

Status of Canister Compaction Simulations



Benjamin Reedlunn, Org. 1554

James Bean, Org. 1554

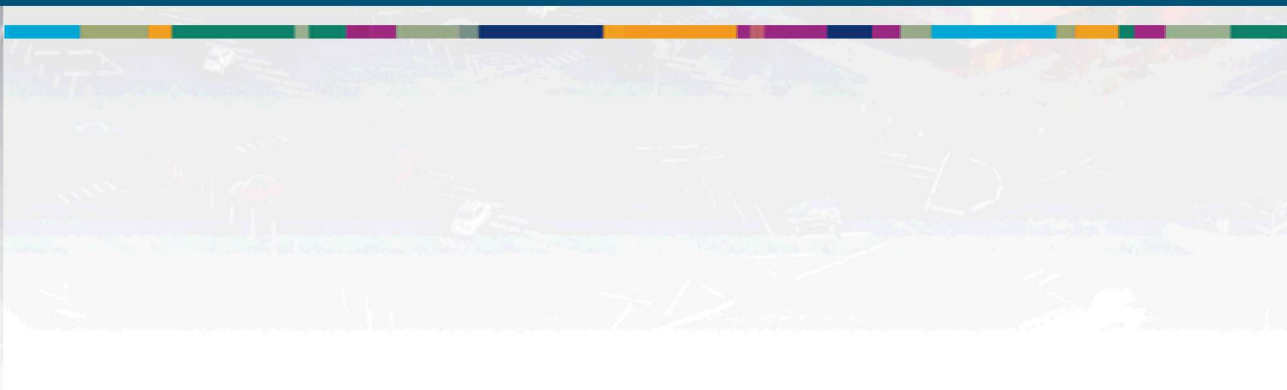


Outline

1. Background
2. Model Setup
 - a. Numerical Approach
3. Results
 - a. Elastic Canisters
 - b. Elastic-Plastic Canisters
 - c. Elastic-Plastic-Fracturing Canisters
 - d. Empty Room
4. Summary and Potential Future Work



Background



4 Standard Canisters

Schematic

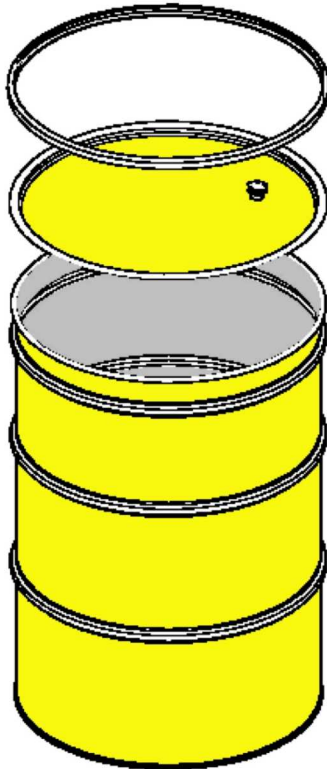


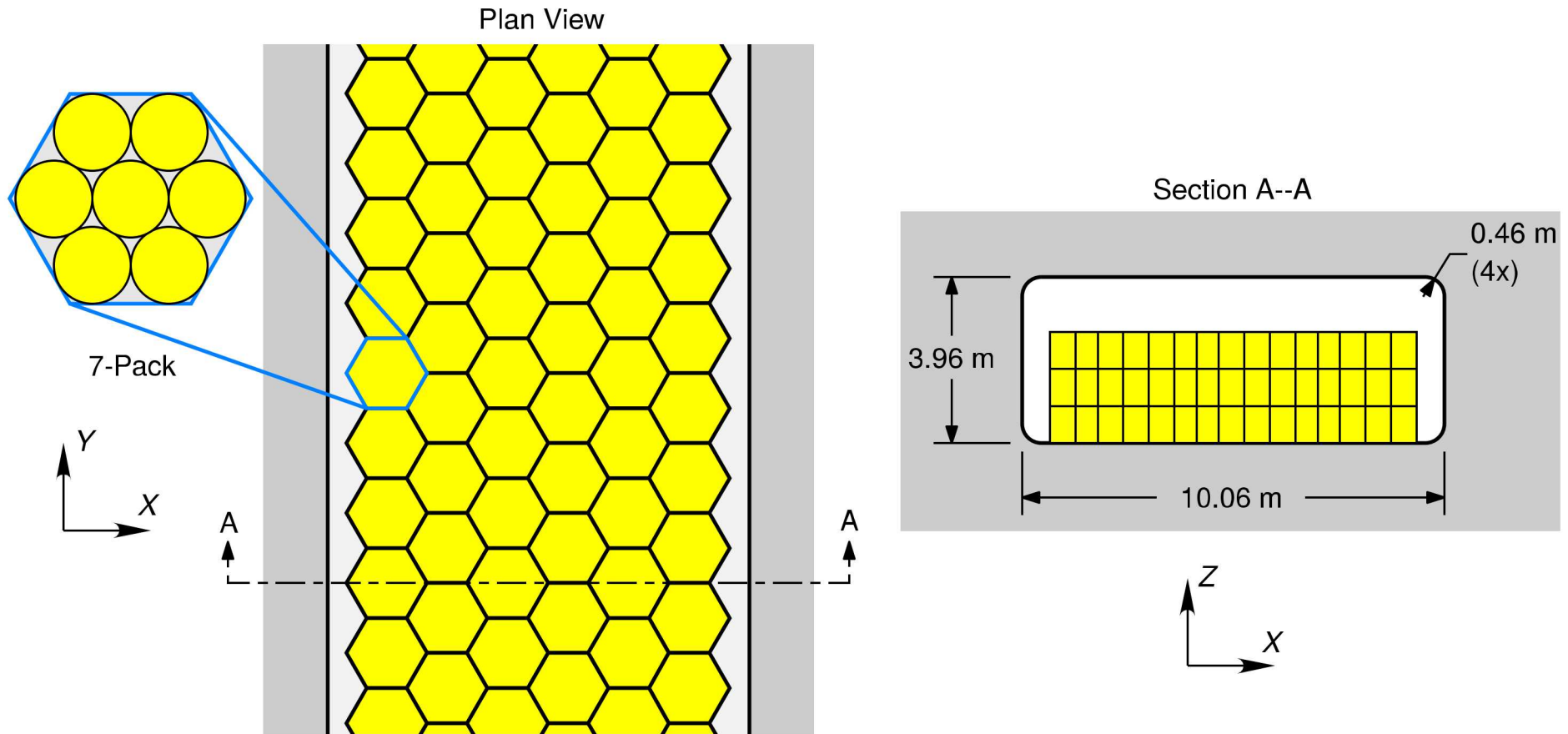
Photo
(with surrogate waste)



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

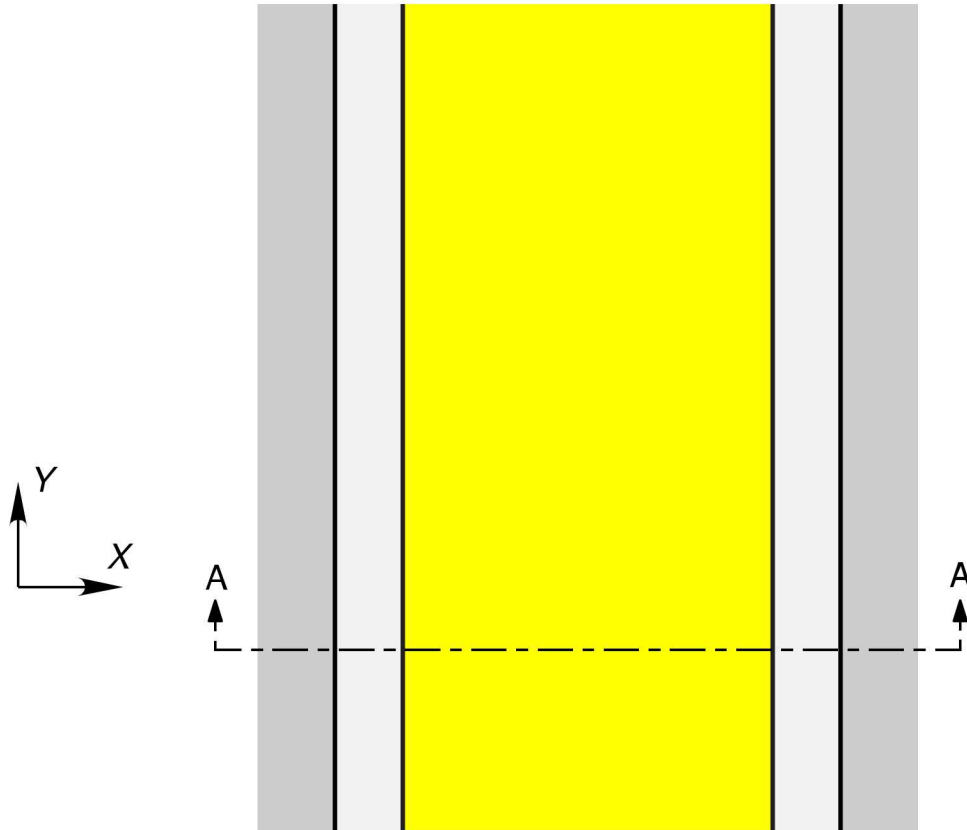
Broome, S.T., Ingraham, M.D., Flint, G.M., Hileman, M.B., Barrow, P.C., and Herrick, C.G., "Laboratory Testing of Surrogate Non-degraded Waste Isolation Pilot Plant Materials", 2016, American Rock Mechanics Assoc., ARMA 16-120

