Westinghouse Fuel Performance Update Meeting

Westinghouse Electric Company LLC
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Westinghouse Fuel Performance Update Meeting

April 13, 2010

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Westinghouse Fuel Performance Update Meeting
Agenda
April 13, 2010

Tuesday. April 13, 2010 (Westinghouse, NRC and Customers)

8:00 – 8:15 a.m.	Introductions and Welcome	
8:15 – 9:15 a.m.	1. **PWR Fuel Performance Update** - PWR Fuel Performance - Hardware Update, Issues and Resolution - Future Plans	Tab 1
9:15 – 10:15 a.m.	2. **BWR Fuel Performance Update** - BWR Fuel Performance - Hardware Update, Issues and Resolution - Future Plans	Tab 2
10:15 – 10:30 a.m.	Break	
10:30 – 11:30 a.m.	3. **High Burnup / New Alloy Strategies** - Planned Deployment of Optimized ZIRLO™ to Fleet - High Burnup Program - Update on Vogtle Creep & Growth Program	Tab 3
11:30 a.m. – 12:30 p.m.	4. **Method Improvements / Regulatory Changes** - Reactivity Initiated Accident (RIA) - Full Spectrum LOCA Update - Hydrogen / Oxide / Embrittlement	Tab 4
12:30 – 1:15 p.m.	Lunch/ Informal Discussion between NRC, Customers and Westinghouse	
1:15 – 2:15 p.m.	5. **New Plant Licensing** - ABWR - Topical Availability - Overview and Status of Upcoming Submittals - Licensing Approach	Tab 5
2:15 – 2:30 a.m.	Break	
2:30 – 4:00 p.m.	- AP1000™ - Advanced First Core (Current Fuel Design) - Core Reference Report Format (Table of Contents) - Chapter 15 Changes	
4:00 – 4:30 p.m.	6. **Spent Fuel Pool Criticality Analysis**	Tab 6
4:30 – 4:45 p.m.	Wrap-up	

PWR Fuel Update

Westinghouse/NRC Fuel Update Meeting
Monroeville, PA
April 13, 2010

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Agenda

- **Fuel Reliability Improvement Process**
- Westinghouse Fuel
- Monitoring and Driving Performance
- PIE and Healthy Fuel Exam Results
- Summary

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Fuel Reliability Improvement Process Background

- Westinghouse Flawless Fuel program formally announced in 2002
  - Moved from "find and fix" to "anticipate and prevent"
    - Initiated use of Failure Modes & Effects Analysis methodology to surface potential weaknesses in fabrication processes
    - Quantify fuel margins in key components / features
  - Significant initiative to improve product quality and delivery through:
    - Product and process changes based on potential for fuel failures
    - Customer 1st program embodying HuP, 6-Sigma & Lean principles and Behavioral Differentiation
- Goal of achieving "0" leakers clearly articulated as an organization aspiration – INPO later provided a date!

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Fuel Reliability Improvement Process

- Many initiatives and projects to improve fuel reliability completed and underway
  - New Fuel Assembly Designs
  - Fabrication Process Improvements
  - Inspection Improvements
  - Critical Fuel Reliability Attributes (CFRA) Identified

- Broader engagement and understanding within the Nuclear Fuel organization to internalize gains and achieve reliability levels needed in the manufacturing process
  - Described as a process which produces the key projects for achieving Flawless Fuel
  - CAPs modified to recognize CFRA-related challenges and mobilize quicker response and action

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Fuel Reliability Improvement Process Map

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Fuel Reliability Improvement Projects

- Fuel Reliability Improvement Steering Committee (FRISC) is comprised of senior management from across Nuclear Fuel
- Review of operation feedback data is performed by the Fuel Performance Team – a standing team of technical experts in design and manufacturing – and recommendations are provided to the FRISC
- Sanctioned changes to **Design**, **Process** and **Materials** are implemented as projects following Product Management processes in Nuclear Fuel
  - Shorter-term projects: Fuel Reliability Improvement Projects
  - Longer-term projects: FRI Related Technology Development Projects

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Westinghouse Fuel Reliability Improvement Program – through March 31, 2010 (Fiscal year 2009)

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Westinghouse FRI Related Technology Development Projects – through March 31, 2009

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Agenda

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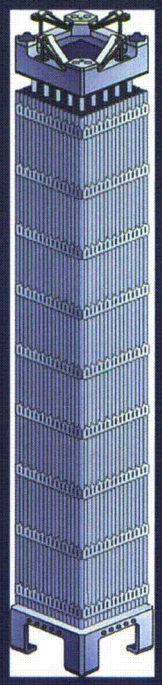
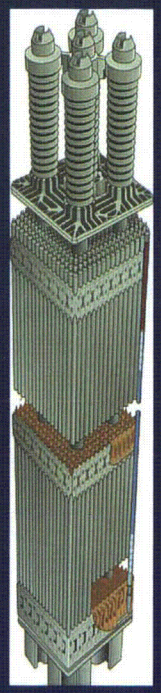
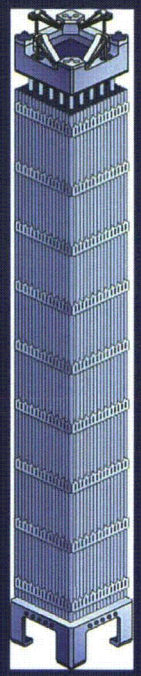
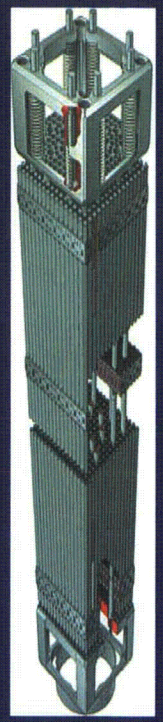
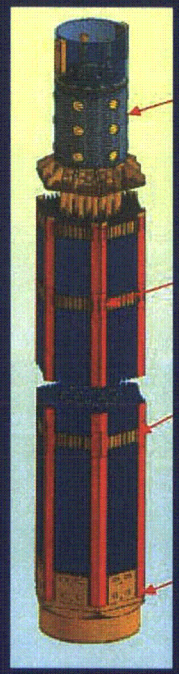
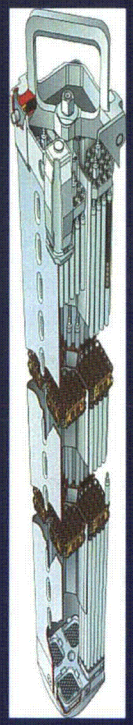
Westinghouse Designs and Manufactures a Broad Array of LWR Fuel Products

Westinghouse PWRs	CE PWRs	B&W PWRs	German PWRs	Russian PWRs	BWRs
					
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Challenges and New Requirements Demand Innovative Improvements Across All Westinghouse Product Lines

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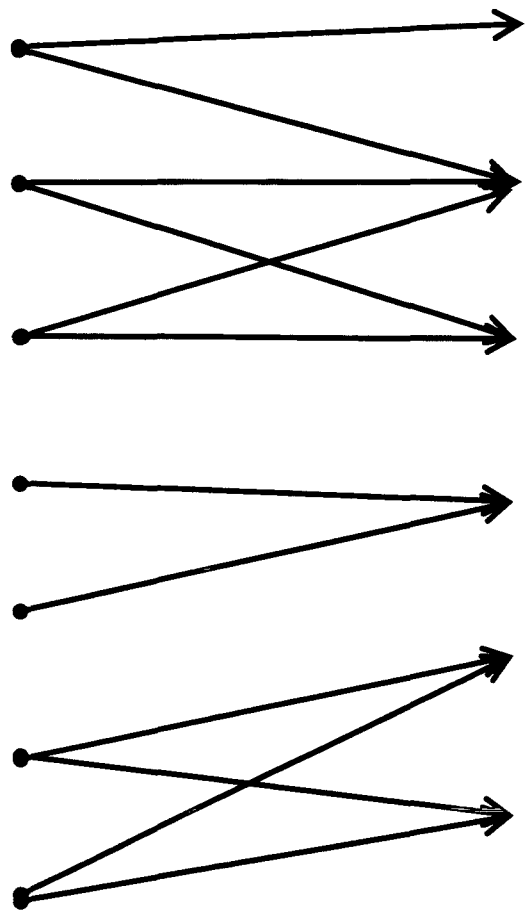
Design Considerations for Fuel Improvements

- Protective Grid
- Mid Grid Design
- IFM Grid Design
- Thimbles Thickness
- Dashpot Design
- Skeleton Material
- Cladding Material



- Debris resistance
- Fretting
- Thermal margin
- Incomplete Rod Insertion / Bow
- Growth
- Corrosion

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Westinghouse Fuel Continuous Innovation

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Agenda

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Trend in Coolant Activity for Westinghouse Supplied Fuel

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Number of Leaking Fuel Assemblies Confirmed during Outages

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Number of Rods per Leakage Mechanism Confirmed during Outages

a, c

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Number of Rods per Product Line Confirmed during Outages

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P-Grid Issue Background

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Improved Cell Sizing Project (Pinning) Completed

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Robust P-grid Design - What is being addressed?

