GFR-He/CO_2 Analysis Using RELAP5/ATHENA

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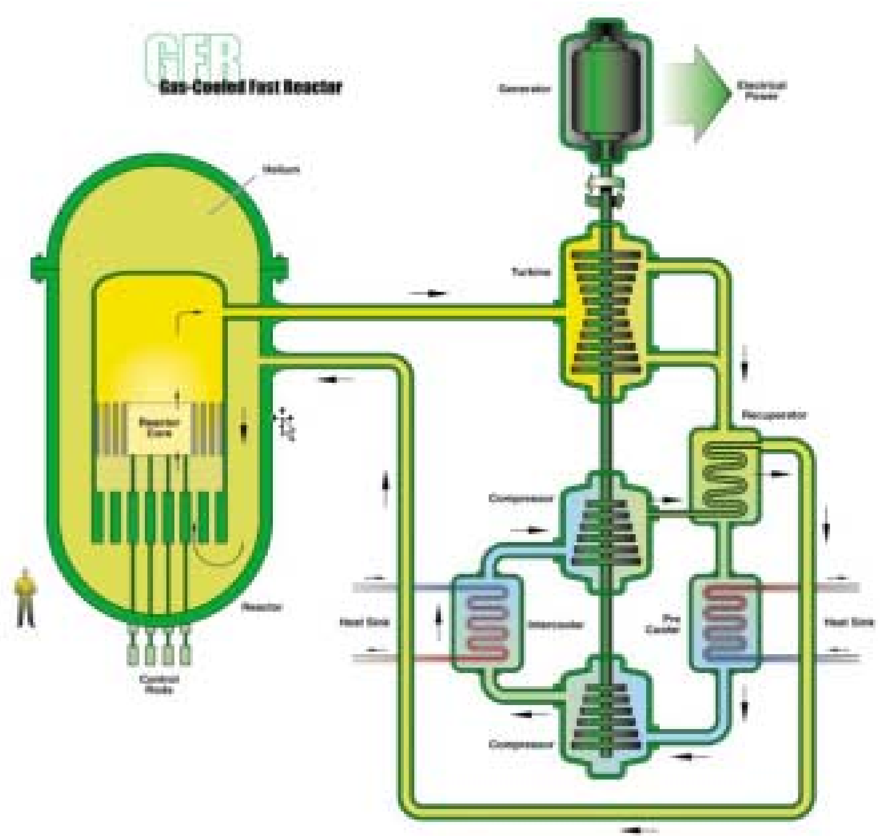
Outline of Presentation

- Gen-IV, Gas-cooled Fast Reactor concept
  - Looking beyond the Next Generation Nuclear Plant
- Impetus for Safety Analysis
  - Is passive safety inherently safe?
- The Large-Break LOCA
  - One of the most severe GFR challenges
- RELAP5/ATHENA Input Model
- Modeling Predictions
  - What the numbers imply
- Conclusions

What is the Gen-IV GFR Reactor Concept?

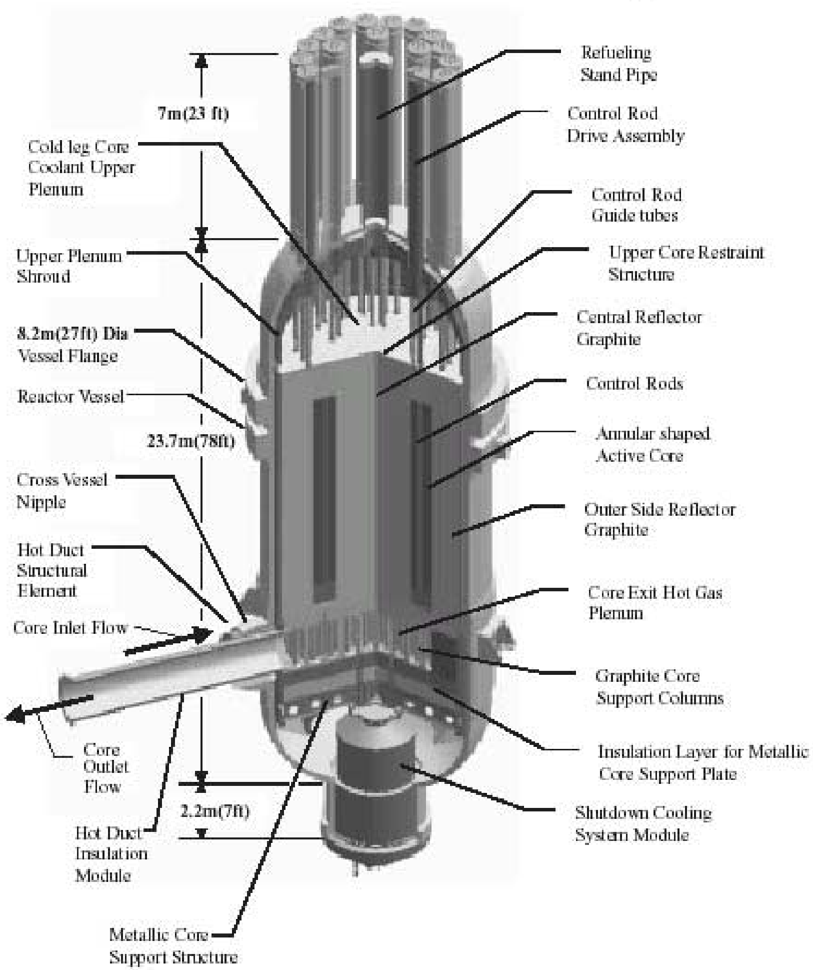
- *Has design specifications of:*
  - *being inherently safe*
  - *using direct Brayton cycle energy conversion with the He option*
  - *featuring high outlet temperatures, which increase thermal efficiency and suggest H_2 production*

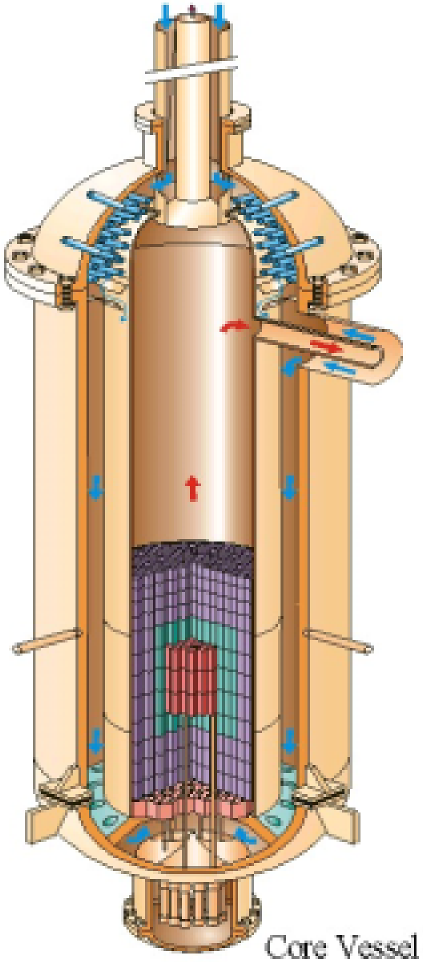


GFR – Looking beyond the NGNP

- *Anticipated deployment: 2025*
- *Neutron flux of 1 x 10^{14} n/cm^2-s*
- *Power density of* <u>*55 MW/m^3*</u> *to 100 MW/m^3*
- *Reference core configuration and fuel:*
  - *Plate/block, UC with SiC matrix*
- *Optional core configuration and fuel:*
  - *pin, U-Zr CERMET*
- *Reference core coolant:*
  - *He at 7 MPa* [490 °C {in}, 842 °C {exit}]
- Optional core coolant:
  - *CO_2 at 20 MPa* [400 °C {in}, 550 °C {exit}]

