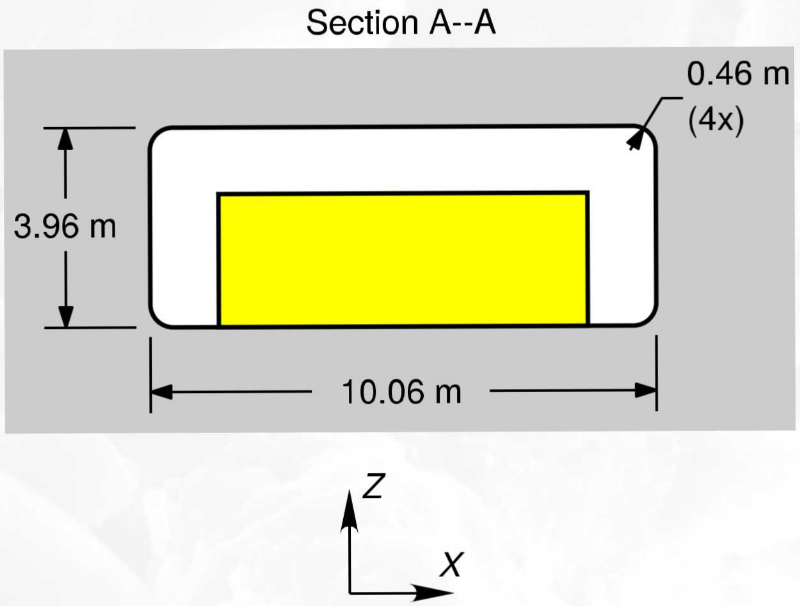
Broome, S.T., Ingraham, M.D., Flint, G.M., Hileman, M.B., Barrow, P.C., and Herrick, C.G., “Laboratory Testing of Surrogate Non-degraded Waste Isolation Pilot Plant Materials”, 2016, American Rock Mechanics Assoc., ARMA 16-120

Canister Emplacement

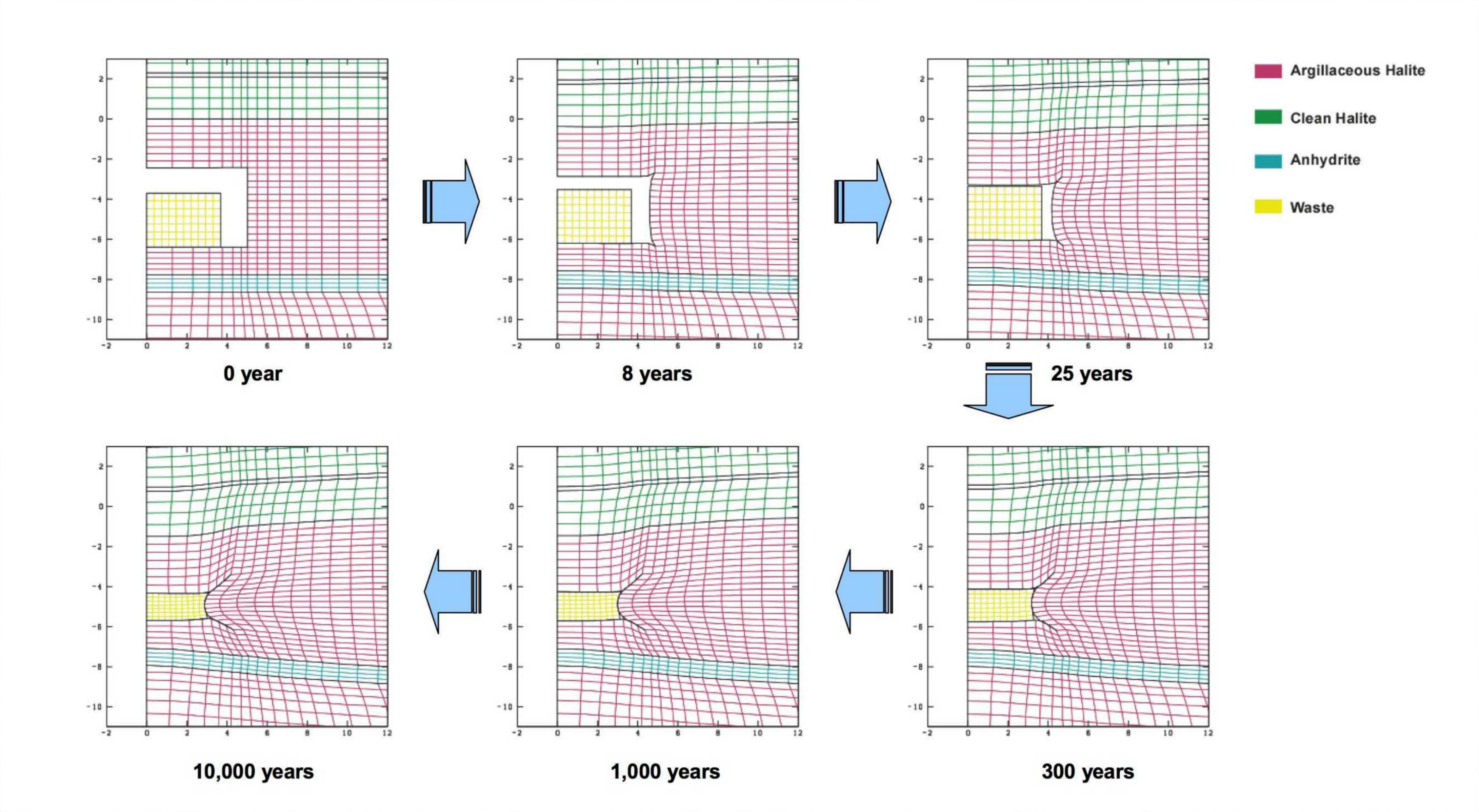


Idealized Model





Idealized Model Results



Park, B.Y. and Hansen, F. D., "Determination of the Porosity Surfaces of the Disposal Room Containing Various Waste Inventories for WIPP PA", 2005, SAND2005-4236

New Canister Design

Schematic

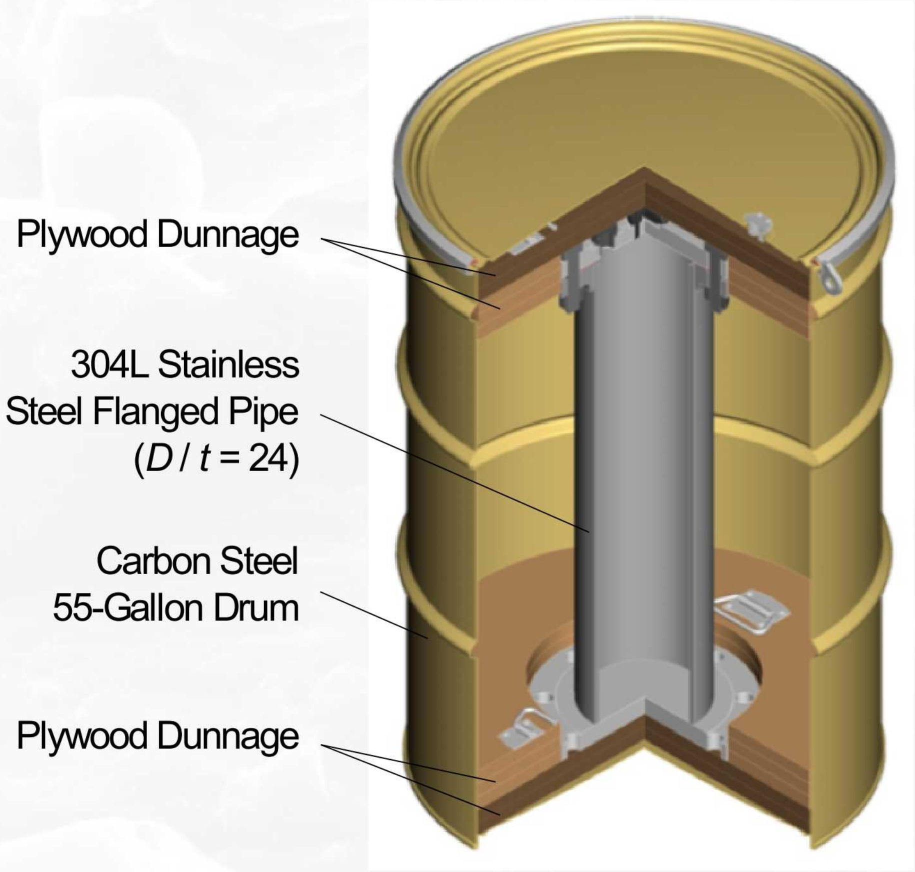
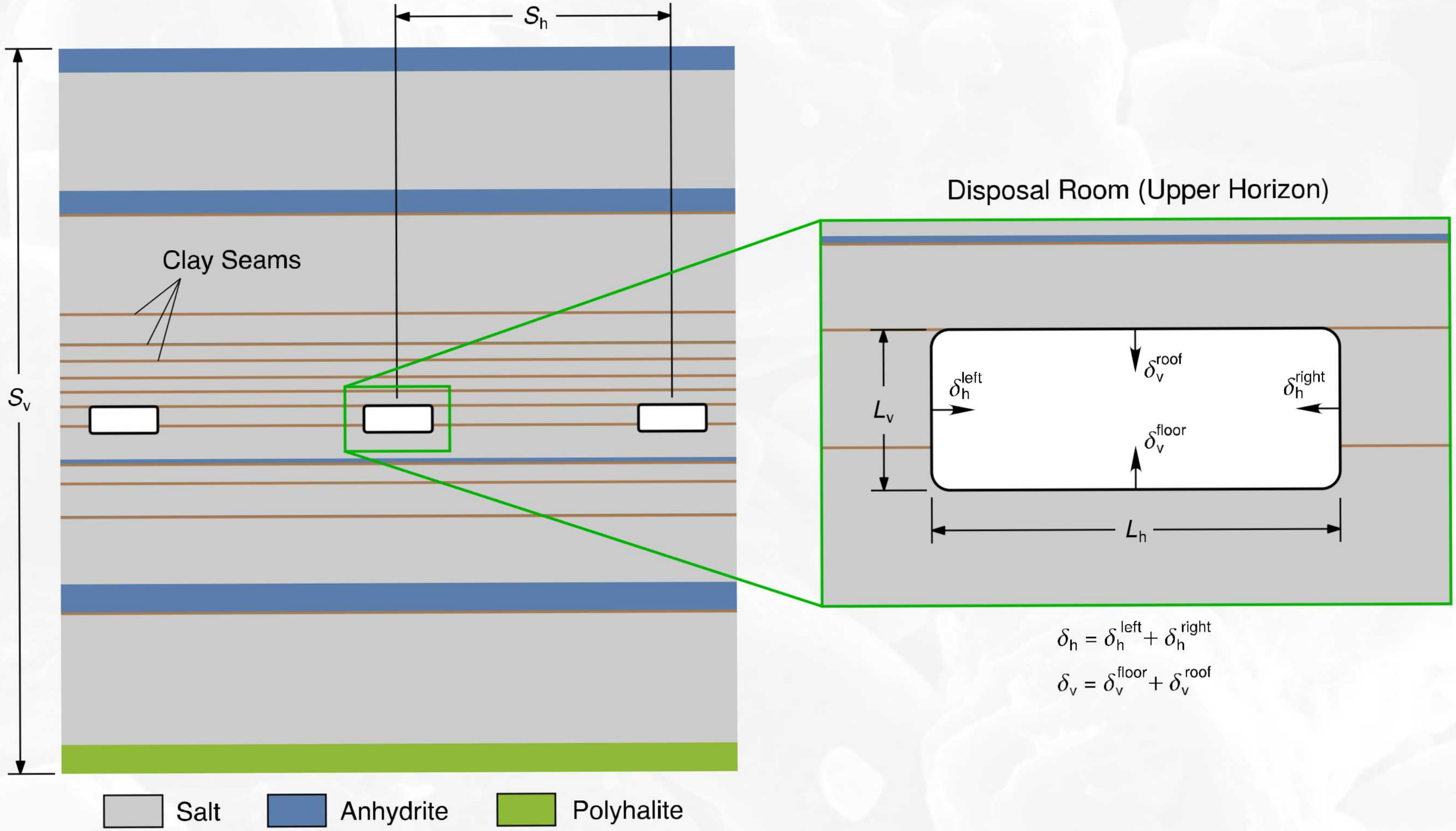


