Idaho National Engineering and Environmental Laboratory

Prismatic Core VHTR Analysis using RELAP5-3D/ATHENA

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Outline

- *Analysis objectives*
- *VHTR description*
- *RELAP5-3D/ATHENA input model description*
- *Benchmarking results*
- *Scoping calculation results*
- *Code implications*

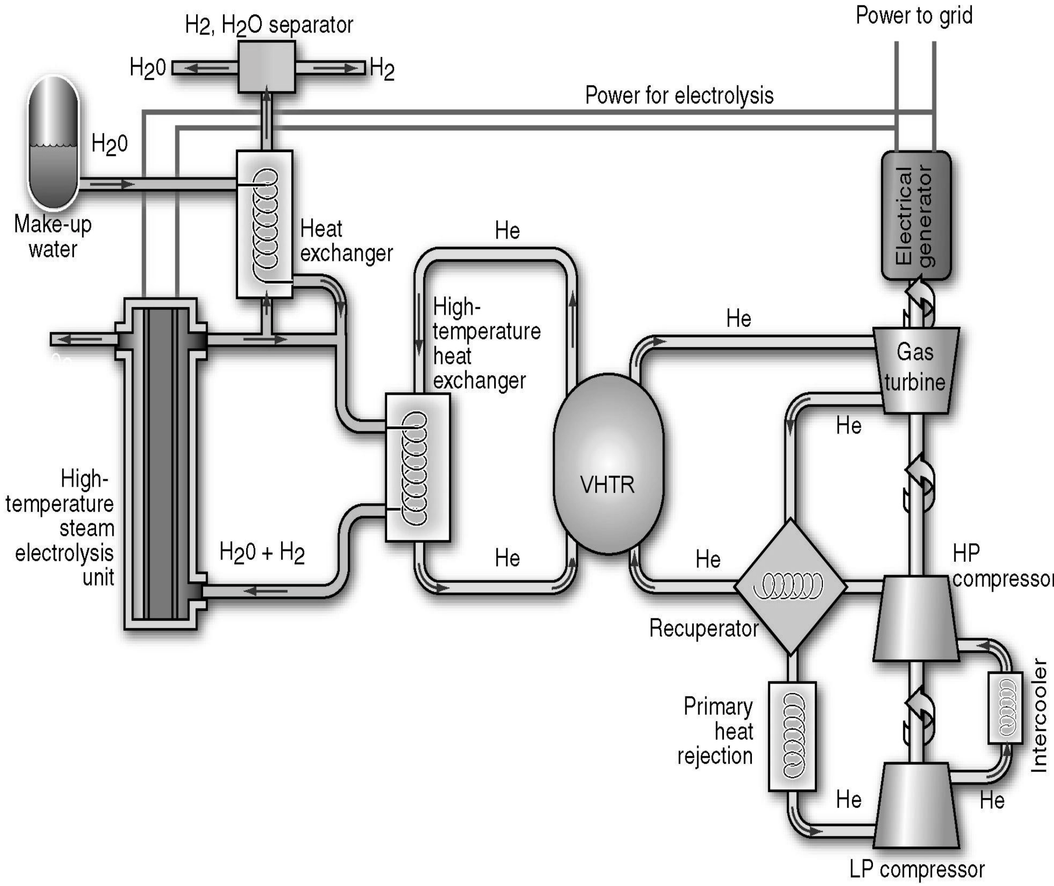
VHTR Analysis Objectives

- *Near term*
  - *develop a representative model of the reactor vessel*
  - *perform scoping analyses to establish basic operating parameters*
- *Longer term*
  - *develop an independent analysis capability for DOE to use during the plant design and licensing phases*

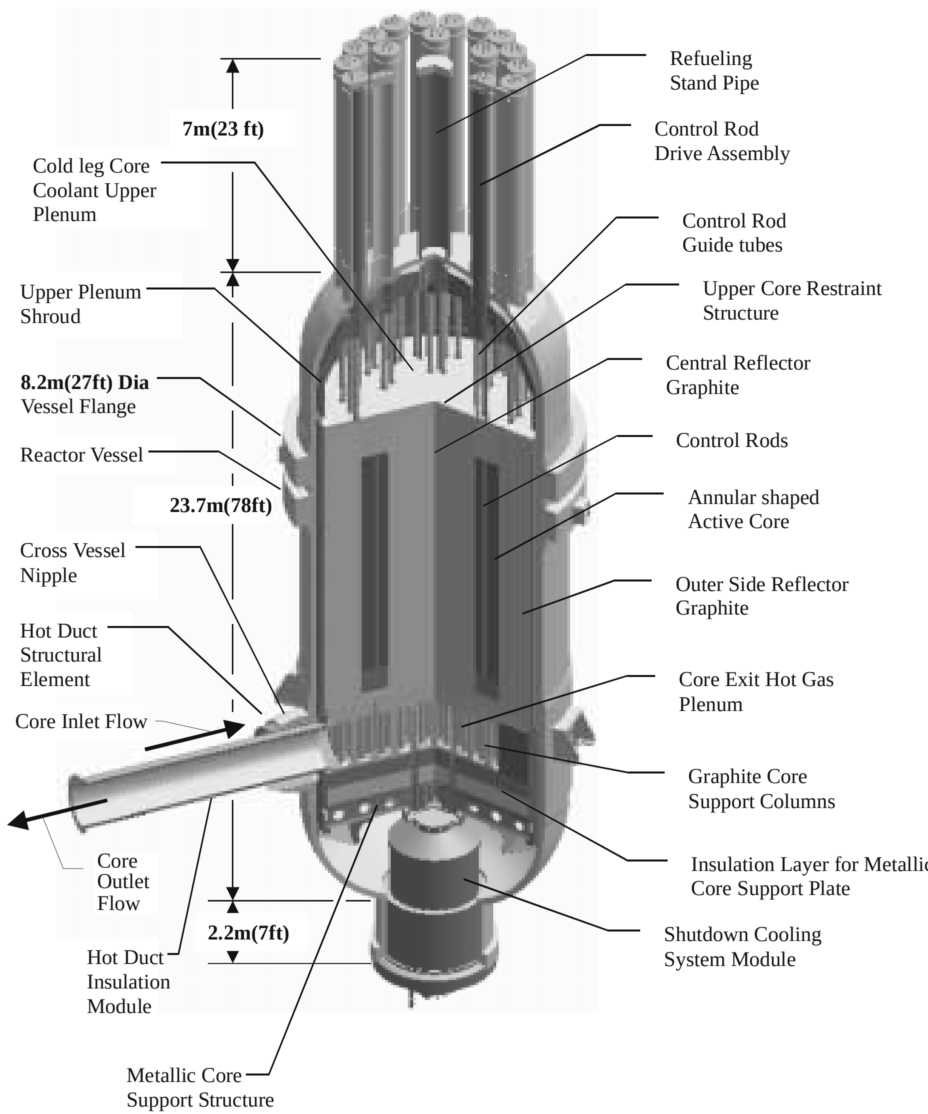
What is the VHTR?

