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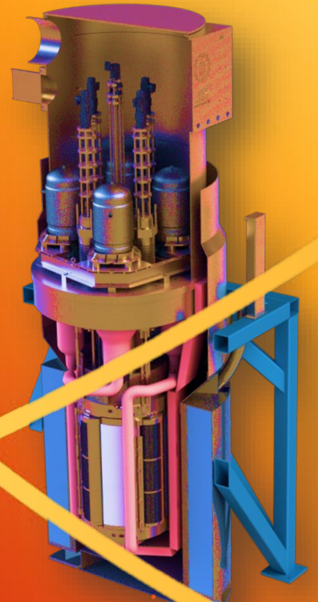

Preliminary MARVEL Accident Scenarios for Heat Extraction System

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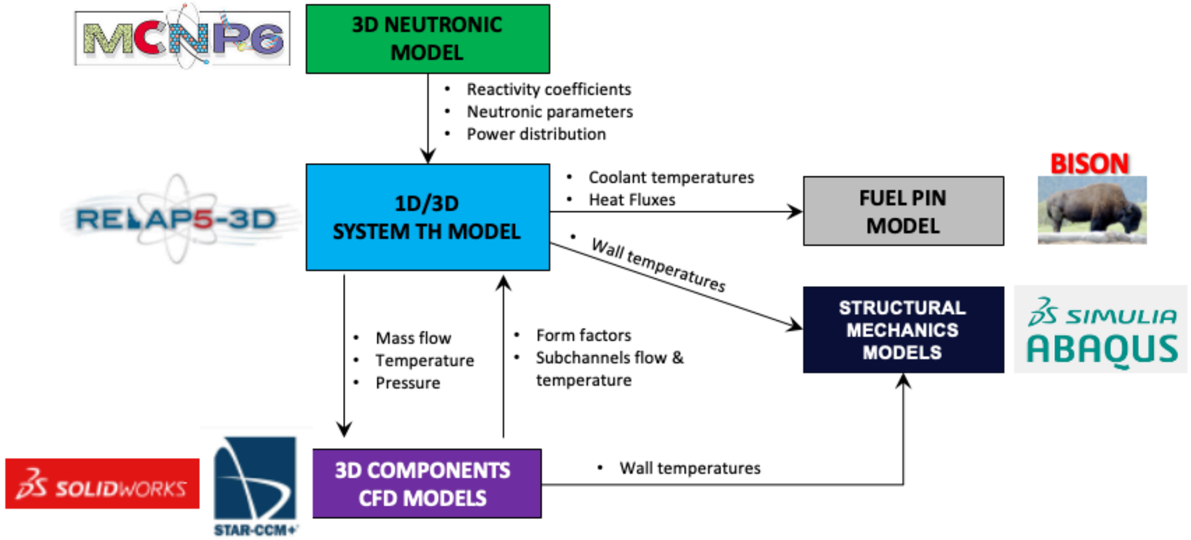
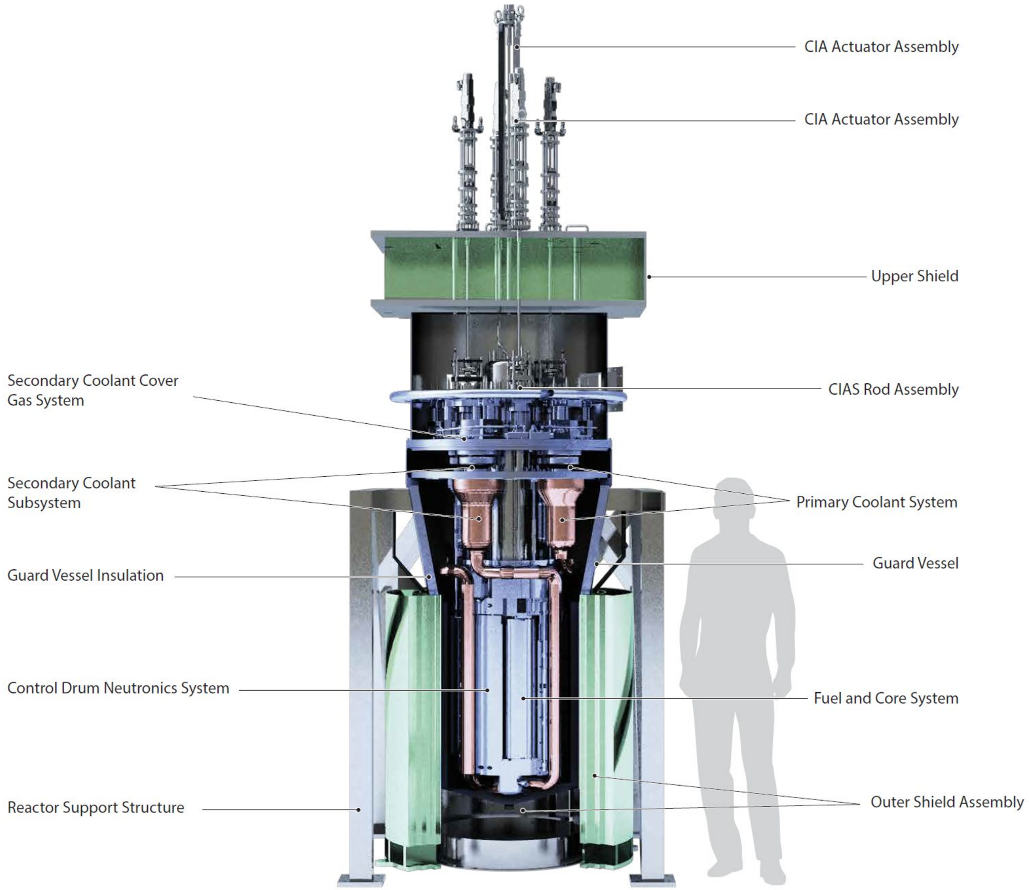
MARVEL Project aims to design, deploy, and demonstrate a microreactor