Photo
(lid and upper dunnage removed)

Model Description

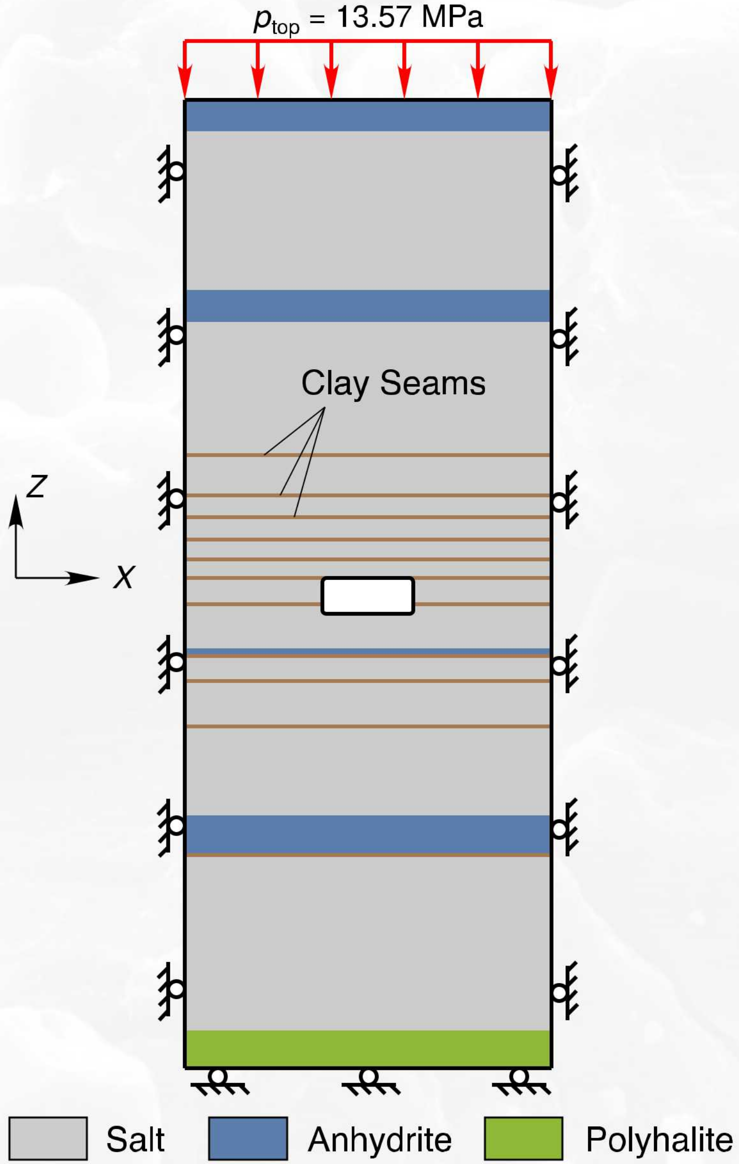
Idealized Stratigraphy



$$\delta_h = \delta_h^{left} + \delta_h^{right}$$

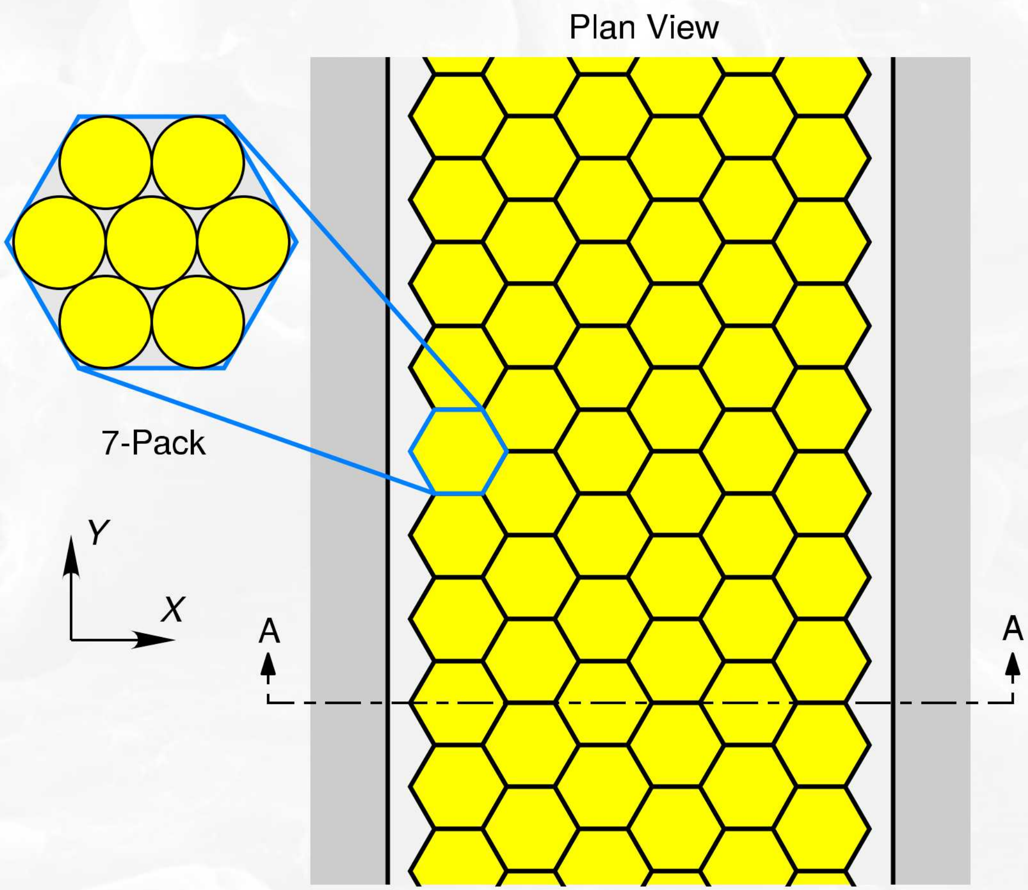
$$\delta_v = \delta_v^{floor} + \delta_v^{roof}$$

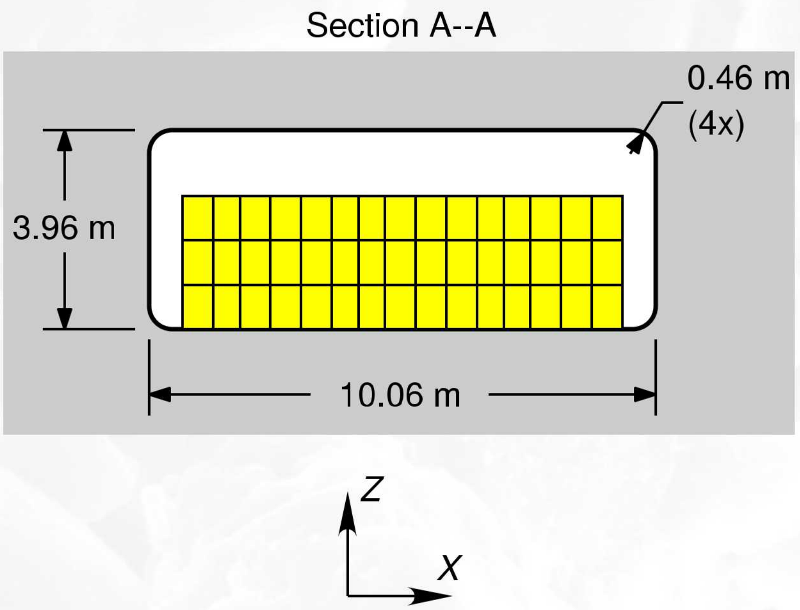
Boundary Conditions and Geomaterial Models



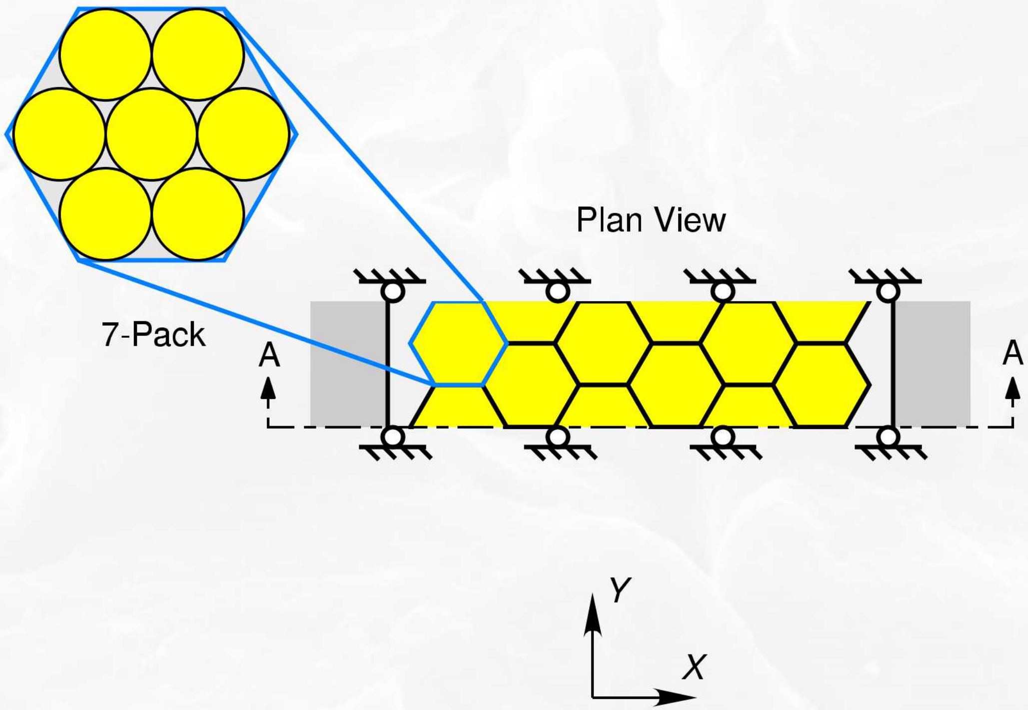
- Salt
  - Munson-Dawson Model
  - Calibration 3B (most recent)
- Anhydrite and Polyhalite
  - Elastic-Perfectly Plastic
  - Drucker-Prager Plasticity
- Clay Seams
  - Coulomb Friction