GFR, NGNP – a difference in flow direction





NGNP with concentric inlet/outlet and <u>downward</u> flow through core

GFR with concentric inlet/outlet and <u>upward</u> flow through core

Impetus for Safety Analysis

- *Gen-IV reactor concepts have the directive of having enhanced safety systems*
- *Ideally the reactors will circumvent an accident scenario with minimal operator intervention*
- *The high power density of the GFR will effectively challenge any Decay Heat Removal System (DHRS)*
- *A passively-safe GFR DHRS may require innovative components and engineering design*
- *Safety analyses and experiments are necessary to validate any DHRS designs*

Challenge of the Large-Break LOCA

- *A double guillotine break of the inlet and outlet legs*
- *Decay Heat: 13% [SCRAM], 1.5% [1 hr], 1.2% [2 hr] of 600 MW*
- *Gen-IV Objective:*
  - *Complete decay heat removal with a passive DHRS*
  - *DHRS should maintain temperature limits for a minimum time period of three days*
- *Maximum matrix temperature limit < 2000 °C*

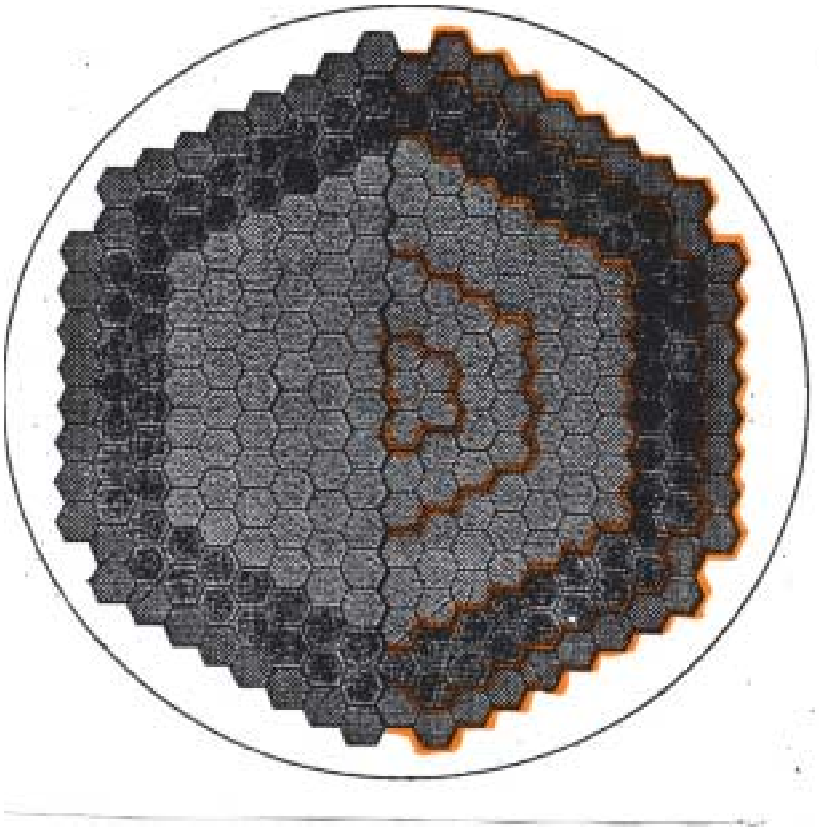
ATHENA Model: GFR Specifications

- *Coolants: He and S-CO_2*
- *Fuel: UC with SiC matrix*
- *TiN radial reflector and BC neutron shield*
- *Overview of system parameters:*

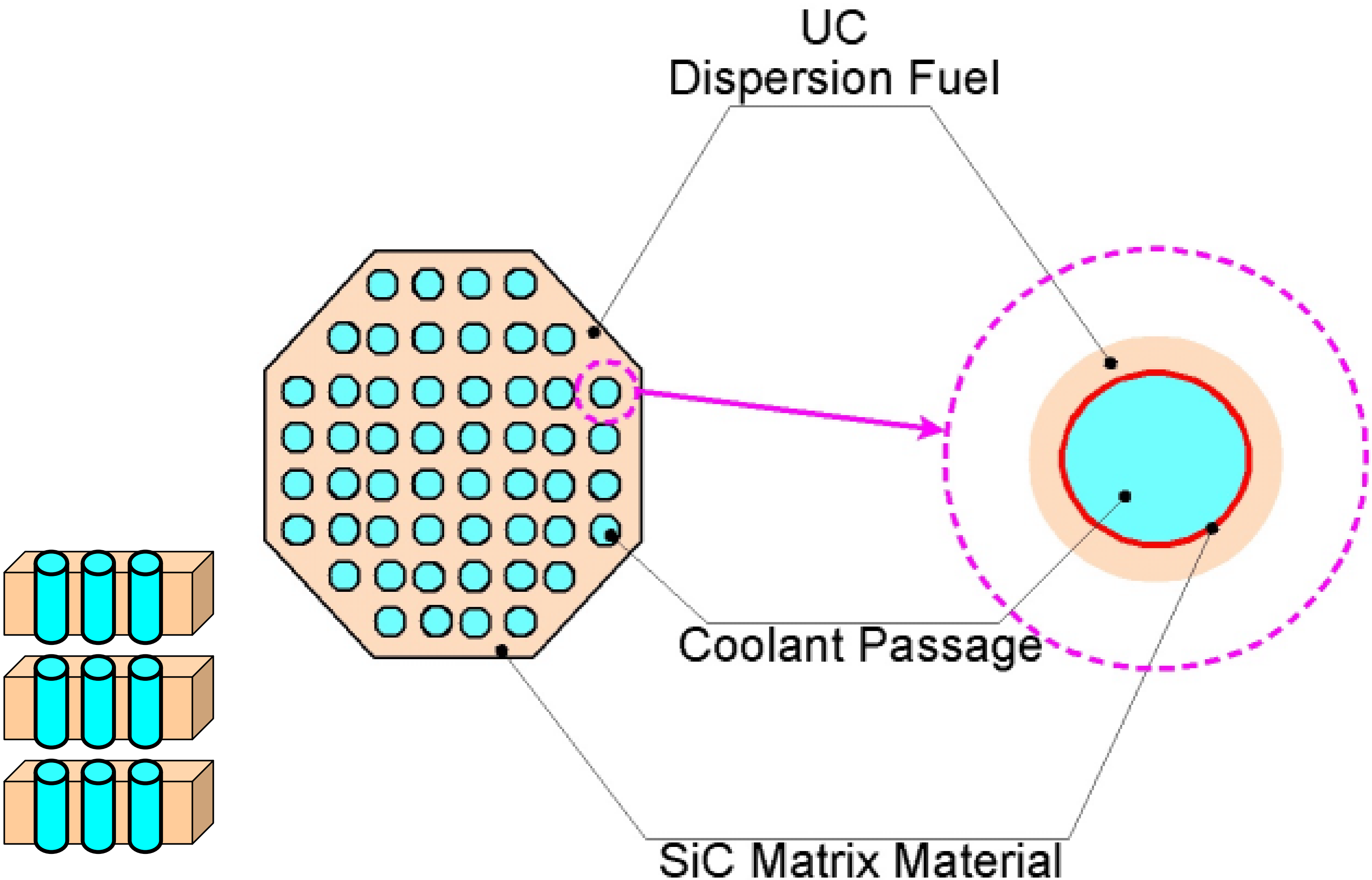
System Parameter	He	S-CO_2
Power Level	600 MW_{th}	600 MW_{th}
Coolant Pressure	7 MPa	20 MPa
Inlet Temperature	490 ºC	400 ºC
Outlet Temperature	850 ºC	550 ºC
Mass Flow Rate	330 kg/s	3260 kg/s
Inlet Flow Area	8.35 m^2	8.35 m^2
Outlet Flow Area	6.42 m^2	6.42 m^2
Reactor Cavity Cooling System (RCCS)	GA-MHR	GA-MHR

