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UW–Madison WRCCS

MELCOR Analysis of a Scaled NGNP Reactor Cavity Cooling System Experiment

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MELCOR Cooperative Assessment Program (MCAP)

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Outline

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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

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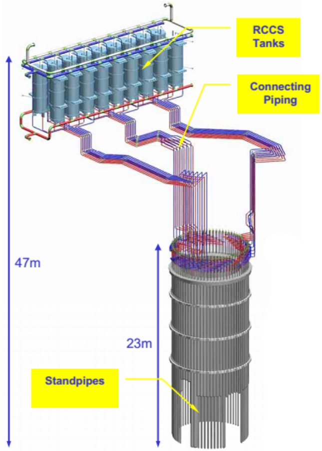
Figure: From "PBMR Auxiliary Systems" [pdf], part of *Summary of Public Meeting with PBMR (PTY) LTD* [nrc.gov].



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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

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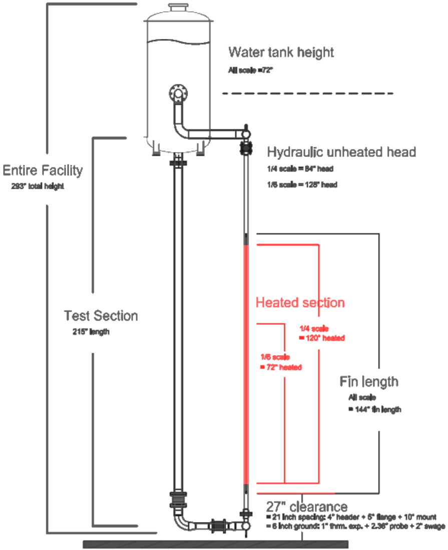

WRCCS Features

- ∼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

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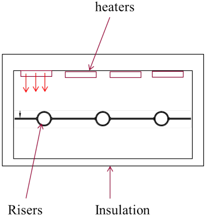
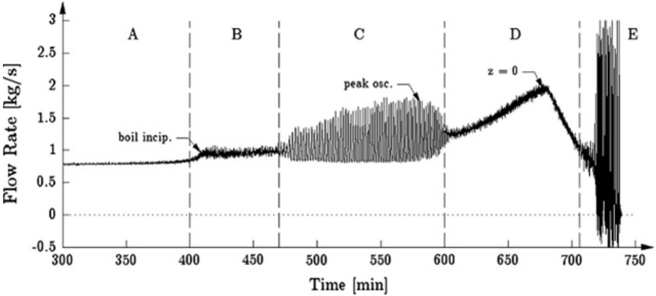
- ∼330 gallon tank, rated for 2 atm
- Heater Array
  - maximum ∼40 kW radiant power
  - 34 heaters, 17×2 array (old)
  - 36 heaters, 9×4 array (new)
- Instrumentation
  - Flow meter (total system flow rate)
  - Numerous thermocouples
  - Differential and absolute pressure
  - Void mesh sensors (new)



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

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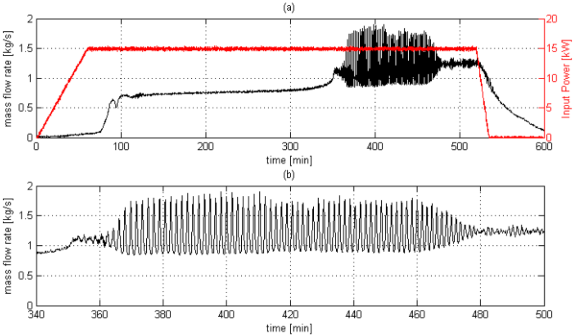
- Chose the most mature test for benchmark modeling.
- Parameters
  - Initial tank fill: 60%
  - Power profile: Uniform
  - No active cooling

