



Thermal-Hydraulic Response of a Prototypic BWR Spent Fuel Assembly under Naturally Convective Conditions

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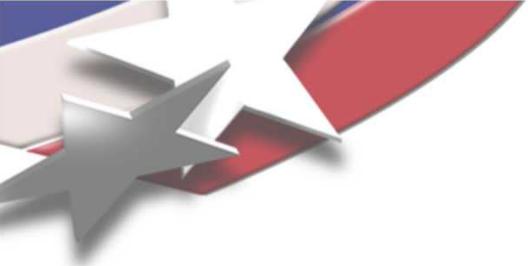
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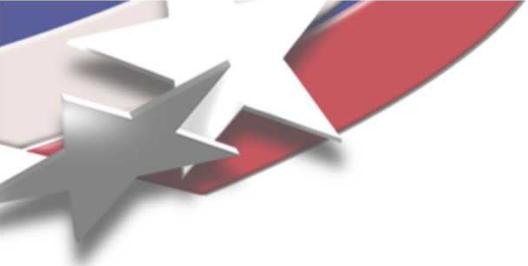
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Outline

- **Objective**
- **Experimental Approach**
- **Hardware**
- **Experiments**
- **Data and MELCOR calculations**
- **Summary**



Objectives

- Validate MELCOR's ability to predict thermal-hydraulic response of a heated assembly
 - **Prototypic GE 9x9 BWR Hardware**
 - Full length, prototypic GE 9x9 BWR components
 - Fuel simulated by electric heater rods with Incoloy cladding
 - **Assembly cooled by natural convection**
 - Measure air flow rate into assembly
 - Quantify heat-up rates and temperatures throughout



