Thermal-Hydraulic Analysis of a Versatile Coupled Test Reactor

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Outline

- Background
- Reactor description
- Model description
- Results
- Conclusions

Background

- The United States currently has no domestic fast neutron test and irradiation capabilities even though there are potential US vendors for fast reactors including TerraPower (sodium or molten salts), General Atomics EM2 (gas), and Westinghouse LFR (lead)

- A Versatile Coupled Test Reactor (VCTR) concept has been proposed that will fulfill research and development needs requiring high fast and thermal neutron fluxes

- The primary mission is to provide thermal and fast neutrons for irradiation of fuels and materials in a manner complementary to ATR and to HFIR

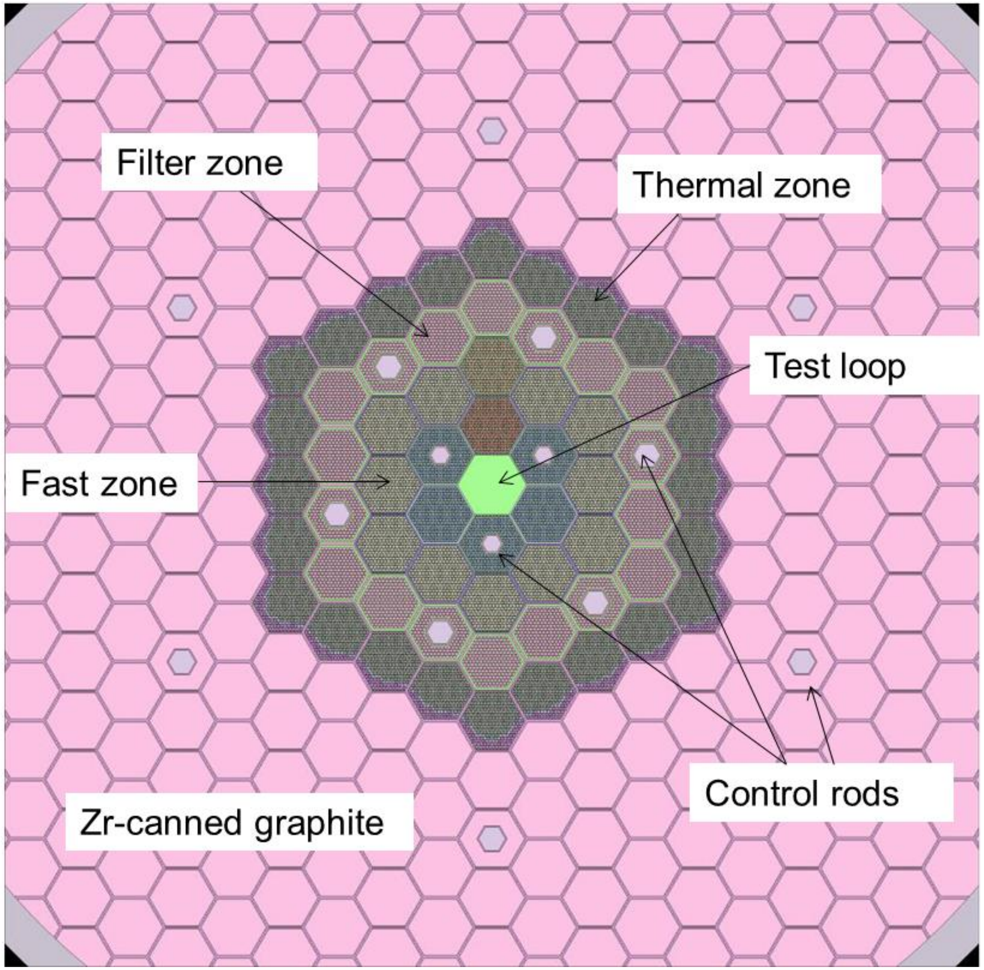
Background (cont'd)

