Agenda and Slide Presentations for the 2016 Westinghouse Fuel Performance Update Meeting (Non-Proprietary)

April 2016

(192 pages attached)

Westinghouse Electric Company LLC
1000 Westinghouse Drive
Cranberry Township, PA 16066

Westinghouse Fuel Performance Update Meeting
(NRC and Customers)
Tuesday, May 3, 2016

8:30 am - 8:45 am	Welcome, Introduction, and Safety Brief
8:45 am - 10:15 am	Pressurized Water Reactor (PWR) Fuel Performance Update
10:15 am - 10:30 am	BREAK
10:30 am - 10:45 am	AXIOM™ Cladding Update
10:45 am - 11:15 am	Accident Tolerant Fuel (ATF) Status on the Westinghouse Program
11:15 am - 11:30 am	Update on NSAL-14-5: Lower Than Expected Critical Heat Flux Results Obtained During Departure from Nucleate Boiling Testing, and revision to the WNG-1 Correlation
11:30 am - 12:45 pm	LUNCH
12:45 pm - 1:15 pm	Update on 10 CFR 50.46c Breakaway Testing of Cladding and Licensing Path
1:15 pm - 1:45 pm	PAD5 Licensing Status Update
1:45 pm - 2:00 pm	BREAK
2:00 pm - 3:00 pm	Boiling Water Reactor (BWR) Fuel & Control Blade Performance Update
3:00 pm - 3:45 pm	Cooling Deficiency Events at Leibstadt NPP (KKL)
3:45 pm - 4:00 pm	BREAK
4:00 pm - 4:30 pm	Triton11™ Fuel Update
4:30 pm - 4:45 pm	HiFi™ Cladding for Westinghouse BWR Fuel
4:45 pm	Adjourn

Westinghouse Fuel Performance Update Meeting

(NRC)

Wednesday, May 4, 2016

8:30 am - 8:45 am	Welcome, Introduction, and Safety Brief
8:45 am - 9:00 am	Westinghouse Organization Update - An update on the current Westinghouse Organizational Structure
9:00 am - 12:00 pm	Open discussion topics including but not limited to: [ ]^{e}
12:00 pm	Adjourn

Pressurized Water Reactor (PWR) Fuel Performance Update

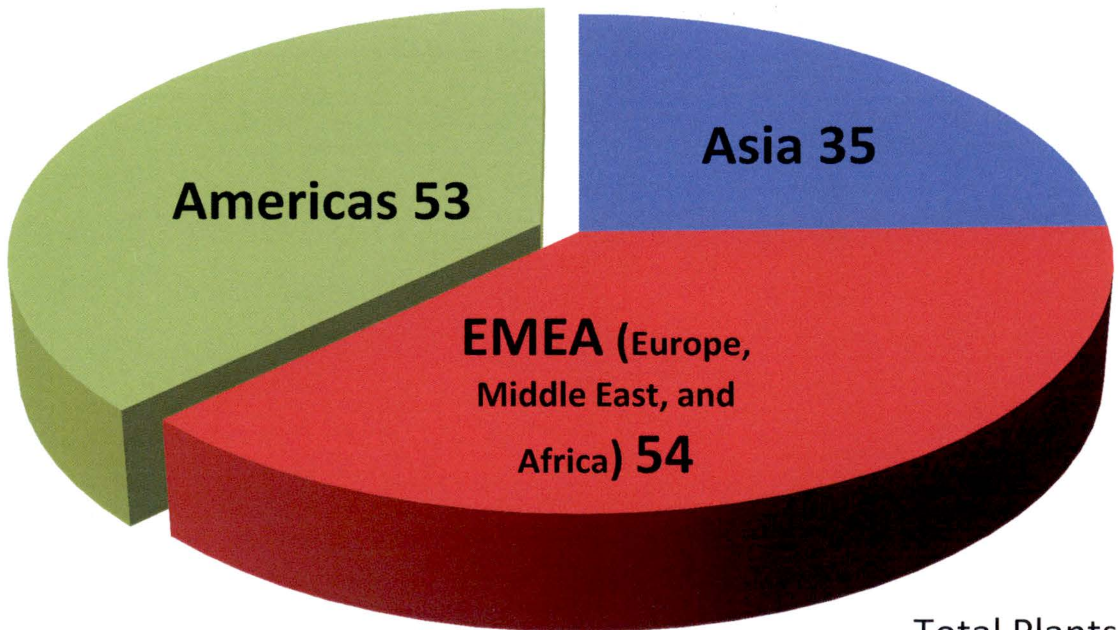
Jeff Norrell, PhD
Director
Product Engineering

Agenda

- Leak free plants
  - Nuclear fuel reliability progress
  - Historical trends
- Fuel reliability improvement process
- Update on recent PIE results
- Summary