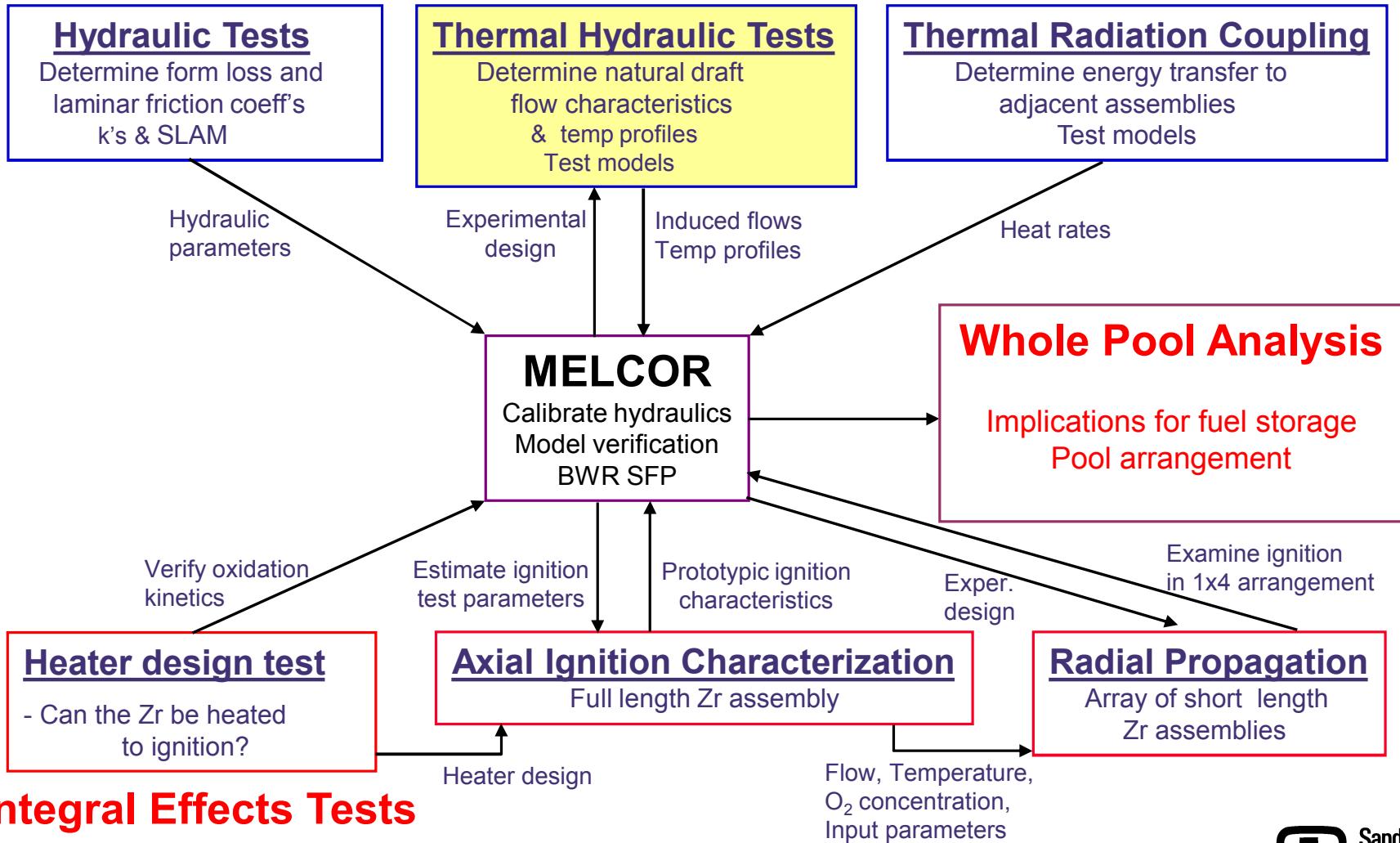
Context of Phased Experimental Approach

COMPLETE

- Heater Design Tests
 - Test electrical heater design & performance
 - Preliminary data on “zirc fire” onset
- Separate Effects Tests (no “zirc fire”)
 - Hydraulics
 - Single, full length, prototypic 9x9 BWR assembly (Stainless steel rods)
 - Forced flow, form and friction loss measurements
 - Thermal Hydraulics
 - Single, full length, prototypic 9x9 BWR assembly (Incoloy heater rods)
 - Induced natural draft flow measurements
 - Thermal Radiation Coupling
 - Multiple, partial length, 9x9 BWR assembly sections (Incoloy heater rods)
- Integral Effects Tests (with “zirc fire”)
 - Axial
 - Single, full length, prototypic 9x9 BWR assembly
 - Temp profiles, induced flow, axial O₂ profile, nature of fire
 - Radial
 - Multiple, partial length, 9x9 BWR assemblies
 - Set inlet flow, temperature and O₂ content
 - Determine nature of radial fire propagation

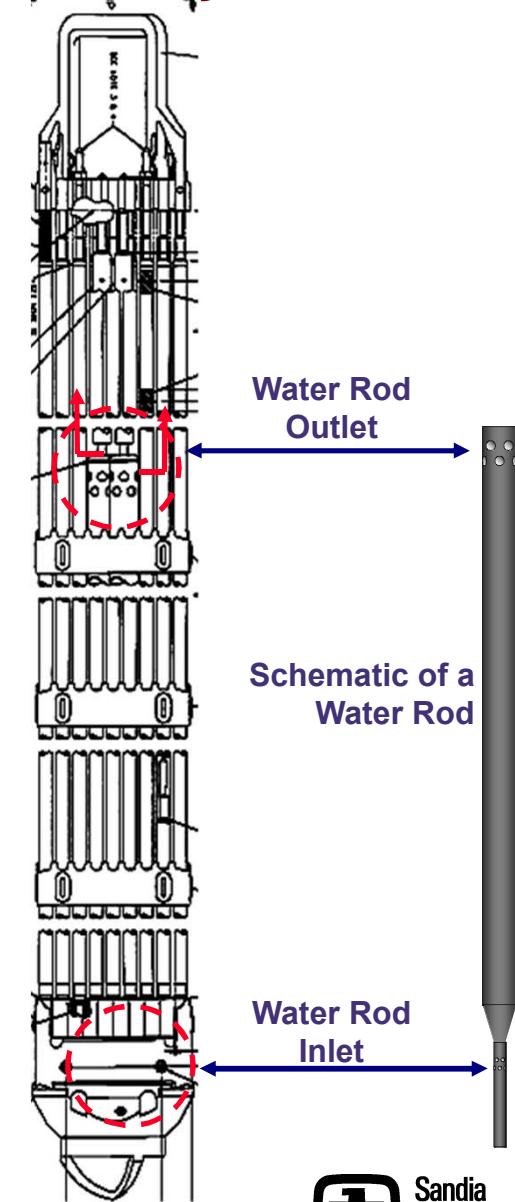
Experimental Program Design

Separate Effects Tests



GE 9x9 BWR Assembly

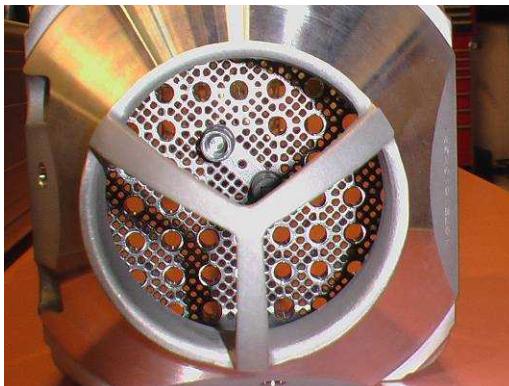
- 74 fuel rods, 8 of these are partial length
 - Partial length rods end 2/3 the length up assembly
 - Results: Step change in hydraulic diameter and power profile
- 7 spacers
- 2 water rods
 - Inlet and outlet holes allow air flow
 - Orifice plug restricts flow
 - Still allows additional cooling
- Outer Zr canister