- Identify challenges industry designers will encounter before they do so we can help brainstorm solutions
- Provide stakeholders outside of nuclear with the opportunity to engage with a real reactor prior to making decisions on how to use nuclear for their needs





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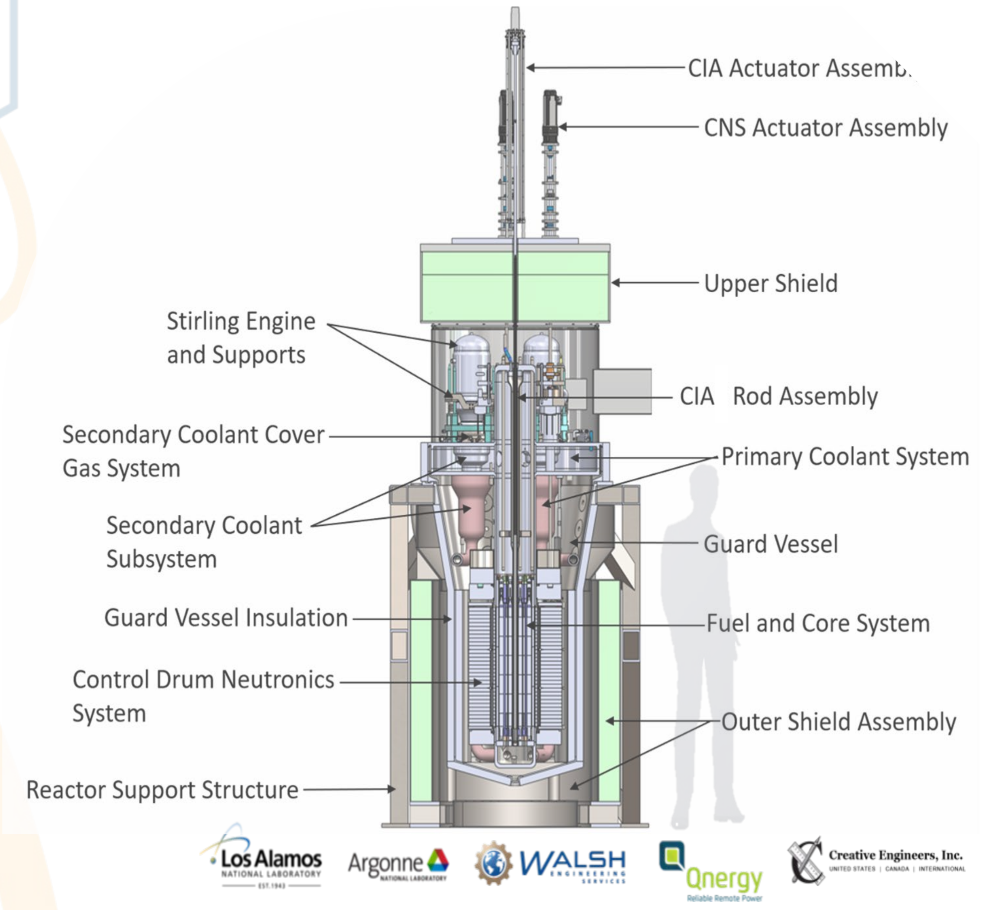
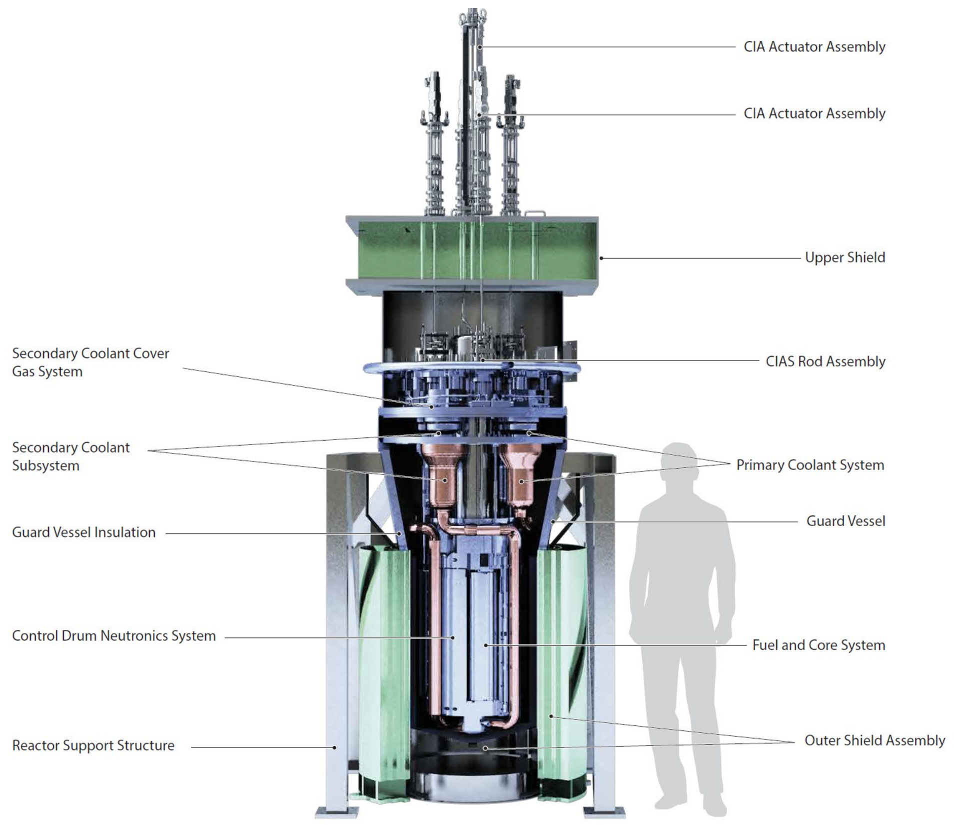
Original MARVEL design used Stirling engines connected to the intermediate heat exchanger (IHX)