Westinghouse Fueled Plants by Region

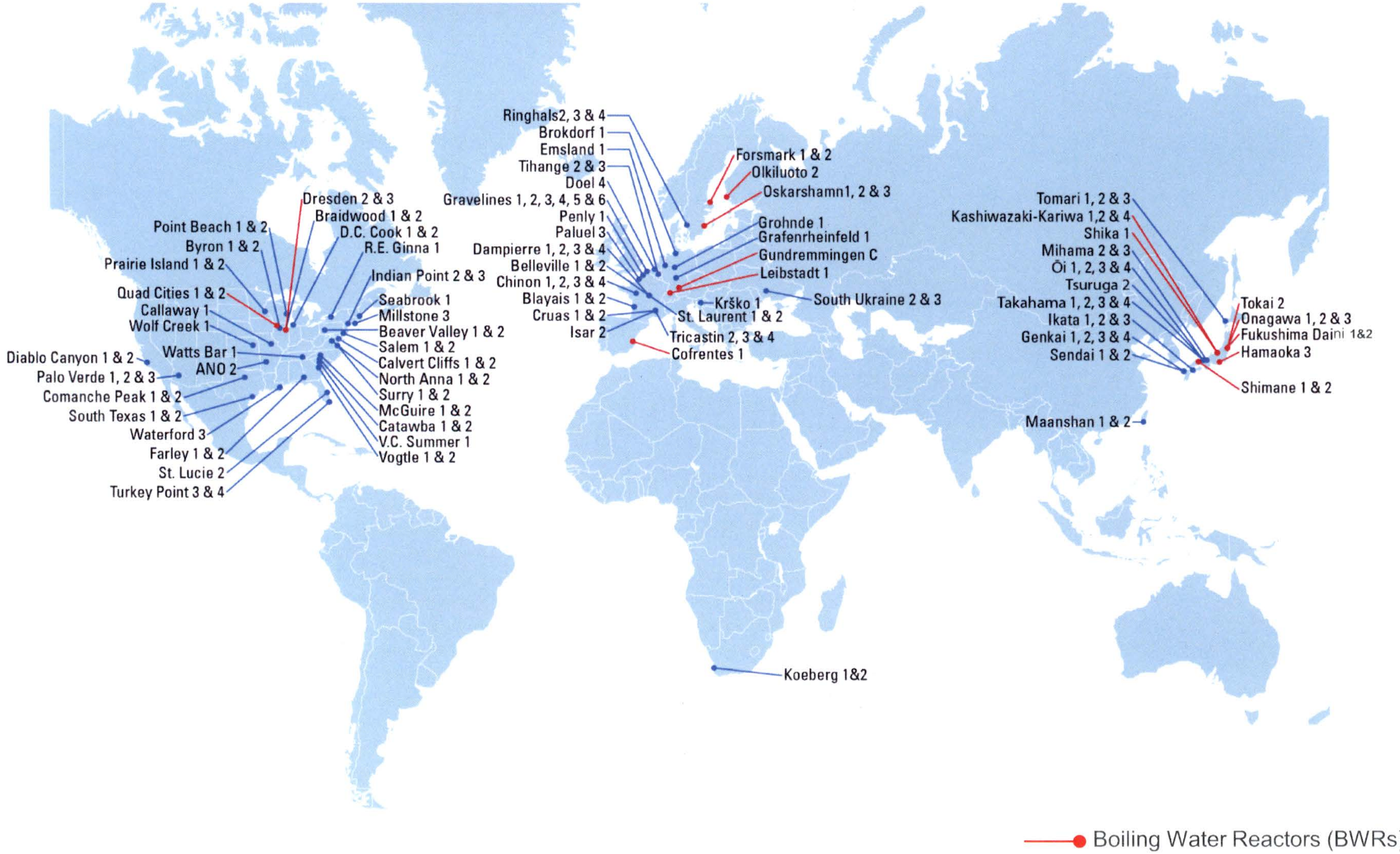
Westinghouse Fueled Plants by Region (March 2016)



Total Plants: 142

Global Fuel Reliability Process Required to Achieve and Maintain 100% Leak-Free, Issue-Free Fuel

Worldwide Map of Westinghouse-fueled Power Plants



Nuclear Fuel Reliability Progress – March 2016

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Historical Performance of Westinghouse Fueled Plants

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Driving to Flawless Fuel Through Design – Current Status

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Driving to Flawless Fuel Through Design – Challenges

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Driving to Flawless Fuel Through Design – Challenges

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Driving to Flawless Fuel Through Design – Activities

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Driving to Flawless Fuel Through Design – Activities

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Driving to Flawless Fuel Through Design – Activities

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Agenda

- Leak free plants
  - Nuclear fuel reliability progress
  - Historical trends
- Fuel reliability improvement process
- Update on recent PIE results
- Summary

Fuel Reliability Improvement Process

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Fuel Reliability Improvement Process

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Fuel Reliability Improvement Process

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Agenda

- Leak free plants
  - Nuclear fuel reliability progress
  - Historical trends
- Fuel reliability improvement process
- Update on recent PIE results
- Summary

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Visual Inspection Results

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Visual Inspection Results

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Visual Inspection Results

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Peripheral Rod Growth Results

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Fuel Assembly Growth Results

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Fuel Rod Oxide Thickness Results

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Rod M13: Summary of Fiberscope Observations

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Summary

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Questions?

