Fluent/RELAP5-3D Coupling

Analysis of Mixing in VHTR Lower Plenum

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The Right Answer in CFD

CFD and the GT-MHR Analysis

- What is CFD?
- CFD in the nuclear industry
- GT-MHR Analysis details

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What is CFD?

- CFD, Computational Fluid Dynamics, is the science of using computational methods to solve physical flow and heat transfer problems.

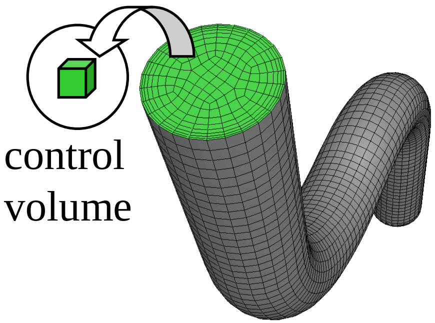
- With advances in computer technology, CFD has become a common tool for equipment design, R&D and process optimization.

What is CFD?

- CFD process entails
  - subdividing the domain into smaller pieces
  - Solving general conservation (transport) equations for mass, momentum, energy, species (gas components), etc.,

$$\underbrace{\frac{\partial}{\partial t}\int_V \rho\phi\, dV}_{\text{unsteady}} + \underbrace{\oint_A \rho\phi \mathbf{V}\cdot d\mathbf{A}}_{\text{convection}} = \underbrace{\oint_A \Gamma\nabla\phi\cdot d\mathbf{A}}_{\text{diffusion}} + \underbrace{\int_V S_\phi\, dV}_{\text{generation}}$$

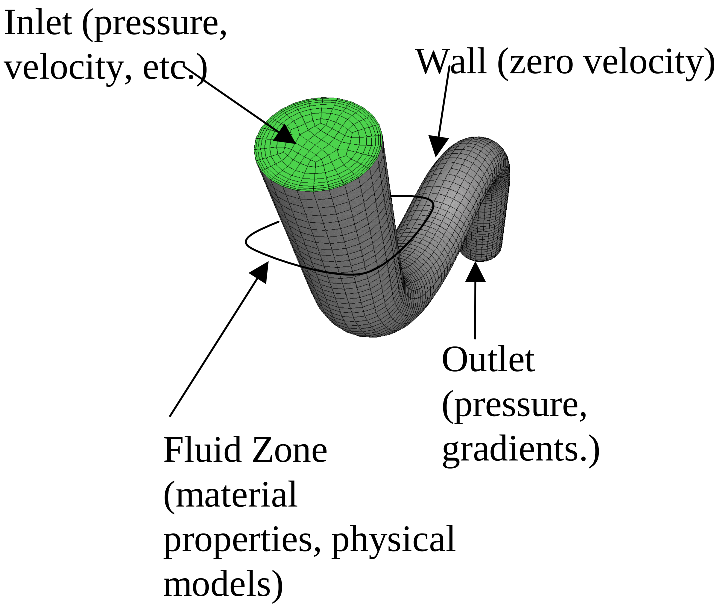
Eqn.	ϕ
continuity	1
x-mom.	u
y-mom.	v
energy	h



Fluid region of pipe flow is discretized into a finite set of control volumes (mesh).

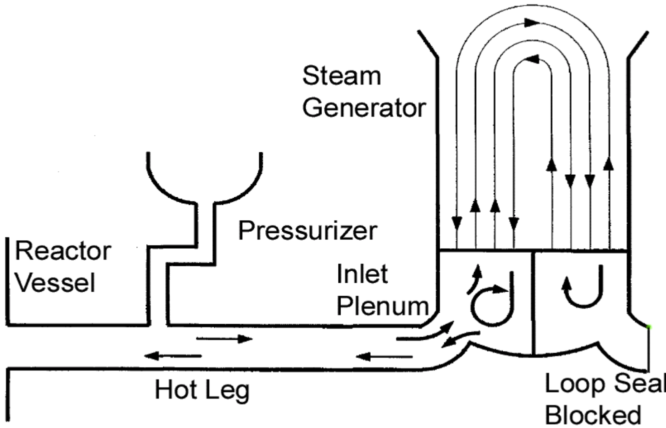
What is CFD? (2)

- A given CFD model contains:
  - Grid/Geometry
  - Physical Models
    - Turbulence
    - Multiphase
    - etc.
  - Boundary Conditions
- Linear equations are solved iteratively



Example: Severe Accident Steam Generator Flows

- FLUENT is used to simulate the flow in a steam generator following a severe loss of coolant accident
- Due to blockage in the coolant loop and seals, cooling is impaired
- The simulation is used to determine the extent of the cooling failure – whether it is restricted to the coolant piping or extends into the steam generator tubing



Courtesy of the US Nuclear Regulatory Commission

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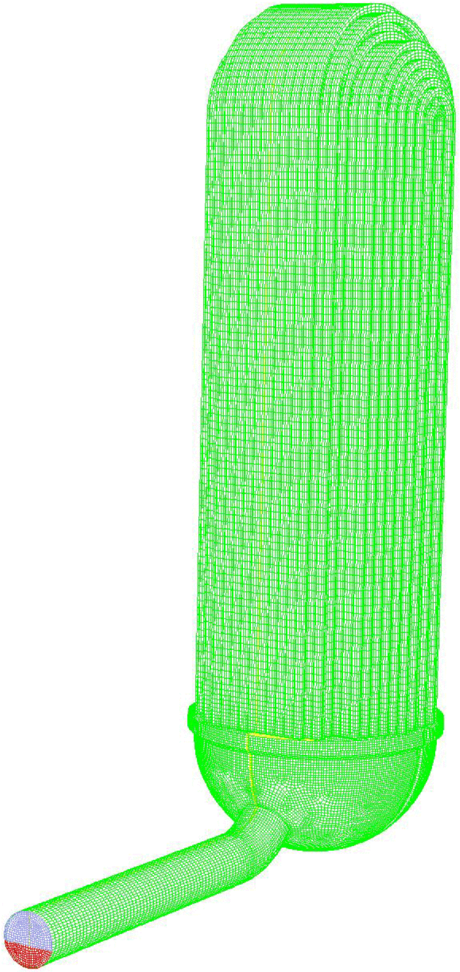
Severe Accident Steam Generator Flows