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Key Changes for the Robust P-Grid

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Current P-grid versus Robust P-grid Prototype

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Agenda

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Westinghouse Plant Priorities for Fuel Surveillance Inspection Guidelines (FSIG) Baseline Inspections

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Healthy Fuel Inspection Results

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Healthy Fuel Inspection Results (continued)

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Healthy Fuel Inspection Results (continued)

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Summary

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Questions?

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Westinghouse Non-Proprietary Class 3

BWR Update

Westinghouse/NRC Fuel Update Meeting
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April 13, 2010

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Agenda

- **BWR Fuel Performance**
  - **Overall BWR Fuel Performance**
  - **Cladding Performance**
  - **Channel Performance**
  - **Water Chemistry**
- BWR Fuel Hardware Update, Issues and Resolution
- Future Plans

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Fuel Technology Program

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Leaking Fuel Mechanisms (Primary) – Worldwide BWR Fuel Rods

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Fuel Rod Inspections 2007-2009
Secondary Fuel Rod Degradation

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Agenda

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Cladding Growth

a, b, c

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Cladding Corrosion

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Cladding Performance

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Cladding Performance (continued)

- All BWR customers are using [ ]a,c
- [ ]a,c is standard component of SVEA-96 Optima2
- [ ]a,c has shown to have an excellent performance in a wide range of operating conditions (water chemistry, Linear Heat Rates etc)
- Large performance database going back to 1994 when the first [ ]a,c demos were loaded

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Agenda

- BWR Fuel Performance
  - Overall BWR Fuel Performance
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Growth – *Differential growth being the key bow driver*

a, b, c

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Channel Bow
Symmetric Lattice

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Channel Performance
Corrosion

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Channel Performance Examinations in [ ]a,c

[ ]a, c

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Summary - Channel Performance

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Agenda

- BWR Fuel Performance
  - Overall BWR Fuel Performance
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  - Channel Performance
  - **Water Chemistry**
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Water Chemistry Experience

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Water Chemistry Experience

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Water Chemistry Experience
Diagnostics Example – Condensed Plant Status

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BWR Fuel Performance Update

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Agenda

- BWR Fuel Performance
  - Overall BWR Fuel Performance
  - Cladding Performance
  - Channel Performance
  - Water Chemistry
- **BWR Fuel Hardware Update, Issues and Resolution**
  - **SVEA-96 Optima-2**
  - Control Rod Blades (CRBs)
    - [ ]a,c CRB Extension Issue
- Future Plans

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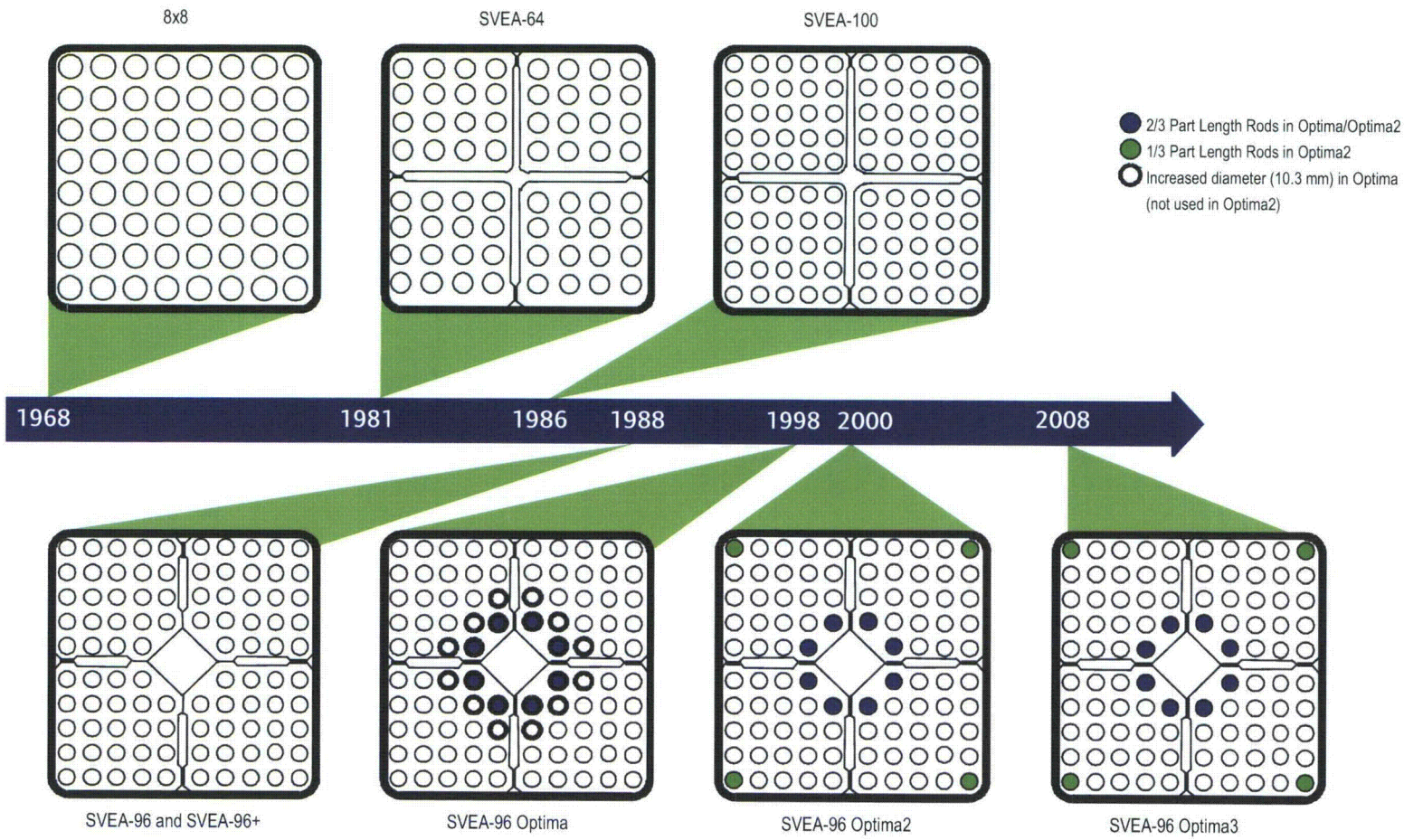
BWR Fuel Lattices
Westinghouse Fuel Design Evolution



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BWR Fuel Burnup Experience, up to January 2010

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SVEA-96 Optima2 – Key Features

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SVEA-96 Optima2 BWR Fuel

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SVEA-96 Optima2 – Inspection Sample

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Summary - SVEA-96 Optima2

- SVEA-96 Optima2 is an excellent base for
  - high power density/power uprates
  - long and flexible cycles
  - high burnup

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Agenda

- BWR Fuel Performance
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  - Cladding Performance
  - Channel Performance
  - Water Chemistry
- BWR Fuel Hardware Update, Issues and Resolution
  - SVEA-96 Optima-2
  - **Control Rod Blades (CRBs)**
    - **[ ]a,c CRB Extension Issue**
- Future Plans

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Design CR 82M-1

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Design CR 99

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[ ]a,c CRB Extension Issue

- CRB operated in BWRs built by Westinghouse are equipped with an extension welded to the absorber cross and in the other end connected to the control rod drive
- In BWRs built by [ ]a,c, a socket or velocity limiter is welded to the absorber cross and then connected to the CRD system

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Comparison of Control Rod Blades for BWRs

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General

[ ] a, c

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CRD Crud Removal Flow and Mixing Zone in [ ]a,c