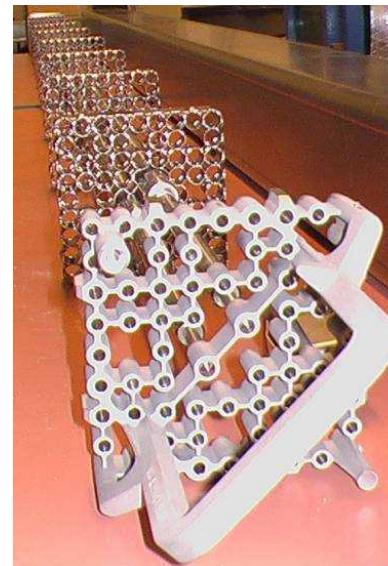


Actual Hardware

- **Prototypic GE 9x9 BWR Hardware**
 - **Full length, prototypic GE 9x9 BWR components**
 - **Electric heater rods with Incoloy cladding**



Nose piece & debris catcher



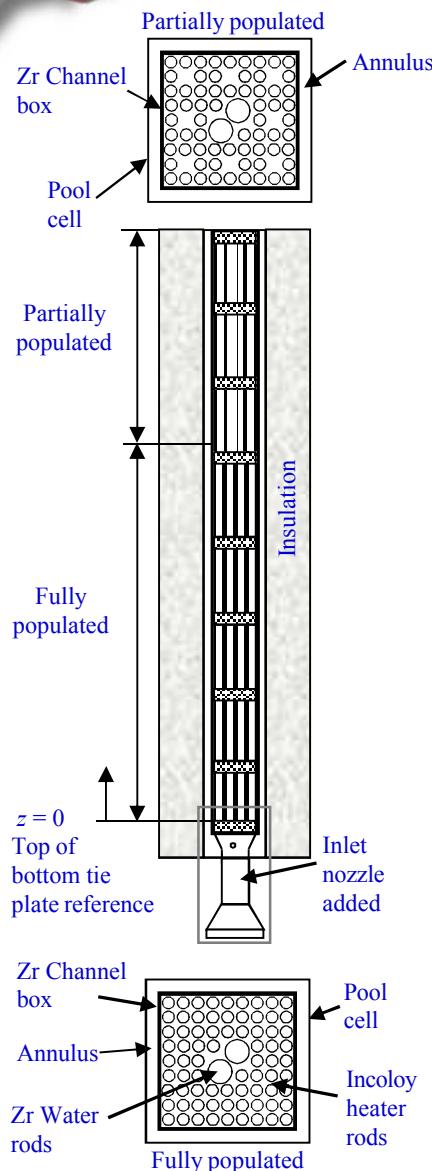
Upper tie plate



BWR channel, water rods & spacers

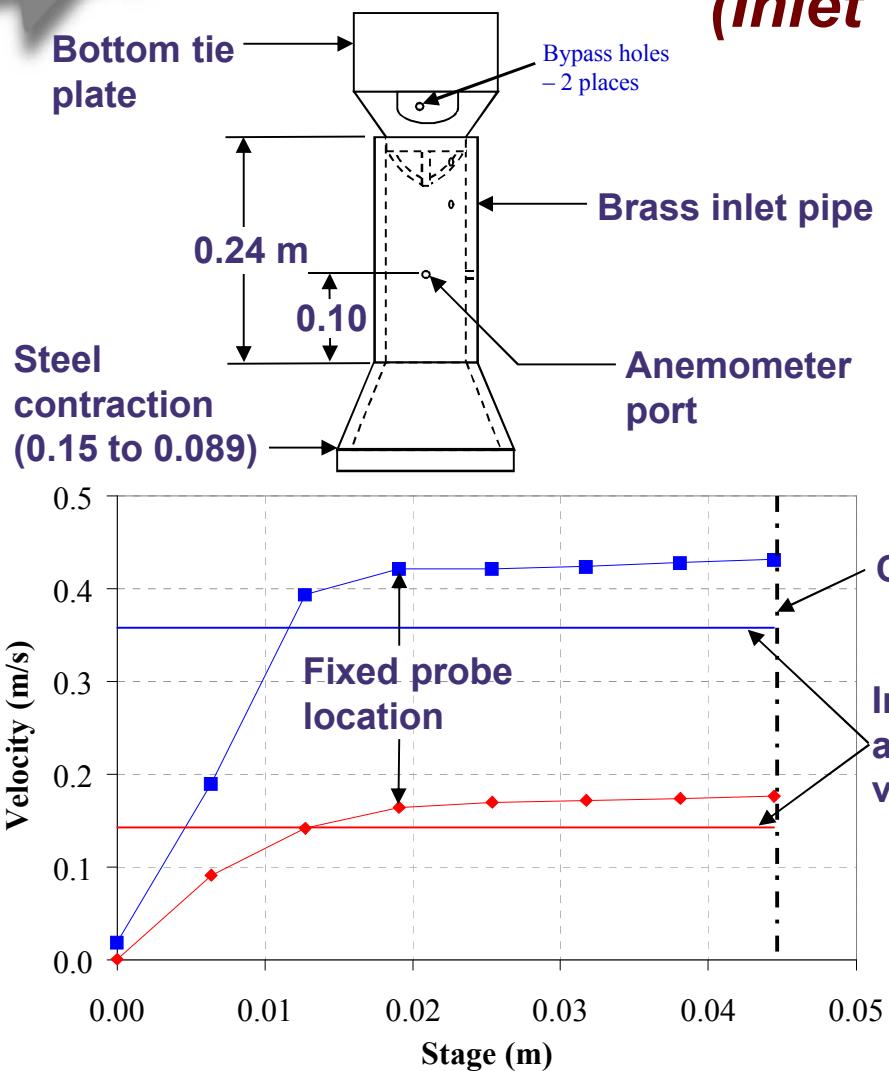
Separate Effects Tests

(Thermal-Hydraulic)



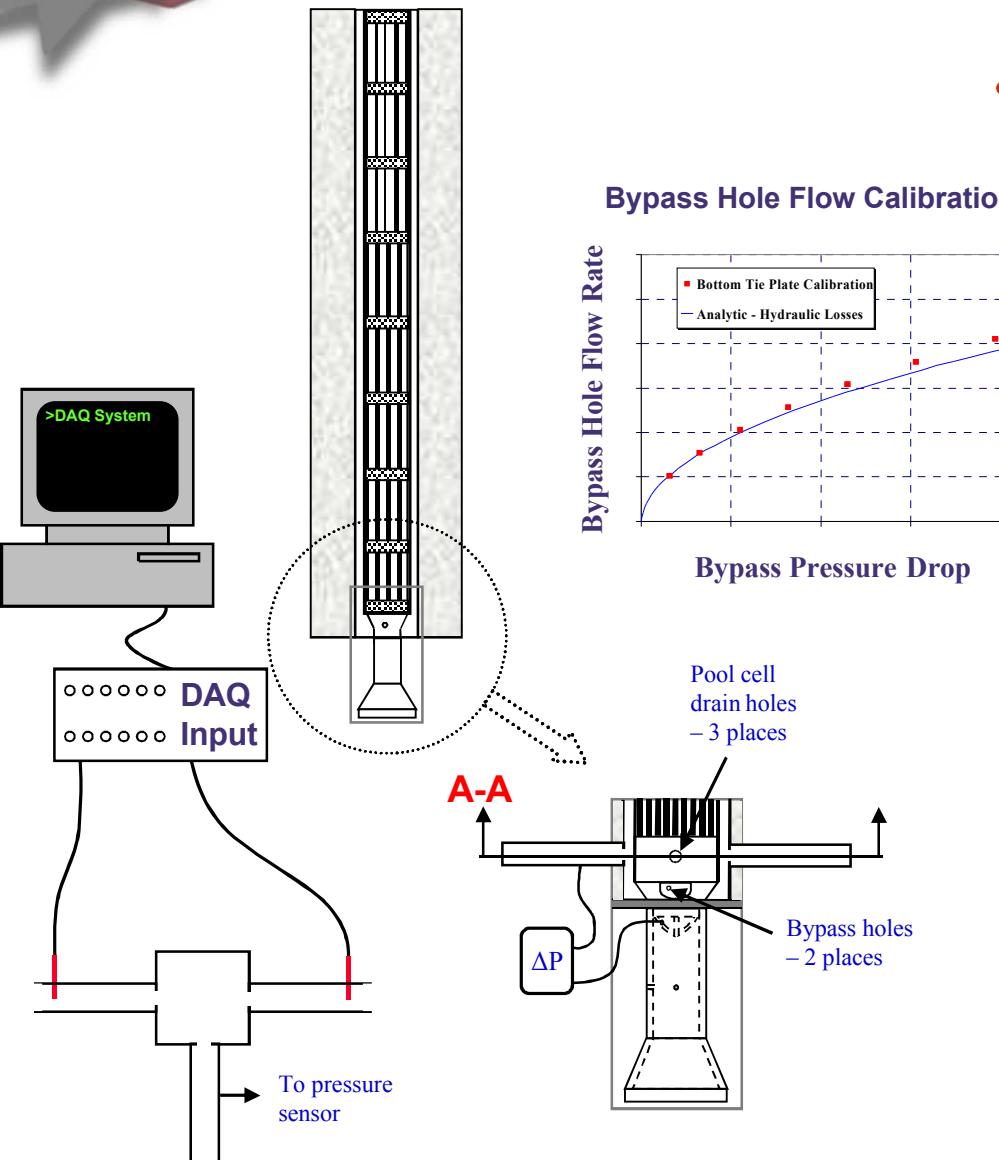
- Single, full length, prototypic Incoloy assembly
 - Inside single prototypic pool rack cell
 - Annular flow characterized
 - Incoloy heater rods
 - 0.430" diameter (0.438" in stainless assembly)
 - Thermocouple instrumented
 - Allows heating to temps around 900 K
 - Avoid Zr component oxidation
 - Repeat some forced flow pressure drop measurements
 - Excellent agreement with unheated stainless assembly
 - When small difference in rod diameter considered
 - Measure naturally induced flow
 - Bundle and annulus
 - Function of assembly power (steady state exit temp)
 - Thermal and hydraulic response highly coupled
 - Delicate balance makes predictions difficult
- Use to set inlet flow & temp in partial length tests

