



UW-Madison WRCCS

MELCOR Analysis of a Scaled NGNP Reactor Cavity Cooling System Experiment

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September 17, 2015

Outline



DEPARTMENT OF
Engineering Physics
UNIVERSITY OF WISCONSIN-MADISON

① Motivation

② Experiment

③ Modeling

- Tank Nodalization

- Heat Loss Considerations

- Interphase friction

④ Conclusion



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2 Experiment

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4 Conclusion



Reactor Cavity Cooling System (RCCS)

- Ultimate heat sink for reactor decay heat
- Most designed for passive cooling
- Two popular fluids: air and water

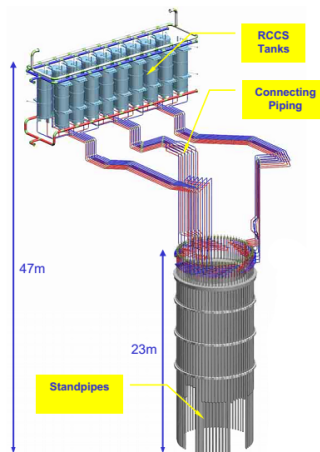
Table: List of RCCS designs from *Experimental Studies of NGNP Reactor Cavity Cooling System With Water* [[pdf](#)].

Reactor	Coolant	Mode	Country	Power [MW]
HTTR	Water	Forced	Japan	30
HTR-10	Water	Natural	China	10
PBMR	Water	Natural	South Africa	265
GT-MHR	Air	Natural	Russia	600
MHTGR	Air	Natural	USA	450



PBMR RCCS

Figure: From “PBMR Auxiliary Systems” [pdf], part of *Summary of Public Meeting with PBMR (PTY) LTD* [nrc.gov].



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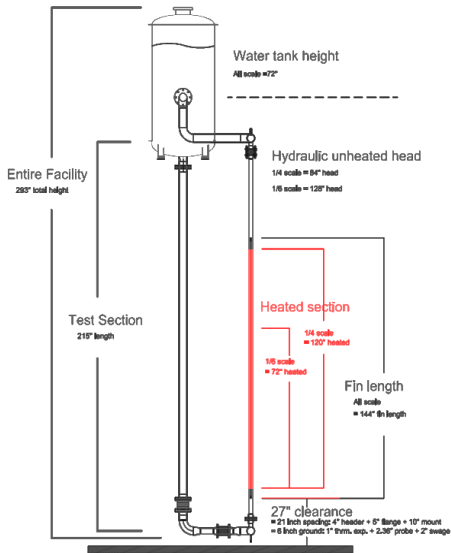
WRCCS Purpose



- Characterize both single and two-phase behavior of a scaled-version of the Reactor Cavity Cooling System (RCCS) with water coolant operating via natural circulation.



WRCCS Facility





WRCCS Features

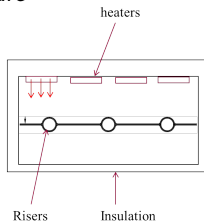
- ~ 330 gallon tank, rated for 2 atm
- Heater Array
 - maximum ~ 40 kW radiant power
 - 34 heaters, 17×2 array
- Instrumentation
 - Flow meter (total system flow rate)
 - Numerous thermocouples
 - Differential and absolute pressure





WRCCS Features

- ~330 gallon tank, rated for 2 atm
- Heater Array
 - maximum ~40 kW radiant power
 - 34 heaters, 17×2 array (old)
 - 36 heaters, 9×4 array (new)
- Instrumentation
 - Flow meter (total system flow rate)
 - Numerous thermocouples
 - Differential and absolute pressure
 - Void mesh sensors (new)