- VCTR design goals are:
  - A prototypical fast flux ($>4\times10^{15}$ n/cm^2-s)
  - A thermal flux similar to ATR ($> 5 \times 10^{14}$ n/cm^2-s)
  - An irradiation environment that allows for testing with different reactor coolants
  - Beam tubes, irradiation vehicles for isotope production, etc.
  - Can be designed for a thermal core, fast core, or coupled core

VCTR description

- Sodium cooled core
  - 18 fast fuel assemblies
  - 24 thermal fuel assemblies
  - Moderator is canned graphite
  - Low enriched uranium
- Core geometry within the operating range of existing fast reactors
- Loop type design

VCTR description (cont'd)



Work areas

- Neutronic calculations (SERPENT)
  - Steady state
- Thermal-hydraulic calculations (RELAP5-3D)
  - Steady state
  - Transient
    - Protected loss of flow
    - Protected loss of heat sink
- Reactor kinetics
  - Coupling of fast and thermal cores
- System engineering
  - Layout of components
  - Fuel and experiment handling

RELAP5-3D model of the VCTR represents

- Primary coolant system
  - Reactor
  - Reactor tank
  - Two external coolant loops containing centrifugal pumps, intermediate heat exchangers (IHXs), and piping
- Secondary coolant system
  - IHXs
  - Boundary conditions
- Reactor core based on neutronic conceptual design
- Other components scaled from JOYO test reactor

RELAP5-3D model of the VCTR core

- Fuel assemblies modeled with six 1-D channels
  - Three channels each in the fast core and thermal core
    - Low power, average power, and high power
    - Radial power peaking factors assumed to be 0.9, 1.0, and 1.1
    - Active fuel is 1.0 m tall
  - Orifices used in the fast core to achieve similar outlet temperatures as in the thermal core
  - Artificial valves used in each channel to represent the flow resistance of the wire-wrapped fuel rods as a function of Reynolds number
- 1-D channels used to represent the side reflector, which acts as a filter between the fast and thermal cores, and the graphite moderator
  - Orifices used to reduce the flow in the side reflector and moderator

RELAP5-3D model of the VCTR core (cont'd)

- Fast reactors typically have a large temperature variation within an assembly due to subchannel and hot pin effects
  - Subchannel effects not represented by the 1-D models
  - The temperature in the worst subchannel is typically about 50°C higher than the average temperature
- The steady-state temperature limit is likely to be 600°C or slightly higher

Steady-state results at 100% power

Parameter	Value
Primary side:	
Core power, MW	266.6
Total primary mass flow rate, kg/s	1388
Cold leg temperature, °C	350
Hot leg temperature, °C	501
Secondary side:	
Total secondary mass flow rate, kg/s	1270
IHX inlet temperature, °C	293
IHX outlet temperature, °C	457

- Temperatures are representative of operating sodium-cooled fast reactors

Steady-state results at 100% power (cont'd)

