AREVA Inc.

2015 Fuel Performance Meeting

June 2 – 3, 2015
Richland, Washington

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2015 Fuel Performance Meeting

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AREVA / NRC Annual Fuel Performance Meeting

Richland, Washington
June 2 – 3, 2015

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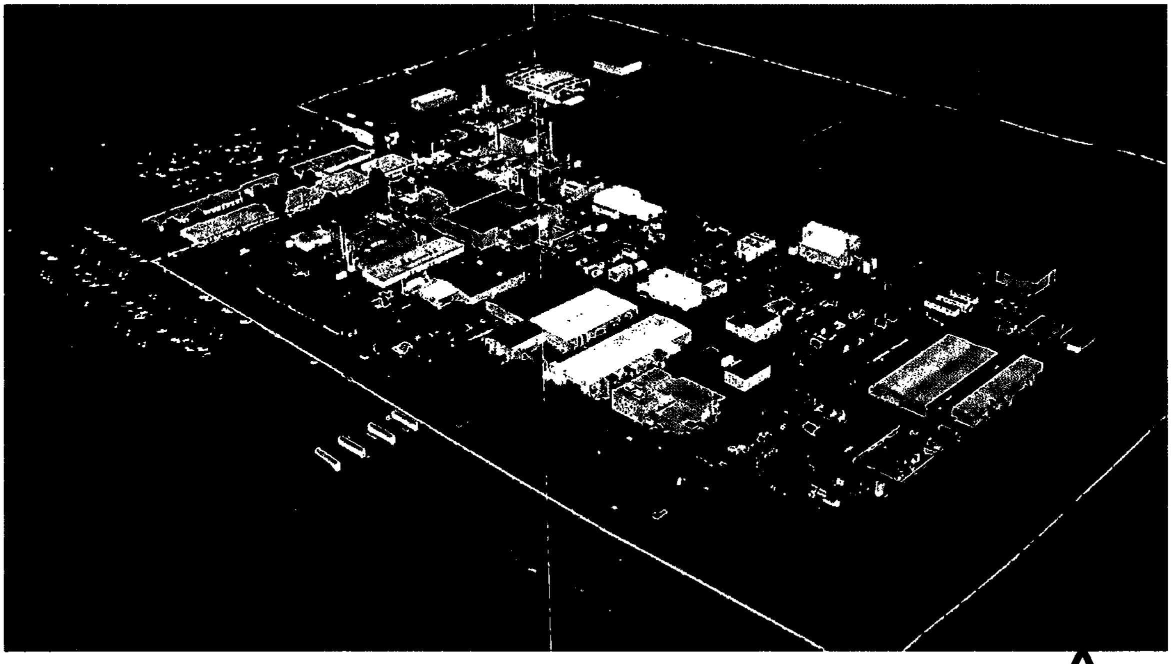
Safety Message



Fuel Performance Meeting Objectives

- Increase NRC's knowledge of AREVA's fuel activities, facilities, products and strategies
- Discuss AREVA's submitted and planned topical reports and associated customer needs
- Increase NRC's understanding of AREVA's:
  - Advanced codes & methods development
  - Fuel designs, operating experience, observations and solutions
- Beneficial to NRC Staff and AREVA
  - Exchange ideas and expectations on fuel issues
  - Open communication and questions encouraged

Agenda – June 2, 2015
Morning

- 7:45 **Badging Process** – A. Meginnis, et al.
- 9:00 **Welcome, Introductions and Safety Message** – A. Meginnis/J. Rowley
- 9:10 **NRR Management Discussion** – J. Dean/C. Jackson
- 9:40 **NRR Updates**
  Pilot LTR Review Process – J. Dean
  Topical Report Change Management – J. Dean
  RIA RG and SRP Development Insights – P. Clifford
- 10:10 **Break**
- 10:25 **Description of AREVA Inc.** – A. Meginnis
- 10:45 **U.S. Fuel Business Objectives** – S. Wilkerson
- 11:05 **AREVA Fuel Topical Reports** – R. Pederson
- 11:30 **Lunch**

Agenda – June 2, 2015
Afternoon

- 12:30 **Introductions and Safety Message** – A. Meginnis/B. Tilden
- 12:45 **NRC Staff Requested Topic** (telecon)
  B&W plant LBLOCA – TACO3 and TCD – J. Holm/J. Klingenfus
- 1:00 **Manufacturing Plant Tour** – B. Tilden
- 4:00 **Test Facility Tour** – K. Duggan
- 4:45 **Fuel Product Display** – S. Cole/J. Hartman/N. Garner
- 5:15 **Wrap-up of Day 1** – A. Meginnis
- 5:30 **Adjourn**

Agenda – June 3, 2015 Morning

- 7:45 **Badging/Escort** – A. Meginnis
- 8:00 **Safety Message** – A. Meginnis
- 8:05 **U.S. PWR Advanced Methods** – K. Segard
- 9:05 **Break**
- 9:20 **Overview of PWR Fuel Designs** – J. Hartman
- 10:05 **PWR Operating Experience & Fuel Exams** – S. Mazurkiewicz
- 11:00 **AREVA Fuel's Single-Phase CFD Capabilities** – T. Keheley
- 12:00 **Lunch**

Agenda – June 3, 2015 Afternoon

- 1:00 **Human Performance Lab Demo** – L. Hope
- 2:00 **New BWR core Engineering Methods**
  AURORA-B Methodology Suite – K. Quick
  Generic ATWSi Methodology – D. Tinkler
- 2:45 **Break**
- 3:00 **BWR Fuel & Channel Design**
  ATRIUM™ 11 Lead Test Assembly Irradiation Program & Poolside Inspection Results – S. Cole
- 4:00 **BWR Operating Experience & Fuel Exams** – N. Garner
- 5:00 **Wrap-up/Actions** – A. Meginnis
- 5:15 **Closing Remarks**
- 5:30 **Adjourn**

Description of AREVA Inc.

Alan Meginnis
Sr. Regulatory Affairs Manager

Richland, Washington
June 2 – 3, 2015

AREVA

What is AREVA and What Do We Do?

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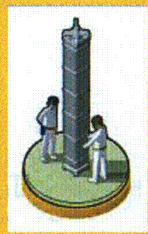
AREVA Competencies

Mines

- Exploration
- Mining Projects
- Mining
- Treatment
- Reclamation

Front End

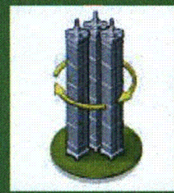


- Chemistry
- Enrichment
- Fuel

Reactors & Services

- New Builds
- Equipment
- Installed Base
- Nuclear Measurement

Back End



- Recycling
- Nuclear Site Development
- Logistics
- Fuel Storage
- Clean-up

Renewable Energies

- Wind
- Hydrogen and Energy Storage
- Bioenergy

AREVA Fuel Business Unit

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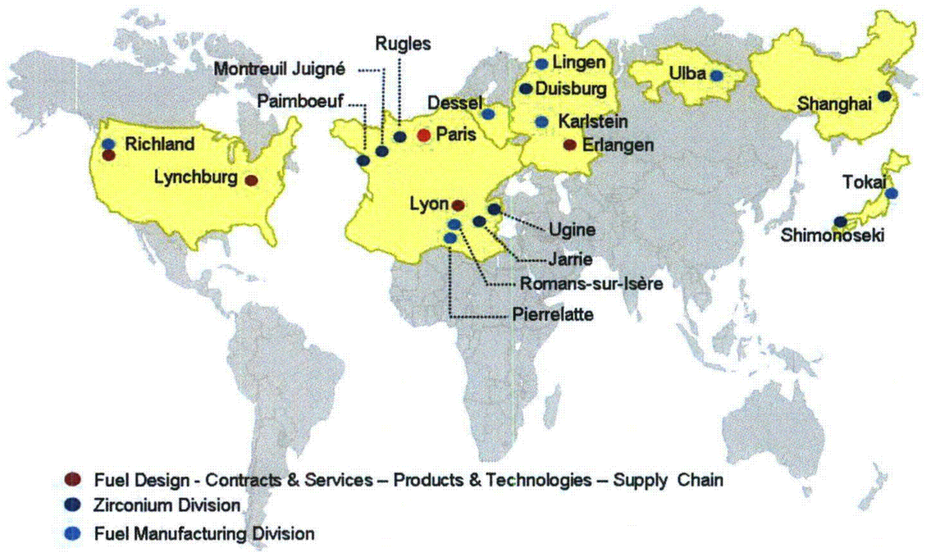
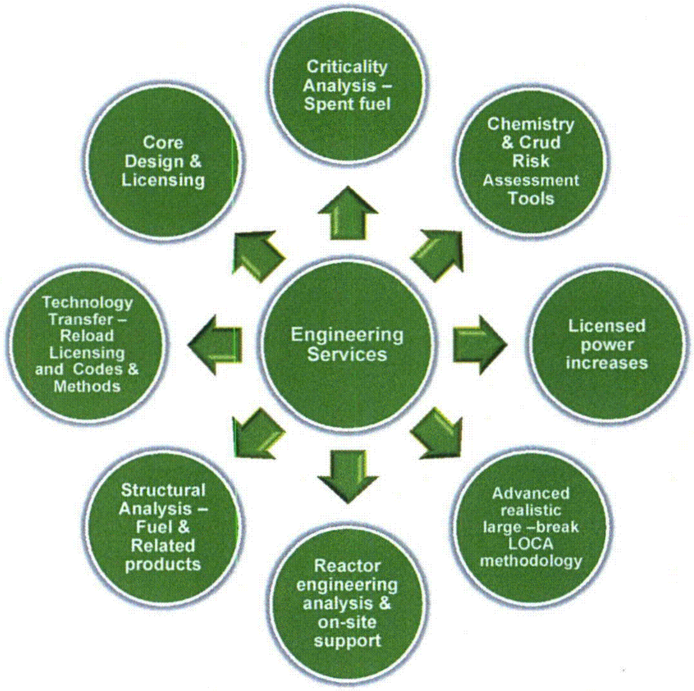
AREVA FUEL ACTIVITIES



A diverse expertise serving utilities worldwide

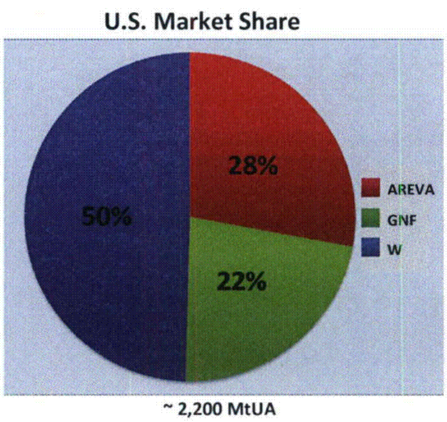
AREVA U.S. Fuel Facilities

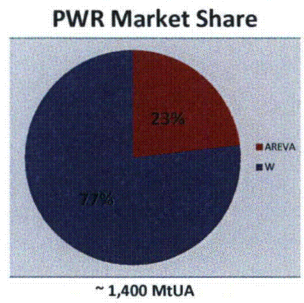
Engineering Services

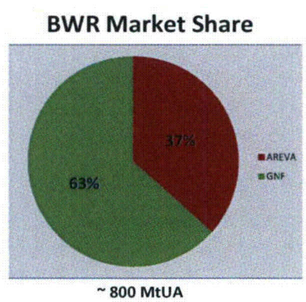


MARKET TREND ANALYSIS
U.S. Market Share

Updated
1st Qtr. 2015



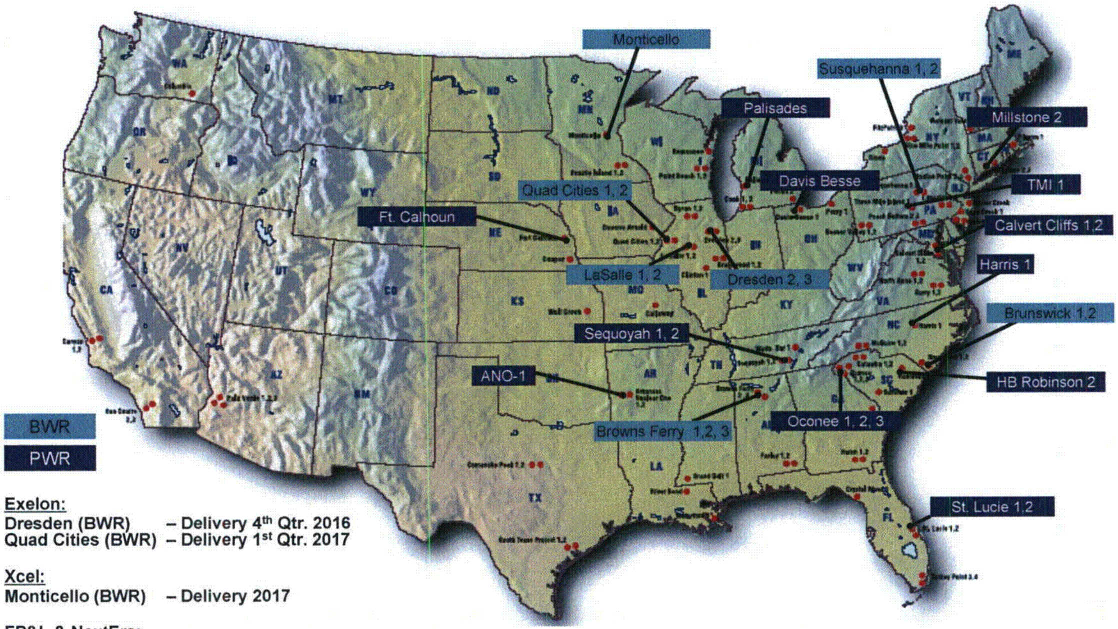




Six new units added since December 2011

- *Xcel / Monticello (BWR)*
- *FPL / St. Lucie 2 (CE16)*
- *Exelon / QC & DRE (BWR)*

AREVA U.S. Fuel Customers



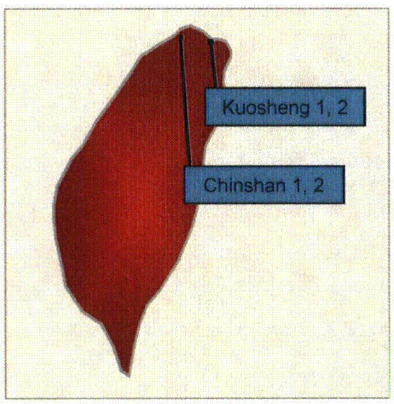
Exelon:
Dresden (BWR) – Delivery 4th Qtr. 2016
Quad Cities (BWR) – Delivery 1st Qtr. 2017

Xcel:
Monticello (BWR) – Delivery 2017

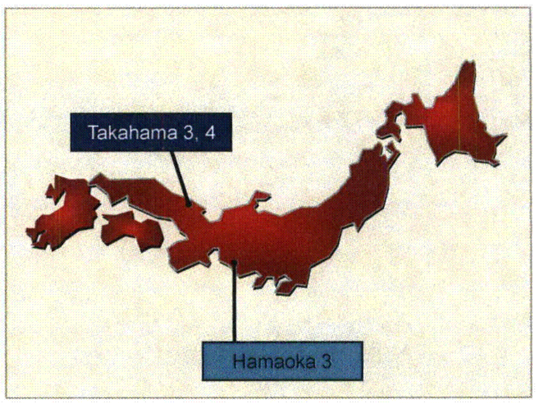
FP&L & NextEra:
St. Lucie 2 (PWR) – Delivery 1st Qtr. 2017

