Application of RELAP5 to the BR2 and RHF Research Reactors for the GTRI Fuel Conversion Project

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Introduction and Outline

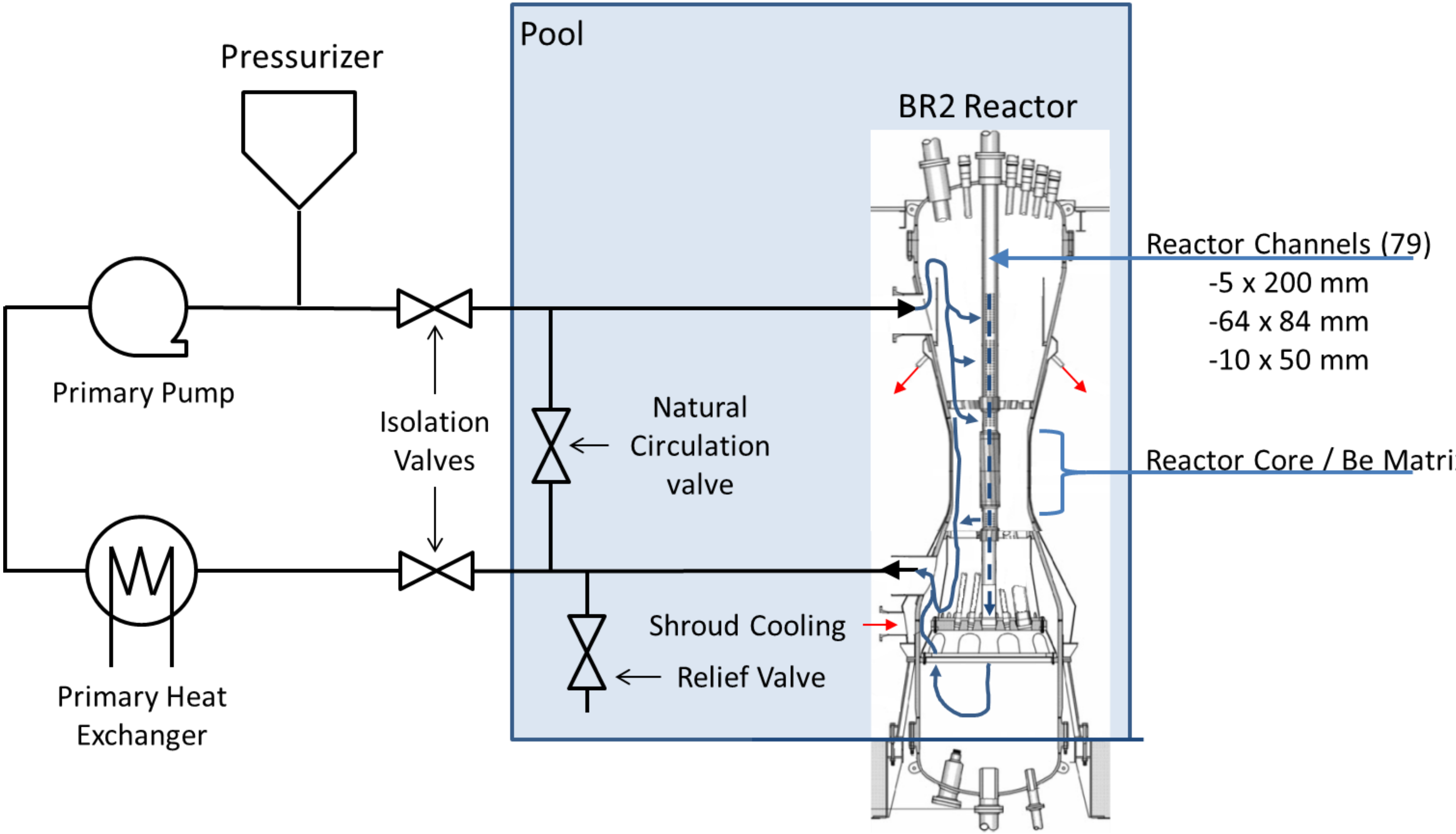
Introduction: Global Threat Reduction Initiative (GTRI)

- Led by National Nuclear Security Administration (NNSA)
- US Government Highly Enriched Uranium (HEU) minimization effort
- Program includes:
  - Design and safety analyses – define LEU element, produce licensing case
  - Development of advanced Low Enriched Uranium (LEU) fuels
  - Mo-99 production technology development
- Successful HEU to LEU fuel conversion for many research reactors around the world.

Outline: This presentation

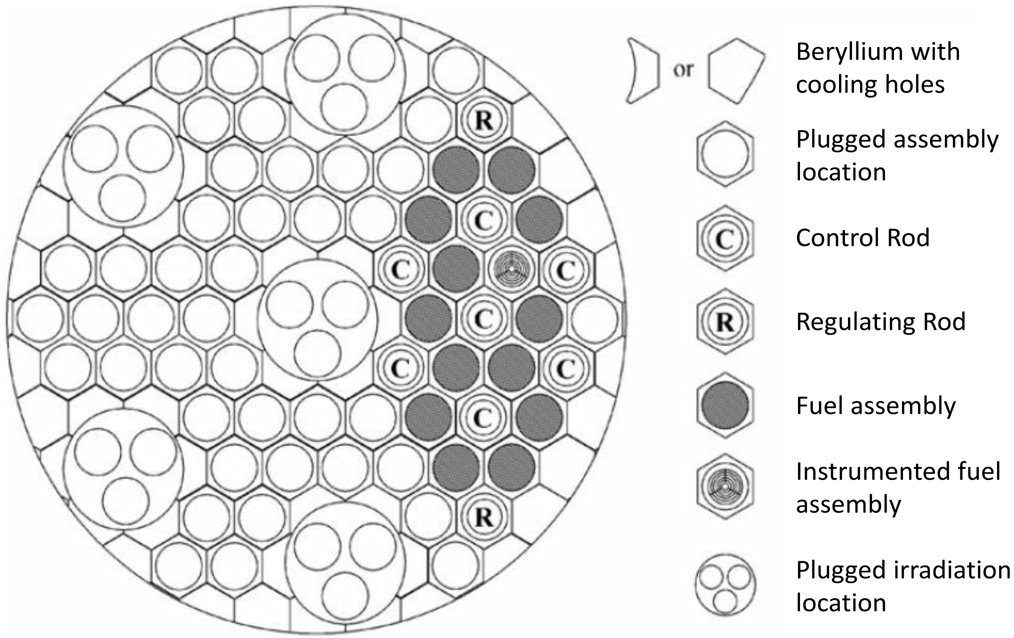
1. SCK-CEN Belgian Reactor 2 (BR2)
2. Institut Laue-Langevin (ILL) High Flux Reactor (RHF)
   - Reactor description
   - RELAP5 model
   - Loss-of-flow / offsite-power simulations
   - Summary