ATHENA Model: GFR Core Cross Section

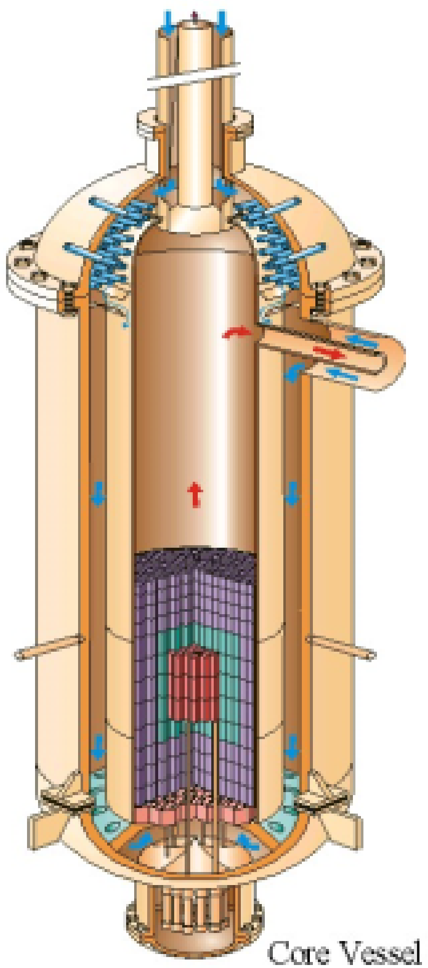
Core Parameter	Value
Thermal Power	600 MW_{th}
Average Power Density	50 MW/m^3
Axial Power Peaking	1.25
Core Height	1.7 m
Fuel Assemblies	127
Width of Fuel Assembly	20 cm
Coolant Holes/Assembly	91
Coolant Void Fraction	40 %