Data Source: FSDD October 23, 2013

Taiwan and Japan Fuel Customers



Taiwan



Japan

BWR

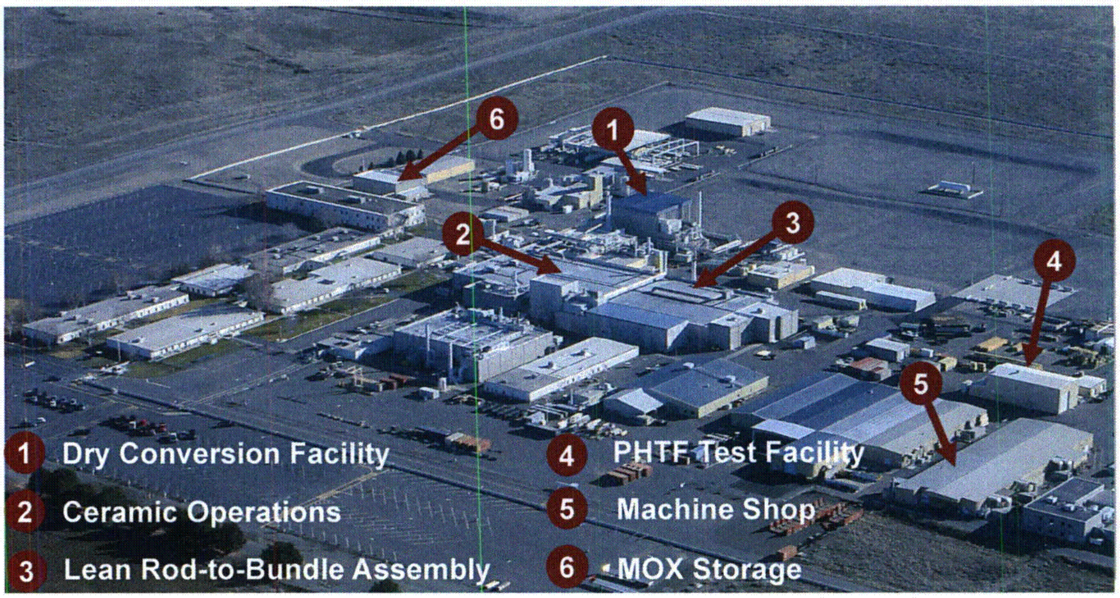
PWR

U.S. Plant/Lattice Types Supported

General Electric BWR	Combustion Engineering PWR	Babcock & Wilcox PWR	Westinghouse PWR
BWR – 3 10x10	14x14	15x15 Raised Loop	17x17, 15x15 3-Loop
BWR – 4 10x10	15x15	15x15 Lowered Loop	17x17 4-Loop
BWR – 5 10x10	16x16		

- AREVA supports a wide variety of different plant types with fuel products, codes and methods
- Globally, AREVA supports additional plant designs and has extensive operating experience

Achieving Fuel Fabrication Excellence
Richland Fuel Fabrication Facility



Richland Site – Extensive Capabilities

PWR and BWR Fuel Fabrication

- UO_2 and GAD Pellet Manufacturing
- Type B Uranium Material Processing (BLEU)
- RCCA's, BPRA's and Other Control Components
  - Complex machining
  - Burnable poison pellet

Plant Technical Capacities (tU/year)

Powder	1,600
Pellets	1,200
FA	1,200

Manufacturing Services

- ADU Conversion Process
- Combustible Material Incineration and U Recovery From Ash ($SCCO_2$)
- UF_6 Cylinder Cleaning, Recertification and Storage
- Non-irradiated fuel disassembly

Engineering

- BWR Engineering : core design & analysis, codes and method development
- Product Development : Fuel Assembly Test loop

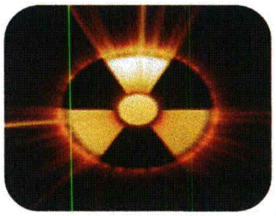
Commitment to Health & Safety Achieving Operational Excellence

Safety

- Our people view personnel and nuclear safety as an intrinsic core value
- AREVA uses utility specific Health & Safety Plan
- We measure effective performance
- Safety conscious work environment

ALARA

- 2 REM limit per person annually (rolling)
- Reduction in radiation exposure is a top priority for AREVA
- Equipment designed for dose savings



Human Performance

- Observation brief from previous day with specific focus area for the day
- Assessments performed for trends / focus areas
- CRs generated for each product line for review and action

Discussion

Acronyms/Nomenclature

- ADU — Ammonium Diuranate
- BLEU — Blended Low-Enrichment Uranium
- BPRA — Burnable Poison Rod Assembly
- CFD — Computational Fluid Dynamics
- GAD — Gadolinium
- LTR — Licensing Topical Report
- RCCA — Rod Control Cluster Assemblies
- RG — Regulatory Guide
- RIA — Reactivity Insertion Accident
- SRP — Standard Review Plan

U.S. Fuel Business Objectives

Scott Wilkerson
Vice President, Engineering
Fuel Business Unit

Richland, Washington
June 2 – 3, 2015

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Agenda

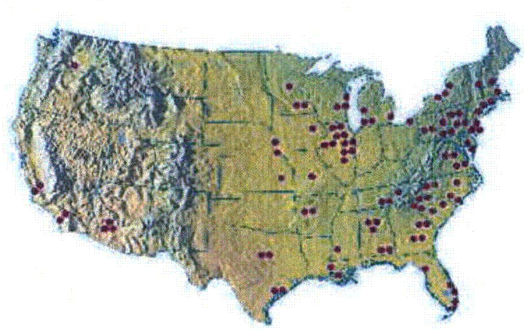
- ▶Objectives
- ▶U.S. Market Overview
- ▶New Technology Pipeline
- ▶Opportunities
- ▶Moving Forward
- ▶Summary

Objectives

- Inform the NRC of AREVA Fuel's business objectives including the introduction of new products and technology that support continuous improvements of technology and enhancing overall safety.
- Underscore the linkage between development investments and the future market.
- Engage the NRC to apply resources to review AREVA's submittals, supporting timely and predictable introduction of advanced fuel products.

U.S. Market Overview

AREVA has provided Fuel Assembly Products to ALL Segments



- AREVA intends to remain a primary vendor long into the future.

Industry Health

- AREVA successfully reduced the failure rate of AREVA fuel products.
- Similar to operational excellence in plant operations, the industry's health also relies upon continuous improvements in the product value: both in terms of performance AND safety.
- AREVA already has more technology in the pipeline.

New Technology Pipeline

- AREVA has invested in innovative BWR fuel products such as
  - Fuel Assembly: ATRIUM 11
  - Debris Prevention: Third Generation Fuel Guard
  - Advanced Fuel Channels: Beta Quenched BWR Zr
- AREVA has invested in innovative PWR fuel products such as
  - Fuel Assembly: GAIA
  - Material: Q12 alloy
- Substantial additional investments in Advanced Analytical Codes and Methods for both PWRs and BWRs (i.e., ARCADIA, AURORA-B)
  - Directly addresses the existing "legacy" software issues
- Additional investments will be made when there is credible business case → Investments must pay off
- Timely and predictable batch implementation of new technology is mandatory in order to achieve Investment Pay Off

Timely NRC review and approval is key to our success.

U.S. Opportunities
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Now may be the last time for major innovative change.

Licensing Plans
10 Parallel NRC Reviews

[ ]

Licensing Plans
10 Parallel NRC Reviews

Strong partnership with customers and engagement with NRC to manage workflow is necessary for success.

Moving Forward

- **Industry stakeholders gain value through the timely introduction of new technology.**
  - Dependent on timely, efficient NRC review and approval of submittals.
- **AREVA is partnering with our customers to facilitate implementation certainty.**
- **AREVA is engaging NRC through a variety of tools:**
  - Drop-in meetings with various levels of NRC management
  - Pre-submittal tactical meetings, well in advance of submittals
  - Pre- and post- submittal meetings
  - Delivering high quality topical reports
  - Hosting audits and supporting clarification telecons
  - Timely communications

How else can we support the objective of timely & efficient?

Summary

- ▶ AREVA plans to remain a primary vendor long into the future.
- ▶ Industry's health relies upon continuous improvements of technology.

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- ▶ AREVA is engaging both our customers and the NRC to achieve timely and predictable introduction of new products on the market.

AREVA Fuel Topical Reports

Ronda Pederson
Advisory Engineer
Fuel Regulatory Strategy

Richland, Washington
June 2 – 3, 2015

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Agenda

- ▶ Objectives
- ▶ AREVA Fuel topical reports
  - Submitted topical reports
  - Planned submittals
- ▶ Licensing objectives and tactics
- ▶ Summary

Objectives

- Provide an overview of AREVA Fuel topical reports, submitted and planned.
- Summarize key aspects of AREVA's licensing objectives and tactics.
- Discuss with NRC management how to achieve timely, efficient reviews to support AREVA Fuel business goals.

Today

- NRC has 9 AREVA Fuel submittals: 5 active and 4 inactive

[ ]

- Customers recognize safety benefits of advancements, yet see licensing risk due to the uncertainty in NRC's review period for submittals
- AREVA and our customers are actively pursuing NRC approval of submitted topical reports to support site-specific LARs
  - EMF-2328, SBLOCA, Supplement 1
  - EMF-2103, Revision 3, SRELAP5 RLBLOCA Methodology

Submitted Fuel-related LTRs
5 of 9 are under "Active" NRC review

1. EMF-2328, SBLOCA, Supplement 1
2. EMF-2103, Rev 3, SRELAP5 RLBLOCA Methodology
3. ANP-10323P, "Fuel Rod Thermal Mechanical Methodology for BWRs and PWRs" - GALILEO™
4. ANP-10300, "AURORA-B: Evaluation Model for BWRs; Application to Transient and Accident Scenarios"
5. ANP-10335P, "ACE/ATRIUM 11 Critical Power Correlation"

AREVA is committed to supporting NRC's efficient review.

Submitted Fuel-Related LTRs
"Active" NRC Reviews

1. **EMF-2328, SBLOCA, Supplement 1**
   - Submitted March 2, 2012. Received draft SER dated April 27, 2015.
   - Submitted comments on the draft SER on May 11, 2015.

2. **EMF-2103, Rev 3, SRELAP5 RLBLOCA Methodology**
   - Submittal on September 13, 2013 addressed NRC's draft RAIs.
   - Audit in September 2014.
   - Responded to RAIs on January 16, 2015.

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AREVA is committed to supporting NRC's efficient review.

Submitted Fuel-Related LTRs "Active" NRC Reviews

3. **ANP-10323P, "Fuel Rod Thermal Mechanical Methodology for BWRs and PWRs" - GALILEO™**
   - **Submitted August 1, 2013.**
   - **Addresses legacy code issue - thermal conductivity degradation.**
   - **NRC acceptance letter dated March 27, 2014.**
     - RAIs expected by July 31, 2014; Draft SER by December 2015.
   - **Rough draft RAIs received April 21, 2015.**

4. **ANP-10300, "AURORA-B: Evaluation Model for BWRs; Application to Transient and Accident Scenarios"**
   - **Submitted December 23, 2009.**
   - **Status changed to active in June 2013; Selected by NRC for pilot project for improving the TR review process.**
   - **RAI dated February 25, 2015.**
   - **Partial response submitted on February 27, 2015; remaining information to be submitted in June 2015.**

Submitted Fuel-Related LTRs "Active" NRC Reviews

5. **ANP-10335P, "ACE/ATRIUM 11 Critical Power Correlation"**
   - **Submitted 2/27/15.**
   - **NRC notified Regulatory Affairs of acceptance in April 2015.**

AREVA is committed to supporting NRC's efficient review.

Submitted Topical Reports 4 of 9 Reviews are Inactive

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Submitted Topical Reports Inactive NRC Review Status

1. BAW-10247PA, Revision 0, Supplement 1 (RODEX4)
   - Submitted December 23, 2009.
   - RAI responses submitted in April 2013 and November 2013.
   - Hydrogen model (submitted in response to RAI 1) is related to a commitment in the GALILEO™ submittal.

[

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AREVA requests that NRC prioritize activating this review.

Submitted Topical Reports
Inactive NRC Review Status

2. **ANP- 10332P Rev.0 "AURORA-B: An Evaluation Model for BWRs; Application to LOCA Scenarios"**
   - Submitted March 24, 2014.
   - NRC's review is on hold until the technical review for AOO is substantially complete.
3. **ANP-10333P, Rev 0, "AURORA-B: An Evaluation Model for BWRs; Application to CRDA"**
   - Submitted March 31, 2014.
   - NRC's review is on hold until the technical review for AOO is substantially complete.
4. **EMF-2310PA, Revision 1, Supplement 1, SRP Chapter 15, Non-LOCA Methodology for PWRs**
   - Submitted December 15, 2011 to address legacy issue.

[ ]

Licensing Plans
2015 Planned Submittals

[ ]

Topical Reports Strategies

Fuel Regulatory Objectives

- **Obtain timely, efficient NRC review and approval of topical reports.**
  - Expand upon the successful open dialogue to achieve timely and efficient completion.
- **Achieve AREVA's objectives for deployment of advanced fuel and C&M technologies in the U.S.**
  - BWRs: ATRIUM™ 11 fuel and the AURORA-B C&M Suite
  - PWRs: GAIA fuel and the ARCADIA® C&M Suite

AREVA's Licensing Process
What are current challenges?

- Timely application of NRC resources
- Review duration
  - Delayed RAI receipt
  - Quantity of RAIs
  - Delayed review of RAI responses
  - Multiple rounds of RAIs
  - Significant resources needed to respond to RAIs
- Consistency of reviewer expectations
- Timely receipt of SER

AREVA's Licensing Process
What's working?

- 3-year projection for planned topical report submittals
- Frequent communications with NRC, at all levels of management, including Commission, discussing priorities
- Early pre-submittal tactical meetings with NRC provide:
  - Early NRC feedback
  - Opportunity to adjust scope and level of detail within planned schedule

AREVA's Licensing Process
What's working?

- Improved quality of topical reports
  - Use of template, consistent with NRC's Standard Review Plan
  - Structured for easier review and use
  - Clear safety benefits and clear scope of applicability
  - Explicit, where necessary

- Improved review process
  - Use of audits is intended to reduce RAIs and improve efficiency
- Continued engagement throughout the review process
- Licensee presence and communication of schedule needs

Summary

- AREVA promptly responded to NRC's identified concerns regarding use of legacy methods.
- AREVA and our customers are actively supporting NRC's review of submittals.
- AREVA and our customers need timely, efficient NRC reviews to support our objectives for ATRIUM™11, GAIA, ARCADIA® and AURORA-B suites.
- AREVA seeks NRC feedback on our strategy to advance methods & achieve efficient NRC reviews.

Acronyms/Nomenclature

- AREAM – AREVA Rod Ejection Analysis Methodology
- ARITA – ARCADIA®/RELAP Integrated Transient Analysis
- ATWSI – Anticipated Transient Without Scram with Instability
- C&M – Codes and Methods
- CRDA – Control Rod Drop Accident
- LAR – License Amendment Request
- LOCA – Loss of Coolant Accident
- LTR – Licensing Topical Report
- PWR – Pressurized Water Reactor
- RAI – Request for Additional Information
- RLBLOCA – Realistic Large Break Loss of Coolant Accident
- SBLOCA – Small Break Loss of Coolant Accident
- SER – Safety Evaluation Report

B&W Plant LBLOCA – TACO3 and TCD

John Klingenfus
Advisory Engineer
LOCA Methods

Richland, Washington
June 2-3, 2015

AREVA

Agenda

- Chronology of Thermal Conductivity Degradation (TCD) in AREVA's deterministic Appendix K based topical report, BAW-10192, "BWNT Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants"
- Key aspects of BAW-10192 TCD Supplement
- Next Steps

Chronology of TCD in B&W LOCA

AREVA has continuously evaluated TCD-related issues and applied them in the B&W LOCA EM

BAW-10192 TCD Supplement

- AREVA expects to apply an increased fuel temperature uncertainty (TCD bias) to TACO3 and GDTACO VAFTs to adequately bound the VAFTs produced by COPERNIC2
- The method of adjustment and supporting information to account for TCD will be documented in a Supplement to BAW-10192P-A, Rev 0, "BWNT Loss-of-Coolant Accident Evaluation Model for Once-Through Steam Generator Plants"
- A revision to BAW-10179P-A "Safety Criteria and Methodology for Acceptable Cycle Reload Analyses" is planned to capture the TCD EM supplement

Preliminary TACO3 UO_2 Hot Rod VAFT Uncertainty Adjustments

[ ]

TCD Adjusted Limits

- Conservatively penalized LOCA LHR limits are currently imposed on the axial power imbalance curves for all B&W plants. These penalties will be maintained until new LHR limits are performed with an approved Supplement that accounts for a TCD uncertainty bias on the VAFTs used in the LOCA.
- With the imposed LHR reductions at MOL and some at EOL, BOL cases still typically produce the limiting PCT.
- Following TCD Supplement approval, new plant specific analyses are planned for all B&W plants.

