Evolving the ATHENA Model of a LOCA Analysis for the Generation IV Gas-cooled Fast Reactor

Ryan Winningham

The Ohio State University

August 15, 2005

Mentor: Theron Marshall Ph.D.

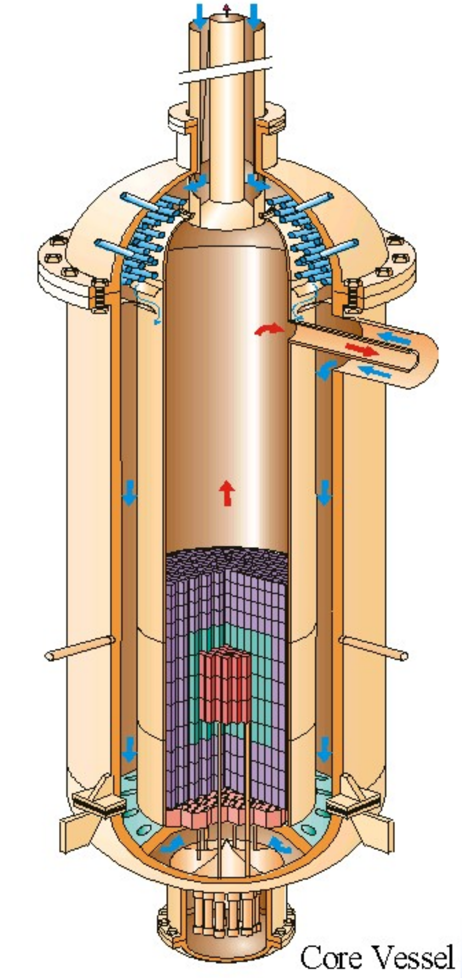
Idaho National Laboratory

Presentation Outline

- Overview of RELAP5/ATHENA GFR model
- Outline of Research Tasks
- Completed Work
- Work in Progress
- Future Work
- Questions

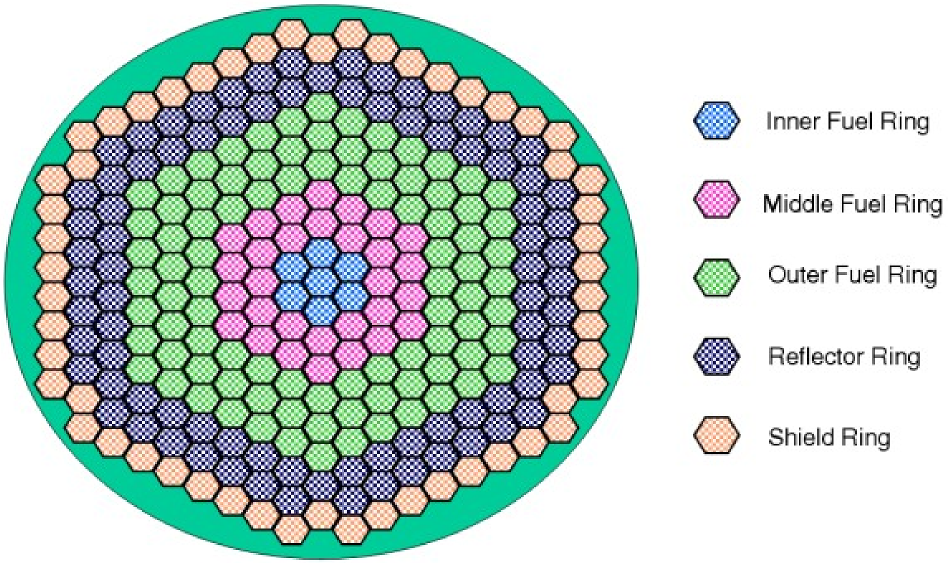
Generation IV Helium Gas-Cooled Fast Reactor

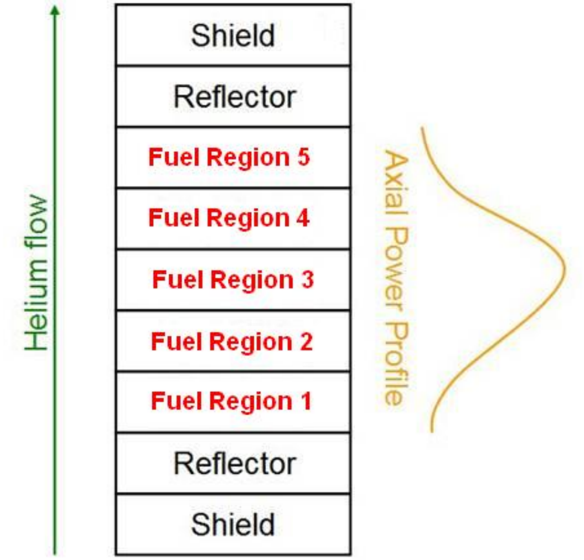
- The Gas-Cooled Fast Reactor (GFR) is one of six Generation IV designs
- The 600MW$_{th}$ GFR uses a direct-cycle helium turbine for electricity generation, or can optionally use its process heat for thermochemical production of hydrogen due to the 850°C outlet temperature
- Through the combination of a fast spectrum and full recycle of actinides, the GFR minimizes the production of long-lived radioactive waste.



RELAP5/ATHENA GFR Core Layout

- **Three radial core sections**
  (Inner Ring, Middle Ring, Outer Ring)
- **Five axial core regions per ring**