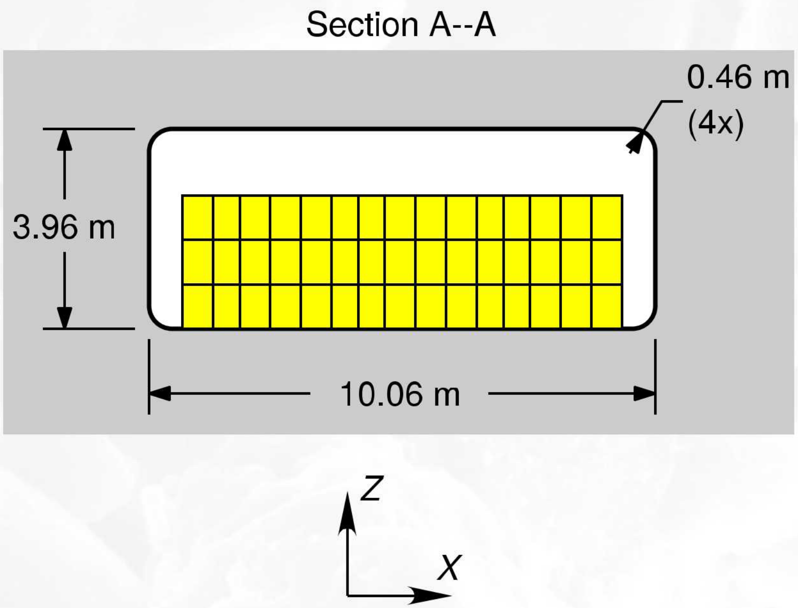
Canister Configuration and Boundary Conditions



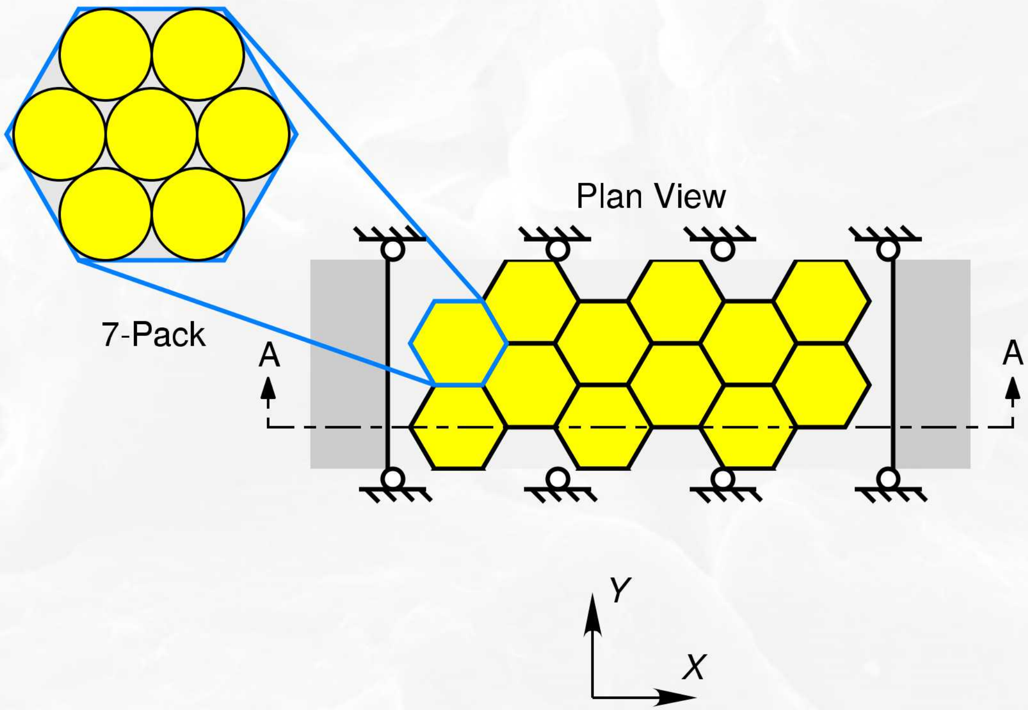


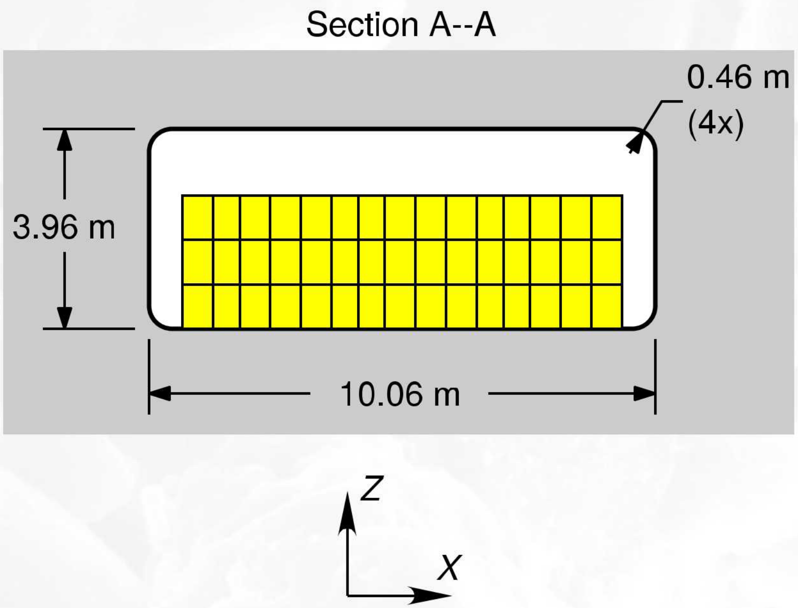
Canister Configuration and Boundary Conditions





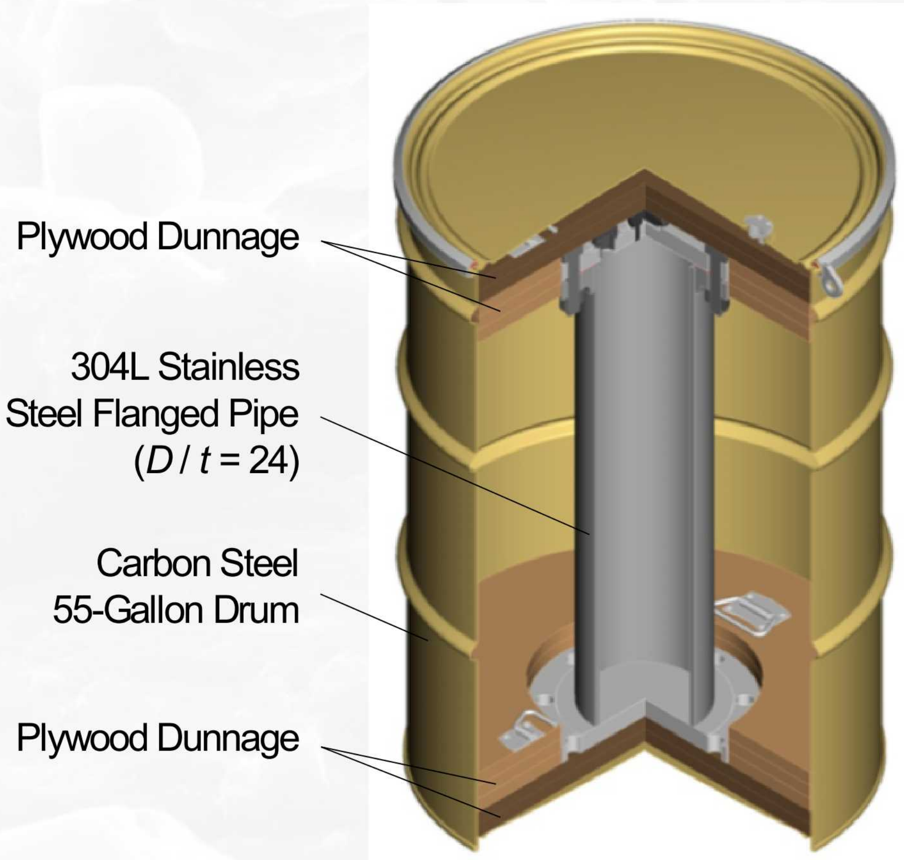
Canister Configuration and Boundary Conditions