- One of the six selected Generation IV reactor concepts
- Helium cooled, graphite moderated, thermal neutron spectrum reactor
- Passively safe
- Reactor vessel coolant outlet temperature of 1000°C
- Will be used for generating both electricity and hydrogen

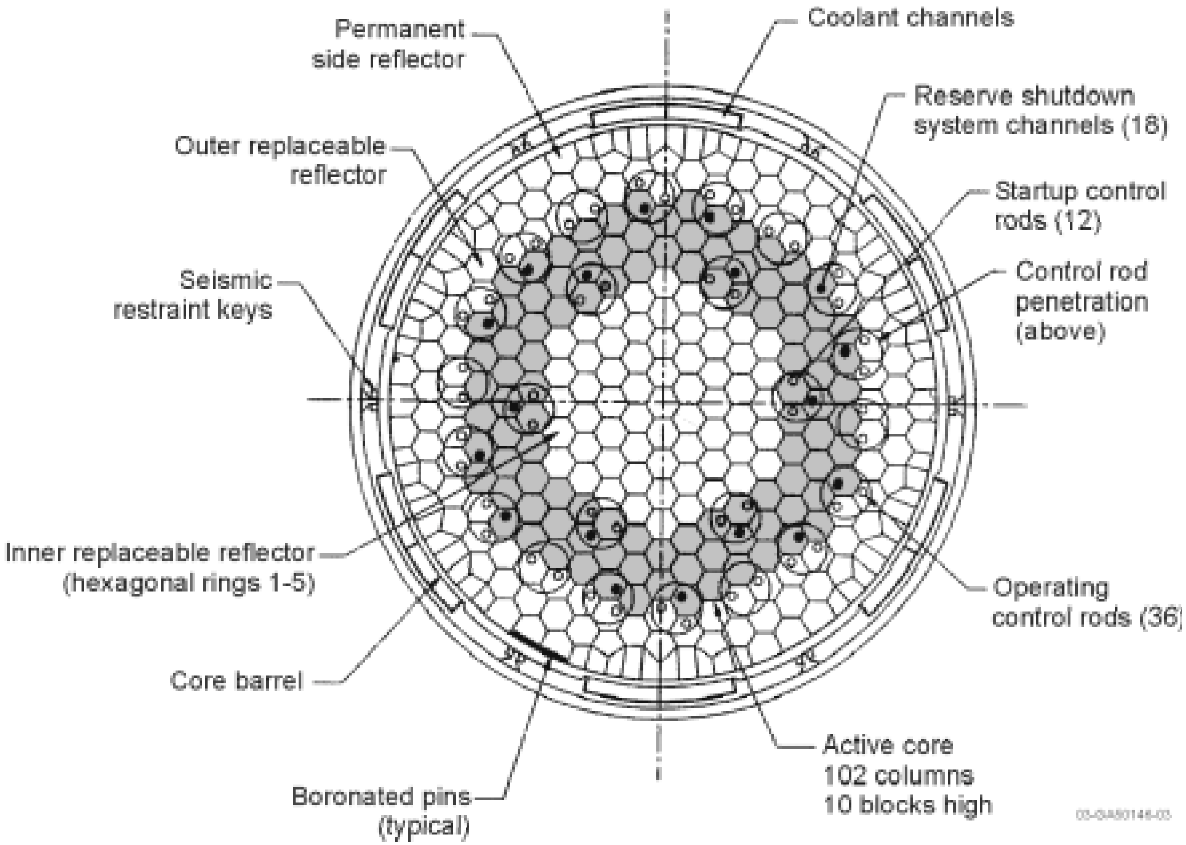
VHTR Plant Schematic



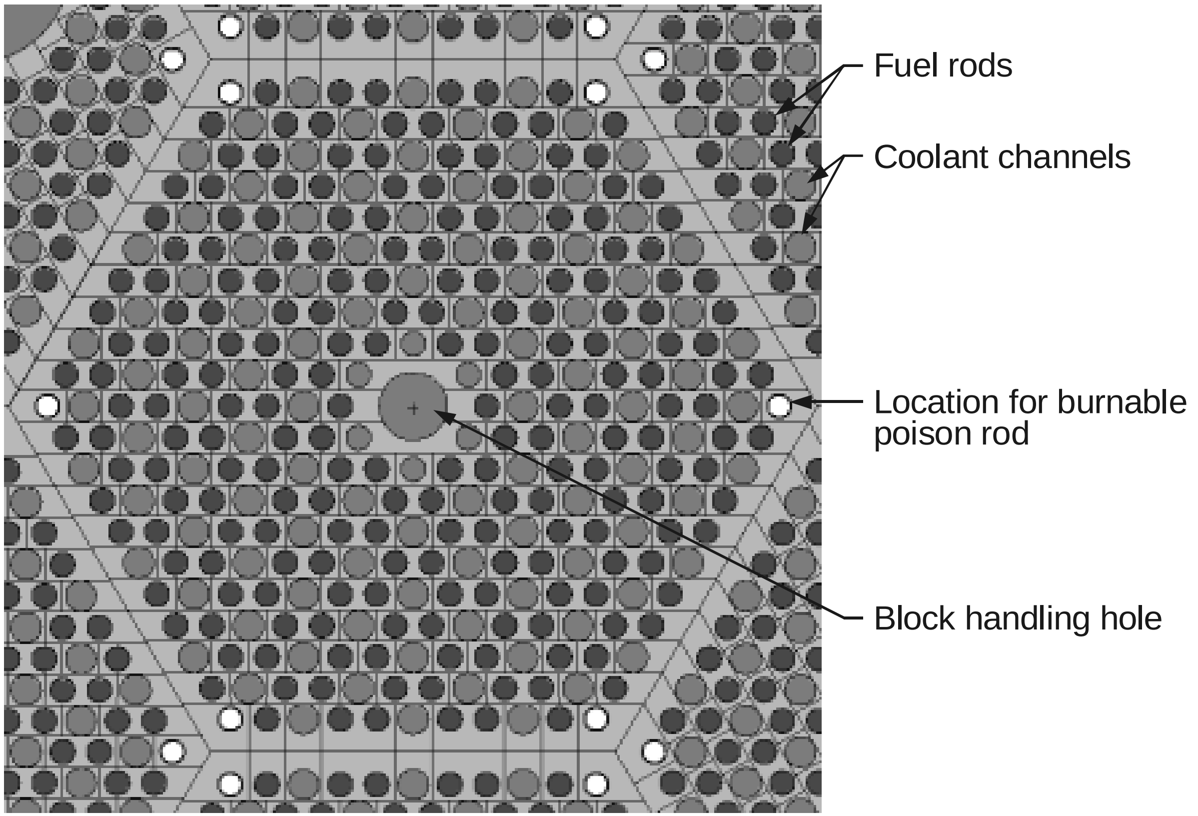
Reactor Vessel Cutaway



Reactor Vessel Cross Section



Fuel Element Cross Section



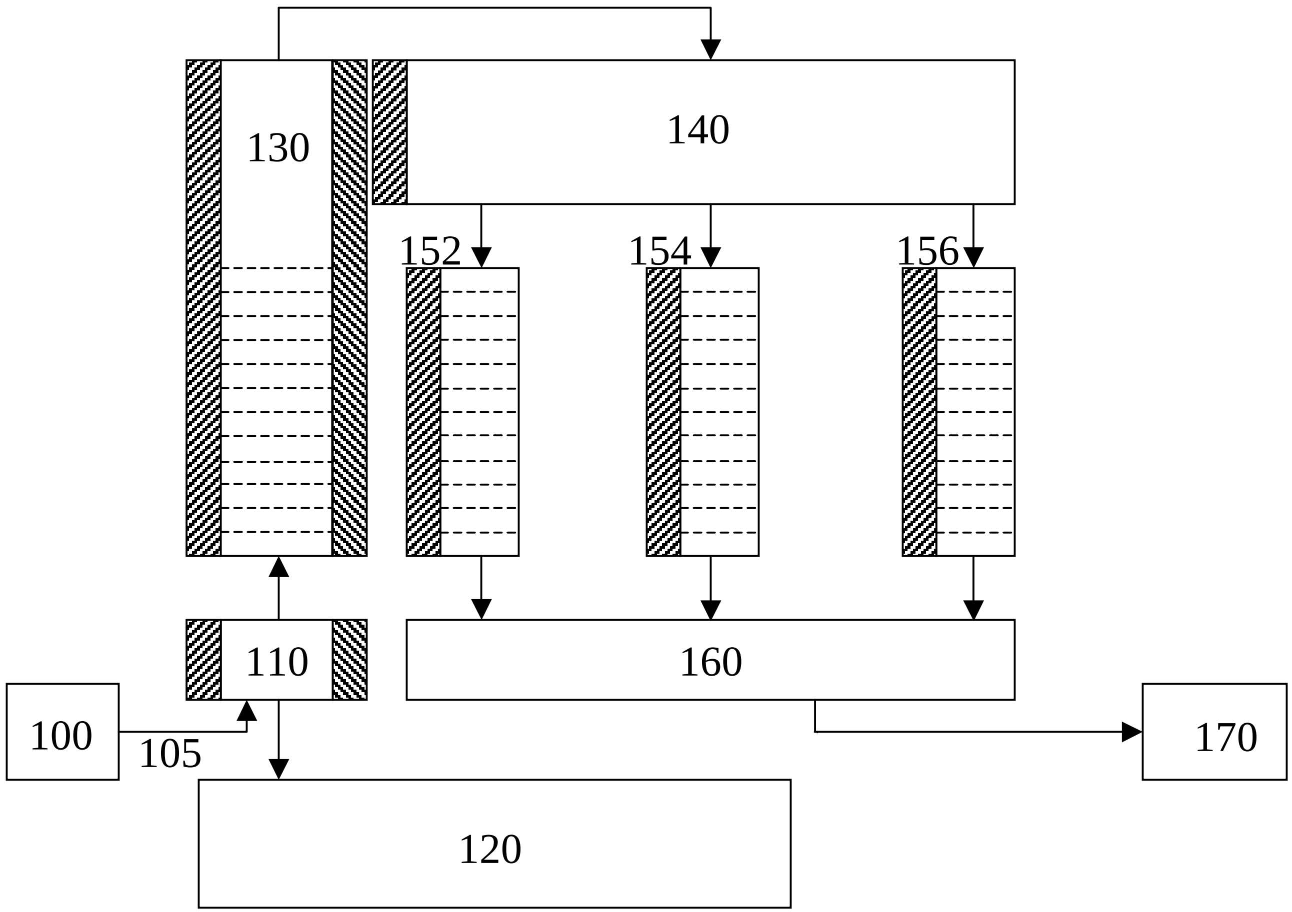
Model Overview

- *A simplified RELAP5-3D/ATHENA system model is being used, in which the balance of plant has been neglected thus far.*
- *Reactor vessel with helium coolant*
- *Reactor cavity with water coolant and dry noncondensible air*
- *Reactor cavity cooling system with water coolant and dry noncondensible air*

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
- Boundary conditions
  - coolant inlet temperature
  - coolant outlet pressure
  - inlet flow rate adjusted during steady state to provide desired outlet temperature