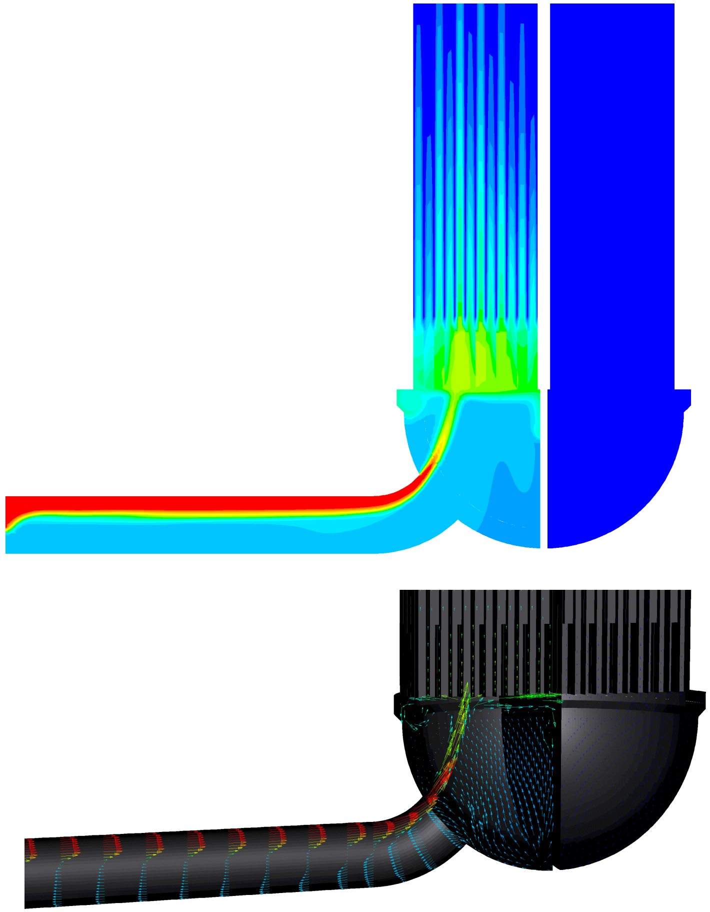
- A mesh of over 500,000 cells is used for the simulation
- The 216 tubes inside the generator are modeled with a square cross section
- A porous media is used inside the tubes
  - This avoids the need to resolve the boundary layer flow in the tubes
- Results are compared to data from a 1/7th scale Westinghouse facility

Courtesy of the US Nuclear Regulatory Commission



Severe Accident Steam Generator Flows

- Temperature contours on the symmetry plane (top) show hot coolant on the top of the pipe
- Velocity vectors (bottom) show the directions of the hot and cool liquid flows
- The predicted average hot and cold temperatures are within 1.5 – 2K of the measured values



Courtesy of the US Nuclear Regulatory Commission

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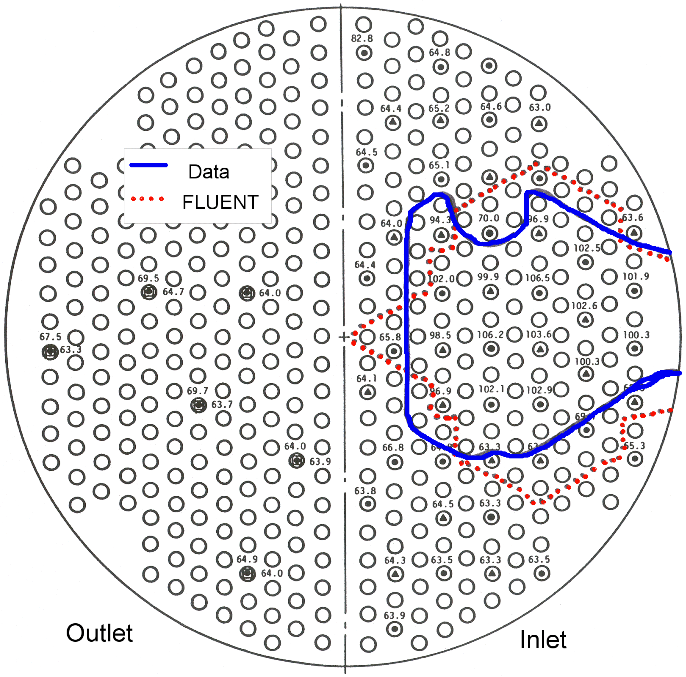
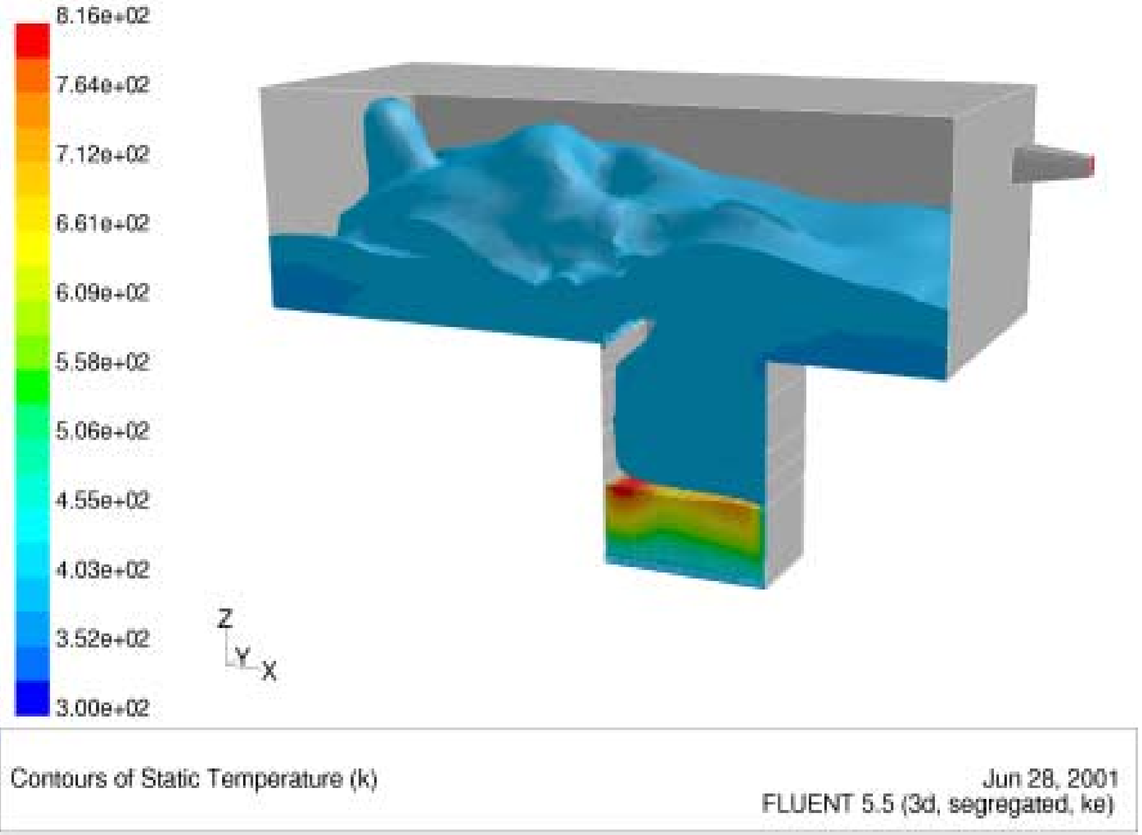
Severe Accident Steam Generator Flows