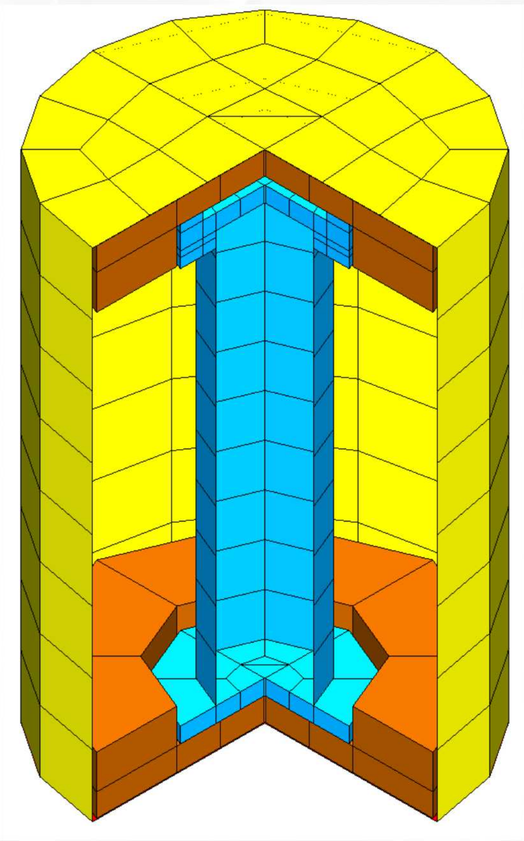


Canister Finite Element Model

Schematic

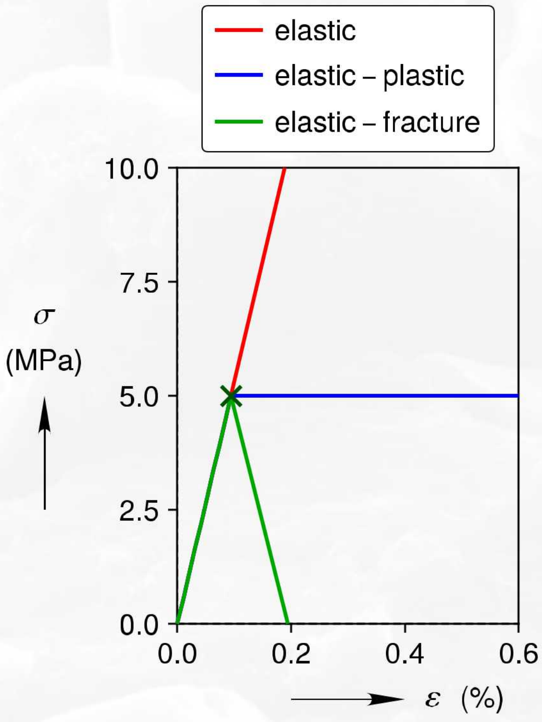


Finite Element Mesh

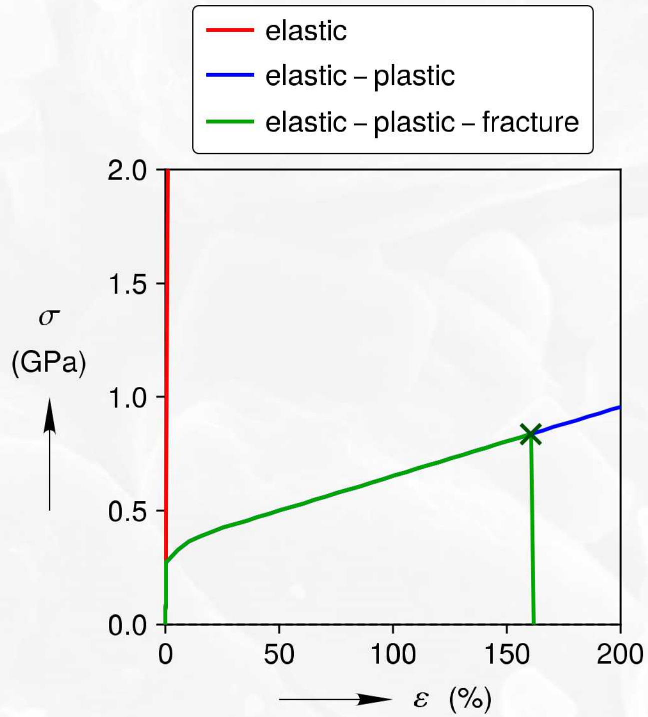


Canister Material Models: Uniaxial Tension

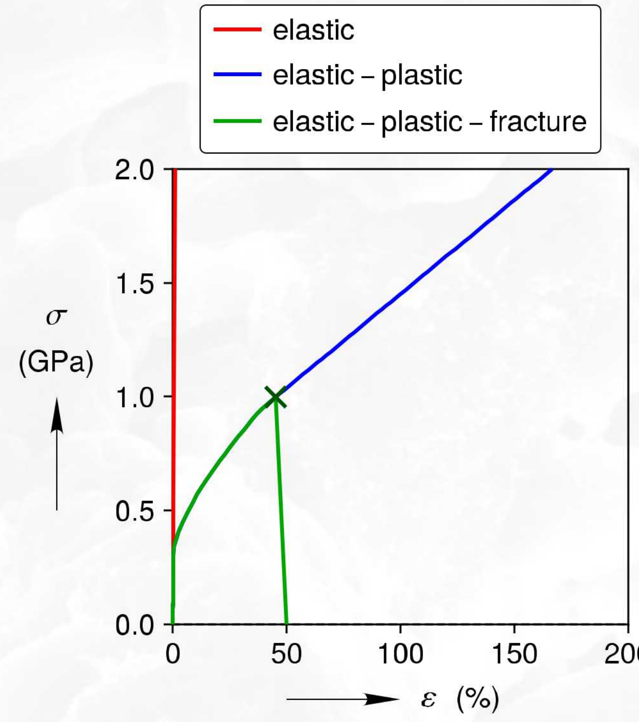
Plywood Dunnage



Carbon Steel 55-Gallon Drum



Stainless Steel Flanged Pipe



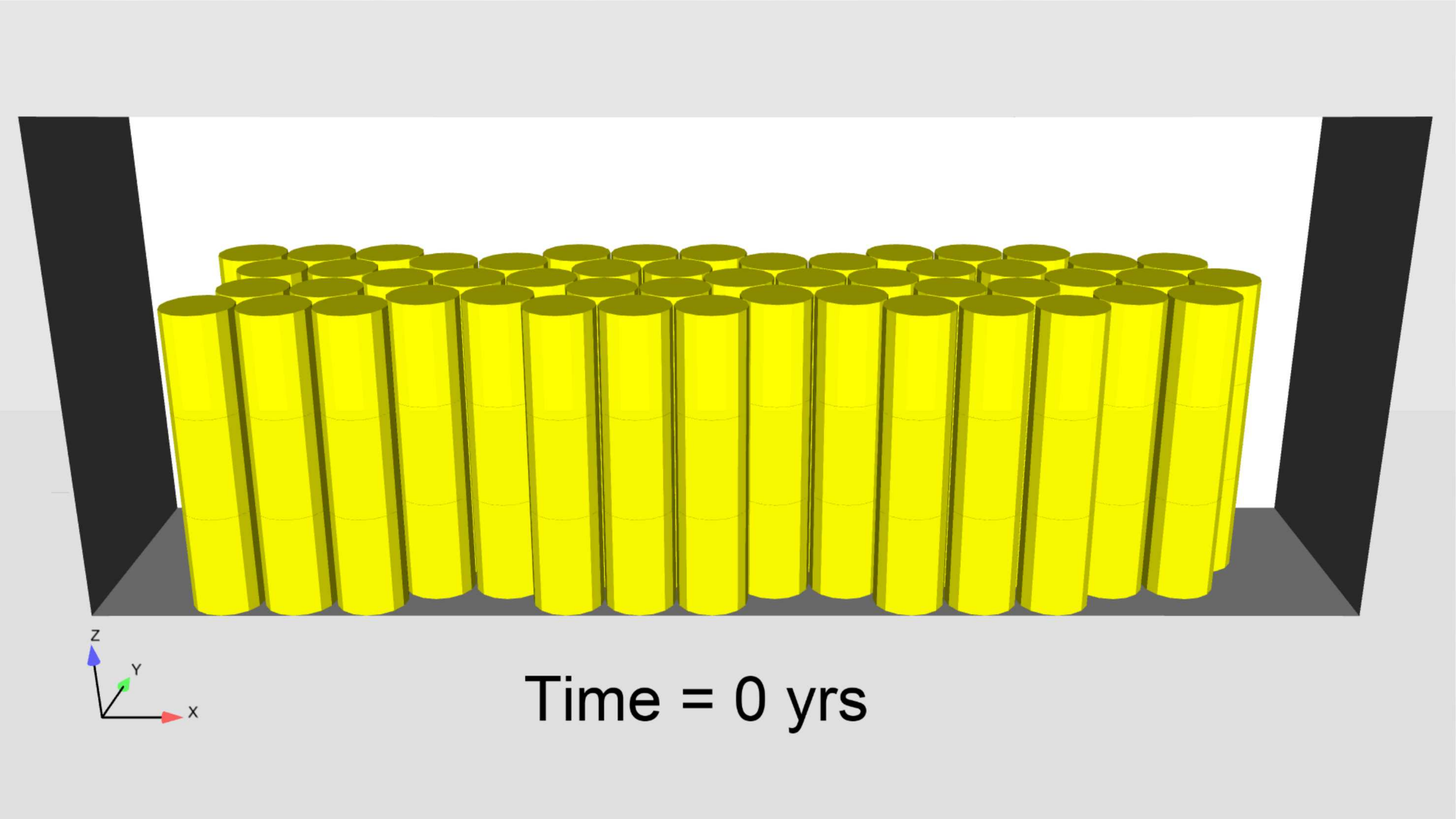
Potential Numerical Approaches

- Standard approaches:
  - Explicit Dynamics
    - Robust
    - Issue: time step is ~1 μs
  - Implicit Quasi-statics
    - Relatively robust, arbitrarily large time steps
    - Issue: solver cannot converge due to rigid body translations
  - Implicit Dynamics
    - Relatively unused, arbitrarily large time steps
    - Issue: contact and implicit dynamics do not play nice together

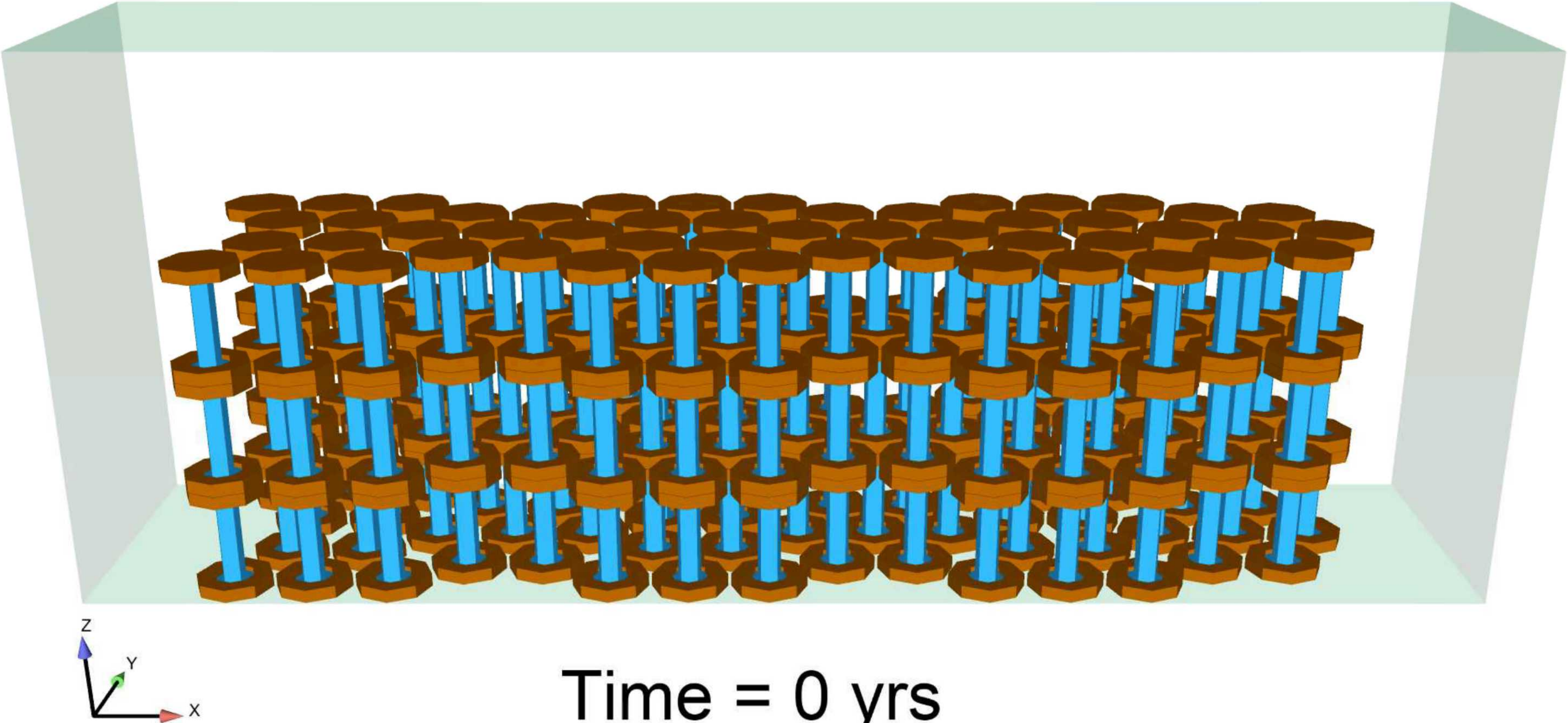
- Innovative Approaches:
  - Uncouple geomechanics from canister deformation
    - Enables explicit dynamics
    - Issue: difficult to determine final state
  - Speed up salt viscoplasticity
    - Enables explicit dynamics
    - Issue: cannot go too fast