[ ]a, c

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Control Rod Issue in [ ]a,c

[ ]a, c

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CRB Extension Issue in [ ]a,c

[ ]a, c

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Summary – CRB Extension Issue

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Agenda

- BWR Fuel Performance
  - Overall BWR Fuel Performance
  - Cladding Performance
  - Channel Performance
  - Water Chemistry
- BWR Fuel Hardware Update, Issues and Resolution
- **Future Plans**
  - **SVEA-96 Optima3**

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SVEA-96 Optima3

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SVEA-96 Optima3 - An Integrated Product

– Enhanced hardware including new spacer

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SVEA-96 Optima3
Sub-bundle Top and Bottom Ends

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SVEA-96 Optima3 Spacer with Mixing Vanes

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Debris Fretting Mitigation TripleWave™ and Spacer Synergy

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SVEA-96 Optima2 Fuel vs. SVEA-96 Optima3 Fuel Debris Mitigation

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TripleWave+ Testing

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SVEA-96 Optima3 - 2003 LFA Inspection

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SVEA-96 Optima3 - 2004 LFA Inspection

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Summary - SVEA-96 Optima3

- Further enhancements with SVEA-96 Optima3
  - An evolutionary design
  - Key proven components of SVEA-96 Optima2 maintained
  - All loop tests completed successfully

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Questions?

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Optimized ZIRLO™ Cladding Rollout Plans

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Agenda

- Customer Value
- Availability
- Implementation Process
- SER Conditions & Limitations
- LAR Submittals
- Rollout Schedules

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Customer Value of Optimized ZIRLO™ Fuel Cladding

- Provides improved fuel margins
  - Clad corrosion
  - Rod internal pressure
  - Post-LOCA clad oxidation

- By using Optimized ZIRLO™ fuel cladding, the customer may
  - Increase peaking factors and reduce the number of feed assemblies
  - Enable plant uprating
  - Extend cycle length
  - Operate to higher rod burnup levels

- Customers value good performing fuel products that increase revenue, reduce costs and/or improve plant operations

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Availability of Optimized ZIRLO™ Fuel Cladding

- Substantial data base exists for Optimized ZIRLO™ fuel cladding
  - Robust and ongoing irradiation test program
  - Three cycles of successful LUA operation at two U.S. plants
  - Multi-region operation at two CE-NSSS plants
- Manufacturing capability to produce fuel assemblies with Optimized ZIRLO™ fuel cladding is in place
  - New annealing furnace installed and operating at Westinghouse's Blairsville, PA Specialty Metals Plant
  - Qualification testing completed for most fuel rod diameters
- Westinghouse is offering Optimized ZIRLO™ fuel cladding as a priced option for all of our fuel product lines
  - W14, W15, W16, W17, CE16

Optimized ZIRLO™ Implementation Process

- Provide customer with licensing requirements
  - WCAP-12610-P-A & CENPD-404-P-A Addendum 1-A, July 2006
  - White paper on the implications of the ten Conditions & Limitations (C&Ls) in the SER
  - Westinghouse Letters demonstrating SER compliance in response to C&Ls 6 and 7

- Prior to start of reload design, conduct Challenge Board Review
  - Customer focused review of implementation plan
  - Board consists of customer and Westinghouse members
  - Reload design team presents plans for implementation
  - Addresses engineering, licensing and manufacturing schedules

- Change management process
  - Designed to inform both customer and Westinghouse engineers who are new to the use and requirements of Optimized ZIRLO™

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SER Conditions & Limitations

- 10CFR50.46 exemption request required
  - Submitted by Licensee
  - Westinghouse provides LAR template, modified to customer needs
- Additional data submittal requirements
  - Westinghouse provides to NRC annually and notifies customers
- Meet existing standards and requirements
  - 62 GWd/MTU lead rod burnup
  - All standards & methodologies applicable to ZIRLO™ cladding
- Meet modified standards and requirements
  - Maximum fuel waterside corrosion
  - Decreased Yield and Ultimate Tensile Strength (temporary)
  - If using LOCBART or STRIKIN-II, may need to re-evaluate
  - Reduced PCT limit during the Locked Rotor Event

Background

- Two CE-NSSS plants are currently using Optimized ZIRLO™ cladding in region quantities
- Nine plants have firm plans and dates to use Optimized ZIRLO™ cladding
- Seven plants have been provided quotes or have fuel contract options to buy Optimized ZIRLO™ cladding
- These plants represent nearly 40% of the Westinghouse U.S. fleet
- NRC rule on Post-LOCA Clad Oxidation is likely to increase the demand for Optimized ZIRLO™ fuel cladding as it will recover lost margin

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Estimated Optimized ZIRLO™ Clad Usage by Year for U.S. Plants

- Spring 2011 - Four plants
- Fall 2011 – Two plants
- 2012 – Ten plants
- 2013 – Eight plants
- 2014 – Four plants

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High Burnup Program

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Agenda

- High Burnup Direction
- High Burnup Needs
- Westinghouse Alloy Development
- Optimized ZIRLO™ Properties and Experience
- Optimized ZIRLO™ Irradiation Programs
- Optimized ZIRLO™ Performance

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High Burnup Direction

- Step 1
  - PWR: Increase burnup to [ ]a,c using Optimized ZIRLO™ for fuel rod cladding for both Westinghouse and CE NSSS.
  - BWR: Increase burnup to [ ]a,c using [ ]a,c

- Step 2
  - PWR: Increase burnup to [ ]a,c for all fuel designs using [ ]a,c
  - BWR: Increase burnup to [ ]a,c for all fuel designs using [ ]a,c

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High Burnup Needs

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Westinghouse Alloy Development

Zircaloy-4 ⇨ ZIRLO™ ⇨ Optimized ZIRLO™

Reduced corrosion and growth.

Evolutionary improvement to ZIRLO™, [ ]a,c corrosion reduction.

	Zircaloy-4	ZIRLO™	Optimized ZIRLO™
Niobium			
Tin			
Iron			
Chromium			
Microstructure			

a,b,c

[ ]a,c

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Optimized ZIRLO™ Properties

- Creep properties designed to be similar to ZIRLO™
  - The lower tin results in [ ] a,c
  - Countered by [ ] a,c
- Use of [ ]a,c means also that Optimized ZIRLO™ unirradiated mechanical properties are affected, i.e., [ ] a,c
- [ ]a,c
  - Hot cell exam was performed to obtain data. The report is being finalized.
  - [ ]a,c

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Optimized ZIRLO™

- Developed based on vast ZIRLO™ experience
  - [

]a,c

but with

- Significantly improved corrosion properties

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Optimized ZIRLO™ Experience

- Used in [ ]a,c units, worldwide
- More than [ ]a,c fuel rods
- High burnup experience to above [ ]a,c
- Licensed in the U.S.
- First two reloads in U.S. Plants are undergoing their second cycle
- Other U.S. and European plants are expected to begin reload use during the next two years

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Optimized ZIRLO™ Irradiation Programs

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Optimized ZIRLO™ Oxide Thickness [ ]a,c Compared to ZIRLO™

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Optimized ZIRLO™ Rod Growth

[ ]a,c

a,b,c

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Hot Cell Examinations on Optimized ZIRLO™ Rods

- Hot cell exams performed on rods after one and two cycles
- Typical measurements include:
  - Rod diameter and length
  - Cladding oxide
  - Cladding hydrogen
  - Pellet stack position
- Provide irradiated materials for ramp tests and mechanical tests
- Results of exams are used to validate:
  - Fuel performance code models
  - Accuracy of poolside measurements
  - Mechanical behavior under accident conditions (RIA, LOCA)

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Optimized ZIRLO™ Hydrogen Measurement

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Update on Vogtle Creep & Growth Program

