Pressurized Conduction Cooldown and Normal Operations Scaling

VHTR Cooperative Agreement

Program Review Meeting

February 25, 2009

PCC Event Scaling

- Single phase natural circulation heat transfer in the core.
  - Completed for DCC event.
  - Applies to PCC event.
    - Property similarity cannot be assumed.
- Scaling of inlet plenum mixing.
  - Importance during the PCC event.
  - Jets may be exiting at different temperatures due to differences in channel powers.
  - Governing equations.
    - Similar to those for exchange flows.
  - Non dimensional groups.
    - Density ratio.
      - Equal to unity due to temperature similarity.
    - Peclet number.
      - Reduces to one for turbulent flow.

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PCC Event Scaling

- Non dimensional groups.
  - Reynolds number.
    - Channel diameters.
      - Prototypical size due to manufacturing difficulties.
    - Assume…
      - Temperature similarity.
      - Perfect gas.
      - Viscosity of the helium as a function of temperature only.
        - » High temperatures of the coolant in relation to the critical temperature of helium.

$$\left(\Pi_{\mathrm{Re}}\right)_R = \left(\frac{\rho_j u_j d_j}{\mu_j}\right)_R = \left(P u_j\right)_R$$

$$\left(\Pi_{\mathrm{Re}}\right)_R = \left(P\right)_R \left(\frac{l\dot{q}_{core}}{P a_c}\right)_R^{\frac{1}{3}} = \left(\frac{P^2 l\dot{q}_{core}}{a_c}\right)_R^{\frac{1}{3}}$$

For Natural Circulation Velocities

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PCC Event Scaling

$$\left(\dot{q}_{core}\right)_R = \left(Pa_c\right)_R \left(\frac{l}{\Pi_F}\right)_R^{1/2} = 1:1989$$

- Decay core power ratio calculated from natural circulation loop analysis.
- Assumes…
  - Similar temperatures.
  - Perfect gas.
- Lower core decay power would not be able to reach temperature similarity.
  - Heat loss and heat storage characteristics of the vessel are developed using the DCC natural circulation core power.
  - 1:113.7 power ratio.
- Higher power improves Re scaling for inlet plenum mixing.

$$\left(\Pi_{\mathrm{Re}}\right)_R = \left(\frac{P^2 l \dot{q}_{core}}{a_c}\right)_R^{\frac{1}{3}} = 1:13.5$$

Normal Operations

- Principal phenomenon of interest is the core and outlet plenum flow distributions.
  - Local phenomena.
  - Conduct loop scaling to determine boundary conditions.
- Forced convection.
  - Operator has the ability to select a mass flow rate through the operation of the circulator.
    - Limits determined by the design and operational characteristics of the circulator.
  - Operator also has the ability to select a core heat input.
    - Limits determined by heater design.
  - Can set a temperature rise using heaters and mass flow rate.
- Assume…
  - Steady state conditions.
  - Heat transfer through the core is dominated by the forced convection effects.

Normal Operations

Core Temperature Rise

$$\left(\Delta T_{core}\right)_R = \left(\frac{\dot{q}_{core}}{\dot{m}C_p}\right)_R$$

Assuming prototypical temperature rise…

$$\left(\dot{q}_{core}\right)_R = \left(\dot{m}c_p\right)_R$$

Normal Operations

- Scaling of outlet plenum mixing
  - Amount of mixing that occurs as jets exit the bottom of the core is an important phenomena.
    - Jets may be exiting at different temperatures due to the differences in channel powers.
- Non dimensional groups.
  - Density ratio.
    - Equal to unity due to temperature similarity.
    - Buoyancy will not place as large a role in scaling.
  - Peclet number.
    - Reduces to one for turbulent flow.

Normal Operations

- Non dimensional groups.
  - Reynolds number.
    - Channel diameters.
      - Prototypical size due to manufacturing difficulties.
    - Assume…
      - Temperature similarity.
      - Perfect gas.
      - Viscosity of the helium as a function of temperature only.
        - » High temperatures of the coolant in relation to the critical temperature of helium.

$$\left(\Pi_{\mathrm{Re}}\right)_R = \left(\frac{\rho_j u_j d_j}{\mu_j}\right)_R = \left(P u_j\right)_R$$

$$\left(\dot{m}\right)_R = \left(a_c\right)_R$$

Mass flow rate to achieve Re scaling.

$$N_R = \left(\frac{a_c}{a_{channel}}\right)_R = \left(a_c\right)_R$$

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Normal Operations

$$(\dot{m})_R = (a_c)_R = 1:56.85$$

$$N_R = \left(\frac{a_c}{a_{channel}}\right)_R = (a_c)_R = 1:58.85$$

$$(\dot{q}_{core})_R = (\dot{m})_R = 1:56.85$$

Assuming temperature similitude.

- Scaling Ratios.
  - Core power ratio of 1:56.85 not practicable.
    - Would drive HTTF core power to over 10MW.
  - A more realistic core power ratio would be closer to 1:1000 for a 600kW HTTF core modeling a 600MW VHTR core.
    - Result in a velocity ratio closer to unity resulting in a model Reynolds number about 17.5 smaller than the prototypical.
    - If flow is in similar regime between model and prototype, the distortions introduced may not be significant.

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Questions?

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