Results

Elastic Canisters

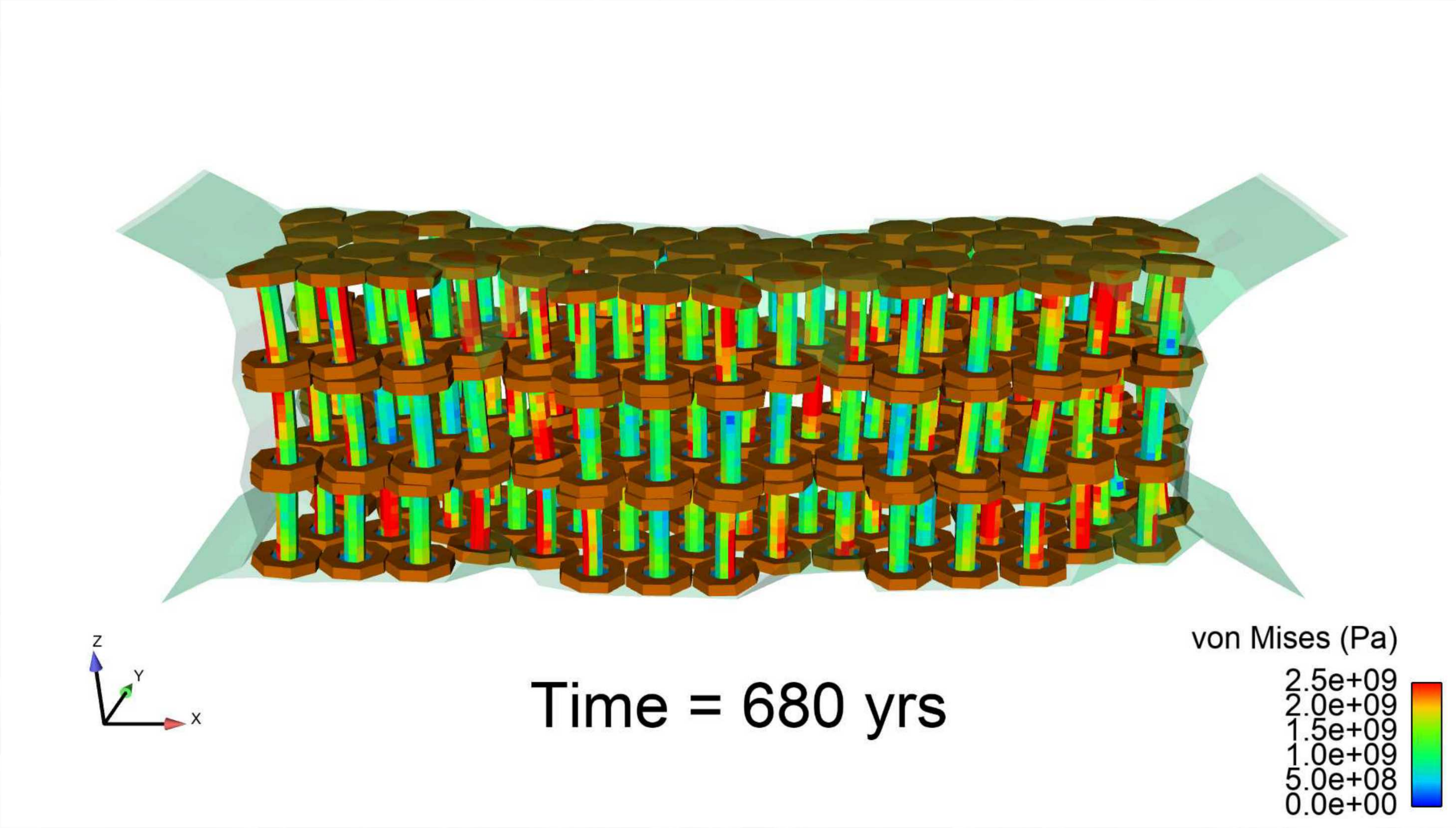


Elastic Canisters

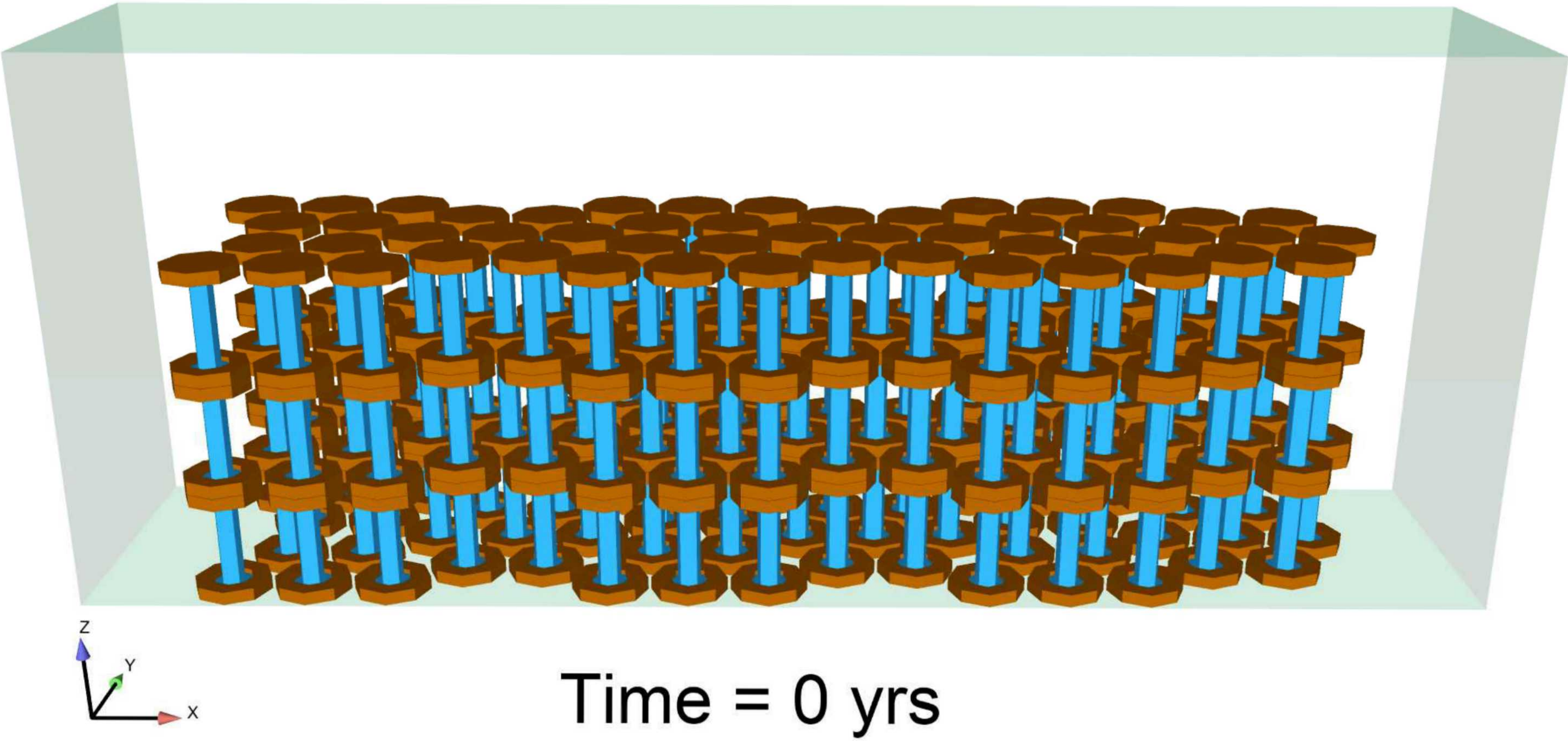


Time = 0 yrs

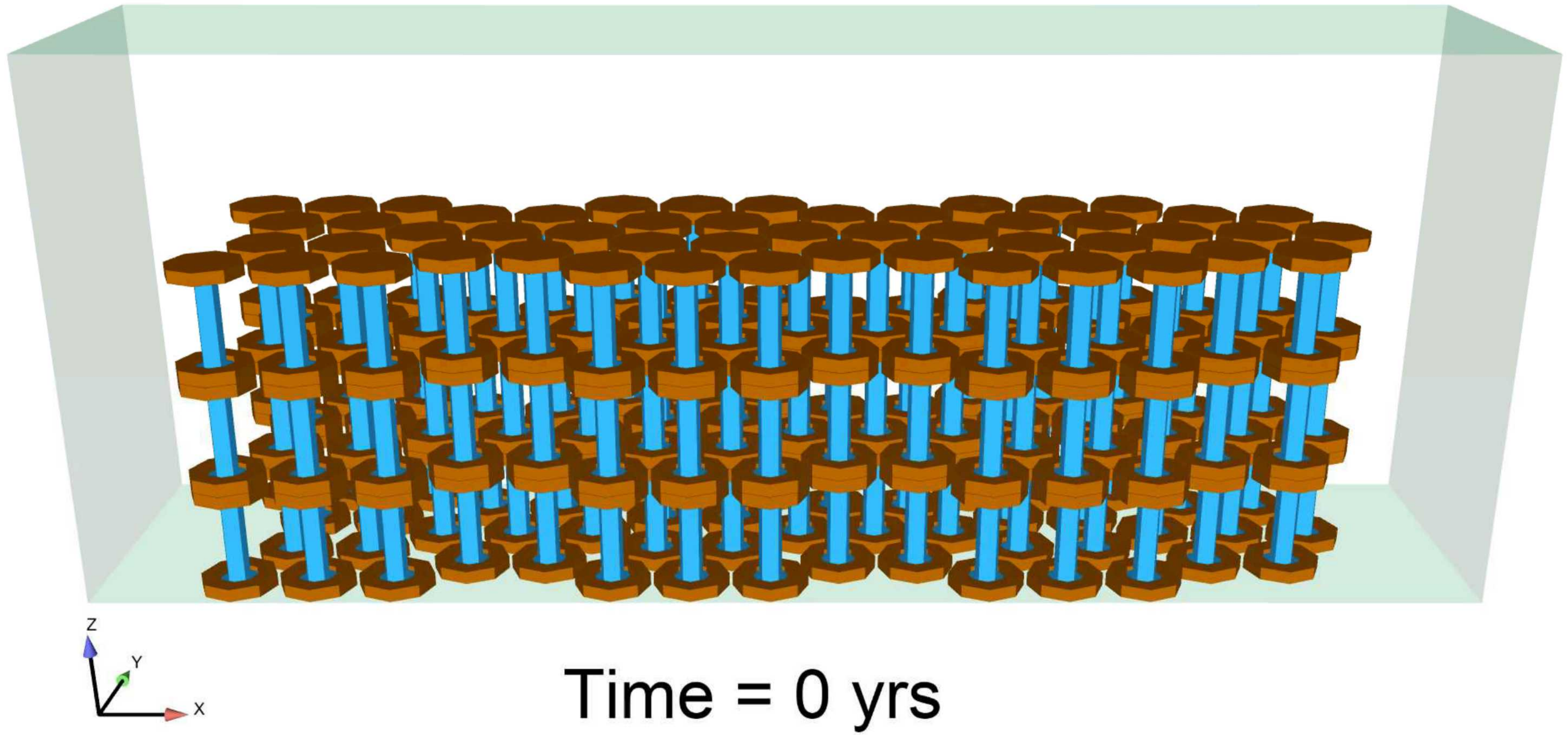
Elastic Canisters



Elastic-Plastic Canisters

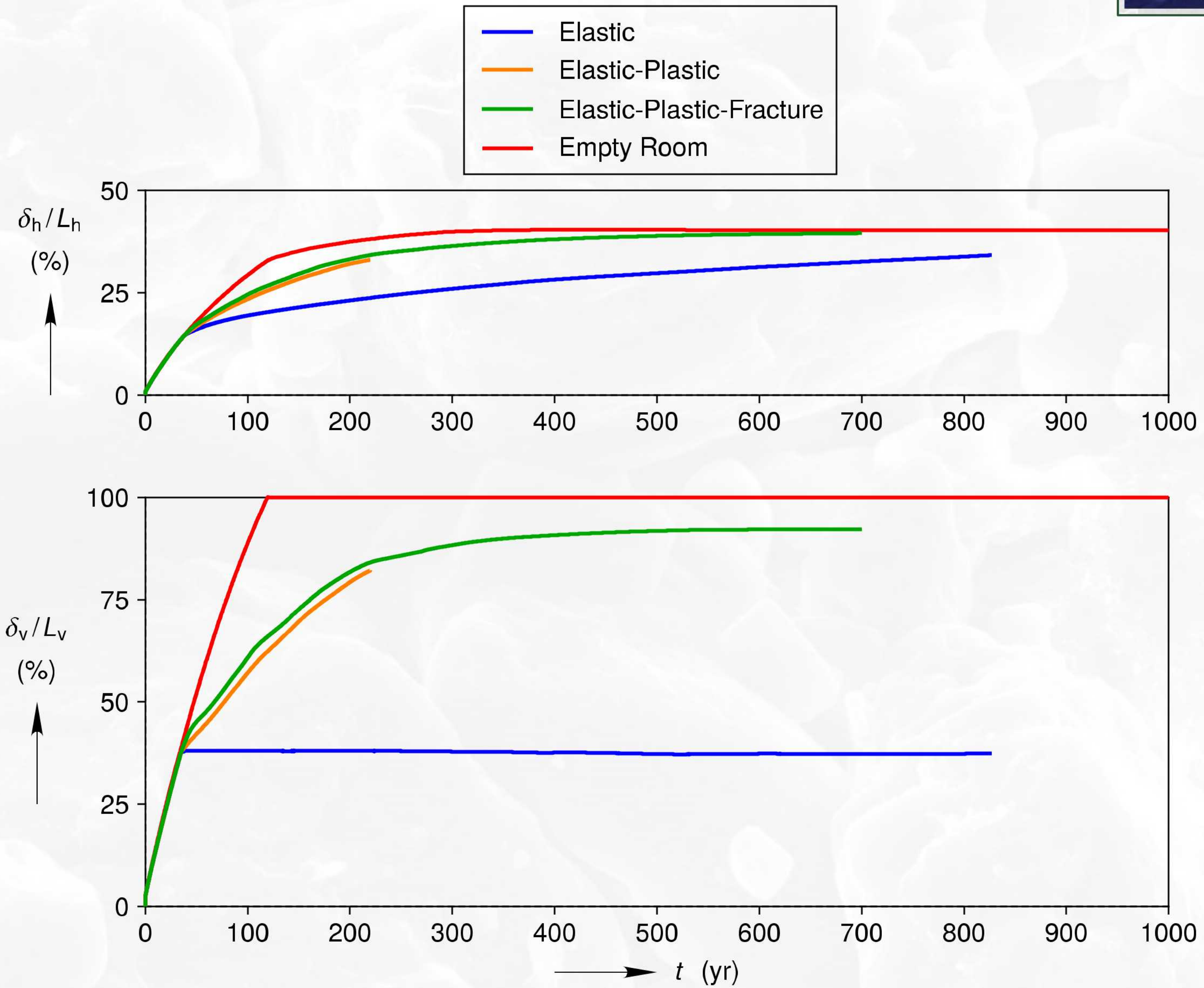


Elastic-Plastic-Fracturing Canisters

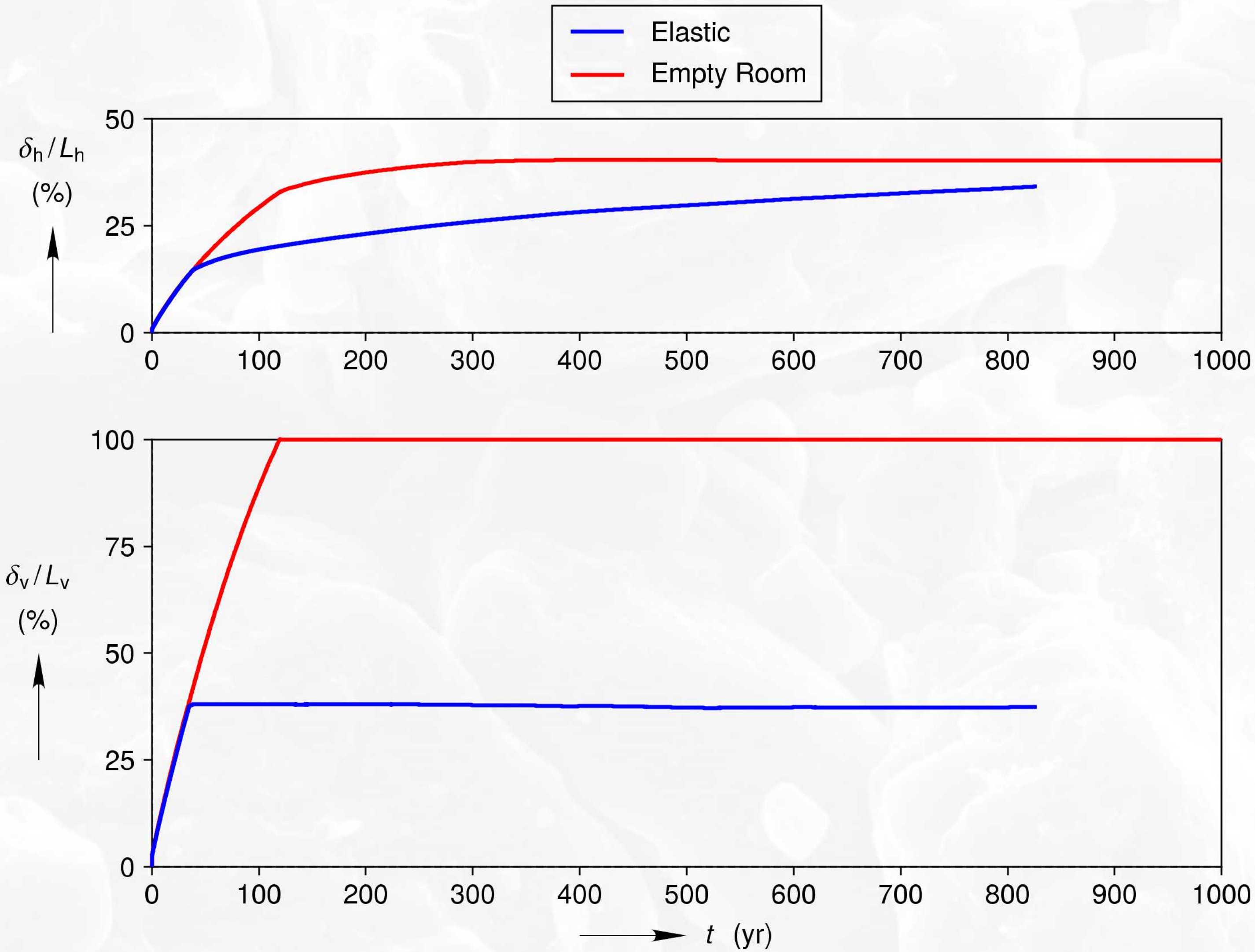


Time = 0 yrs

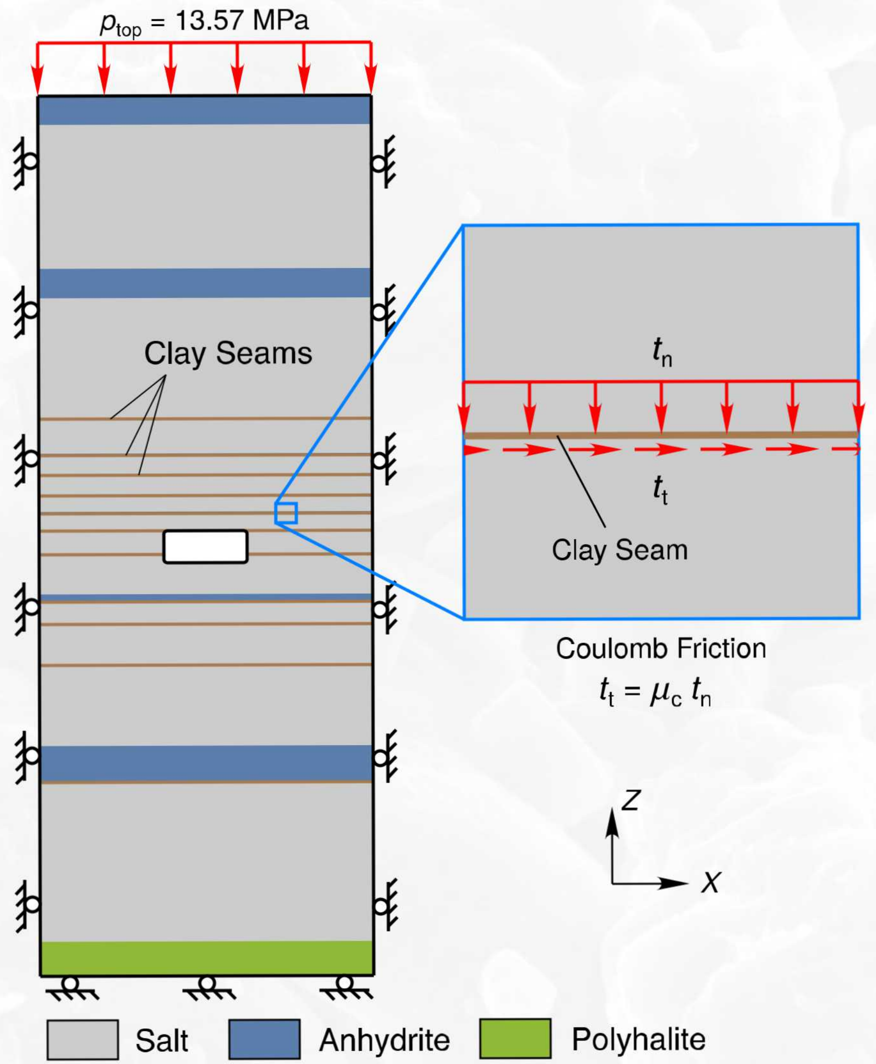
Quantitative Comparisons



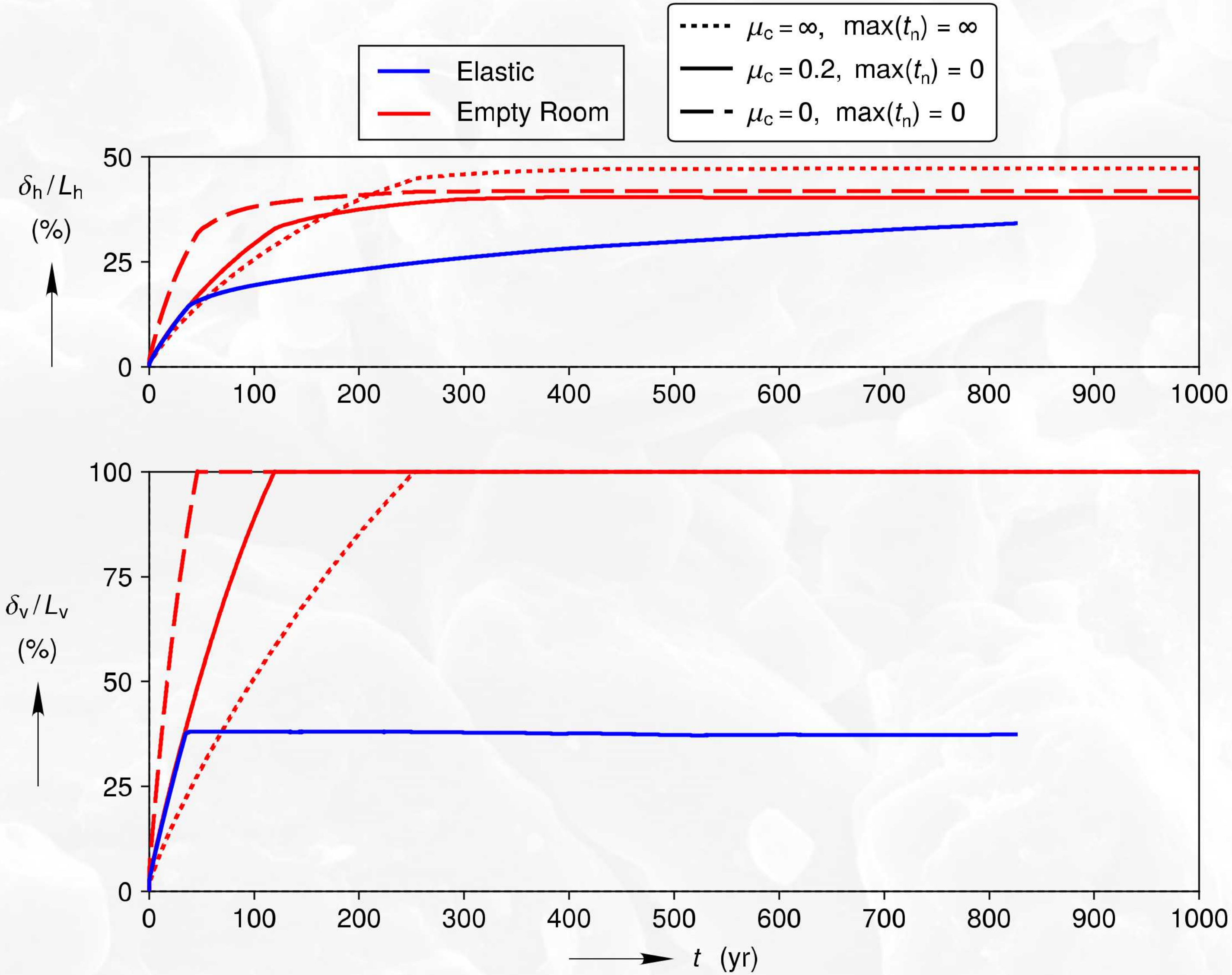
Quantitative Comparisons



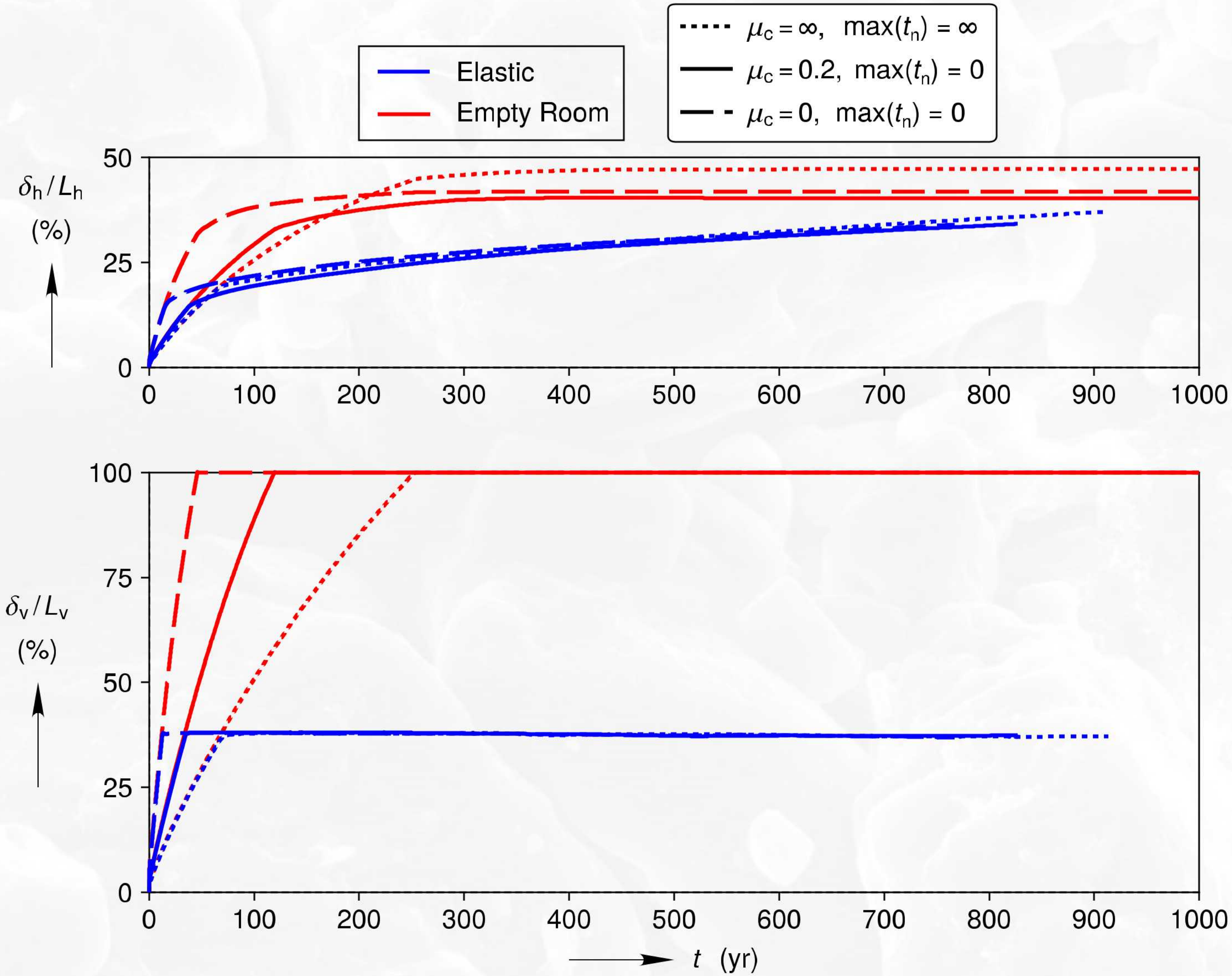
Impact of Clay Seams



Impact of Clay Seams



Impact of Clay Seams



Summary
and
Potential Future Work

