ICP

IDAHO CLEANUP PROJECT

Densification and Shape Change of Calcined High Level Waste during Hot-Isostatic Pressing

Troy P. Burnett, P.E.
Danielle E. Lower

Presented at the COMSOL Conference, October 2011

CH2M•WG
IDAHO, LLC

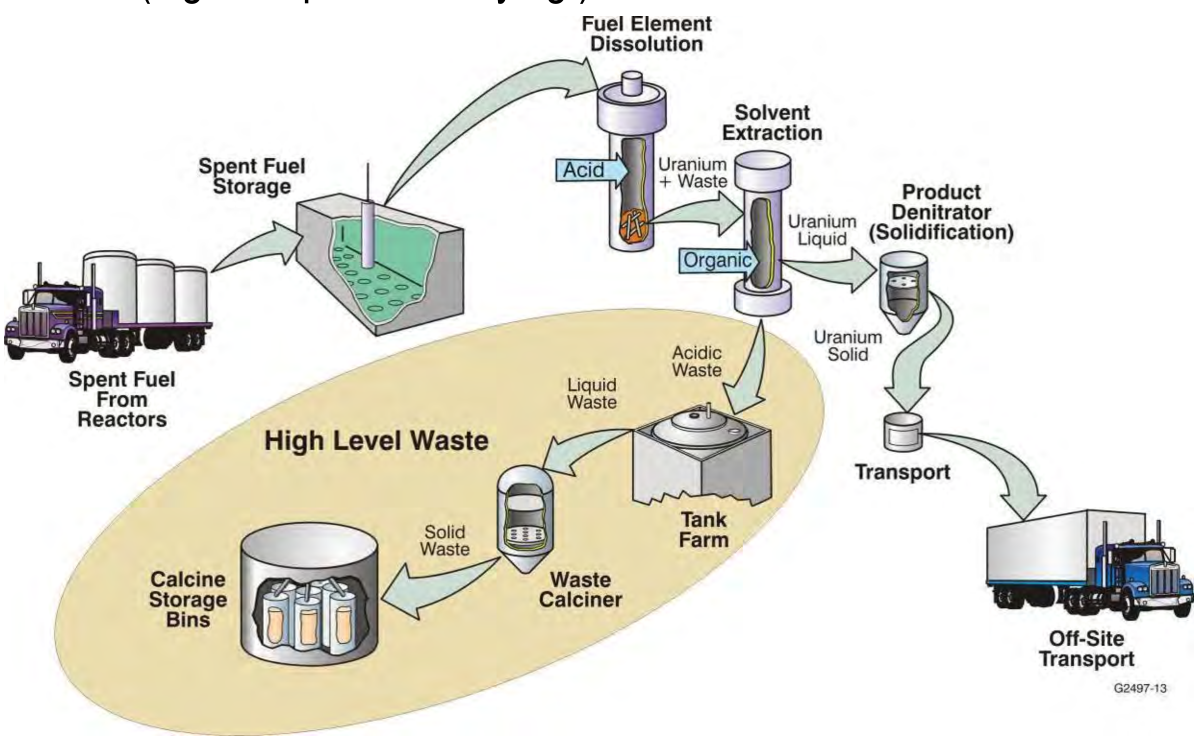
SAFELY PLAN • MOTIVATE • DELIVER

Calcine Densification and Shape Change

- Troy P. Burnett, P.E.
  - BS Engineering Idaho State University
  - Practicing engineering for 11 years
  - Working on the Calcine Disposition Project for two years
- Danielle E. Lower
  - BS Mechanical Engineering University of Idaho
  - MS Mechanical Engineering Montana State University
  - Naval Reactors Facility
- CH2M-WG Idaho (CWI)
  - Contracted to perform work on the Idaho Cleanup Project for the Idaho National Laboratory

Calcine Densification and Shape Change

- History of Calcine and the Calcine Disposition Project (CDP)
  - The lab received spent nuclear fuel from all over the world
  - Processed fuel from 1953 until 1992
  - Used solvent extraction to separate Uranium
  - Conversion of liquid, high-level radioactive waste to solid by calcination process (high temperature drying)