Canister Emplacement

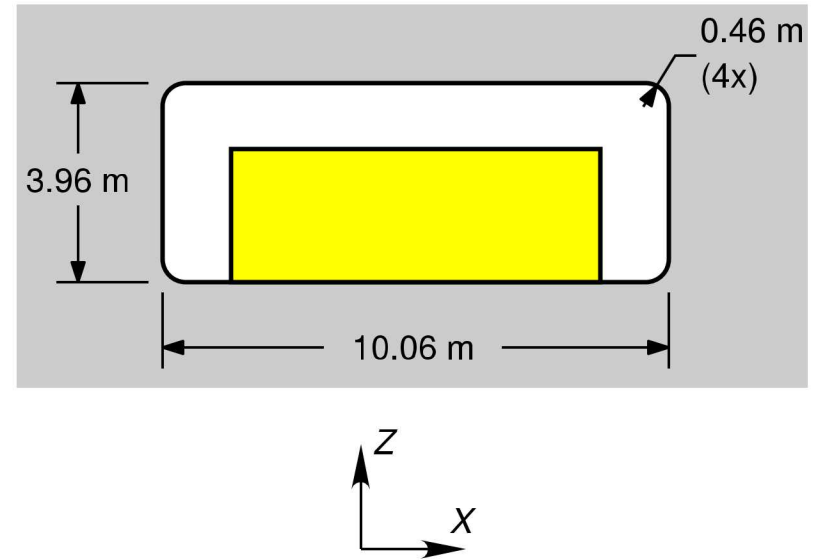


Idealized Model

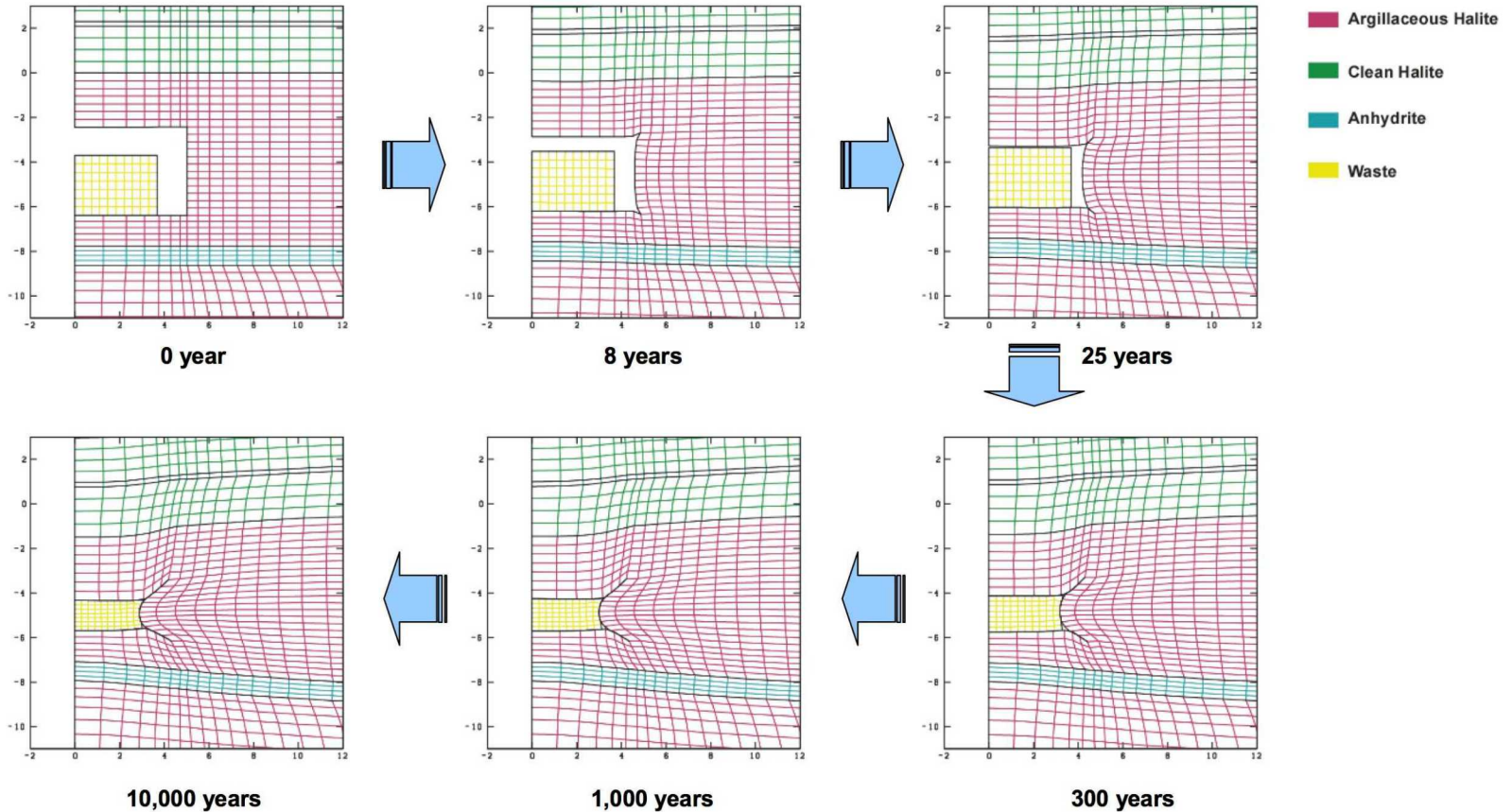
Plan View



Section A--A



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

8 | New Canister Design

Schematic

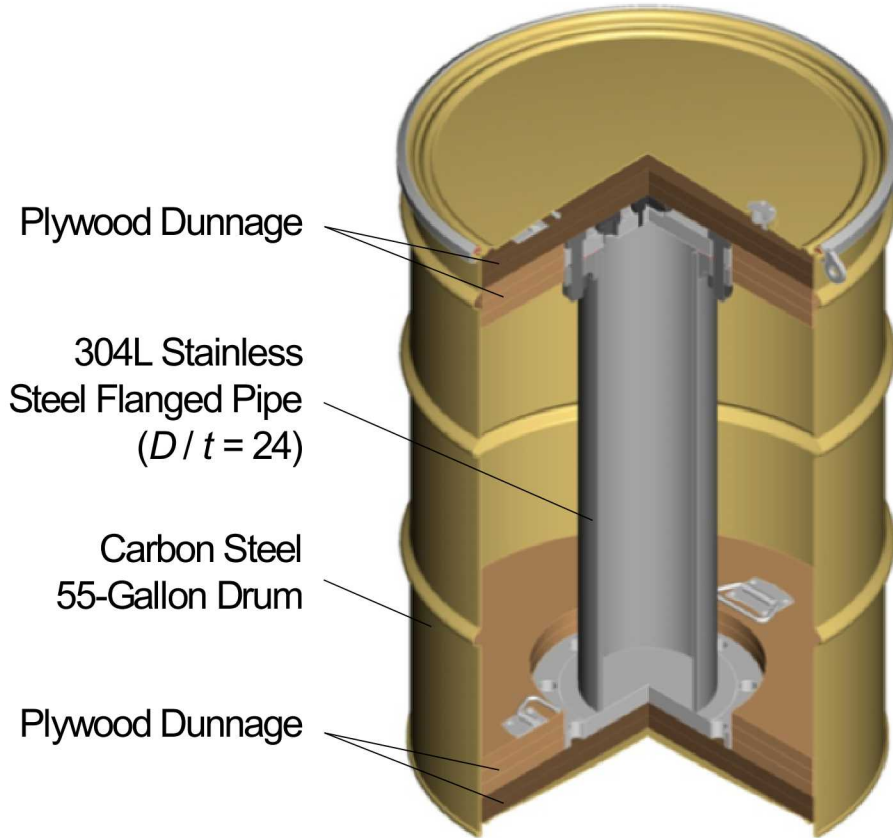
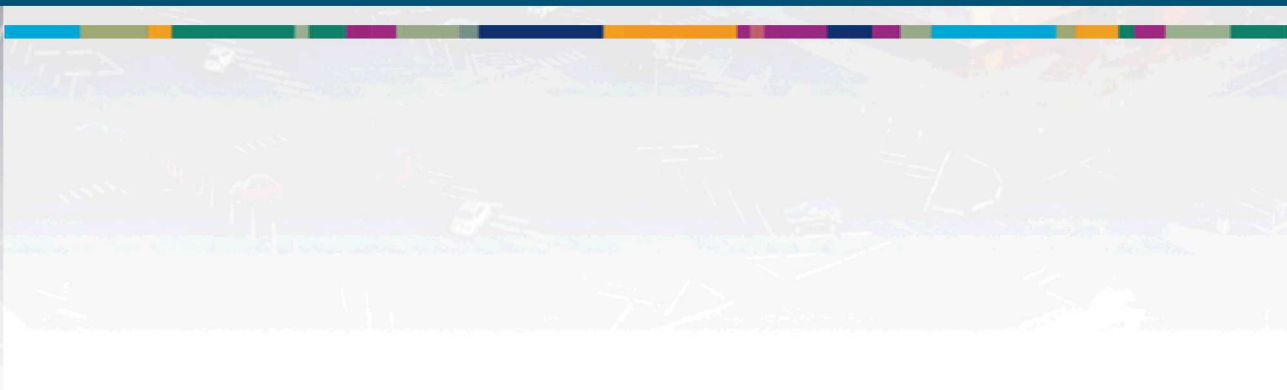


Photo
(lid and upper dunnage removed)