Summary

- Explicitly modeled each canister and sped up the salt viscoplasticity to squeeze 1000’s of years into seconds
- Elastic canisters had highest horizontal closure rate at 800 yr, but the stresses were unreasonably high.
- Elastic-Plastic canisters deformed in a highly heterogeneous manner, calling homogenization into question.
- Elastic-Plastic-Fracturing canisters were almost identical to Elastic-Plastic canisters and similar to an empty room.
- Glued clay seams produce most empty room horizontal closure, but elastic canisters are fairly insensitive to clay seams.
- More than 50 % horizontal closure appears unlikely.

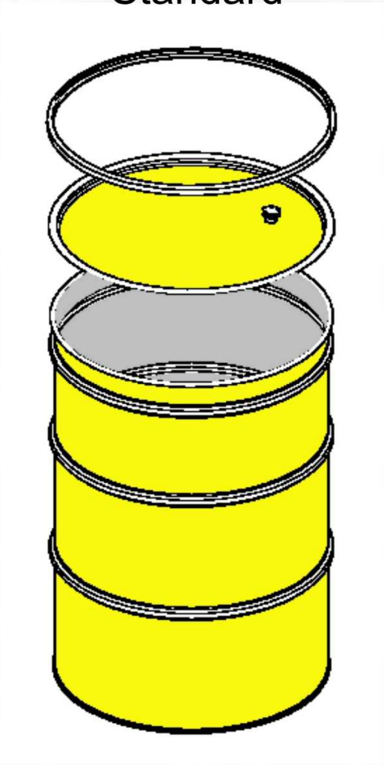
Potential Future Work

- Numerics
  - Investigate why plywood disappears
  - Stop half canisters from penetrating the walls
  - Refine mesh
- Geomechanics
  - Switch to lower horizon and/or rooms near edges of panels
  - Attempt to include roof falls
- Canisters
  - Adjust stainless steel parameters to match published data
  - Build a homogenized canister model to compare against
  - Vary frictional behavior
  - Add viscous effects to stainless steel and plywood
  - Add MgO sacks
  - Include gas pressure due to degradation
  - Include more canister rows
  - Stack canisters off-center
  - Allow canister materials to corrode and rot

