Nuclear PWR Analysis

Backup Power Response Time as a Function of Pressurizer Size

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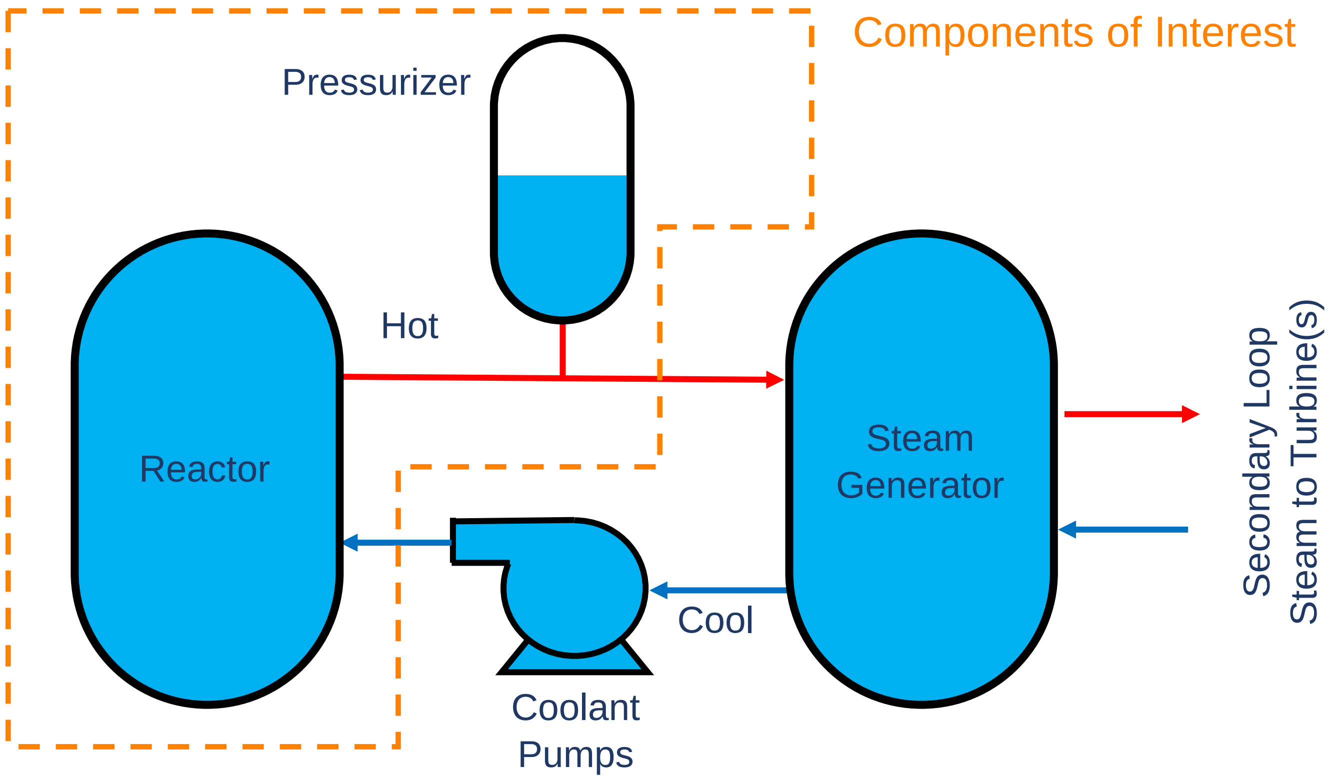
Background: Nuclear Power Generation

Light Water, Pressurized Water Reactor (PWR)