Helium flow

Shield

Reflector

Fuel Region 5

Fuel Region 4

Fuel Region 3

Fuel Region 2

Fuel Region 1

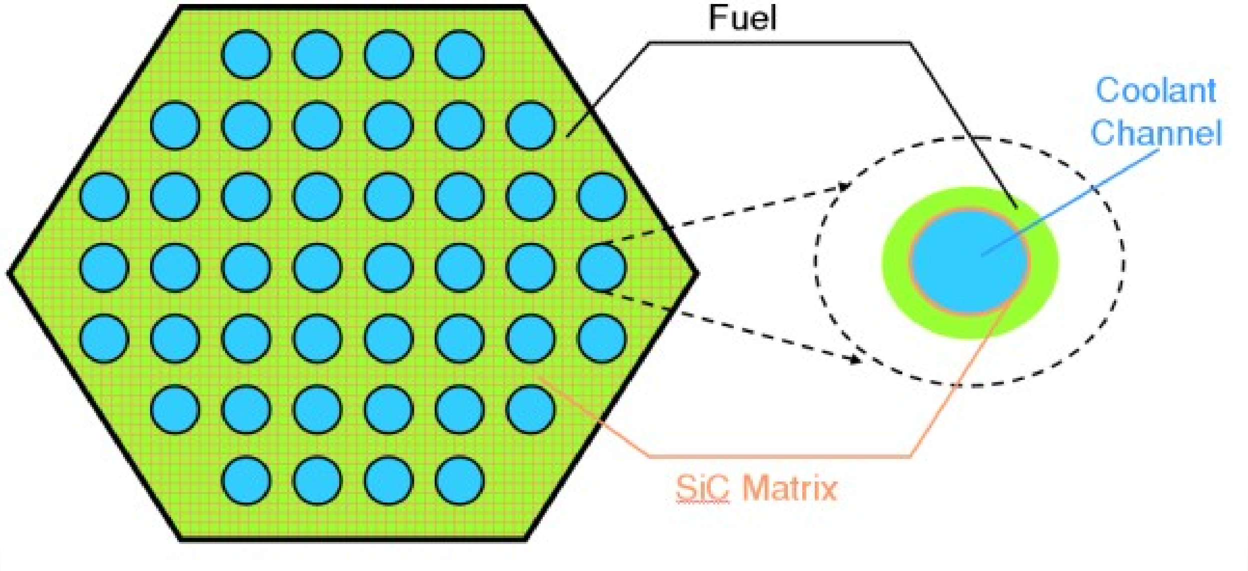
Reflector

Shield

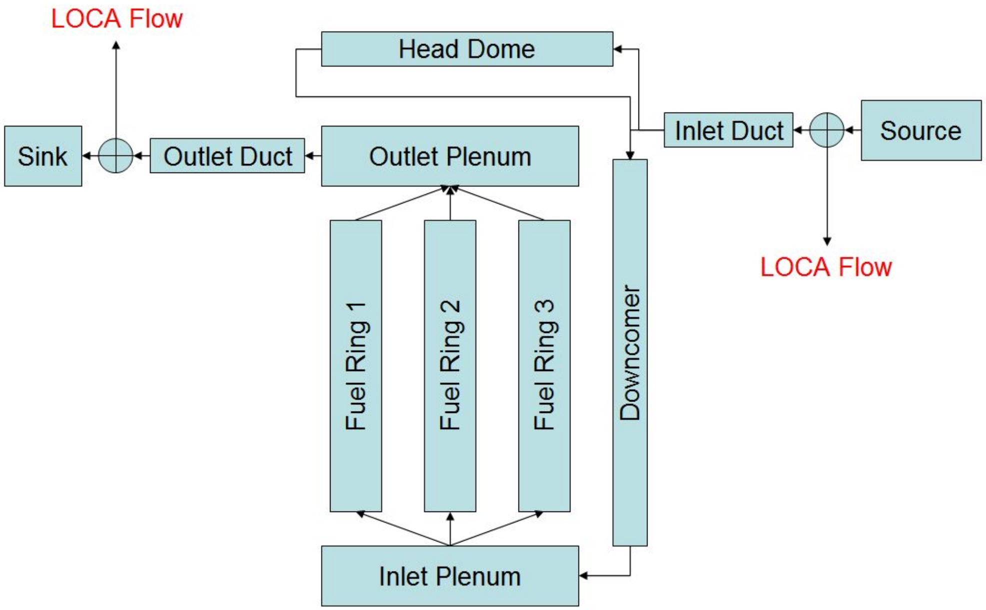
Axial Power Profile

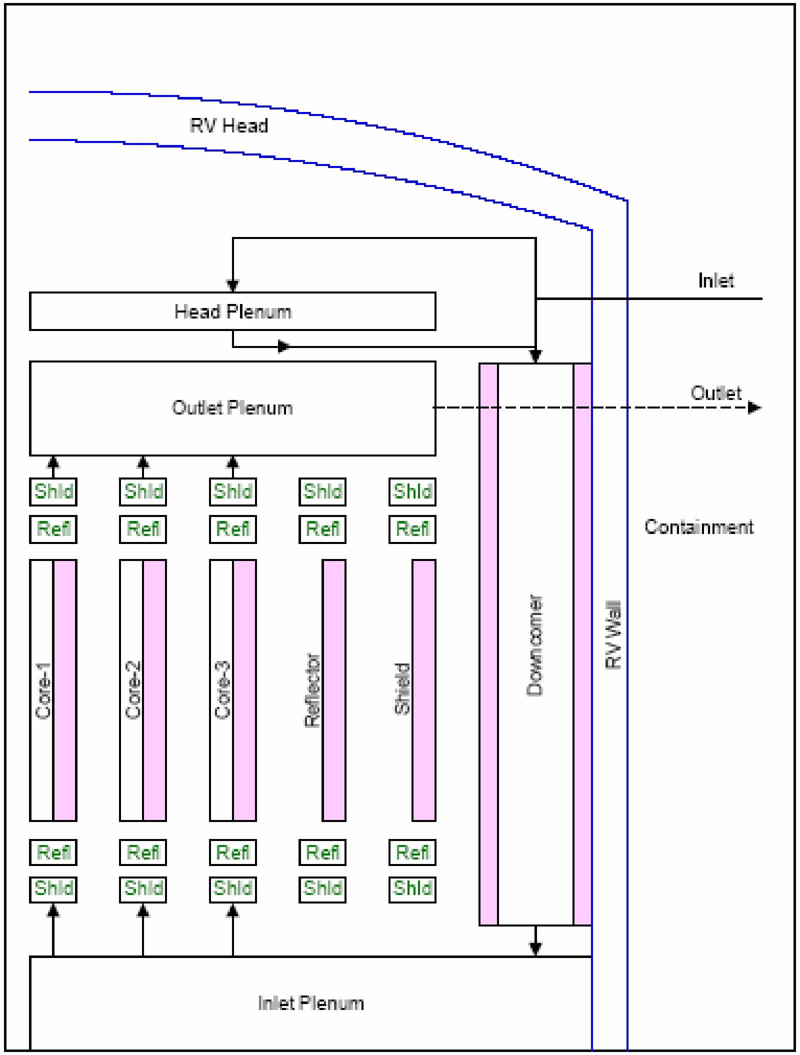
Fuel Design

- The GFR prismatic fuel block contains fuel material dispersed in a SiC matrix
- Same unit cell methodology that is used in VHTR thermal analysis