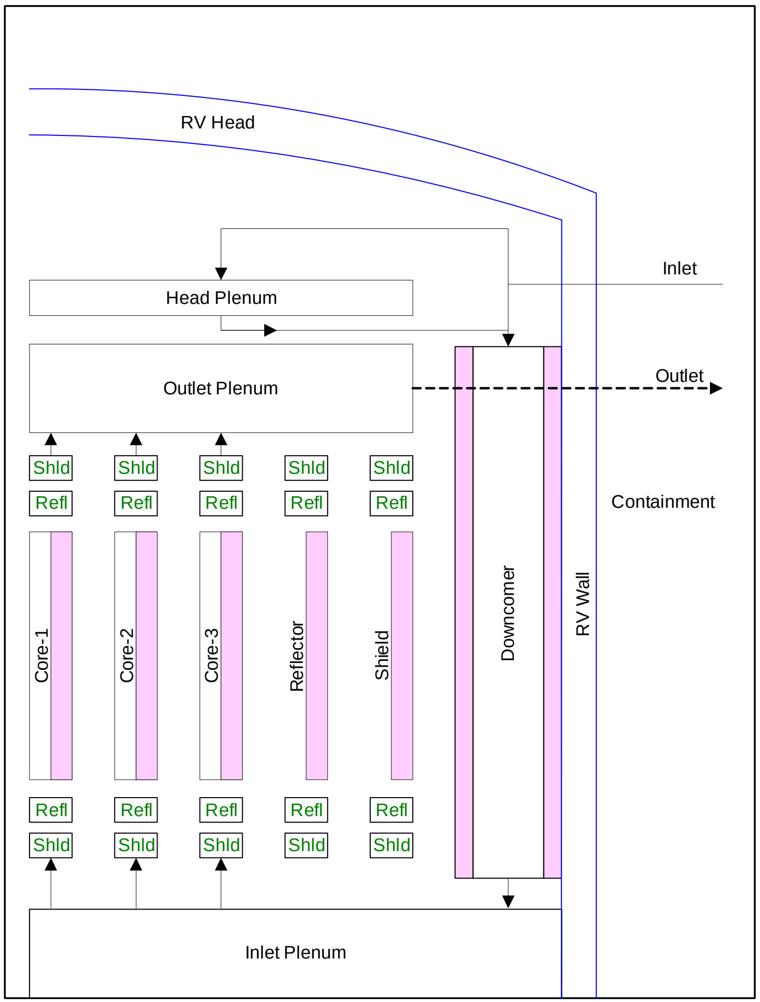


ATHENA Model: Unit Cell Heat Structure

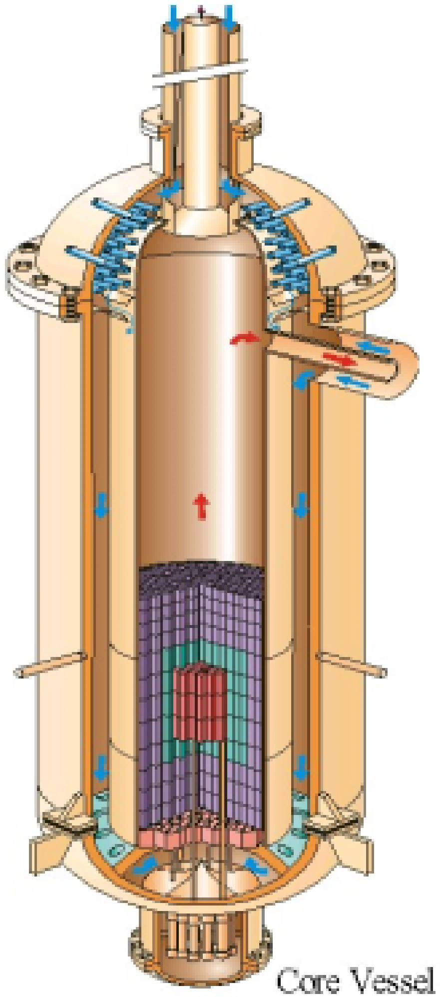


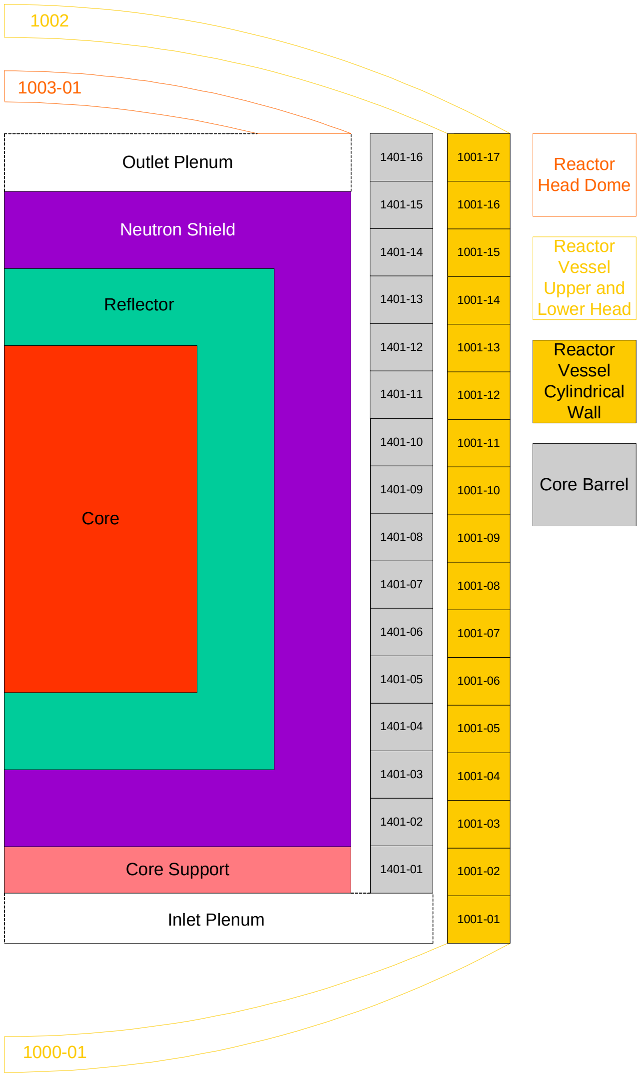
ATHENA Model: Hydraulic Nodalization



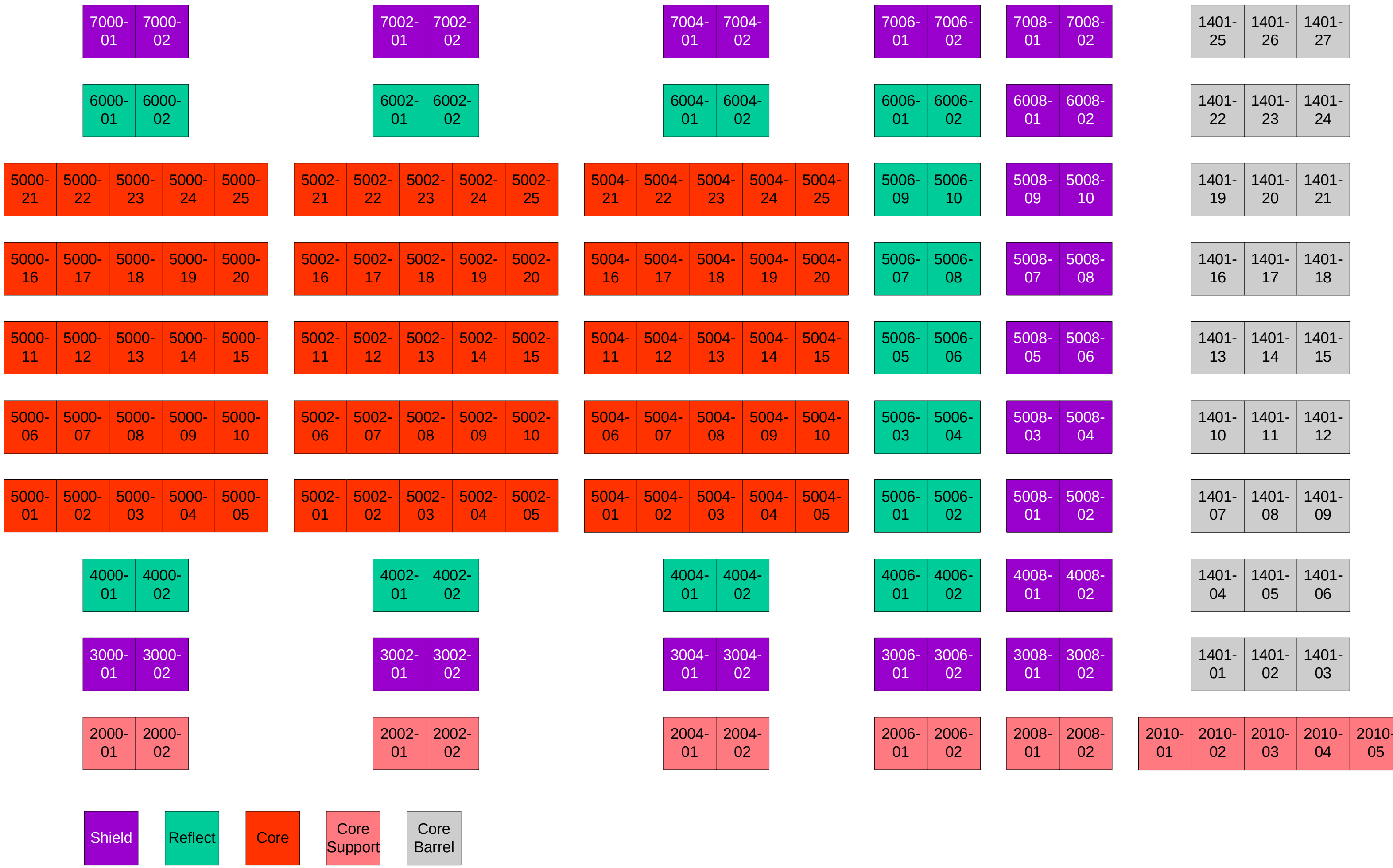


ATHENA Model: Conduction Circuit

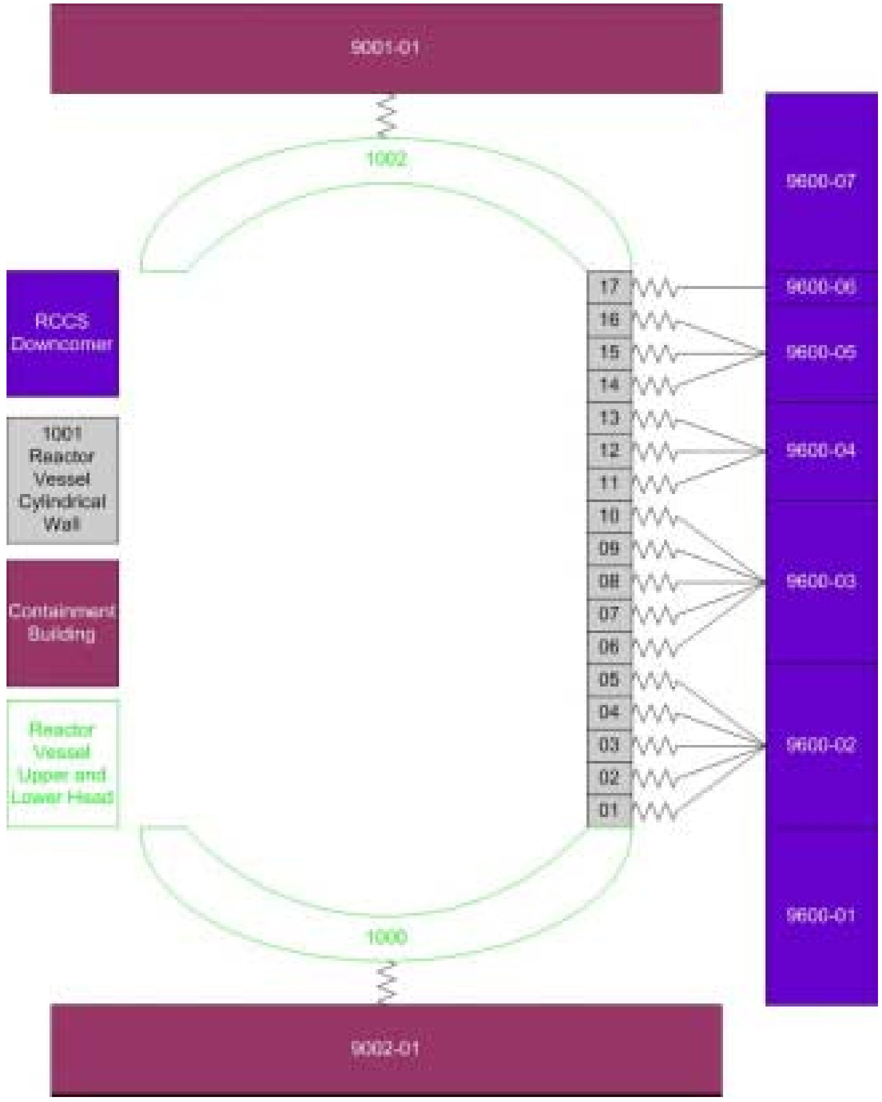




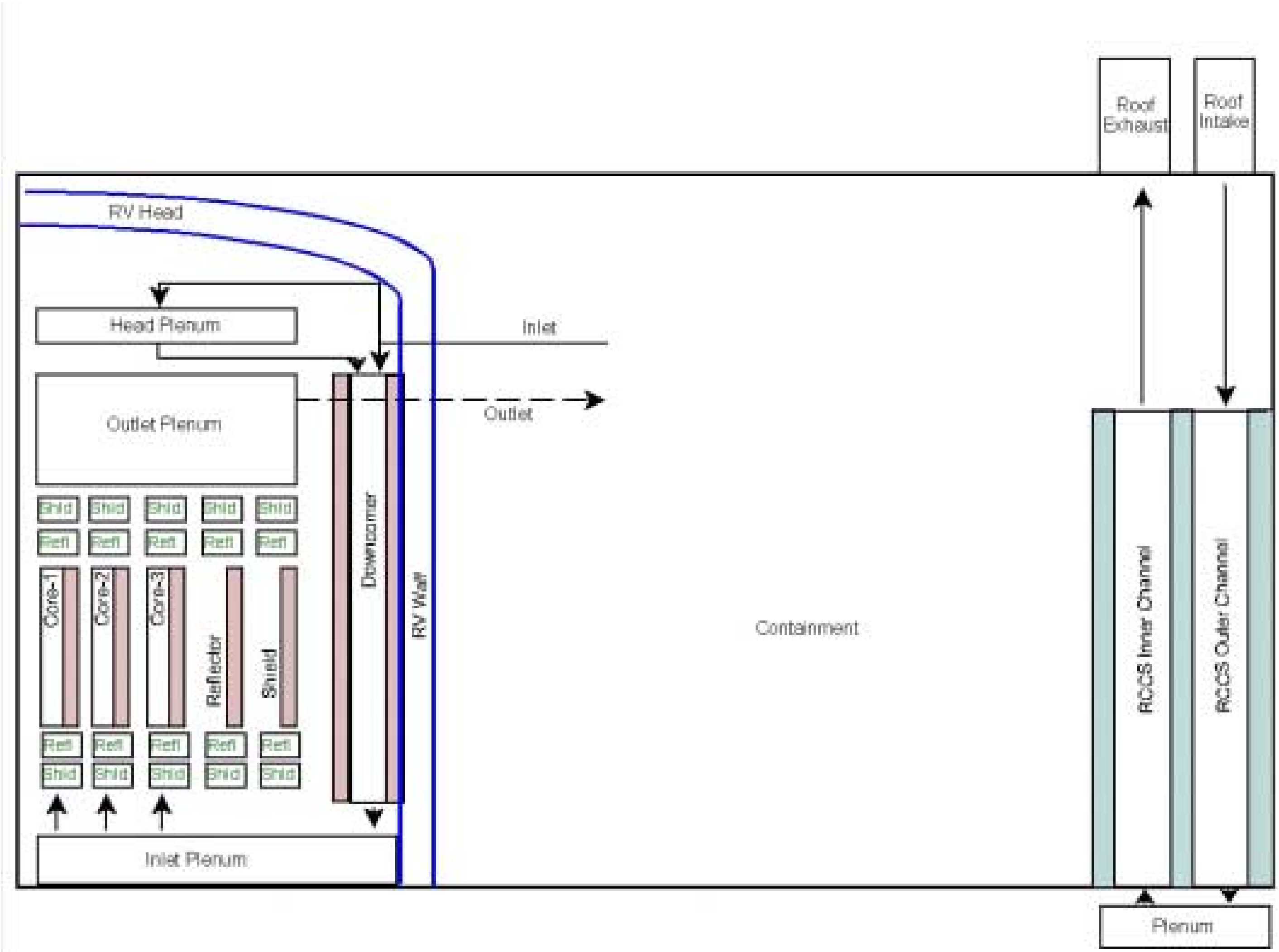
ATHENA Model: Core Nodalization



ATHENA Model: Radiation Circuit



ATHENA Model: Core, Containment, RCCS



ATHENA Model: Input Deck Specifics

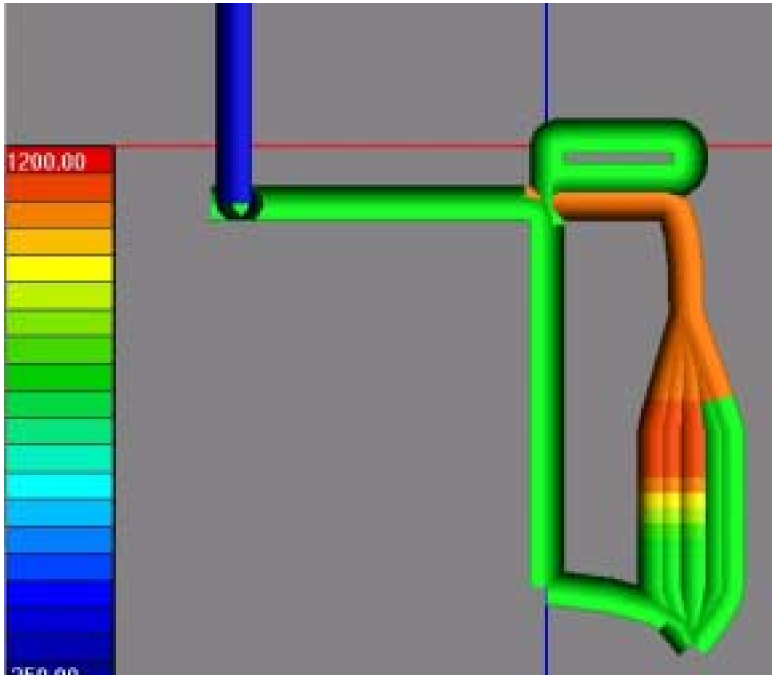
- *Heat Structures: 134*
- *Mesh Points: 725*
- *Hydrodynamic Volumes: 144*
- *Volume:*
  - *Coolant (He/CO_2): 6,608 m^3*
  - *RCCS (air): 816 m^3*
- *Mass:*
  - *He Coolant: 9,348 kg*
  - *CO_2 Coolant: 44,402 kg*
  - *RCCS 947 kg*

ATHENA Model: Boundary Conditions

- *Specified:*
  - *coolant inlet temperature* [490°C, He] [400°C, CO_2]
  - *coolant outlet temperature* [842°C, He] [550°C, CO_2]
- *Calculated:*
  - *coolant flow rate calculated during steady state to provide desired outlet plenum temperature*
- *Assumed:*
  - *SCRAM curve of PWR*
  - *No gamma/neutron heating in reflector/shield*
  - *Containment pressure maintained* [~0.8 MPa, He] [~1.8 MPa, CO_2]
  - *RCCS is the DHRS (baseline case)*