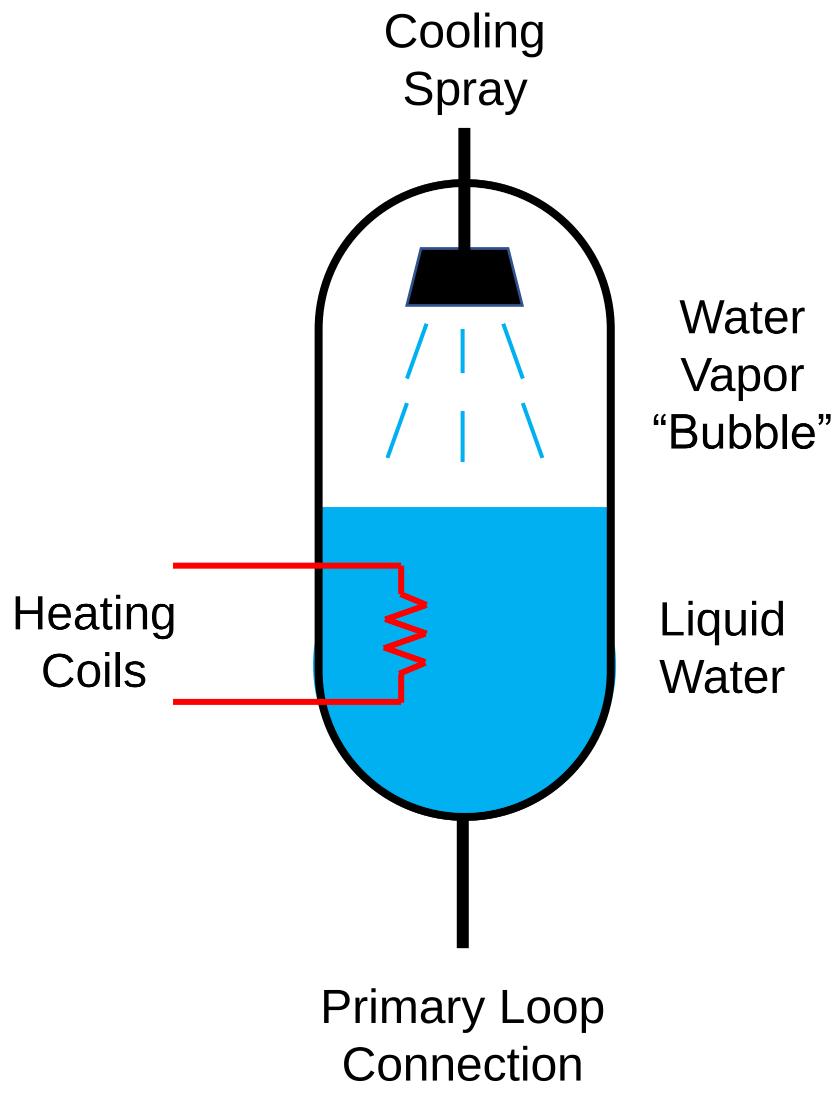
- Primary Coolant Loop – Heat generated by fission in the reactor is carried by a liquid coolant (water) to the secondary loop
- Secondary Coolant Loop – Heat from the primary loop is used to create steam that flows through a turbine to generate electricity

Simplified Schematic of PWR Primary Coolant Loop



Background: Pressurizer Operation

- For a PWR, coolant in the reactor must remain in liquid form during normal operation
- The pressurizer is a pressure vessel that is generally half filled with liquid and half filled with vapor by volume
- Pressurizer operation:
  - Below Setpoint – Heating coils activate and increase its temperature and system pressure
  - Above Setpoint – A cool water spray reduces its temperature and system pressure
- Secondary pressurizer functions may include:
  - Acting as a “spring” to absorb system pressure fluctuations
  - Ensuring the reactor is flooded with liquid coolant
  - May contain pressure relief and/or safety valves