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Transient Analysis Workflow

RELAP5-3D

- Reactor Safety Calculations
- Provide boundary conditions for CFD

STAR-CCM+

- Uses RELAP5-3D boundary conditions to generate volumetric temperature gradients
- Both steady-state and transient analysis

ASME Analysis

- Ensure stresses from thermal gradients do not comprise material performance
- Uses CFD results as boundary conditions

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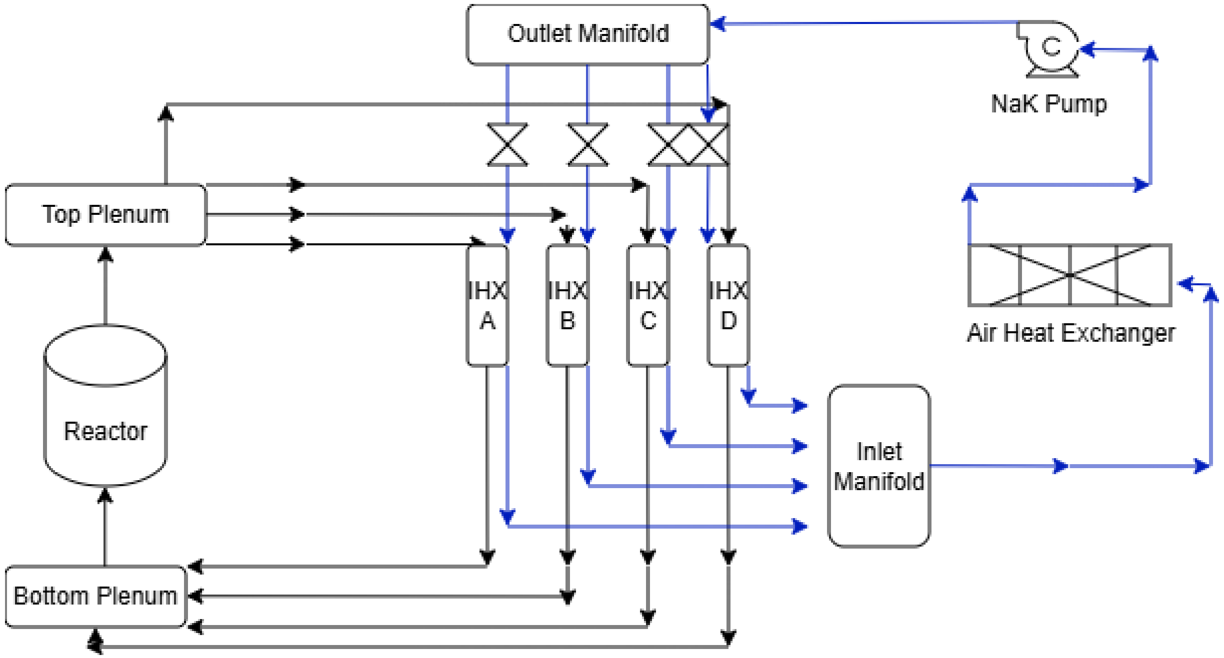
System Configuration