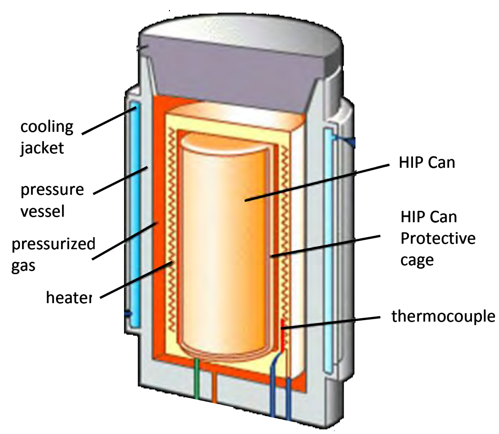


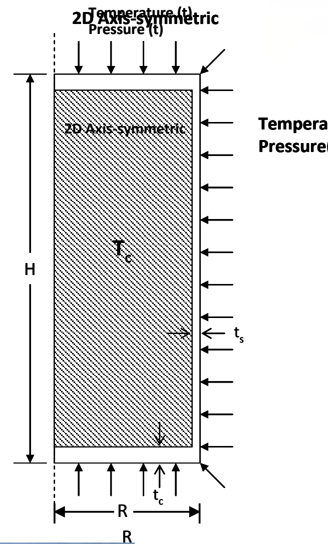
Calcine Densification and Shape Change

- What is calcine?
  - Dry granular powder
  - Stored in large bins
    - 12.2 million pounds of calcine
    - 4,400 cubic meters
  - Highly radioactive
    - All handling is done by remote equipment
    - Must be confined in shielded cells at all times
  - Leachable
- Purpose of the Calcine Disposition Project
  - Create a stable, long term waste form
  - Process calcine using Hot Isostatic Pressing technology (HIP)

Calcine Densification and Shape Change

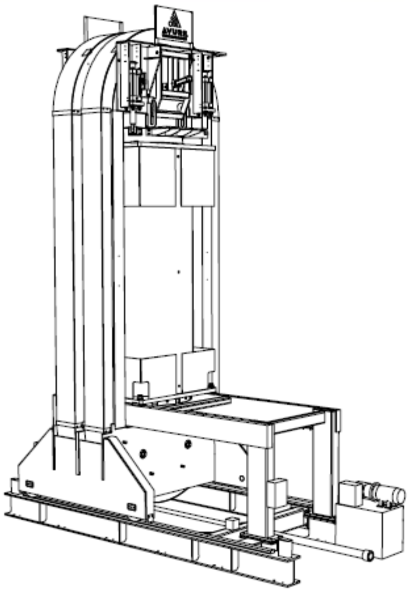
- Hot Isostatic Pressing (HIP)
  - HIP process
    - A process that is used to reduce the porosity and increases the density of metals and ceramics.
    - Materials are exposed to a high temperature and pressure environment.
  - HIP uses
    - Aerospace industry – Turbine blades
    - Automotive industry – Turbo chargers, Valves
    - Medical industry – Prosthetic devices
    - Petroleum industry – Valve bodies
  - HIP use for the Calcine Disposition Project
    - Densification of ceramic powder
    - Create a stable monolithic waste form