- Predictions of the number of tubes carrying hot flow are compared to data
- FLUENT over predicts the region of hot flow by 16 tubes, or 7% of the total bundle
- Overall, the CFD results are in very good agreement with data and provide more information than a limited number of thermocouples can



Courtesy of the US Nuclear Regulatory Commission

Example: Pool Storage



Courtesy of USNRC

- The USNRC used FLUENT to analyze an accident scenario in which there was a loss of water from a storage pool.
- Peak temperatures and cooling patterns were successfully predicted under various scenarios, including different ages of the spent fuel
- The pool is filled to capacity with fuel rods in high density racking.
- Shown is a surface of constant temperature along with contours of temperature in the region of the stored rods.

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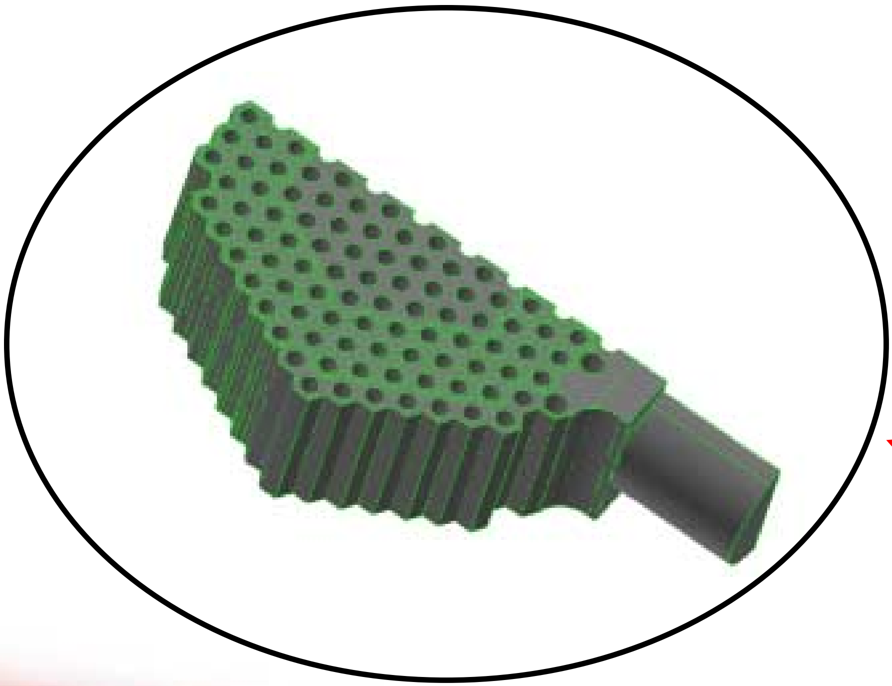
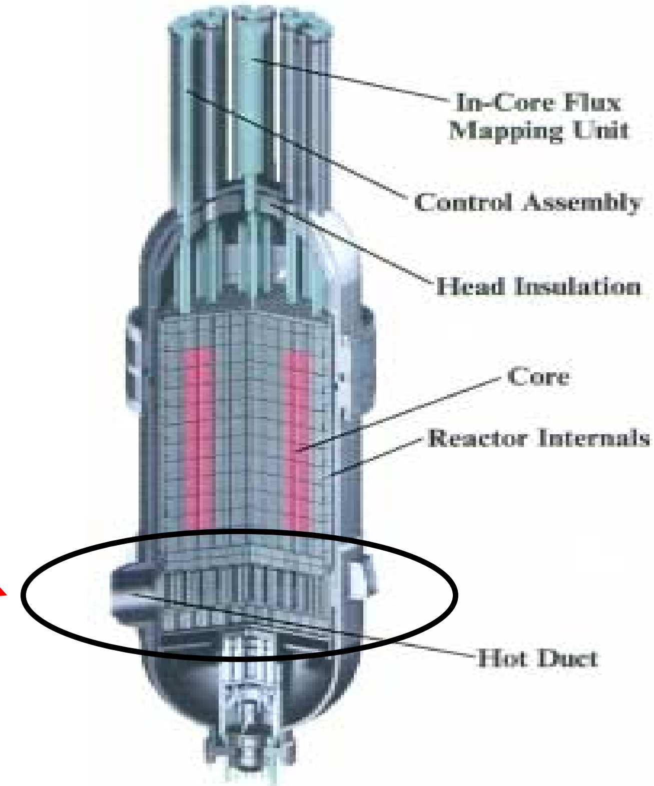
GT-MHR Lower Plenum Analysis