Full-Length Incoloy Assembly (Inlet Velocity Profiles)



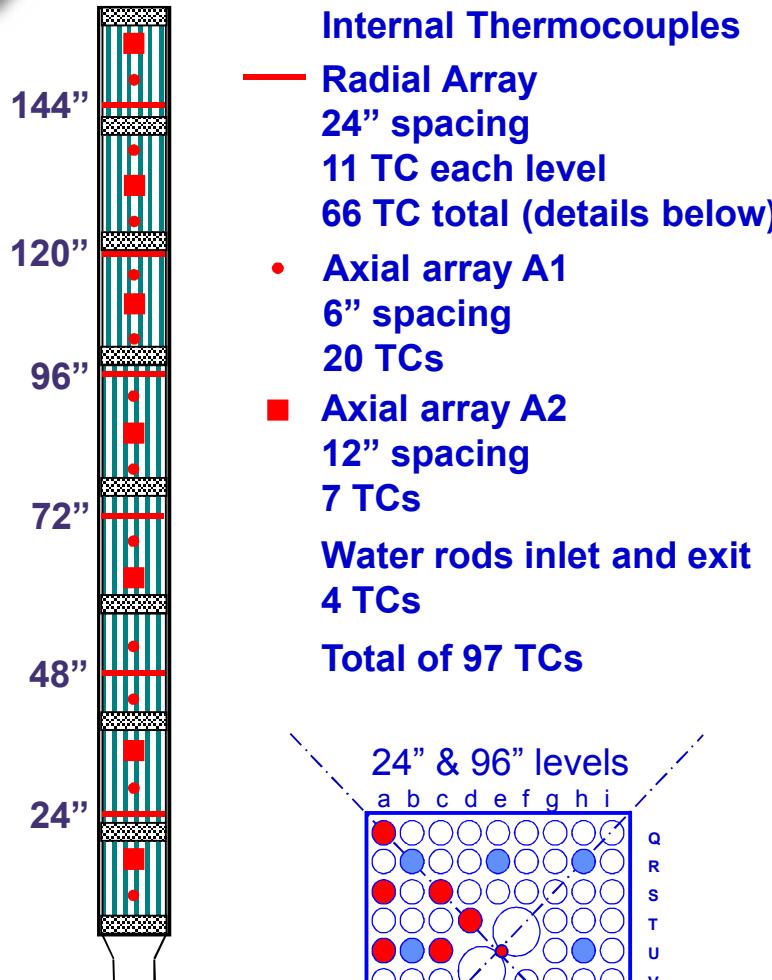
- Forced flow calibration for hot wire anemometry (No heating)
 - Flow rate prescribed by mass flow controllers
 - Measurements show good agreement, typically within 7%
- Hot wire probe fixed in location shown for natural draft experiments