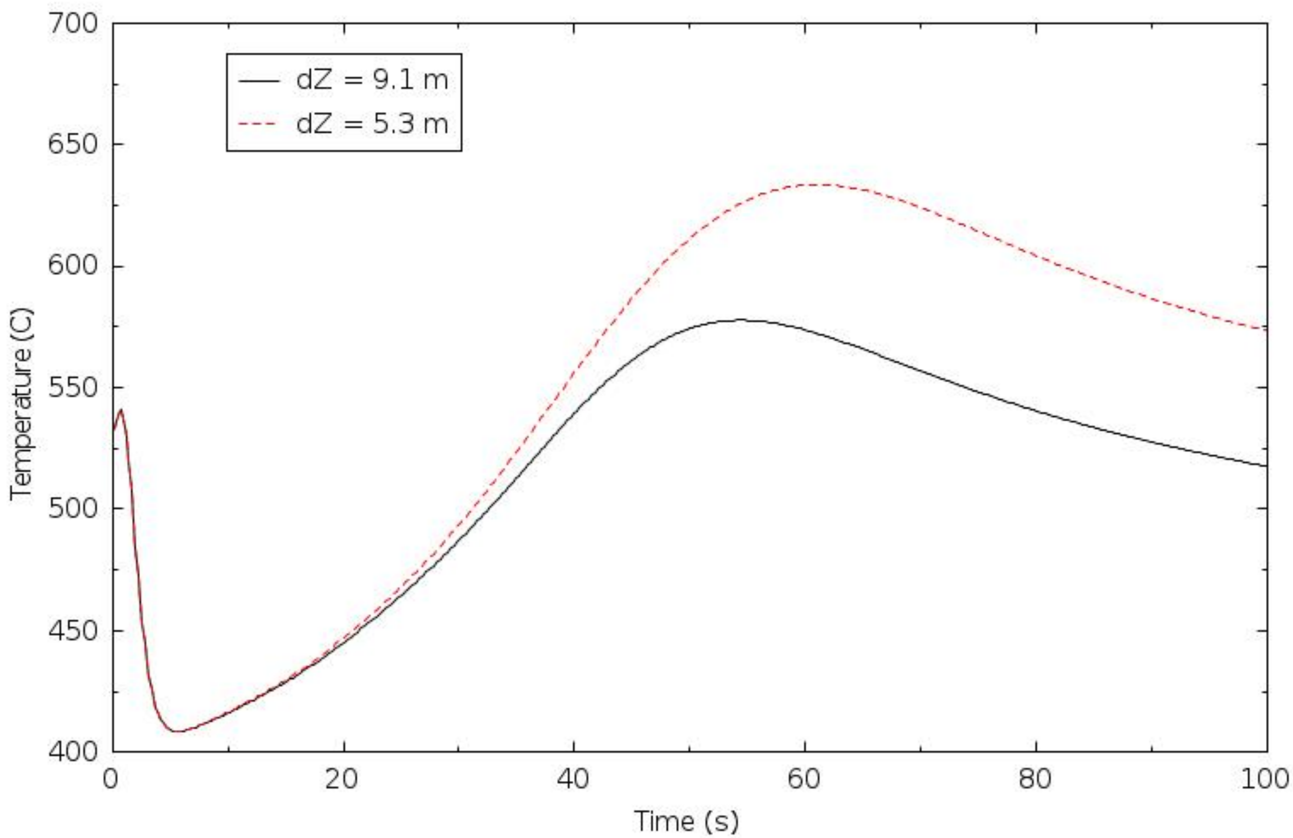
Parameter	Fast Core	Thermal Core	Side Reflector	Graphite
Assemblies	18	24	18	267
Power, MW	104.0	162.6	0	0
Tin, °C	350	350	350	350
Tout, °C	511	511	350	350
Peak clad temperature, °C	532	533		
Peak fuel temperature, °C	613	640		
Flow, kg/s-assembly	28.2	33.1	4.43	0.02

- The maximum cladding temperature is expected to be less than 600°C after accounting for subchannel effects and is therefore acceptable