BR2 Research Reactor

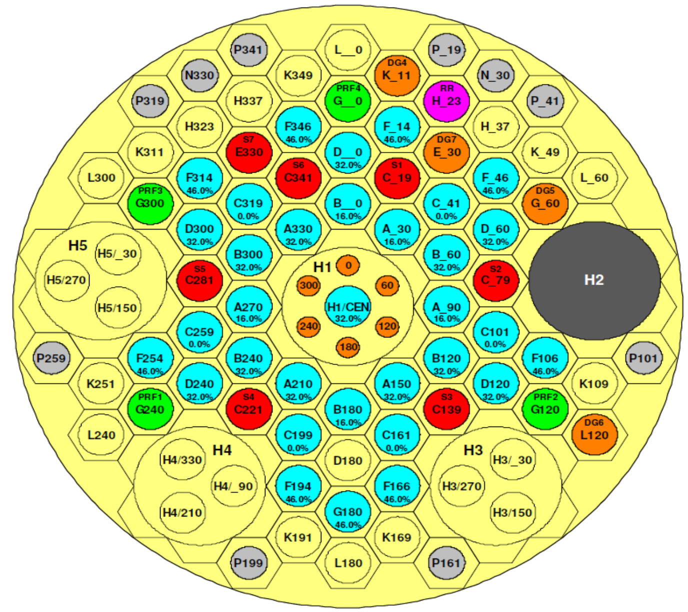


BR2 Reactor Core

1963 Core Configuration



Current Representative Core Configuration



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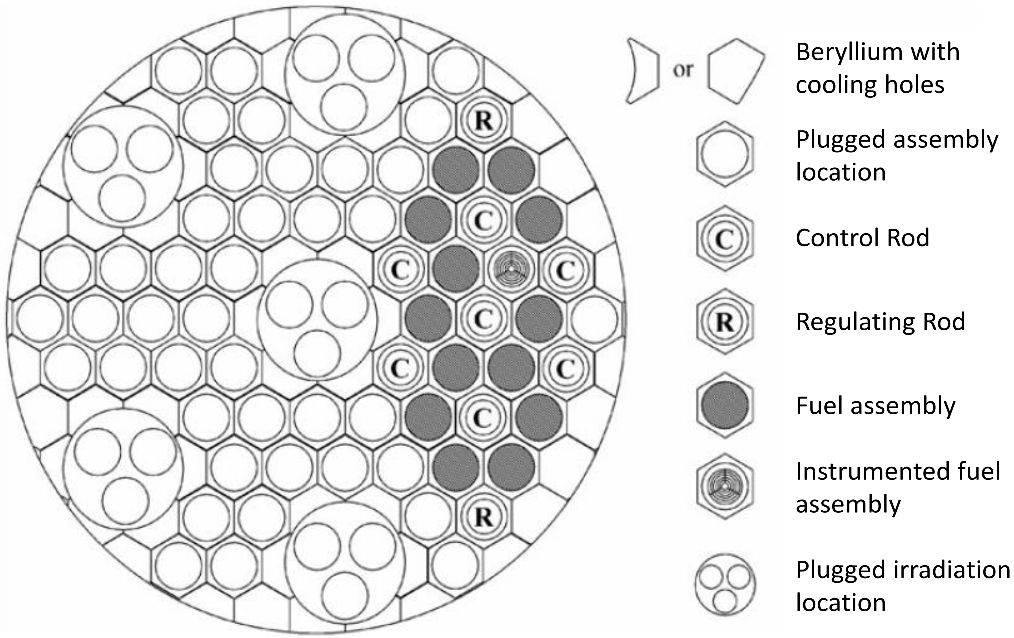

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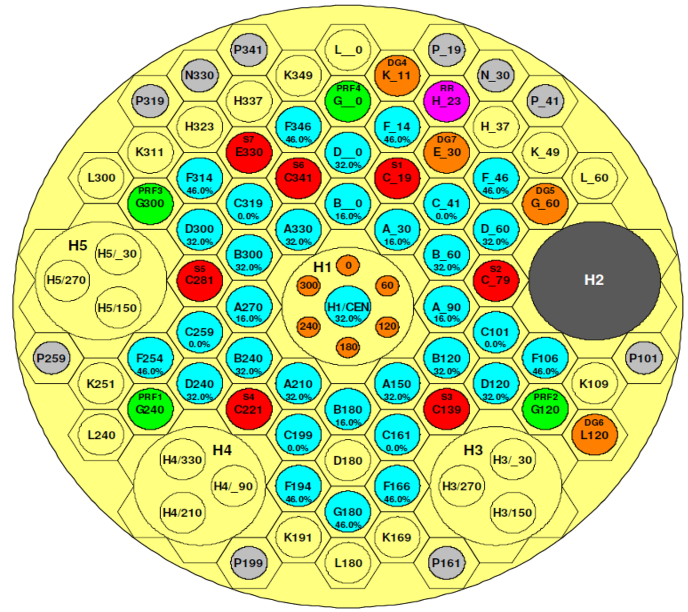
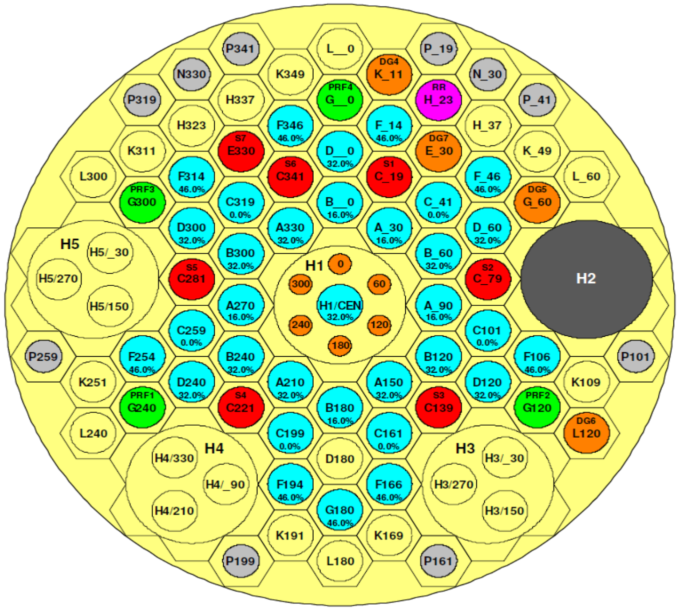


Conversion Strategy

1. Empirically calibrate RELAP5 model to 1962 BR2 and mock-up facility hydraulic data
2. Apply model to 1963 loss-of-flow experiments and reproduce peak cladding temperatures
3. Extend model to current representative core (31 fuel elements)
4. Repeat accident scenarios with HEU and LEU fuel to simulate conversion impact on safety.