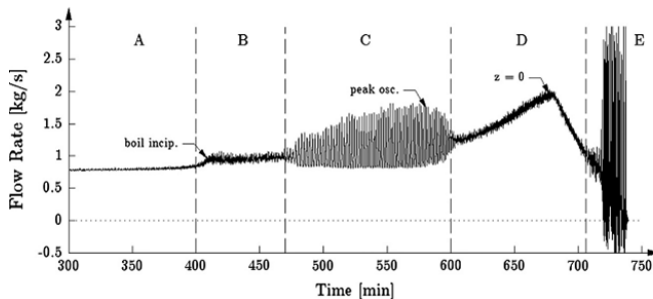




Boiling Features

- A. Single-phase heat-up
- B. Boiling incipience
- C. Boiling oscillations
- D. Continuous circulations
- E. Geysering

Figure: Source: “Influences of boil-off on the behavior of a two-phase natural circulation loop”, 2014., *Int. J. of Multiphase Flow*, 60, 135-148.

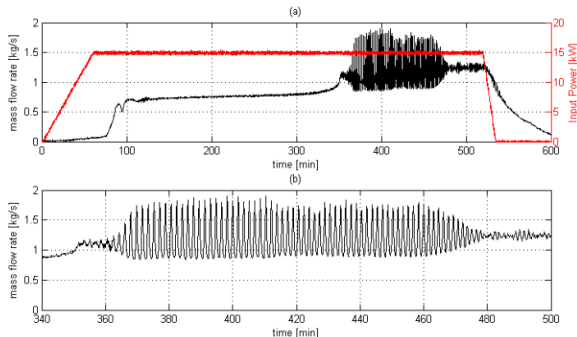




Benchmark Test

- Chose the most mature test for benchmark modeling.
- Parameters
 - Initial tank fill: 60%
 - Power profile: Uniform
 - No active cooling

Figure: Energy balance and mass flow rate of benchmark





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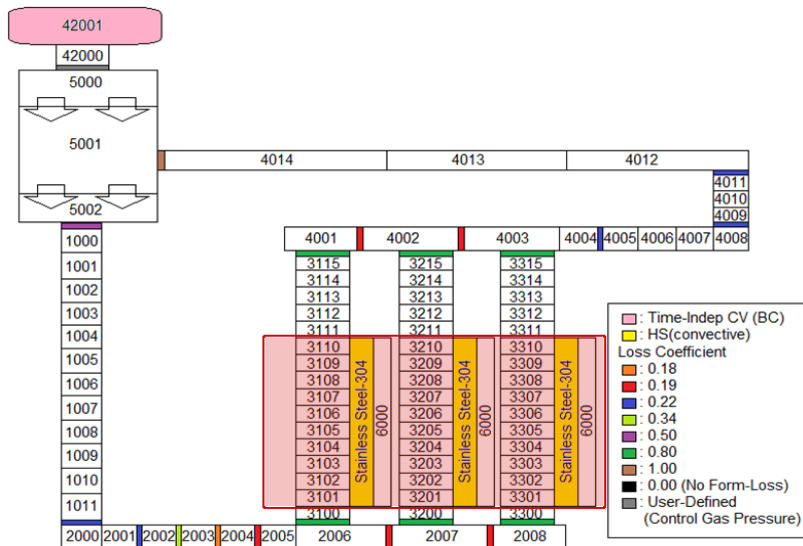


Development

- Started from simple adiabatic design
- Investigated several other variations:
 - Tank Nodalization
 - Heat losses
 - Reduced power
 - Heater box losses and air infiltration
 - Heat box and network piping losses
 - Interphase friction



Base Nodalization: Network

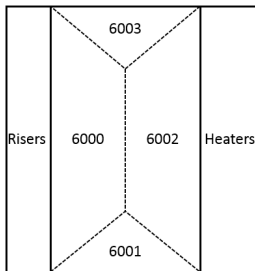


Not to-scale

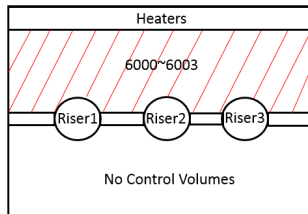


Base Nodalization: Heater Box

3110	Stainless Steel-304	6000	3210	Stainless Steel-304	6000	3310	Stainless Steel-304	6000
3109			3209			3309		
3108			3208			3308		
3107			3207			3307		
3106			3206			3306		
3105			3205			3305		
3104			3204			3304		
3103			3203			3303		
3102			3202			3302		
3101			3201			3301		