Hydrodynamic Volumes and Heat Structures





Outline of Research Tasks

Task 1 - Development of a hot channel

Task 2 - Radial and axial flux distribution

Task 3 - Inlet plenum orificing

Task 4 - SiC thermal conductivity investigation

Task 5 - LOCA transient / Containment modeling

Task 6 - GFR core modeling in FLUENT

Development of a Hot Channel

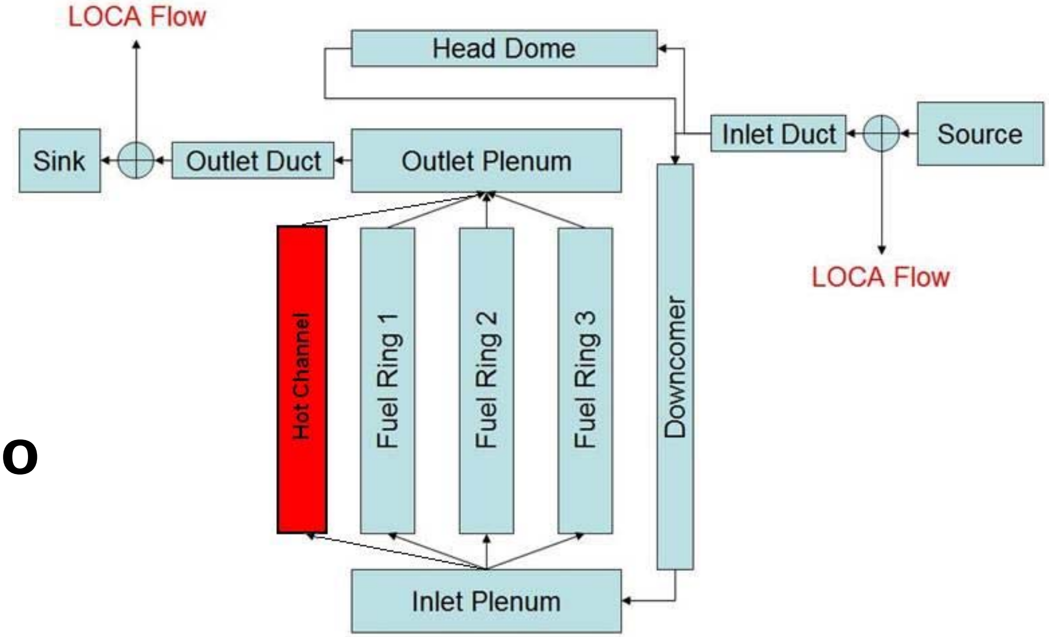
- Two tasks for different needs
  - Hot channel as a heat structure (fuel temperature monitoring)
  - Hot channel as a hydrodynamic volume and heat structure (coolant property monitoring – used for stability analysis, FLUENT comparison)

Hot Channel as a Heat Structure

- **Hot channel heat structure added to inner core ring**
- **The heat structure represents the equivalent annulus of fuel for one coolant channel**
- **There are 637 coolant channels in the inner core ring (7 assemblies, 91 coolant channels each)**
- **No impact on inner ring coolant temperatures**

Hot channel as a Hydrodynamic Volume and Heat Structure

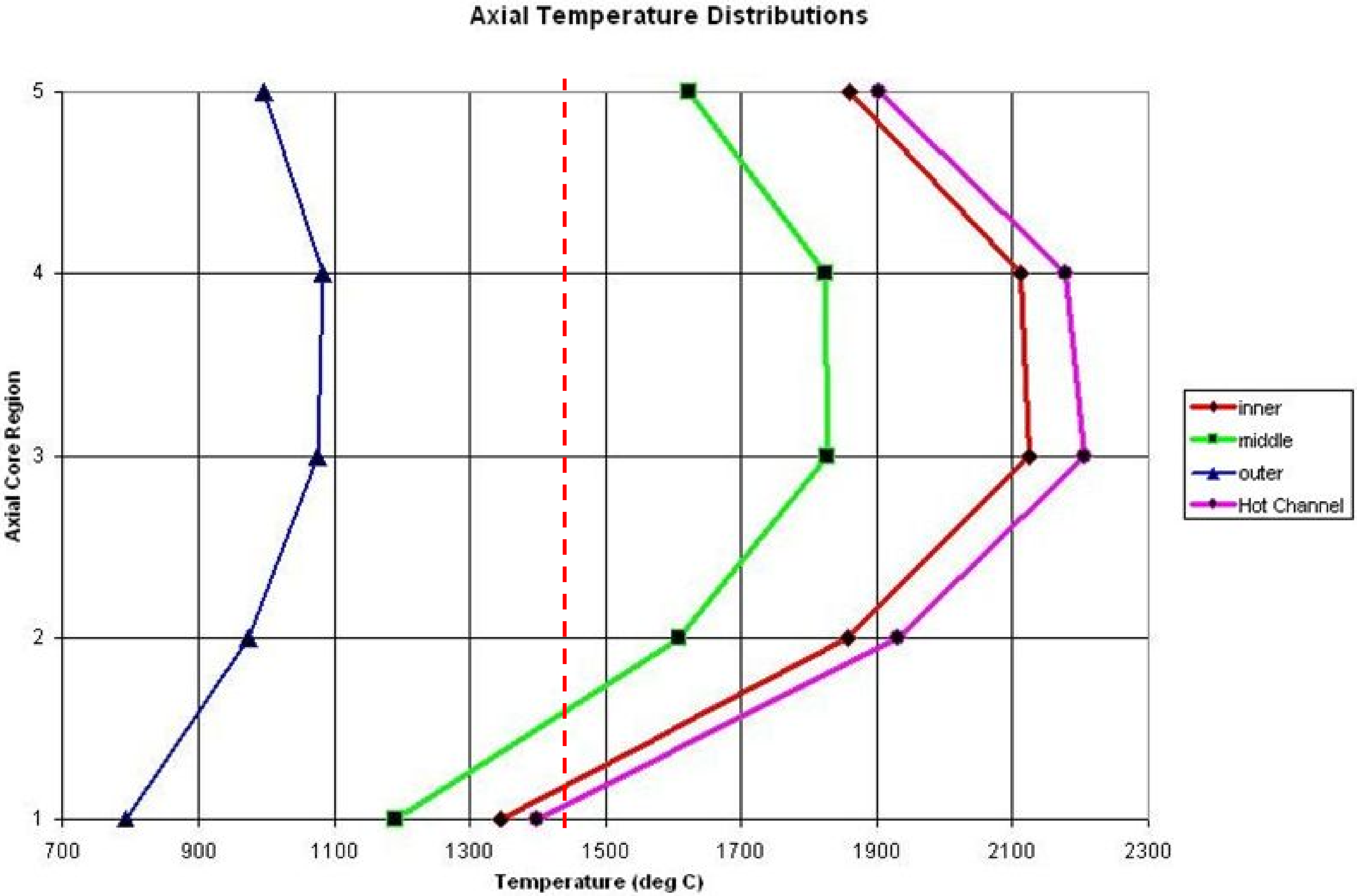
- New hydrodynamic volume added to core geometry to represent a single coolant channel
  - Removed one channel from inner ring
- Heat structure added to the single hot channel
- Provides fuel and coolant property data for the hot channel