Reactor Core model

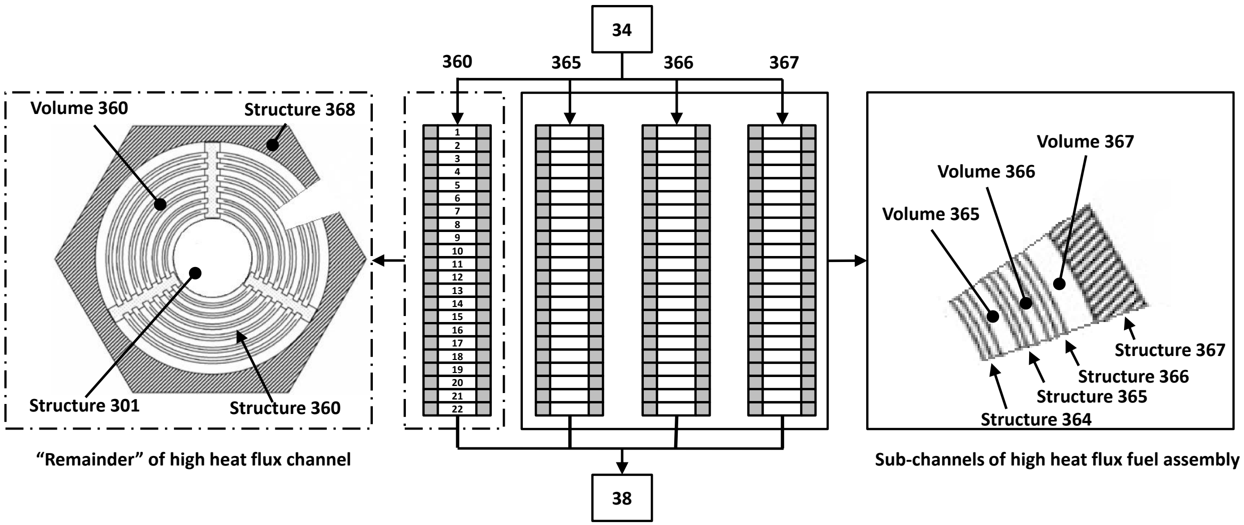


<u>Reduce 79 channels into 4 relevant RELAP5 channels</u>

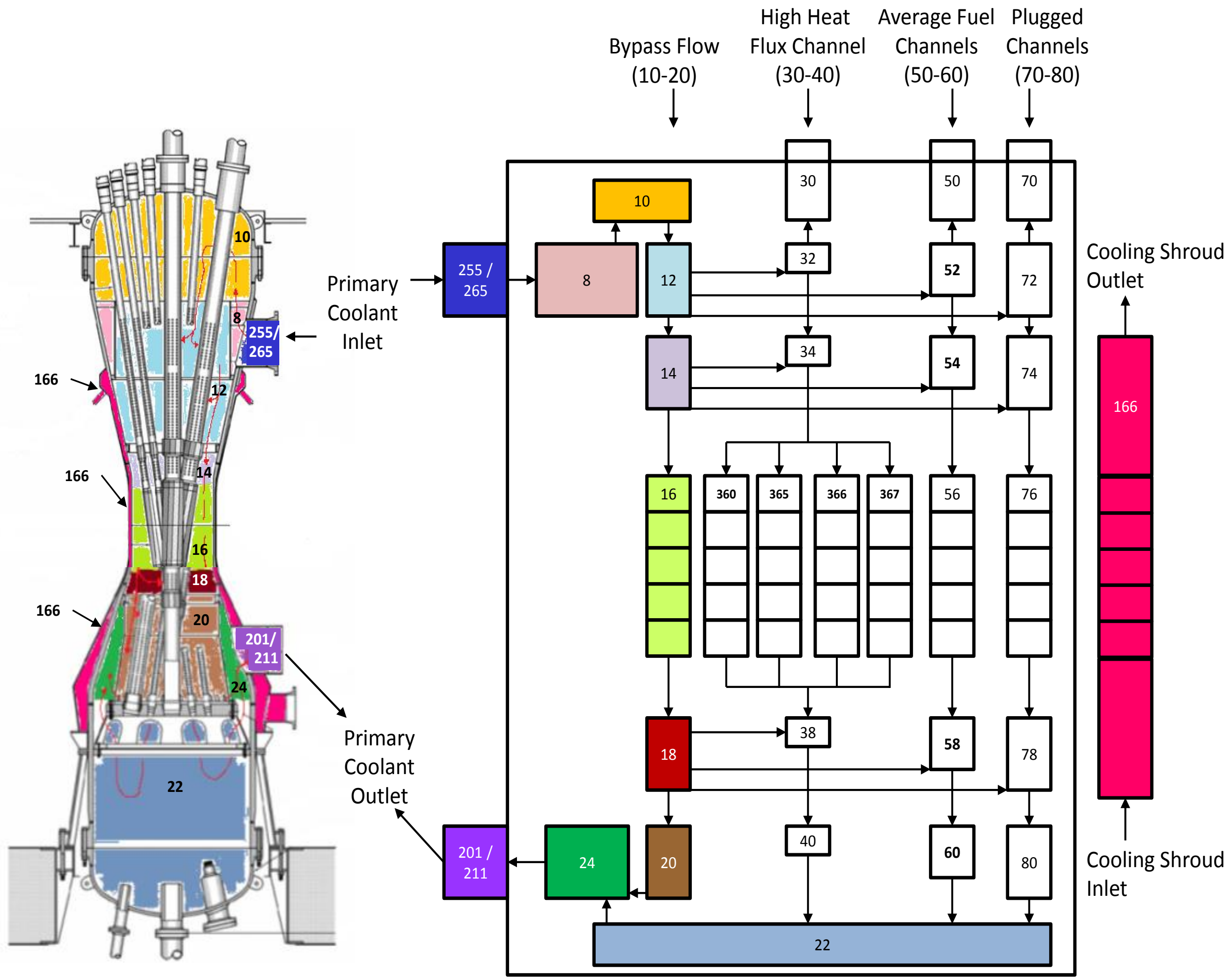
1. Limiting fuel element (high heat flux)
2. Remaining fuel elements
3. Remaining channels (plugged channel)
4. Core bypass