Protected loss of flow

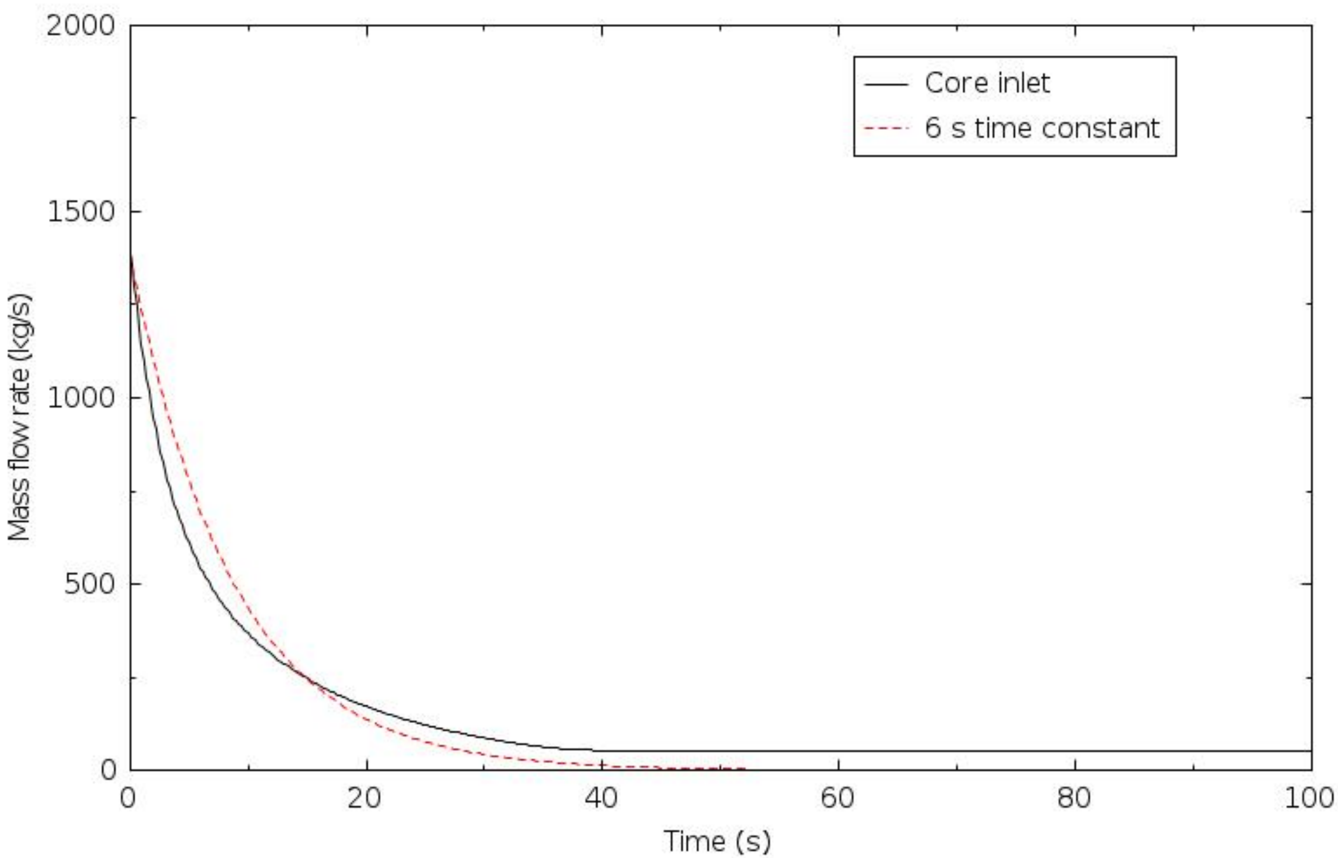
- Transient was initiated by a trip of the primary coolant pumps
- Pump inertia was adjusted to obtain a six second flow halving time
- Reactor was assumed to scram
- The elevation change (dZ) between the centers of the core and the IHXs was varied parametrically to determine its effect on the transition to natural circulation
  - The elevation change varied from 9.1 m to 5.3 m
- The flow on the secondary side of the IHXs was reduced to 1.9% of the total to provide decay heat removal