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

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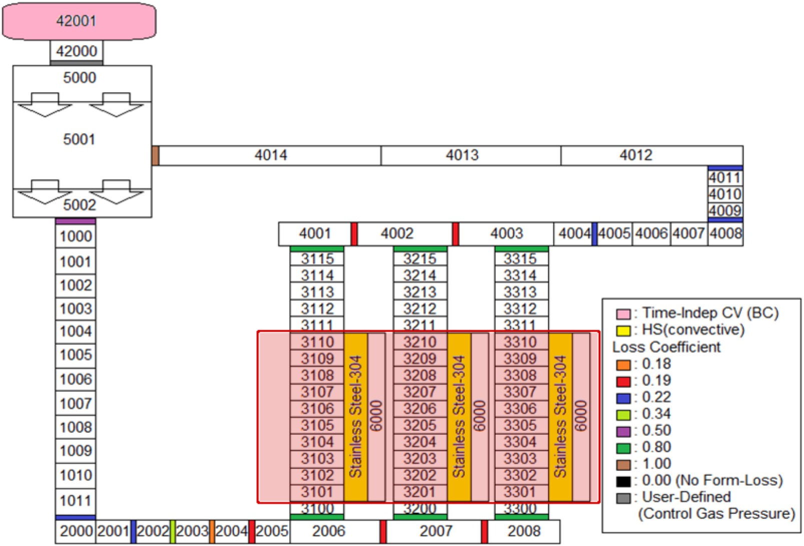

Not to-scale

Base Nodalization: Heater Box

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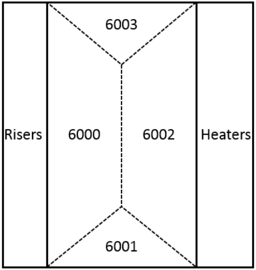
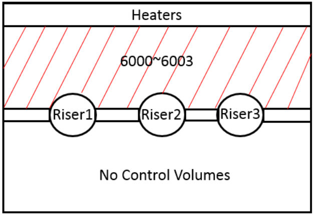
$\Downarrow$



Side View

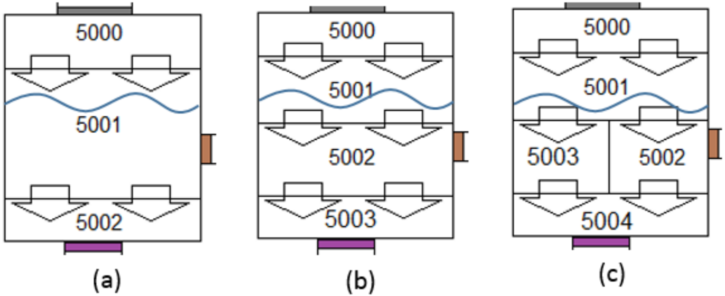


Top View

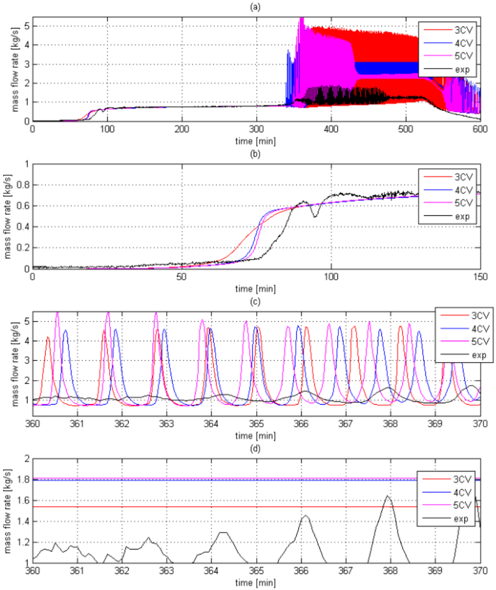
Not to-scale

Outline

Variations


5000
5001
5002
(a)
5000
5001
5002
5003
(b)
5000
5001
5003
5002
5004
(c)

Comparison


(a)
mass flow rate [kg/s]
time [min]
3CV
4CV
5CV
exp
(b)
mass flow rate [kg/s]
time [min]
3CV
4CV
5CV
exp
(c)
mass flow rate [kg/s]
time [min]
3CV
4CV
5CV
exp
(d)
mass flow rate [kg/s]
time [min]
3CV
4CV
5CV
exp