<u>Limiting fuel element</u>

- 10^{o} hot stripe



Reactor Vessel Model



<u>Channel contents</u>

Averaged into 6 axial segments

<u>Crossflow paths</u>

100's of ~6mm diameter holes

<u>Flow distribution at 2.1 kg/cm^2</u>

Bypass = 360.0 kg/s

Fuel element = 35.7 kg/s

Control rod = 7.4 kg/s

Plug = 2.25 kg/s

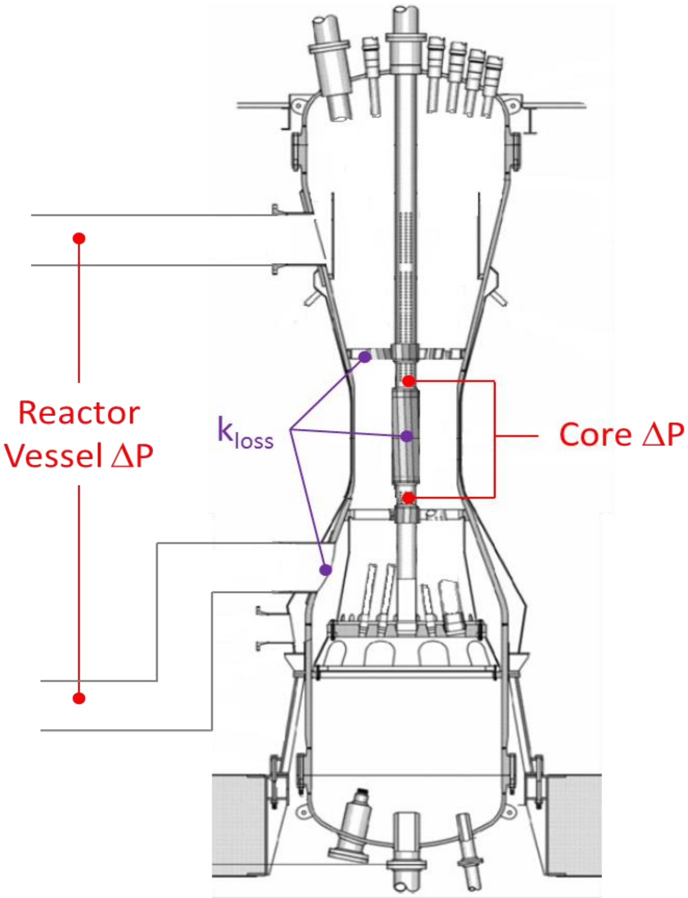
<u>Pressure distribution</u>

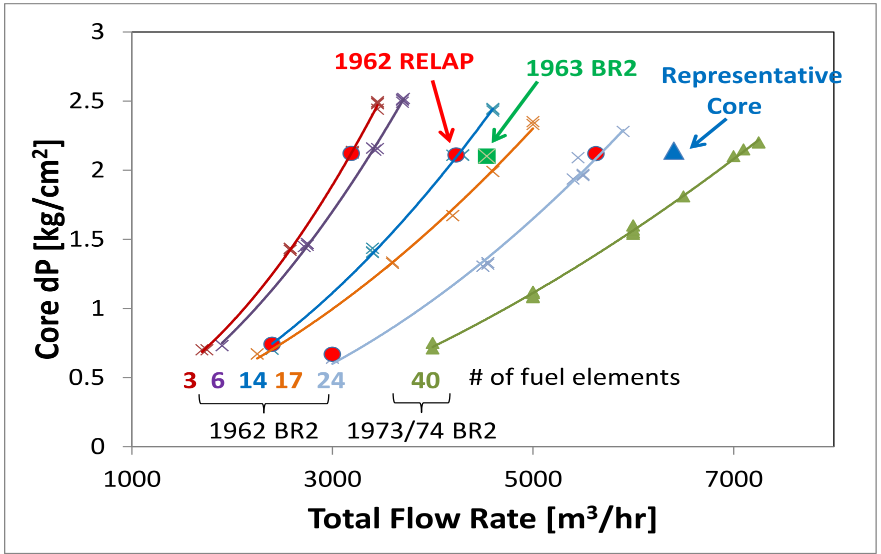
Core dP

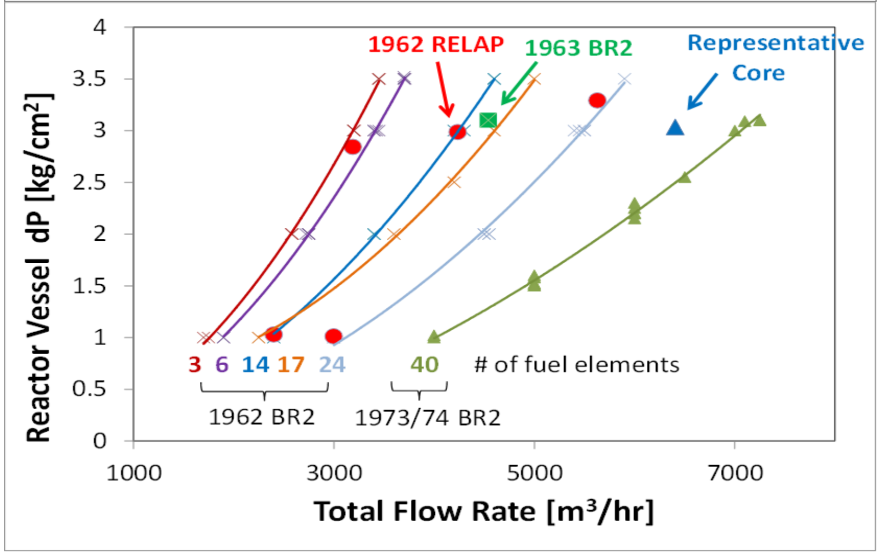
Vessel dP

Other locations

Reactor Vessel and Core Calibration

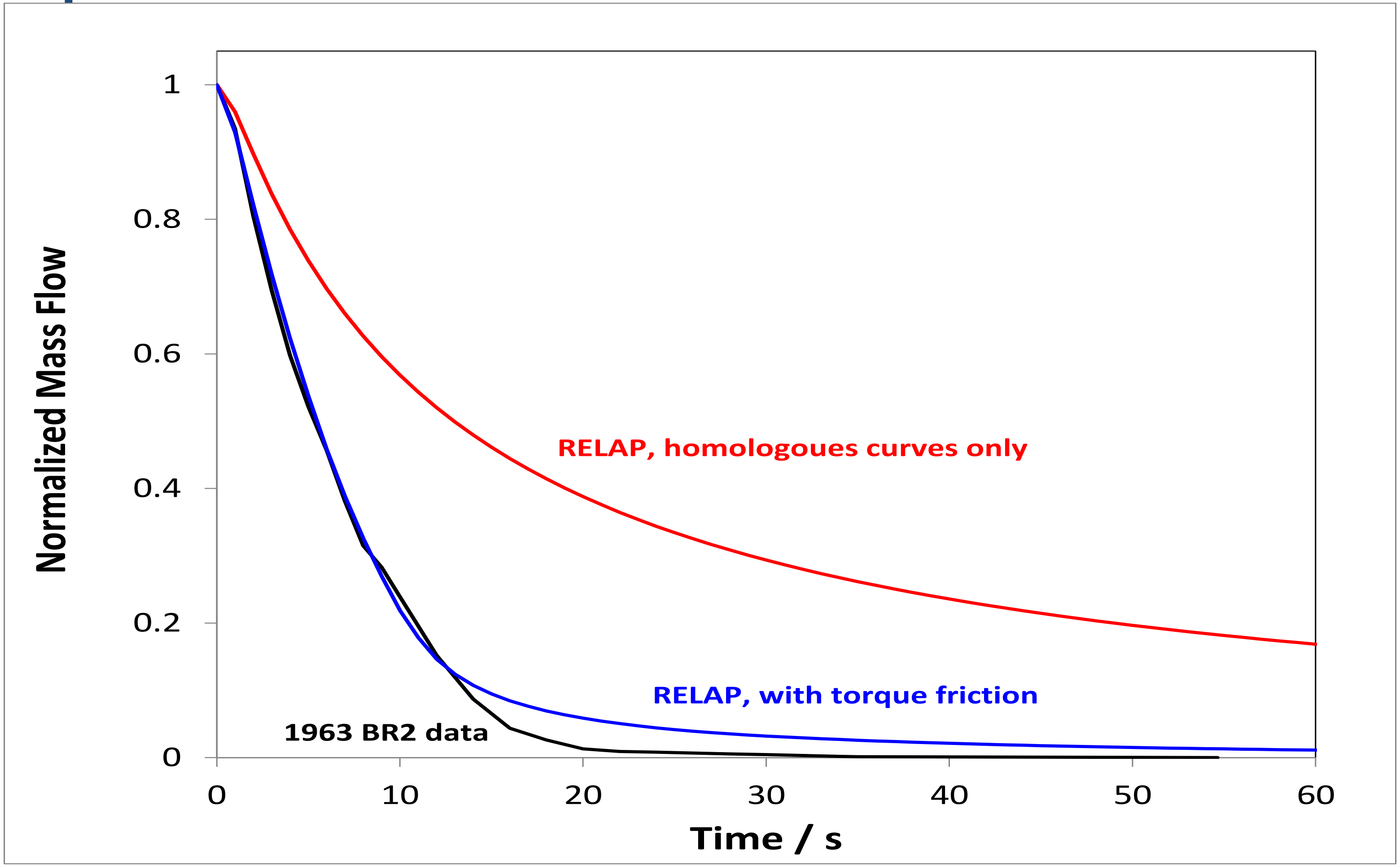






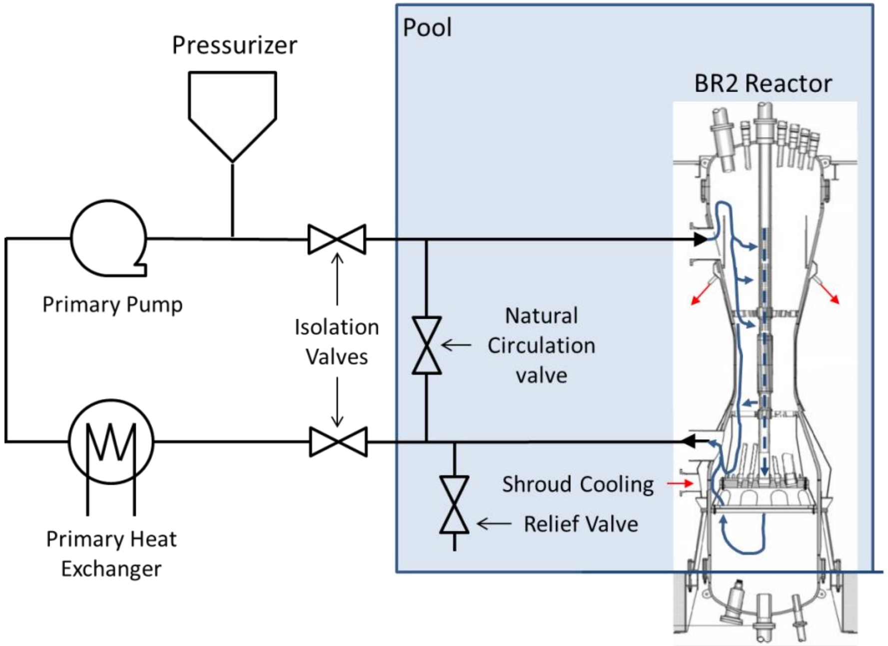
- Empirically calibrated to available data
- Excellent agreement for core ΔP
- Almost excellent agreement for vessel ΔP

Pump Coast Down



- Torque friction adjusted to match measured flow rate.
- Measurement data assumed to be unreliable below 10% of flow.

1963 Loss-of-Flow Experiments / Simulations



Test A (loss-of-flow)

- 400 W/cm^2
- Natural circulation valve **open**

Test C (loss-of-flow)

- 600 W/cm^2
- Natural circulation valve **open**

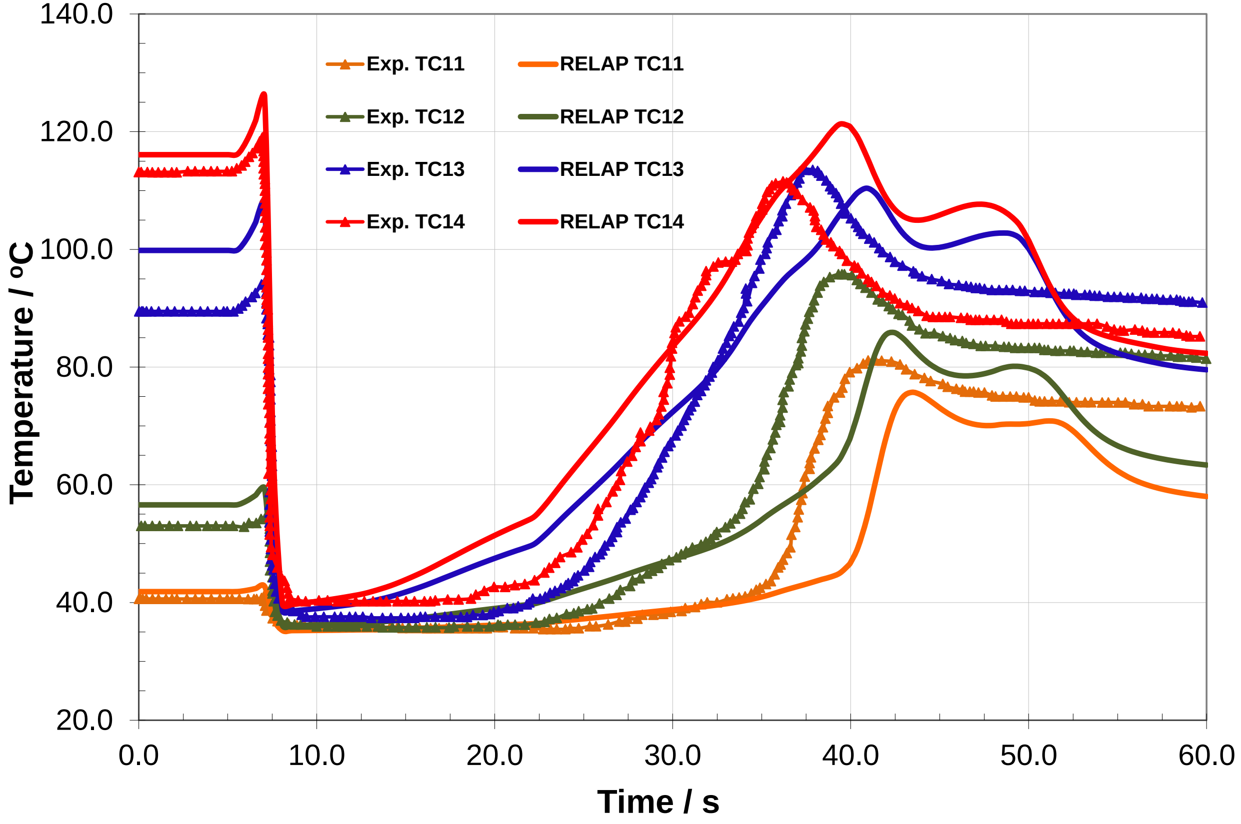
Test F (loss-of-flow, loss-of-pressure)