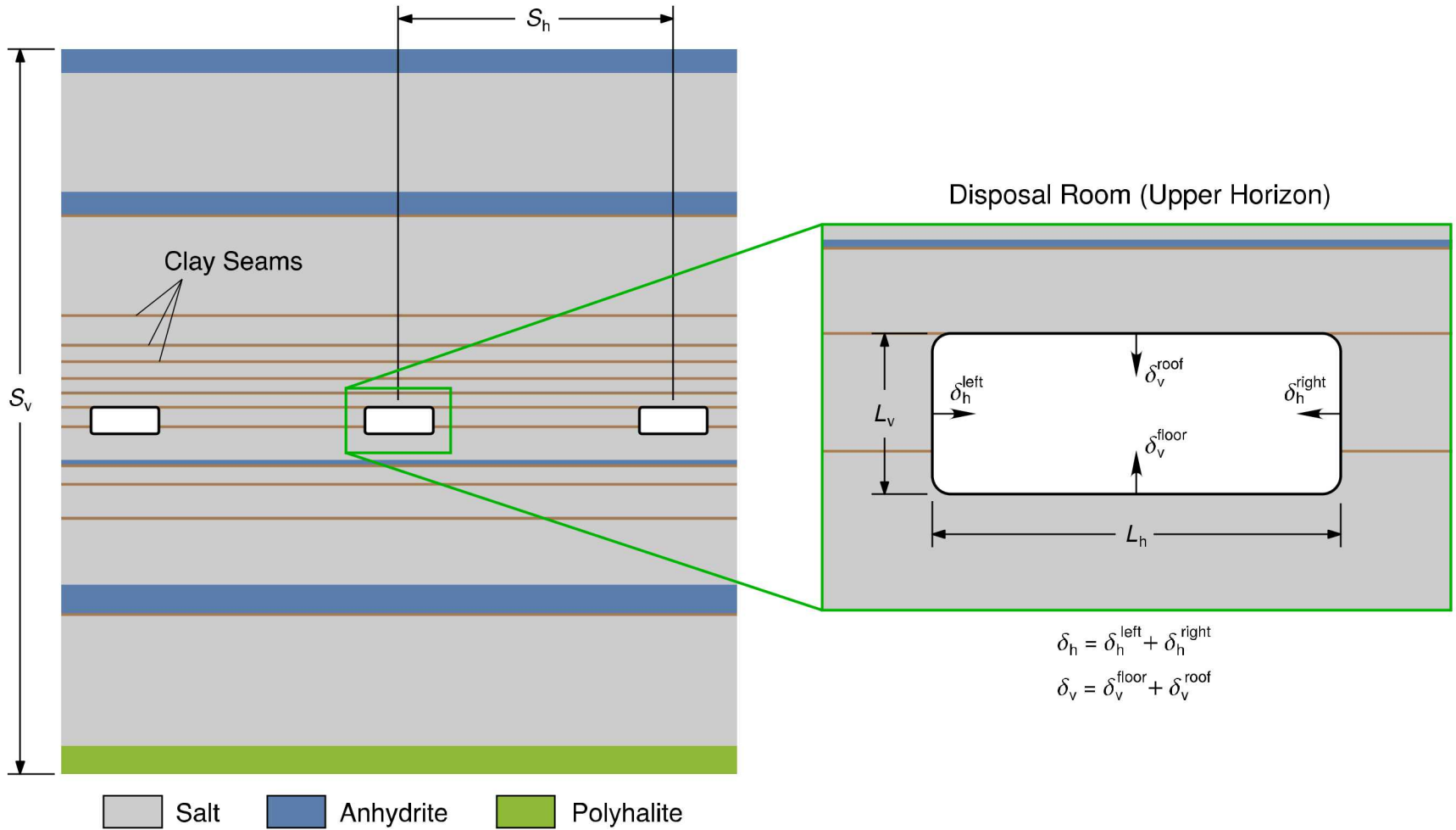




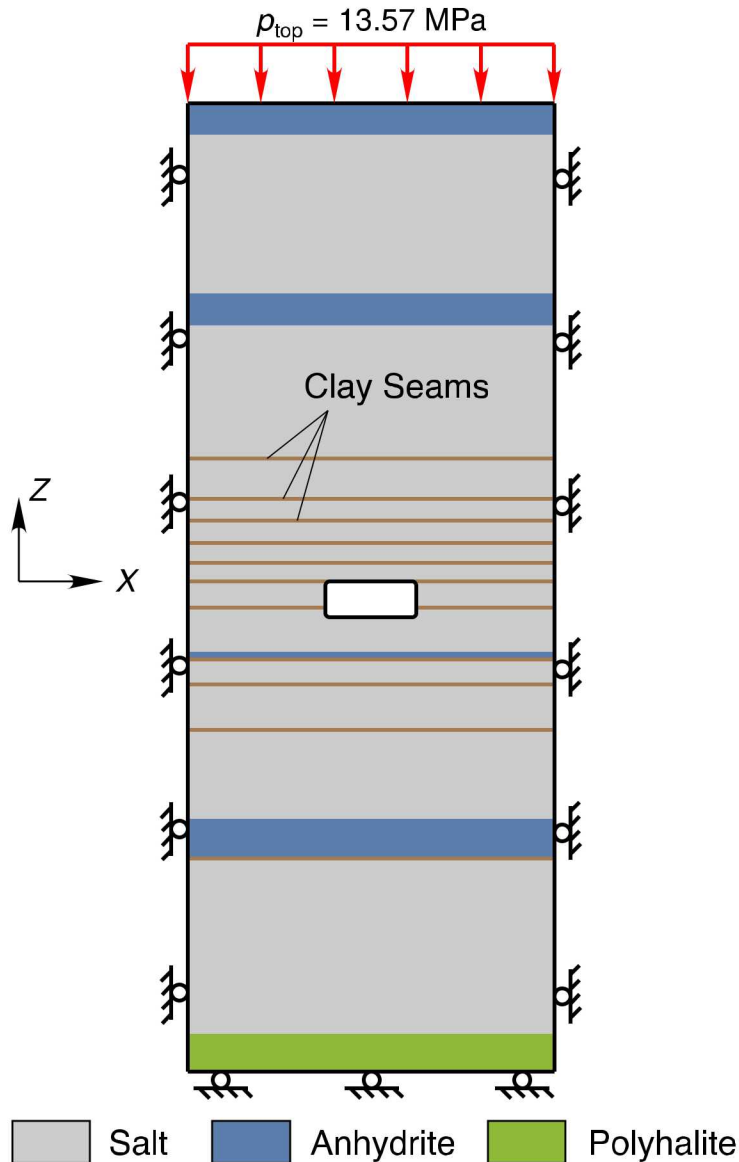
Model Description



Idealized Stratigraphy



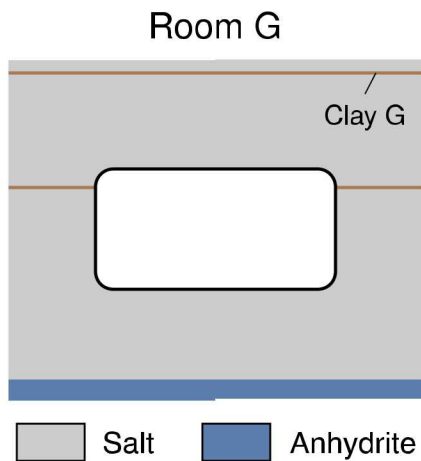
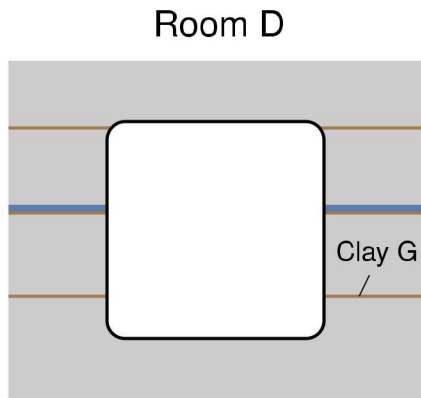
Boundary Conditions and Geomaterial Models



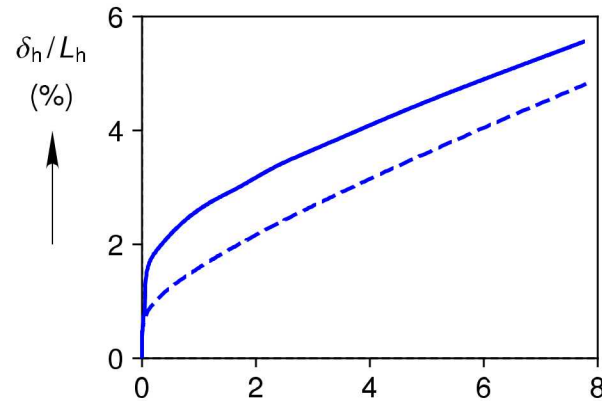
1. Salt
 - a. Munson-Dawson Model
 - b. Calibration 3B (most recent)

2. Anhydrite and Polyhalite
 - a. Elastic-Perfectly Plastic
 - b. Drucker-Prager Plasticity

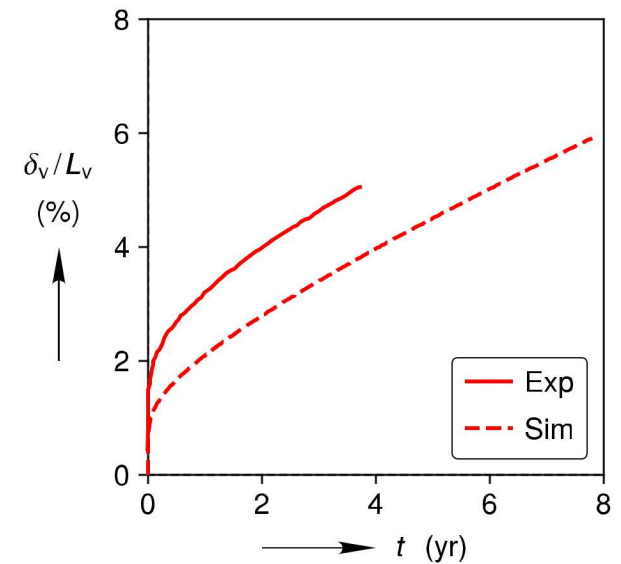
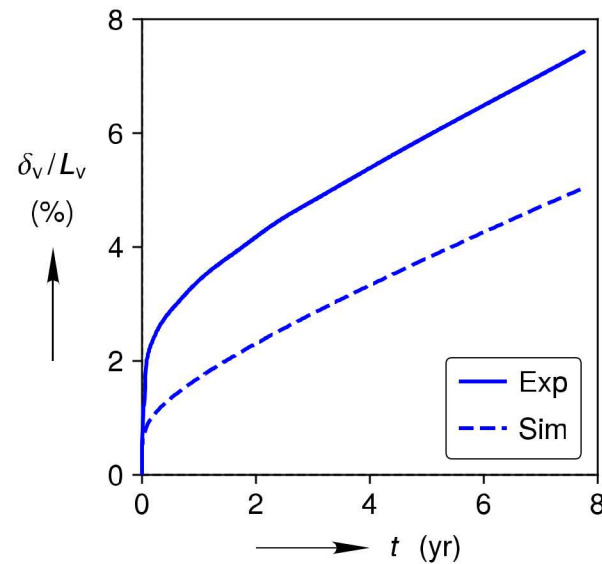
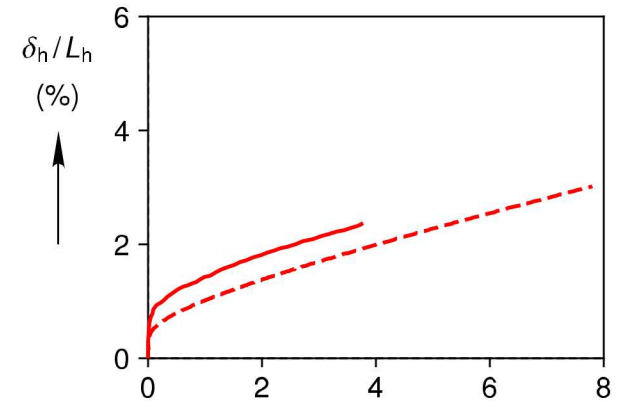
3. Clay Seams
 - a. Coulomb Friction