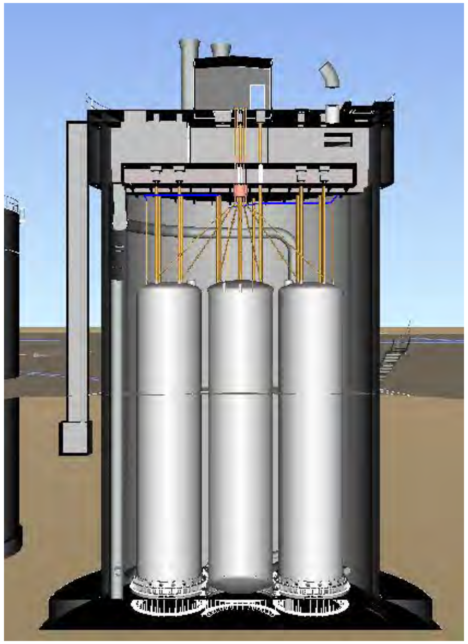


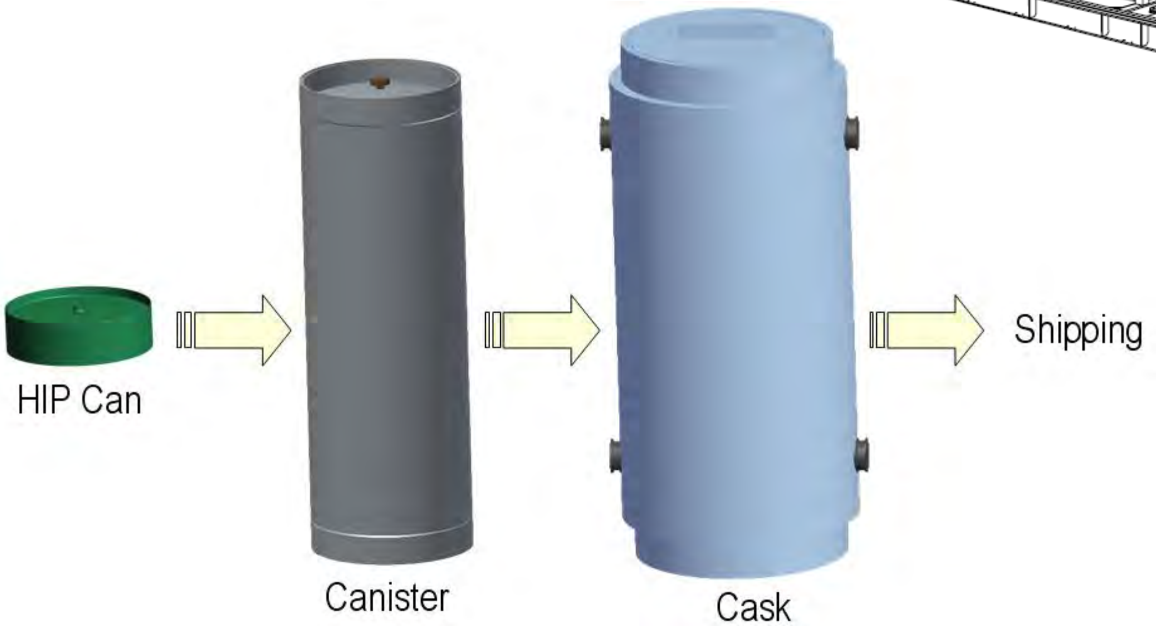


Calcine Densification and Shape Change

- The Calcine Disposition Project
  - Retrieve high level waste (HLW) calcine from storage bins
  - Package in Hot Isostatic Press (HIP) can
  - Process filled HIP can using Hot Isostatic Press
  - Package HIP treated can in storage canister