- 400 kW/cm^2
- Natural circulation valve **open**
- Relief valve **open**

Power Split

Region	Steady State	Transient		
		0.1s	25s	50s
Fuel	0.959	0.824	0.744	0.718
Beryllium	0.026	0.112	0.163	0.180
Other	0.015	0.064	0.093	0.103

Fuel Cladding Temperature (Test A)



- Good agreement at steady state
- Good agreement in magnitude of peak cladding temperature
- Similar agreement for Tests C and F

BR2 Summary

Presentation

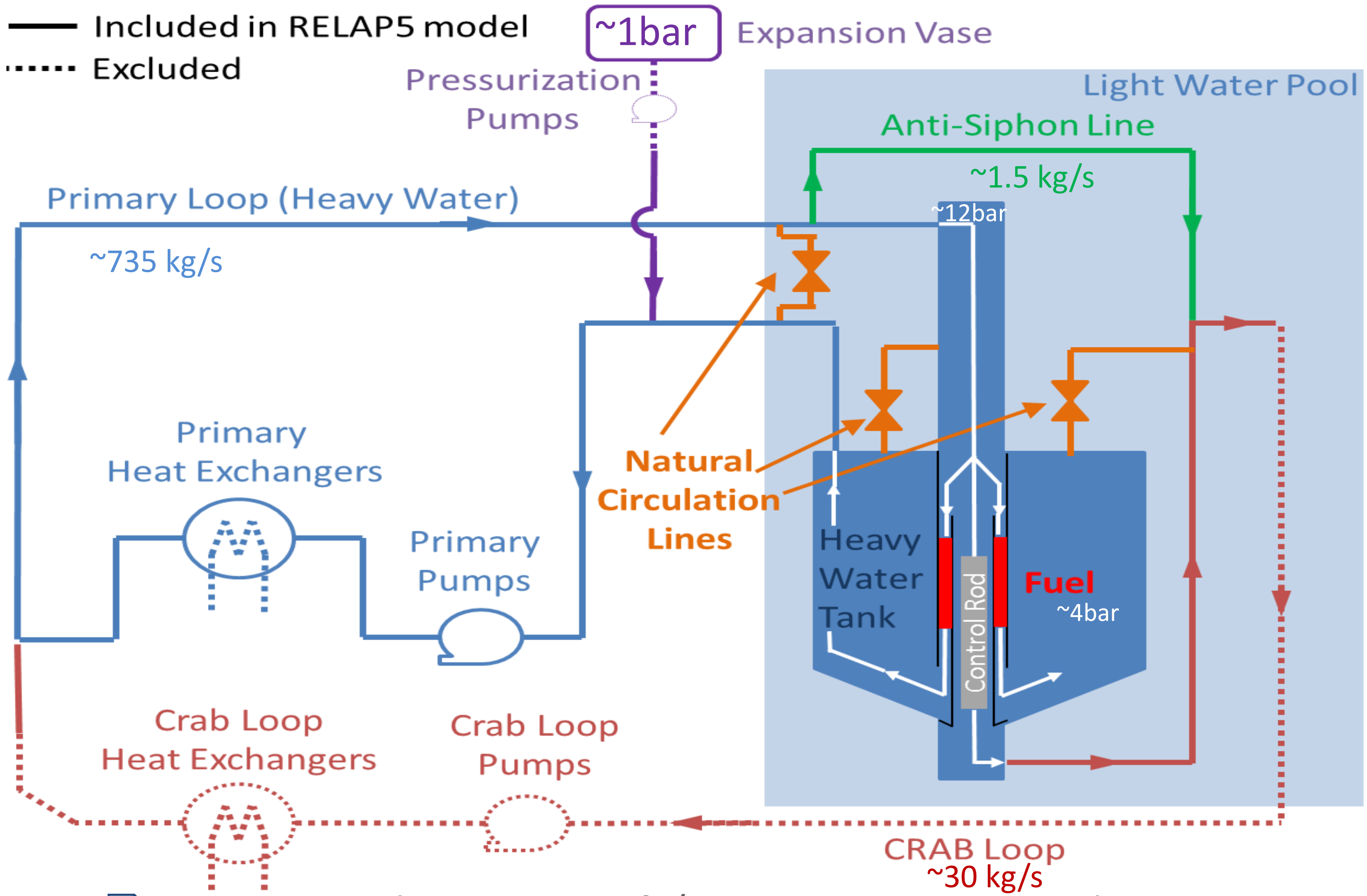
- RELAP5 model developed for BR2 reactor vessel
- Model empirically calibrated to reactor and hydraulic mock -up facility data
- Applied model to 1963 core configuration (15 fuel elements) and successfully reproduced loss of flow and loss of pressure experiments.

Ongoing work

- Extending model to current representative core (31 fuel elements) and repeating accident scenarios with HEU and LEU fuel to simulate conversion impact on safety.