- Hydraulic resistance of each secondary loop is slightly different, and servo valves were used to adjust the resistance to keep flow rates in each loop approximately equal
- Secondary NaK valves can be closed to stop flow to each IHX



Name	Steady State Value	Transient Value
Peak Fuel Centerline Temperature Limit	900°C	900°C
Peak Cladding Temperature Limit	764°C	764°C
Maximum Bulk Coolant Temperature Limit	530°C	704°C (650°C for anticipated events)

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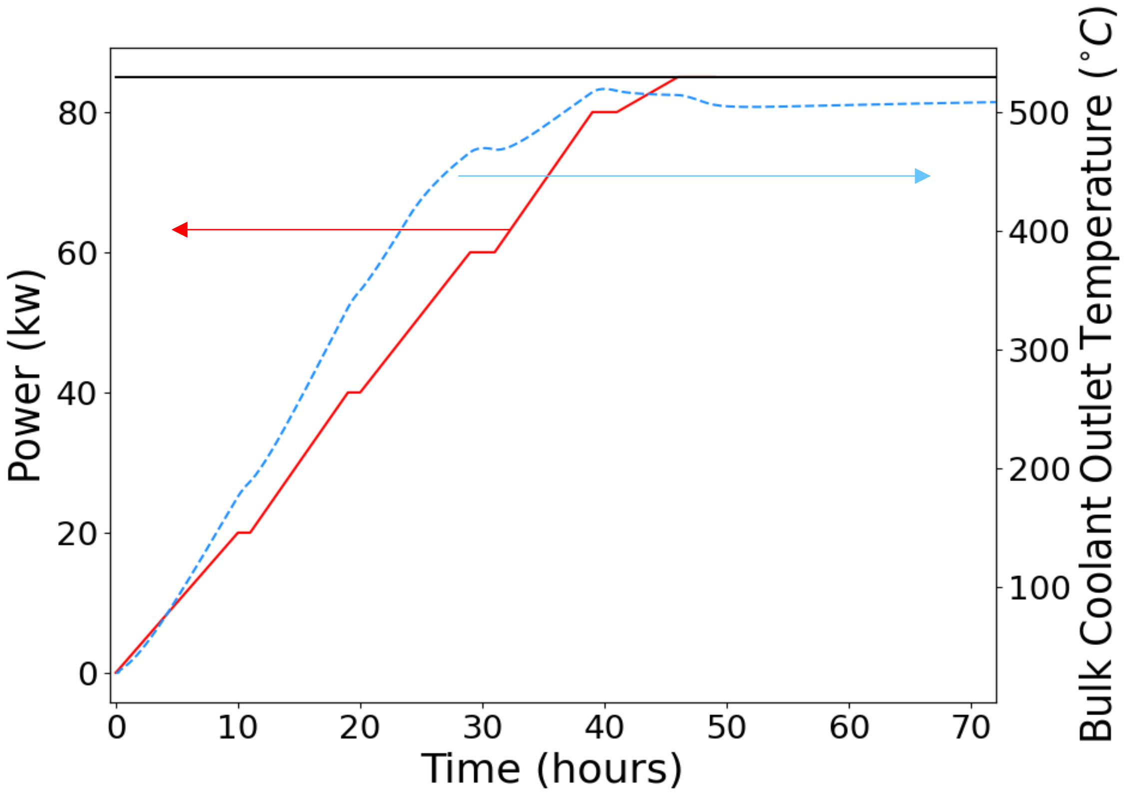
Startup Transient

