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Protecting People and the Environment

RIC 2009
Thermal Hydraulics & Severe Accident Code Development & Application

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Thermal-Hydraulic and Ignition Phenomena Characterization of Prototypic Pressurized Water Reactor Assemblies

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Objectives

- **Provide prototypic thermal hydraulic and zirc-fire data for accident code validation under air flow conditions associated with:**
  - **Spent fuel pool complete LOCA**
    - **Arrangement of high density fuel racks for mitigation strategy**
  - **Late phase core melt progression**
  - **Complete loss of water during refueling**
  - **Dry cask storage (thermal Hydraulic data**
- **Data is needed to assess:**
  - **Cladding ballooning**
  - **Flow correlation (Pressure drop vs. Velocity) at low Re numbers**
  - **Initiation of zirc fire**
  - **Assess potential for propagation of "zirc fire"**
  - **Mitigation strategies concerning fuel assembly management**
- **Pre-test (Blind) and Post test code to data comparison**
- **BWR experiment and analysis is completed and will be available.**

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Technical Motivation

- **Why not interpret BWR results for PWR ?**
  - **Geometry of PWR differs significantly from BWR**
- **Previous BWR results not applicable**
  - **More rods, larger footprint**
  - **No water rods**
  - **No partial length rods**
- **No Zr canister**
  - **Site specific storage cell defines annulus**
  - **May alter axial and radial burn front propagation**
  - **An analogous PWR study is required.**

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Scope of Work

- **Full length 17×17 PWR Assemblies**
  - **Otherwise similar to BWR study**
- **Phase 1 Testing**
  - **Single heated full length assembly**
    - **Insulated "Hot neighbor" BC**
  - **Pre-ignition and ignition testing**
- **Phase 2 Testing**
  - **Five (5) full length assemblies in 1×4**
    - **Center heated, peripheral unheated**
    - **"Cold neighbor" BC**
    - **Pressurized rods in two peripheral assemblies**
  - **Rod ballooning, requires design testing**
  - **Pre-ignition and ignition testing**

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What is new and different?

- **Experience with the BWR project allowed to make improvements in the PWR experimental design**
  - **All full length PWR assemblies**
    - **Commercially available 10.72 mm (0.422 in.) ZIRLO rods can be made into 9.52 mm (0.375 in.) heaters**
    - **All assemblies naturally draft in 1×4 experiments**
      - ❖ **No complex flow and temperature control required**
  - **Fully prototypic peripheral assemblies in 1×4 experiments**
    - **Allows pressurization of peripheral rods**
      - ❖ **Ballooning**

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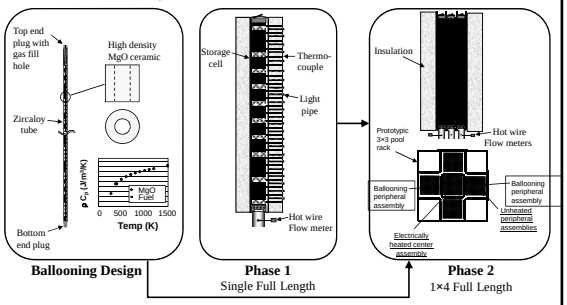
PWR Testing (Technical Summary)



Ballooning Design

Phase 1
Single Full Length

Phase 2
1×4 Full Length

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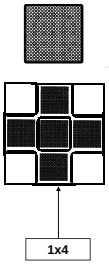
Proposed Testing Program for PWR 17x17



Description	Purpose	Assembly	Rod material
Ballooning rod design	Test pressurized rod performance, preliminary data on ballooning as function of initial internal pressure	Single rod	Zircaloy
Separate Effects	Hydraulics – Determine form loss and laminar friction coefficients	Single Prototypic	Stainless Steel
Pre-Ignition	Thermal hydraulics – Determine temperature profiles and induced convective flow	Single Prototypic	Zircaloy
Ignition	Axial Ignition – Temp profiles, induced flow, axial O_2 profile, nature of fire	Single Prototypic	Zircaloy
Pre-ignition	Thermal radiation coupling and induced convective cooling in a 1 x 4 arrangement	1×4 Prototypic	Zircaloy
Ignition with ballooning	Radial fire propagation and effect of fuel rod ballooning	1×4 Prototypic	Zircaloy

= Completed

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Phase 1: Axial Heating and Burn Propagation

- **Insulated "Hot neighbor" Boundary**
- **Test Assembly**
  - **Single Westinghouse 17×17 RFA PWR skeleton**
  - **9.52 mm (0.375 in.) electric heater rods made from 10.72 mm (0.422 in.) ZIRLO tube**
    - **Same heater design as in BWR study**
- **Pre-ignition Tests**
  - **Analogous to BWR testing except:**
    - **Two storage cell sizes**
- **Ignition Test**
  - **Similar to BWR burn except:**
    - **Lack of channel box may alter axial propagation**
      - **O2 bypass more likely**

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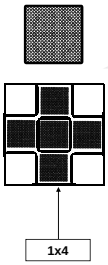
Proposed Testing Program for PWR 17x17



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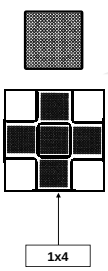
= Completed

Phase 2: Radial Heating and Burn Propagation

- "Cold Neighbor" Boundary
- Test Assembly
  - 5 full length assemblies in 1×4 arrangement
    - Center heated, peripheral unheated
  - Two peripheral assemblies with all pressurized rods
    - Strain gauges on some rods
      - ❖ Provide internal pressure indication
  - Single prototypic 3×3 pool cell
- Pre-ignition Tests
  - Analogous to BWR testing
    - Natural draft flow in peripherals
- Ignition Test
  - Effect of ballooning
    - Indicated by induced flow in peripheral assemblies
    - Pressure relief indicated by strain gauges

Proposed Testing Program for PWR 17x17



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= Completed

Ballooning Rod Design

- Prototypic Components
  - 9.50 mm (0.374 in.) ZIRLO tubing, Zr-4 end plugs and stainless springs
    - Welding and helium backfill by Westinghouse Inc.
  - High density MgO ceramic pellets
    - Same length and OD as UO2 pellets
    - Hole in center sized so thermal mass matches spent fuel
      - ❖ 3.2 mm (0.126 in.) hole

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Ballooning Rod Performance Testing

- Single rods tests in tube furnace
- Rods with solid MgO pellets for baseline
  - Excessive thermal mass
  - Sized for correct gas volume
  - 1.72, 2.07, and 2.41 MPa He
- Rods with hollow MgO pellets
  - Correct thermal mass
  - Increased gas volume
  - Find pressure that best represents baseline

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Numerical Support

- Main objective of project to provide prototypic data for code validation
- Three component numerical effort
  - Experimental design
  - Pre-test predictions
  - Post-test analysis
- Data available to all project participants
  - Test plans
  - Spreadsheet data files
  - Modeling database

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Summary

- BWR ignition testing completed for over 3 years
  - Testing prototypic hardware vital
    - Eliminate scaling arguments
    - Represents fuel design intricacies
  - Established experimental expertise and nuclear vendor relationships
- Significant differences between PWR and BWR assemblies
  - 264 PWR fuel rods vs 74 BWR fuel rods,
  - 11 PWR spacers vs 7 BWR spacers
  - No canister on PWR
- PWR ignition testing proposed over 3 years
  - Improved cost effectiveness
    - Personnel, testing capabilities and facilities well suited for proposed testing
  - All full length assemblies
  - Includes ballooning
    - In unheated peripheral assemblies

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