Protected loss of flow: maximum cladding temperature



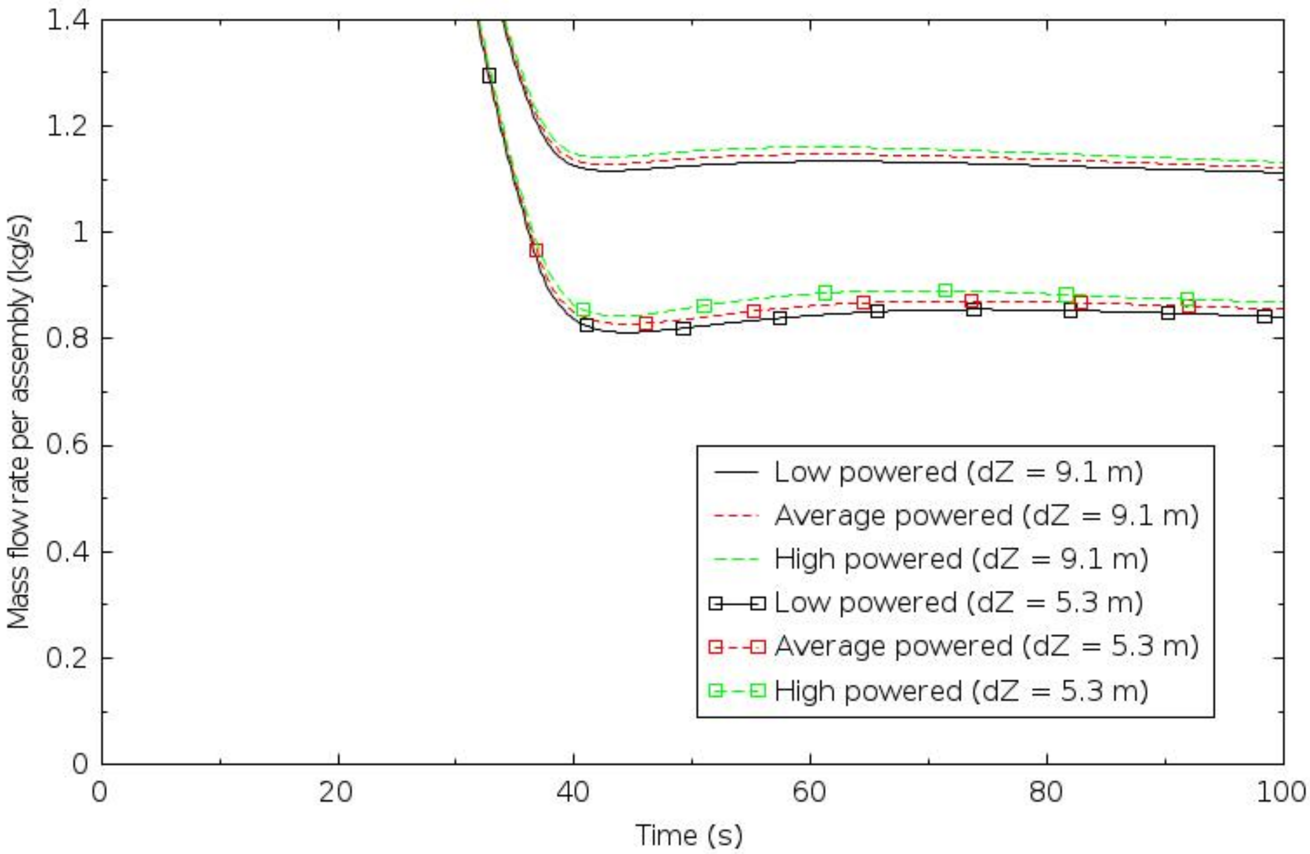
- With an elevation change of 9.1 m, the maximum cladding temperature remained below the anticipated steady-state temperature limit of 600°C