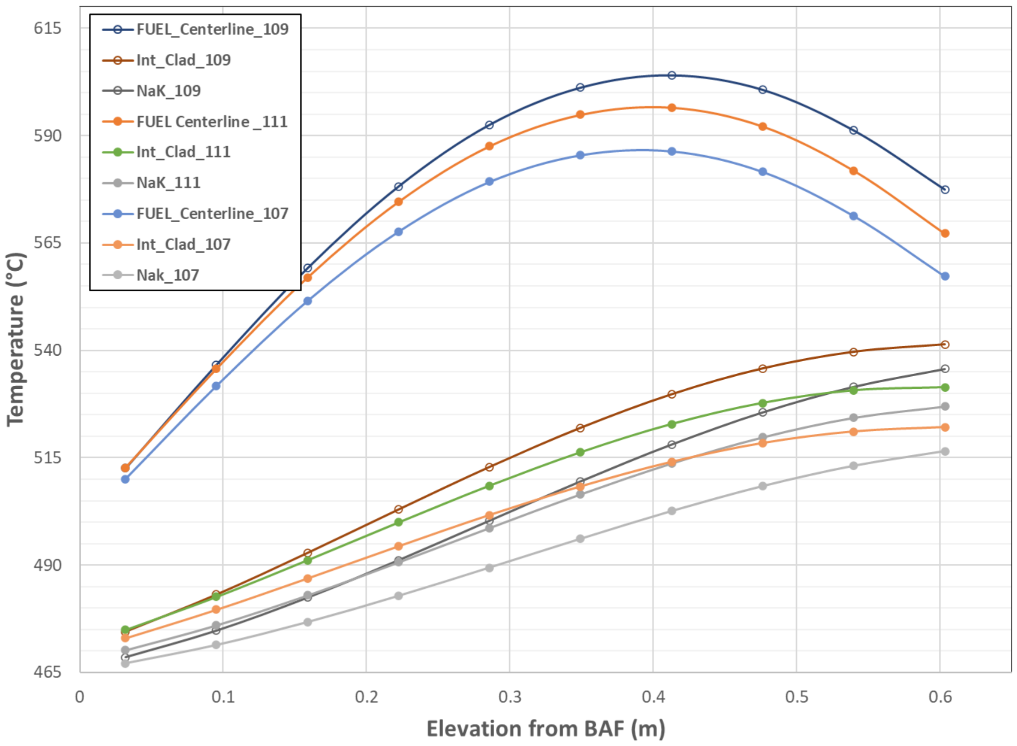
- Power is ramped from 0 to 100% linearly over 48 hours, with a few holds
- Startup can create challenging thermomechanical stresses, especially in the top plenum
- Event Sequence:

Time (hh:mm:ss)	Condition
00:00:00	Secondary NaK flowing at 1 kg/s, Air Heat exchanger at 0.09 kg/s. Reactor power at 0 kW
00:00:00	Reactor power ramp begins
24:00:00	Ramp Air Heat Exchanger flow from 0.09 to 0.17 kg/s linearly begins Ramp NaK flow from 1 to 2 kg/s begins
48:00:00	Reactor at full power NaK flow at 2 kg/s Air Heat Exchanger flow at 0.17 kg/s
72:00:00	End of startup transient



Normal Operations

- Conservative hot channel factors are used to determine the hot channel peak fuel and cladding temperatures



Parameter (Units)	Value
Reactor Power (kW)	85
Primary Coolant Flow Rate (kg/s)	1.53
Secondary Coolant Flow Rate per IHX (kg/s)	0.5
Best-estimate Peak Fuel Temperature (°C)	605
Best-estimate Peak Cladding Temperature (°C)	539
Hot Channel Peak Fuel Temperature (°C)	669
Hot Channel Peak Cladding Temperature (°C)	638
Bulk Coolant Outlet Temperature (°C)	529
Heat Transferred to Secondary System (kW)	75.4
IHX Outlet Temperature (°C)	446