FLUENT Domain

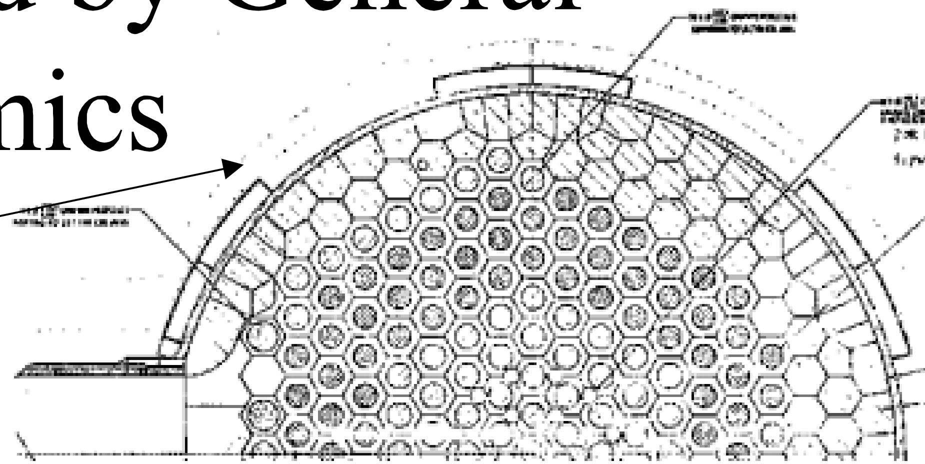


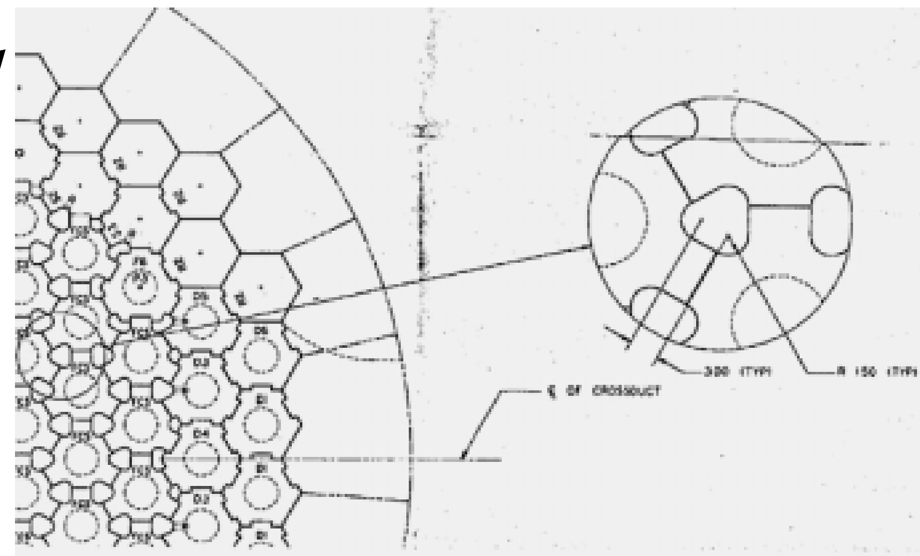
600 MW GT-MHR



Data Provided by General Atomics

- Geometry via drawings
- Output of Sinda model giving core outlet temperatures for each column
- Operating pressure (7 Mpa)
- Flow rate (160 Kg/S helium for ½ model)





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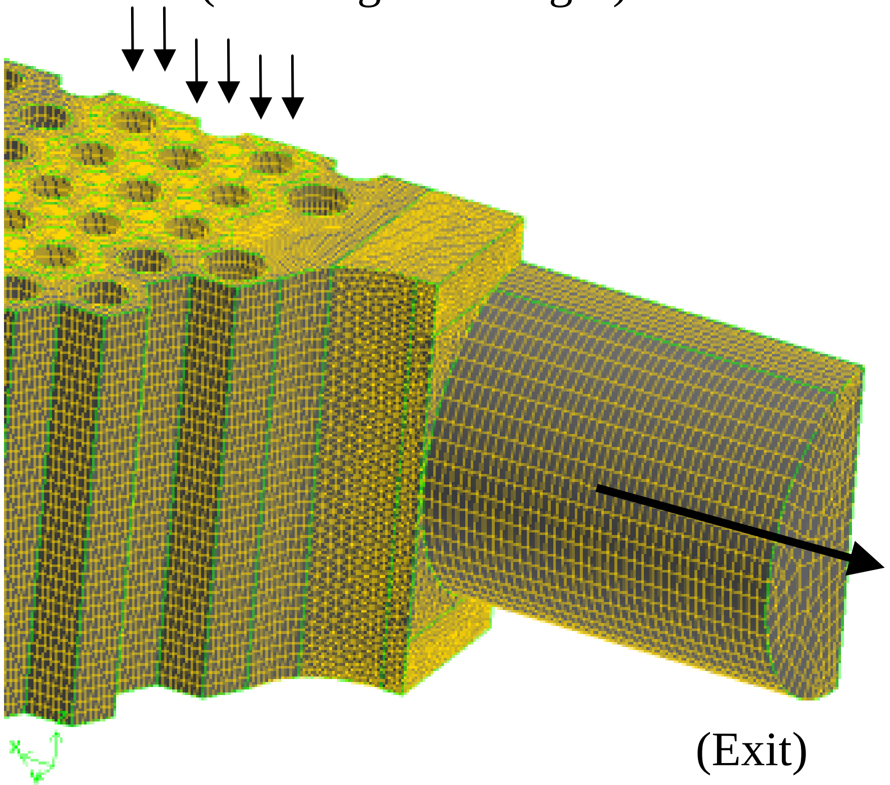
Model Details