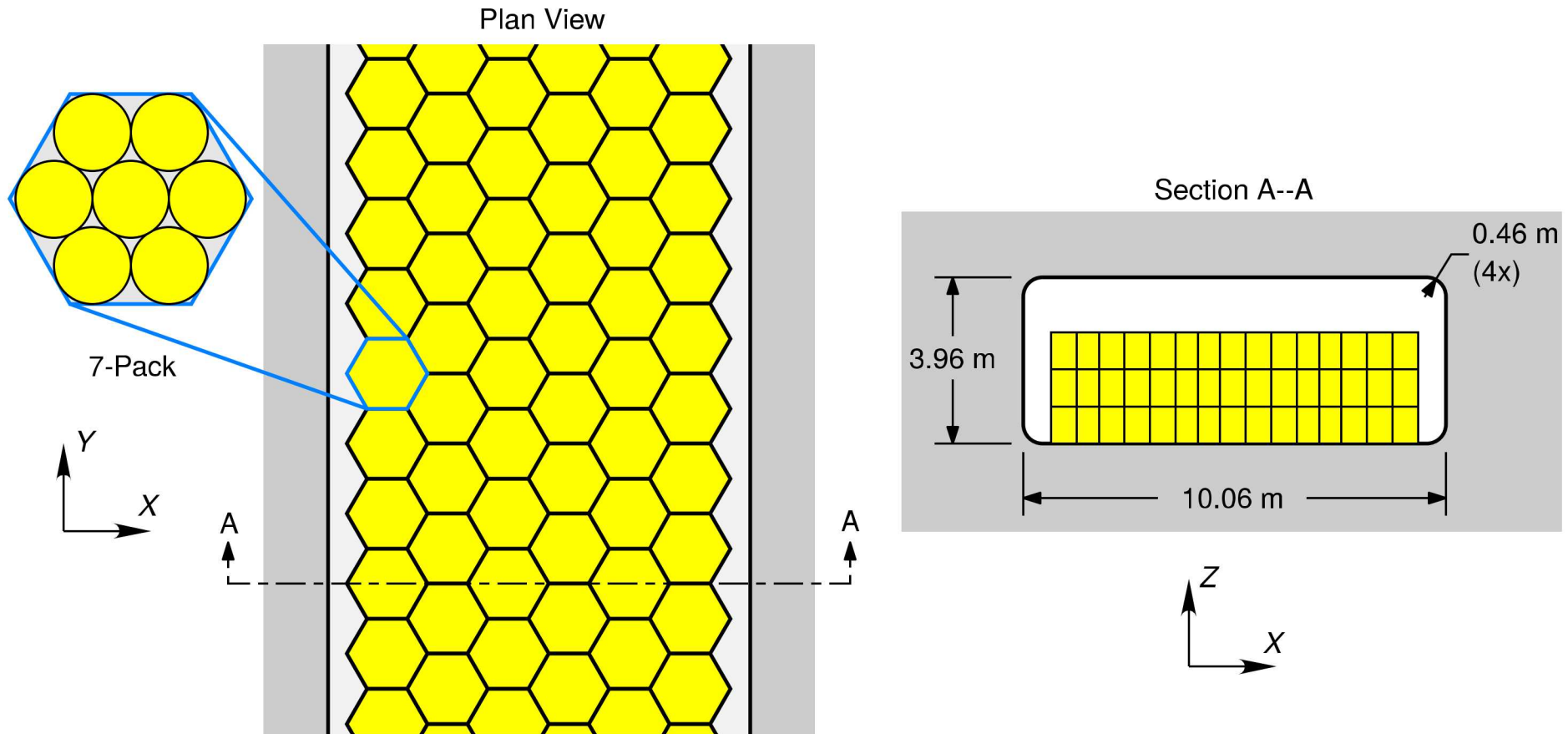


Room D

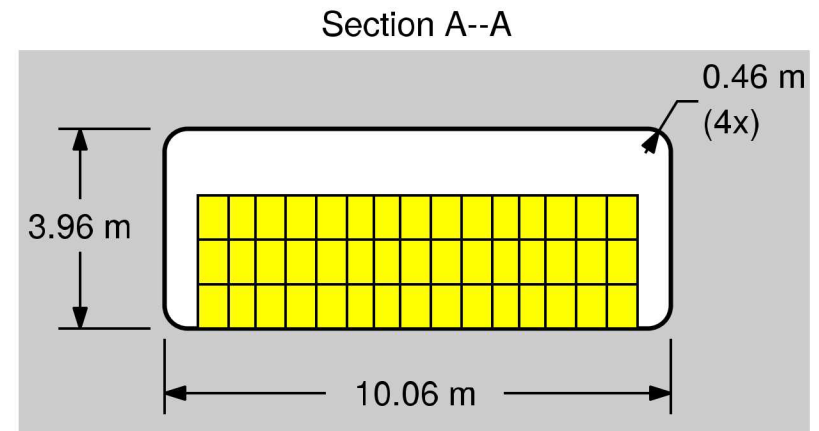
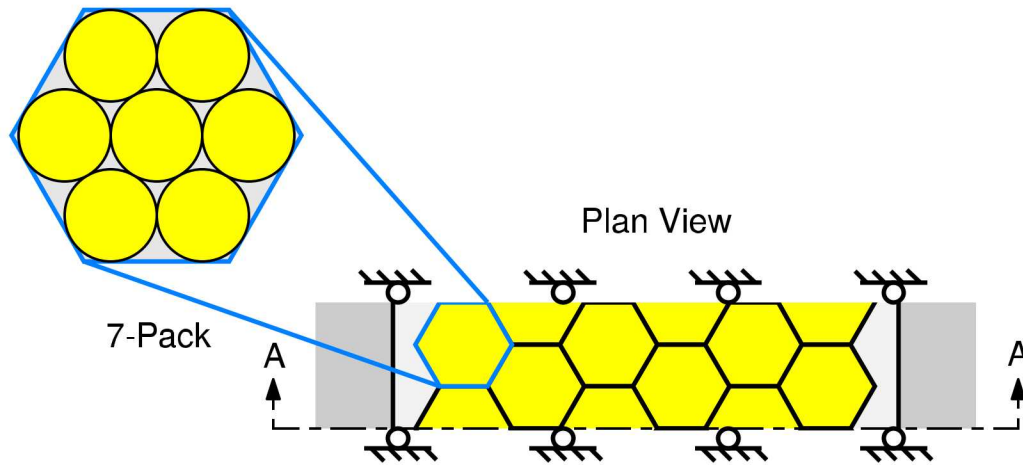


Room G

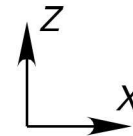
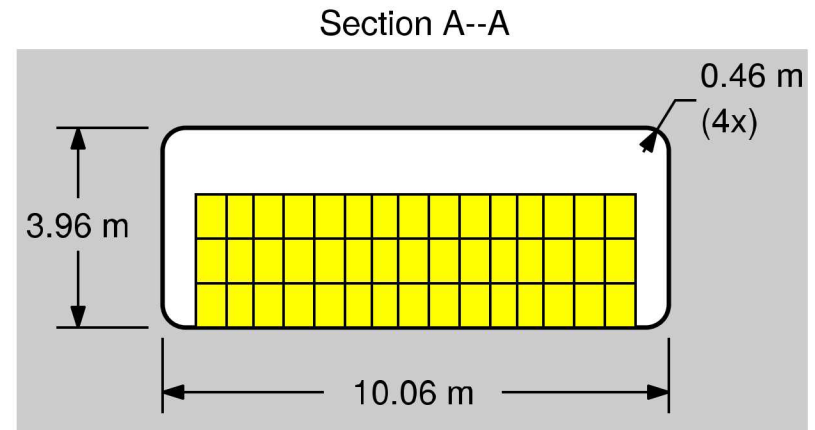
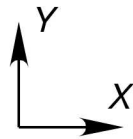
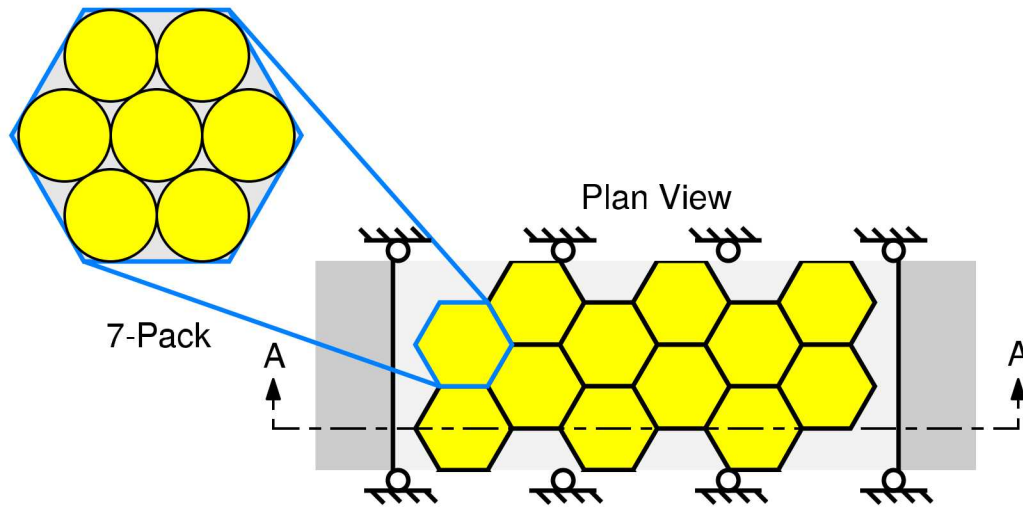