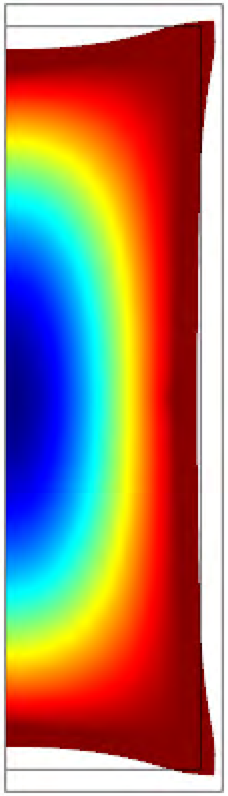






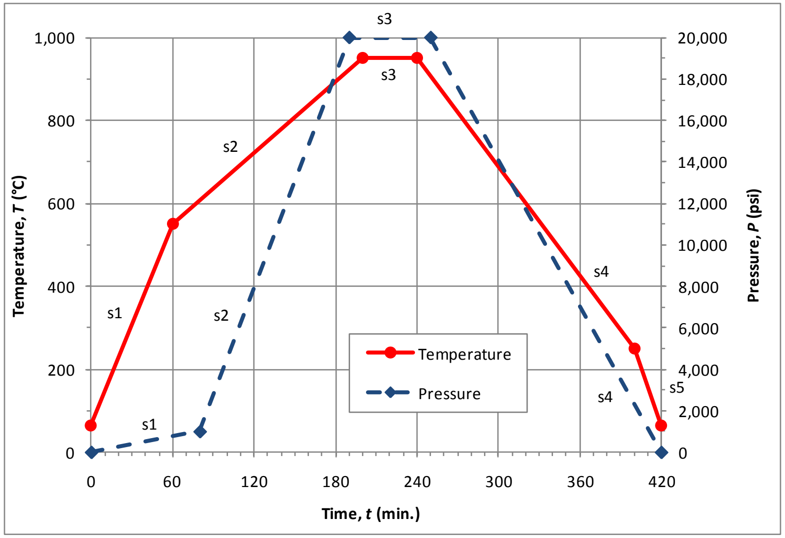
Calcine Densification and Shape Change

- Calcine Disposition Project FEA program
  - Abaqus and COMSOL are being used for analysis of the HIP process as well as the design of process equipment.
  - The focus of this paper is on the analysis of the HIP can
  - The goal for analysis of the HIP can is to accurately predict:
    - HIP can performance
    - Final shape of the HIP can
    - Temperature profile
    - Densification of calcine
  - The modeling effort will be a multi step process
    - We are currently in the first stage of the analysis program
  - Will use FEA to streamline the design
  - Large amounts of experimental data will be obtained to validate the FEA
  - The ultimate goal is to incorporate the FEA into the daily facility operations and controls



Calcine Densification and Shape Change

- Challenges of the analysis
  - This is a transient analysis
  - High temperature – 1000 °C
  - High Pressure – 10 to 20 ksi
  - Large deformation and large strain >30%
  - Multiphysics couplings – heat transfer, solid mechanics, moving mesh, ODE, chemistry, contact, fluid flow
- Known COMSOL analysis limitations
  - Doesn't handle large strain – large deformation
  - Working with COMSOL to improve in this area
  - Alpha version coming soon
- Current analysis approach
  - Empirical approach – modification of thermal expansion coefficient
  - Microscopic approach - deformation mechanisms using ODE

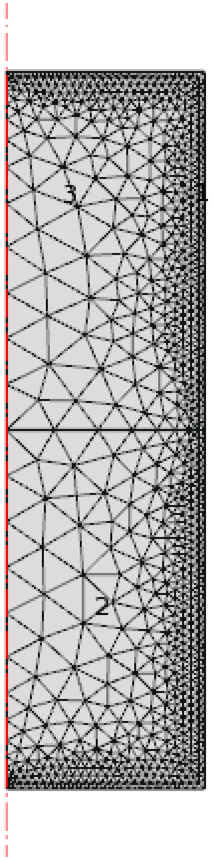


Calcine Densification and Shape Change

- Empirical Approach – Modified Thermal Expansion Coefficient
  - Equations of State
    - Function of temperature and pressure
    - Use equations of state to derive coefficient
    - First-level approximation of volumetric properties
      - Tait equation
      - Spencer-Gilmore Equation
  - Thermal expansion coefficient
    - Linear Volume change:

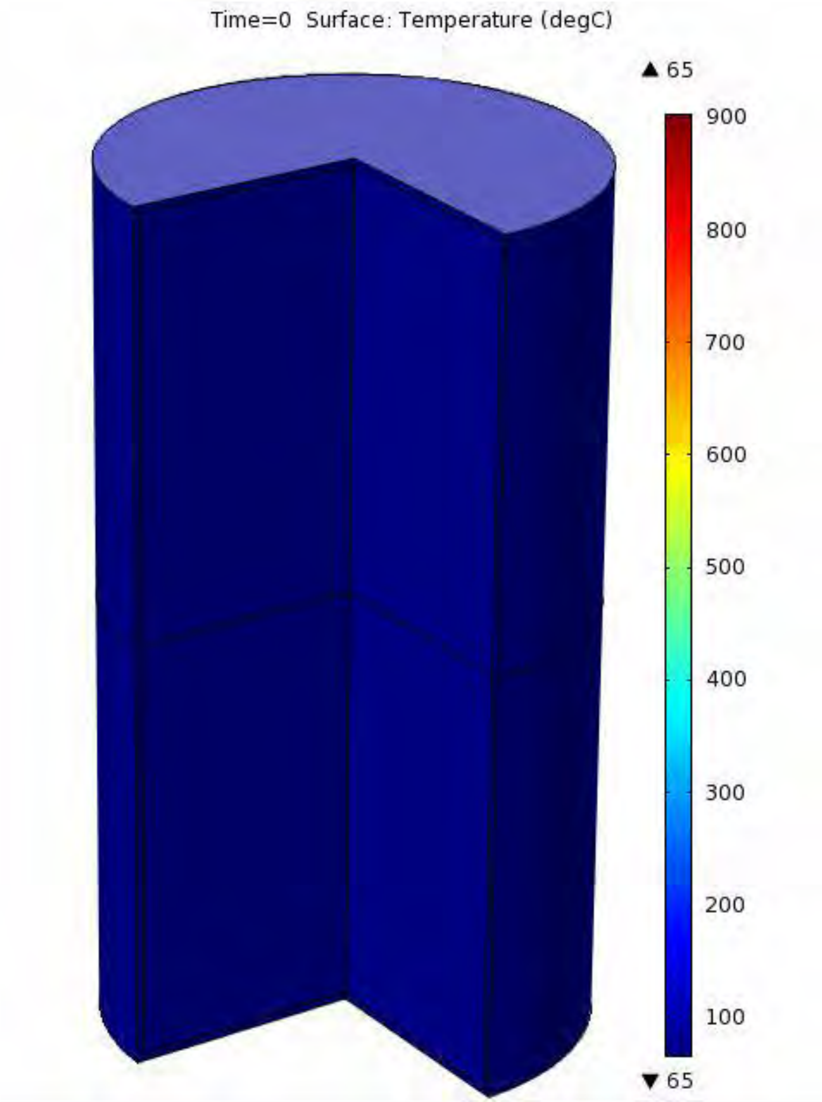
$$\alpha_L = \frac{\left(\frac{\rho_0}{\rho} + \beta \Delta P\right)^{\frac{1}{3}} - 1}{\Delta T}$$

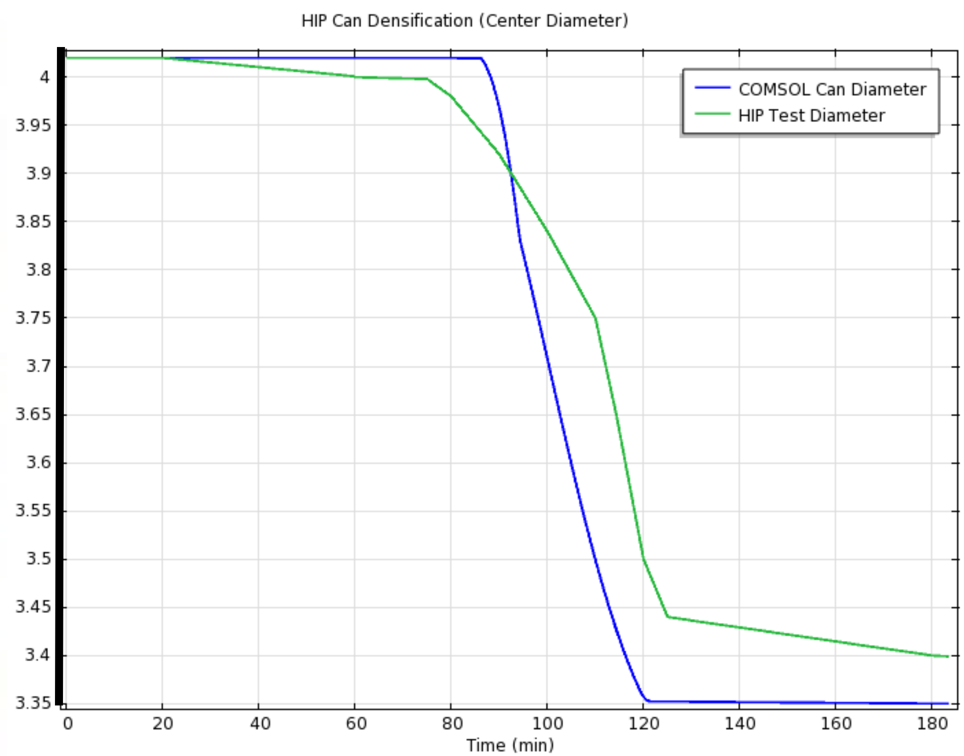
    - ρ and ρ_0 are the final and initial material density
    - β is the material compressibility coefficient
    - Δp is the localized change in pressure
    - ΔT is the localized change in temperature.