- ~ 750,000 cell, symmetric mesh
- Buoyancy enabled
- walls treated as adiabatic surfaces
- working fluid is Helium gas
- inlets located around circular pedestals (shown in figure), which support fuel rods
- horizontal nozzle connection provides exit from domain

(Entering Helium gas)



(Exit)

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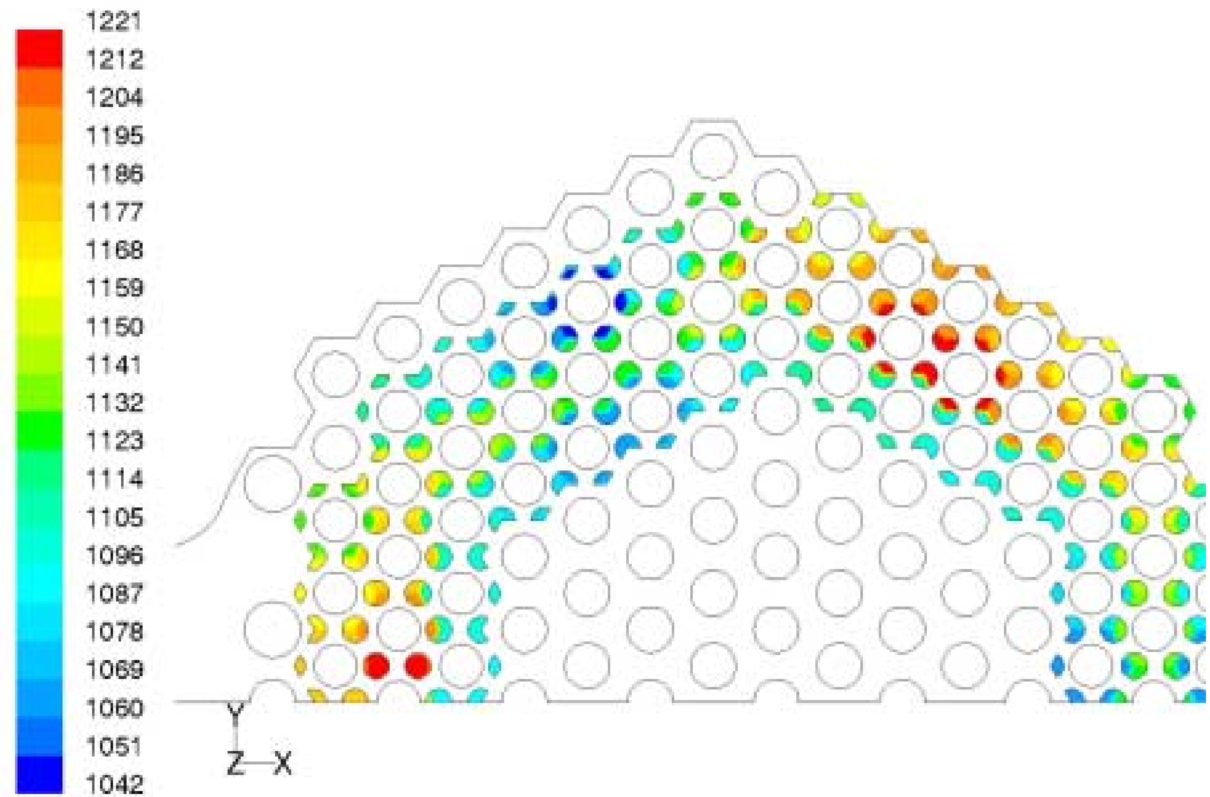
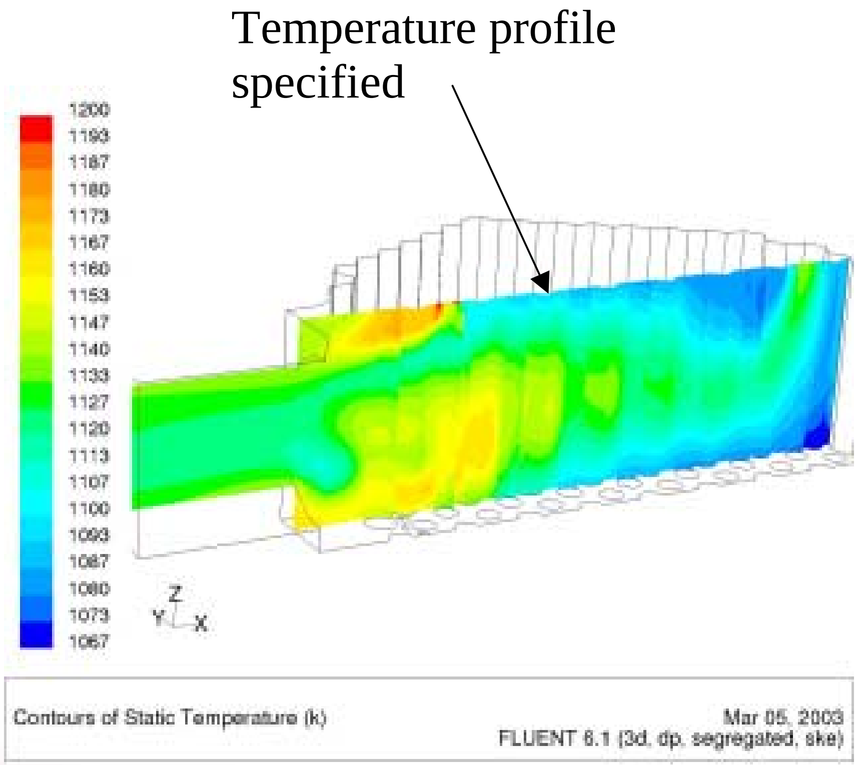
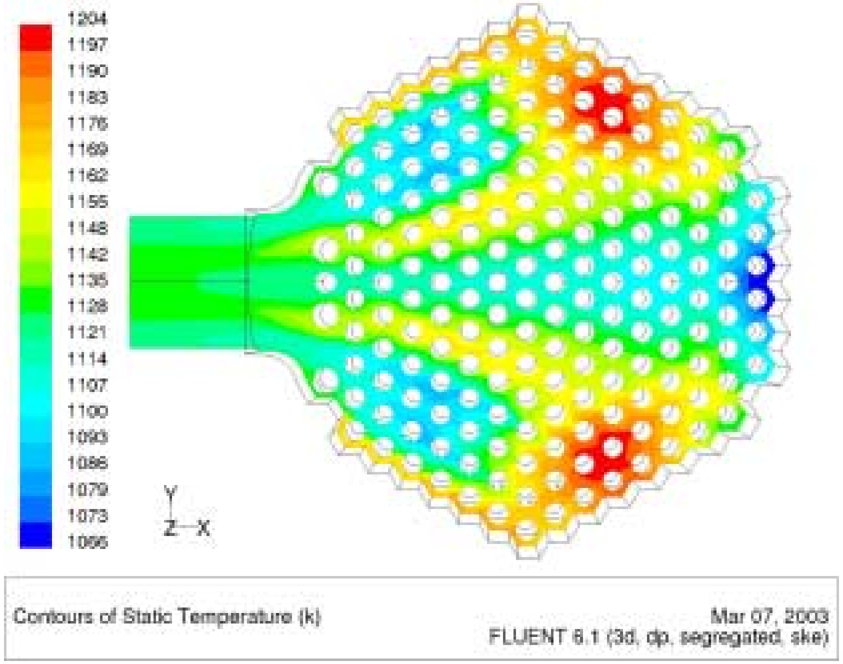
Thermal Boundary Conditions