Annulus Flow Measurements

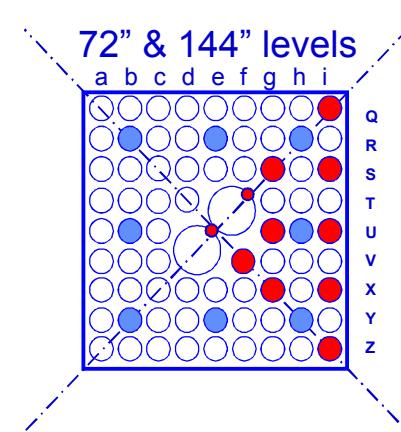
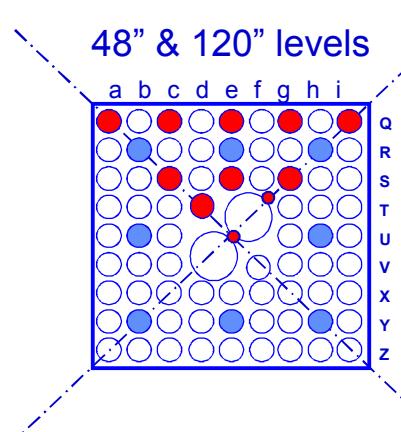
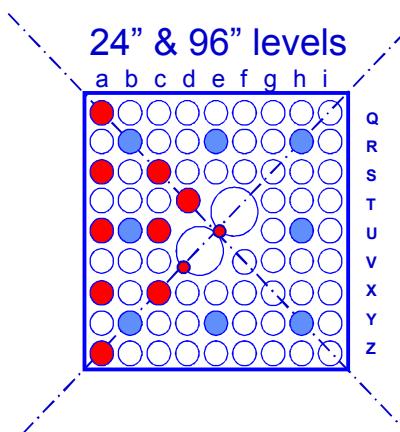


- Annulus flow sources
 - Two bypass holes in tie plate
 - Differential pressure across bypass holes
 - Calibration at Primary Standards Lab
 - Compares well with analytic analysis
 - Open or closed
 - Two pool cell drain holes
 - Hot wire anemometry
 - Fixed position like Inlet
 - Open or closed

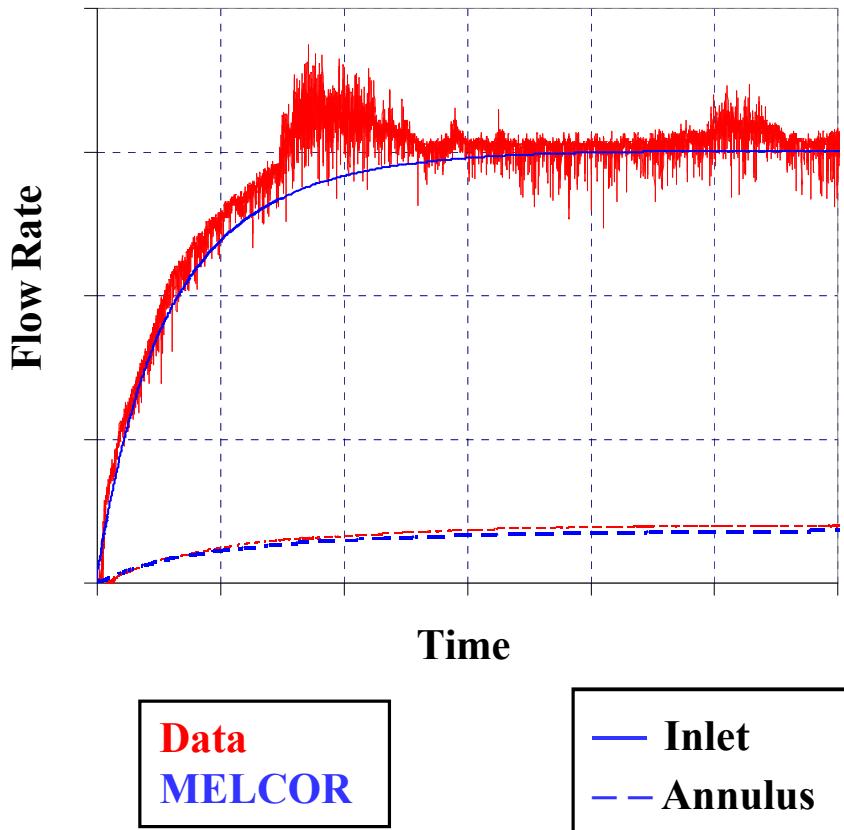
Thermocouple Layout



- 97 Total TC's internal to assembly
- 10 TC's mounted to channel box
 - 7 External wall
 - 24" spacing starting at 24" level
 - 3 Internal wall
 - 96", 120", and 144" levels
- 13 TC's on outer wall of pool cell
- 6 TC's measuring air temp
 - 4 Exit air temps
 - 1 Inlet air temp
 - 1 Ambient
- 2 TC's on outside of insulation