Radial and Axial Flux Distribution

- **5 Axial increments**
  - **1.25 peak-ave power ratio (chopped cosine)**
- **3 (+1 Hot Channel) Radial increments**
  - **1.5 peak-ave power ratio (chopped cosine)**
    - **1.5 peak is placed in the hot channel**

Results of Core Power Distribution



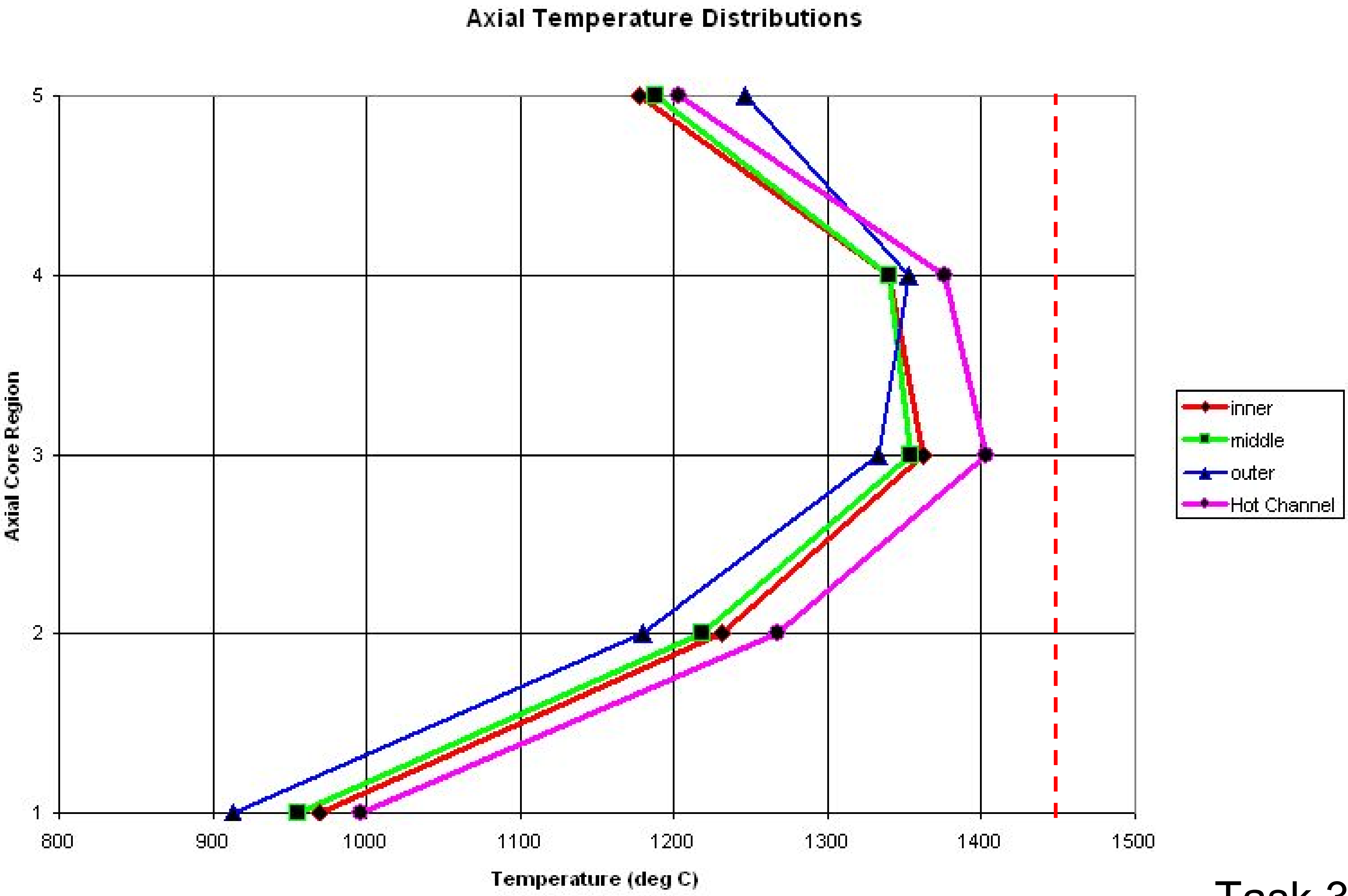
Task 2

Inlet Plenum Orificing

- **Inlet plenum orificing is necessary in order to meet GFR maximum fuel temperature design specifications**
  - **1450 °C normal operation**
  - **1650 °C transient**

	% Constriction	Flow area (m^2)	Mass Flow rate (kg/sec)	% of total flow
Inner Ring (7)	**0.0%**	**0.1456**	**43.04**	**13.2%**
Middle Ring (30)	**52.0%**	**0.2996**	**140.4**	**43.3%**
Outer Ring (90)	**85.5%**	**0.2714**	**141.9**	**43.6%**