Canister Configuration and Boundary Conditions

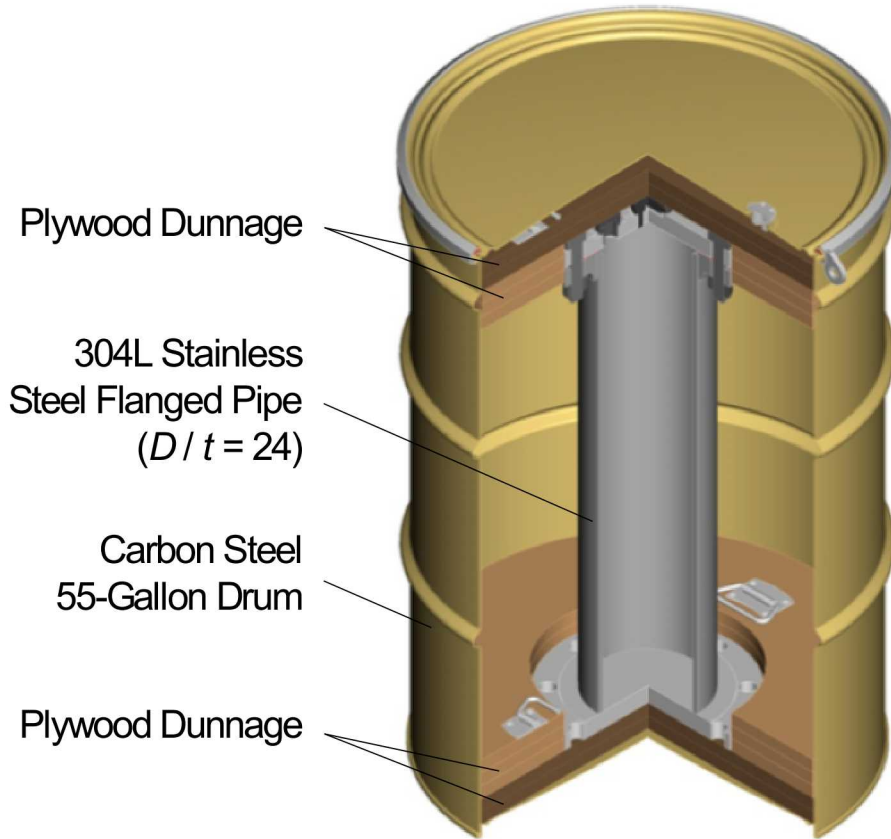


Canister Configuration and Boundary Conditions

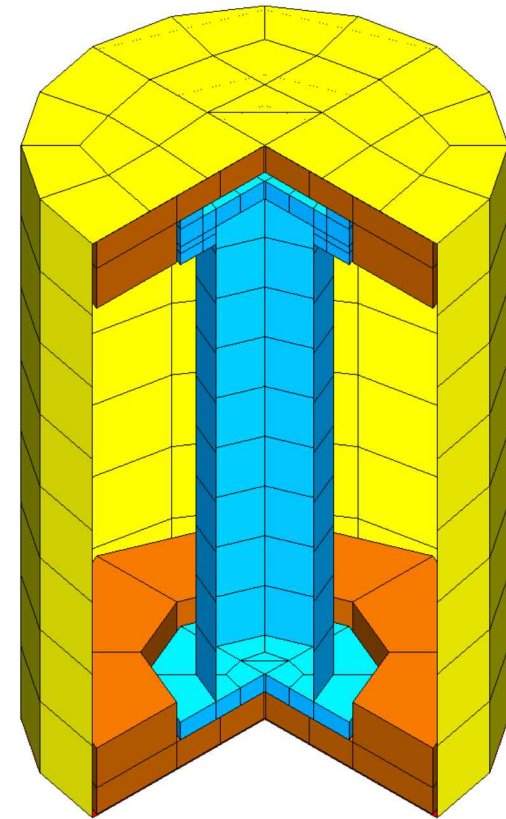


Canister Finite Element Model

Schematic

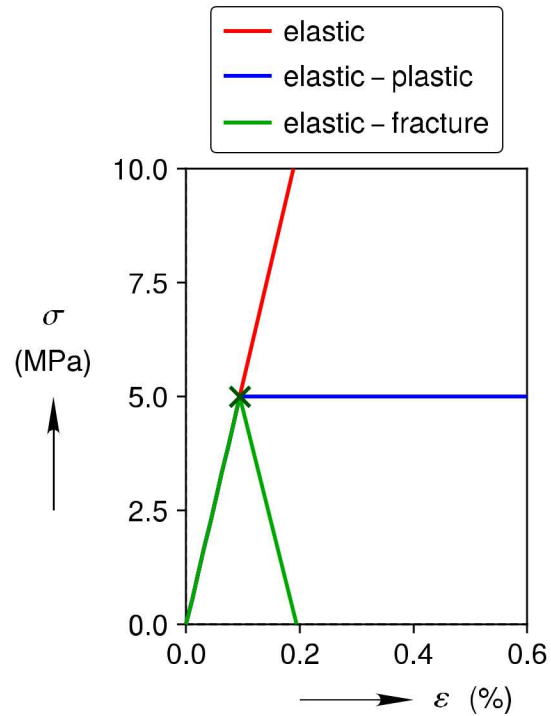


Finite Element Mesh

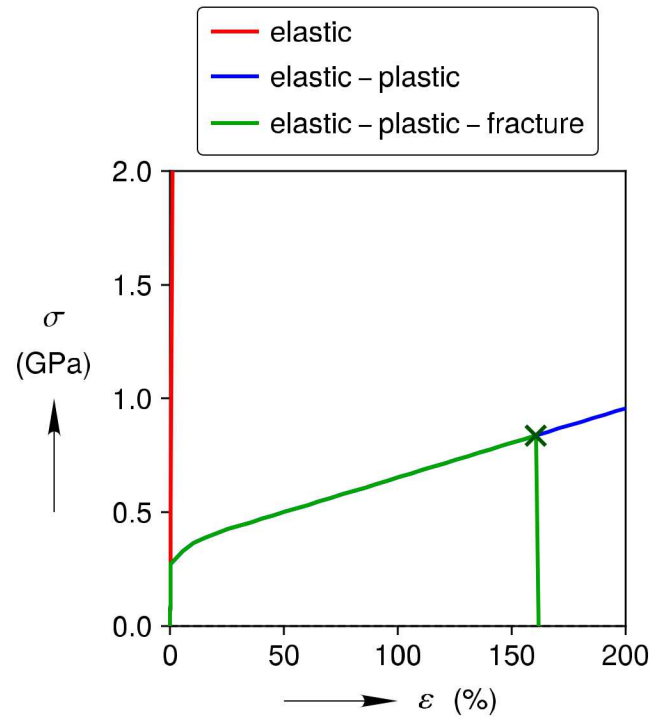


Canister Material Models: Uniaxial Tension

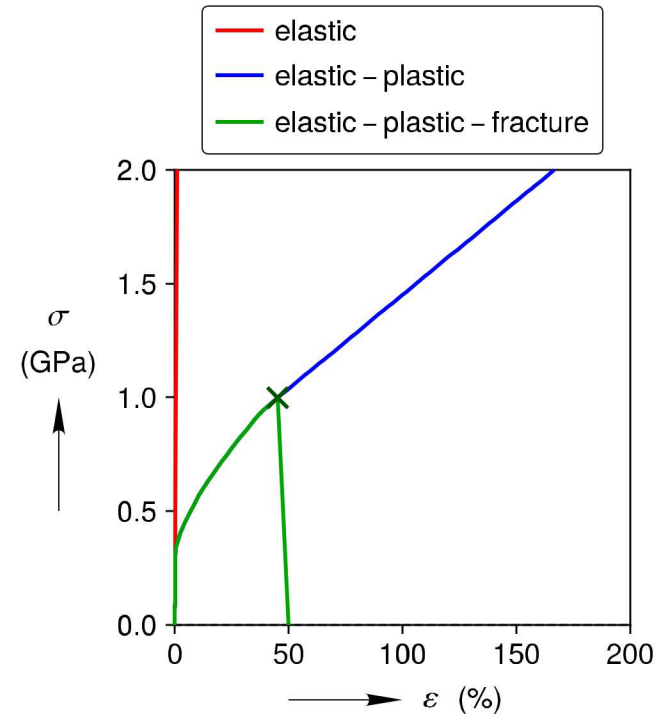
Plywood
Dunnage



Carbon Steel
55-Gallon Drum



Stainless Steel
Flanged Pipe



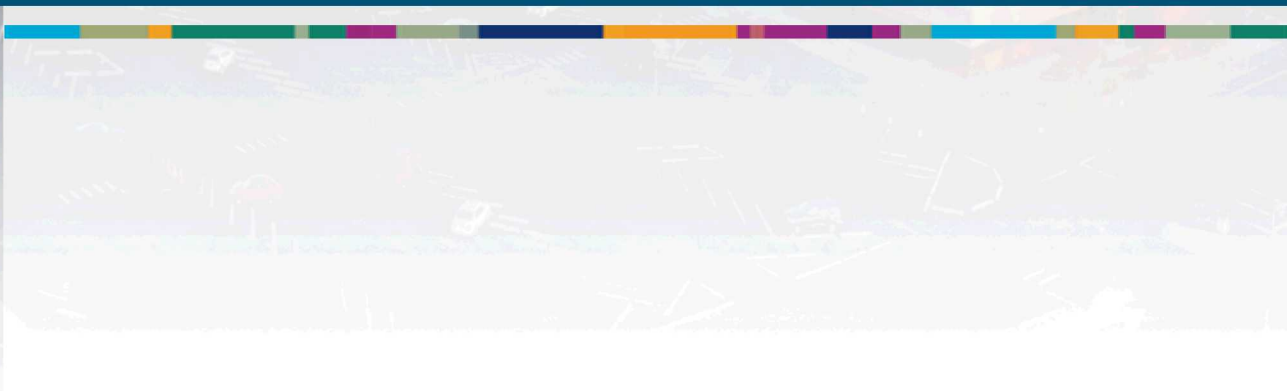
Potential Numerical Approaches

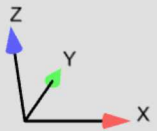
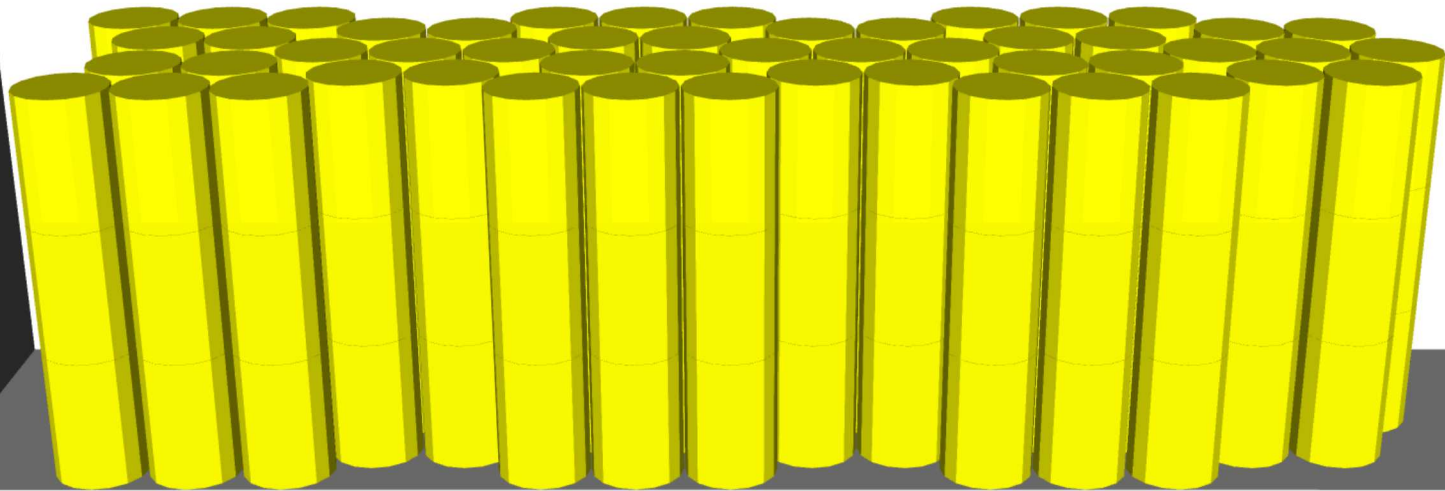
1. Standard approaches:
 - a. Explicit Dynamics
 - i. Robust
 - ii. Issue: time step is $\sim 1 \mu\text{s}$
 - b. Implicit Quasi-statics
 - i. Relatively robust, arbitrarily large time steps
 - ii. Issue: solver cannot converge due to rigid body translations
 - c. Implicit Dynamics
 - i. Relatively unused, arbitrarily large time steps
 - ii. Issue: contact and implicit dynamics do not play nice together

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

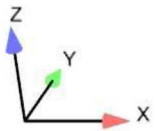
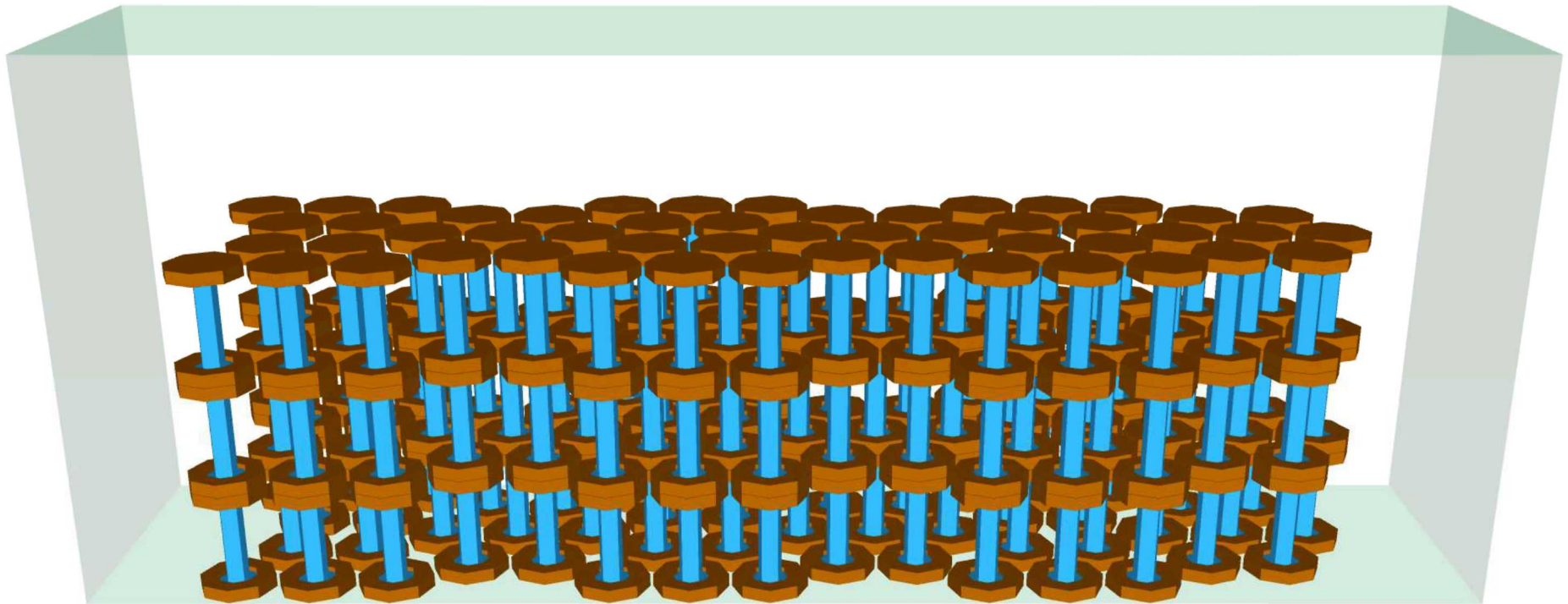