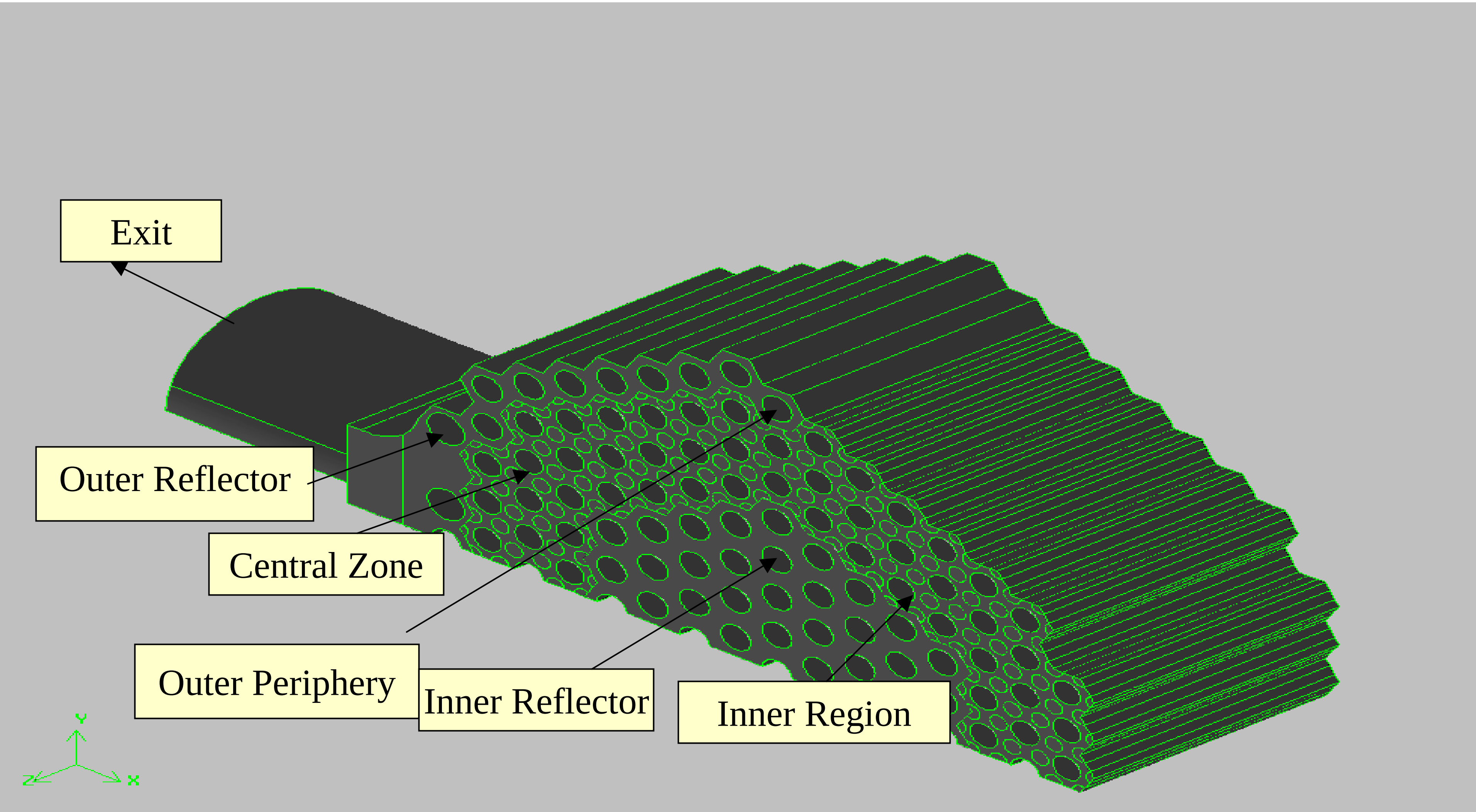
Contours of Temperature Profile Specified at the Velocity Inlets Aug 18, 2003
FLUENT 6.1 (3d, dp, segregated, ske)

GT-MHR Lower Plenum Results:





RELAP5 Coupling: Boundary Conditions Provided at 6 Locations in 1st Calculation…



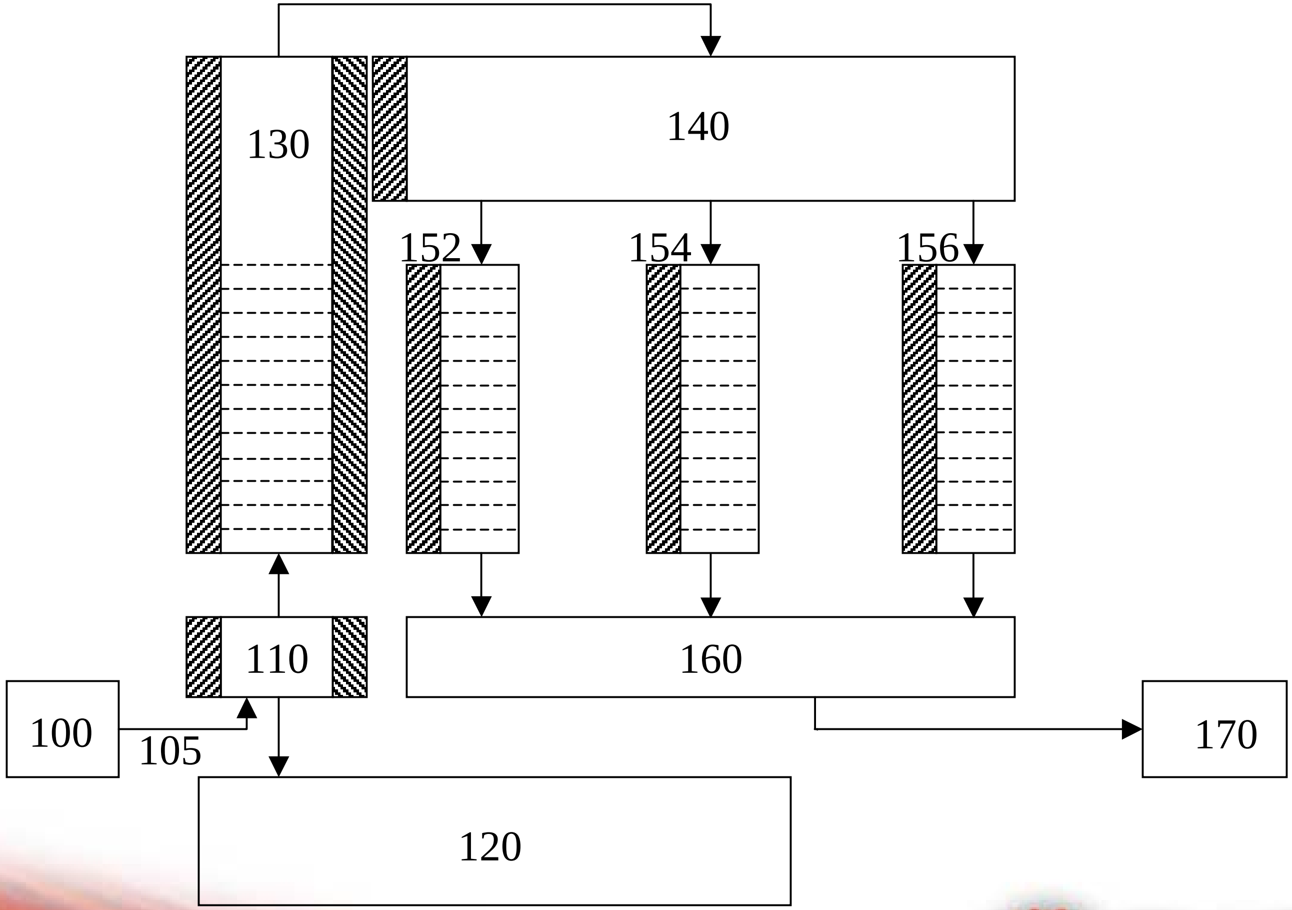
Boundary Conditions…

- Pressure = 7 MPa
- Operating average outlet temperature = 1134 K
- All walls adiabatic
- Inlet velocity = 98.625 m/s (Flow rate = 160 kg/s for ½ plenum)
- Diameter of inlet hole = 200 mm
- Backflow temperature = 1000 K
- Turbulent intensity = 10%

RELAP5 Model Summary: Reactor Vessel Model

- Coolant active and stagnant volumes
- Structures in the core region
  - inner and outer reflectors
  - upper and lower reflectors
  - core barrel
  - upper plenum shield
  - reactor vessel wall and upper head
- Structures below the core are being ignored