Next Steps

- AREVA plans to supplement BAW-10192, LOCA EM, and submit for NRC's review/approval
- AREVA plans to revise BAW-10179P-A, "Safety Criteria and Methodology for Acceptable Cycle Reload Analyses" to capture the TCD EM supplement
- Following NRC's review and approval, AREVA plans to perform plant specific LBLOCA reanalyses to formalize the TCD accounting in the B&W plant LOCA analyses

Acronyms

- BOL: Beginning of Life
- EM: Evaluation Model
- EOL: End of Life
- LBLOCA: Large Break LOCA
- LHR: Linear Heat Rate
- LOCA: Loss of Coolant Accident
- MOL: Middle of Life
- PCT: Peak Clad Temperature
- TCD: Thermal Conductivity Degradation
- VAFT: Volume-Averaged Fuel Temperature

US PWR Advanced Methods

Kevin Segard
Supervisor, PWR Methods and Licensing
AREVA Expert

Richland, Washington
June 2 – 3, 2015

AREVA

Agenda

- Objectives
- Introduction
- ARCADIA® Advancements
- AREA™ Rod Ejection Methodology
- ARITA™ NON-LOCA Methodology
- ARABOW™ Rod/Assembly Bow Methodology
- Summary

Objectives

- **Provide a status on**
  - **ARCADIA® Supplement**
  - **AREA Methodology**
  - **ARITA Methodology**
  - **ARABOW Methodology**
- **Provide an overview of the development of these methodologies**
- **Summarize expectations**
- **Obtain NRC feedback on process**

Background

- **Based on NRC feedback**
  - **AREVA is developing new codes and methods**
  - **Using state of the art codes to develop these methods**
  - **New codes are based on first principles, minimizing the use of empirical formulations**
- **New methodologies allow AREVA to**
  - **Improve safety through a better analytical tools**
  - **Replace legacy methodologies**
  - **Improve modeling of phenomena with more explicit tools**

Status of Codes (1/2)

▶New Codes

- APOLLO2-A – Assembly lattice code
- ARTEMIS™ – 3D core simulator code
- COBRA-FLX™ – Core thermal-hydraulics code
- GALILEO™ – Fuel thermal-mechanical code

ARCADIA®

▶Code Status

- ARCADIA® codes received NRC approval in 2013
- GALILEO™ Currently under review

These state of the art codes provide the foundation for AREVA's PWR Advanced Methods

Status of Codes (2/2)

▶ARCADIA® Supplement incorporates

- Code enhancements
- New core benchmarks
- New transient benchmarks
- Uncertainty definition
  - Total rod worth
  - MTC
  - Doppler

Methods Overview

- **AREA™ Rod ejection methodology**
  - 3D core transient representation
  - Full core pin-by-pin / subchannel-by-subchannel treatment
  - Time in life and power level sensitivity is considered
- **ARITA™ Non-LOCA methodology**
  - Capability to analyze an event in 0D or 3D
  - Full Core subchannel-by-subchannel model for DNB
  - FCM generated using detailed fuel rod-by-fuel rod data
  - Upgraded nodalization in S-RELAP5
  - More detailed (pin-by-pin) FCM analyses
- **ARABOW™ Rod/Assembly Bow methodology**
  - Updated rod/assembly bow method

ARCADIA®
Supplement

AREVA

ARCADIA®

- Approved in 2013
- Consists of
  - ANP-10297P-A "ARCADIA®"
  - ANP-10311P-A "COBRA-FLX™"
- ANP-10297P Supplement 1 to be issued in June 2015
  - Comparisons to cores with MOX identified areas for improvement within the ARCADIA® Codes
  - Improved MEDIAN power reconstruction technique for measured power distributions
  - Addition of a spacer grid model
  - Improved treatment of transients
  - Improvements to ^{148m}Pm branching ratio
  - Upscatter in U and Pu isotopes

Lattice Calculations

- Changes to APOLLO2-A expected to yield higher lattice reactivity

[ ]

Observed pin power differences are within ±1% with RMS < 0.005

APOLLO2-A Validation (1/2)

- **Critical Experiments:**
  - BASALA (Gad)
  - B&W*
  - CAMELEON* (Gad)
  - EPICURE-MOX*
  - EPICURE-UOX*
  - KRITZ-KWU-crit (Pu)*
  - KRITZ-KWU-crit (U)*
  - MISTRAL
  - SAXTON (MOX)
  - VIPEX-VENUS

* Presented in the ANP-10297P-A

APOLLO2-A Validation

- **Additional validations are made against**
  - Fission rate measurements
  - Spent fuel isotopics

ARCADIA® Benchmarks

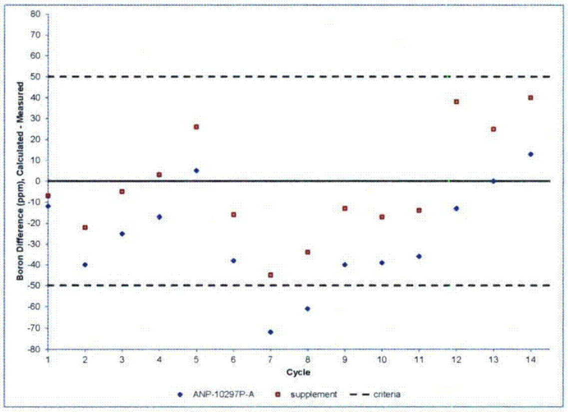
- **Re-analysis of benchmark data (criteria established in ANP-10297P-A)**
  - **HZP Physics Testing**
    - ARO CBC (within ±50 ppm or ±500 pcm equivalent)
    - Individual Rod Worth (within ±15% or ±100 pcm, whichever is larger)
    - Total Rod Worth (within ±10%)
    - ARO ITC (within ±2 pcm/°F)
  - **Core Follow Data**
    - HFP Boron letdown curve (within ±50 ppm or ±500 pcm equivalent)
    - Average assembly power distribution (RMS * 100 of the absolute difference < 5.0)
    - Average core axial power distribution (RMS * 100 of the absolute difference < 5.0)

Core Benchmarks

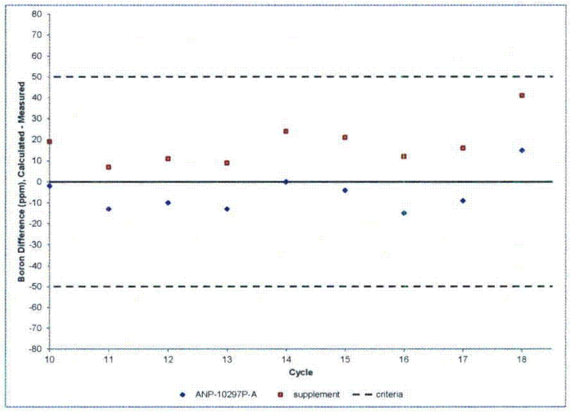
- **Two plants chosen for comparison**
- **Plant A**
  - **Westinghouse 157 Core 17x17 lattice**
  - **Movable fission probe**
  - **14 Cycles benchmarked (Cycles 1 – 14)**
- **Plant C**
  - **Combustion Engineering 217 Core 14x14 lattice**
  - **Fixed Rhodium SPNDs**
  - **9 Cycles benchmarked (Cycles 10 – 18)**

BOC HZP CBC Measurements

Plant A

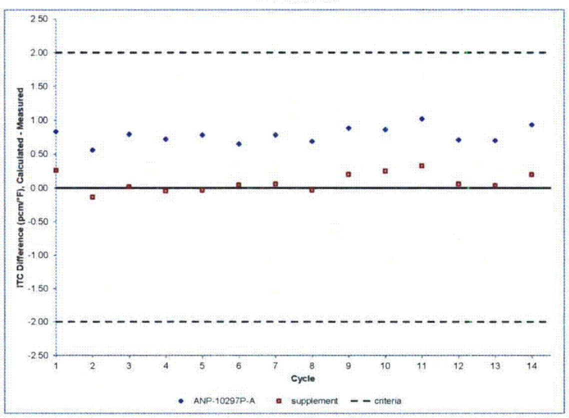


Plant C

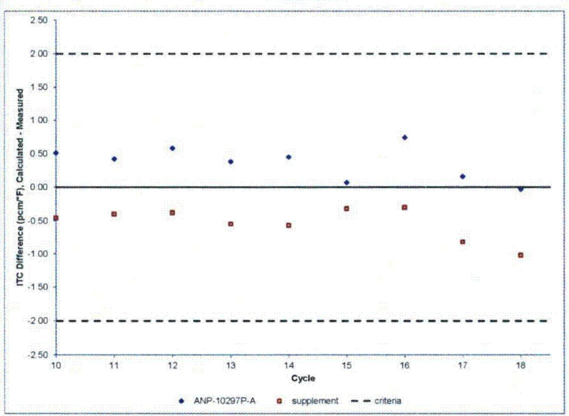


BOC HZP ITC Benchmarks

Plant A

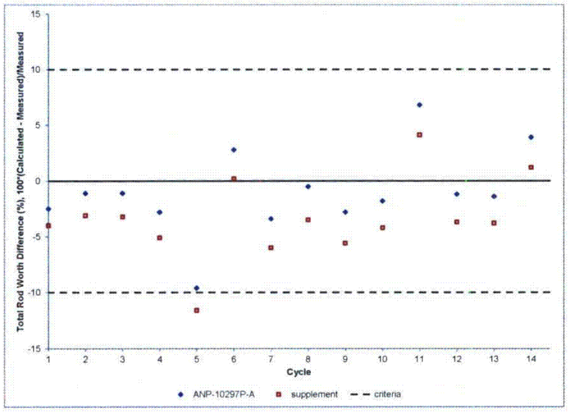


Plant C

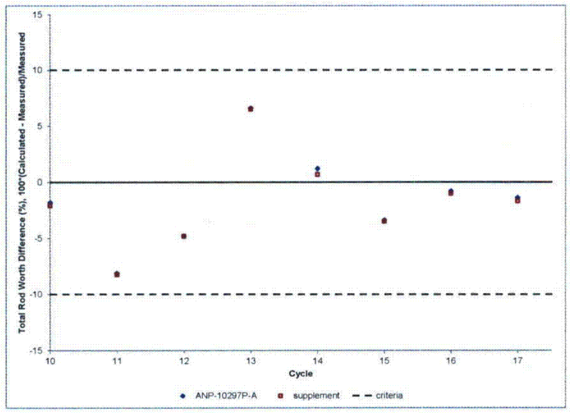


BOC HZP Total Rod Worth Benchmark

Plant A

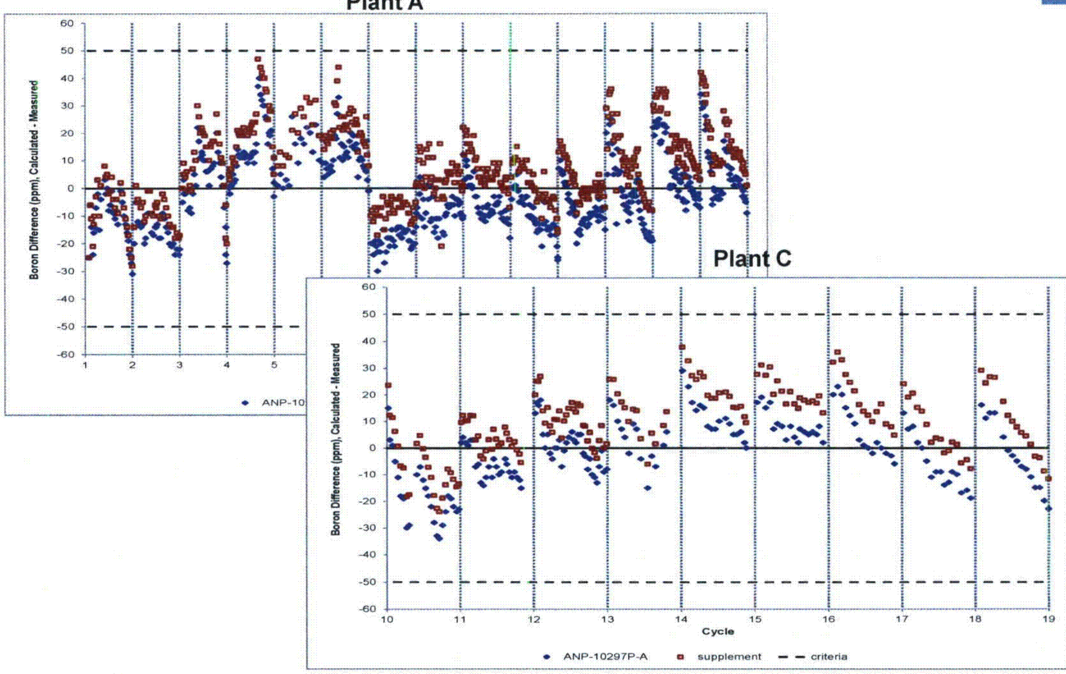


Plant C

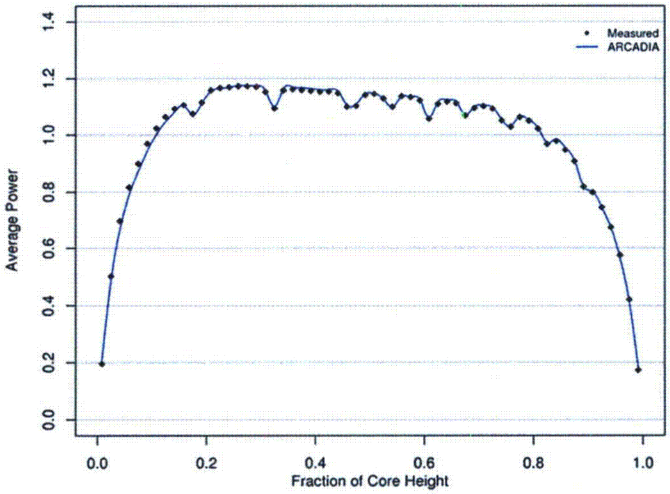


HFP CBC Benchmark

Plant A



Power Distribution



C-M Average Axial Power, RMS Difference *100 = 0.5

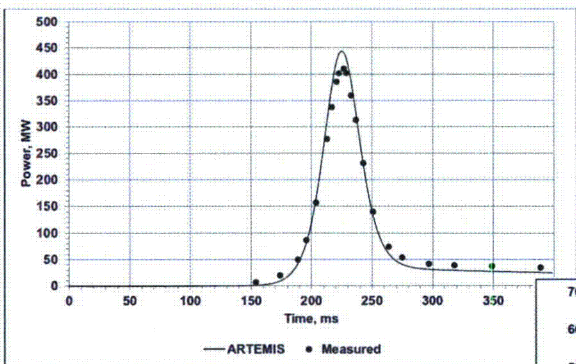
Radial RMS Differences

	ANP-10297P-A (C-M), RMS*100	Supplement (C-M), RMS*100
Cycle 14 BOC	0.7	0.6
Cycle 14 MOC	0.6	0.6
Cycle 14 EOC	0.6	0.7