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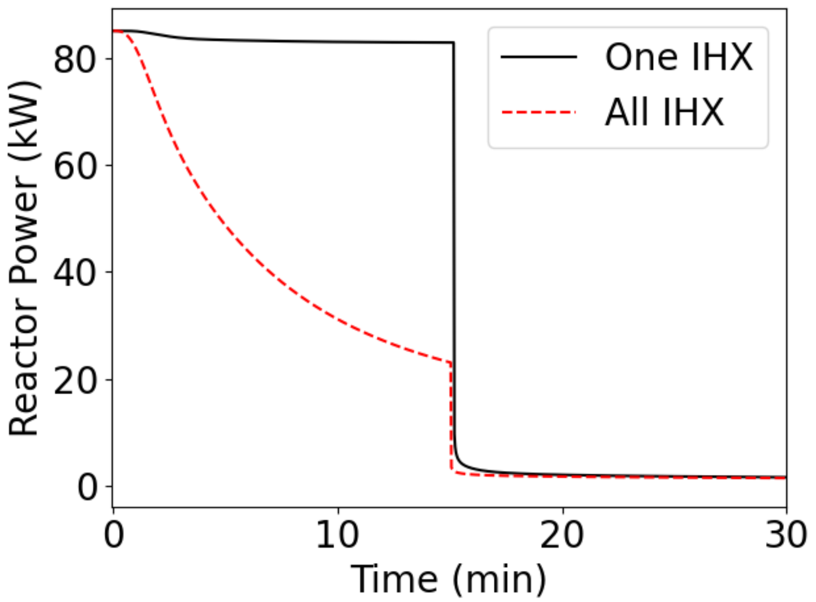
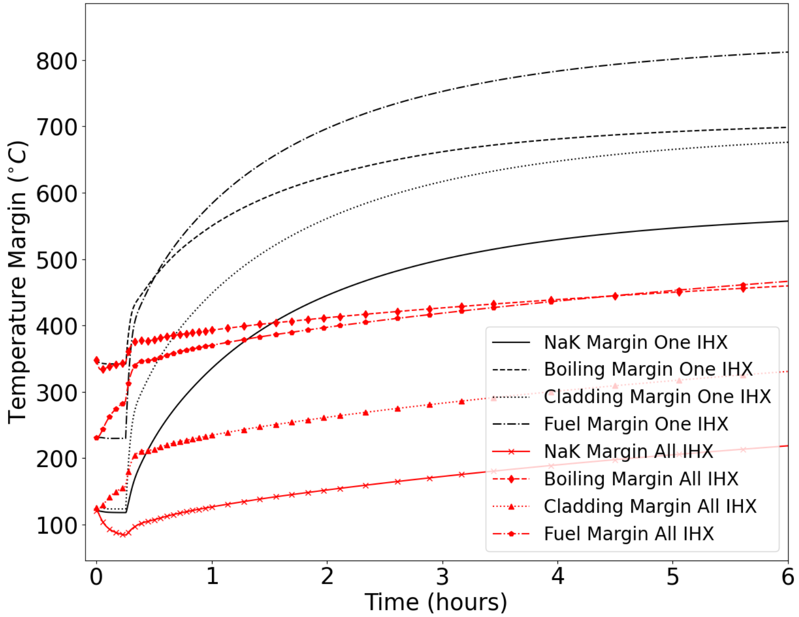
Loss of Heat Sink Accidents

- As an anticipated transient, SCRAM is supposed to occur within 5 minutes, but we allow an extra 10 minutes to ensure this analysis is bounding
- The loss of all IHX is the bounding transient, but loss of one IHX will create asymmetries that can induce stresses

Time (hh:mm:ss)	Condition
00:00:00	Full power steady state
00:00:01	IHX Loop A valve closes instantaneously/All IHX valves close instantaneously
00:15:00	Manual SCRAM Occurs
24:00:00	End of transient