Calcine Densification and Shape Change

- Thermal Expansion Coefficient

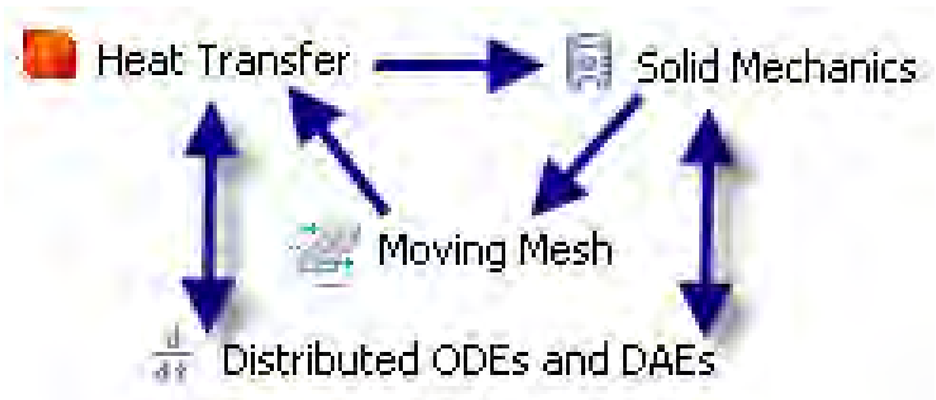




Calcine Densification and Shape Change

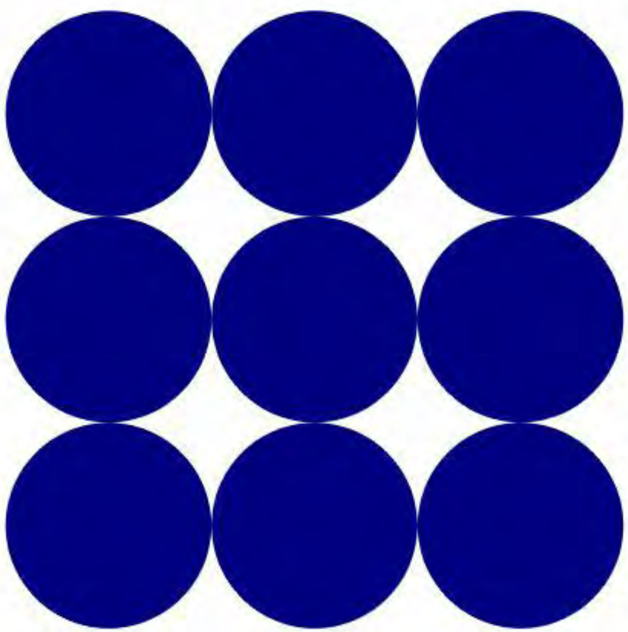
- Microscopic Approach
  - M.F. Ashby - Deformation Mechanisms
    - Plastic Yielding
    - Power-law creep
    - Diffusion
  - Densification Rate equations
    - Pressure
    - Temperature
    - Relative density
    - Grain size
  - COMSOL Model
    - Heat transfer
    - Solid Mechanics
    - Moving Mesh
    - Distributed ODE's