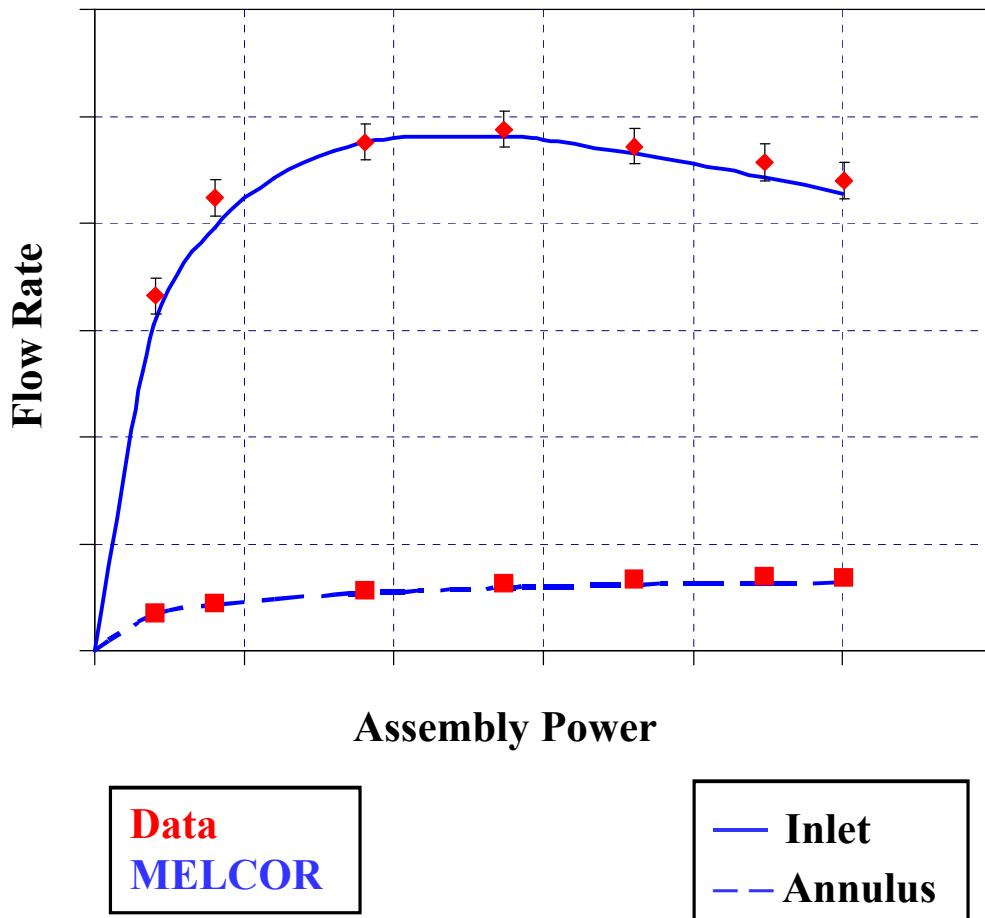


Transient Induced Flow Rate Data and MELCOR



- Total induced flow and flow split to annulus
 - Bypass open, drain holes closed
- Excellent agreement of MELCOR with data
 - Very sensitive to hydraulic parameters
 - Measured prototypic hydraulic parameters required

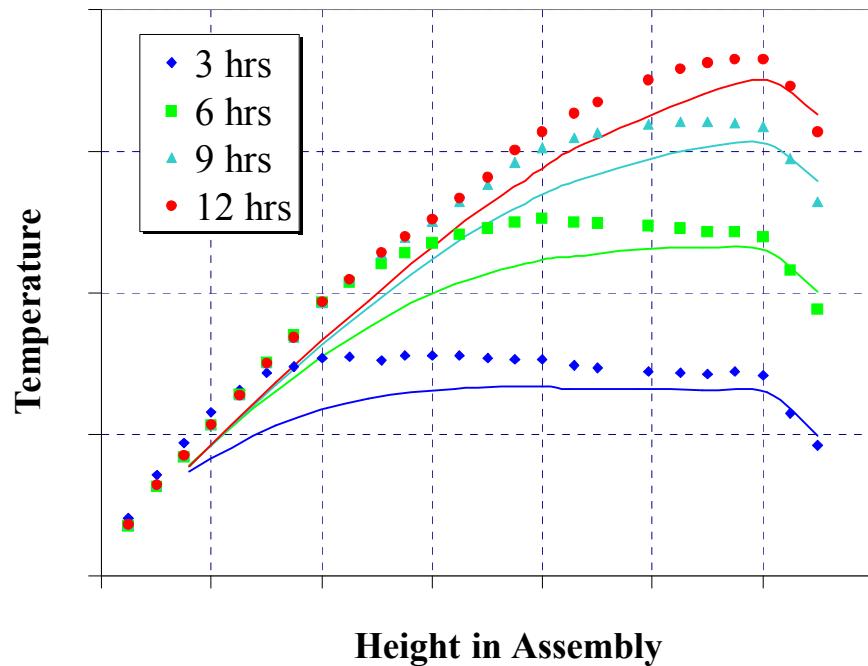
Inlet and Annular Flow Rate dependence on assembly power