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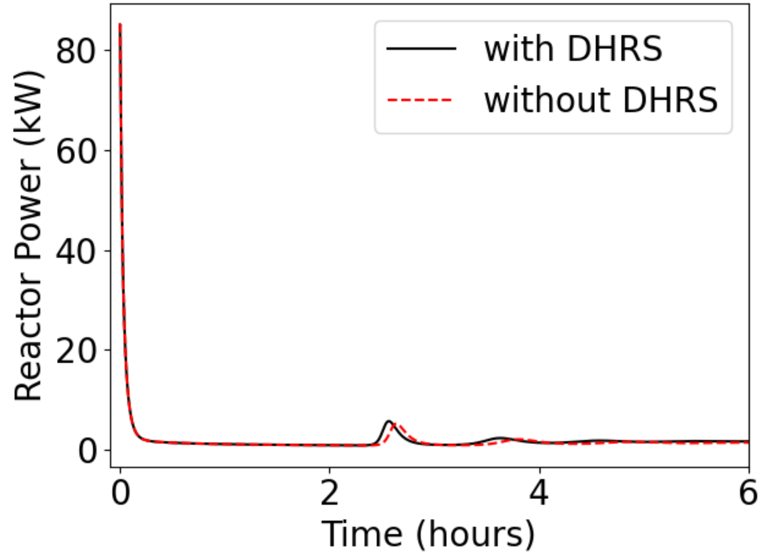
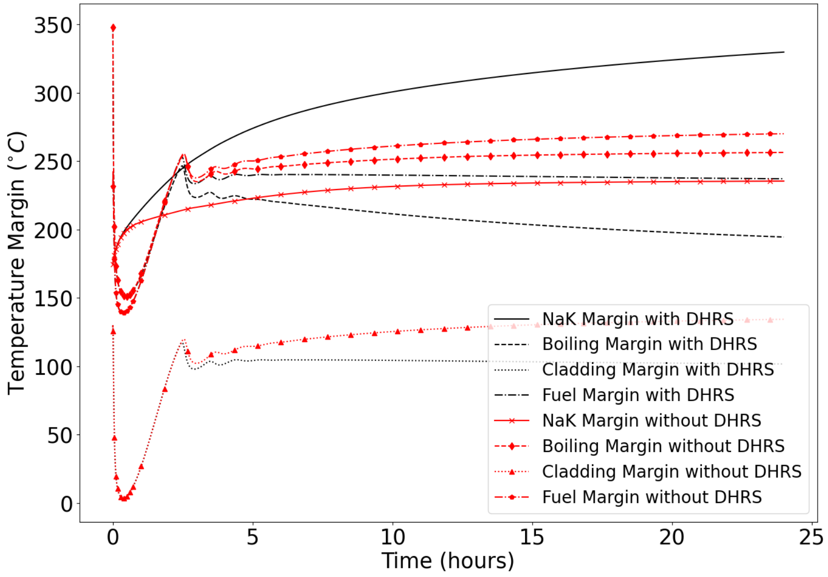
Loss of Flow Accidents

- There is no anticipated pathway for this transient to occur, but we analyze it to ensure survivability
- Without decay heat removal system (DHRS), this is an extremely unlikely event
- Minimum cladding margin is 3.6 K

Time (hh:mm:ss)	Condition
00:00:00	Full power steady state
00:00:01	Valves in PCS close to terminate primary flow. Valves in HES close to terminate secondary flow
00:22:24	Minimum cladding temperature margin
01:26:56	First recriticality
24:00:00	End of transient





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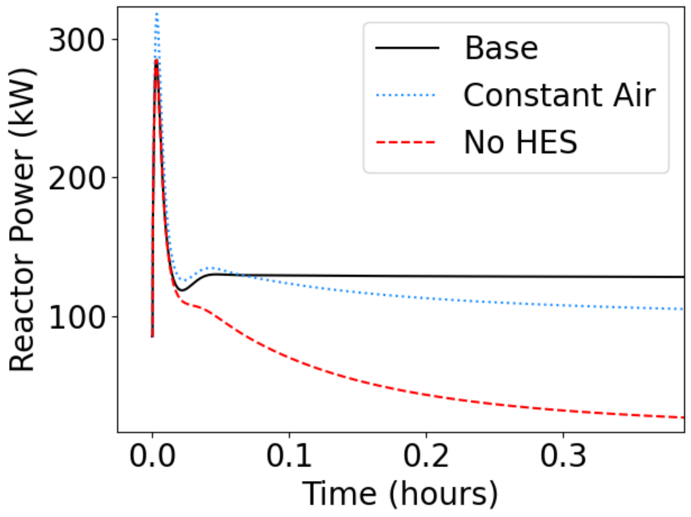
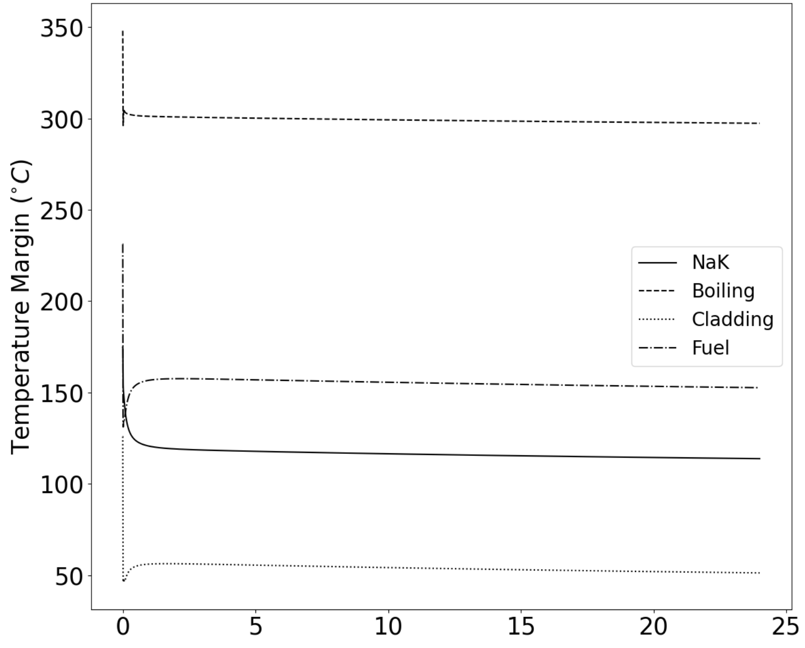
Unprotected Transient Overpower Accidents