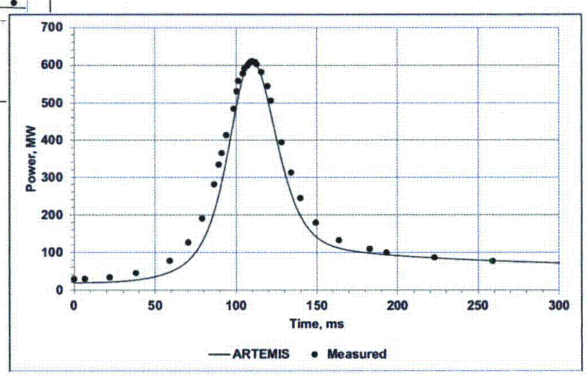
Axial RMS Differences

	ANP-10297P-A (C-M), RMS*100	Supplement (C-M), RMS*100
Cycle 14 BOC	2.6	1.2
Cycle 14 MOC	2.3	0.5
Cycle 14 EOC	2.7	1.3

SPERT Benchmark



- **Test 86**
  - **Peak Power**
    - Measured = 610 ± 60 MW
      Calculated = 444 MW
  - **Integrated Power**
    - Measured = 17 ± 2 MW-s
      Calculated = 14.6 MW-s



- **Test 60**
  - **Peak Power**
    - Measured = 410 ± 41 MW
      Calculated = 444 MW
  - **Integrated Power**
    - Measured = 8.5 ± 1.1 MW-s
      Calculated = 8.85 MW-s
  - **Power Response**

AREA™ Methodology Topical Report

AREVA

AREA Methodology Topical Report Features

- **Features of AREA Transient Models**
  - Every fuel rod in the core is explicitly modeled
  - Every sub-channel in the core is explicitly modeled
- **Power level and cycle burnup are considered**
- **Parameter biasing performed to ensure a conservative analysis**
- **Oxide / Hydrogen pick-up limits established using GALILEO™**

Reactivity Initiated Accident CRDA or CREA

- **Peak Pin ≠ Limiting Pin**
  - Burnup limits will lead to the limiting pin being the worst combination of oxide thickness and Δcal/g
  - Energy deposited in higher burnup pins can be significant
  - ARCADIA - Coupled Codes and Methods will significantly reduce the energy deposition calculated

[ ]

Coupled codes and methods will significantly reduce the energy deposition

ARITA™ Topical Report

AREVA

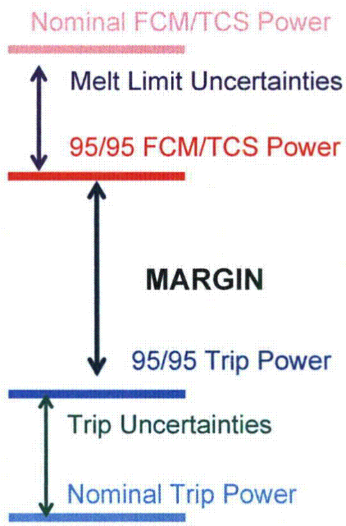
ARITA™ Structure

ARITA™ Consists of

- W and CE Setpoints
- Statistical DNB
- DNB propagation
- Non-LOCA event analysis (0D and 3D)
- Power Distribution Control

Setpoint Methods

- **Methods**
  - More robust statistical treatment of key parameters (uncertainties, trips and limits)
  - Inclusion of GALILEO, TCS and burnt fuel
  - Reduced P-T Space
  - Statistical FCM/TCS limit
  - Simpler, easier to understand and defend
- **Computing Power and Codes**
  - More explicit modeling – power distributions, P-T space, fuel types
  - Removal of simplifying assumptions – binning, multiple RSM
  - Monte Carlo Simulation vs Monte Carlo Integration
  - Integration of codes and functions



Statistical DNB

▶Statistical DNB Methodology

- ◇ Use NRC-approved subchannel code COBRA-FLX™ and NRC-approved CHF correlations.
- ◇ The basis is the current NRC-approved methods described in EMF-1961(P)(A) (CE plants) and EMF-92-081(P)(A) (W plants).

[ ]

DNB Propagation

▶DNB Propagation Methodology

- ◇ DNB propagation methodology included in ARITA topical report.
- ◇ Similar DNB propagation method to currently NRC-approved DNB propagation methodology (XN-NF-82-06 (P)(A) Revision 1 & Supplements 2, 4, & 5).

Non-LOCA Analysis

- **Two evaluation models are available**
  - 0D – using S-RELAP5 with a point kinetics model
  - 3D – using S-RELAP5 coupled to ARTEMIS™ with 3D transient capability
- **Either EM will be justified to evaluate SRP Chapter 15 Non-LOCA events**
  - Rod ejection is addressed in the AREA™ topical report

Evaluation Models

- **0D EM**
  - Non-coupled
  - S-RELAP5 point kinetics
  - Post-processed boundary conditions transmitted to steady-state ARTEMIS™ calculations
  - Similar to currently approved methods
- **3D EM**
  - Synchronous coupling via message passing interface (MPI)
  - ARTEMIS™ calculates 3D core power response
  - S-RELAP5 calculates the system response
  - RPS functions, power-based in ARTEMIS™, system-based in S-RELAP5

Reactor Vessel Mixing

- **Test data under review**
  - EPRI/WCAP
  - Oconee
  - B&W 177 Plant Test Facility
  - LACYDON
  - JULIETTE/ROMEO
  - ROCOM
  - Various publicly available papers
- **Observations**
  - Significant mixing in upper RV downcomer (DC), but very little mixing as flow proceeds downward in DC
  - Highly complex three-dimensional flow patters in RV lower plenum (LP)
  - Approximately uniform velocity distribution at core inlet

0D Analysis Methods (1/2)

- **Methods are similar to currently approved methodologies with the following changes:**
  - S-RELAP5 parametric biasing considers analyzed criteria
  - Intermediate power levels considered
  - Time in life considered
  - S-RELAP5 Hot Spot Model is eliminated
  - MSLB break flow
    - liquid expulsion during level swell (under consideration)
  - Reactor Vessel Modeling
    - RV sectorized based on plant design (e.g., CE, W 3-loop, W 4-loop)
    - RV Nodalization captures asymmetric response
    - Conservative core inlet and core outlet mixing applicable to any plant type

0D Analysis Methods (2/2)

▶Process Flow (uncoupled)

- S-RELAP5 system response with point kinetics using data from approved core simulator code
- S-RELAP5 RCS thermal-hydraulic conditions provided as boundary conditions for DNBR and FCM calculations
- Steady-state ARTEMIS™ is used to evaluate DNBR when required
- GALILEO is used to evaluate FCM when required

3D Analysis Methods (1/2)

▶Similar Methods to 0D Evaluation Model:

- S-RELAP5 parametric biasing considers changes for 3D analysis
  - Biasing may differ from 0d biasing due to coupled analysis
- Intermediate power levels considered
- Time in life considered
- S-RELAP5 Hot Spot Model is eliminated
- MSLB break flow
  - liquid expulsion during level swell (under consideration)
- RV Mixing
  - Conservative core inlet and core outlet mixing applicable to any plant type

3D Analysis Methods (2/2)

- **MPI synchronous communication between S-RELAP5 and ARTEMIS**
  - **S-RELAP5 calculates**
    - Core inlet temperature and flow
    - Core outlet pressure
    - Boron concentration
    - Control Systems
      - Control rod movement
    - SCRAM signal
      - system –based trips
  - **ARTEMIS calculates**
    - Fission power distribution
    - Thermal power distribution
    - Excore detector signals
      - Rod Control and RPS

Lock Rotor Analysis (1/2)

- **Based on 3D ARTEMIS™ Analysis**
  - **Used forcing functions from RELAP AOR**
  - **Parameters biased consistent with AOR**
  - **DNBR evaluated based on a full core 3D subchannel-by-subchannel analysis with rod-by-rod thermal-mechanical data**

PWR Locked Rotor Analysis (2/2)

[ ]

Change in methods results in [ ] DNB Point Improvement

PWR Excess Load from Hot Zero Power

[ ]

400°F Reduction in Maximum Fuel Temperatures

ARABOW™ Topical Report

AREVA

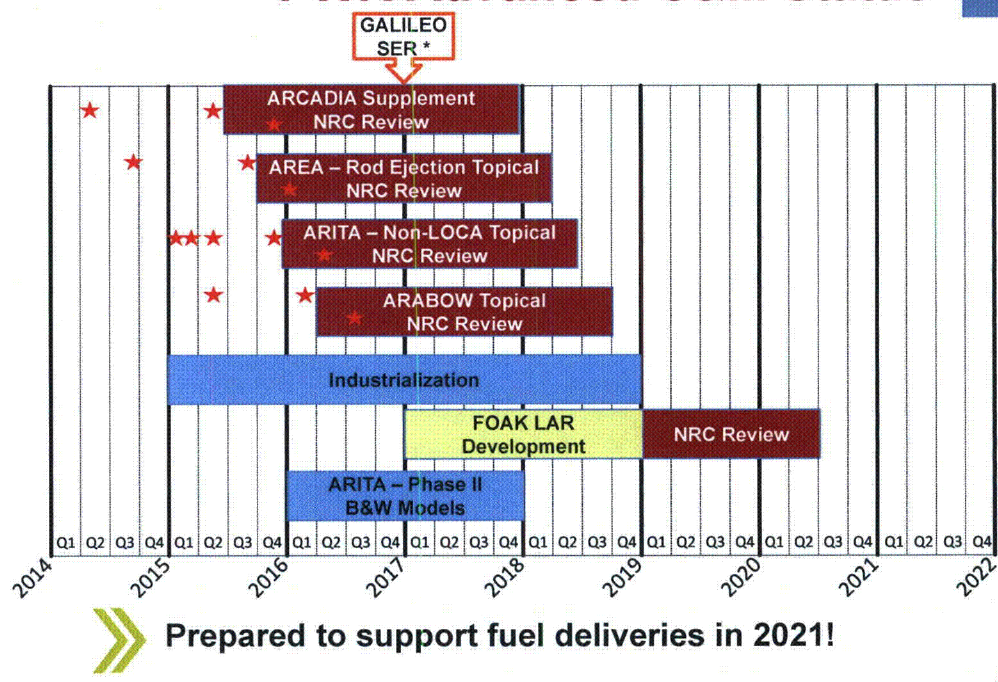
ARABOW™ Status

- ▶New Rod and Assembly Bow topical addresses
  - ◇ Reducing two topical reports into one
  - ◇ Improved rod bow correlation
  - ◇ Improved DNBR correlation
  - ◇ Updated tools available for power peaking determination
- ▶Pre-submittal Tactical meeting being scheduled

Summary

AREVA

PWR Advanced C&M Status



Prepared to support fuel deliveries in 2021!

Summary (1/2)

- New 0D and 3D methods provided a more realistic yet conservative evaluation of PWR cores
- Conservative analyses without fuel failure show reduce risk to radiological releases
- The new methods are not just an implementation of a 3D methodology, but a total revamping of AREVAs philosophy toward providing conservative analysis without overly penalizing

Summary (2/2)

- AREVA remains on task to meet the scheduled submittal dates
- ARCADIA will be submitted this month
- Our new methodologies meet the challenges of the current operating fleet while leaving room to address issues that will come with the next generation of reactors

Acronyms/Nomenclature

- AOR: Analysis of Record
- ARABOW™: AREVA's Rod and Assembly Bow Methodology
- AREA™: AREVA's Rod Ejection Accident Analysis Methodology
- ARITA™: ARCADIA®/RELAP Integrated Transient Analysis Methodology
- ARO: All Rods Out
- CBC: Critical Boron Concentration
- CE: Combustion Engineering
- BOC: Beginning of Cycle
- DC: Downcomer
- DNB: Departure from Nucleate Boiling
- DNBR: Departure from Nucleate Boiling Ratio
- EM: Evaluation Model
- FCM: Fuel Centerline Melt
- HFP: Hot Full Power
- HZP: Hot Zero Power
- ITC: Isothermal Temperature Coefficient
- LOCA: Loss of Coolant Accident
- MPI: Message Passing Interface
- MSLB: Main Steam Line Break
- RV: Reactor Vessel
- SPNDs: Self-Powered Neutron Detector
- SRP: Standard Review Plan
- W: Westinghouse

Overview of PWR Fuel Designs

Joel Hartman
Manager, Fuel Design
Mechanics-Lynchburg

Richland, WA
June 2 – 3, 2015

AREVA

Agenda

- ▶Objectives
- ▶Overview of Key PWR Fuel Assembly Design Features
- ▶Status of U.S. PWR Reloads
- ▶Next Generation PWR Fuel Assembly
- ▶Fuel Assembly Seismic Behavior
- ▶Familiarization with AGORA®-5A

Objectives

- ▶Familiarize the NRC Staff with AREVA's key PWR fuel designs feature, and emphasize the link to performance and improved safety margins.
- ▶Provide an update on AREVA's new GAIA fuel assembly, performance experience, and Lead Fuel Assembly (LFA) program.
- ▶Provide an update on AREVA's advancements in fuel seismic and LOCA methodology.
- ▶Familiarize the NRC Staff with AREVA's AGORA-5A fuel assembly design.

Agenda

- ▶Objectives
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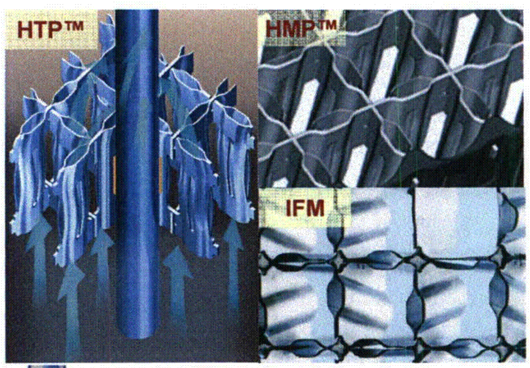
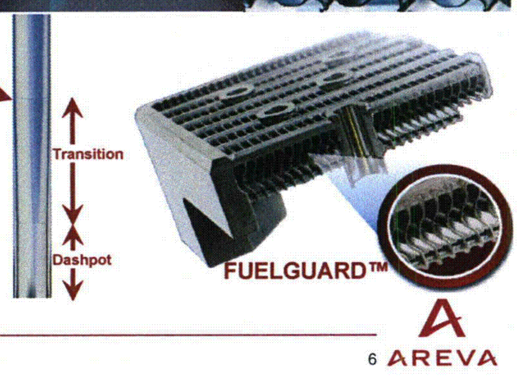
Proven Features of AREVA's HTP™ Product Line (1 of 2)

- Over 17,000 HTP™ assemblies have performed exceptionally as a result of key design elements
- M5® (Zr/Nb) Fuel Rod Cladding
  - Significant reduction in oxidation (factor of 3-5) and hydrogen pickup during design life
  - M5® supports high burnup design criteria for RIA and LOCA fuel performance with low hydrogen pickup
  - Over 20 years of experience (since 1993), including high burnup
    - U.S. reloads since 2000
    - Over 17,300 Fuel Assemblies in over 82 plants

Proven Features of AREVA's HTP™ Product Line (2 of 2)

- Spacer grid designs, which yield superior Grid-to-Rod Fretting (GTRF) performance in challenging flow conditions
  - HTP™ (Zry-4 or M5®) grids: curved flow channels, welded to structure, improved seismic margin
  - HMP™ (Alloy 718) lower grids: straight flow channels
  - IFM (Zry-4) grids: angled flow channels, welded to structure
- MONOBLOC™ Guide Tube
- FUELGUARD™ Bottom Nozzle
  - "No line of sight" through grillage
  - Improves flow stability
  - >15,300 Assemblies





Summary

- ▶AREVA's proven fuel design features have extensive operating experience, including multiple fuel arrays
  - M5® supports high burnup design criteria for Reactivity Initiated Accident (RIA) and LOCA fuel performance with low hydrogen pickup
  - The HTP™ grid effectively mitigates GTRF and provides increased seismic safety margin
  - The FUELGUARD™ is a proven solution in eliminating debris related fuel failures

Agenda

- ▶Objectives
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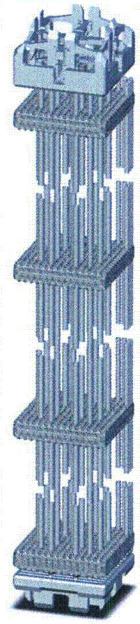
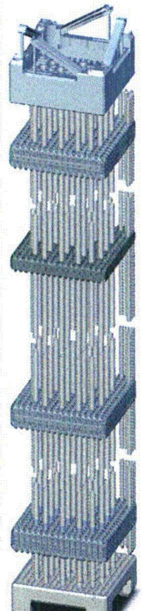
AREVA U.S. PWR Reloads Supply B&W Plants



- Transition to the Mark-B-HTP™ fuel design has been effective in eliminating GTRF failures in challenging flow environments.