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Adiabatic

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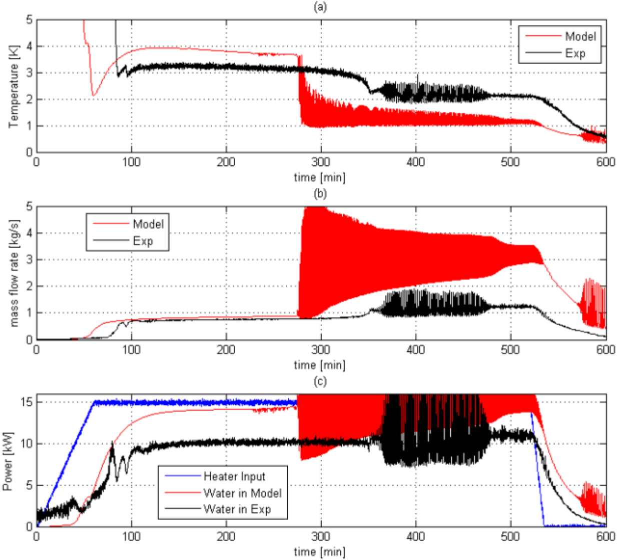

Energy losses

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- 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)

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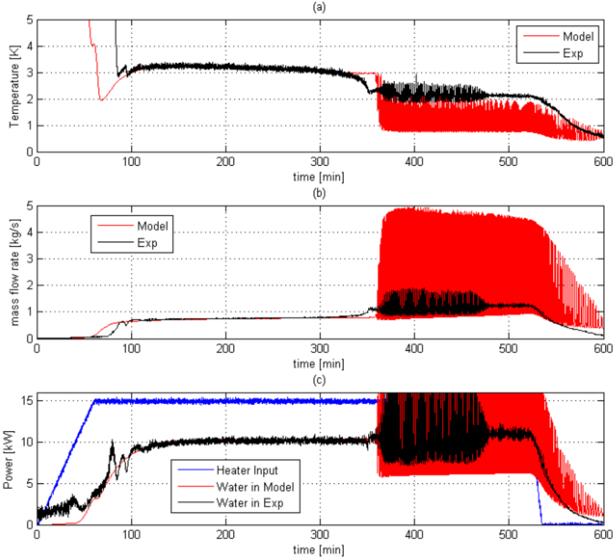
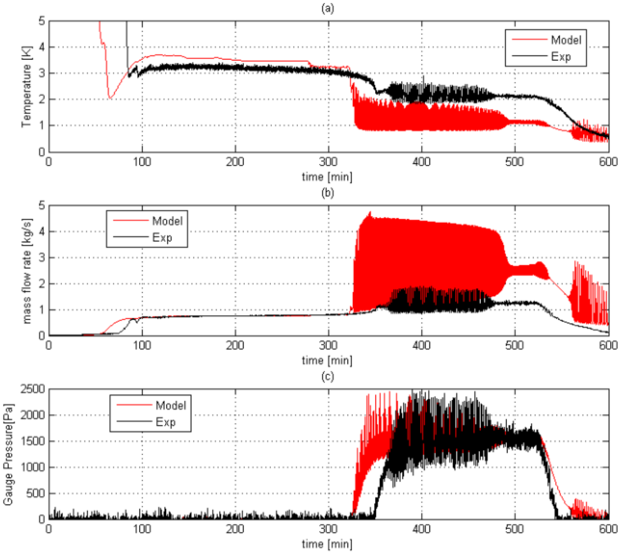


Heater Box Loss (C)



Reduced Power/Convective Losses (D)

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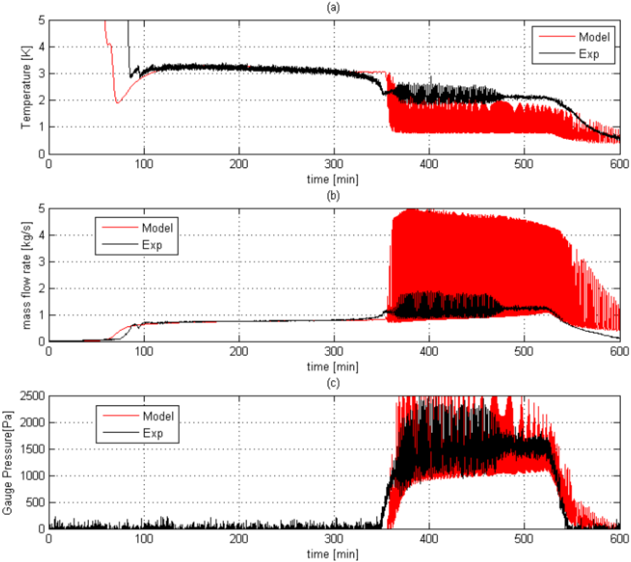