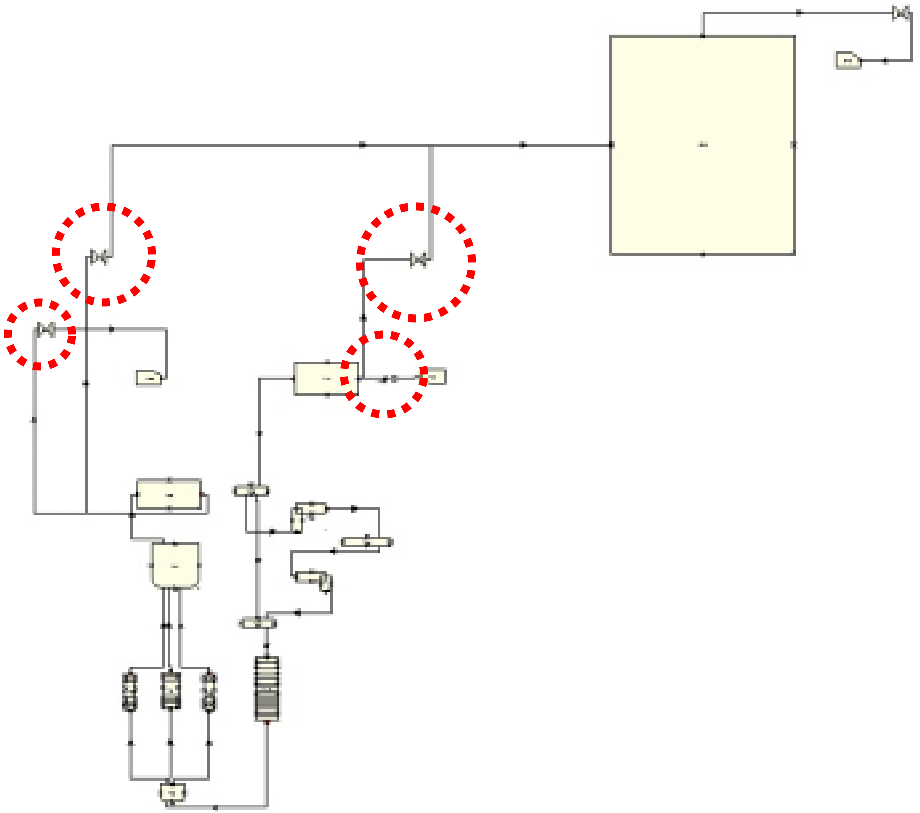
Overview of ATHENA Steady-State Analysis

- *Steady-State Analysis*
  - *determined by constant containment temperature*
  - *volumetric heat capacity decreased by factor of 100*
  - *problem time of 4,200 s*



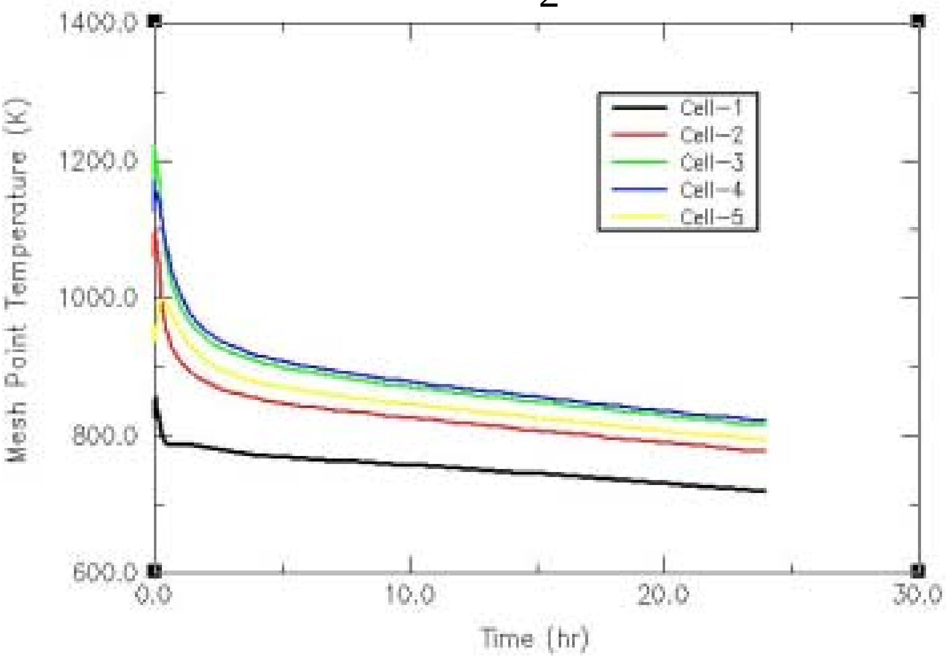
Overview of ATHENA Transient Analysis

- *LB-LOCA Transient*
  - *problem time reset to 0 s*
  - *valves open coolant loop to containment at 10 s*
  - *SCRAM starts at 10 s and finishes at 14 s*
  - *Problem time: 180,000 s (50 hrs)*