Results of Inlet Plenum Orificing



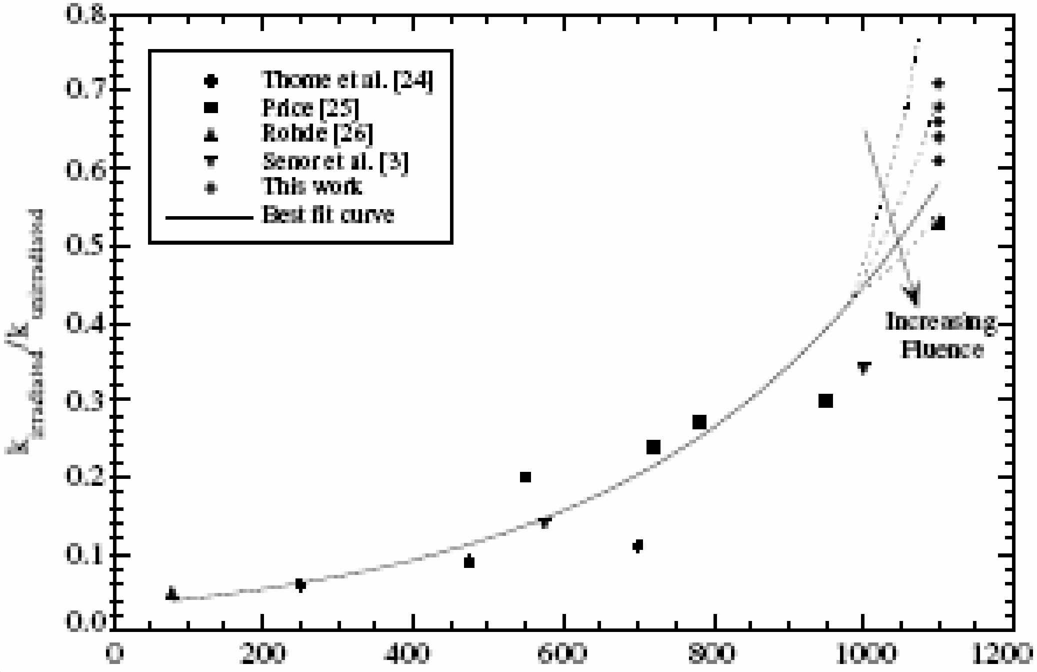
Task 3

Impacts of Inlet Plenum Orificing

- **Increase in core pressure drop from 14 kPa to 73 kPa**
- **Increased pumping power from 1.0 MW to 5.5 MW (0.9% thermal power)**
- **Orificing optimized for end of life core fuel temperatures (high peaking)**
  - **adjustable bypass flow or fresh fuel flux shaping necessary at beginning of life core**

SiC Thermal Conductivity Investigation

- **SiC thermal conductivity drops by $^{1}/_{2}$ -$^{1}/_{3}$ with radiation exposure**
- **The change in thermal conductivity can increase fuel temperatures by as much as 150 °C (conductivity lowered by 1/3)**
- **With GFR fast flux ~10^{15} n/cm^{2}-sec, these effects may be see just weeks from startup**



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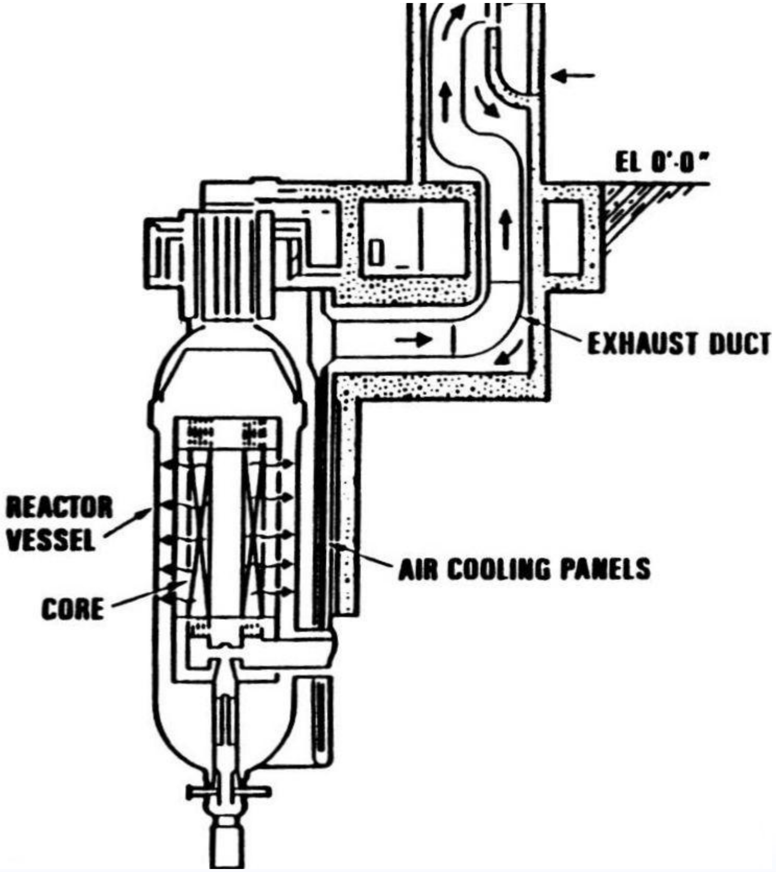
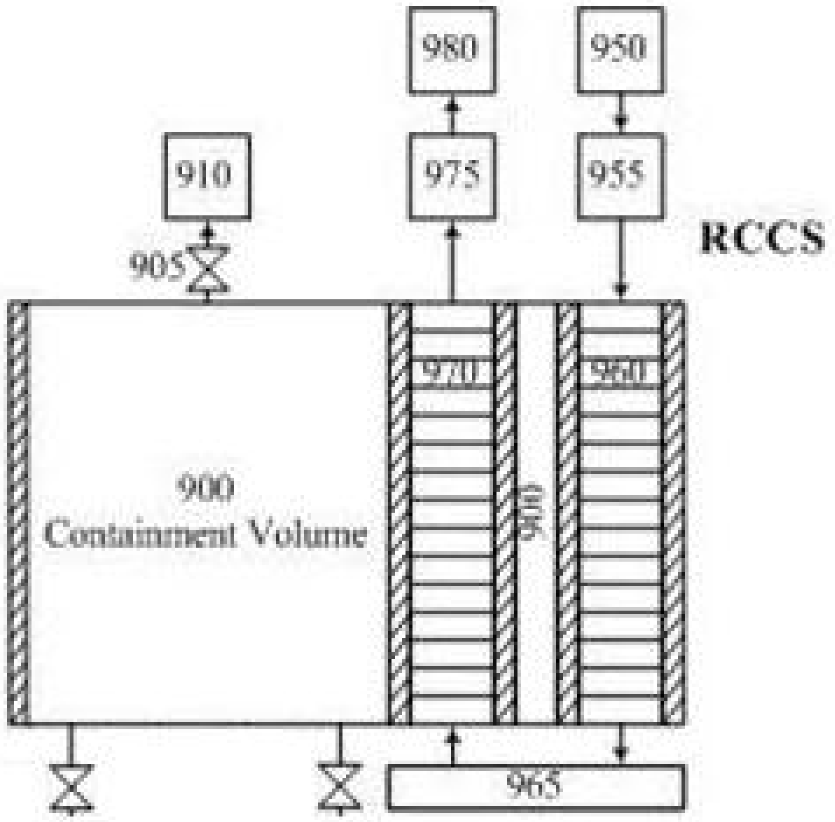
LOCA Transient