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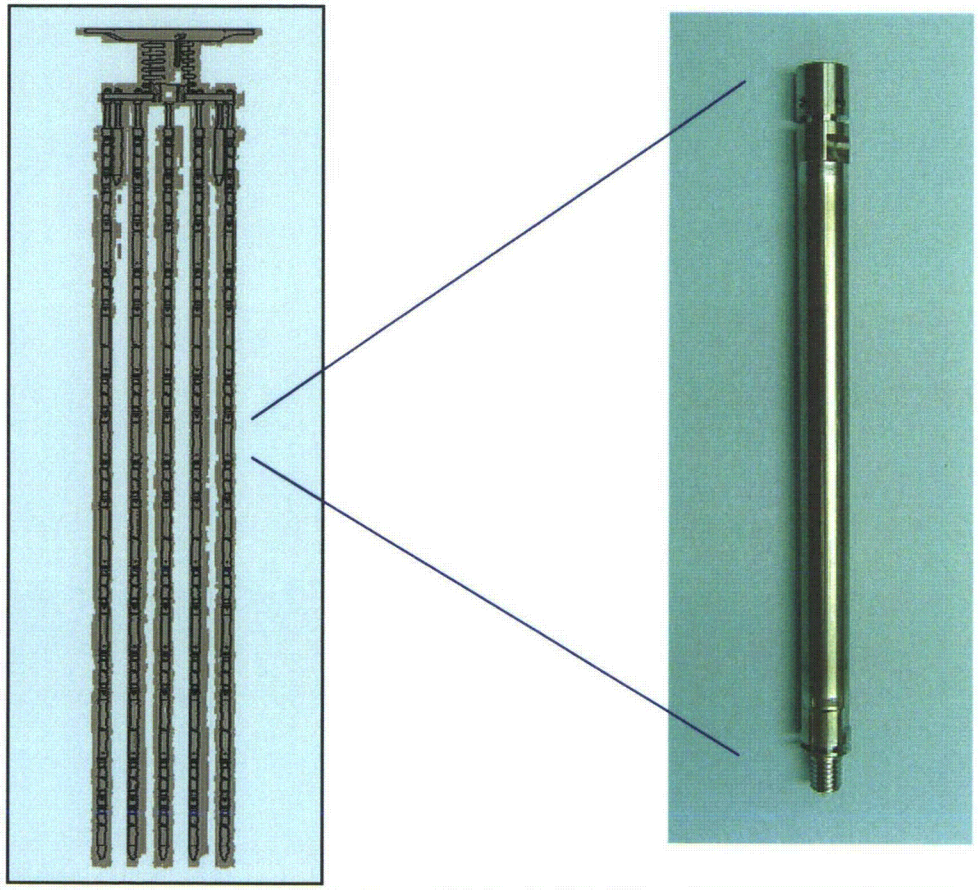
Vogtle Creep & Growth Test - Setup



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Vogtle Creep Capsule Key Results

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Reactivity Initiated Accident (RIA)

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Current Analysis Criteria

- Rod Ejection
  - Maintain coolable geometry
    - NRC interpretation: peak fuel pellet average enthalpy less than 280 cal/g
    - Westinghouse criteria are more restrictive
      - Peak fuel pellet average enthalpy less than 200 cal/g
      - Fuel centerline melting less than 10%
      - Peak cladding temperature less than 3000°F
      - Maximum total Zr-water reaction less than 16%
  - Peak RCS pressure below emergency stress limits
  - Offsite doses within guidelines

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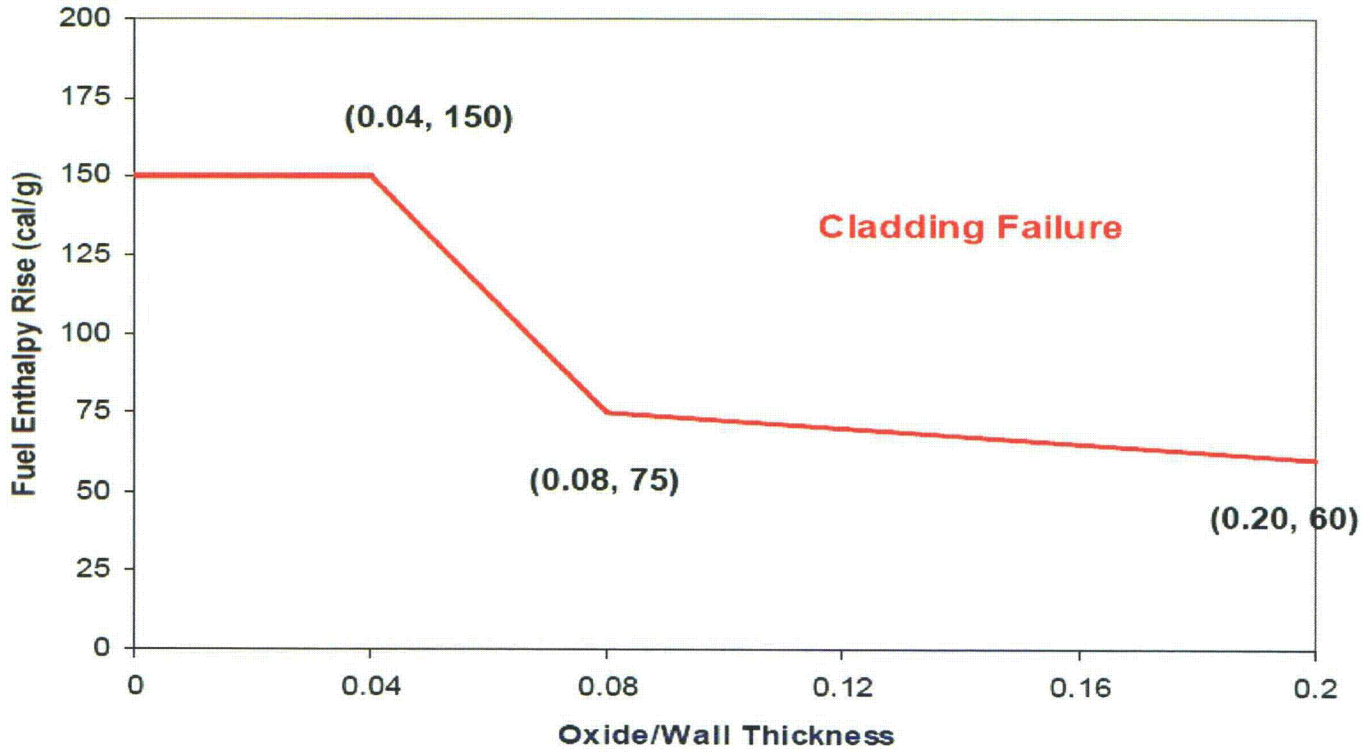
Interim Analysis Criteria (SRP 4.2 Rev. 3)

- Issued March 2007
- Applicable to New Plants, LARs
- Separate the fuel failure and coolability criteria
- New fission product fuel-to-cladding gap inventory for dose calculations