AXIOM™ Cladding Update

Andrew R. Atwood
Manager
Materials and Fuel Rod Design

Overview

- **AXIOM** Cladding Development
- Lead Test Rod Irradiation Experience
- Selection Basis
- Lead Test Assembly Goals
- Preparations for **AXIOM** LTAs

AXIOM Cladding Development

- The development of **AXIOM** cladding is focused on delivering a material for use in high duty operations under aggressive conditions with:
  - Corrosion and hydrogen pickup performance superior to **Optimized ZIRLO™** cladding
  - Maintaining dimensional stability
  - Applicability to challenging water chemistry featuring elevated lithium and high boiling duty

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Sample and Lead Test Rod Irradiation Experience

- **AXIOM** has been irradiated in a variety of reactors worldwide
  - Seven power reactors
  - Two test reactors
  - Max burnup 75 GWD/MTU

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Creep and Growth program

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- Extensive PIE database

Final Alloy Selection Basis

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Lead Test Assembly Program

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AXIOM Program Timeline

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Timeline for **AXIOM** LTAs

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Manufacturing Readiness

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The Westinghouse Accident Tolerant Fuel (ATF) Program

Sumit Ray
Director
Methods, Technology & Licensing

Background

- Westinghouse is developing a fuel solution that provides substantial improvements in accident tolerance
  - Translating into significant improvements in nuclear safety
- Currently exploring both pellet and cladding concepts
  - Coated cladding concepts can deliver significant loss of coolant accident (LOCA) margins as well as modest improvements in severe accident tolerance
  - Silicon Carbide (SiC) cladding concepts can survive accidents such as TMI & likely Fukushima
  - Pellet concepts can deliver game changing fuel cycle economics in addition to ATF benefits

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The Westinghouse and DOE Accident Tolerant Fuel (ATF) Program

Westinghouse Program

2004 to 2012
Explored various cladding and fuel options

Phase 1A

2012 to 2015
Previous phase for exploring potential technologies

Phase 1B

2014 to 2016
Current phase for completion of exploration and manufacture of test rods for Phase 2

Phase 2

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Given the importance of ATF to the nuclear industry, [ ]a, c

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ATF Fuel Options Being Pursued

- Currently six cladding/pellet combinations are being considered
- ***Economic*** benefits come from incorporating a new pellet design and positive impact on plant Core Damage Frequencies
- ***Safety*** benefits come primarily from incorporating a new cladding design
- Westinghouse DOE ATF program includes both new cladding and new pellet designs
  - But we are beginning to narrow down our choice of concepts

		Cladding Options		
		100% SiC composite	Zr_{coated}	Zr_{coated} + $SiC_{wrapped}$
Pellet Options	UN/U_3Si_2	✓	✓	✓
	U_3Si_2	✓	✓	✓

Each ATF feature has elements of both benefits

DOE Program Status

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- Many different coated cladding concepts are being explored
- DOE has confirmed that they will fund our key major program

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- Phase 2 award schedule
  - Proposal to DOE transmitted April 21, 2016
  - Negotiations until about July, 2016
  - Final award August, 2016
  - Start work (continuation of Phase 1B) October 1, 2016
  - End of first portion of Phase 2 September 30, 2021
  - Next part of Phase 2 October 1, 2021
  - [ ]a,c

DOE program proceeding

Status on Utility Interactions

- Progress to date:
  - EXELON & SNC committed utility partners in Phase 2
  - Discussions ongoing with other utilities
- Utility interest focuses on revisiting PRA and Core Damage Frequencies based on a true ATF
- Additional benefit of fuel cycle costs is also recognized

Utility analysis from SNC and Exelon suggest that ATF can significantly contribute to operating cost reductions

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Conclusion & Summary

- Our ATF program focuses on significant accident tolerance improvement, as well as on providing a game changing economic value proposition to the industry

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  - Further contributing to delivering on the Nuclear Promise initiative
- US Utilities are beginning to show substantial interest
- [ ]a,c

Given the significant improvements to nuclear safety, it is extremely important to develop a robust and effective licensing process

Update on NSAL-14-5: Lower Than Expected Critical Heat Flux Results Obtained During Departure from Nucleate Boiling Testing, and revision to the WNG-1 Correlation

Zeses Karoutas

Chief Engineer

Fuel Engineering and Safety Analysis

Agenda

- History of NSAL-14-5 Issue
- Long Term Corrective Action Resolution
- New CHF Correlation (WNG-2) Development

History of NSAL-14-5 Issue

Date	Activity / Milestone
2013	CHF testing of 17x17 RFA (w/o IFM) at Westinghouse ODEN loop
Dec 2013	Identification of Issue: Lower than expected CHF results for a subset of conditions that were previously untested, resulting in non-conservative predictions by the WRB-2M CHF correlation.
Jan-Jun 2014	Potential Issue Opened (followed our Part 21 process). Decision: Not Reportable, No Substantial Safety Hazard
June 2014	NSAL-14-5 Issue and Interim Actions established. • Potentially impacted correlations: WRB-1, WRB-2, WRB-2M, WNG-1 • Current bounding DNB analyses of record (AOR) do not get into the potentially non-conservative region NRC Notified.
Jan 2015	Long Term Corrective Actions (LTCA) defined. The LTCA will address issue for most US plants.
Feb 2015	Presented to NRC during Westinghouse Fuel Performance Update Meeting

WRB-2M M/P versus Local Quality at MDNBR Location for 17x17 RFA (no IFM)

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LTCA Resolution

- Initial LTCA were presented to NRC in February 2015
- Westinghouse worked with subset of customers to refine the final resolution from March – August 2015.
  - Apply a conservative penalty that assumes the fuel rod fails due to DNB if the fluid conditions are in the potentially non conservative sub-region of conditions
  - Utilize 50.59 approach to implement.

