Neutronic Challenges in SCWR Core Design

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Key Differences between SCWR and LWR

- **Coolant Density**
  - Severe coolant density change axially
  - Coolant density is very sensitive to coolant temperature

- **Operating Condition**
  - High pressure and high temperature

- **Cladding Material**
  - High temperature resistant material
  - Higher neutron absorption
A Sample System Code for SCWR Core Design

- WIMS8 used for lattice calculations
  - 172-group library (based on JEF2.2) employed for self-shielding calculations

- Zonal cross sections are functionalized by state parameters,
  \[ \sigma(r_m, T_m, T_f, SB) = \sigma(r_m^0, T_m^0, T_f^0, SB^0) + \frac{\partial\sigma}{\partial r_m} \Delta r_m + \frac{\partial\sigma}{\partial T_m} \Delta T_m + \frac{\partial\sigma}{\partial T_f} \Delta T_f + \frac{\partial\sigma}{\partial SB} \Delta SB \]

- SOLTRAN used for core calculations
  - Interface current nodal formulation of simplified $P_2$ equation in multi-dimensional hexagonal geometry
  - Multi-group, 3-Dimensional geometry
  - Single-phase heat balance equation was adopted for T/H condition update,
    \[ T_{\text{out},k}^{i} = T_{\text{in},k}^{i} + \frac{1}{W \times c_p} \int q_{\text{in},k}^{i}(z)dz \]
Algorithm of WIMS8/SOLTRAN System

Read Input for XS calculations
Write XS (ISOTXS format) files
Read XS (ISOTXS format) files
Initialize T/H properties
Update node-wise XS
Solve diffusion (or SP2) equation
Flux converged?
yes
Update T/H properties
T/H converged?
yes
Edit solution
Loop of T/H update
Loop of outer iteration
Lattice Calculation (WIMS8)

Core Calculation (SOLTRAN)
Convergence Problem

- Eigenvalue of typical PWR converges easily
- Eigenvalue of SCWR oscillates during calculation of T/H condition update
  - T/H properties are very sensitive to coolant temperature
  - Oscillatory behavior is dependent on coolant mass flow rate, core power, inlet temperature, etc
Comparison between SCWR and PWR

Numbers in legends denotes coolant mass flow rate in kg/sec/MWe

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Sensitive to Coolant Mass Flow Rate

Numbers in legends denotes coolant mass flow rate in kg/sec/MWe
Pseudo means pseudo-critical temperature at 25MPa

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Coolant Pressure Effect

Numbers in legends denote coolant pressure in MPa
Effect of Active Core Height

Numbers in legends denotes active core height in cm
Whole Core Calculation

- Power and coolant density are very sensitive to the coolant temperature.
- Power fluctuation is due to the non-uniform radial power shape.
- Neutronic instability may happen during depletion, moving of control rods, perturbation of coolant mass flow, etc.
Challenges

- **Accuracy of codes**
  - Lattice codes for cross section generation
  - Intermediate neutron spectrum (need benchmark)
  - Need higher actinide cross sections for burner design
- **Core calculation code**
  - Multi-group calculation is necessary
  - Convergence problem due to high sensitive T/H properties

- **Challenges**
  - Axial power shape control
    - Water-rod, solid-rod, axial enrichment zoning, etc
  - Radial power shape control (or coolant flow rate control)
  - Reactivity coefficient control
    - Pan-cake type core, Zr-H layers, Thorium fuel, etc
  - Neutronics and T/H coupling calculation for instability analysis
- **Advances core concepts**
  - Burner, Breeder, Multi-purpose reactors, etc
Multi-purposed Mixed Spectrum SCWR

- Inner core (fast spectrum)
  - ~0.7 g/cm³

- Outer core (thermal spectrum)
  - ~0.7 g/cm³
  - ~0.1 g/cm³
  - ~0.4 g/cm³

- Thermal shield

- Coolant inlet
- Coolant outlet
- Control rod
- Core plate
Reactivity Control with Thorium-base Fuel

![Graph showing void coefficient vs. burnup for different fuels](image)

- SCR with 9.98 fissile
- (Th+Pu)O₂ with 9.98 fissile
- (Th+Pu)O₂ with 11.12 fissile