Problem Statement

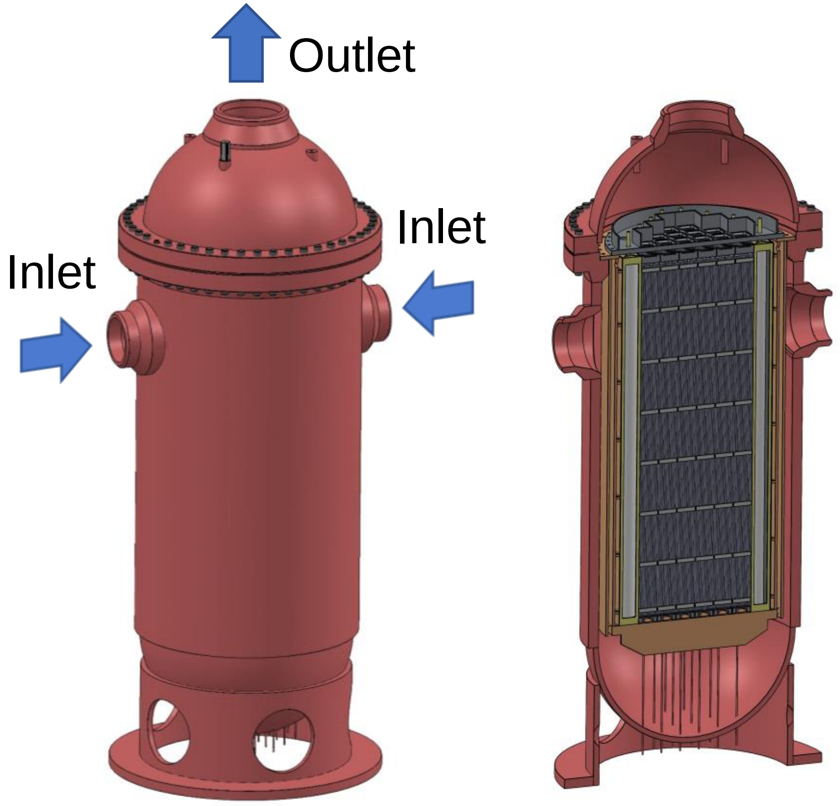
- <u>Loss of Grid Power Scenario</u>

Loss of Electricity → Loss of Coolant Flow → Increased Pressure in Primary Loop → Maximum System Pressure and/or Safety Systems Activate

- <u>Key Question</u>
  - How quickly must backup systems activate to restore coolant flow before maximum pressure limits are exceeded?

COMSOL Reactor Model

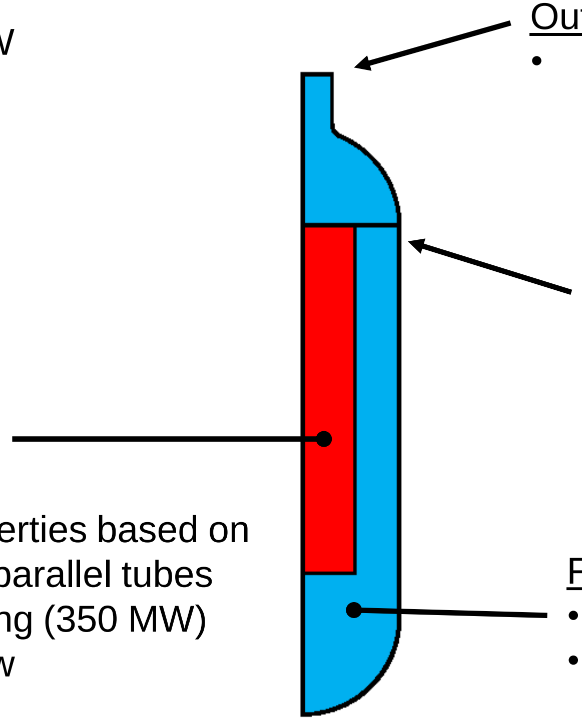
<u>Detailed Reactor Geometry</u>



Energy Impact Center's
Open100 Reactor Vessel

<u>Open100 Reactor</u>
- Reactor Thermal Power – 350 MW
- Number of Fuel Bundles – 24
- Fuel Rod Array – 17x17
- Reactor Fluid Volume – 720 ft^3