LTCA Resolution

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New CHF Correlation (WNG-2) Development

- NSAL-14-5 affected the licensed WNG-1 CHF correlation for non-IFM application
- The new ODEN CHF data is being included with the WNG-1 correlation database in the development of a new correlation, currently called WNG-2
- The WNG-2 topical report will be issued to the NRC at the beginning of 2017.
  - First NRC review of data from Westinghouse ODEN CHF loop.
  - Will include benchmark results (ODEN vs. HTRF).
  - Pre-submittal meeting with the NRC to be scheduled in last quarter of 2016.

Update on 10 CFR 50.46c Breakaway Testing of Cladding and Licensing Path

David Mitchell
Fellow Engineer
PWR Fuel Technology

Agenda

- Status of Westinghouse Breakaway Testing
- Observations on Testing
- Pre Topical Production testing
- Plans for Topical Submittal
- Process for Submittal, Review and Acceptance

Status of Westinghouse Breakaway Testing

- Modified testing setup to conform to latest draft REGULATORY GUIDE 1.222, MEASURING BREAKAWAY OXIDATION BEHAVIOR Guide, October 2015.
  - Main impact was use of type S thermocouples.
- Testing completed on ZIRLO and ***Optimized ZIRLO*** cladding.
- Scoping tests have been performed on LK-3 (Zircaloy-2)
- Work has started on test equipment and on testing procedures for SMP (Blairsville)

Status of Westinghouse Breakaway Testing (Cont'd)

- Completed testing of non-scratched samples from 3 ***Optimized ZIRLO*** and 3 ZIRLO cladding lots at 800 and 950-1050°C.
- Completed all 8 temperatures to 18% CP-ECR or 5000 seconds based on the cladding design with the thickest wall.

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- Completed 1000°C/4300s – 2 Confirmation Runs
- Completed 1000°C/4300s – 3 Scratched Sample Runs

Observations on Testing

- Measured vs Predicted weight gain similar to previous testing
- Thermal histories are excellent. However, as expected the heating rate from [

  ]^{a,c} Westinghouse believes this meets the intent of the requirement.
  - All heating/cooling times <10% of isothermal time
  - Rate from 300°C to within 100°C of target is > 5°C/s.
- No significant impact of scratches on breakaway time observed, but scratches impact visual appearance.
- Tendency noted for samples from ID flushed pickled tubing to breakaway from ID. Not observed with grit blasted samples.
  - Any samples with final ID pickling to be grit blasted or honed prior to test

Summary of breakaway testing to find breakaway temperature

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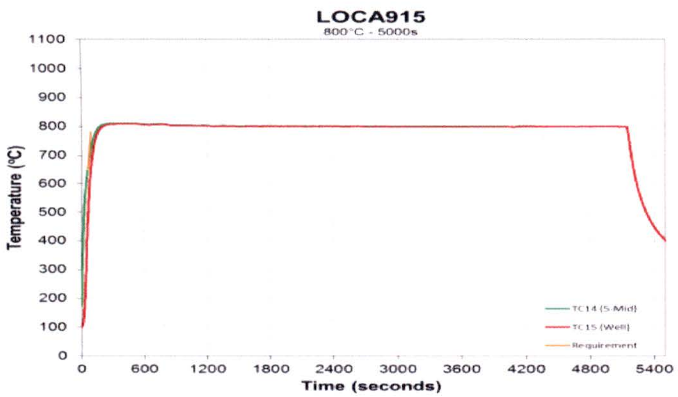
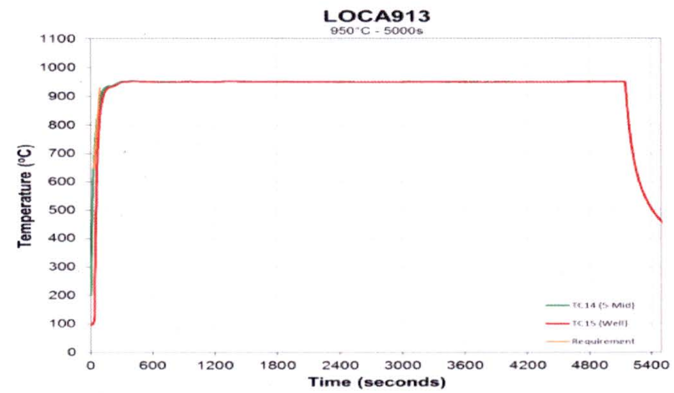
Thermal History