- **The Reactor Cavity Cooling System (RCCS) is a passive means of heat removal that mitigates core damage during a Loss of Coolant Accident (LOCA)**



RELAP5/ATHENA RCCS Model

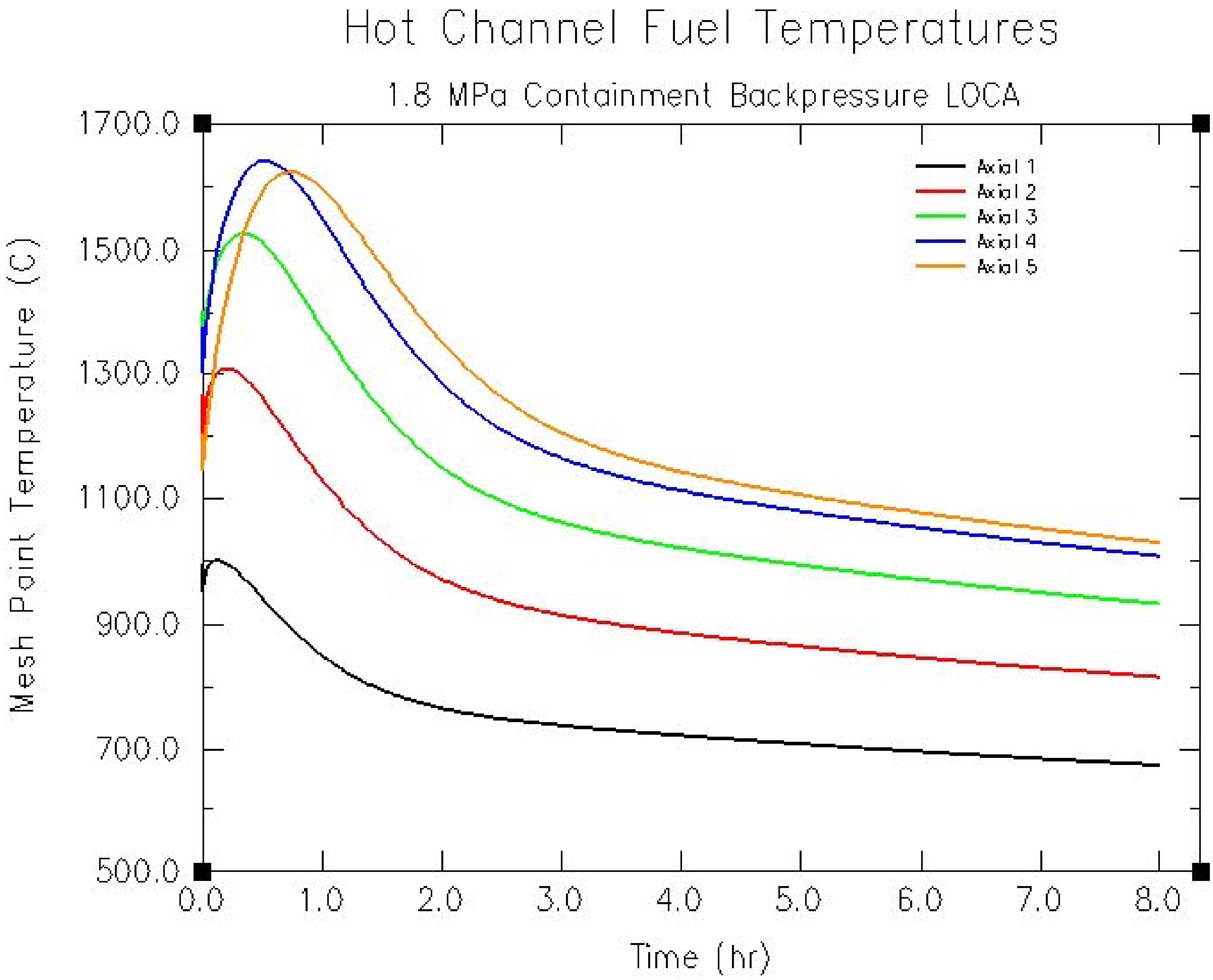
- This is the same RELAP5/ATHENA model of the RCCS that is used in the VHTR
- Air at 27°C enters the inlet plenum (955)
- Then flows down the downcomer (960) attached to the containment wall
- Then up the riser channels (970) and discharged to the upper plenum (975)



Containment Backpressure

- The heat removal capacity of the RCCS is dependent on the containment pressure (air density)
- 1.2 MPa Containment pressure was sufficient to passively cool the core and prevent fuel failure before the addition of the hot channel and radial-axial power distributions
- 1.8 MPa is now necessary to meet GFR maximum fuel temperature design specifications
(1650 °C transient)