Side View



Top View

Not to-scale



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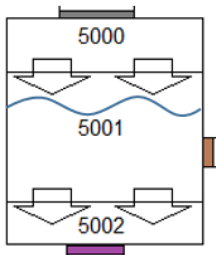
Heat Loss Considerations

Interphase friction

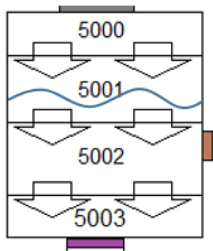
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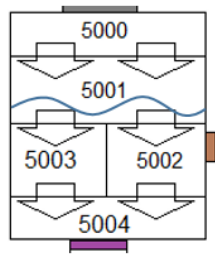
Variations



(a)



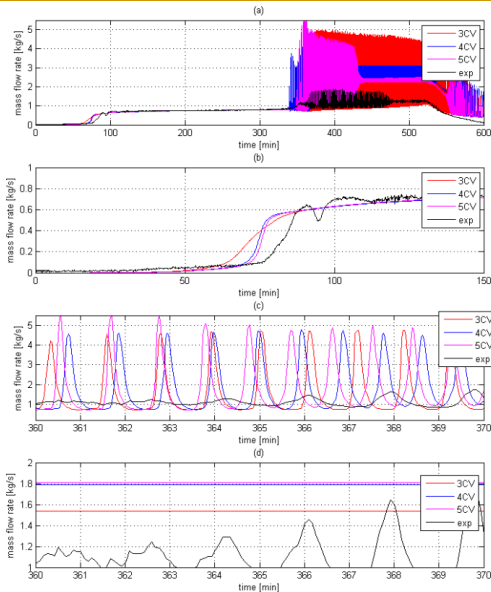
(b)



(c)



Comparison





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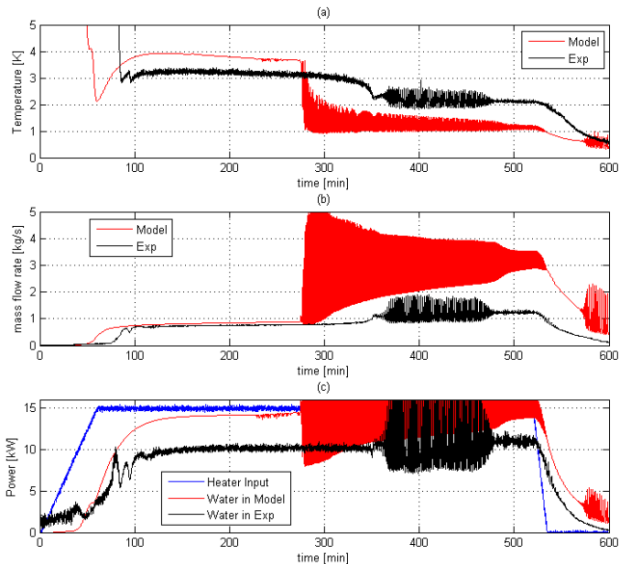
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Adiabatic