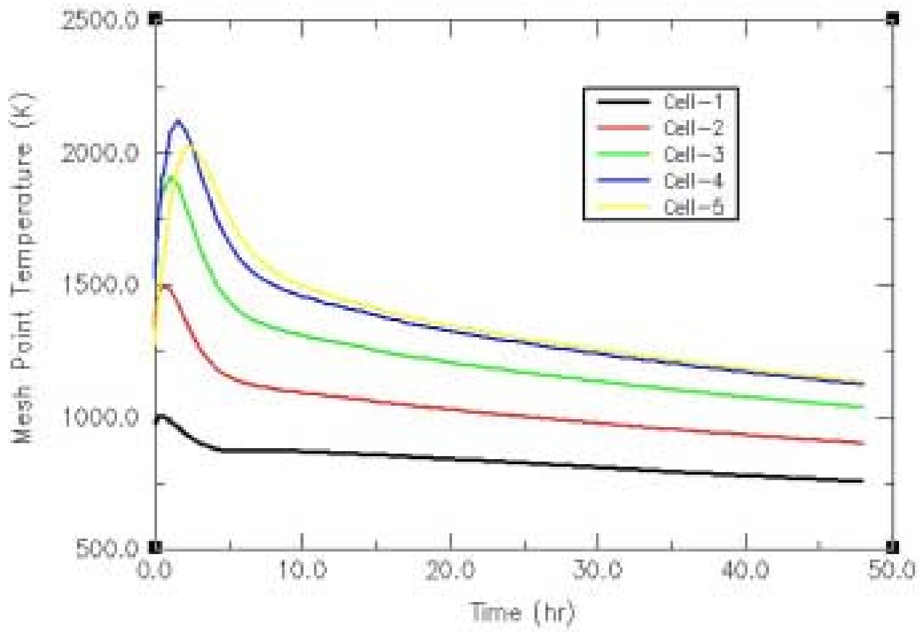


He Case Approaches Matrix Temp. Limit*

CO_2

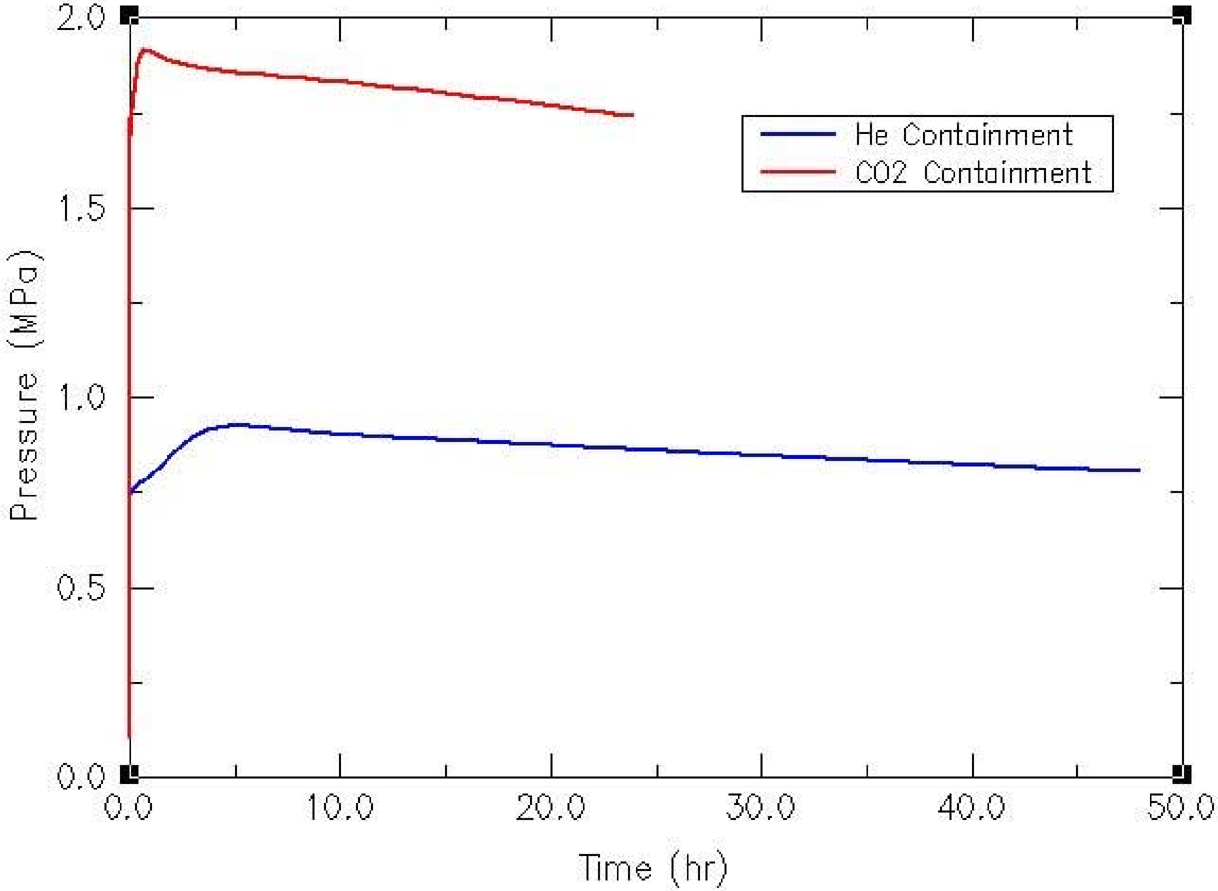


He



*Containment pressure maintained

Containment Pres. Enhances Heat Transfer

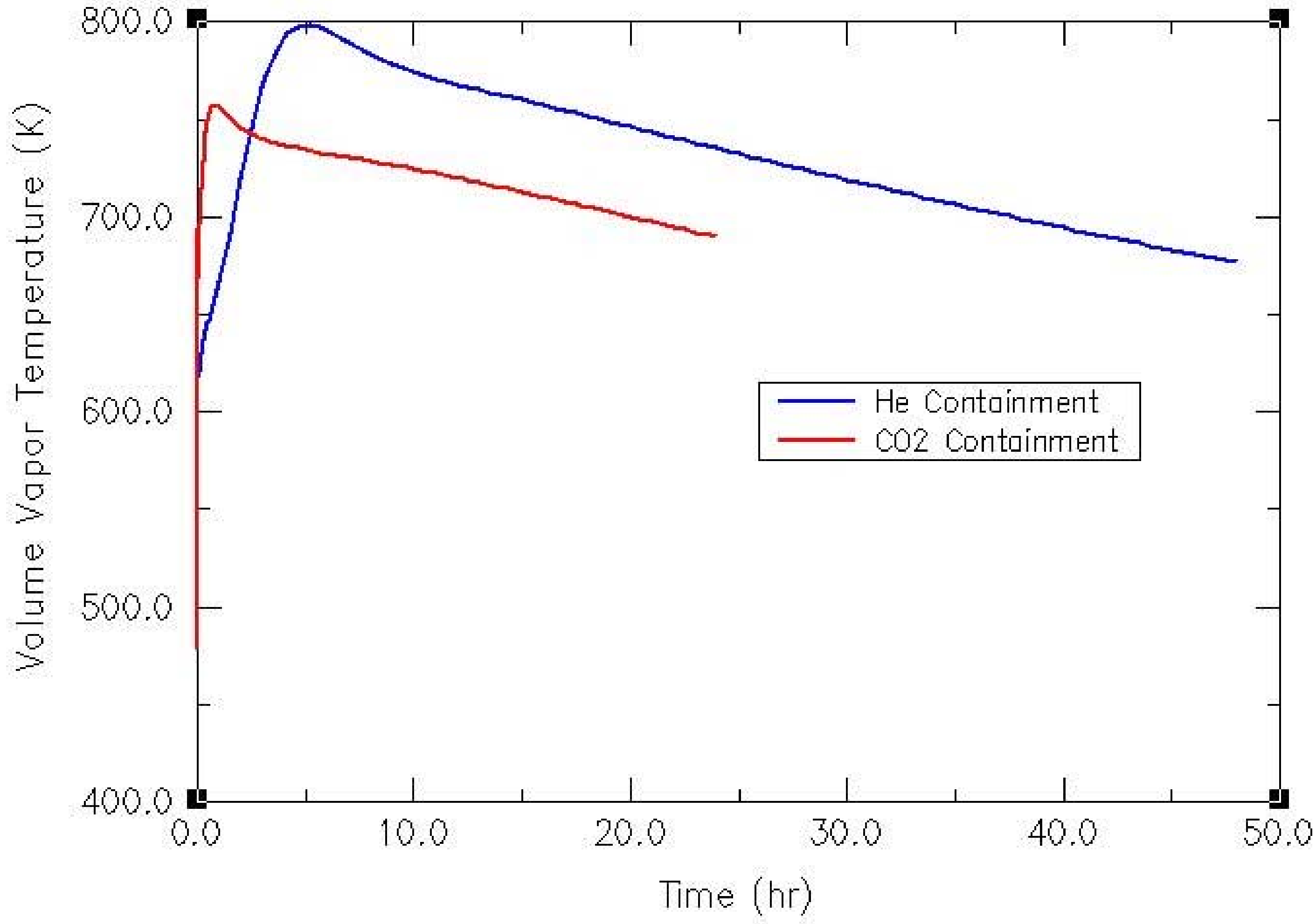


$$Q = \dot{m} \cdot C_P \cdot \Delta T$$

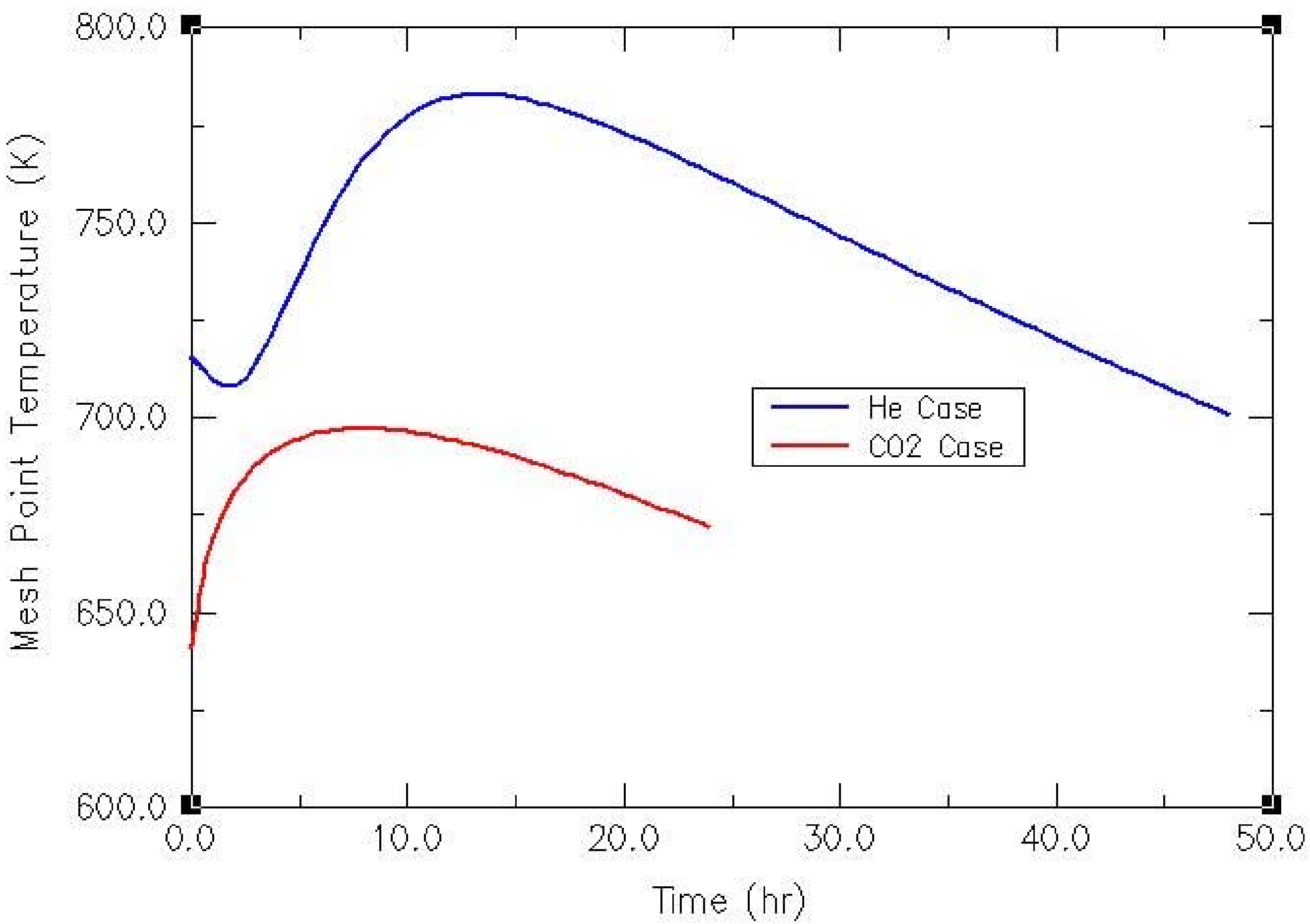
$$\dot{m} = \rho \cdot A \cdot V$$

Containment Volume: 6,063 m^3

Containment Temp. Means More Design Work

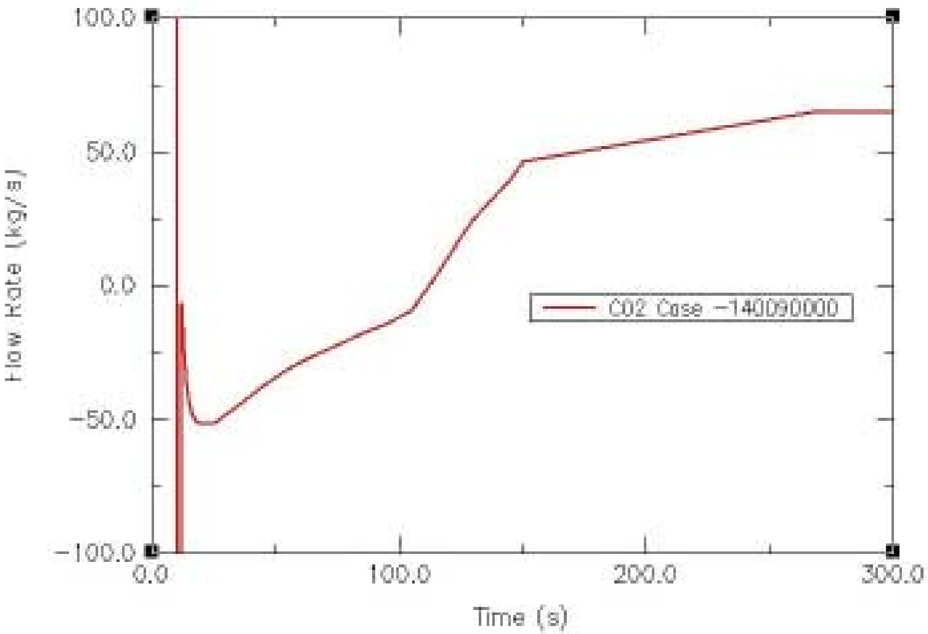


Vessel Temperature Is A Design Challenge