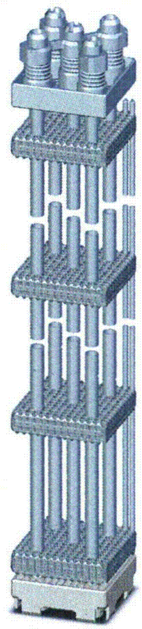
AREVA U.S. PWR Reloads Supply Westinghouse Plants



- HTP™ designs excel in corrosion, fretting, debris resistance, and lateral structural integrity performance.

AREVA U.S. PWR Reloads Supply CE Plants

[ ]



HTP™ designs continue to have excellent fuel performance in challenging flow conditions.

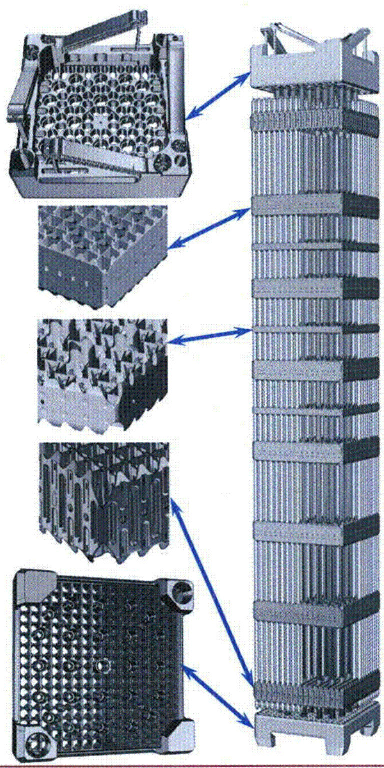
Agenda

- Objectives
- Overview of Key PWR Fuel Assembly Design Features
- Status of U.S. PWR Reloads
- **Next Generation PWR Fuel Assembly**
- Fuel Assembly Seismic Behavior
- Familiarization with AGORA®-5A

GAIA: Next Generation PWR Fuel Assembly

- AREVA's next generation PWR fuel assembly development program is called "GAIA"
- Initial focus: development of a W17 array design
- Four GAIA LFAs were inserted in a European 3-loop W17 plant in July 2012
- Eight GAIA LFAs were inserted in a U.S. 3-loop W17 plant in May 2015

GAIA Fuel Assembly Key Attributes



- **Top Nozzle** (1/4-Turn Quick Disconnect)
- **HMP™ Upper Grid** (relaxed springs)
- **M5® GAIA Spacer Grid (6x)**
- **M5® Intermediate GAIA Mixer (IGM) (3x)**
- **M5® Fuel Rod** (optional Cr-doped)
- **Welded Structure** (8 per connection)
- **Q12™ Alloy MONOBLOC™ GT** (Increased OD)
- **HMP™ Bottom Grid**
- **GRIP™ Bottom Nozzle**

» **Building upon proven experience, the GAIA fuel assembly improves performance and safety margins.**

GAIA Spacer Grid

- The GAIA grid combines proven experience of mixing vane with the line contact fretting resistance of the HTP™
  - Out-of-reactor fretting tests show that fuel rod wear characteristics are similar to HTP grids
- The Intermediate GAIA Mixer (IGM) is based on proven experience of the AFA design

Q12™ Alloy Structural Material

- Mechanical properties and material properties are similar to M5® and Zry-4
- Q12™ MONOBLOC™ guide tubes are manufactured by pilgering (same as cladding and MONOBLOC™ guide tubes
- The final heat treatment leads to a stable fully-recrystallized material condition

Q12™ Alloy Experience Base

Since 2010, AREVA has irradiated 248 fuel assemblies with Q12™ (34 with both guide tubes and grids).

Q12™ Alloy Exhibits Well Behaved Growth Characteristics

GRIP™ Bottom Nozzle

- The GRIP™ represents a combination of technologies:
  - FUELGUARD™ – flow stability
  - TRAPPER® – low ΔP
- Bullet nose interface protects against fuel rod vibration and reduces trailing edge turbulence
- Flow stabilization design evolution:
  - Computational Fluid Dynamic (CFD) evaluations
  - Confirmatory flow tests (Laser Doppler)
- High anti-debris efficiency

The GRIP™ bottom nozzle provides high filter efficiency, minimizes inlet cross flow, with low pressure drop.

Roadmap for U.S. GAIA Introduction

Summary/Conclusions

AREVA's GAIA Fuel Assembly design is focused on...

- **... fuel reliability**
  - Fretting robustness: GAIA grid + HMP™ lower grid + GRIP™ bottom nozzle (minimizing inlet cross flow)
  - Debris resistance: High filtering efficiency of GRIP™
- **... fuel robustness**
  - Improved lateral cage stiffness (thicker GT and 8-point weld to grids)
  - Low creep Q12™ guide tube material
- **... fuel performance**
  - Incorporation of vanes on GAIA grid
  - Intermediate GAIA Mixing grids for CHF performance

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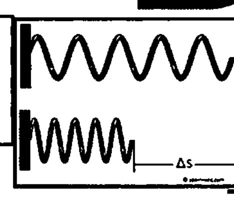
Overview of AREVA Fuel Assembly Seismic Behavior

- ▶ **General fuel assembly seismic performance is based on ability to dissipate the kinetic energy and withstand the impact energy without damaging the fuel**
- ▶ **Key fuel attributes are:**
  - **Fuel assembly stiffness**
    - Stiffness/flexibility determines the amount of energy absorption, hence lower grid stiffness lowers impact loads
  - **Spacer grid strength and stiffness**
    - Strength determines the limit of energy that can be absorbed without significant plastic deformation

Beneficial Stiffness Effect of HTP™

The potential energy stored in a spring under compression is $PE=1/2*k*\Delta s^2$
The force-deflection behavior of a spacer grid can be viewed in the same way.



BOL GAIA Spacer Grid Behavior

EOL GAIA Spacer Grid Behavior

Fuel Seismic/LOCA Methodology

- **Current generic PWR methodology: BAW-10133PA, Rev. 1, including Addendums 1 & 2**
- **Plan to submit new generic PWR topical in [ ]**
- **Scope of methodology update:**
  - Generic applicability to PWRs
  - Streamline and consolidate content from BAW-10133PA
  - Update vertical methodology
  - Update methodology for non-grid stresses
  - Clarification on combination of horizontal and vertical loads
  - Clarification on testing protocols and benchmarking
  - **Definition of grid allowables based on grid deformation**
  - **Definition of test protocol for EOL grids (IN 2012-09*)**
  - **Definition of assembly dynamic characteristics in EOL condition (IN 2012-09)**
  - **Loss-of-Offsite Power (LOOP)**
  - **Definition of guide tube stress allowables (ASME Level C)**

* **NRC Information Notice 2012-09 "*Irradiation Effects on Fuel Assembly Spacer Grid Crush Strength*"**

Fuel Seismic/LOCA Methodology
Fuel Assembly Damping

- **Damping basis augmented with new data to account for irradiation**
- **Damping values based on tests performed on generic full scale fuel assemblies in air and water in both BOL and "EOL" conditions**
- **Damping ratio based on conservative post-processing of test data:**

[ ]

  - **Addresses uncertainties in evolution of other Fluid-Structure phenomena**
  - **Tested values are scaled down to account for temperature effects**

Fuel Seismic/LOCA Methodology Guide Tube Stress Allowable

- ▶ **Industry standard for guide tube faulted stress allowable appears to be ASME Level D* (i.e. structural integrity)**
- ▶ **AREVA believes that Level C* limits are more appropriate**
  - ◈ **GTs must ensure functional integrity (more stringent than structural integrity) for control rod insertability**
  - ◈ **Level C limits allow for limited and controlled plastic strain (in agreement with 10 CFR 50 Appendix S)**

[ ]

*** From ASME B&PV Code, Section II**

Summary

- ▶ **AREVA's spacer grid designs provide an excellent solution to conditions of high seismic / LOCA demand**
  - ◈ **No instance of HTP™ buckling under seismic and LOCA loads in U.S. applications**

[ ]

- ▶ **AREVA is advancing seismic / LOCA methodology to stay ahead of emerging industry issues**
  - ◈ **Information Notice 2012-09**
  - ◈ **Loss-of-Offsite Power (LOOP)**
  - ◈ **Retained margin in damping**
  - ◈ **Appropriate guide tube criteria**

Agenda

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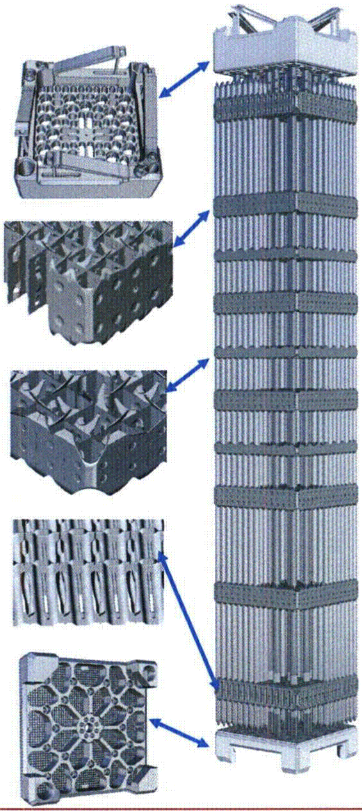
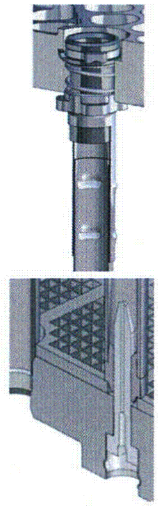
Interest in W15 Product based on European Experience

AGORA® 5A-I Fuel Assembly Attributes



- *Top Nozzle (1/4-Turn Quick Disconnect)*
- *HTP™ Upper Grid*
- AFA 3G™ Improved Mixing Grid (5x)
  - Bi-metallic (M5® strips/Alloy 718 springs)
  - Mixing vanes for DNB performance
- AFA 3G™ Mid Span Mixing Grid (3x)
  - M5® strips, no springs
  - Mixing vanes for DNB performance
- *M5® Fuel Rod w/ Chamfered Pellets*
- Q12™ Alloy MONOBLOC™ Guide Tubes
- *HMP™ Bottom Grid*
- *TRAPPER™ Bottom Nozzle*



Acronyms/Nomenclature

- BOL Beginning Of Life
- CFD Computational Fluid Dynamics
- CHF Critical Heat Flux
- EOL End Of Life
- FA Fuel Assembly
- FR Fuel Rod
- GT Guide Tube
- GTRF Grid-To-Rod Fretting
- IFM Intermediate Flow Mixer
- IGM Intermediate GAIA Mixer
- LFA Lead Fuel Assembly
- LOCA Loss-Of-Coolant Accident
- LOOP Loss-Of-Offsite Power
- PIE Post-Irradiation Examination
- RIA Reactivity Initiated Accident
- Zry-4 Zircaloy-4 alloy

PWR Operating Experience and Fuel Exams

Stephen Mazurkiewicz
Manager, Fuel Reliability and Performance

Richland, Washington
June 2 – 3, 2015

AREVA

Agenda

- **Objectives**
- **PWR Fuel Reliability Overview**
  - **Fuel Rod Failures**
- **Solutions to Historic Fuel Performance Concerns**
  - **Distortion Induced Grid Damage**
  - **Wear due to Baffle Interaction**
  - **Hold-down Spring Cracking**
- **Upcoming Fuel Examinations**

Objectives

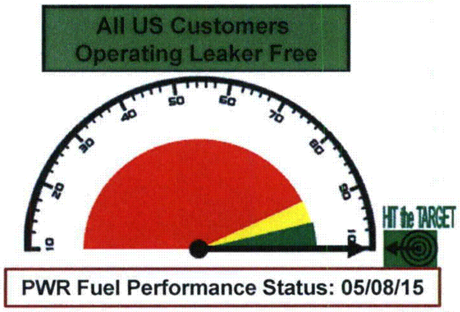
- Provide a status update on the overall performance of AREVA's PWR fuel products
- Provide an overview of fuel examinations and results of recent surveillance campaigns
- Provide an overview of future fuel examination plans
- Engage in dialogue regarding NRC interests and priorities for PWR fuel surveillance

Topic

- Objectives
- PWR Fuel Reliability Overview
  - Fuel Rod Failures
- Solutions to Historic Fuel Performance Concerns
  - Distortion Induced Grid Damage
  - Wear due to Baffle Interaction
  - Hold-down Spring Cracking
- Upcoming Fuel Examinations

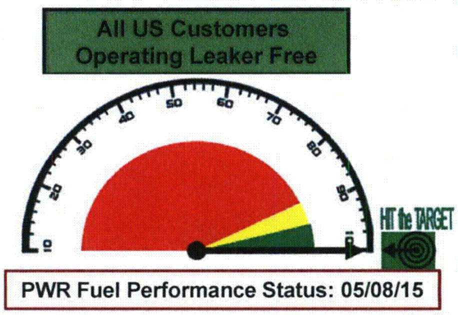
PWR Fuel Reliability Status

- Currently is Failure Free in PWR Market
- Improvement realized with implementation of HTP™ designs
  - All AREVA supplied PWRs have either completed or are transitioning to HTP™ fuel
  - No GTRF-related (Grid-to-Rod Fretting) failures in HTP fuel with Alloy 718 HMP™ lower end grid



PWR Fuel Reliability Status

- Currently is Failure Free in PWR Market
  - Last failed assembly discharged from North Anna-2 in September 2014
- Improvement realized with implementation of HTP™ designs
  - All AREVA supplied PWRs have either completed or are transitioning to HTP™ fuel
  - No GTRF-related (Grid-to-Rod Fretting) failures in HTP fuel with Alloy 718 HMP™ lower end grid



PWR Fuel Failure Mechanisms
(Previous 3 Years)

Driving to Zero Failures:

- **Grid-to-Rod Fretting**
  - Implementation of HTP™
  - No GTRF failures in HTP™ fuel with Alloy 718 end grid
- **Baffle Jetting**
  - Not a fuel-related condition
  - Rod clips are available to minimize the consequences of baffle jetting
- **Manufacturing**
  - Risk of contamination resolved
- **Debris**
  - Robust FUELGUARD™ standard in all currently delivered fuel products

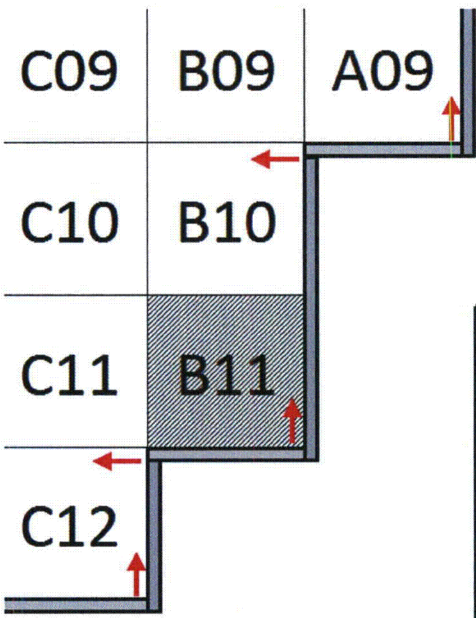
Recent Poolside Fuel Reliability Examinations