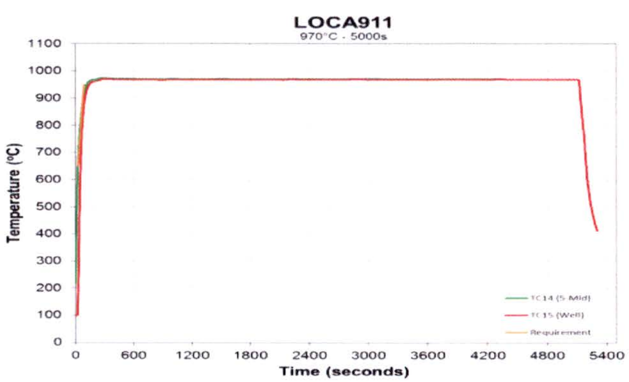
800°C



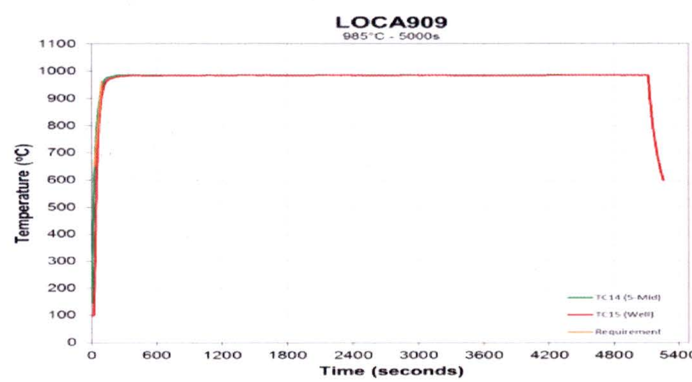
950°C



970°C



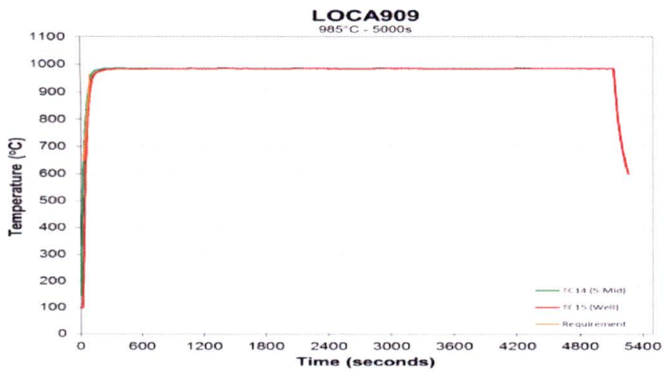
980°C



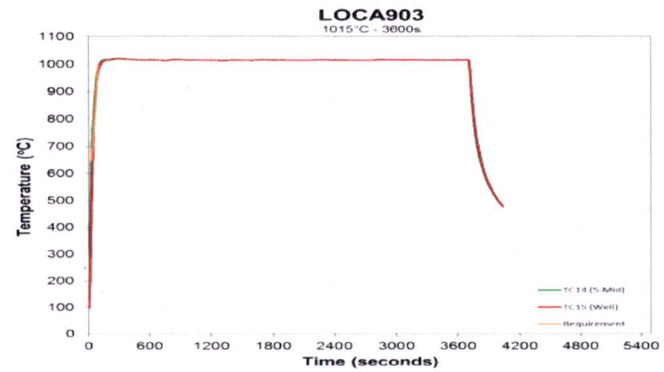
[ ]a,c >5°C/s from 300 to within 100°C of target

Thermal History

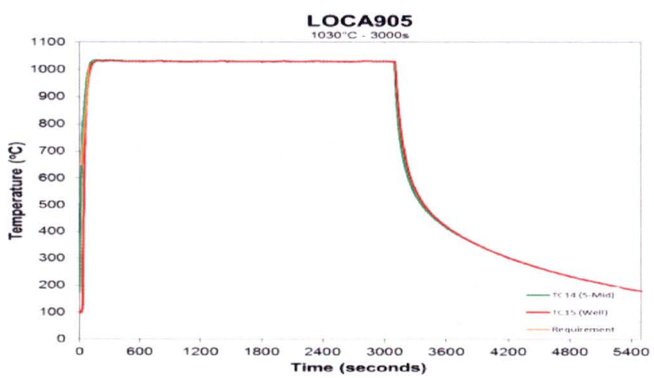
1000°C



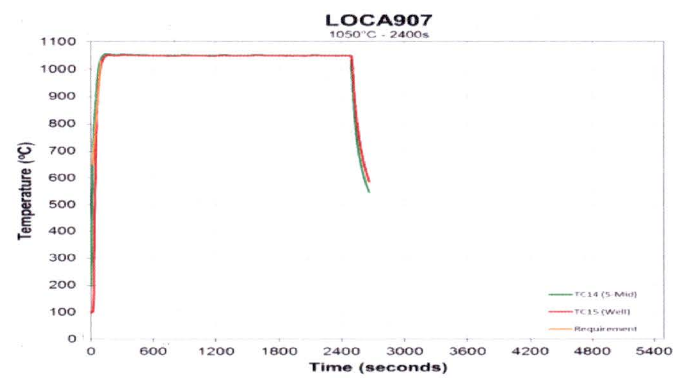
1015°C



1030°C



1050°C



[ ]^{a,c} >5°C/s from 300 to within 100°C of target

Measured vs Predicted Weight Gain

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Hydrogen Measurement Summary