Simplified (2D Axis Symmetric)
<u>Reactor Model Geometry</u>



<u>Outlet</u>
- Pressure coupled to pressurizer model

<u>Internal Wall</u>
- No slip

<u>Fuel Bundles (Red)</u>
- Porous Domain
- Orthotropic properties based on square packed, parallel tubes
- Volumetric heating (350 MW)
- 2 phase fluid flow

<u>Free Flow Domain (Blue)</u>
- Laminar flow
- 2 phase

COMSOL Pressurizer Model

- Global Equations
  - Coolant properties are a function of p and v

$$u = f(p, v)$$

  - Constant volume

$$v = \frac{V}{m_c}$$

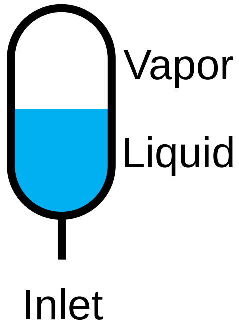
  - Conservation of mass

$$\dot{m}_c = \frac{1}{v(p, \text{Sat. Liq.})} \int (s \cdot \hat{n}) dA_{outlet}$$

  - Conservation of energy

$$u\dot{m}_c + \dot{u}m_c = \dot{m}_c h_{in}(p, \text{Sat. Liq.})$$

Pressurizer Diagram and Specifications



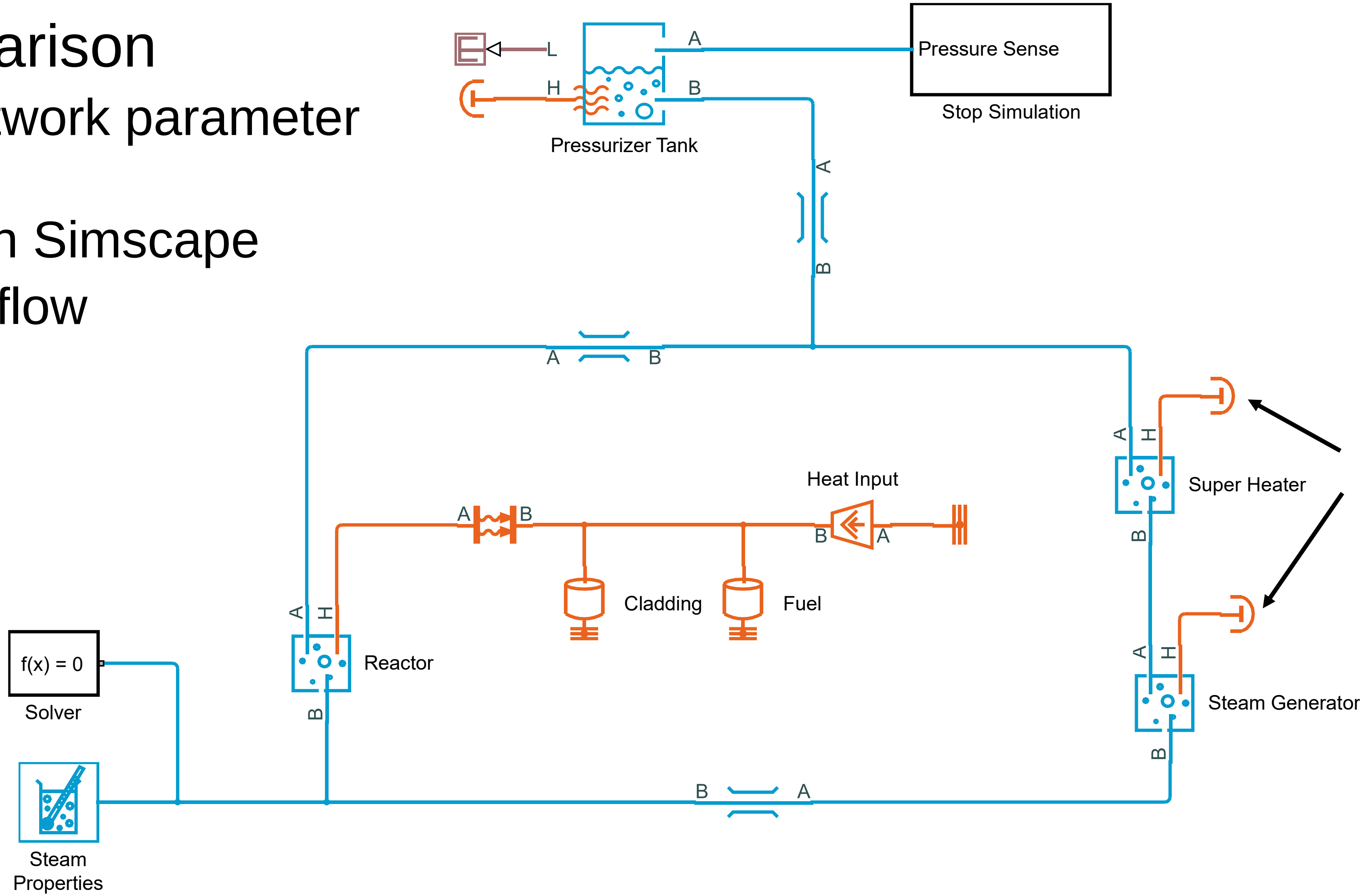
- Typical Fluid Volume – 1500 ft^3
- Initial Temperature – 620°F
- Initial Pressure – 2150 psia
- Maximum Pressure – 2500 psia