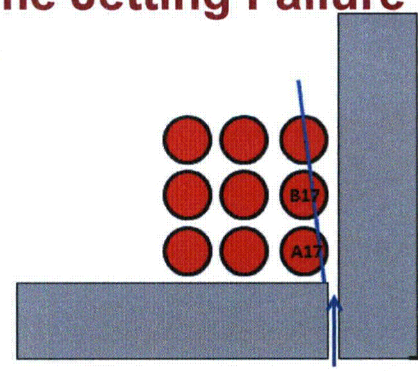
Recent Cause of Failure Examinations

Cause of Failure Examination

- **Cycle 23 started operation in May 2013**
  - **Mixed core of AREVA and Westinghouse fuel**
- **Sipping identified a 3rd cycle Adv. Mark-BW assembly as failed**
  - **Assembly had operated against core baffle in corner location**
- **Assembly experienced substantial damage consistent with baffle jetting**
  - **Baffle jetting cross-flows resulted in substantial wear and failure of rods A17 and B17 (failed rods in included corner)**
- **Baffle jetting is a mechanism which occurs in certain Westinghouse "down-flow" plants**

Baffle Jetting Failure





Baffle Jetting Failure
INPO OE #312978

- To mitigate the potential for additional baffle jetting failures in Cycle 24, the core was redesigned to include an armored assembly in core location B-11

- Extent-of-condition inspections were performed on other Cycle 23 fuel assemblies operating on the baffle for indications of precursors
  - No additional fuel changes were determined to be necessary in Cycle 24

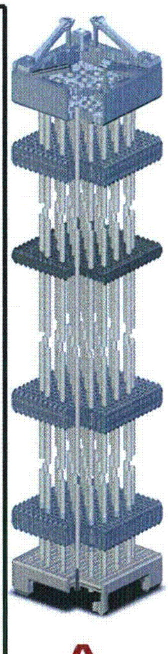
- The long-term corrective action to eliminate the baffle jetting risk would be to redirect the flow on the outside of the core baffle plates from a "down-flow" to an "up-flow" configuration
  - Eliminates the pressure differential across the baffle joints
  - Due to lead time, the "up-flow" conversion was not implemented in Cycle 24

Topic

- Objectives
- PWR Fuel Reliability Overview
  - Fuel Rod Failures
- **Solutions to Historic Fuel Performance Concerns**
  - **Distortion Induced Grid Damage**
  - **Wear due to Baffle Interaction**
  - **Hold-down Spring Cracking**
- Upcoming Fuel Examinations

Recent Fuel Surveillance PIE

Distortion Induced Grid Damage



- Reload efficiency greatly improved
  - Core was successfully loaded ahead of schedule
  - Minimal use of shoehorns and other compensatory measures required

Recent Example of Fuel Assembly Distortion Improvements

Recent Example of Fuel Assembly Distortion Improvements

Recent Example of Fuel Assembly Distortion Improvements

- Inspections confirmed the presence of debris in the debris filters of fuel assemblies
- No fuel failures occurred during Cycle 20

AREVA debris filter technology has proven to be highly effective

Wear Due to Baffle Interaction

Performance Challenges
Hold-Down Spring (HDS) Cracking Issue

Archive Sample Results
Microstructural Comparisons

Hot Cell Examination Results
M3-C-180-A1 – Oxide Removal

- **After oxide removal, a well developed network of slip lines surrounding the large cracks becomes evident**
  - **Slip lines are indicative of large local strains**
- **Oxidation of slip lines likely occurred during operation**

[ ]

Failure Mechanism

[ ]

RCA Summary

[ ]

Topic

- ▶ Objectives
- ▶ PWR Fuel Reliability Overview
  - ◇ Fuel Rod Failures
- ▶ Solutions to Historic Fuel Performance Concerns
  - ◇ Distortion Induced Grid Damage
  - ◇ Wear due to Baffle Interaction
  - ◇ Hold-down Spring Cracking
- ▶ Upcoming Fuel Examinations

Upcoming PWR Fuel Surveillance Campaigns

[ ]

Summary/Conclusions

- AREVA remains at an all-time high for leaker free performance
- Currently Leaker Free in PWR Market
  - HTP™ implementation has reduced the number of failed rods
  - Baffle jetting failure was a unique failure mode
  - Solutions to known performance issue have been effective
- Continuous experience feedback from AREVA's active PIE program helps maintain high quality in robust products

Acronyms/Nomenclature

▶ B&W	Babcock and Wilcox
▶ BWR	Boling Water Reactor
▶ CE	Combustion Engineering
▶ FME	Foreign Material Exclusion
▶ GTRF	Grid-to-Rod Fretting
▶ HDS	Hold-down Spring
▶ LFA	Lead Fuel Assembly
▶ NRC	Nuclear Regulatory Commission
▶ OCO	Oconee
▶ ORNL	Oak Ridge National Laboratory
▶ PIE	Post Irradiation Examination
▶ PFZ	Precipitate Free Zone
▶ PWR	Pressurized Water Reactor
▶ SCC	Stress Corrosion Cracking
▶ TMI	Three Mile Island

Overview of AREVA Fuel Single-Phase Computational Fluid Dynamics Capabilities

Thomas H. Keheley
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Supervisor, CFD & Thermal Hydraulic Testing

Richland, Washington
June 2 – 3, 2015

AREVA

Agenda

- **Objectives**
- **Overview**
- **Single-Phase CFD Validation Status**
- **Current Applications**
  - **PWR / BWR Fuel Analysis and Design**
  - **Special Problems and Diagnosis of System Interaction**
- **Long-Term Outlook**
- **Summary**

Objectives

- Provide an overview of AREVA Fuel's single-phase CFD methods with emphasis on experimental validation status and current applications
- Obtain NRC feedback on a long-term vision for integrating CFD analysis into product development, design optimization, and fuel analysis process, including support to safety analysis

Overview

- Computational Fluid Dynamics (CFD) can provide high-fidelity numerical solutions to the mass conservation, momentum, and energy equations that govern the fluid flow through reactor cores
  - Detailed pressure, velocity and temperature fields used to evaluate fuel components thermal hydraulic performance
  - Physics behind deleterious phenomena such as grid-to-rod fretting (GTRF) or flow conditions leading to Crud-Induced Power Shift and Crud-Induced Localized Corrosion (CIPS/CILC)
- AREVA developed and validated reliable predictive tools that combine high-fidelity CFD modeling with traditional empirical elements, used to:
  - Support product development
  - Design experiments and supplement testing
  - Improve design methods
  - Provide high-resolution input to safety analyses

Fuel CFD Network

Efficiency
- Sharing best-practices
- Library of CFD tools (subroutines, ...)
- Follow competitor & research publications

Communication
- Global team, with common projects and daily interactions
- Common technical data repository

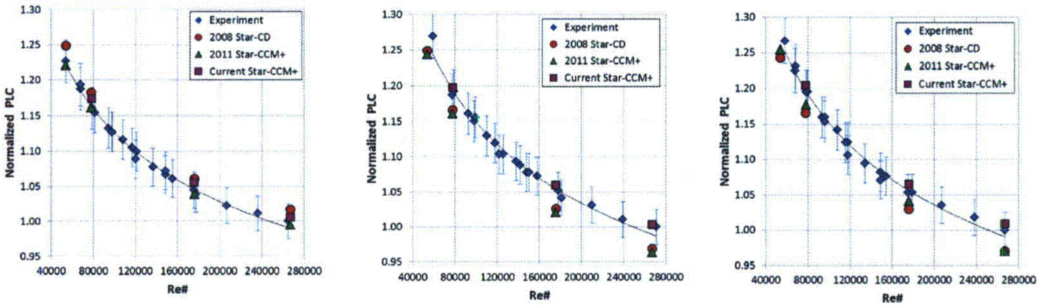
Quality
- Peer Review for each task/project
- Qualification of code versions
- User-independent modeling

Single-Phase CFD Methods Development and Validation Status

- AREVA's CFD methods for specific applications evolved in terms of physics, turbulence models, CAD treatment, and mesh optimization
- Changes to modeling techniques driven by multiple factors:
  - Advancements in commercial CFD codes
  - Significant growth in high power computing
  - Availability of experimental data for validation
- Fuel methods built around CD-adapco™ software:
  - The original CFD methods developed in the '90s using STAR-CD®
  - STAR-CCM+® methods incorporate the legacy best practices and take advantage of advanced meshing capabilities and physics
- Multiple benchmarking efforts based on:
  - AREVA proprietary data from facilities such as Le Creusot Technical Center, Erlangen Technical Center, CEA's HERMES, etc.
  - Participation in collaborative benchmarking projects such as the recent EPRI Round Robin
  - Per procedure, all testing should be predicted or available for CFD benchmarking (cf FSOP-13)

Validation of Single-Phase CFD Method for PLC Calculations

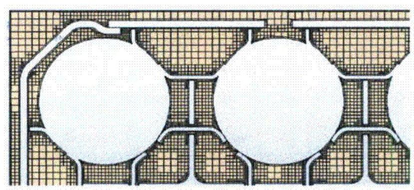
Sample validation results for selected PWR Spacer Grids



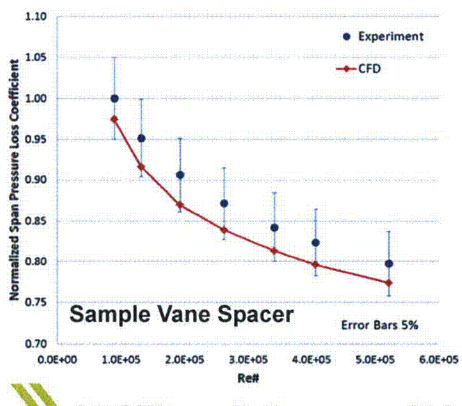
Rigorous validation efforts carried out to ensure an optimal trade-off between accuracy and computational cost

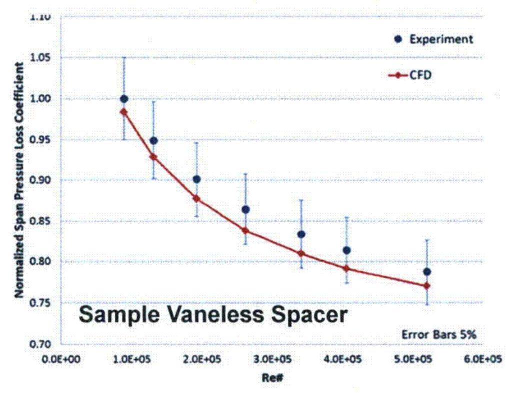
High-Resolution PLC Validation for PWR Spacer Grids

- **CFD PLC validation against test data for actual 17x17 hardware**
  - **Complete Re# Range**
  - **The same modeling and mesh setup used for four different 17x17 spacer geometries**



High Quality Mesh to Capture Geometric Details





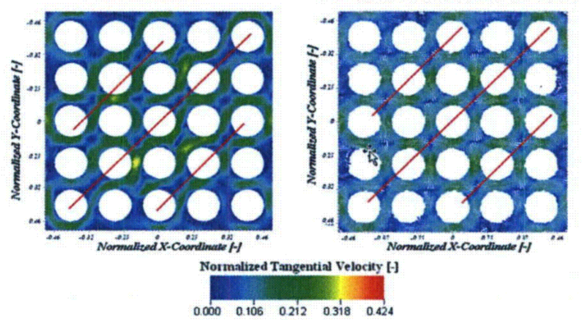
All CFD predictions are within the measurement uncertainty

Validation of Single-Phase CFD for Thermal Mixing Predictions

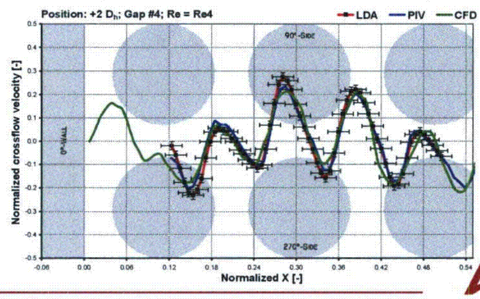
- CFD-grade data from AREVA's Technical Center in Erlangen
- PIV and LDA non-intrusive measurements downstream of several 5x5 spacer designs for a wide range of Re#
- Characterization of thermal mixing requires high-fidelity turbulence models and fine computational grids

» Point-to-point deviation between prediction and test: 1.5 to 4.2% of average bundle velocity

PIV Measurements *CFD Predictions: Realizable k-ε Model*



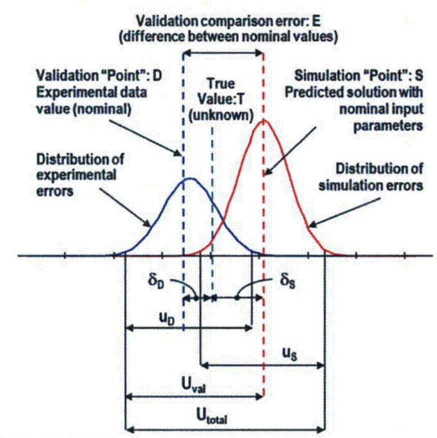
Cross-flow profiles 8 Dh downstream of spacer grid



Uncertainty Analysis

- ASME V&V20 procedure for CFD methods provides a reliable means to evaluate prediction errors and set confidence intervals
- Measurement uncertainty
  - LDA: 1.8% of the largest tested axial velocity
  - PIV: 1.5% of the largest tested axial velocity
- Simulation uncertainty <1.8% of the largest averaged bundle velocity

» Simulation uncertainty similar to measurement uncertainty



NOMENCLATURE:

δ_D Measurement error

δ_S Simulation (prediction) error

u_D Measurement uncertainty, 95% confidence level on the mean

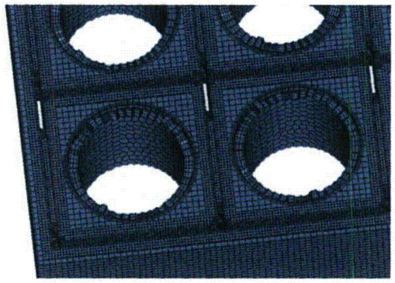
u_S Simulation (prediction) uncertainty, 95% confidence on the mean

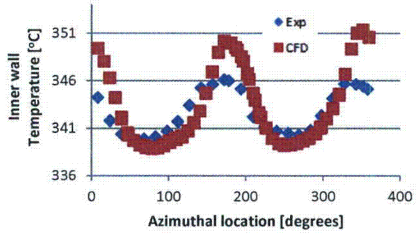
U_{val} Validation uncertainty, 95% confidence level on the mean

U_{total} Total validation uncertainty, 95% confidence level on the mean

Advanced Single-Phase Modeling: EPRI Round Robin CFD Benchmark

- Evaluate capabilities of CFD used for Level IV CIPS/CILC assessments
- Comparison against CEA data from 5x5 MGV experiments
  - Flow field, pressure drop, rod inner-wall temperature
- Conjugate Heat Transfer used to obtain accurate local heat flux hence local temperature crucial to determine location of hot spots
- CFD predictions in good agreement with experimental data
  - Temperature distribution around central rod, 8 hydraulic diameters downstream the grid
- Reports issued by EPRI detailing the use of CFD and recommendations





» CFD proved to be effective at predicting localized phenomena and assessing conditions leading to CRUD deposition

Single-Phase CFD Methods Application to Fuel Analysis and Design

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Single-Phase CFD Application: Spacer Grid Design Optimization

- CFD can capture impact of subtle geometry changes on performance
- Multi-span models can describe behavior of mixed-geometry FA's