PWR PCMI Cladding Failure Threshold

FIGURE B-1: PWR PCMI Fuel Cladding Failure Criteria



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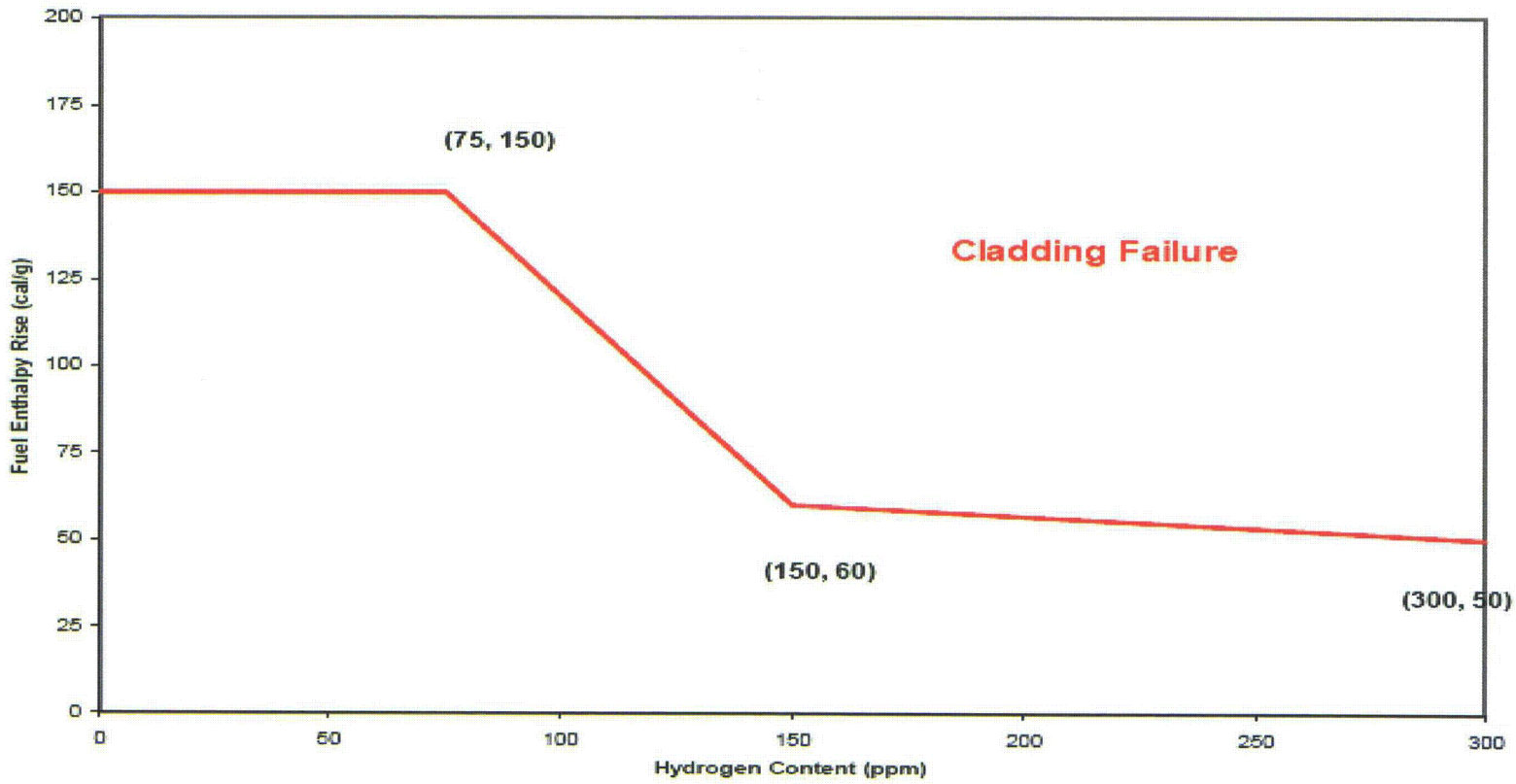
BWR PCMI Cladding Failure Threshold

FIGURE B-2: BWR PCMI Fuel Cladding Failure Criteria



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PWR RIA Limits vs. Oxide Thickness

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Major Methods/Models Needed for Implementation

- Approval of 3D RIA method (WCAP-15806-P-A)
- Approval of Cladding Alloy Dependent Models
  - Corrosion model
  - Hydrogen pickup model
  - Cladding ductility as function of hydrogen
  - Accounting for uncertainties
- Approval of plant technical specifications to allow new method

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NRC Inputs Still Needed

- Final form of PCI criteria with accounting for high temperature capsule results from NSRR.
- More detail on coolability justification for exceeding cladding failure threshold.
- Acceptance of hot cell testing for:
  - Relative ductility to Zircaloy-4 under RIA conditions
  - Absolute ductility under RIA conditions
- Acceptability of limited centerline melt for at-power events.
- Position on when existing plants need to conform to new criteria.

Impact of New Criteria

- Burnup dependent advanced (3D) analysis is likely required
- “No fuel melt" criterion would likely require 3D analysis for HFP cases
- Licensing implementation is not defined
- No agreed upon / defined methodology for fuel dispersal/mechanical energy generation
- Additional work / justification is needed for HZP & HFP (part power issues)

Westinghouse 3D Rod Ejection Methodology (WCAP-15806-P-A)

- Will be used to address New RIA Criteria
- SER received in 2003
  - "The basic 3-D rod ejection methodology is generally applicable to all Westinghouse and CE NSSS PWRs."
- Already used in several plant analyses
- Continues to employ Westinghouse reload safety analysis methodology (WCAP-9272)

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1D vs. 3D Comparison

- Performed to demonstrate the conservatism in 1D methodology & margin gain via 3D methodology

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Full Spectrum LOCA Update

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Agenda

- Drivers for Enhanced LOCA Margins
- Full Spectrum LOCA Development Program Objectives
- NRC Initiatives to be Addressed with Full Spectrum LOCA
- Program Status/Schedule

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Current Westinghouse Technology

Large Break LOCA

- Best-estimate methods based on Westinghouse COBRA/TRAC (PD2) well established
  - ASTRUM (2004), CQD (1996)
    - Valid from 1 ft^2 to DEG (2 * 4.12 ft^2)
    - Marviken assessments down to 0.76 ft^2
- Appendix K methods based on BASH (1986) and EM99 (1999) Evaluation Models

Small Break LOCA

- Appendix K methods based on NOTRUMP (1985), S2M (1997)

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Drivers for Enhanced LOCA Margins

Current Environment

- Increased regulatory scrutiny of Appendix K methods
- NRC expectation to consider pre-transient oxidation can be problematic due to Appendix K conservatisms
  - 3-loop Westinghouse and some Combustion plants have little SBLOCA margin
- Extended Power Uprates (EPU) further challenge limits

Future Environment

- Rulemaking to address ANL high burnup LOCA test results will reduce margins further
- Large Break Redefinition initiative

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Full Spectrum LOCA Development Program Objectives

Develop Code/Methodology to address all break sizes for Westinghouse/Combustion fleet in a single analysis

- Develop assessment strategy for all high and medium ranked phenomena/physical processes for each sub-scenario (small, intermediate & large break)
- Improve models as needed based on code assessment results
- Use advanced statistical uncertainty methods
- **Eliminate Small Break LOCA as a Design Constraint**

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Full Spectrum LOCA Scenario

"The break size considered in the Westinghouse FSLOCA methodology includes any break size such that break flow is beyond the capacity of the normal charging pumps up to and including a double ended guillotine rupture with a break flow area two times the pipe area."

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NRC Initiatives to be Addressed with Full Spectrum LOCA

- Accommodate expected revisions to ECCS Acceptance Criteria in 10 CFR 50.46(b)
  - Change process initiated with Research Information Letter 0801
  - Advance Notice of Proposed Rulemaking issued in August 2009
  - New limits may be problematic at intermediate burnups for a subset of plants
    - Margin generated with Full Spectrum LOCA can be used to offset lower oxidation limits, potential for double-sided oxidation requirement away from break

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NRC Initiatives to be Addressed with Full Spectrum LOCA (cont.)

- Facilitate implementation of voluntary Large Break LOCA Redefinition Option (Revisions to 10 CFR 50.46(a))
  - Break size sampling can vary (small => DEG if maintain current requirements, small => transition break size (TBS) if optional licensing basis pursued)

Prior NRC Updates

December 13, 2005 (LTR-NRC-05-68)
- Drivers, PIRT approach, code selection, assessment matrix

October 18, 2006 (LTR-NRC-06-59)
- Code development progress, assessment matrix update, submittal outline

June 11-12, 2007 (LTR-NRC-07-29)
- PIRT review, code development progress, assessment results

December 3, 2007 (LTR-NRC-07-61)
- Advanced statistical methods being used

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High Level Overview of Full Spectrum LOCA Methodology

- Break sizes spectrum divided into two regions to provide adequate coverage of all possible LOCA scenarios
- Models range of applicability and code assessment extended to cover all LOCA scenarios
- Improved statistical procedures to minimize variability in predictors for a more robust compliance with 10 CFR 50.46 acceptance criteria

Typical PCT Sample in Region I (Small Breaks) Demonstration FSLOCA Analysis for a 3-Loop PWR

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Typical PCT Sample in Region II (Larger Breaks) Demonstration FSLOCA Analysis for a 3-Loop PWR

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Program Status/Schedule

- Finalizing Topical Report
- Final Design Review
- Expect to submit by the end of Summer 2010
  - Will schedule pre-submittal meeting accordingly

Westinghouse is requesting the NRC to factor review of Full Spectrum LOCA into its resource planning

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Westinghouse Non-Proprietary Class 3

Hydrogen / Oxide / Embrittlement

Westinghouse/NRC Fuel Update Meeting
Monroeville, PA
April 13, 2010

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Topics

- Regulatory Changes
  - SRP 4.2 Revision 3
  - 10 CFR 50.46 ANPR
- Method / Material Improvements
- Hydrogen / Oxide / Embrittlement
- Summary