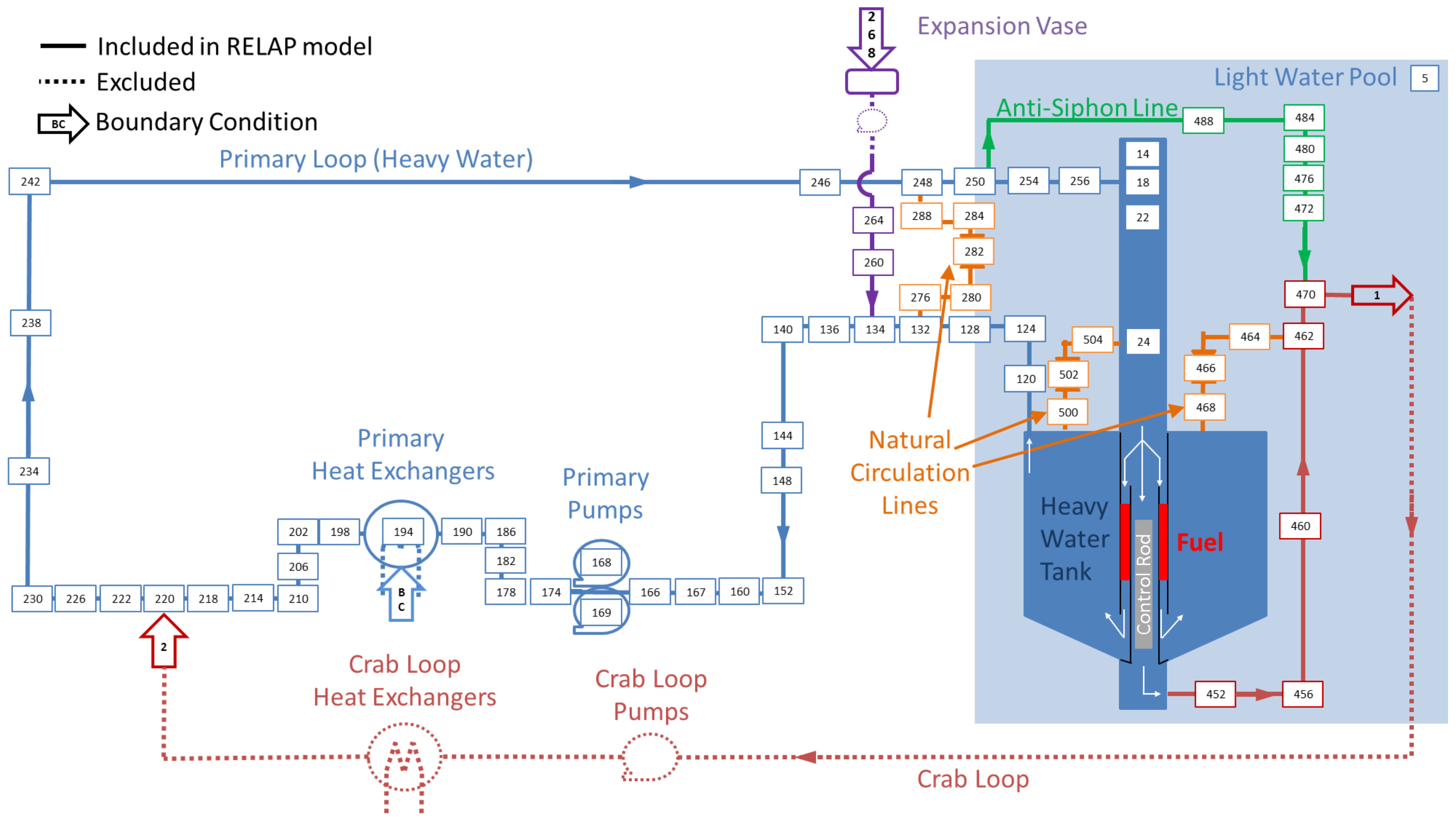
RHF Research Reactor

- 58.3 MW thermal
- Heavy water cooled / moderated

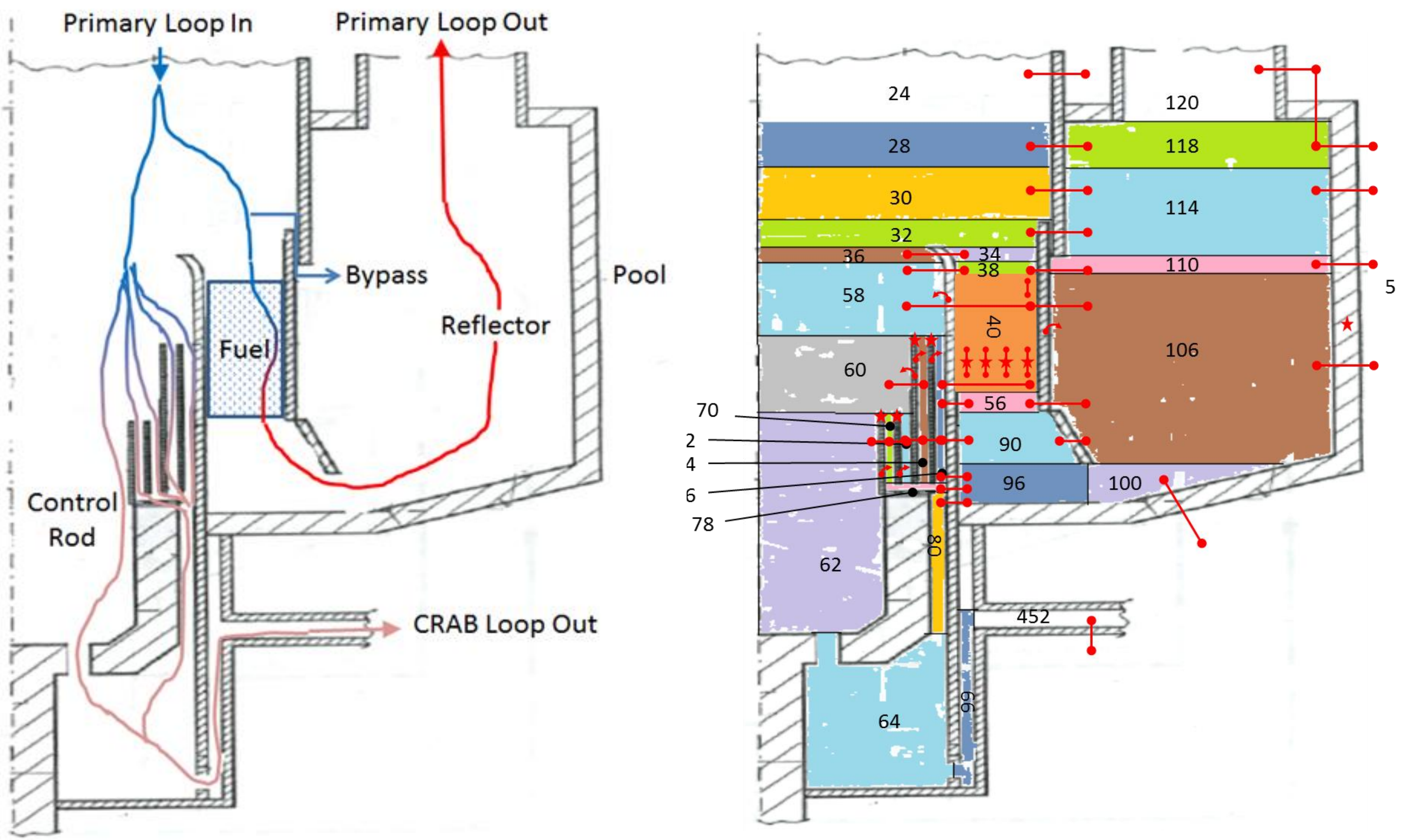


- RELAP5 simulations to verify/support CATHARE simulations

RELAP5 RHF Model



RELAP5 Heavy Water Tank Model

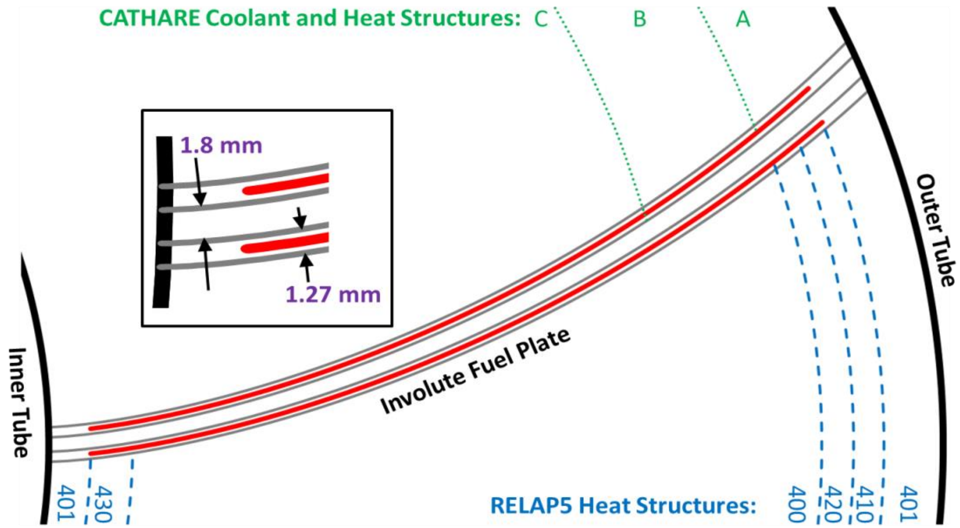


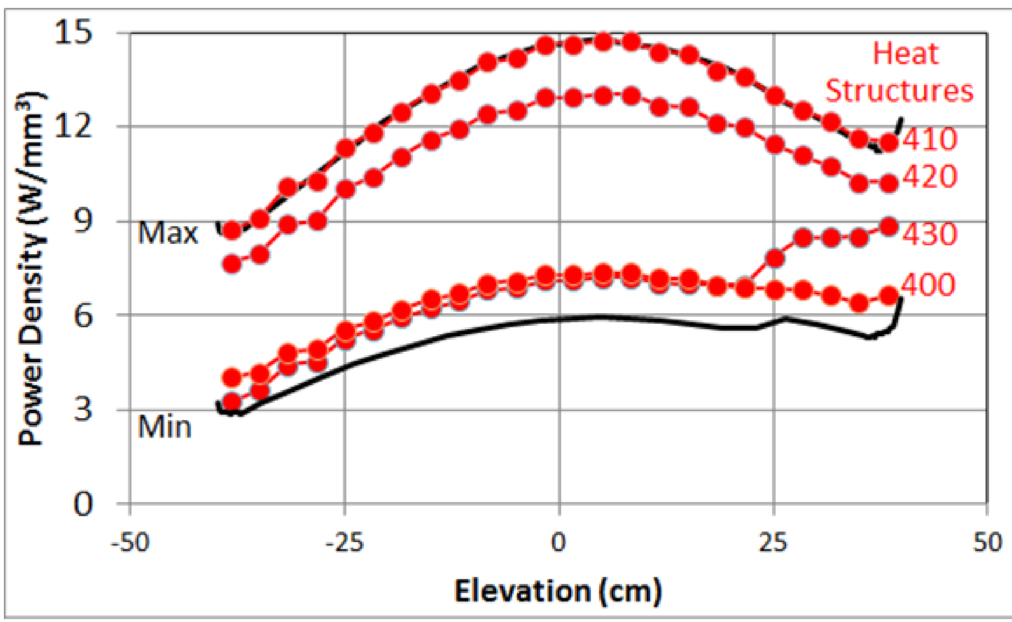
- ❑ Axisymmetric view of heavy water tank