VHTR Vessel Hydraulic Nodalization—Bypass Not Shown



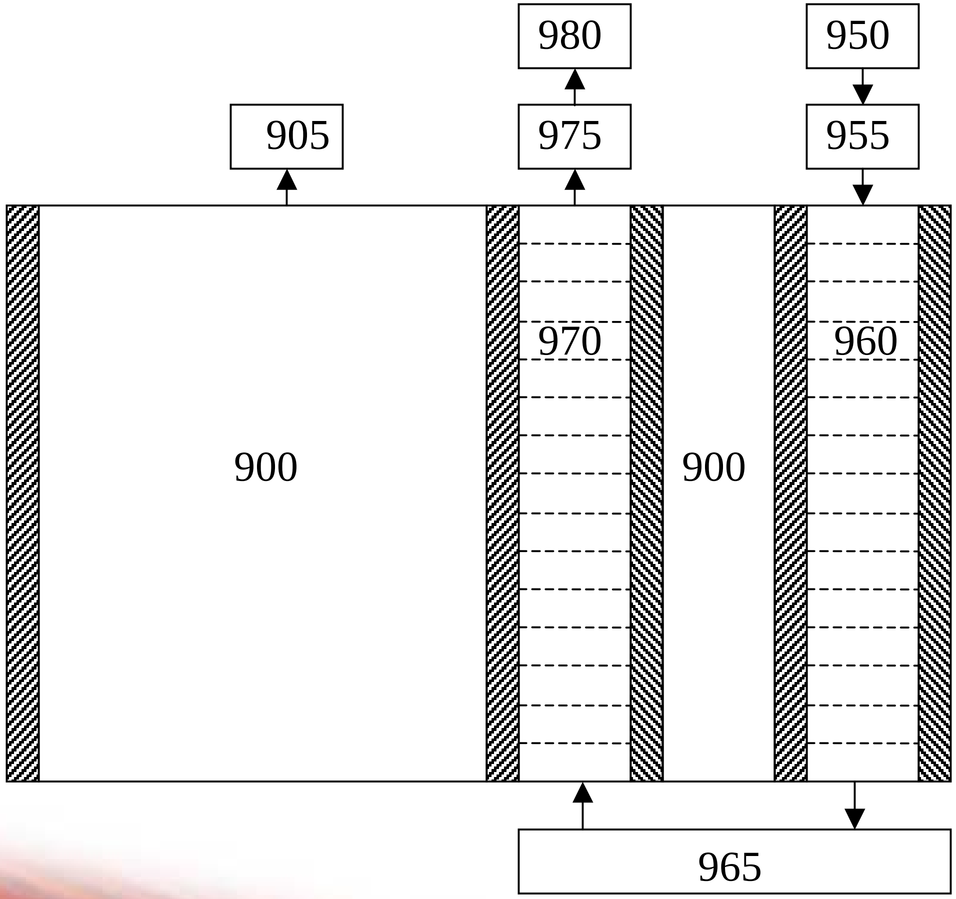
Other Candidate Coupled Calculations

- Reactor cavity cooling system
- Coupled through heat transfer boundary

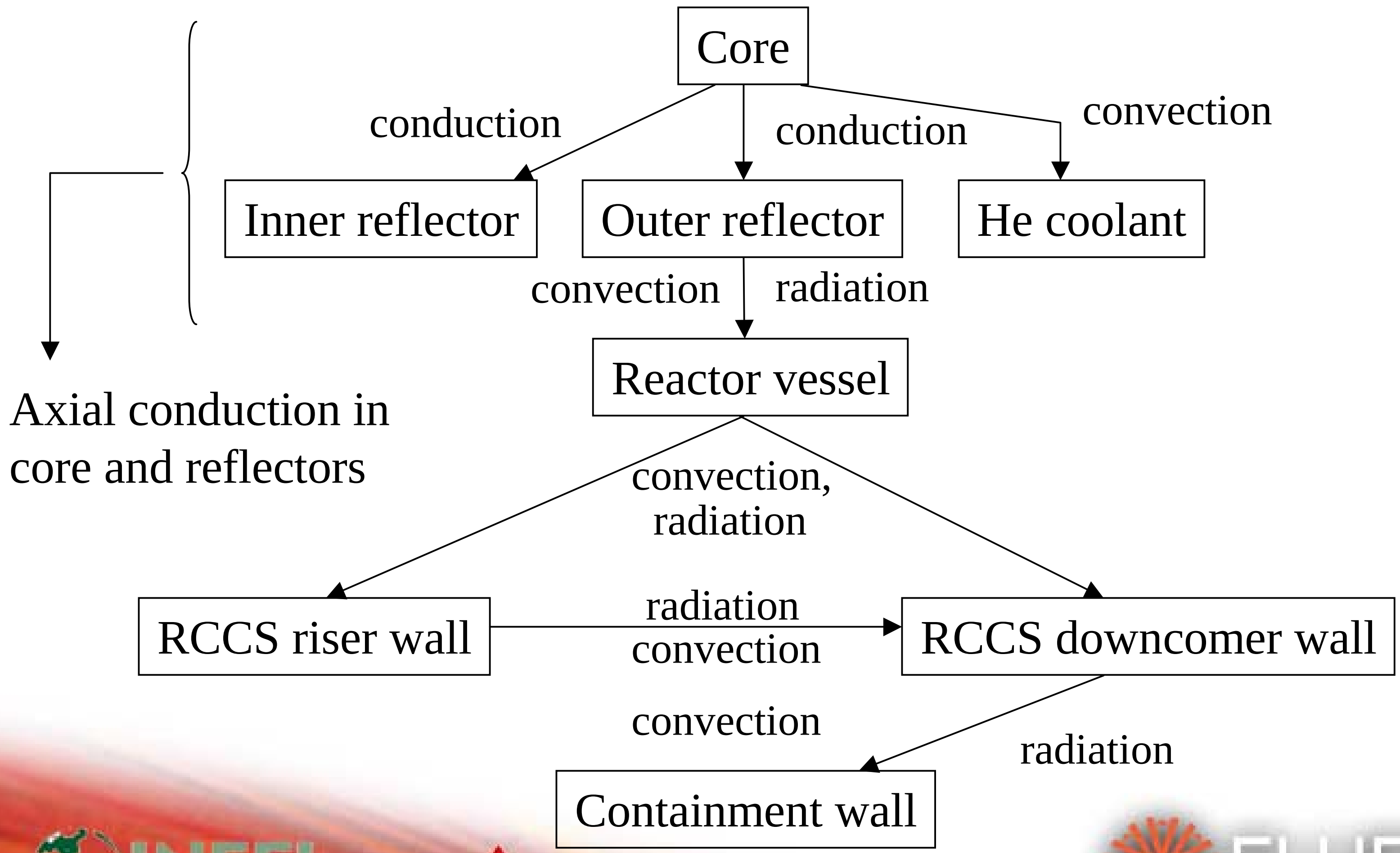
RELAP5 Model Summary: Ex-vessel Model

- Containment air volume
- Reactor cavity cooling system (RCCS)
  - Inlet plenum/downcomer piping
  - Lower distribution plenum
  - Riser/outlet plenum
  - Riser, downcomer, and outer metal walls
- Containment concrete wall and surrounding soil (behind RCCS downcomer)
- Other structures/walls neglected

VHTR Reactor Cavity Nodalization



RELAP5 Model Summary: Heat Transfer Modeling with RCCS Model



Status & Schedule…

- Modifying coupling protocol to work with Fluent 6.1 (work previously done for Fluent 5.5)

- Will perform calculation in Sept on Sun workstation.