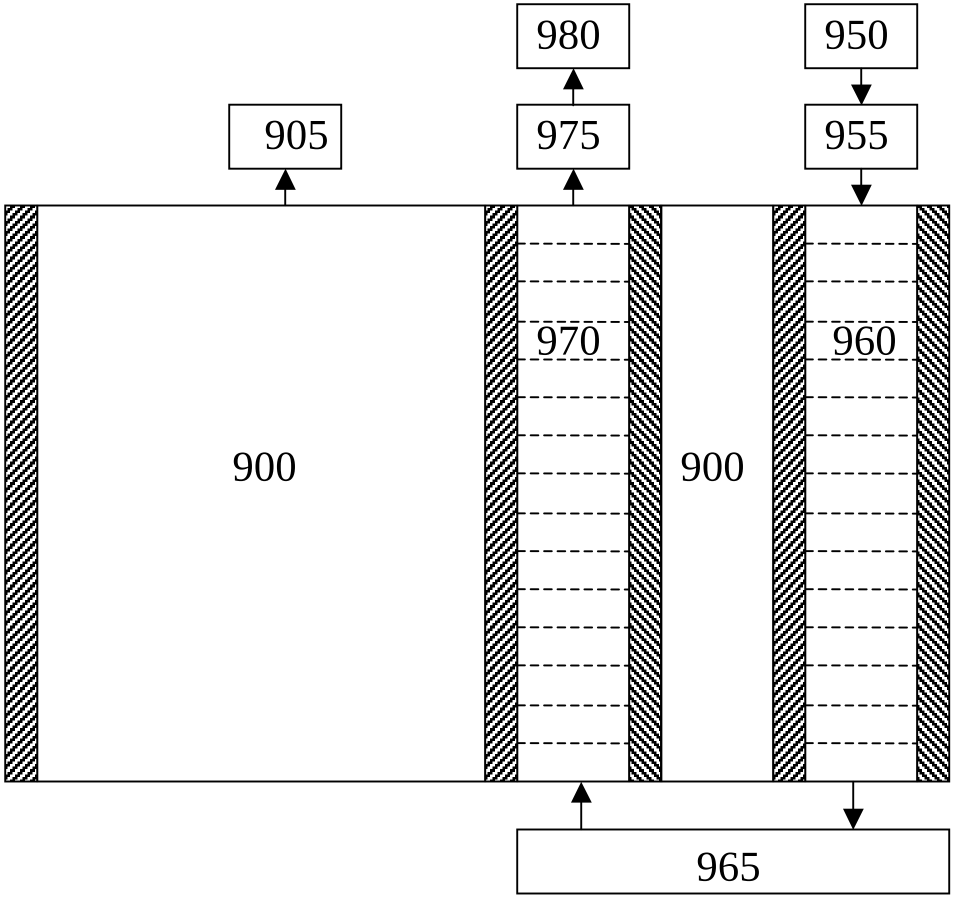
VHTR Vessel Hydraulic Nodalization



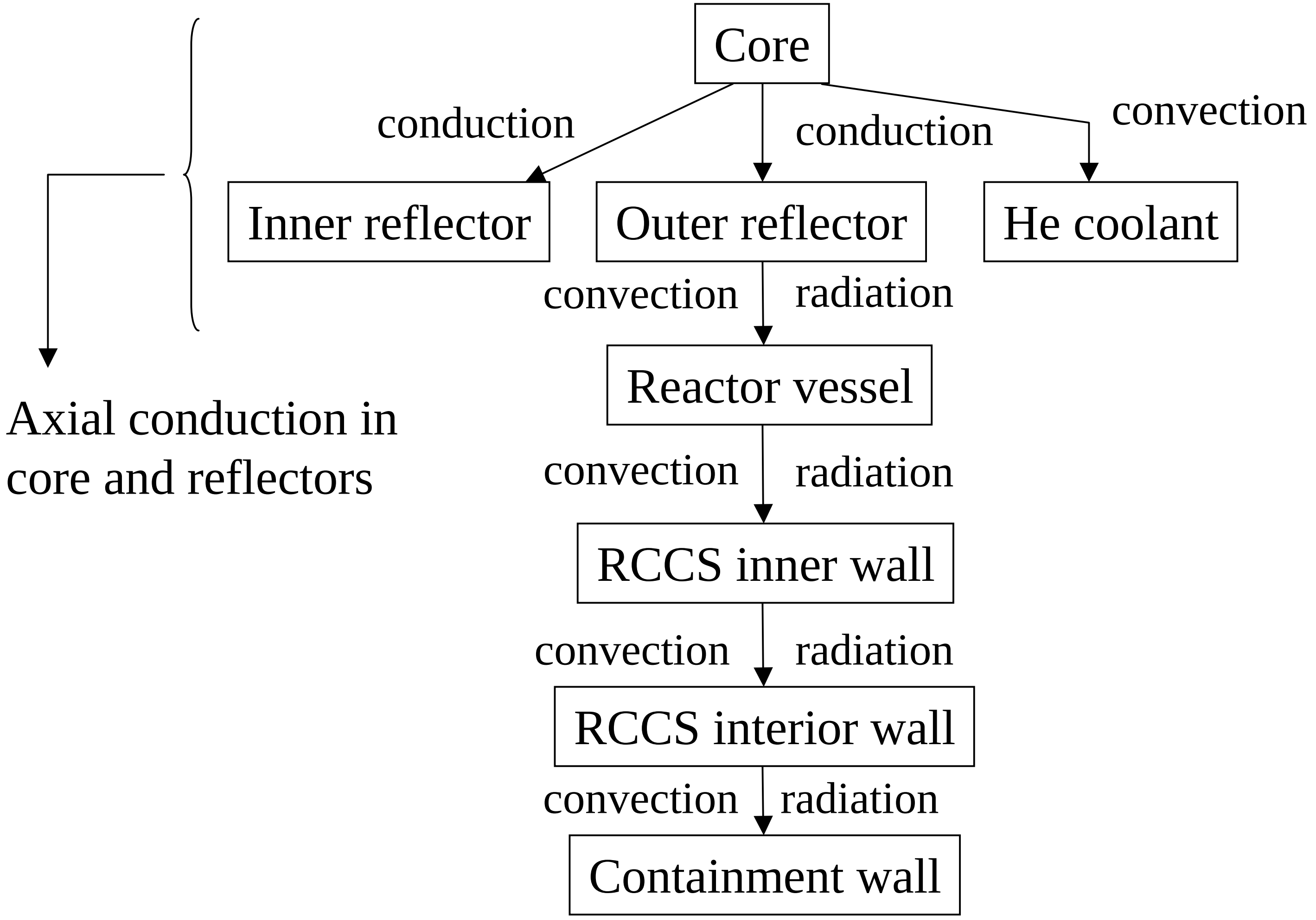
Ex-vessel Model

- 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

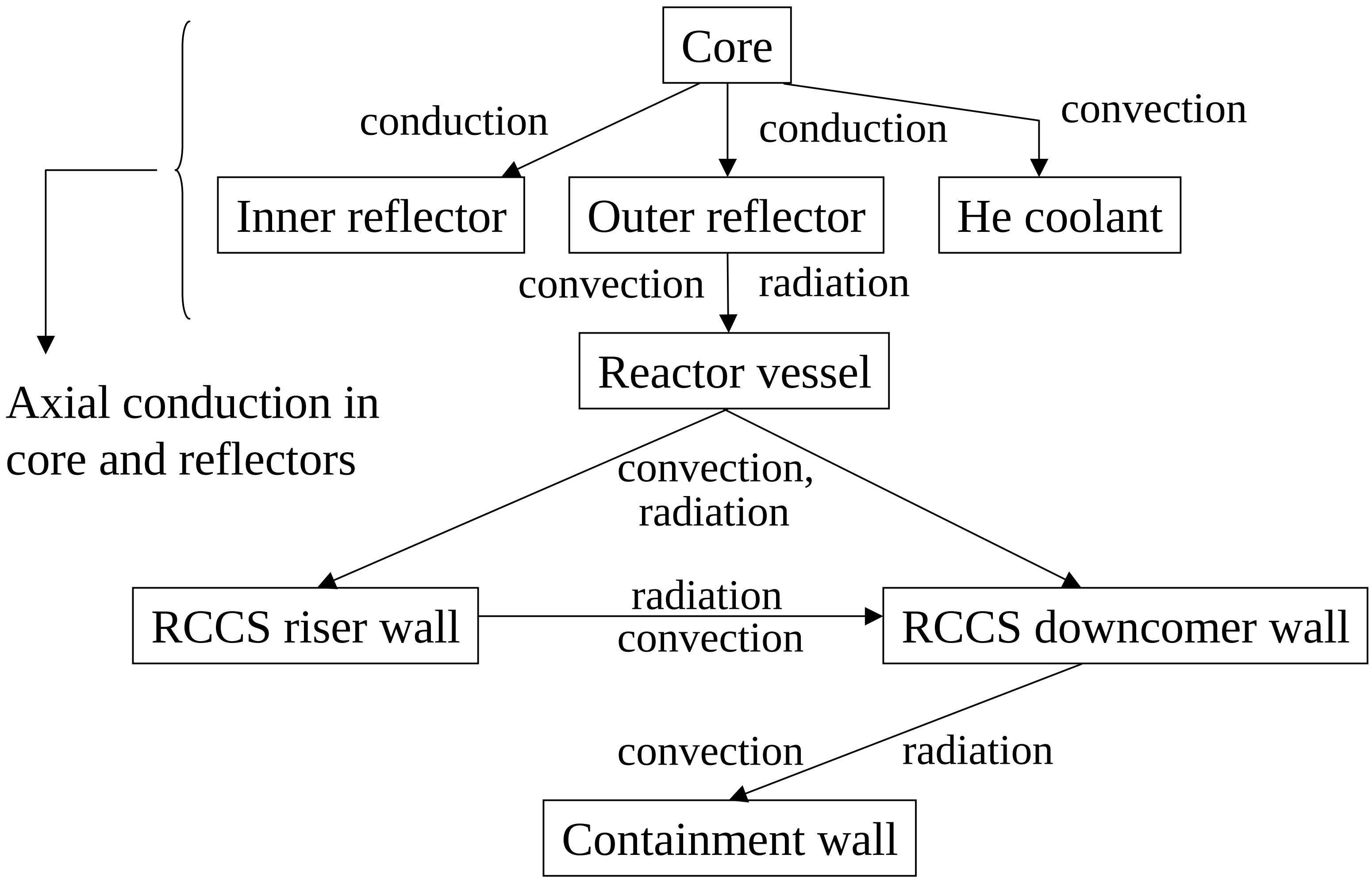
VHTR Reactor Cavity Nodalization



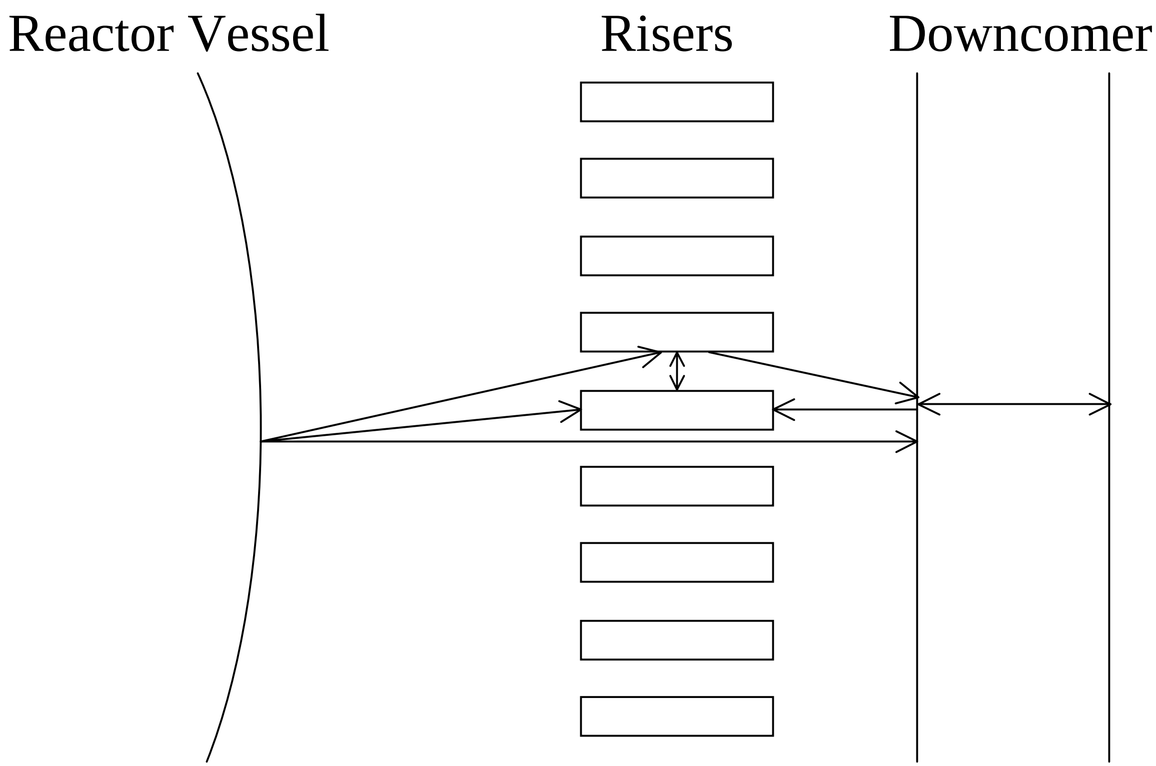
Heat Transfer Modeling with Original RCCS Model



Heat Transfer Modeling with Revised RCCS Model



Reactor Cavity Radiation Modeled



GT-MHR Benchmarking

- *The model is being benchmarked against calculations performed for the gas turbine-modular helium reactor (GT-MHR) by General Atomics.*
- *The steady state conditions for the VHTR model are adjusted to match the GT-MHR values (outlet temperature of 850°C, lower inlet temperature, higher flow rate).*
- *High and low pressure conduction cooldown (loss of forced flow) transients are modeled.*

The 3-structure riser model has improved the RCCS modeling.