Results

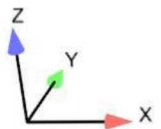
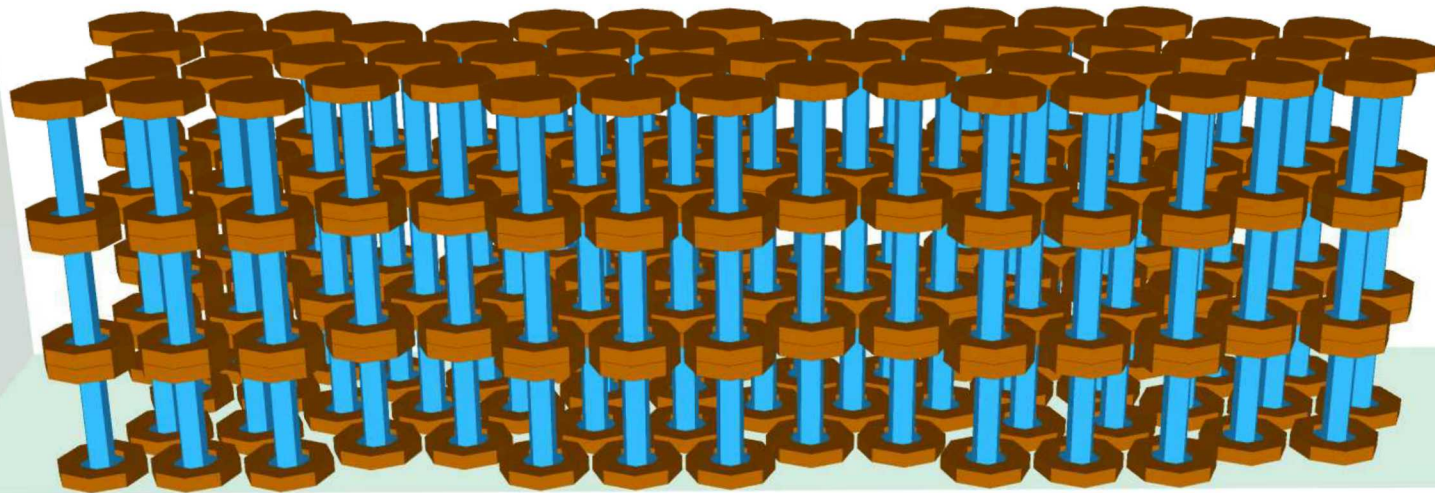




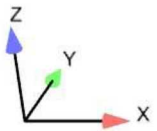
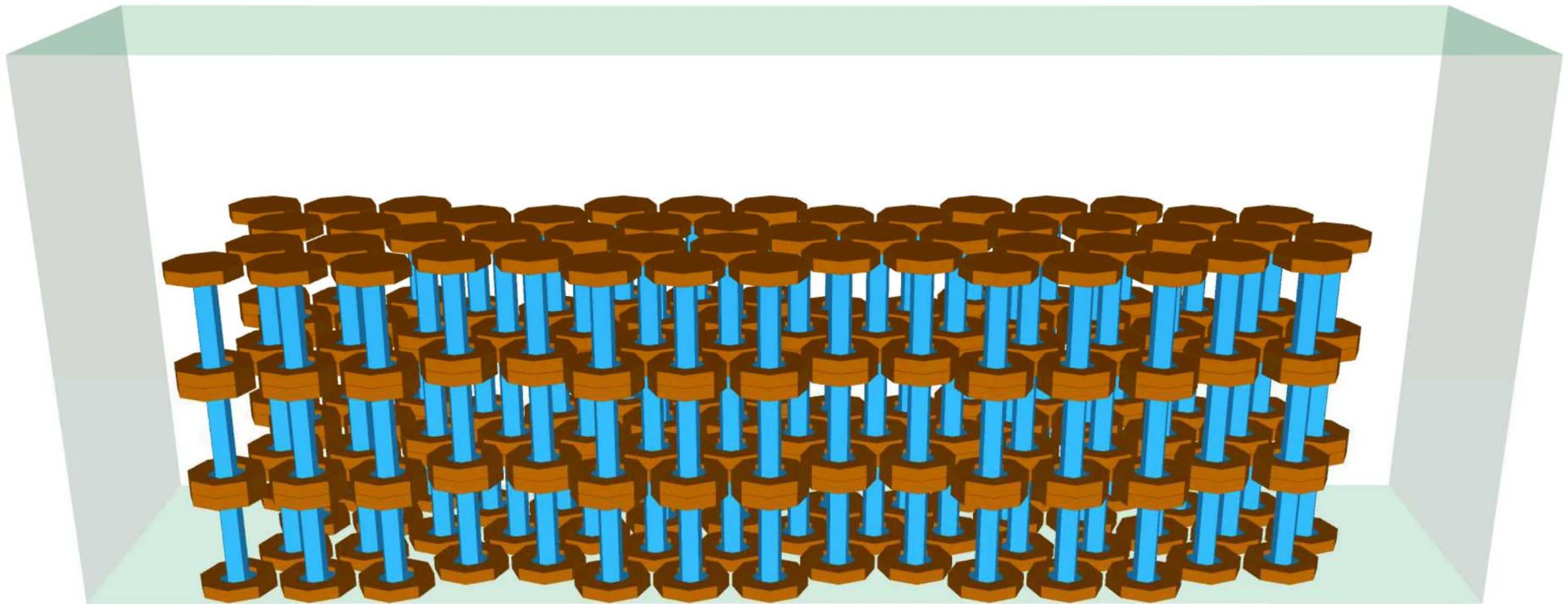
Time = 0 yrs



Time = 0 yrs

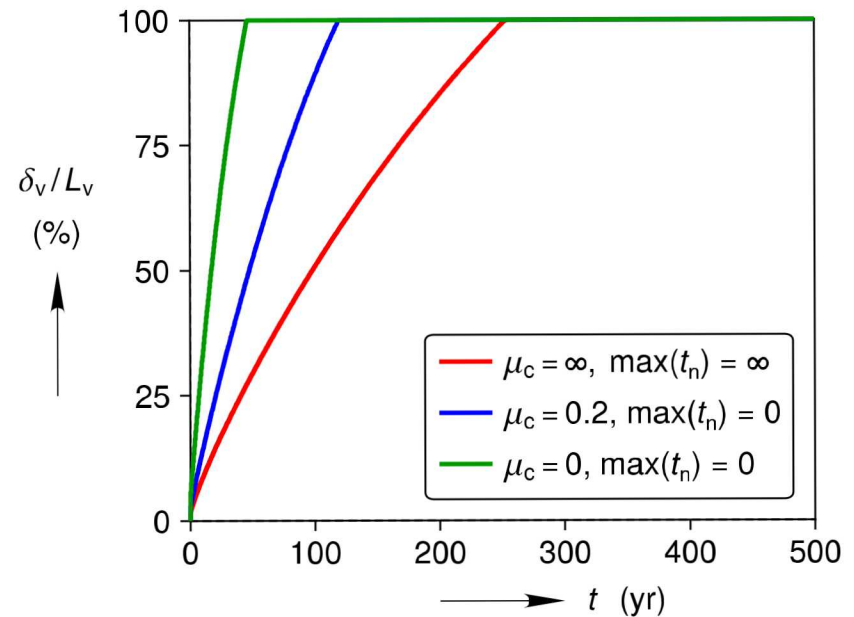
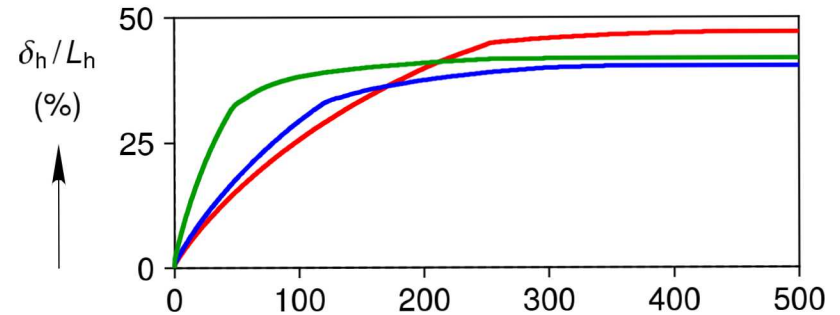
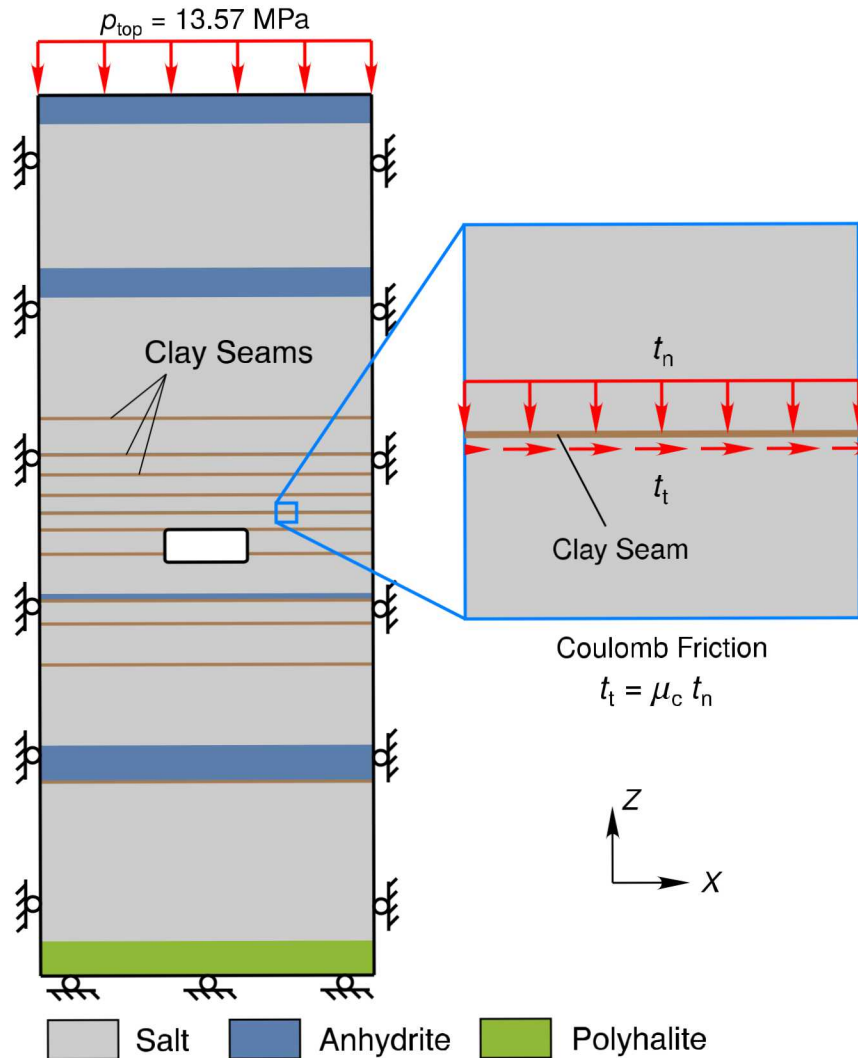