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All hydrogen measurements below 200 ppm

Plans for production testing

- Testing established breakaway temperature for ZIRLO and Optimized ZIRLO claddings.
  - 1,000°C and 4,300 seconds.
  - No significant scratch impact.
- Safety analysis determined a maximum transient time of 2,000 seconds (time > 800°C).
- Developing visual standards for use in production testing.
- Production testing will then be performed on tube samples without scratches for [ ]a,c seconds at 1,000°C.
- Cladding is then certified to have a breakaway time of ≥ [ ]a,c seconds and released for fuel rod fabrication.

Pre Topical Production testing

- Have been testing production cladding lots from SMP at Churchill facility.

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- Using this data to develop visual standards

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Plans for Topical Submittal

- Current projections are for submittal of ZIRLO and ***Optimized ZIRLO*** cladding topical which will include LK-3 cladding.
- Topical will serve as template for approval of future cladding alloys.
- Initial plan is to perform test once per ingot.
- Topical will include discussion on reduction of testing with development of database.

Process for Submittal, Review and Acceptance

- Plan to submit stand alone WCAP Will serve as template for future cladding alloys.
- Current plan is to submit ~ 6 months following final rule becoming effective.
- Westinghouse will request a pre-submittal meeting after final rule.
- NRC's anticipated review plan and schedule?

Need well defined path for submittal and approval to minimize disruption with 50.46c

PAD5 Licensing Status Update

Robert Oelrich
Manager
PWR Fuel Technology

PAD5 RAI Status

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On schedule for all RAI commitments

PAD5 Methodology Status

- PAD5 Status
  - Westinghouse target (best case) dates for licensing are: a,c

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  - Westinghouse and NRC continue to hold regular communications to monitor and engage in active discussions to track review and approval.

PAD5 Implementation Areas

- PAD5 implementation includes a number of disciplines
  - The implementation plan was presented at the PWROG

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Summary

- PAD5 licensing strategy developed to support timely NRC review

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PAD5 Team committed to support timely completion of PAD5 licensing review

Boiling Water Reactor (BWR) Fuel Performance Update

Jeremy King
Product Manager
Westinghouse Nuclear Fuels

Outline

- BWR Fuel Performance
  - Fuel Failure Statistics
  - Cladding Performance
  - Channel Performance
  - Control Blade Performance

- Conclusions

BWR Fuel Overview
Evolution over 50 Years

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Global Primary Fuel Leakers Statistics

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Fuel Leakers Statistics December 2015

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Summary of 2015 Leakers

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Debris Fretting Mitigation
TripleWave™ /TripleWave+™ Debris Filter Experience

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Outline

- BWR Fuel Performance
  - Fuel Failure Statistics
  - Cladding Performance
  - Channel Performance
  - Control Blade Performance

- Conclusions

Collection of Data 2015

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SVEA-96 Optima3 Visual Observations

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SVEA-96 Optima3 Visual Observations

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Growth Measurements **ADOPT**™ Pellets

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Growth Measurements High Density Pellets

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Cladding Performance Summary

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Outline

- BWR Fuel Performance
  - Fuel Failure Statistics
  - Cladding Performance
  - Channel Performance
  - Control Blade Performance

- Conclusions

Channel Measurements

- Channel measurements are performed on a regular basis by Westinghouse and our customers
  - Westinghouse
    - Channel length, channel oxide and in some cases channel bow
  - Customers
    - Channel bow (geometry) measurements on a regular basis with own equipment

Channel Measurements Performed in 2015

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Channel Measurements Performed in 2015 (cont.)

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Data and Experience in 2015
Channel Growth

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Data and Experience in 2015 Channel Oxide

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Data and Experience in 2015
Channel Bow (Symmetrical Lattice)

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Data and Experience 2015
Channel Bow Zry-2

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Data and Experience 2015
Channel Bow Zry-2 Beta Quench (BQ)

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Data and Experience 2015
Channel Bow Zry-4 BQ

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Data and Experience 2015
Channel Bow Low Tin ZIRLO

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Deliveries **Low Tin ZIRLO** Channels

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Potentially Life Limiting Phenomena for BWR Fuel Channels

- Channel elongation
- Channel bow
- Channel creep (bulge)
- Corrosion
- Hydrogen up-take

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Verification Program **Low Tin ZIRLO** Channels

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Verification **Low Tin ZIRLO** Channels

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Verification **Low Tin ZIRLO** Channels

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Verification **Low Tin ZIRLO** Channels