Case	Concrete max T (K)	RV outer wall T (K)	RCCS max wall T (K)	RCCS outlet air T (K)	RCCS flow rate (kg/s)	RCCS power (MW)
Target (GA)	322	719	596	547	14.3	3.30
Scoping analysis model	347	706	527	450	19.1	2.90
Current model	321	698	621	545	14.2	3.31

Reduced decay heat has improved the transient benchmark.

Case	Peak Fuel T(°C)			Peak Vessel T (°C)		
	Steady	HPCC	LPCC	Steady	HPCC	LPCC
Target (GA)		1238	1521	480	497	490
Scoping analysis model	964	1504	1730	458	571	619
Lower decay heat model	971	1285	1514	455	471	520
Lower pressure transient		1369			490	

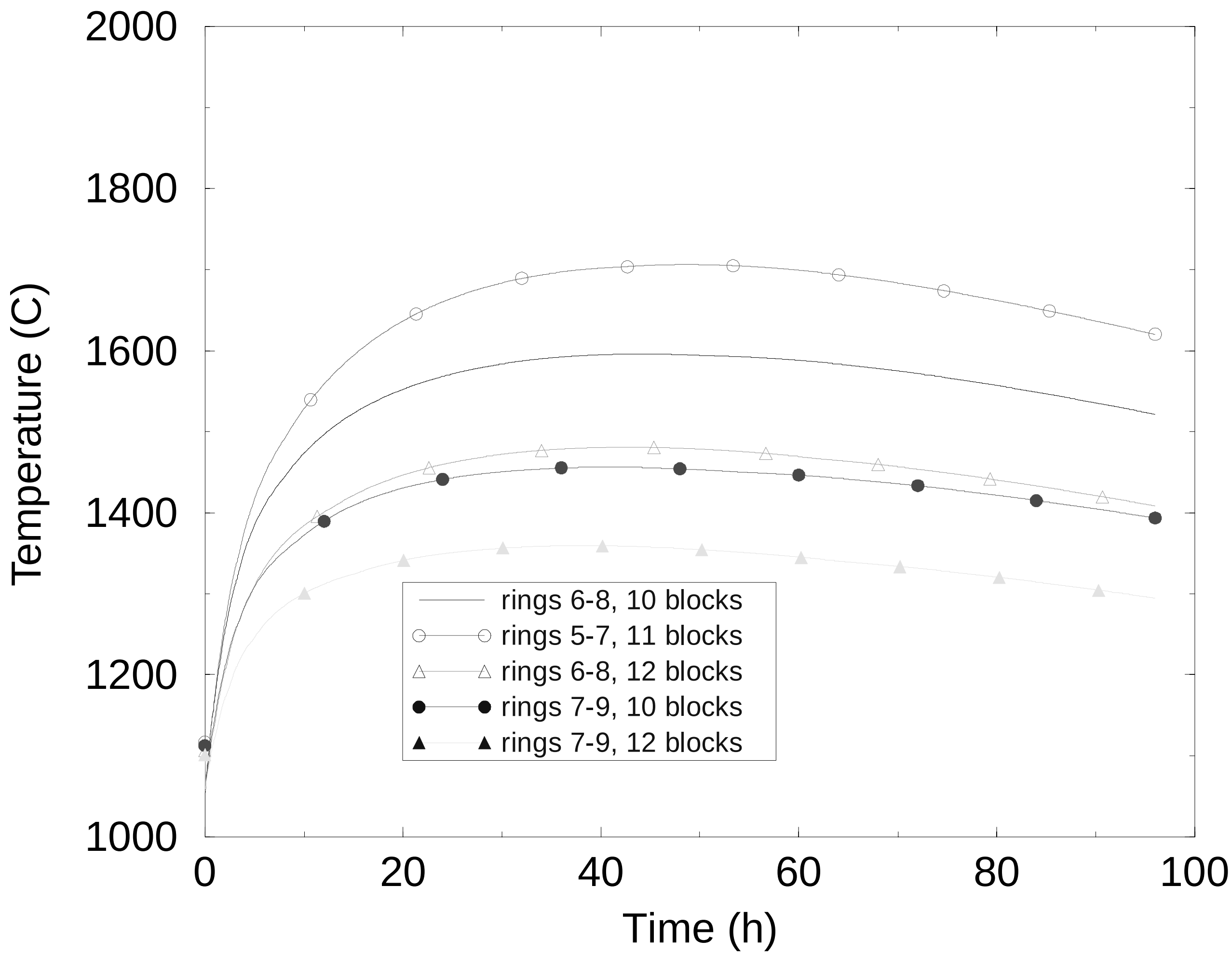
Scoping Transient Calculations

- *Objectives*
  - *Provide feedback to the neutronics development on the effects of different core geometries*
  - *Determine modeling sensitivities*
- *High pressure conduction cooldown*
  - *60-s flow coastdown*
  - *Steady state operating pressure maintained*
- *Low pressure conduction cooldown*
  - *10-s blowdown to atmospheric pressure*
  - *Air ingress precluded*