Piping Loss Comparison

- 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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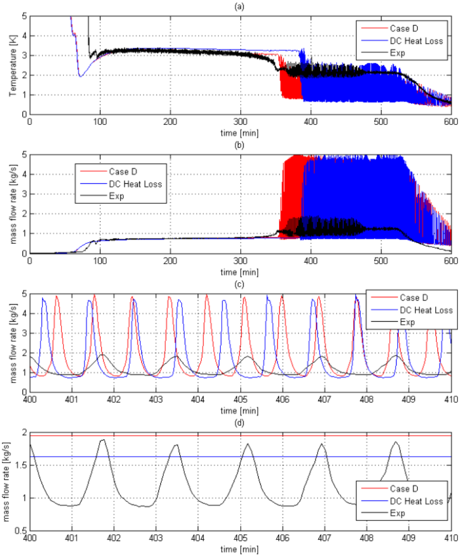

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Interphase friction

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

Interphase friction

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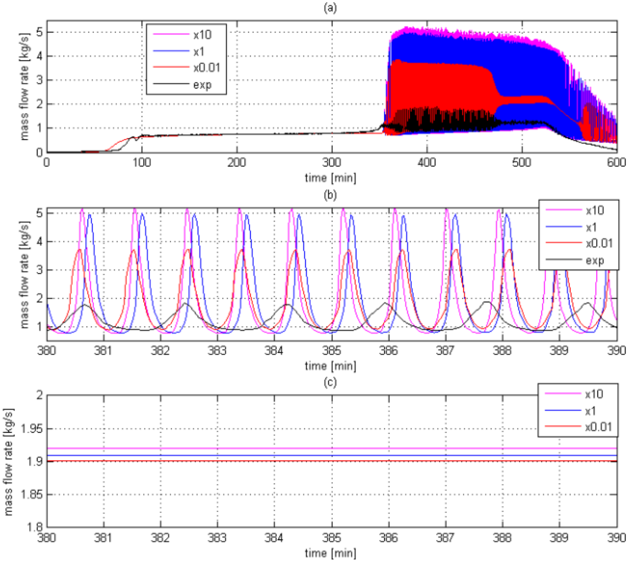

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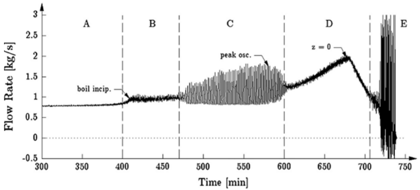
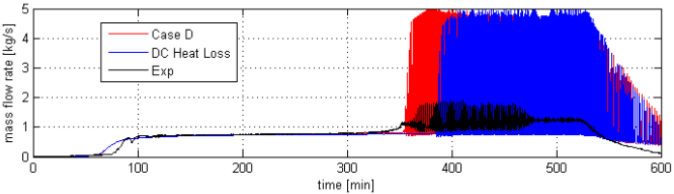
Conclusions

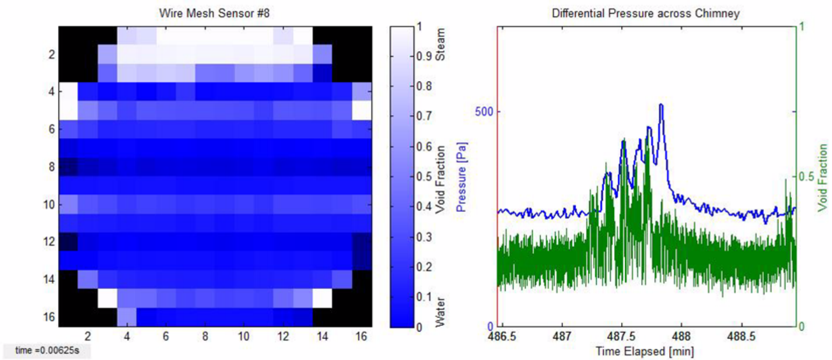
- MELCOR is able to qualitatively model the Heat-Up and Boiling Oscillation regimes
- Period/Amplitude discrepancy may imply some two-phase dissipation terms are missing





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