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Channel Performance Summary

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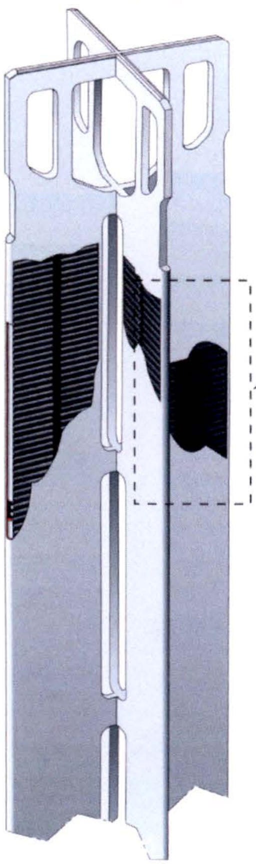
- Very limited bow (2 mm) when operated at high inch-days
  - At the same inch-day levels (operated in the same cells) Zry-2 experienced bow up to 14 mm

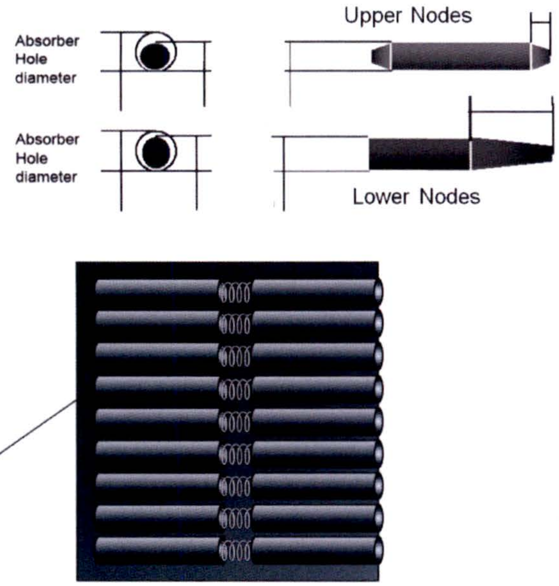
Outline

- BWR Fuel Performance
  - Fuel Failure Statistics
  - Cladding Performance
  - Channel Performance
  - Control Blade Performance
    - CRB Product Overview
    - Westinghouse CRB Deliveries
    - Summary of 2015 Inspections
    - 3rd Generation CR99 Inspections
    - CR 82M-1 Performance
- Conclusions

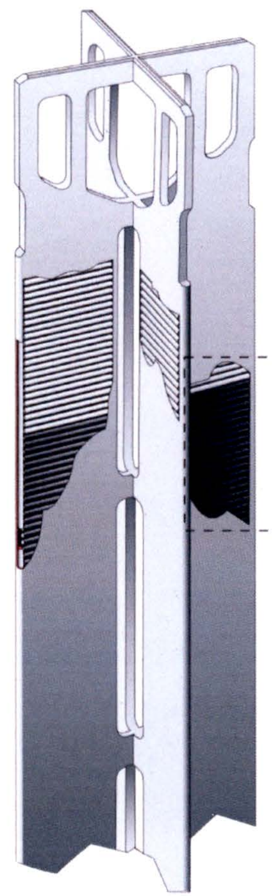
Current Westinghouse BWR Control Rod Blades (CRBs)

CR99

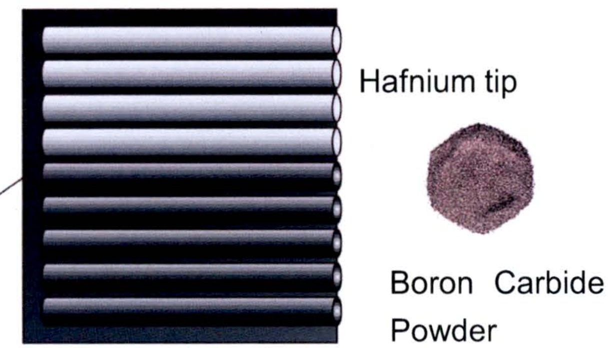




- High Performance CRB
- HIP B4C pins
- 316L SS
- Power Regulation

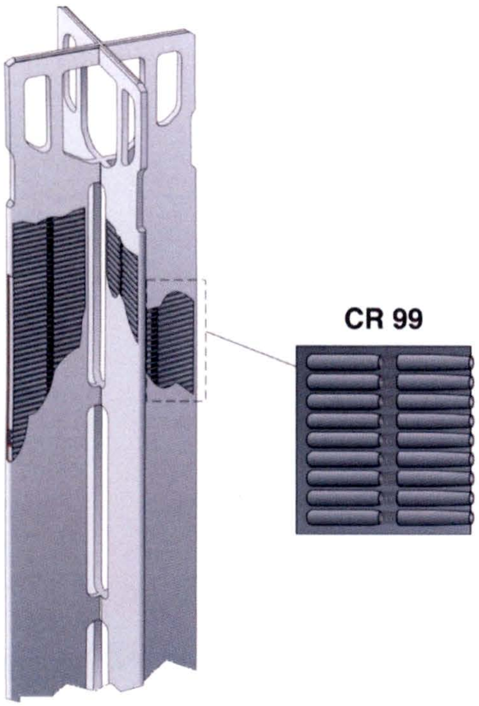


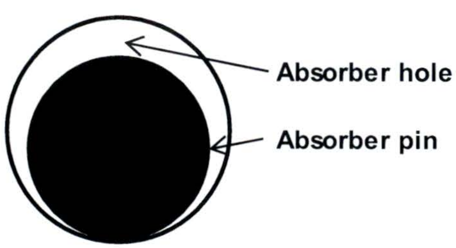
CR 82M-1



- Mid-duty/Shut down CRB
- Hafnium tip
- B4C powder
- 316L SS
- >40 years as Shutdown CRB