Regulatory Changes

- SRP 4.2 Revision 3
  - Currently applicable to new plant licensing covered under 10 CFR Part 52
  - The proposed limits for PWRs and BWRs are noted below: The PWR limit is based on oxide/wall per fuel enthalpy rise, whereas the BWR limit is based on hydrogen content per fuel enthalpy rise

FIGURE B-1: PWR PCMI Fuel Cladding Failure Criteria

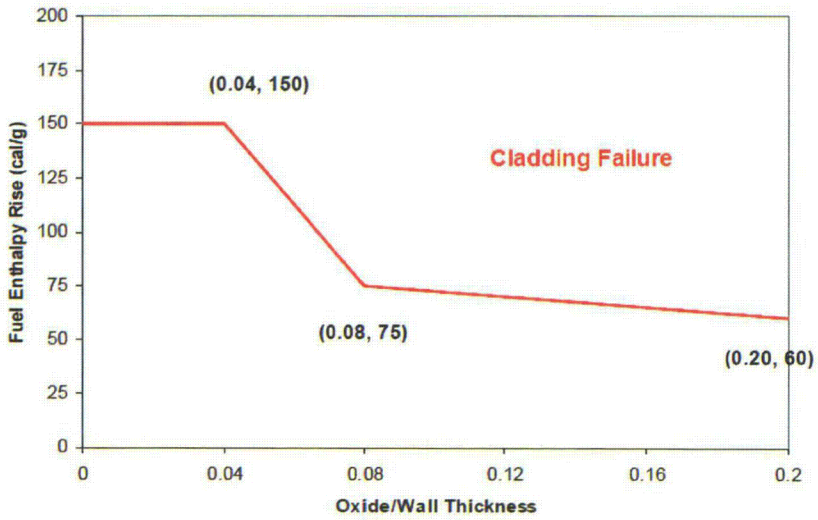
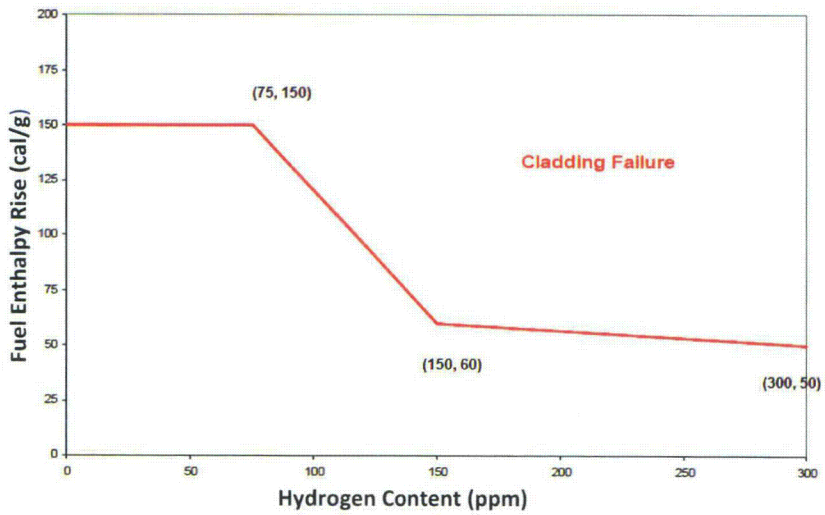


FIGURE B-2: BWR PCMI Fuel Cladding Failure Criteria



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Regulatory Changes

- 10 CFR 50.46 ANPR
  - Advance Notice of Proposed Rulemaking: Performance-based Emergency Core Cooling System Acceptance Criteria issued August 13, 2009 in the Federal Register
  - Approach that would expand the applicability of the rule to all current and future cladding materials
  - Modify the reporting requirements and address the issues raised in a petition for rulemaking (PRM) regarding crud and oxide deposits and hydrogen content in fuel cladding
  - The NRC sponsored research conducted by the Argonne National Laboratory (ANL), as well as jointly funded programs at the Kurchatov Institute and the Halden Reactor project, revealed that alloy composition has a minor effect on embrittlement, but the cladding corrosion which occurs as fuel burnup increases has a substantial effect on embrittlement

Method / Material Improvements

- 3D Rod Ejection: WCAP-15806-P-A: Discussed in Another Presentation

- Westinghouse Clad Corrosion Model for ZIRLO™ and Optimized ZIRLO™: WCAP-12610-P-A/CENPD-404-P-A Addendum 2

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Method / Material Improvements (continued)

- Optimized ZIRLO™: WCAP-12610-P-A/CENPD-404-P-A Addendum 1-A

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- AXIOM:

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- References:

(1) Garde, A., Mitchell, D., Slagle, W., "Hydrogen Pick-up Fraction for ZIRLO™ Cladding Corrosion and Resulting Impact on the Cladding Integrity," Top Fuel 2009, Paper 2136, 2009.

(2) Garde, A. M. et. al., "Advanced Zirconium Alloy for PWR Application", Accepted for Platform Presentation at the 16th ASTM International Zr Symposium, Chengdu, China, May 2010. Submitted for Publication in JAI.

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Figure 1

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Figure 2

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Hydrogen / Oxide / Embrittlement

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Figure 3

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Summary

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ABWR Fuel Licensing Overview

Westinghouse/NRC Fuel Update Meeting
Monroeville, PA
April 13, 2010

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Agenda

- Licensing Overview
- ABWR Licensing Plan
- Current Status of LTR Work

BWR Application of Westinghouse Codes and Methodologies

- The current U.S.-licensed methodology for fuel and safety analysis is for reload analyses and fuel vendor transition
- Nevertheless, Westinghouse has broad experience from FSAR work and initial cores in Europe:
  - The applicability of Westinghouse Codes and Methodologies for ABWRs and full-scope FSAR work is not licensed yet in the U.S.

Westinghouse BWR Code Overview

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Changes Introduced by ABWR and Full-Scope Fuel Related FSAR Applications

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Licensing Topical Report (LTR) Schedule

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Interface Amongst Transient LTRs

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Interface Amongst Transient LTRs (continued)

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Fast Transients - Analysis Methods

- Westinghouse transient methods (main methods)
  - BISON - for core average system response calculations in 1-D
  - BISON/SLAVE - for hot channel CPR response calculations in 1-D
  - POLCA-T - System code with 3-D kinetics model based on POLCA7

Fast Transients - Analysis Methods (continued)

- Licensing topical reports
  - ASEA Atom RPA 90-90-P-A, "BISON - A One-Dimensional Dynamic Analysis Code for Boiling Water Reactors", December 1991
  - CENPD-292-P-A, "BISON – One-Dimensional Dynamic Analysis Code for Boiling Water Reactors: Supplement 1 to Code Description and Qualification", July 1996
  - WCAP-16606-P-A, “Supplement 2 to BISON Topical Report RPA 90-90-P-A”, January 2008
  - WCAP -16747-P “POLCA-T: System Analysis Code with Three-Dimensional Core Model”, March 2007. Awaiting final SE

Fast Transients - Analysis Methodology

- Fast Transients
  - The following events are explicitly described in Westinghouse's Reference Safety Report for BWR:
    - Generator load rejection without bypass
    - Turbine trip without bypass
    - Feedwater controller failure - maximum demand
    - Pressure Regulator Failure – Closed

Fast Transients - Analysis Methodology (continued)

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"Qualification of a Control System Model" LTR 1

Objectives

- Description of all components
- Separate component validation
- Integral plant measurement verification

Current Status

- Licensing of the model development process
- Applicable to all BWR design plants
- LTR submitted according to plan in mid October 2009
- 45 RAIs were received in March 2010

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"Extended Qualification of the BISON Code" LTR 2

Objectives

- Provide additional qualification of the BISON code
- Remove SER restriction about reverse flow through recirculation pumps
- Describe an advanced control rod insertion model and its qualification
- Describe pump motor and frequency converter models
- Describe Post Dryout and rewet models along with qualification

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"Fast Transient and ATWS Methodology" LTR 3

Objectives

- Describe a complete methodology for the fast transients analyses that is not included in the current NRC-approved reload fuel licensing methodology
- Introduce new modern uncertainty methodology based on use of Monte Carlo
- Use of non-limiting Fast Transients analysis has been performed for all Westinghouse (ASEA-ATOM)-built BWR plants and approved by several European authorities
  - currently ongoing for several ASEA-ATOM-built BWR plants for power uprates and periodic safety reviews
- Demonstrate using the BISON code, but the methodology is intended to be generic