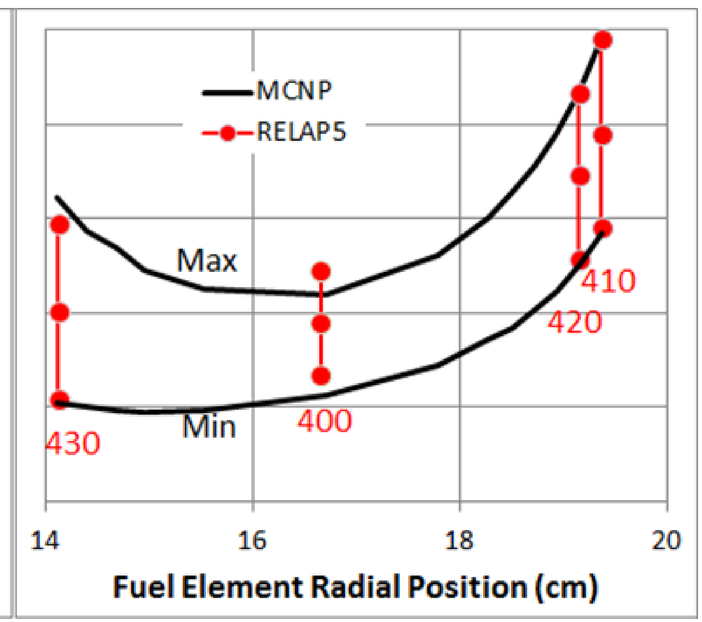
Fuel element

One fuel element: 280 involute plates

- Axial discretization = 26 segments, 24 in heated region
- 5 heat structures
- 1 and 4 coolant volumes

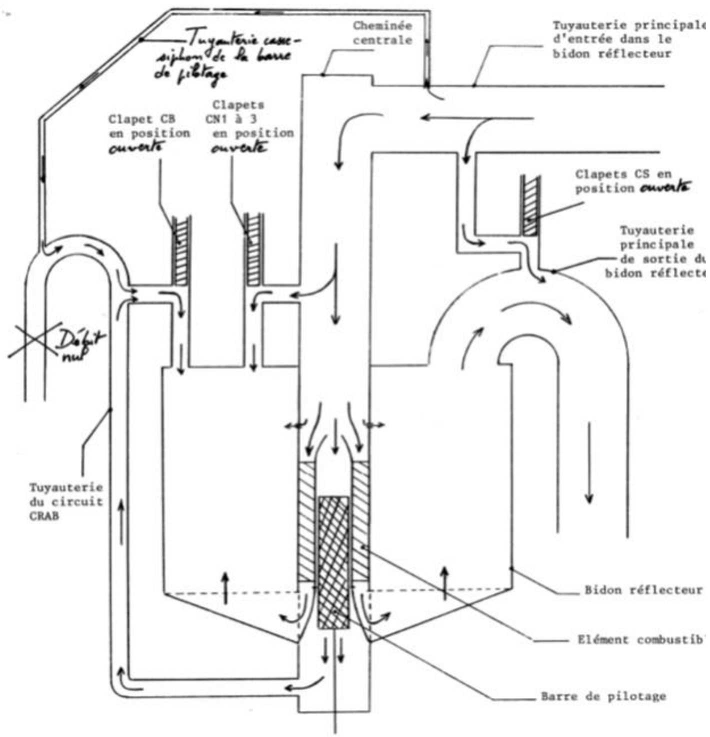


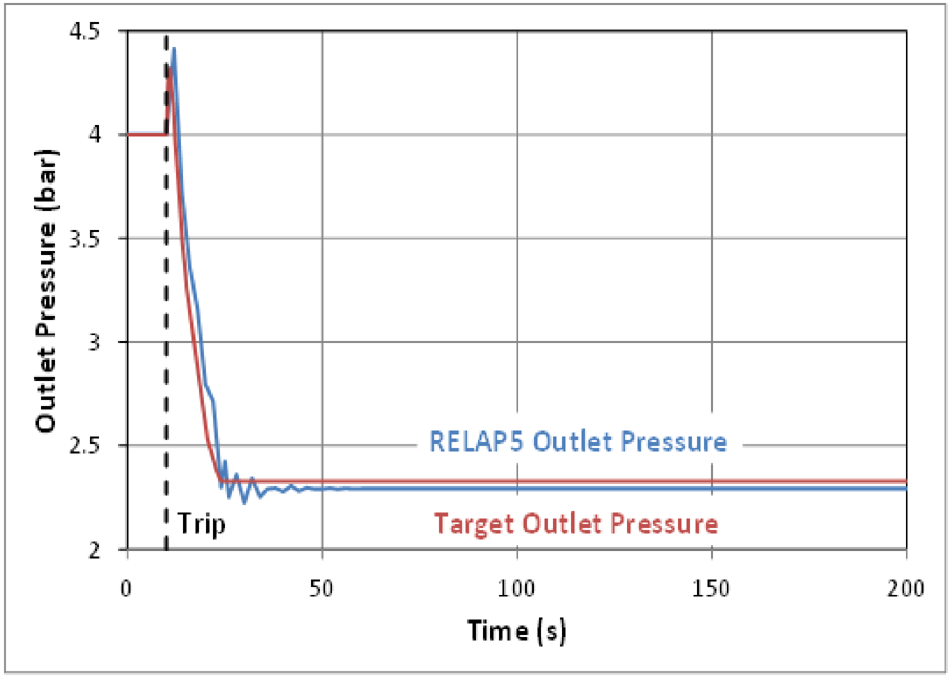




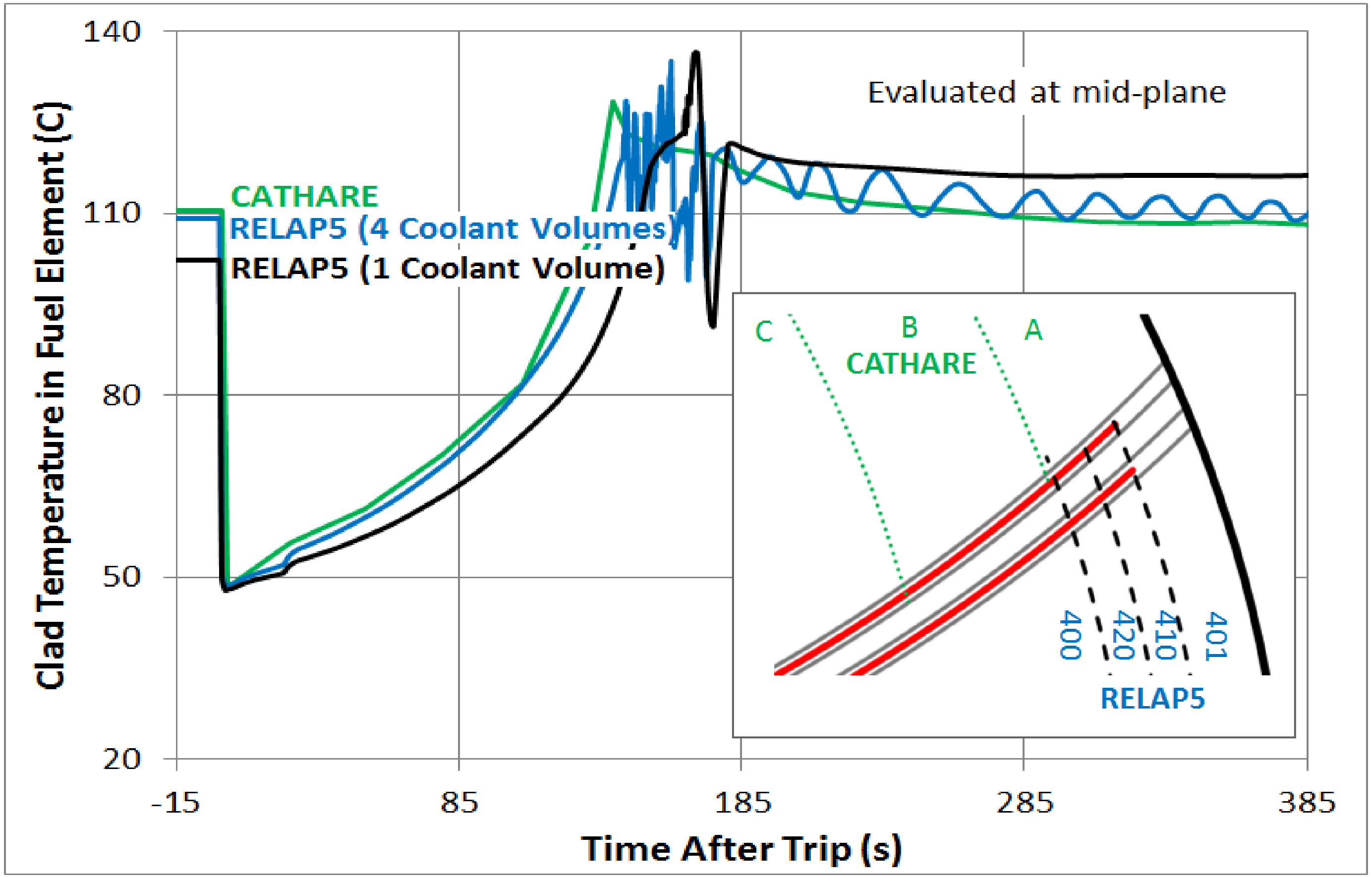
Measured data

- Normal operation flow and pressure distribution. Good agreement.
- Transient primary loop pressure, crab loop flow. These are model inputs.
- Valve timing for unheated loss-of-offsite-power test. ~Calibration
- Pump coast down. ~Calibration
- Comparison to previous CATHARE model simulations