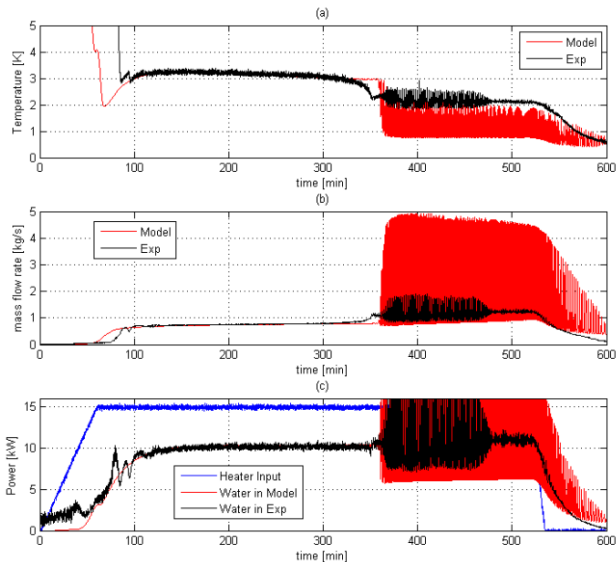


Energy losses

- Experiment is not adiabatic: ~ 4.5 kW lost in test section
- Two different paths were considered
 - Reduced power: artificially lower heater power
 - Heater box loss: add convective losses and air infiltration to heater box

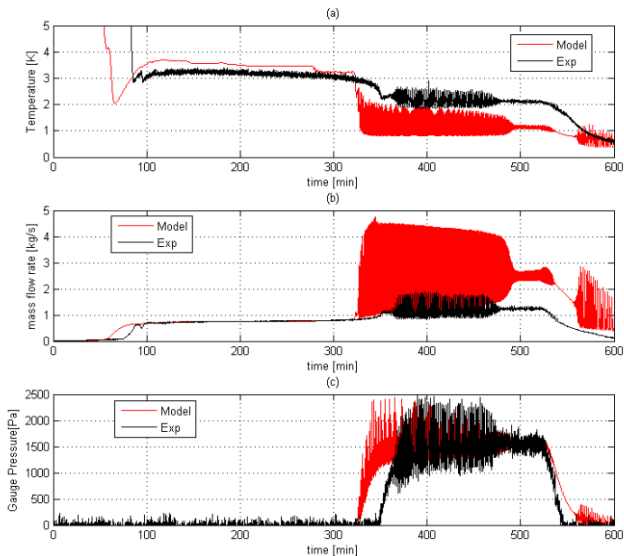


Reduced Power (B)



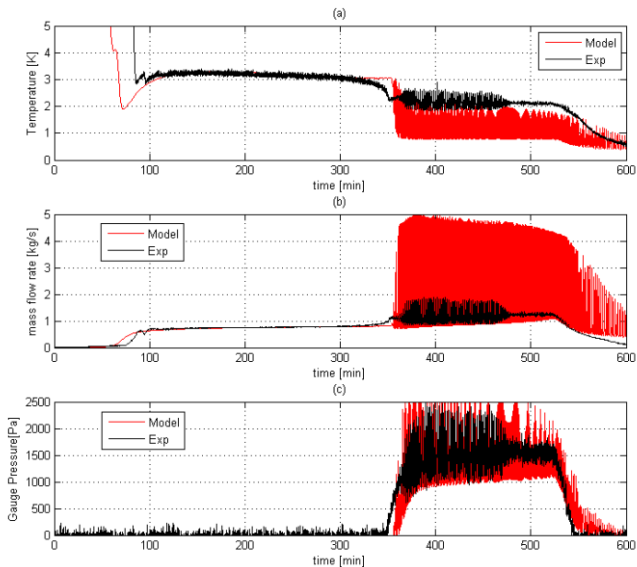


Heater Box Loss (C)





Reduced Power/Convective Losses (D)



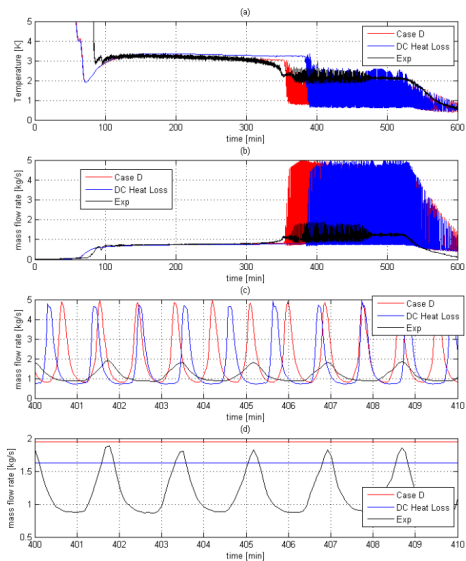


Piping Loss Comparison

- Additional network piping losses quantified: ~ 2 kW
- Doesn't affect temperature rise
- Does affect period and average mass flow rate