- Inlet flow initially increases with power
 - Slowly decreases after peak
- Excellent agreement between experiments and MELCOR
 - Within experimental uncertainty for majority of data
 - Correct flow prediction required for correct temperature predictions

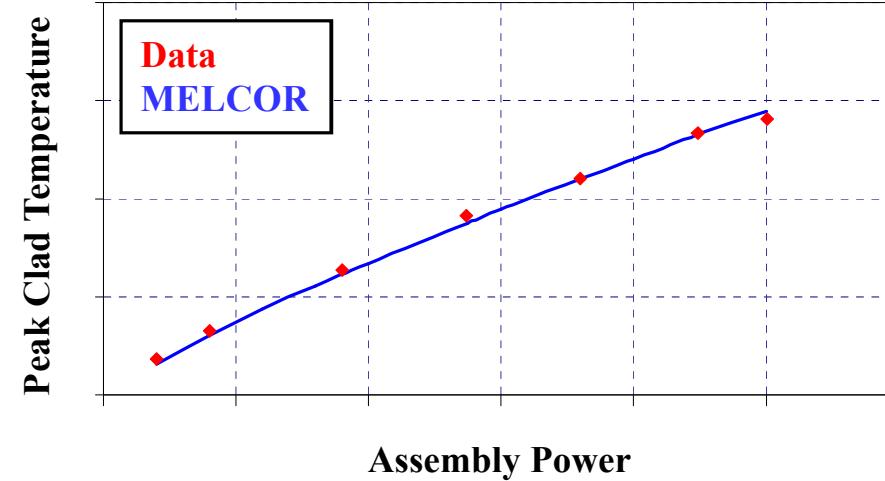
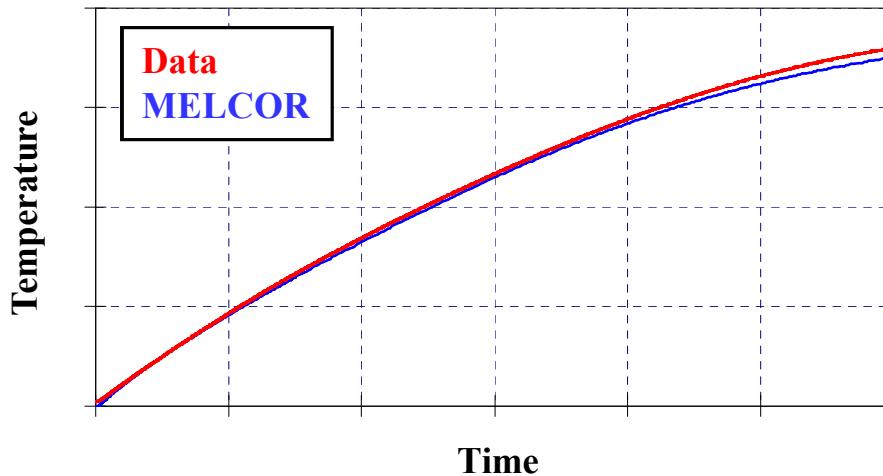
Axial Temperature Gradient

Data and MELCOR



- Points are data, lines are MELCOR
 - Good agreement
 - Peak temperatures
 - Near top of assembly
 - Measured prototypic hydraulic parameters required

Peak Temperatures



- **Transient response**
 - Average temperatures at 144" level
 - Excellent agreement with MELCOR (within 3%)
- **PCT vs. assembly power at 12 hrs**
 - MELCOR within 5% for all cases



Summary

- Thermal-hydraulic response of prototypic assembly quantified
 - Induced flow quantified
 - initially increases with power
 - steadily declines after peak
 - Axial and radial temperature profiles measured
- MELCOR accurately predicts response of heated assembly
 - Within 5% of PCT for all cases
 - Within experimental uncertainty of induced flow rate for majority of data
- Measured prototypic hydraulic parameters required