Application to Lower Nozzles Design Optimization

- CFD analysis successfully used for PWR and BWR Bottom (and Upper) Nozzles design optimization

Application to Lower Tie Plate Design Optimization: ATRIUM11™

[ ]

- Minimized pressure losses through 3rd Generation FUELGUARD™ and Transition Piece design optimization prior to final testing

Understand the Impact of the Side Entry Orifice to BWR Inlets

[ ]

- Impact of side entry on flow distribution
- Relative evaluation of fretting risk between several design iterations
- Impact of new filters on water channel flow
- Confirmed by final testing

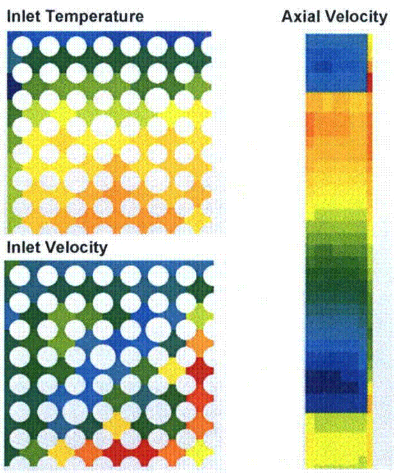
- Increased understanding of BWR inlet conditions
- Enhanced design applied to ATRIUM11™

Special Problems and Diagnosis of System Interactions

Level IV CRUD Assessment

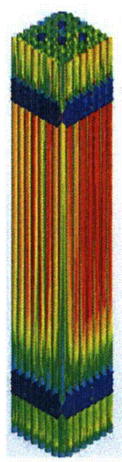
Mapped Sub-channel Code Values

Sub-channel Code



CFD

CFD Results: Detailed wall and fluid characteristics



Chemistry Code

High-resolution Level IV CRUD analysis is a well established non-safety related application

Support of Broken Connecting Bolt Analysis

[ ]

CFD instrumental in confirming and explaining observed phenomena

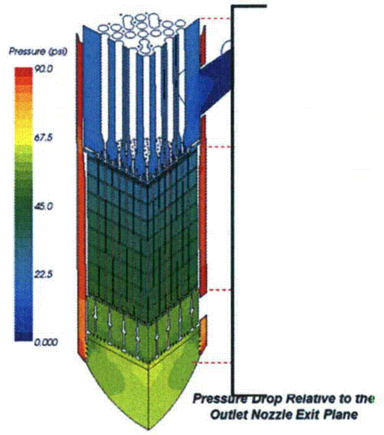
BWR Lower Plenum Transient

[ ]

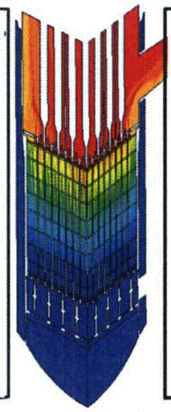
- Transient analysis of inadvertent initiation of High Pressure Coolant Injection system
- Full model of the vessel (including jet-pumps, lower plenum)
- Full transient, inputs from system code
- CFD provided a more realistic mixing input for the transient analysis

CFD analysis successfully used to get insight into the High Pressure Coolant Injection flow phenomena

Full Reactor Analysis



Pressure Drop Relative to the Outlet Nozzle Exit Plane

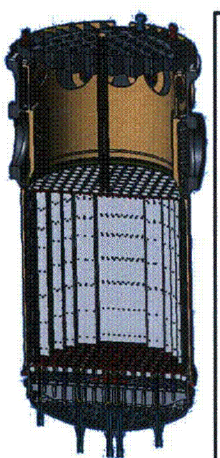


450 mil elements ¼ reactor model

- **"Virtual Reactor" flow and thermal solutions**
  - **Higher resolution and accuracy than sub-channel codes**
  - **Captures interactions between core, internals and vessel**
  - **Suitable for steady state and transient analyses**

Analysis of real geometry at in-core operating conditions

Flow Induced Vibrations: CFD for GTRF Assessments



- **Cross-flow velocity is the main GTRF driver; CFD analysis provides detailed flow field information to FIV assessments**
- **Other structural assessments use CFD pressure and acoustic load estimates to confirm conservatism of traditional methods**

CFD part of the Integrated System Modeling of RV internals

Long-Term Outlook

[ ]

Design of Experimental Tests, Pre-Test Screening, Virtual Testing

[ ]

Design experimental tests to capture the most relevant data
Expand physics-based knowledge of product performance

Application: Engineering Support

- **Solutions to challenging problems**
  - **Diagnose system interactions outside the scope and capabilities of system/sub-channel codes or testing capabilities**
  - **Support design changes, customer-specific product implementation, extension of operational limits**
- **Risk Assessments and Root-Cause Analyses**
  - **Support disposition of field issues, degraded conditions, out-of-spec deviations, minor manufacturing non-conformances**
- **Improve understanding of complex physics such as:**
  - **Peripheral effects (inlet, outlet, by-pass)**
  - **Impact of baffle penetrations flow on GTRF**
  - **Lower plenum anomaly impact on fuel performance, etc.**

CFD analysis can provide physics-based justification for engineering judgment and assumptions

Future Product Development and Licensing Support

[ ]

Improve the quality of licensing materials by providing supplemental high-fidelity information

Summary/Conclusions

- **Single-phase methods are mature and can provide reliable solutions to complex engineering problems that cannot be accurately solved by system, sub-channel, and special-purpose codes**
- **Within the nuclear industry, AREVA is a leader in championing CFD; with current capabilities, pressure losses, flow fields, and thermal mixing within fuel bundles can be predicted with an uncertainty comparable to the measurement uncertainty**
- **AREVA needs NRC feedback on our long-term vision of integrating CFD into fuel analysis and design, enhancing our testing, and continuously improving the quality of licensing materials**

List of Relevant Publications (1)

- M. Leberig, N. Alleborn, M. Glück, J. Jones, Ch. Kappes, C. Lascar, G. Sieber, "AREVA NP's Advanced Thermal Hydraulic Methods for Reactor Core and Fuel Assembly Design", *Top Fuel 2009*, Paris, France (2009).
- J.H. Jones, M.G. Martin, T.H. Keheley, R.L. Harne, M.G. Pop, C. Lascar, J-P.Simoneau," AREVA's Comparative Process for CILC Risk Assessment Using Subchannel and CFD Modeling", LWR Fuel Performance Meeting, Top Fuel, WRFPM, Orlando Florida, (2010).
- C. Lascar, N. Alleborn, M. Leberig, J. Jones, M. Martin, "Recent developments in CFD and their impact on fuel assembly optimization", *KTG Jahrestagung Kerntechnik*, Berlin Germany, (2010).
- T. Keheley, M. Martin, A. Hatman, C. Lascar, N. Alleborn, A.e Chatelain, "Counter Current Flow Limitation Prediction Using CFD," The 14th International Topical Meeting on Nuclear Reactor Thermal Hydraulics (NURETH-14), Toronto, Ontario, Canada, September 25-29, (2011).
- A. Chatelain, K. Goodheart, N. Alleborn, C. Baudry, J. Lavieville & T. Keheley, "*Two-Phase CFD Simulation of DNB and CHF Prediction Behind Spacer Grids with NEPTUNE_CFD and Star-CCM+*," Proceedings of Top Fuel Reactor Fuel Performance, Manchester, UK, (2012).
- S. Opel, N. Alleborn, P. Pohl, K. Greene, A. Chatelain, "*Advanced CHF Prediction by F-COBRA-TF and CFD Analysis to Support PWR and BWR Fuel Product and Methodology Development*," Proceedings of Top Fuel Reactor Fuel Performance, Charlotte, NC, USA, (2013).
- K. Goodheart, N. Alleborn, A. Chatelain & T. Keheley, "*Analysis of the Interfacial Area Transport Model for Industrial 2-Phase Boiling Flow Applications*," Proceedings of NURETH 13, Pisa, Italy, (2013).
- C. Lascar, E. Jan, K. Goodheart, T. Keheley, M. Martin, A. Hatman, A. Chatelain, and E. Baglietto, "Example of Application of the ASME V&V20 to Predict Uncertainties in CFD Calculations," *Proceeding of the 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH-15-070*, Pisa, Italy, May 12-17 (2013).

List of Relevant Publications (2)

- C. Lascar, M. Pierre, K. Goodheart, M. Martin, A. Hatman, and J-P. Simoneau, "Validation of a CFD Methodology to Predict Flow Fields within Rod Bundles with Spacer Grids," *Proceeding of the 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH-15- 069*, Pisa, Italy, May 12-17 (2013).
- K. Goodheart, A. Ylönen, V. De Cacqueray, H-M Prasser, "CFD Validation of Void Distribution in a Rod Bundle with Spacer," Proceedings of the 22nd International Conference on Nuclear Engineering, ICONE22, July 7-11, 2014, Prague, Czech Republic, (2014).
- A. Hatman, G. Williams, M. Martin, T. Keheley, C. Lascar, K. Goodheart, and A. Chatelain, "CFD Analysis of Reactor Core Flow Field in Support of FIV Diagnosis," *Proceeding of the 15th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH-15- 064*, Pisa, Italy, May 12-17 (2013).
- M. Martin, T. Keheley, K. Vogel, K. Goodheart, A. Hatman, A. Chatelain, "Validation of AREVA's Best Practices in the EPRI Round Robin Benchmark," *Proceeding of the 16th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH-16* (2015).
- A. Hatman, A. Chatelain, K. Goodheart, M. Martin, T. Keheley, *"A Review of AREVA's Experimental Validation of State-of-the-Art Single-Phase CFD Methods with Application to PWR Fuel Analysis and Design ," Proceeding of the 16th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH-16* (2015).
- L. Charlot, M. Martin, T. Keheley, A. Hatman, A. Chatelain, K. Goodheart, F. Wehle, *"Use of CFD to design AREVA's newest BWR fuel design: the ATRIUM 11TM," Proceeding of the 16th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, NURETH-16* (2015).

Acronyms/Nomenclature

- **CAD – Computer Aided Design**
- **CFD – Computational Fluid Dynamics**
- **CEA – Commissariat a l'energie atomique**
- **Dh – Hydraulic Diameter**
- **FA – Fuel Assembly**
- **FIV – Flow Induced Vibrations**
- **FOAK – First-of-a-Kind**
- **GTRF – Grid to Rod Fretting**
- **LDA – Laser Doppler Anemometry**
- **MVG – Mixing Vane Grid**
- **PIV – Particle Image Velocimetry**
- **RANS – Reynolds Averaged Navier-Stokes**
- **RV – Reactor Vessel**
- **SSG – Simple Support Grid**
- **V&V – Verification and Validation**

Update on New BWR Core Engineering Methods

Kevin Quick
Dan Tinkler

Richland, Washington
June 2 – 3, 2015

AREVA

Agenda

- **AURORA-B Methodology Suite**
  - **Industry catalysts for advanced methods**
  - **AURORA-B: Foundation for change**
  - **AURORA-B: Licensing topical reports**
    - Anticipated Operational Occurrences (AOO)
    - Control Rod Drop Accident (CRDA)
    - Loss of Coolant Accident (LOCA)
- **AURORA-B Summary**
- **ATWSi Methodology to support extended flow window licensing**
- **ATWSi Summary**

Objectives

- ▶Demonstrate AREVA's commitment to address changes in regulatory requirements and customer needs
- ▶Provide an overview and status of AURORA-B methods relative to industry needs
- ▶Provide an overview of future generic ATWSi methodology development
- ▶Obtain NRC feedback on AREVA's BWR Core Engineering Outlook

AURORA-B Methodology Suite

Kevin Quick
Supervisor, Codes & Methods
TH-Richland

AREVA

AURORA-B Methodology Industry Catalysts

- **The NRC expects licensing methods that address outstanding concerns**
  - Elimination of legacy issues associated with approved methods
    - Phenomenological inadequacies
    - Computational simplifications
    - Application uncertainties due to legacy balancing of assumptions and conservatisms
  - Validation and application uncertainty analyses that capture current understanding of phenomena
  - Support evolutionary changes in regulatory focus

AURORA-B Methodology Industry Catalysts

- **Licensees need**
  - Effective understanding of margins
  - Accurate predictions of capability and behavior of their reactors
  - Smooth licensing of operating cycles based on generic approvals

AREVA is developing C&M that meet industry needs and are adaptable to the future.

AURORA-B
A New Foundation

- **The AURORA-B software incorporates high fidelity physics models that, when coupled with appropriate application methodologies, simultaneously address legacy issues and demonstrate compliance with new regulatory criteria.**
  - **Fully addresses NRC concerns on Thermal Conductivity Degradation (TCD) via RODEX4**
  - **Revised CRDA failure criteria and release fractions**
  - **Incorporated fuel relocation with the fuel swelling and rupture model in LOCA**
  - **10 CFR 50.46c application**
  - **GSI-191 application (debris clogging in the reactor system)**

AURORA-B
A New Foundation

[ ]

Status and Overview

- Three AREVA BWR methodologies have been submitted to the NRC
  - AURORA-B AOO – Active Review
  - AURORA-B CRDA – Accepted for Review, Inactive
  - AURORA-B LOCA – Submitted, Inactive
- Approval of these three methodologies will address proposed changes in regulatory requirements
- Active review of CRDA and LOCA prior to completion of the AOO SE will minimize the potential for concurrent generic and plant specific submittals of the methods

[ ]

Integrated Schedule Supporting ATRIUM™ 11

[ ]

AURORA-B AOO Review Reaching Resolution

- Draft RAIs provided in June 2014
- Audit held with NRC in September 2014
  - Phased approach on draft/preliminary RAI responses agreed upon
  - February 2015 target for the 1st phase was met
  - June 2015 is the target for the entire set of preliminary responses
- AREVA requests an audit in September to bring resolution to outstanding issues

Licensees have expressed interest in AURORA-B AOO for certain applications.

AURORA-B Summary/Conclusions

- AURORA-B Methodology Suite is integral to…
  - AREVA's ongoing support of the BWR fleet
  - Insertion of ATRIUM 11 in BWRs
- AREVA is committed to working with the NRC to…
  - Reach resolution concerns/issues
  - Establish a robust change control process regarding the identification of code vs. methodology changes

Approval of the AURORA-B methodologies will provide long-term dividends as the industry continues to evolve.

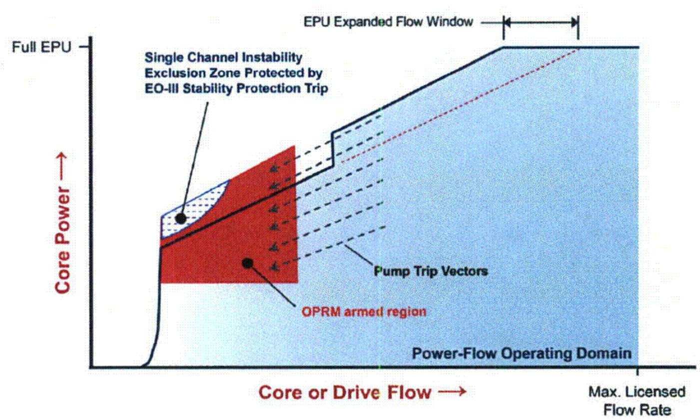
Generic ATWSi Methodology

Dan Tinkler
Lead Applications and Methodology Engineer
TH-Richland

AREVA

Background ATWSi Analysis

- **Definition of Extended Flow Window (EFW)**
  - **Any flow window up to and including MELLLA+**



Background ATWSi Analysis

- **AREVA has pursued two ATWSi paths**
  - **Simplified ATWSi intended for near-term fuel transition**
    - Uses conservative assumptions in areas where detailed modeling is not possible
  - **Generic ATWSi envisioned to be the long-term solution**
- **Two codes have been developed for a simplified ATWSi analysis**
  - **AISHA [ ]**
  - **SINANO [ ]**
  - **These codes currently are supporting a plant specific LAR for EFW**
    - currently under NRC review

Background ATWSi Analysis

- **AISHA**

[ ]

Background ATWSi Analysis

- SINANO

[

]

- Elements of the New Post-Dryout Model in SINANO

[

]

Background ATWSi Analysis

[

]

AREVA has performed unique world-class experiments to obtain data in support of model validation.