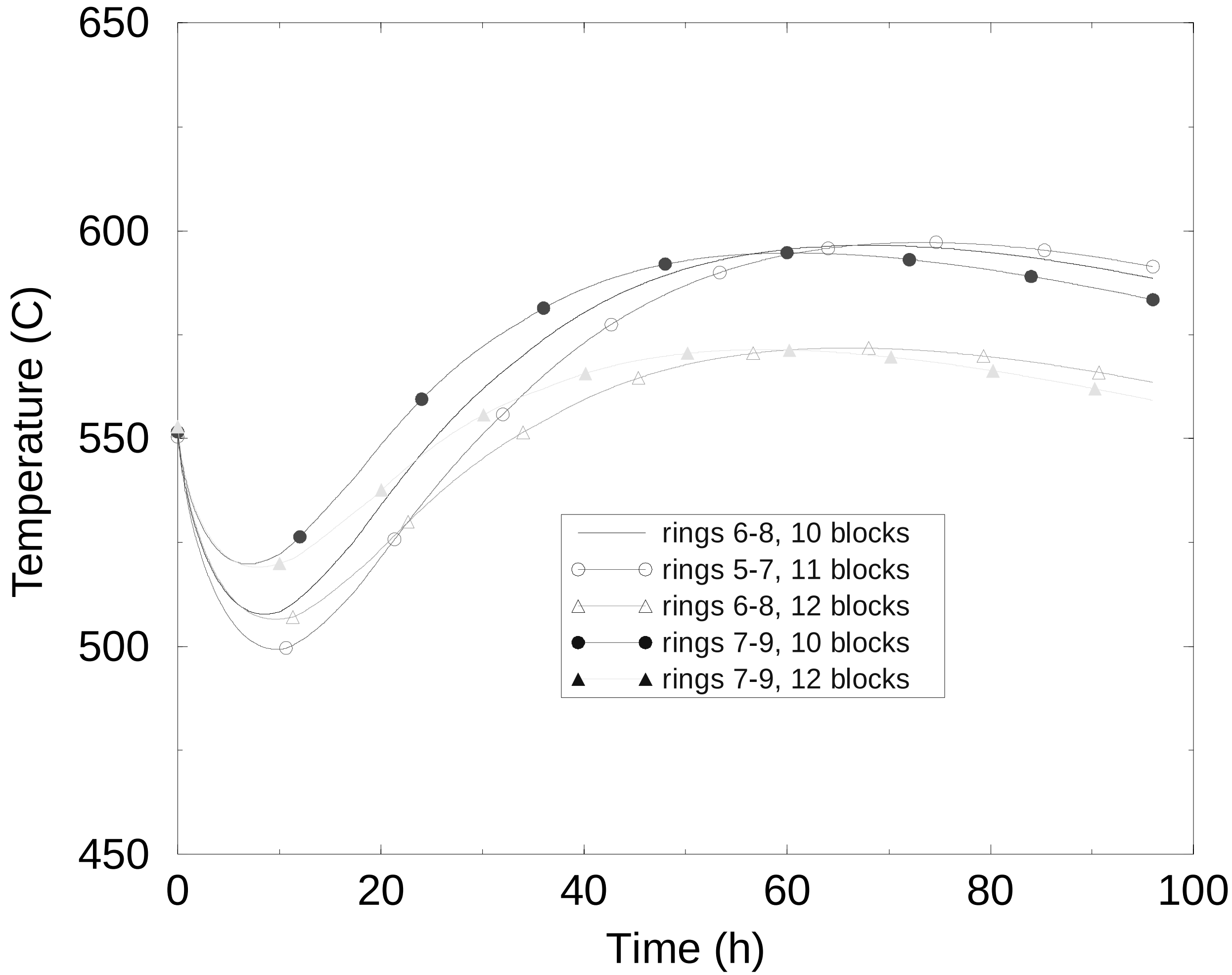
Core Configuration Calculations

Fuel rings	Core height (blocks)	Reactor vessel dP (kPa)	Peak Fuel T (°C)			Peak Vessel T (°C)		
			Steady	HPCC	LPCC	Steady	HPCC	LPCC
6-8	10	71	1119	1596	1807	551	597	643
6-8	11	75	1112	1535	1728	552	583	627
6-8	12	79	1107	1481	1659	552	572	611
5-7	11	92	1064	1707	1937	551	597	644
7-9	10	56	1113	1457	1622	552	595	634
7-9	12	62	1102	1360	1502	553	571	606