- With heat extraction system active, this is considered an unlikely event
  - Constant air HX speed
  - Variable air HX speed (Base)
- Without heat extraction system active, this is considered an extremely unlikely event
- 0.40$ inserted over 0.1 seconds
- Minimum cladding margin is 46°C and occurs for constant air heat exchanger flow
- For No HES scenario, valves close 1 second after reactivity insertion starts





Case	Asymptotic Power (kW)
Base	131
Constant Air	97
No HES	11

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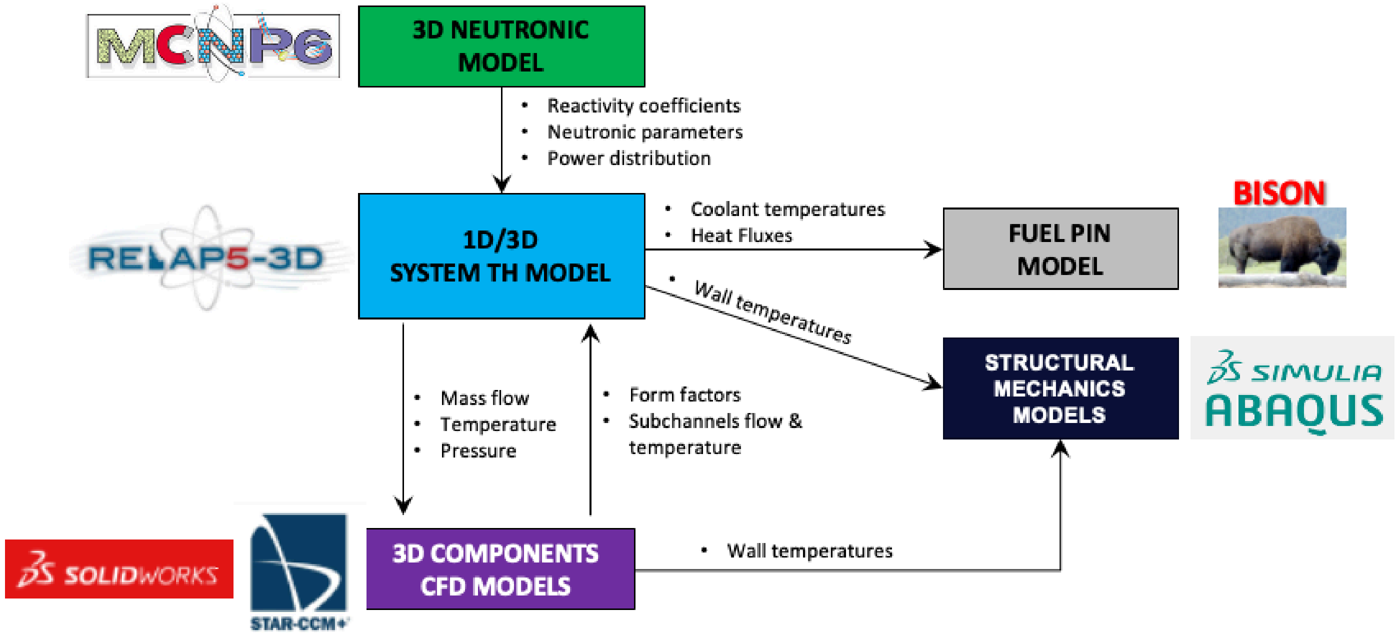
Conclusions

- Preliminary analysis shows these transients are all survivable from a nuclear safety standpoint
- Ongoing analysis in support of full-power operations uses temperature and flow conditions predicted by RELAP5-3D to inform CFD analysis
- CFD analysis will inform thermomechanical analysis



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