Time = 0 yrs

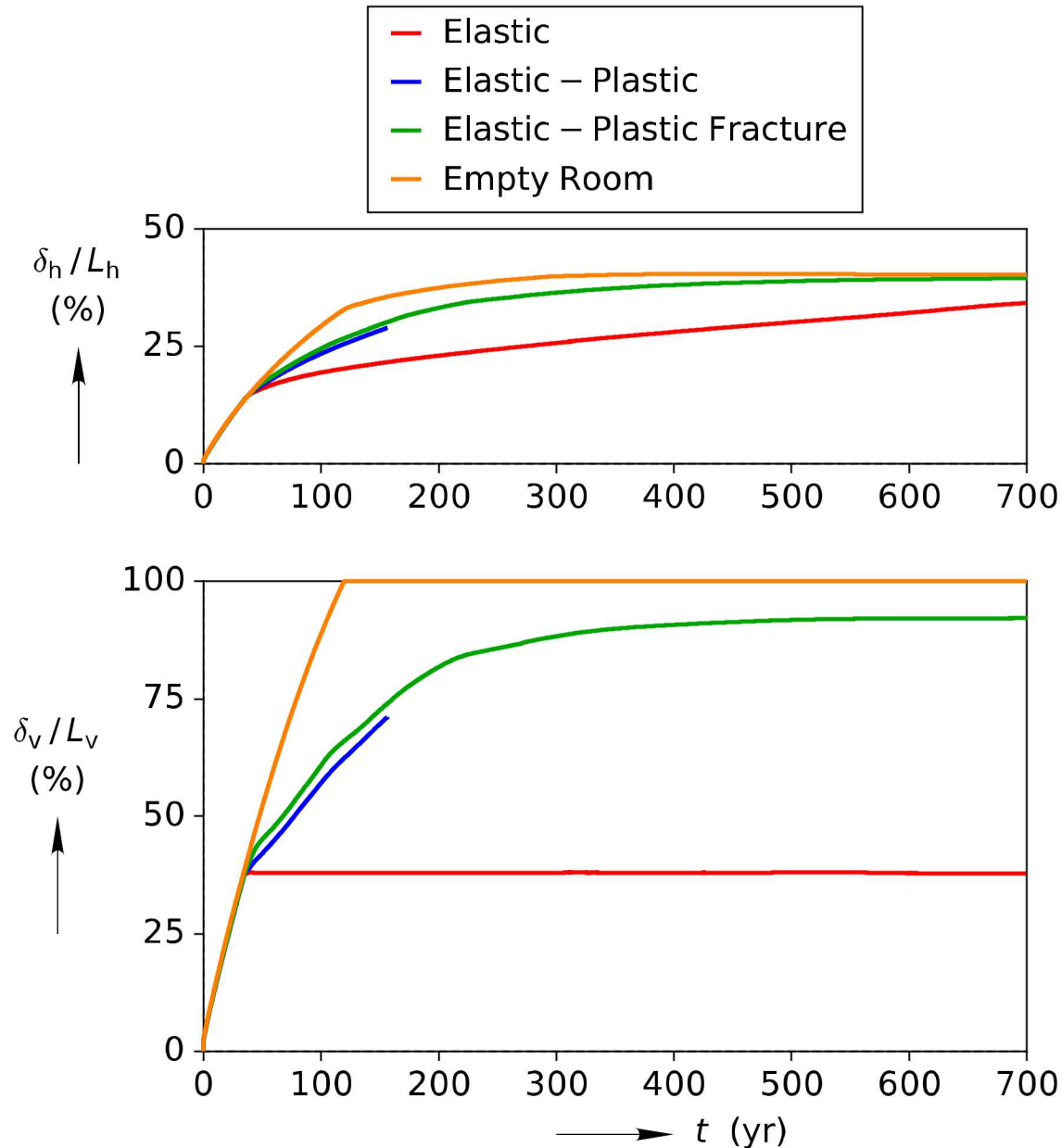


Time = 0 yrs

Empty Room: Impact of Clay Seams

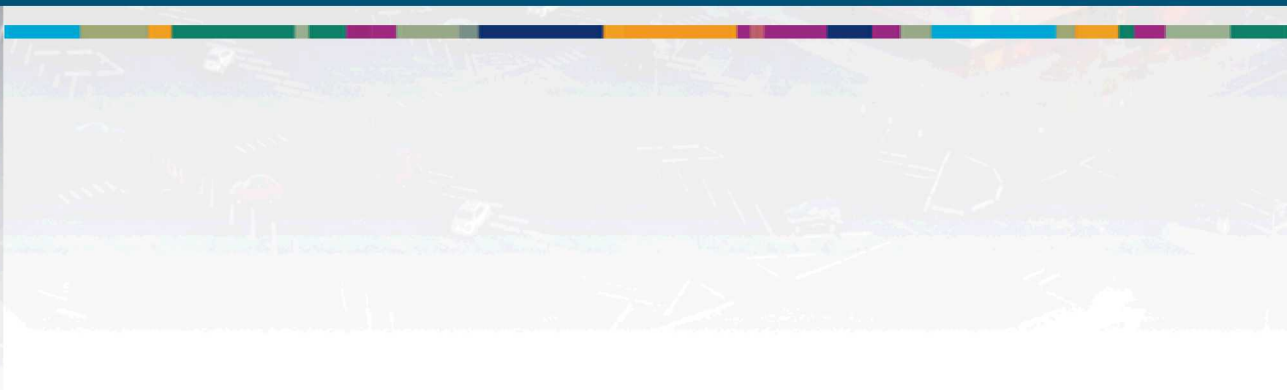


Quantitative Comparisons





Summary and Potential Future Work



Summary

1. Homogenized canisters vs. explicitly simulating canister components
2. Sped up the salt viscoplasticity to squeeze 1000's of years into seconds
3. Results
 - a. Elastic canisters prop open the vertical closure causing the highest horizontal closure rate at $t = 700$ yr. On the other hand, the stresses are unreasonably high.
 - b. Elastic-Plastic canisters deform in a highly heterogeneous manner, calling homogenization into question.
 - c. Elastic-Plastic-Fracturing canisters resist closure only slightly more than an empty room.
 - d. Glued clay seams produce most horizontal closure in the empty room, but a filled room could change the sensitivity.
 - e. More than 50 % horizontal closure appears unlikely.

Potential Future Work

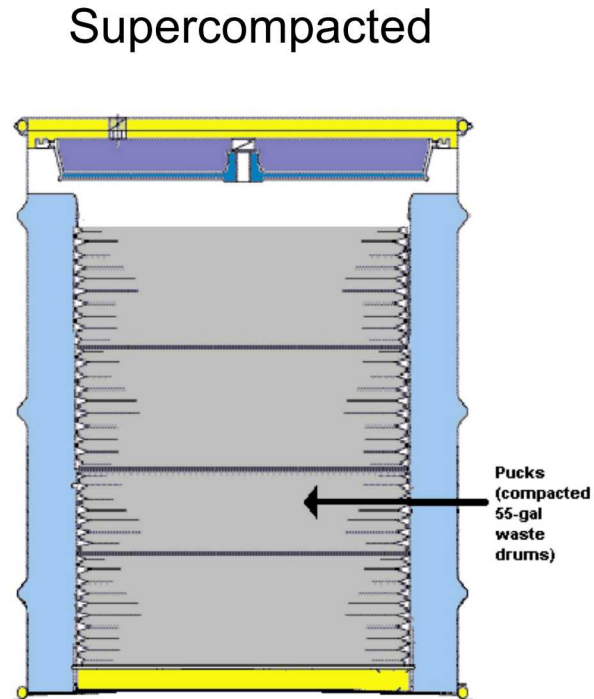
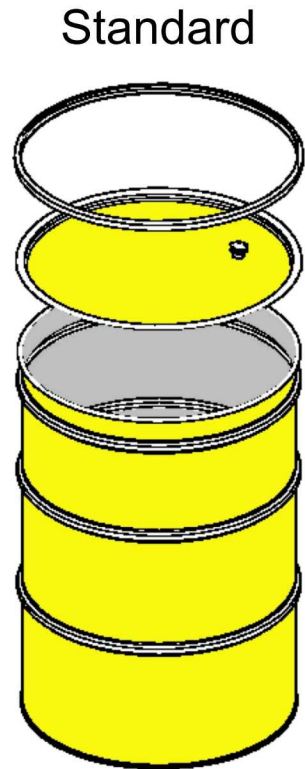
1. Numerics
 - a. Investigate why plywood disappears
 - b. Stop half canisters from penetrating the walls
 - c. Refine mesh
2. Geomechanics
 - a. Vary clay seam behavior
 - b. Switch to lower horizon and/or rooms near edges of panels
 - c. Attempt to include roof falls
3. Canisters
 - a. Adjust stainless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