Background ATWSi Analysis

[ ]

Generic Approach for ATWSi

- The following information is in the planning and development stage and subject to change
- Goal: Full Simulation of ATWSi Event
  - Modify and enhance RAMONA5 for ATWS Requirements
    - Currently used for Stability OPTION III and Enhanced OPTION III
  - Full transient model able to model the limiting event (Turbine Trip with Bypass)

[ ]

Generic Approach for ATWSi

Generic Approach for ATWSi

▶Benchmarking to Support NRC Submittal

Summary/Conclusions

- AREVA has performed unique world-class experiments in support of new methodology.
- AREVA has built tools and methods to analyze a simplified ATWSi for fuel transitions to support the extended flow window.
  - Use of these simplified codes to guide development of the generic ATWSi leverages lessons learned and allows AREVA to incorporate feedback from the review of the simplified ATWSi.
- The new methodology and application brings greater clarity to technical and regulatory issues including ATWSi.

Acronyms/Nomenclature

AOO	Anticipated Operational Occurrence
ATWS	Anticipated Transient Without Scram
ATWSi	Anticipated Transient Without Scram with Instability
BWR	Boiling Water Reactor
C&M	Codes and Methods
CHF	Critical Heat Flux
CRDA	Control Rod Drop Accident
EFW	Extended Flow Window
KATHY	KArlstein Thermal-HYdraulic test facility
LOCA	Loss of Coolant Accident
LAR	Licensing Amendment Request
MELLLA+	Maximum Extended Load Line Limit Analysis Plus
OECD	Organisation for Economic Co-operation and Development
SE	Safety Evaluation
TCD	Thermal Conductivity Degradation
TH	Thermal Hydraulic

BWR Fuel & Channel Designs ATRIUM™ 11 Lead Test Assembly Irradiation Program & Poolside Inspection Results

Steven Cole
BWR Product Line Manager

Richland, Washington
June 2 – 3, 2015

AREVA

Objectives

ATRIUM™ 11 LTA Fabrication, Richland WA

- Provide high level overview of the primary BWR Product R&D initiatives and NRC support areas
- Recap the new ATRIUM™ 11 design features
- Provide an overview of the ATRIUM™ 11 LTA program
- Share the ATRIUM™ 11 poolside irradiation results

Overview of AREVA's BWR Product Improvement Activities (1/4)

Overview of AREVA's BWR Product Improvement Activities (2/4)

- AREVA provided product design and performance details during May 12 pre-submittal meeting

Overview of AREVA's BWR Product Improvement Activities (3/4)

Overview of AREVA's BWR Product Improvement Activities (4/4)

ATRIUM™ 11 Design Recap (1/5)

ATRIUM™ 11 Design Recap (2/5)

ATRIUM™ 11 Design Recap (3/5)

[ ]

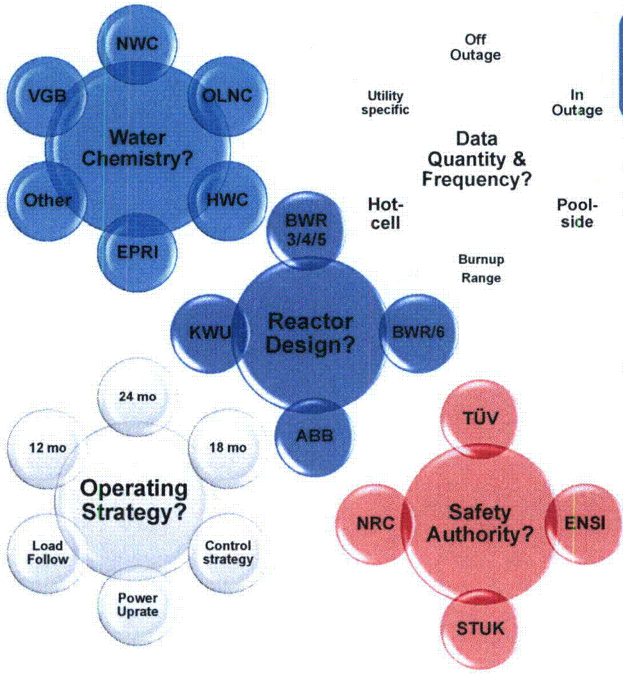
ATRIUM™ 11 Design Recap (4/5)

[ ]

ATRIUM™ 11 Design Recap (5/5)

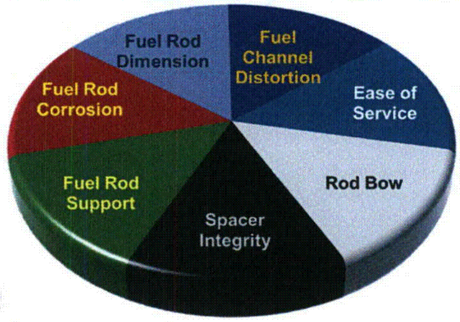
Overview of design verification activities for new ATRIUM™ 11 features

LTA Program Generic Considerations



LTA program scope needs to address the data collection requirements, AND…

account for the possible different operating regimes and licensing environments



» Impossible to succeed without strong support from utility partners

The primary ATRIUM™ 11 demonstration program

[ ]

ATRIUM™ 11 PIE Roadmap Status May 2015

[ ]

ATRIUM™ 11 Materials Under Irradiation

[ ]

- All fuel assemblies equipped with advanced materials have performed flawlessly.

ATRIUM™ 11 LTA
Key Inspection Results

AREVA

Fuel Channel Visual Inspection

[ ]

Excellent visual appearance with no unusual corrosion or mechanical anomaly.

3rd Generation FUELGUARD™ Visual Inspection

Perfect mechanical integrity of all new features.
No indication of unusual flow behavior.

Visual assessment of Fuel Rod Straightness

- The ATRIUM™ 11 rod bow performance is excellent, with no visible sign of abnormal fuel rod gap closure.

Visual assessment of spacer integrity

[ ]

- The ATRIUM™ 11 spacer mechanical performance is so far excellent.
- [ ]

ATRIUM™ 11 Fuel Assembly Growth

[ ]

ATRIUM™ 11 Fuel Channel Growth

[ ]

ATRIUM™ 11 Fuel Rod Growth

[ ]

ATRIUM™ 11 Fuel Rod Diameter Change

[ ]

ATRIUM™ 11 Mid-Span Oxide

[ ]

Shadow Corrosion Prevention Through Spacer Design (1/2)

[ ]

[ ]

The positive effect of the reduced Alloy 718 proximity ATRIUM™ 11 spacer is evident from the fuel rod visual appearance

ATRIUM™ 11 Fuel Service Demonstration

[ ]

Summary

- AREVA's R&D activities are addressing the key BWR fuel performance issues
- Continued NRC support is needed to ensure solutions are available to resolve safety concerns

[ ]

- The LTA program has been designed to confirm the performance of new design features for the spectrum of operating regimes
- Measurements to date confirm the expected performance and demonstrate in-reactor serviceability
- AREVA together with our customers and the NRC are executing the plan to realize the performance and reliability benefits of the ATRIUM™ 11 in reload applications

Acronyms/Nomenclature

- 3GFG: 3rd Generation FUELGUARD™ lower tie plate debris filter
- ABB: ASEA Brown Boveri
- ASEA: Allmänna Svenska Elektriska Aktiebolaget (Sweden)
- BQ: Beta-Quench Heat Treatment
- BWR: Boiling Water Reactor
- CSDM: Cold Shutdown Margin
- ENSI: Swiss Federal Nuclear Safety Inspectorate
- EOL: End of Life
- EPRI FRP: Electric Power Research Institute Fuel Reliability Program
- FA: Fuel Assembly
- FME: Foreign Material Exclusion
- HWC: Hydrogen Water Chemistry
- KWU: Kraftwerk Union (Germany)
- LAR: License Amendment Request
- LHGR: Linear Heat Generation Rate
- LTA: Lead Test Assembly
- LTP: Lower Tie Plate
- MCPR: Minimum Critical Power Ratio
- NWC: Noble Water Chemistry
- OLNC: Online NobleChem, a trademark of GE Hitachi Nuclear Energy for platinum injection into primary system
- PCI: Pellet Clad Interaction
- PIE: Post-Irradiation Examination
- PLFRs: Part Length Fuel Rods
- STUK: Radiation and Nuclear Safety Authority, Finland
- TR: Topical Report
- UTP: Upper Tie Plate
- VGB PowerTech: the European technical association for power and heat generation.
- Zry-BWR: AREVA proprietary fuel channel material

BWR Operating Experience and Fuel Exams

Norman Garner
Technical Sales Manager

Richland, Washington
June 2 – 3, 2015

AREVA

Agenda

- **Objectives**
- **BWR Fuel Reliability Overview**
  - **Fuel Rod Failures**
  - **Control Rod Interference from Fuel Channel Distortion**
- **2014 Fuel Examination Campaigns**
  - **Zry-4 Fuel Channel Measurements**
  - **Online Platinum Injection Surveillance**
  - **Recovery and Root Cause Evaluations of Load Chain Event**
- **Future Fuel Examination Campaigns**

Objectives

- Provide a status update on the overall performance of AREVA's BWR fuel products
- Provide an overview of fuel examinations and results from 2014 campaigns
- Provide an overview of future fuel examination plans
- Engage in dialogue regarding NRC interests and priorities for BWR fuel surveillance

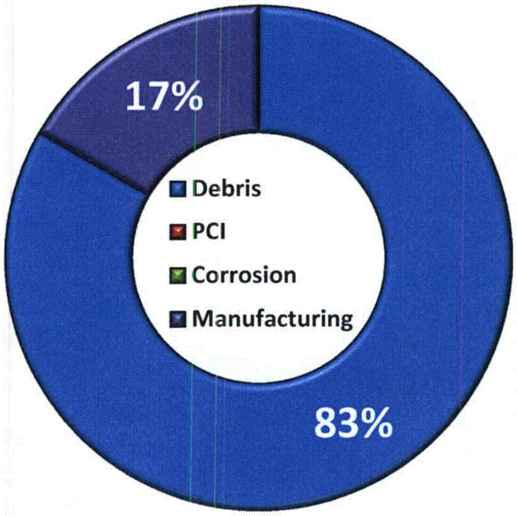
BWR Fuel Rod Reliability Status

- AREVA BWR Market is Failure Free

[ ]

[ ]

BWR Failure Mechanism Trends
(Previous 3 Years)



Driving to Zero Failures:

- **Debris**
  - Advanced FUELGUARD™ filters are displacing 1st generation FUELGUARD™
- **PCI**
  - Improved pellet quality
  - Enhanced maneuvering guidelines
- **Corrosion**
  - Optimized Zry-2 alloy content
  - Advanced crud and corrosion risk assessment tools
- **Manufacturing**
  - Risk of contamination resolved

Fuel Channel Distortion Update
US Operating Experience 2005-2015

» Discharge of Zry-2 fuel channels and fuel in BWR/6 cores coupled with improved channel bow management have reduced control blade interference frequency

Recent BWR Poolside Surveillance and Service Campaigns

[ ]

[ ] Campaign Objectives

- Collect data on high burnup/high fluence Zry-4 channels in limiting core locations to augment AREVA's Zry-4 fuel channel performance database,
- Investigate channels associated with three slow-to-settle (STS) events declared following a SCRAM in November 2012,
- Provide additional data to update the Zry-4 fuel channel bow correlation, and
- Investigate the role of early control bladed exposure on the amount of channel distortion in Zry-4.

[ ]

Zry-4 Fuel Channel Measurement

Scope of campaign:

- Characterization of 100 thrice burned Zry-4 fuel channels
  - Bow, bulge, and twist measurements
  - Burnup ranging from ~41 to ~51 GWd/MTU
  - Early control of up to 188 Effective Full Insertion Days
- Detailed visual examination of 8 fuel channels
  - Oxide and length measurements
- All channels of 100-mil uniform wall design

[ ]

[ ]

Fuel Channel Selection

[ ]

» **Majority of fuel channels selected had 3rd cycle fluence gradients favoring bow toward the controlled face**

Zry-4 Fuel Channel Performance Measurement Observations

- ▶ **Relatively high levels of bow were accommodated without slow-to-settle cells**
  - Improved core management is able to mitigate effects of bow
- ▶ **Bow shows widening scatter as fluence gradients increase**
  - Confirms that Zry-4 is not fully satisfactory for current operations
- ▶ **Bulge and twist data remains within expected ranges**

Recent BWR Poolside Surveillance Campaigns

* On-line Noblechem™ (OLNC) is a trademark of GE Hitachi Nuclear Energy

[ ]
2nd Cycle OLNC Assessment

- [ ] lead plant for OLNC
  - First application during Cy15 and second application during Cy16
- Surveillance measurements were taken to support comparisons to pre-OLNC performance data
  - Liftoff (tenacious crud + oxide) measurements were taken on rods from bundles operated in Cycles 15 & 16

[ ]

[ ]
Liftoff Measurement Data

[ ]

» Data for bundle exposed to OLNC in first two cycles shows higher peak liftoff and wider data scatter

[ ]

OLNC Surveillance Observations

- Measurements show an apparent effect of OLNC on both magnitude and variability of liftoff levels
  - Absolute value of total liftoff (crud + oxide) remains well below limit for oxide only in mid-span of [ ]
- Operations of AREVA fuel under OLNC remains satisfactory for current coolant chemistry and operating environment
- Further modifications of coolant chemistry need to consider an elevated baseline from pre-OLNC conditions
- Concurrent measurements of rod and bundle growth and rod profilometry showed respective performance results are within design limits and are consistent with expected results

Recent BWR Poolside Surveillance Campaigns

[ ]

December 28, 2014

- Hoist operators noticed a drop in the load cell reading while lifting a 3rd cycle ATRIUM™ 10 fuel assembly for shuffling to a new core position (18-month cycles)
  - After confirming reading and load cell functionality, the assembly was left in place for further evaluation
- Visual examination showed the upper tie plate and fuel channel to have shifted up relative to the fuel rod array

Fuel Assembly Removal from Core

- AREVA developed and rapidly deployed a repair technique to lift the assembly
  - Four (4) Part Length Fuel Rods were removed and replaced with temporary tie rods extending through the lower tie plate grid
  - Design was adapted from tools used to recover PWR fuel with failing guide tube swage connections

[ ]

Location of Load Chain Fracture

[ ]

[ ]

Fracture details

[ ]

Appearance of Fracture Surface

Side views of fracture

Detail of probable initiation point

Micrograph Examination Sample Selection

A transverse section was taken and both faces were prepared for metallographic examination

Profile of transverse section through fracture surface

Micrograph Observations
Grain Structure at Fracture Surface

[

]

Status

[

]

▶ **Part 21 deviation determination is complete:**

- **This issue has been classified as a deviation as a result of the quality indeterminate status of the connecting bolt**
- **It is not classified as a defect because it does not result in a potential significant safety hazard**

Upcoming BWR PIE Campaigns

Summary

- ▶ AREVA's U.S. BWR market is failure free

Acronyms/Nomenclature

- BQ: Beta-Quench
- EOL: End-of-Life
- FC: Fuel Channel
- LTA: Lead Test Assembly
- OLNC: Online NobleChem, a trademark of GE Hitachi Nuclear Energy for platinum injection into primary system
- PCI: Pellet-clad interaction
- PIE: Post Irradiation Exam
- SCC: Stress Corrosion Cracking
- STS: Slow-to-Settle
- Zry-BWR: AREVA proprietary variation of Zry-4 with iron and chromium above ASTM specification