Protected loss of flow: core inlet flow



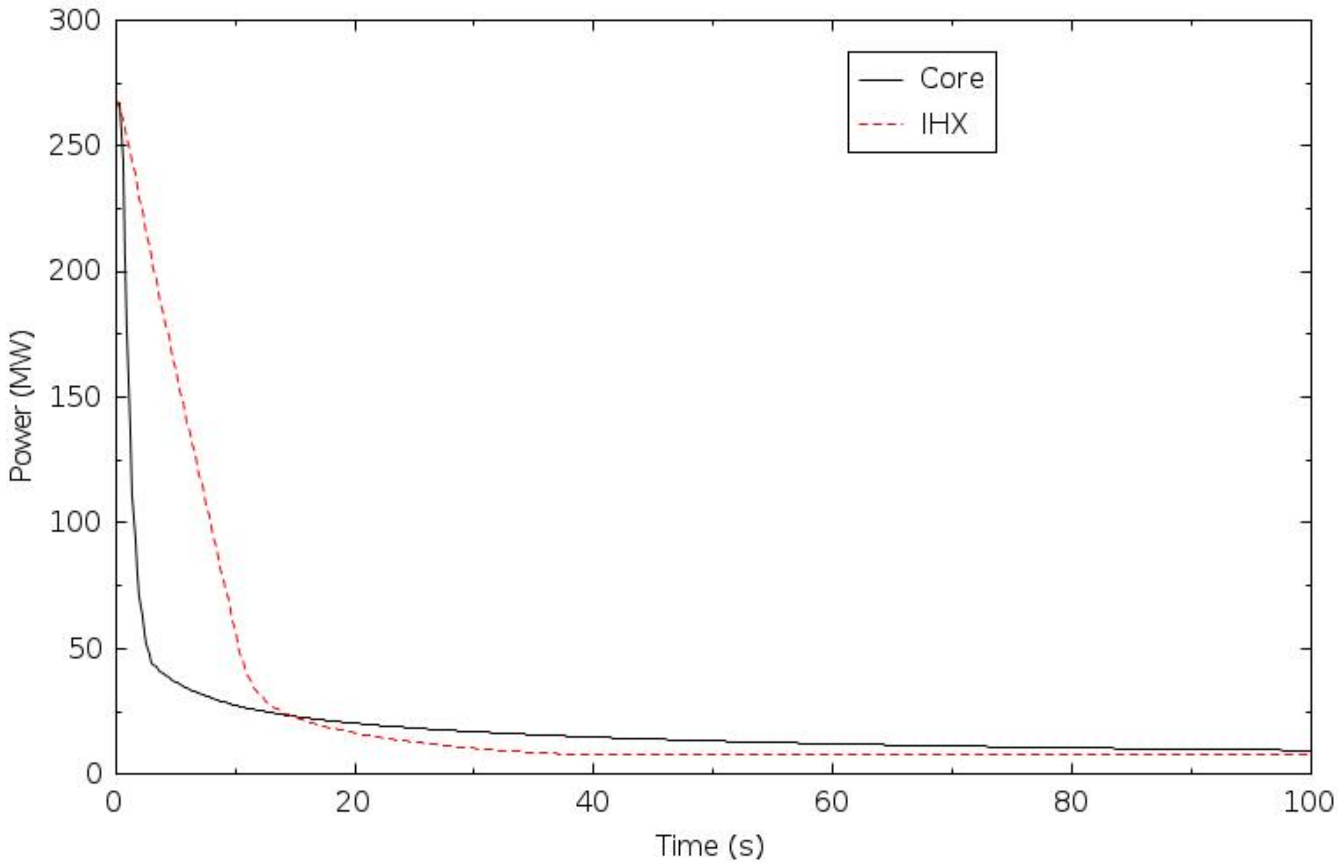
- dZ = 9.1 m
- 6 s time constant is typical for fast reactors
- Natural circulation fully established by 40 s

Protected loss of flow: channel inlet flow



- The elevation change significantly affects the magnitude of the natural circulation flow and somewhat affects the variation in flow between channels