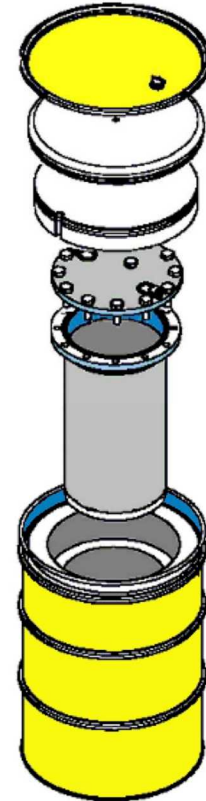
Extra Slides



Current Canister Design Examples



Pipe Overpack



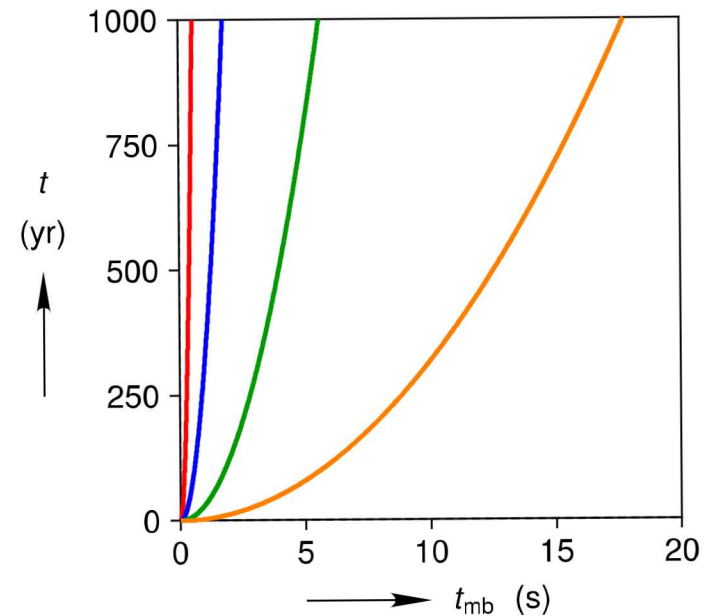
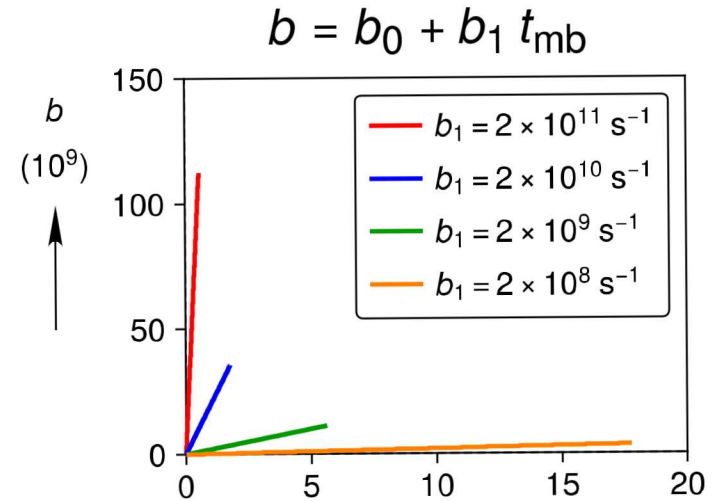
Park, B.Y. and Hansen, F. D., "Determination of the Porosity Surfaces of the Disposal Room Containing Various Waste Inventories for WIPP PA", 2005, SAND2005-4236

Speeding Up the Viscoplasticity

$$\dot{\epsilon} = \dot{\epsilon}^{\text{el}} + \dot{\epsilon}^{\text{vp}} + \dot{\epsilon}^{\text{th}}$$

$$\dot{\epsilon}^{\text{vp}} = A b \exp\left(\frac{Q}{RT}\right) \dot{\sigma}^n$$

$$dt = b dt_{\text{mb}}$$

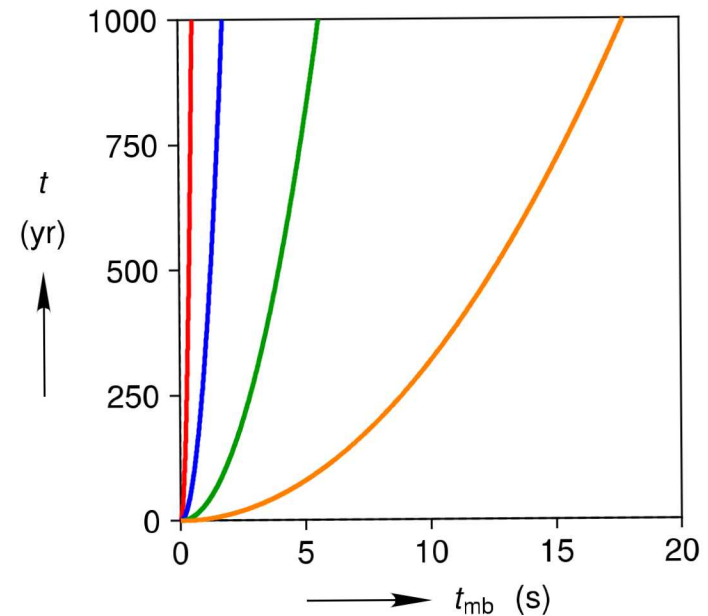
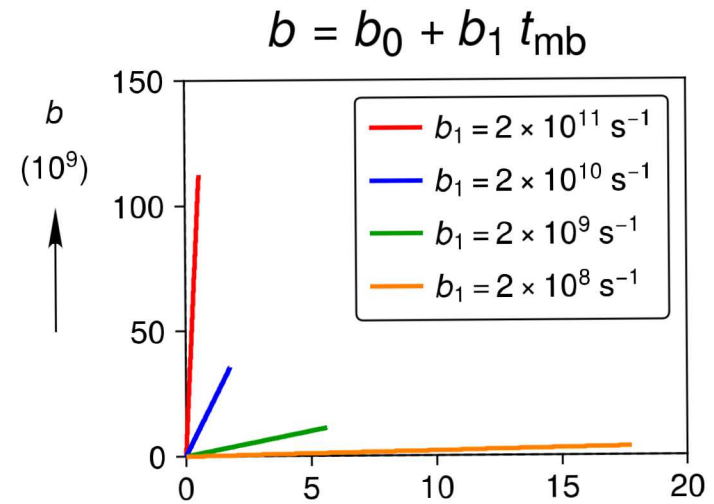


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$$\dot{\epsilon} = \dot{\epsilon}^{\text{el}} + \dot{\epsilon}^{\text{vp}} + \dot{\epsilon}^{\text{th}}$$

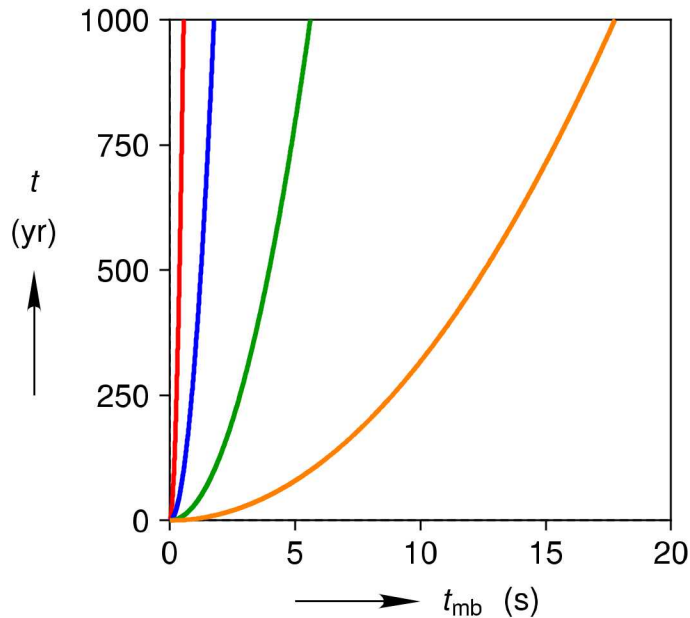
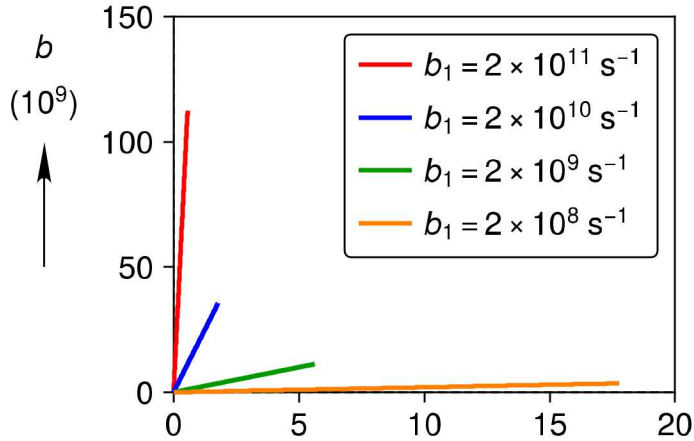
$$\dot{\epsilon}^{\text{vp}} \propto A b \exp\left(-\frac{Q}{RT}\right) \bar{\sigma}^n$$

$$b = \frac{dt}{dt_{\text{mb}}}$$

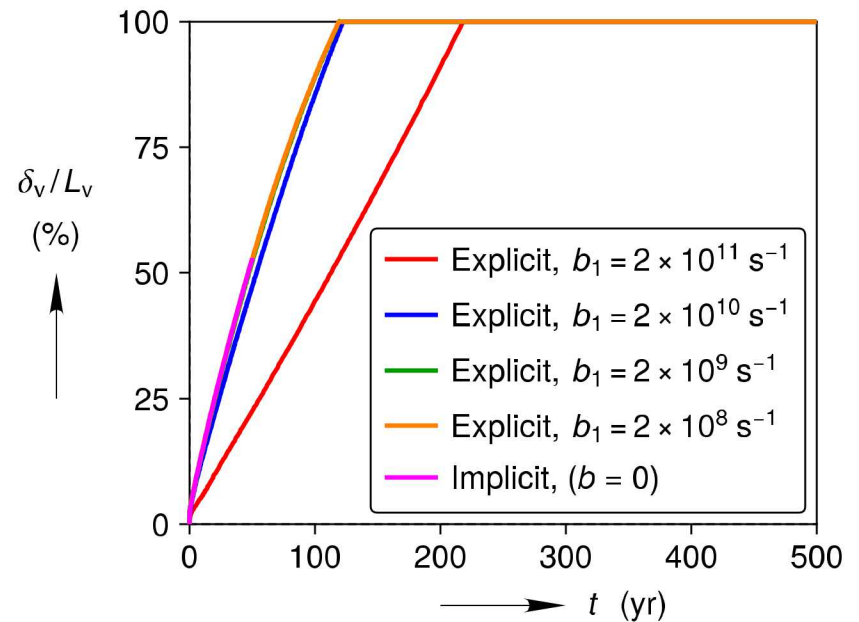
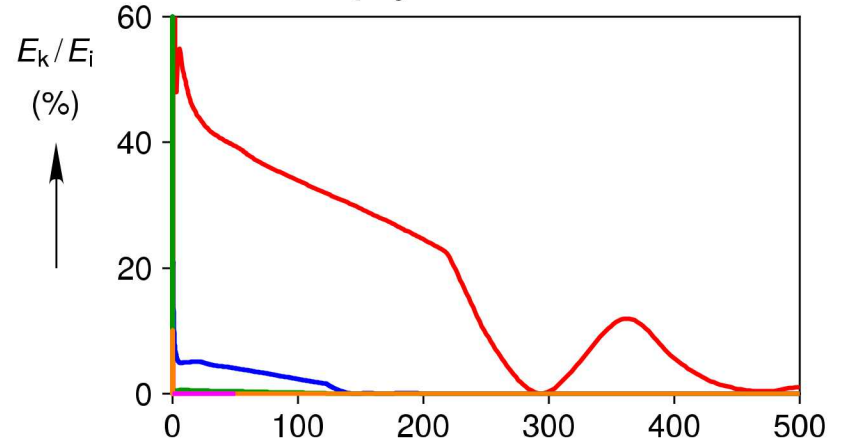


Scaling Ramp Rate Selection

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



Empty Room Sims



Empty Room Mesh Convergence Study