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"Transient Methodology for Chapter 15" LTR 3

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"Transient Methodology for Chapter 15" LTR 3 (continued)

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"Qualification of POLCA-T for AOO and ATWS" LTR 4

Background

- LTR 4 will qualify POLCA-T for Chapter 15 analyses including ATWS

Objectives

- To be submitted as two appendices (4a (Appendix C) for AOO and 4b (Appendix D) for ATWS) to the POLCA-T Topical Report
- Transients and ATWS verification and validation

"Qualification of POLCA-T for AOO and ATWS" LTR 4 (continued)

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"Qualification of POLCA-T for AOO and ATWS" LTR 4 (continued)

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"Revision of Reference Safety Report for BWR Fuel and Core Analysis" LTR 10

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"Revision of Reference Safety Report for BWR Fuel and Core Analysis" LTR 10 (continued)

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"Revision of Reference Safety Report for BWR Fuel and Core Analysis" LTR 10 (continued)

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Stability – LTR 5

Objective

- Demonstrate adequacy of methodology for:
  - Determining the OPRM (Oscillating Power Range Monitor) trip setpoint
  - Confirming adequacy of the OPRM armed region
  - Developing exclusion zones in the power/flow map to be used when the OPRM is out-of-service (Backup Stability Protection) for the ABWR plants

Current Status

- NRC pre-submittal meeting scheduled for May 5, 2010.
- On schedule - June 2010 submittal

LOCA – LTR 6

Objective

- Demonstrate applicability of LOCA methodology to ABWRs
- Demonstrate ABWR Emergency Core Cooling System (ECCS) performance
- Demonstrate ability to predict peak cladding response to early dryout due to fast pump coast-down
  - Additional validation of internal pump model
  - Validation of dryout prediction (FRIGG loop tests)

Current Status

- Submitted on schedule on Sept 30, 2009
- Under review by the NRC

Primary Containment - LTR 7

Objective

- Obtain NRC approval for the Westinghouse GOTHIC ABWR primary containment modeling methodology
  - The GOTHIC ABWR primary containment modeling methodology will mimic the DCD methodology to the extent practical with GOTHIC code

Primary Containment - LTR 7 (continued)

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Secondary Containment - LTR 8

Objective

- Obtain NRC approval for GOTHIC sub-compartment analysis methodology
  - GOTHIC sub-compartment model results have been compared with test data as part of the code qualification effort
  - NRC has reviewed and approved other sub-compartment modeling applications with GOTHIC (Reference: ML041410566)
  - GOTHIC sub-compartment model results will be compared with benchmark results from the approved Westinghouse sub-compartment analysis code (TMD)
  - Appendix E for WCAP-16608 will be submitted to document the Westinghouse sub-compartment design analysis methodology

Secondary Containment - LTR 8 (continued)

Current Status

- Delayed to April 2010
- NRC has been informed of the delay
- NRC pre-submittal meeting scheduled for March 24, 2010.

Hydrodynamic Loads - LTR 9

Objective

- Obtain NRC approval for a GOTHIC pool swell calculation methodology
  - GOTHIC pool swell model results have been compared with Marviken test data as part of the code qualification effort
  - GOTHIC pool swell analyses results have been accepted by the NRC for Technical Specification changes for Mark III containments for limited applications (Reference: ML031290397)
  - The GOTHIC pool swell model results will be compared with the DCD benchmark results

Current Status

- Submitted ahead of schedule in Sept 2009
- Under review by the NRC

"Control Rod Blades" – LTR 11

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"Control Rod Blades" – LTR 11 (Continued)

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Summary

- Westinghouse codes and methods been successfully used for several reactors in the U.S. and in Europe, at nearly all commercial BWR types
- They are licensed/accepted in several countries:
  U.S., Spain, Switzerland, Germany, Finland and Sweden
- A plan to apply for NRC license of Westinghouse Fuel, Control Rod Blades, codes and methodologies for ABWR and full-scope FSAR application has been defined and is now underway
  - To date 4 LTRs have been submitted to the NRC on-time
- Over the remaining 6 months, significant work is underway involving a global team to support the submittal of the remaining 8 LTRs to the NRC
- This work will license all fuel related FSAR work and ABWR-type designs in the U.S.

Questions?

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AP1000 Fuel Update
Core Reference Report Overview

Westinghouse/NRC Fuel Update Meeting
Monroeville, PA
April 13, 2010

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Westinghouse Approach to Initial Core Load

The AP1000 fuel, core components and core design are being developed in three distinct stages:

1. NRC Certified Design ⇨ DCD (Rev 15)
2. Certified Design Amendment ⇨ DCD (Rev 16) + DCD (Rev 17) + DCD (Rev 18) ⇨ COL approval
3. Final Design ⇨ DCD (Rev 18) + COL + Core Reference Report (CRR) ⇨ Core and Fuel Design at Initial Plant Start-up

This process allows the use of the best fuel product, core components and core design at the time of initial plant start-up consistent with the ongoing advancements we are seeing today.

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Approach to Initial Core Load (continued)

- Final Design ⇨ COL + Core Reference Report
  - Submitted after the initial COL is approved, but prior to initial fuel load with sufficient time for NRC review and approval
  - Core Reference Report to be submitted to the NRC for review and approval (consistent with the requirements to address Tier 2* items)
    - Addresses enhancements to fuel assembly and core components design
    - Addresses initial fuel loading pattern, control rod designations and associated core physics parameters
    - Provides an updated safety analysis
  - The standardized Core Reference Report for the AP1000 fleet would be submitted for incorporation into the New Plant License following the NRC guidance (DC/COL-ISG-011, Nov 09)
  - Provides for NRC review & approval of initial core

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Approach to Initial Core Load (continued)

AP1000 Core Reference Report (CRR) attributes

- Meets guidelines of DC/COL-ISG-011 for departures consistent with example of "... information that may change frequently during a review..."
- Consistent with recent NRC staff presentations (Chris Van Wert's "Post-COL Fuel Design License Amendments" given by NRO)
- The AP1000 Core Reference Report once reviewed and approved by the NRC would include the final changes to fuel assembly and component design, core design, and the necessary supporting safety analysis prior to initial core load
- The report presents the COL holder's Cycle 1 initial core fuel loading pattern, control rod designation (both RCCA and GRCA), and associated core physics parameters at the time of initial plant startup

Next step for Initial Core Load

- AP1000 Core Reference Report
  - Reviewed and approved by the NRC
  - Addresses final changes to the methods, core, fuel and core components design prior to initial core load
- Core Reference Report to be submitted to the NRC consistent with construction schedule to maximize opportunity to incorporate fuel and core design evolutions
  - Allow sufficient time for NRC review
- Current schedule indicates
  - Pre-submittal meeting in the 3rd Quarter 2010
  - Prior meetings with NRC proposed that the Core Reference Report be submitted following approval of the first COL

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Core Reference Report

Fuel and Core Design evolutions that will be addressed in the Core Reference Report:

- Advanced Core Design enhancements:
  - Multi-zoned designs
  - Low Leakage Core
  - Alternative burnable absorbers
- Reference to newly Approved Methodology
- Advancements in Fuel Assembly design
- Changes to the DCD licensed Gray Rod design
- Safety Analysis results

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First Core Loading Pattern Comparison

DCD 1st Core Design	Advanced 1st Core Design

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Uses Westinghouse experience to design a 1st core representative of today's standard reloads

- Consistent with today's Low Leakage Loading Pattern reload cores
- Eases transition from first core to reload

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Burnable Absorbers for AP1000 Designs

- Integral Fuel Burnable Absorber (IFBA)
  - Thin coating of ZrB_2 on the surface of the fuel pellets
  - Primary burnable absorber for all cycle designs
- Discrete absorbers in guide thimbles
  - Wet Annular Burnable Absorber (WABA) placed into guide thimbles
  - Replaces Pyrex design in DCD

Proven burnable designs used in the current operating units

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Methodology Enhancements

- All Methodology used will have been previously approved by the NRC
- New References to be added in Core Reference Report
  - Qualification of Two-Dimensional Transport Code PARAGON, WCAP-16045-P-A *(Approved)*
  - Qualification of the NEXUS Nuclear Data Methodology, WCAP-16045-P-A Addendum 1-A *(Approved)*
  - Westinghouse Control Rod Ejection Accident Analysis Methodology Using Multi-Dimensional Kinetics, WCAP – 15806-P-A *(Approved)*
  - Qualification of the New Pin Power Recovery Methodology (WCAP-10965 Addendum 2) *(Under Review)*