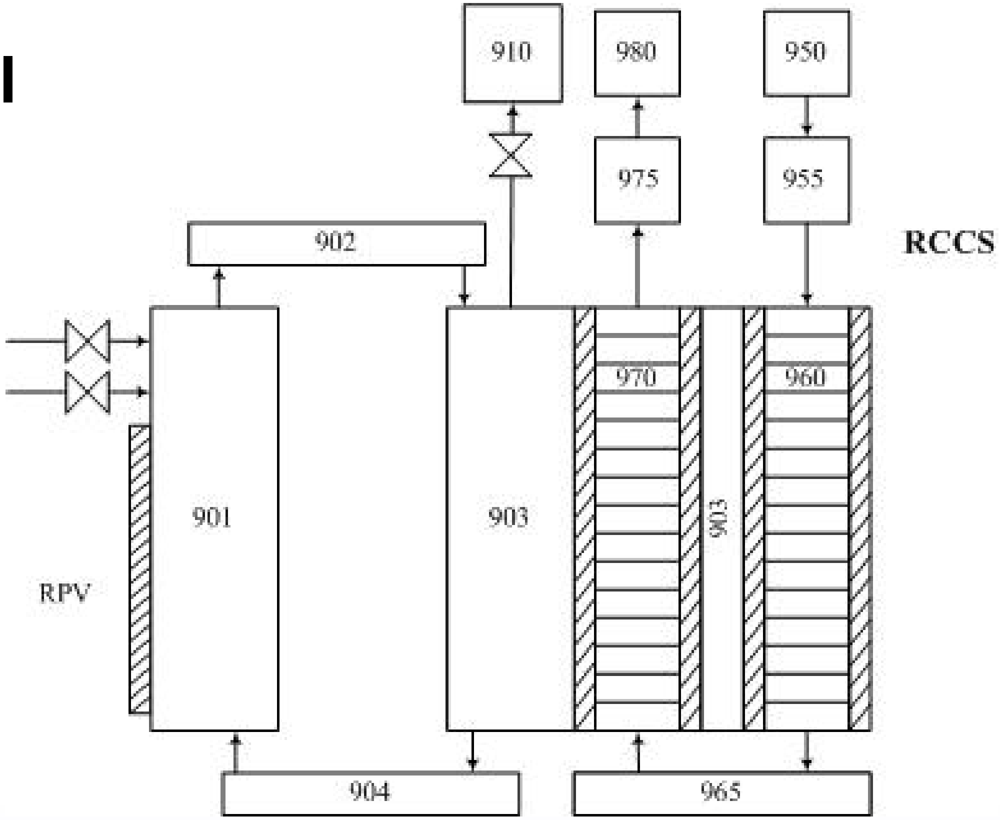
RCCS Performance (Old Containment)



Task 5

New Containment Model

- Used to investigate heat removal by natural circulation in containment
- Containment modeled as two concentric annuli
- Loop flowrates will be based off FLUENT modeling results

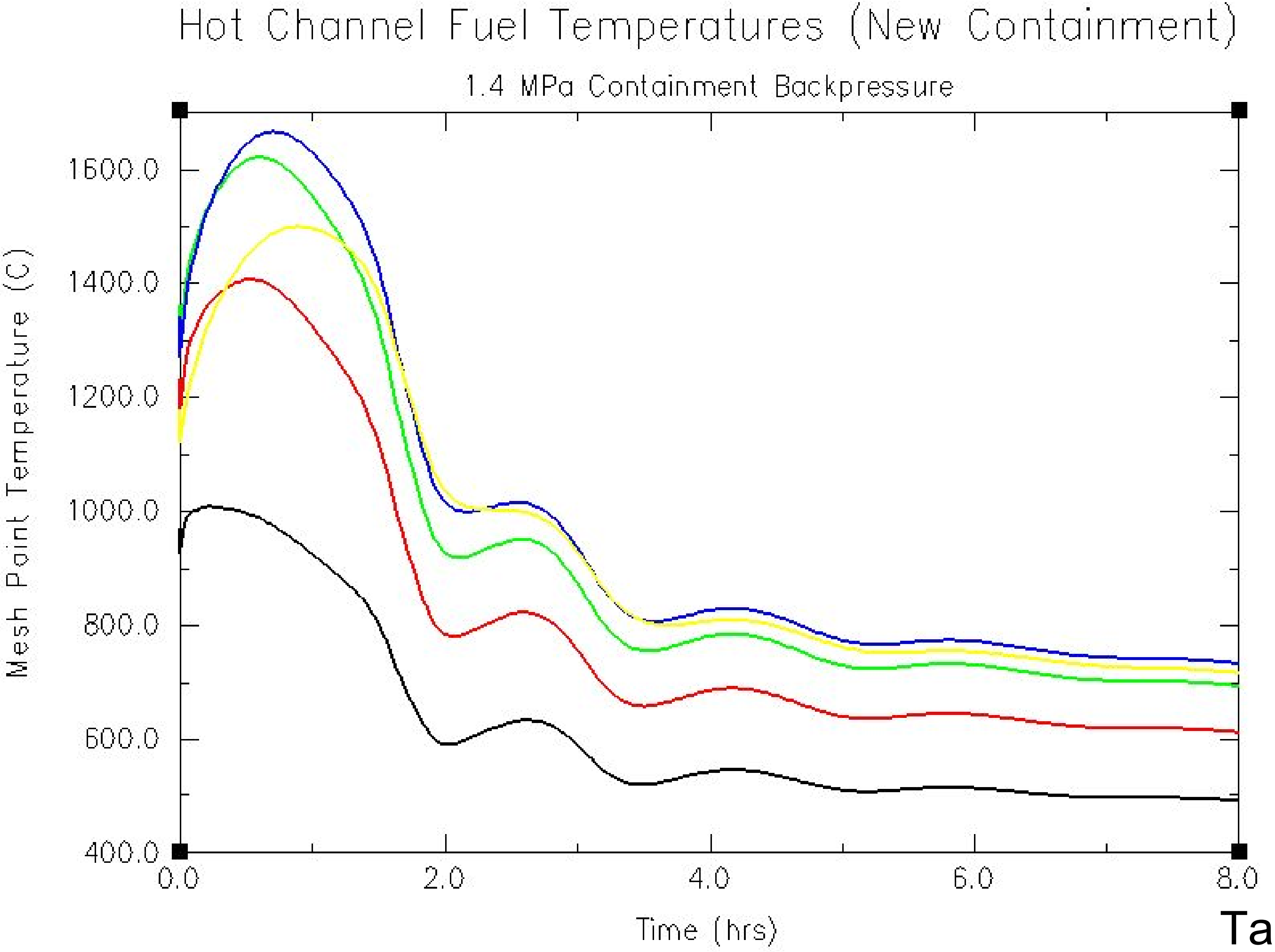


New Containment Model (Preliminary Results)

- Possible to lower containment pressure from 1.8MPa to 1.4MPa and still achieve 1650 °C transient depressurization design parameter
- Shows natural circulation in containment and the core

- Future Work
  - FLUENT benchmark of containment
  - Adjustment of containment size
  - Investigate flow instabilities

RCCS Performance (Preliminary Results)