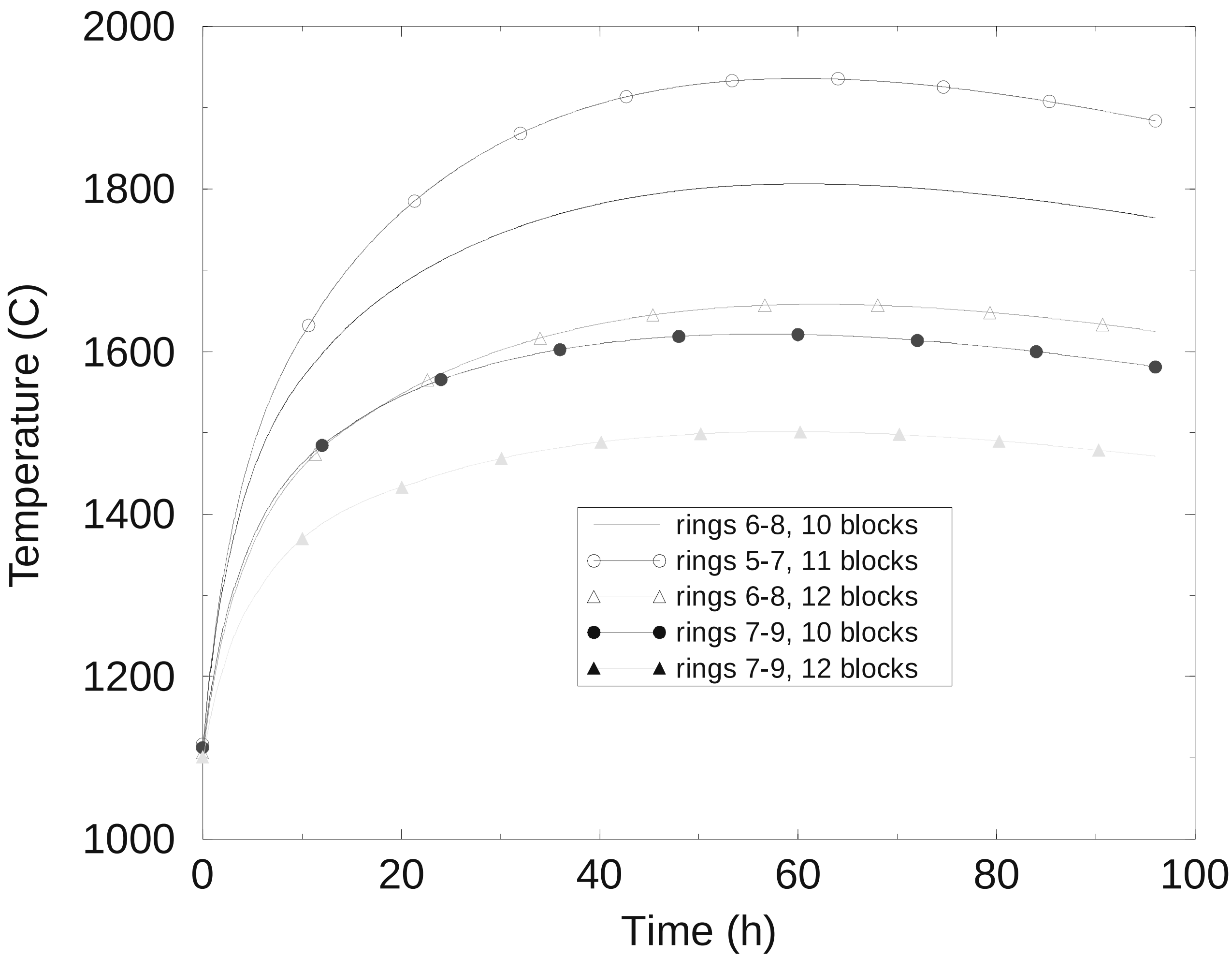
HPCC Peak Fuel Temperatures



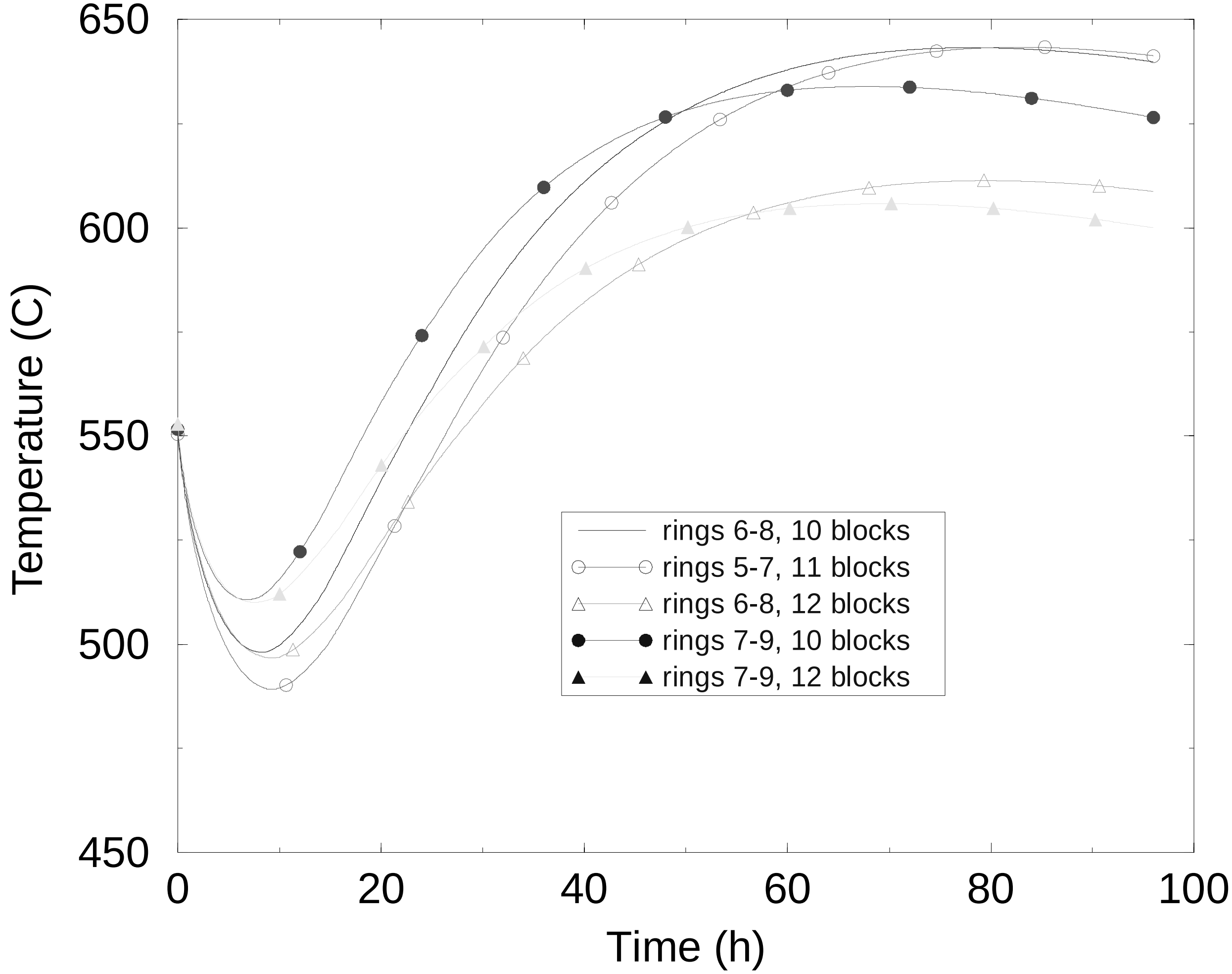
HPCC Peak Vessel Temperatures



LPCC Peak Fuel Temperatures



LPCC Peak Vessel Temperatures



Modeling Sensitivity Calculations

Case	Reactor vessel dP (kPa)	Peak Fuel T (°C)			Peak Vessel T (°C)		
		Steady	HPCC	LPCC	Steady	HPCC	LPCC
Base	71	1119	1596	1807	551	597	643
Coolant channel diameter reduced	79	1125	1628	1805	551	603	643
Flat axial and radial power profiles	71	1094	1530	1684	551	585	618
Inner reflector heat capacity increased	71	1119	1522	1694	551	583	622
0.1 mm He gap around fuel	71	1133	1604	1813	551	598	645
Bypass channel in inner reflector	61	1170	1547	1749	551	587	626
Bypass channel in outer reflector	61	1180	1549	1784	550	582	634
Decay power reduced 15%	71	1119	1483	1682	551	566	610
New RCCS model	71	1119	1574	1792	538	538	567

Code Results Summary

- *The code and model appear to be able to provide reasonable results for the VHTR loss of flow transients.*
- *Thermal-hydraulic analyses indicate that changes in the core configuration may be helpful.*
- *Decay power and power distribution may have large impacts on the calculated transient fuel temperatures.*

Code Improvement Possibilities

- Axial conduction capability (outside of reflood) for the heat structures
- Air ingress modeling (molecular diffusion)
- Extend/improve the decay heat model to account for the epithermal neutron spectrum in gas reactors
- Extend the material property definition options available to the user
- Allow SCDAP structures to participate in RELAP5 radiation/conduction enclosures