Basic Design of CR 99





High-density boron carbide absorber pins

- ~100% of theoretical density (compared with 70% of standard boron carbide powder)
- Drastically improved material properties and control over the swelling process and the mechanical performance

Optimized pin design – to improve mechanical performance

- Pin diameter smaller than hole diameter – allows for free expansion of the absorber pins
- Reduced pin diameter in the top – to manage axial depletion peaks at CR top
- Tapered ends – to manage radial depletion peaks at edges

CR 99 Generations (all generations based on the same basic design)

- **Gen 1** (1999): Prototype, operated in [ ]^{a,c} and examined by PIE (Post Irradiation Examination) in Studsvik
- **Gen 2** (2003): Operated in [ ]^{a,c} and evaluated in the current PIE measurement program
- **Gen 3** (2007): Currently under NRC review. Improved mechanical performance obtained by increased hole diameter and reduced pin diameter (otherwise identical to Gen 2)

Westinghouse Control Rod Deliveries

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2015 Inspections

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CR 99 Inspection Results 2015 – [ ]a,c

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CR 99 Surveillance – [ ]a,c

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CR 82M-1 Performance

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CRB TIP Traces from Plant B

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Plant F Normal LPRM Detector Response

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Plant F Unexpected LPRM Detector Response

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Visual Inspection Results CRB at 38-31

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Visual Inspection Results CRB at 14-23

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Visual Inspection Results CRB at 14-19

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Chemistry Data from Plant A and B

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Plant E Visual Examinations

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Summary of Indications

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CR 82M-1 Performance Summary

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Outline

- BWR Fuel Performance
  - Fuel Failure Statistics
  - Cladding Performance
  - Channel Performance
  - Control Blade Performance

- Conclusions

BWR Fuel Performance Conclusion

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Cooling Deficiency Events at Leibstadt NPP (KKL)

Uffe Bergmann
Fellow Engineer
BWR Methods & Technology

Outline

- Summary of event
- Detailed inspections
- Root cause analysis
- Conclusions

Cooling Deficiency in KKL - Background

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Cooling Deficiency Event in KKL –

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Evidence for dryout leaker

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Cooling Deficiency Event in KKL – Initial Assessment

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Summary Visual Inspections

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Additional Inspections - June 2015

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Gamma-scanning - Selected fuel rods

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Gamma-scanning - Results

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Gamma-scanning - Conclusions

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SVEA-96 Optima2 Operating Experience

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SVEA-96 Optima2 Operating Experience

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Root Cause Analysis – Fault Tree

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Conclusions

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Planned Actions

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TRITON11™ Fuel Update

Uffe Bergmann
Tech Lead
BWR Fuel Development

Outline

- Design Overview
- Test and Verification
- Performance Summary
- Safety and Reliability Improvements
- Development Schedule
- Summary

Design Overview
- Fuel Lattice Geometry

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Design Overview
- Materials

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Design Overview
- Fuel Channeling Concept

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Design Overview
- [ ][a,c]

[ ][a,c]

Design Overview
- Fuel Bundle Lower Parts

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Design Overview
- Fuel Bundle Upper Parts

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Design Overview
- Fuel Rod Design

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Design Overview
- Channel

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Design Overview
- Spacers

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Test and Verification
- Dryout Testing in FRIGG Loop

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Test and Verification
- Lateral Load Cycling Test of Spacers

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Test & Verification
- Function and Strength of [ ] a,c

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Performance Summary (comparison to Optima3)

[ ]a,c

Performance Summary (comparison to Optima3)

[ ]a,c

Proven Reliability Features

a,c

Safety and Reliability Improvements

a,c

Development Schedule

a,c

Summary

a,c

HiFi™ Cladding for Westinghouse BWR Fuel

Javier Romero
Senior Engineer
Materials and Fuel Rod Design

Agenda

- Purpose
- Overview
- Performance and Experience
- Summary - Plan for Licensing Submittal

Purpose

- Westinghouse is preparing a licensing topical report for application of **HiFi** as fuel cladding material for boiling water reactor (BWR) nuclear fuel, as an alternative for Zircaloy-2 cladding.

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Overview

a,b,c

[ ]

Overview - Development

a,c

Overview - Manufacturing

a,c

Performance and Experience – Out-of-Reactor

a,b,c

In-Reactor Experience

a,b,c

In-reactor Experience – Corrosion

a,b,c

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In-reactor Experience – Hydrogen Pickup

a,b,c

[ ]

In-reactor Experience

a,b,c

Expanding Experience

a,c

Summary - Plan for Licensing Submittal

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