Piping Loss Comparison





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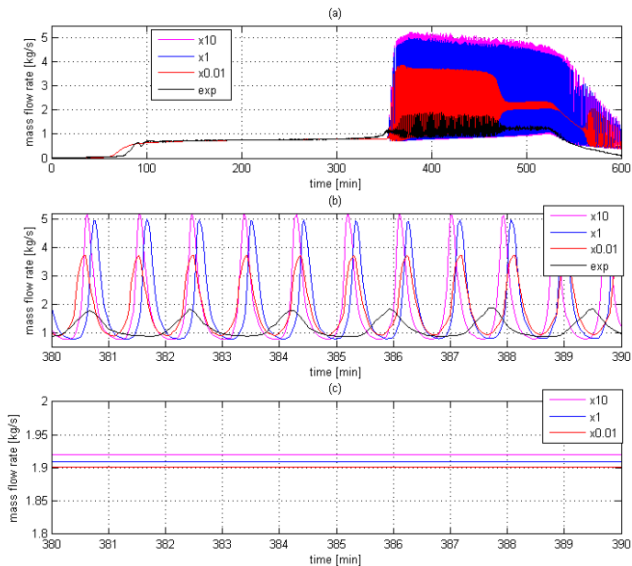


Interphase friction

MELCOR's interphase friction term was considered to account for period discrepancy.



Interphase friction



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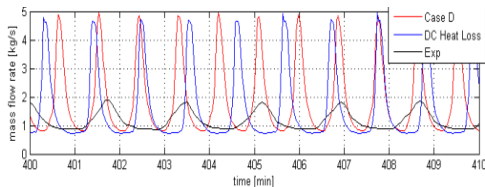
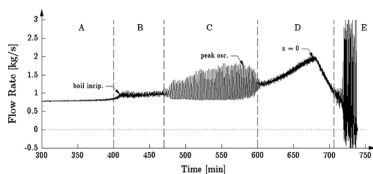
- Interphase friction

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Conclusions

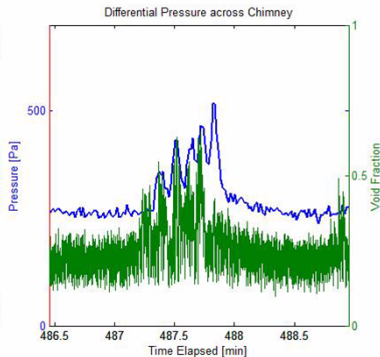
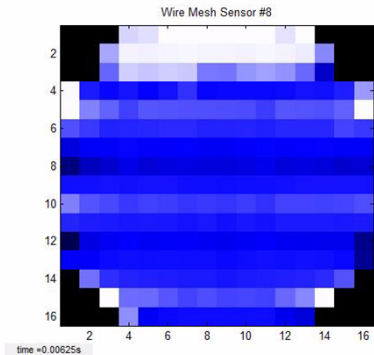
- MELCOR is able to qualitatively model the Heat-Up and Boiling Oscillation regimes
- Period/Amplitude discrepancies still exist
 - Experiment/Model peak-to-trough amplitude [kg/s]: 1 / 4
 - Experiment/Model peak-to-peak period [min]: 1.7 / 1
- Discrepancy may imply some two-phase dissipation terms is missing





Current and Future Work

- Installed Void Mesh Sensors in boiling region of experiment
- Use data to infer relationships among system variables (e.g., pressure losses, voiding, and mass flow rate).





Questions