Variable Names

- Specific internal energy, u
- Absolute pressure, p
- Specific volume, v
- Pressurizer volume, V
- Coolant mass, m_c
- Velocity vector at reactor outlet, s
- Specific Enthalpy at pressurizer inlet, h_{in}

MATLAB Lumped Parameter Model

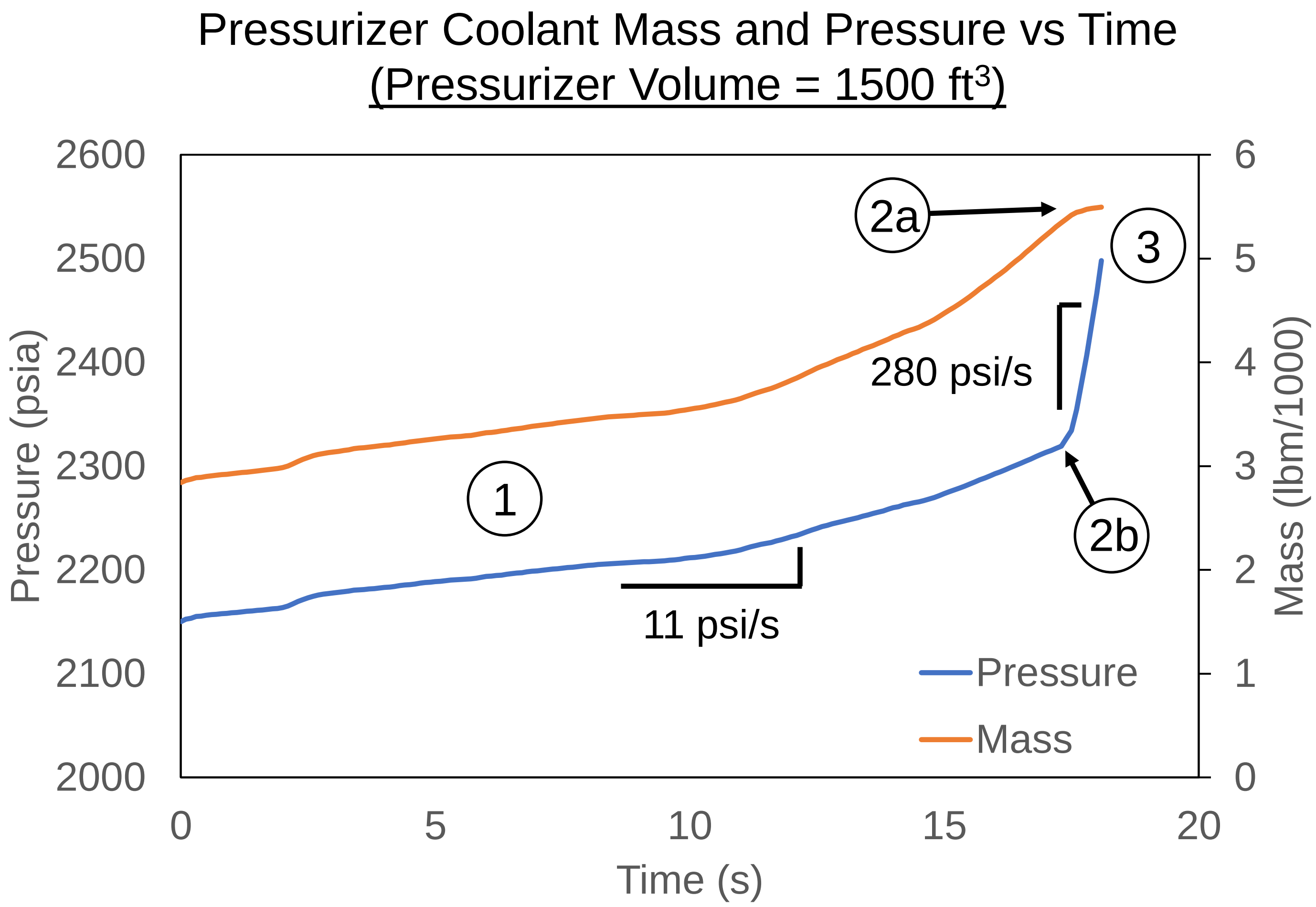
- Model Comparison
  - Lumped network parameter model
  - Created with Simscape
  - Two-phase flow