Protected loss of flow: core and IHX powers

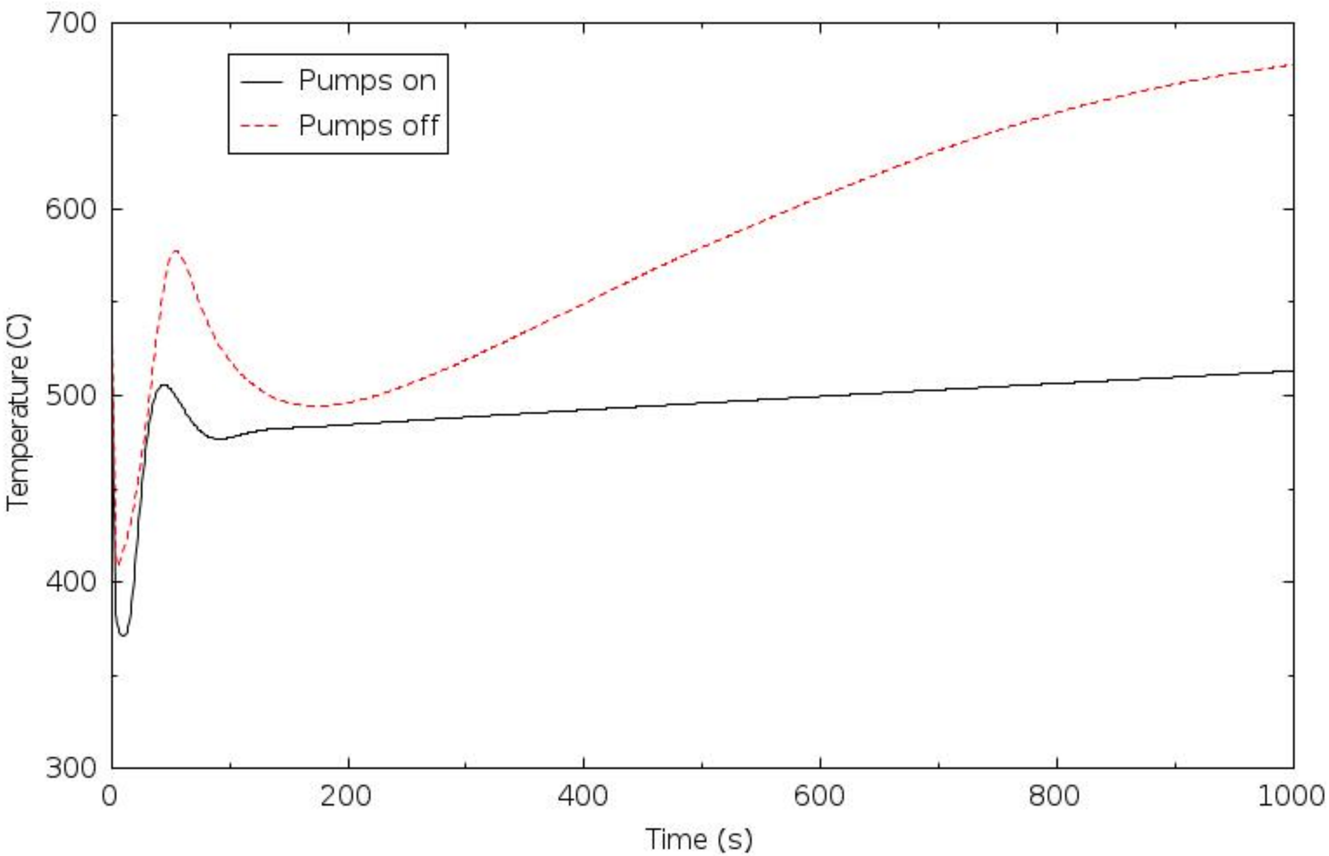


- The core and IHX powers were nearly equal by 100 s

Protected loss of heat sink

- The flow on the secondary side of the IHXs was assumed to decrease to zero in 10 s
- Reactor was assumed to scram
- No decay heat removal systems were assumed to operate
- Two calculations were performed
  - Primary coolant pumps on
  - Primary coolant pumps off (station blackout)

Protected loss of heat sink: maximum cladding temperature



- The decay heat removal systems are not required to operate until about an hour with pumps on, but must operate within 10 minutes with pumps off to keep the maximum temperature less than 600° C

Conclusions

- Preliminary thermal-hydraulic calculations of the VCTR indicate that the design appears reasonable
- More detailed design information is needed
  - for the power distribution within the core
  - for other components including the external loops, secondary system, and the decay heat removal system
  - for the point kinetics model of the coupled reactor
- More transients should be analyzed including unprotected transients