Task 5

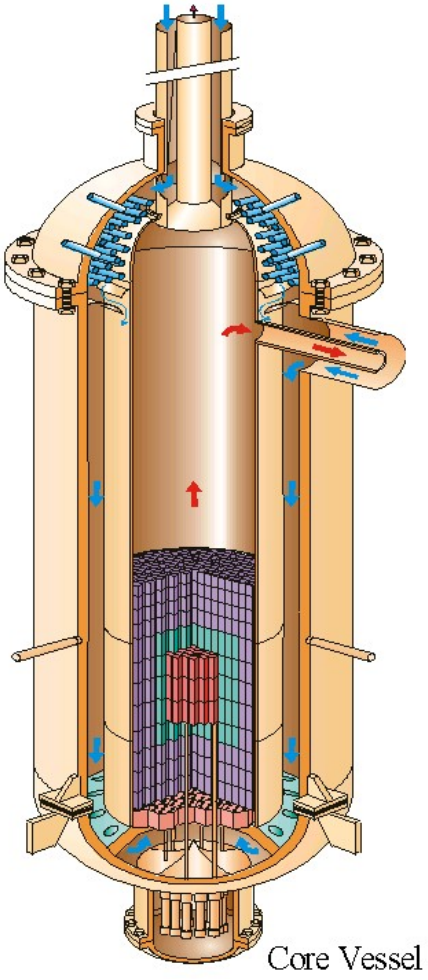
GFR Core Modeling in FLUENT

- Created 3 FLUENT geometries to investigate core flow under natural circulation conditions.
  - Single coolant channel
  - 3 channels with lower plenum (inlet)
  - 3 channels with lower and upper plenum
- Benchmarked geometries against RELAP5/ATHENA GFR hydrodynamic hot channel
- Currently working on natural circulation flow and viscosity induced flow starvation.

Future Work

- **FLUENT modeling of Containment/RCCS decay heat removal for LOCA**
- **Update core design to align with the U.S./French I-NERI GFR concept (2400MW$_{th}$)**

Questions?



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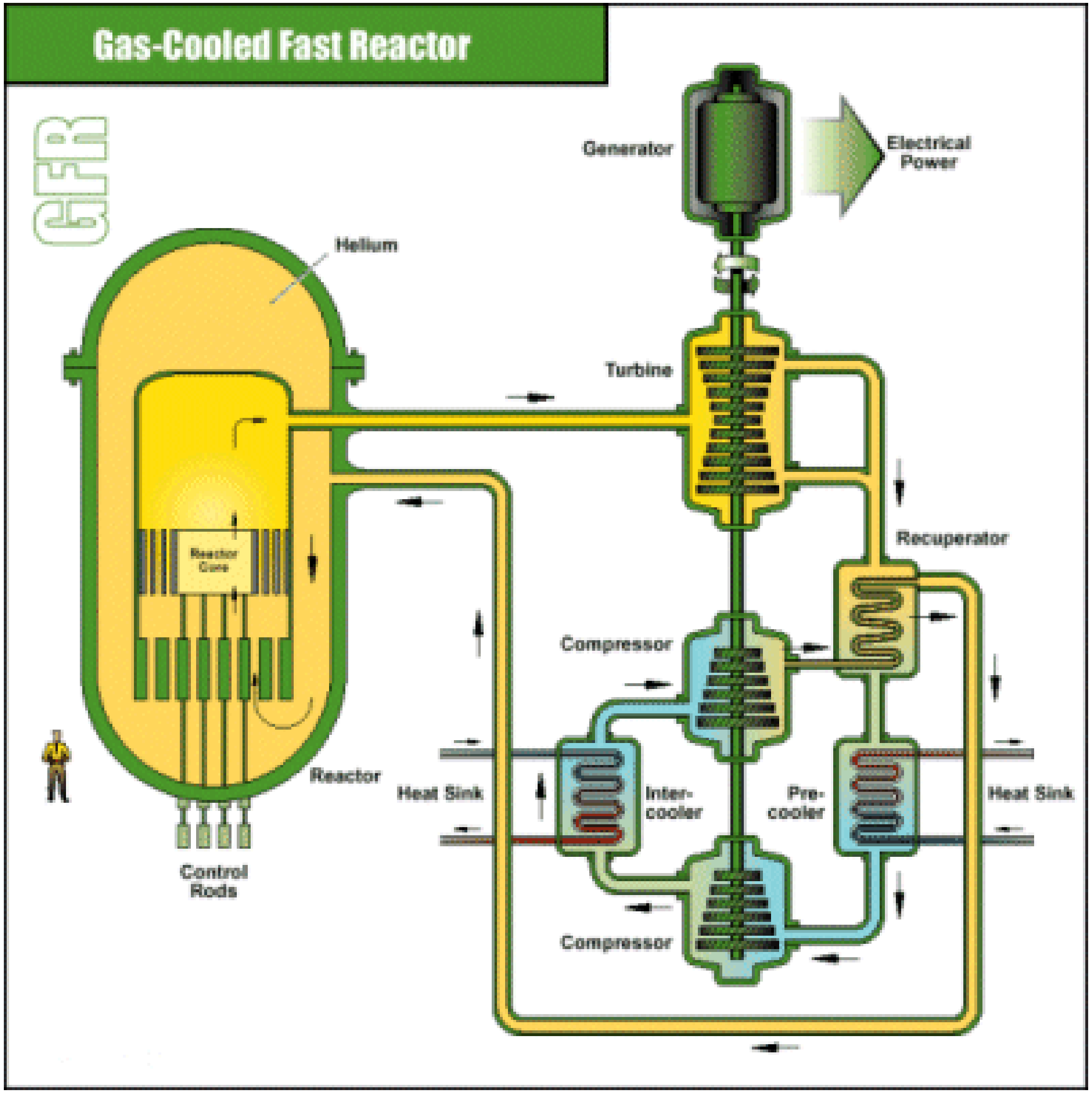

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Acknowledgements

Larry Zirker, Kevan Weaver, Theron Marshall (INL)
Richard Christensen, Audeen Fentiman, Brian Hajek (OSU)

Supplemental Slides

Design Specs

Reactor Design Parameter	Conceptual Data
Power plant	600 MW_{th}
Net efficiency	48% (helium, direct cycle)
Coolant pressure	9 MPa
Outlet coolant temperature	850°C (helium, direct cycle)
Inlet coolant temperature	490°C (helium, direct cycle)
Nominal flow and velocity	330 kg/s and 40 m/s
Core volume	10.9 m^3 (H/D ~1.7/2.9 m)
Core pressure drop	~ 0.04 MPa
Volume fraction (%) Fuel/Gas/SiC	50/40/10
Average power density	55 MW/m^3
Reference fuel compound	(U, Pu)C/SiC (50/50%) 17% Pu
Breeding/Burning performances	Self-Breeder
Maximum fuel temperature	1174°C (normal operation) < 1650°C (depressurization)
Fuel management	multi-recycling
Primary vessel diameter	< 7 m