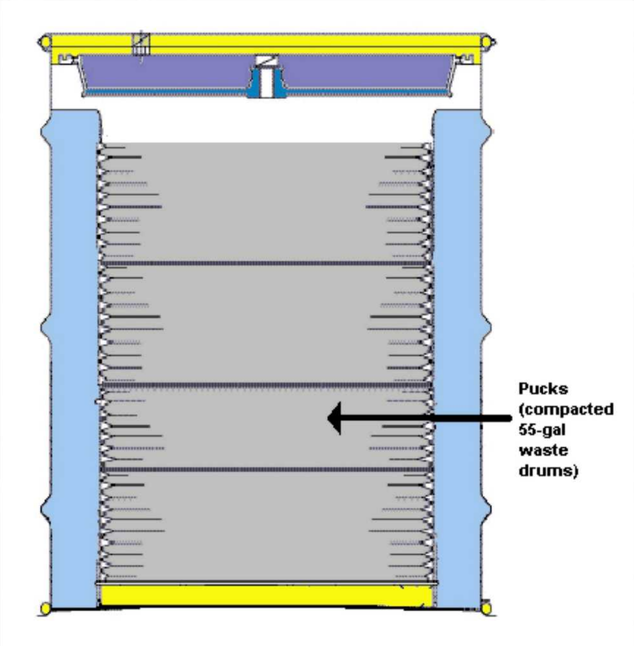
Extra Slides

Current Canister Design Examples

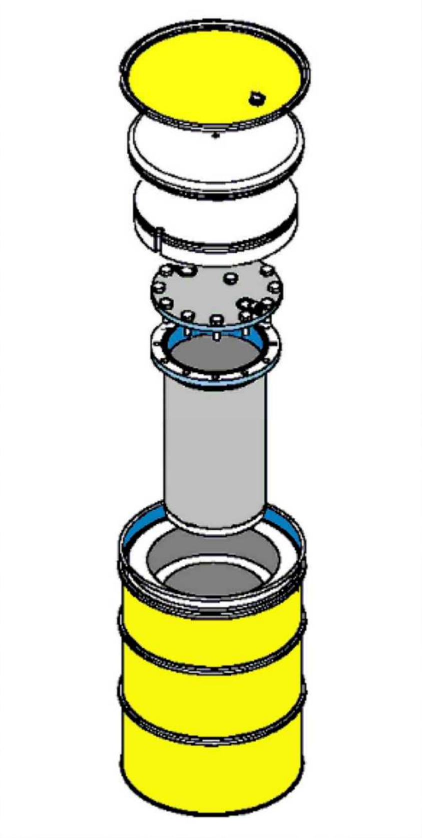
Standard



Supercompacted



Pipe Overpack



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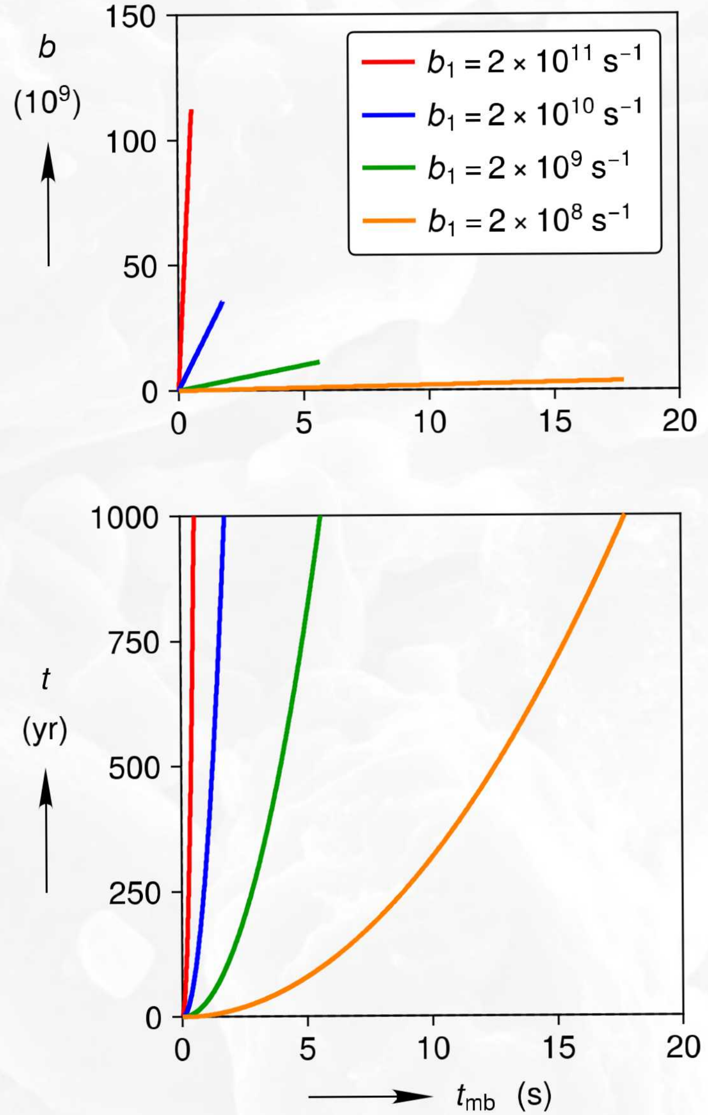
Speeding Up the Viscoplasticity

$$\dot{\varepsilon} = \dot{\varepsilon}^{\mathrm{el}} + \dot{\varepsilon}^{\mathrm{vp}} + \dot{\varepsilon}^{\mathrm{th}}$$

$$\dot{\varepsilon}^{\mathrm{vp}} \propto A b \exp\left(-\frac{Q}{RT}\right) \bar{\sigma}^{n}$$

$$\mathrm{d}t = b\,\mathrm{d}t_{\mathrm{mb}}$$

$$b = b_0 + b_1 t_{\mathrm{mb}}$$



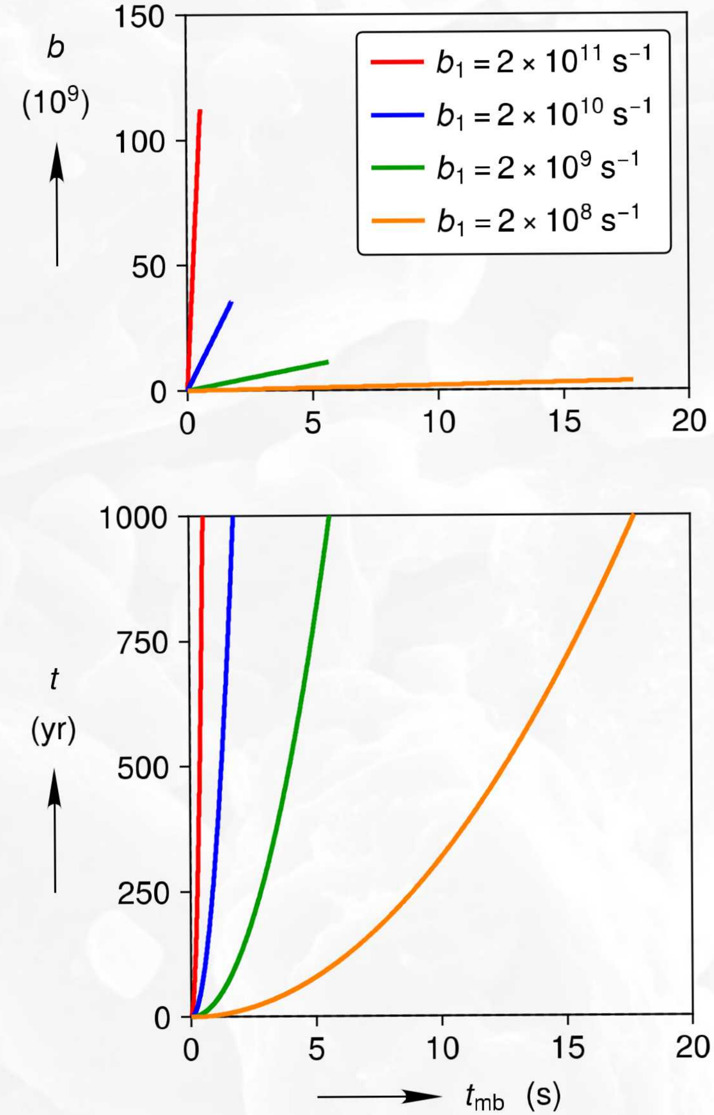
Speeding Up the Viscoplasticity

$$\dot{\varepsilon} = \dot{\varepsilon}^{\mathrm{el}} + \dot{\varepsilon}^{\mathrm{vp}} + \dot{\varepsilon}^{\mathrm{th}}$$

$$\dot{\bar{\varepsilon}}^{\mathrm{vp}} \propto A\, b \exp\left(-\frac{Q}{R\,T}\right)\, \bar{\sigma}^{n}$$

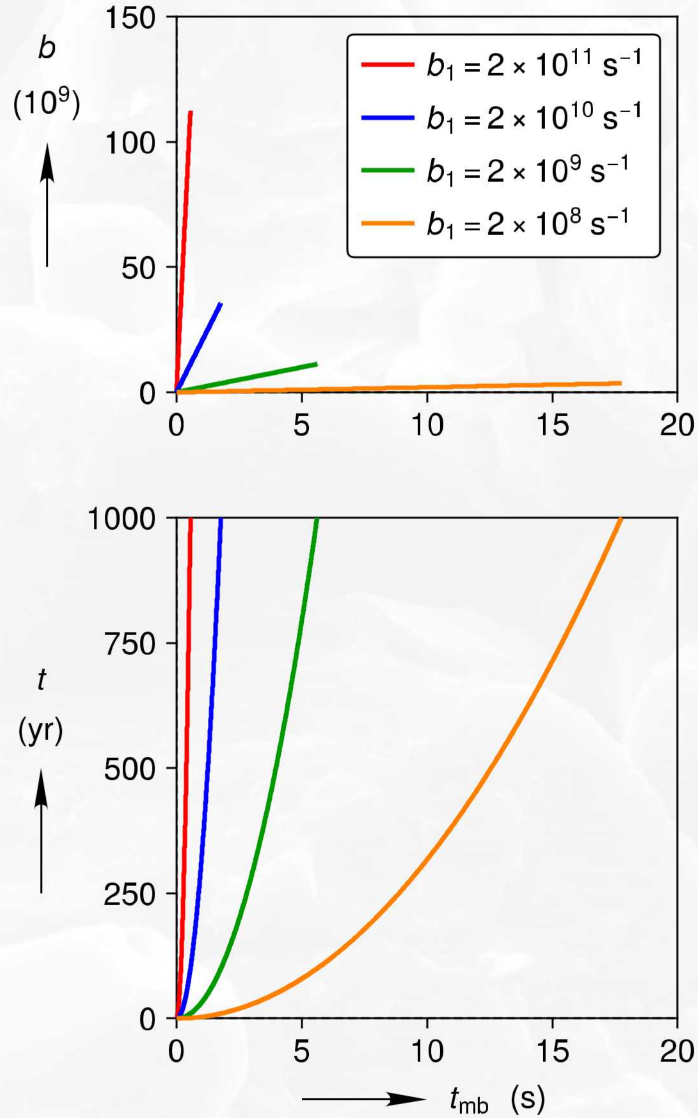
$$b = \frac{\mathrm{d}t}{\mathrm{d}t_{\mathrm{mb}}}$$

$$b = b_0 + b_1\, t_{\mathrm{mb}}$$

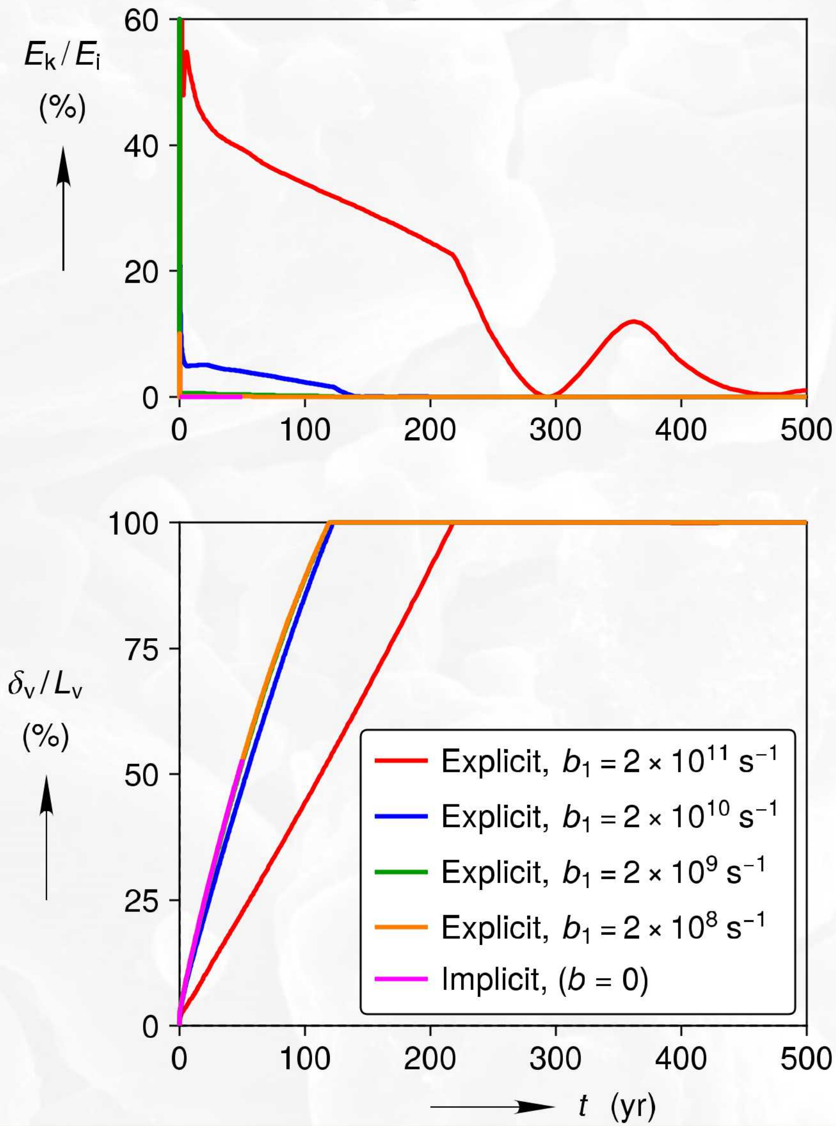


Scaling Ramp Rate Selection

$b = b_0 + b_1\, t_{mb}$



Empty Room Sims



Empty Room Mesh Convergence Study