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Fuel Overview

- Basic fuel design is the Westinghouse 17X17 and 17X17 XL Robust Fuel Assembly (RFA)
- Substantial operating experience with this design
- Improvements in fuel assembly design from the DCD Rev. 17
  - Final grid heights will be specified in the Core Reference Report
  - Robust P-grid will be incorporated

Control Assembly Features in Core Reference Report

Rod Cluster Control Assembly (RCCA) and Gray Rod Cluster Assembly (GRCA)

- Cast spider replaces the brazed spider
  - More robust design provides:
    - Improved operating reliability
    - Improved manufacturability
  - Significant industry operating experience
- Ion nitride coating of the RCCA and GRCA rodlets
  - Improved wear resistance
  - Significant industry operating experience

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Advanced Gray Rod Control Assembly (GRCA) Design

- Westinghouse has developed an advanced GRCA rodlet design utilizing Tungsten as a gray absorber material
- Tungsten (W) has significant advantages over the currently approved materials (i.e., Ag-In-Cd):
  - Melting point of tungsten is over 6000°F
  - Extremely low irradiation swelling
  - Optimal reactivity worth for this application meeting overall licensed GRCA rod worth while providing more uniform power distribution
  - Enhanced mechanical and nuclear performance (increased lifetime and constant reactivity)
  - Tungsten rodlet (W-24) meets existing GRCA design criteria
- Tungsten generates significantly less waste due to its enhanced lifetime

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Advanced Gray Rod Control Assembly (GRCA) Design (cont.)

- Plan is to have design ready in time for standardized application in the U.S. and the rest of the world, including China
- Tungsten Topical Report *(Enhanced GRCA Rodlet Design, WCAP-16943)* is currently under review by NRC
  - RAIs were received by Westinghouse
  - Responses have been submitted to NRC

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Safety Analysis Impacts

- Safety Analysis revised to include impacts of:
  - Advanced First Core
  - Fuel and core components design changes
  - Changes resulting from work progressing towards Design Finalization and described in DCD revisions.
  - Will incorporate system changes explicitly analyzed for the Core Reference Report including:
    - Rod drop time
    - Piping resistances
    - Piping configurations
    - Accumulator, CMT, RV nozzle resistances and geometry changes
  - Will provide an integrated safety analysis reflecting current design

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Safety Analyses Overview

- Non-LOCA Analyses
  - Rod Withdrawal from Subcritical
  - Rod Withdrawal at Power
  - Boron Dilution
  - Loss of Load / Turbine Trip
  - Feedwater Malfunction
  - Excessive Load Increase
  - Hot Zero Power Steamline Break
  - Hot Full Power Steamline Break
  - RCS Depressurization
  - Partial / Complete Loss of Flow
  - Locked Rotor
  - Rod Ejection using new RIA requirements
  - Feedline Break
  - Inadvertent CMT/CVS Actuation
  - Dropped Rod
  - Inadvertent PRHR
- LOCA Analyses
  - Large Break LOCA analyses
  - Small Break LOCA analyses
- Dose Analyses
  - Source term updated for the Advanced First Core

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Core Reference Report Format

- Follows format of previously submitted fuel update reports (e.g., Upratings, RTSRs, etc.)
- Table of Contents:
  - –Introduction and Summary
  - –Fuel Mechanical Design Features
  - –Nuclear Design
  - –Thermal and Hydraulic Design
  - –LOCA / Non LOCA Transient Analyses
  - –Appendices
    - Markups to DCD Chapters 4, 15 and 16
    - Completed Sections without markups

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Summary

- AP1000 Core Reference Report
  - Submitted for Review and Approval by the NRC after the initial COL is approved
  - Addresses final changes to the methods, core, fuel and core components design prior to initial core load
  - Provides integrated Safety Analysis
  - Follows format of previously submitted fuel update reports (e.g., Power Uprates, Reload Transition Safety Reports (RTSRs), etc.)

Questions?

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Spent Fuel Pool Criticality Analysis

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April 13, 2010

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Topics of Discussion

- Background
- Lessons Learned
- SFP Criticality Topical Report
- Recent Changes in NRC Reviews
- Summary

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Background

- WCAP-14416: Approved in 1996
- July 2001, the NRC notified Westinghouse that WCAP-14416 methodology could no longer be used.

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Background/Recent History

- [ ]a,c analysis was withdrawn, major issues identified by the USNRC were:
  - Validation of computer codes, consistent use of computer codes to address RAIs
  - Application of the Depletion Uncertainty
  - Selection of bounding axial burnup profile (Blanket vs. Non-blanketed)
  - Burnable Absorbers during depletion
  - Reactivity effect of soluble boron on uncertainties, neglecting minor structural materials
  - Interface Calculations

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Lessons Learned

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SFP Criticality Topical Report

- Computer Codes
- Validation through Benchmarking
- Acceptance Criteria
- Depletion Parameters and Operating Conditions
- Axial Burnup Distribution
- Uncertainty and Bias Analysis
- Accident Analysis
- Rack Module Interfaces/Full Pool Models

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SFP Criticality Topical Report (continued)

- Computer Codes

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SFP Criticality Topical Report (continued)

- Benchmarking

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SFP Criticality Topical Report (continued)

- Depletion/Core Operating Parameters
  - Moderator Temperature/Density
  - Fuel Temperature
  - Core operating soluble boron concentration
  - Power Density and Operating History
  - Burnable Absorbers (WABA, BPRA, etc)
  - Integral Absorbers (IFBA, Gad)

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SFP Criticality Topical Report (continued)

- Axial Burnup Distribution

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SFP Criticality Topical Report (continued)

- Uncertainty Analysis
  - Manufacturing Uncertainties (Fuel and Rack Tolerances)
  - Eccentric Positioning
  - Depletion Uncertainty
  - Burnup Record Uncertainty
  - Monte Carlo Uncertainty
  - Validation Uncertainty
- Bias Analysis
  - Pool Moderator Temperature and Density
  - Validation Bias

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SFP Criticality Topical Report (continued)

- Accident Analysis
  - Single misloaded fresh fuel assembly in most reactive location
  - Single misplaced assembly outside of rack (if possible)
  - Dropped fuel assembly (horizontal and vertical)
  - Rack Lateral Shift (Seismic)
- Offset with soluble boron

Recent Changes in NRC Review

- Previous approval of methods has been guarantee of approval in subsequent applications.

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- RAI questions need to be screened for accuracy and applicability
  - Confusion between Boral blistering and Boraflex degradation
  - Questions on existing racks when new racks are being added
  - RAIs on subjects clearly explained and justified in the analysis

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New SFP Criticality Efforts

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Summary

- Analyses performed today have more detailed descriptions, justification and analysis than just three years ago due to revised NRC expectations.
- Previously approved plant specific analyses provides no assurance that those methodologies will be approved in subsequent submittals.

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Westinghouse Fuel Performance Update Meeting
Agenda
April 14, 2010

<u>Wednesday, April 14, 2010 Licensing Review (Westinghouse and NRC)</u>

8:00 – 8:15 a.m. Westinghouse Organization

8:15 – 9:00 a.m. Topical Reports and Schedules

9:00 a.m. – 12:30 p.m. General Licensing Topics

- Very Long-Term Dry Storage and Transportation of SNF – Role of the Front End of the Fuel Cycle (NRC presentation)
- Other Topics of Interest (from NRC)

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- Process Issues
- Other Topics of Interest

Westinghouse Non-Proprietary Class 3

Westinghouse Organization

Westinghouse/NRC Fuel Update Meeting
Monroeville, PA
April 14, 2010

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Westinghouse Fuel Performance Update Meeting

April 14, 2010

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Current Westinghouse Fuel Engineering Organization

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Current Westinghouse Organizations that Interface with the NRC

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President and CEO
Aris Candris

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Topical Report Schedules

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PWR Topical Report Schedules

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PWR Topical Report Schedules (Continued)

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AP1000 Topical Report Schedules

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BWR Topical Report Schedules

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ABWR Licensing Topical Report (LTR) Schedules

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General Licensing Topics

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