Heat ports normally connected to secondary loop

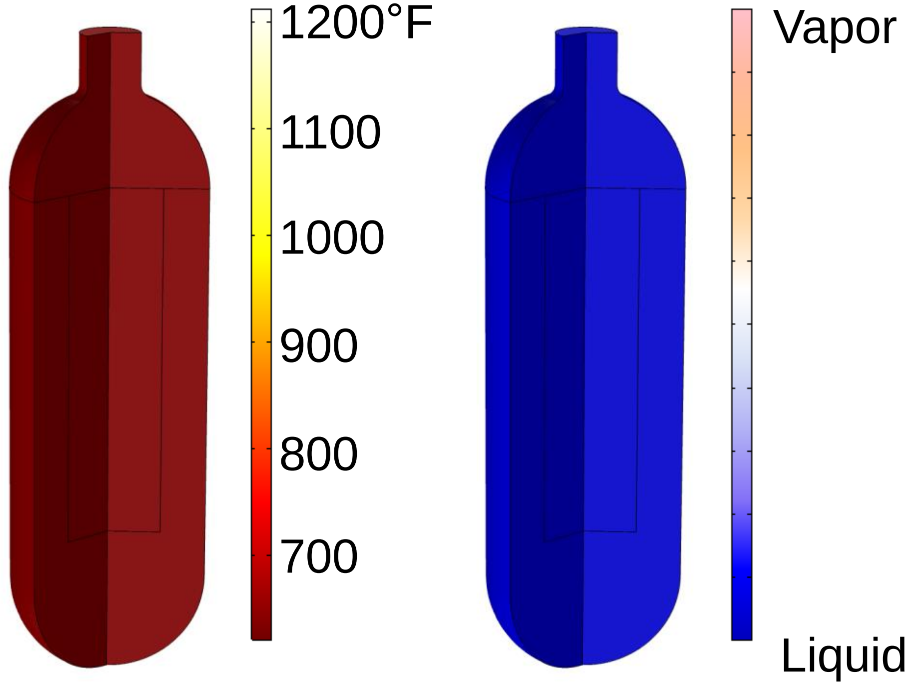
COMSOL Simulation Results

1. Initially, mass and pressure rise gradually as reactor heat builds
2. Once the pressurizer is nearly full of liquid
   a. Mass flow into the pressurizer slows down dramatically
   b. System pressure rises quickly
3. Maximum system pressure (2500 psi) is reached after ~18s



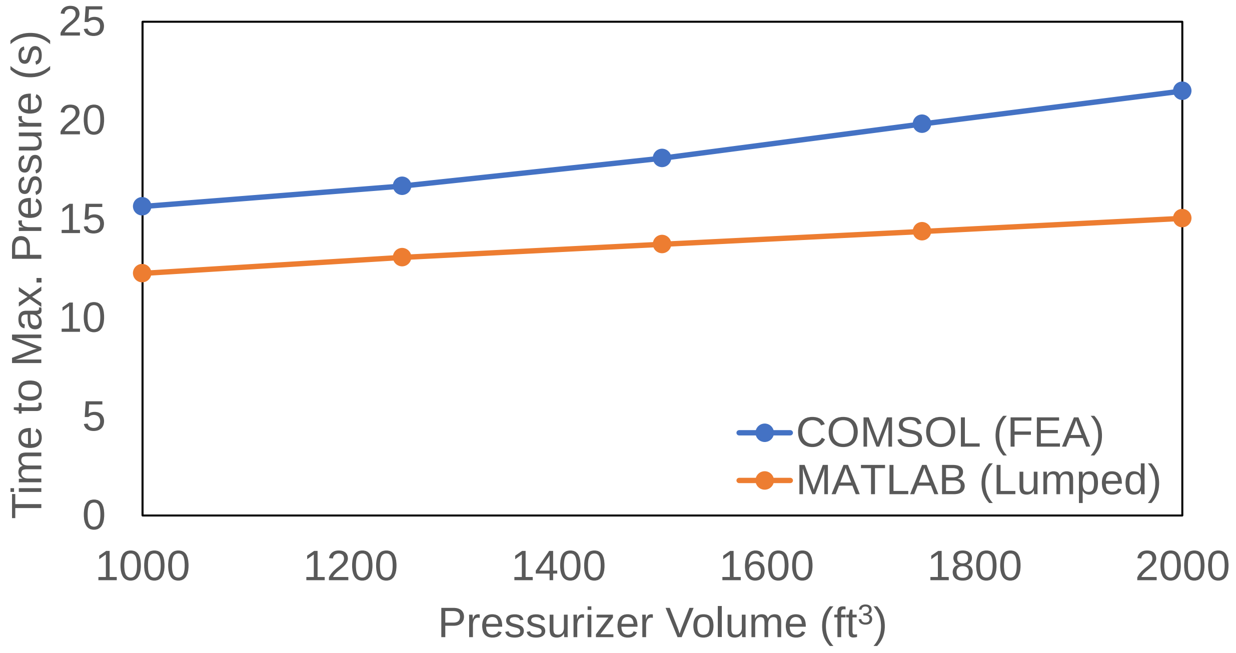
Simulation Results

Temperature and Phase Fields in Reactor for Pressurizer Volume 1500 ft^3



x2 Playback speed

Time to Reach Maximum System Pressure (2500 psia)



Backup systems should restore coolant flow in ~10-15s (depending on pressurizer size) to keep system pressure below its limit

Conclusions

- Despite significant differences in the two modeling approaches, similar times were predicted to reach maximum system pressure
- Backup systems must restore coolant flow in approximately 10-15s depending on the size of the pressurizer

On behalf of the Energy Impact Center Engineering Team,
Thanks for Watching!

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