$$\frac{d}{dt}D = K_D \cdot f(D)$$



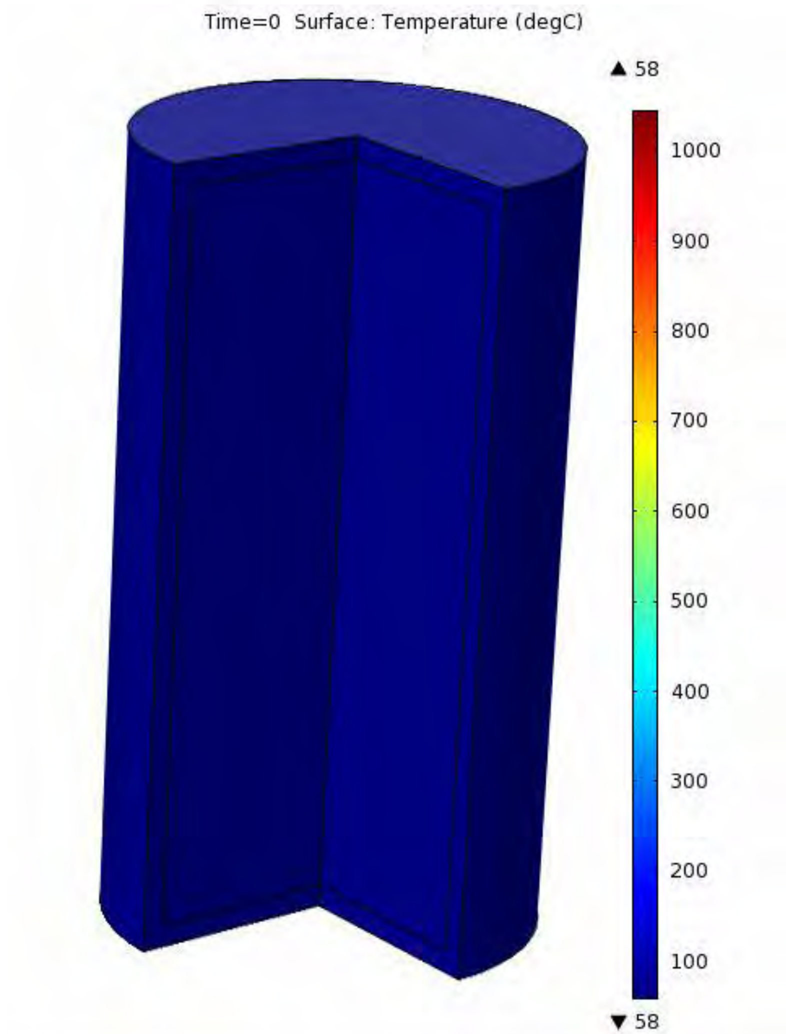
Calcine Densification and Shape Change

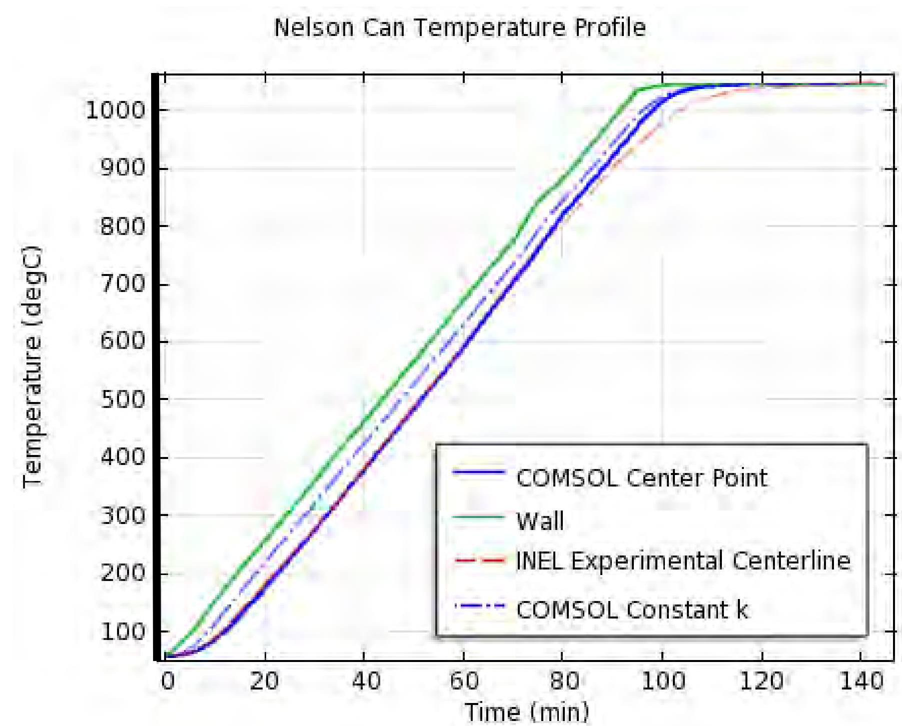
- The densification process during HIP
  - Random packing in contact with approximately 7 other particles
  - Particle centers must move together for densification



Calcine Densification and Shape Change

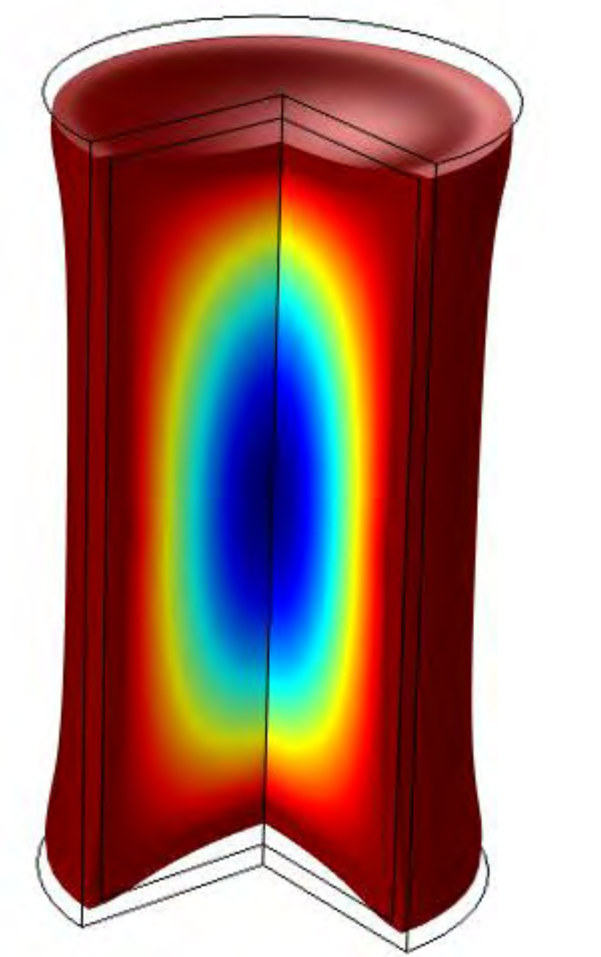
- Deformation Mechanisms





Calcine Densification and Shape Change

- Conclusion
  - The two methods show good agreement with experimental results in the shape change, densification, and temperature profile
- Future analysis
  - Incorporate plasticity in the can
  - Incorporate large strain and large deformation
  - Include contact between the can and calcine
  - Include the chemical reactions in the calcine
- Ultimate goal
  - High fidelity analytical model
  - Use analytic results to validate HIP can performance before the first radioactive can is treated
  - Use analysis in the daily operation and control of the facility



Calcine Densification and Shape Change

- Questions?