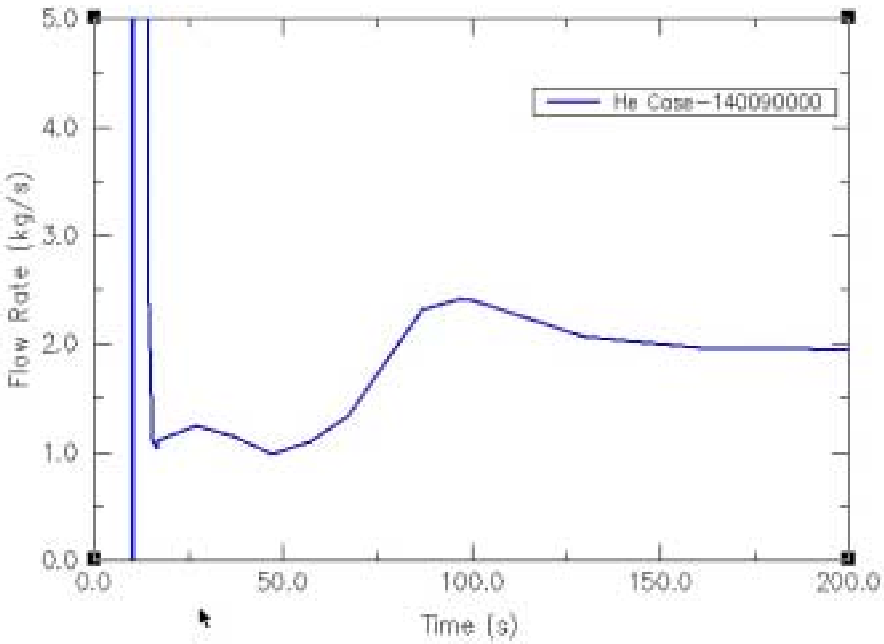


CO_2 Downcomer Flow Shows Flow Reversal

CO_2



He



Conclusions and Future Work

- *The RELAP5 results compare well with expected temperature and pressure trends*
- *The temperature limit of the core matrix material may be reached when He is the coolant*
- *The densities of the two coolants play an important part in the DHRS performance*
- *Future work will include:*
  - *sensitivity studies on containment transient pressure*
  - *CO_2 injection for the He DHRS*
  - *Analysis with CERMET fuel pins*