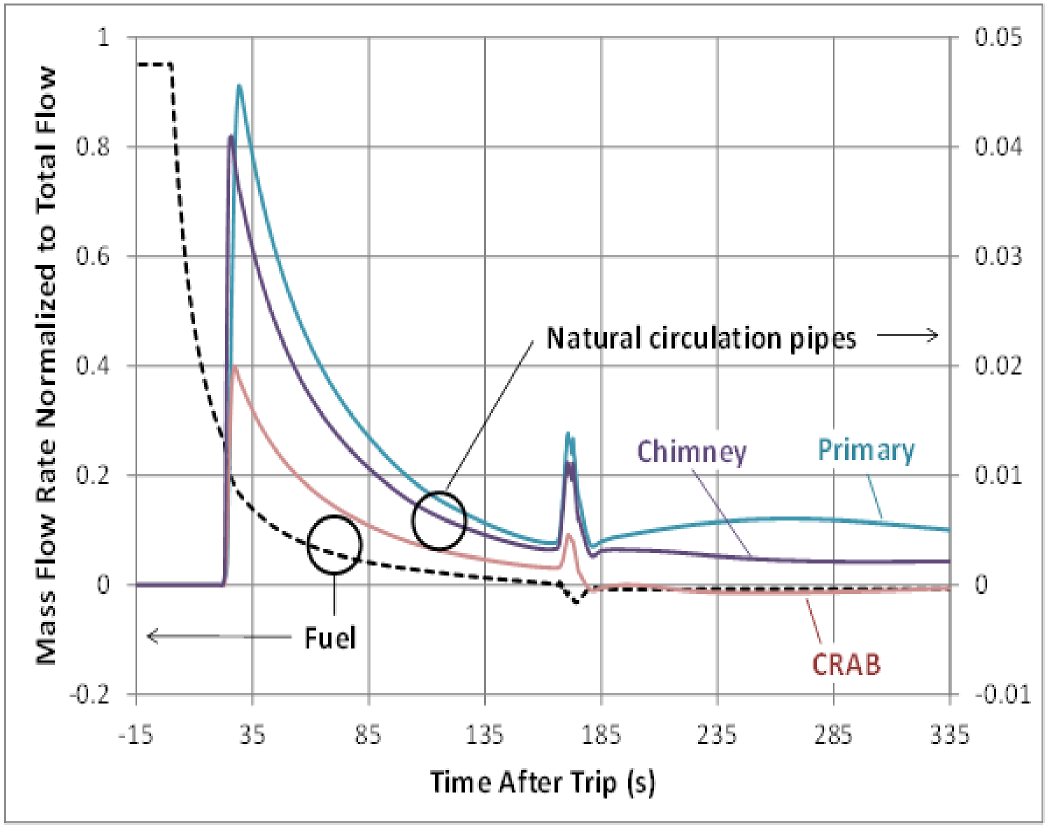
Flow Reversal and Peak Cladding Temperature

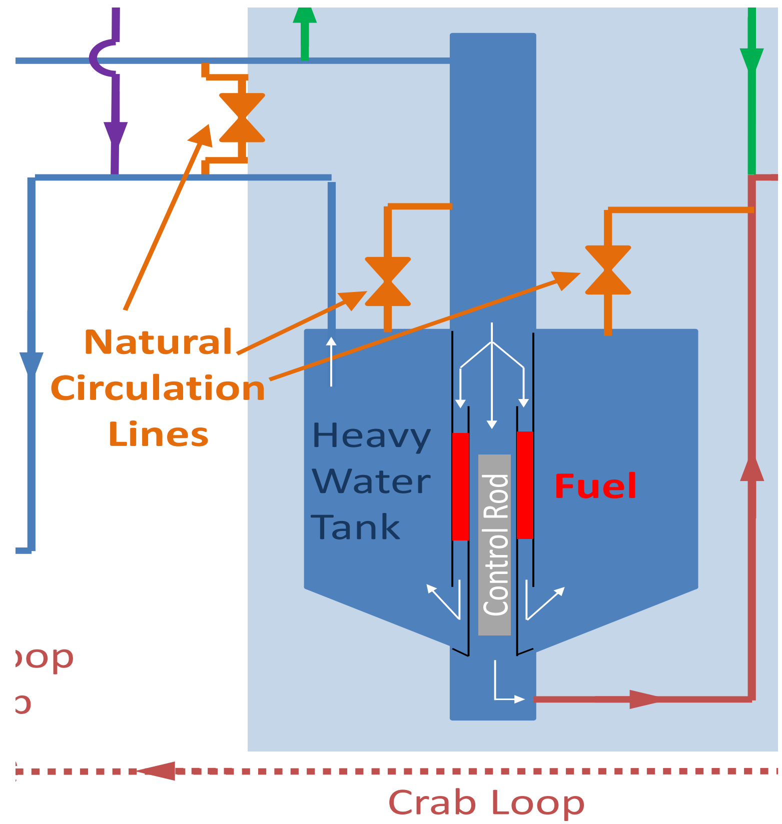


- Good agreement between CATHARE and RELAP5
- Oscillations at peak due to void generated during flow reversal
- Oscillations after peak due to saturated coolant

Preliminary Loss-of-Offsite-Power Simulation

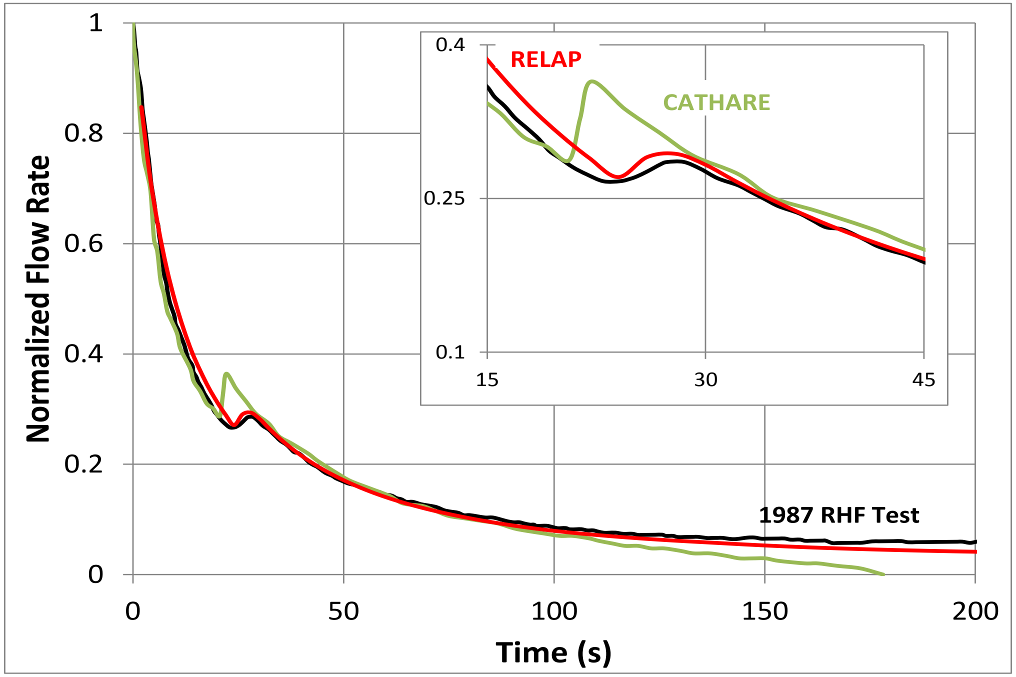
Results for flow distribution in reference HEU core.





Minor Loss Coefficients and Tee's

Location of Natural Circulation Piping	Maximum flow (kg/s)		Long term flow, 800 s (kg/s)	
	CATHARE	RELAP5	CATHARE	RELAP5
Primary Piping	60	35	4.34	2.7
Chimney	80	32	2.9	1.8
CRAB	15	15	-1	~0



Natural Circulation Flow

- RELAP5 < CATHARE Model
- CATHARE model doesn't include k_{loss} for Tee's
- k_{loss} for Tee's significant contribution to simulation differences.

RHF Summary

Presentation

- Description of RELAP5 model
- Results for preliminary loss-of-offsite-power simulation with HEU fuel
- Similar results (not shown) for both HEU and LEU core
- Natural circulation flow dependent on minor loss coefficients at tee junctions

Ongoing work

- Working towards a finalized model...
- Identifying key simulations to perform
- End result is to support/confirm CATHARE code simulations.

Thank You

Questions?