AREVA Inc.
2016 Fuel Performance Meeting

June 1 – 2, 2016
Rockville, MD

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2016 Fuel Performance Meeting

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AREVA / NRC Annual Fuel Performance Meeting

Rockville, MD
June 1–2, 2016

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Fuel Performance Meeting Objectives

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

Agenda – June 1, 2016
Morning

- ▶ 10:00 **Introductions and Safety Message** – J. Rowley / N. Hottle
- ▶ 10:05 **NRR Management Discussion** – T. McGinty et al.
- ▶ 10:45 **NRR Updates**
  Pilot LTR Review Process – J. Dean
  Topical Report Change Management – J. Dean
- ▶ 11:00 **AREVA Inc. Regulatory Perspectives** – G. Peters
- ▶ 11:15 **U.S. Fuel Product Implementation Plans** – R. Freeman
- ▶ 11:30 **Lunch**

Agenda – June 1, 2016
Afternoon

- 12:30 **Introductions and Safety Message** – J. Rowley / N. Hottle
- 12:45 **BWR Operating Experience and Fuel Exams** – N. Garner
- 1:45 **ATRIUM™ 11 Irradiation Program & Poolside Inspection Results** – S. Cole
- 2:45 **Break**
- 3:00 **BWR Topical Reports Overview** – R. Pederson
- 3:15 **Update on BWR Advanced Engineering Methods** – K. Quick
- 4:15 **Wrap-up of Day 1**
- 4:30 **Adjourn**

Agenda – June 2, 2016 Morning

- 9:00 **Introductions and Safety Message** – J. Rowley / N. Hottle
- 9:15 **PWR Fuel Designs and Operating Experience** – B. Friend
- 11:00 **Break**
- 11:15 **RIA Criteria Revision Status Update** – P. Clifford
- 11:25 **10 CFR 50.46c Rule Change**
  NRC – P. Clifford
  AREVA – L. Gerken
- 12:00 **Lunch**

Agenda – June 2, 2016 Afternoon

- 1:00 **Introductions and Safety Message** – J. Rowley / N. Hottle
- 1:10 **PWR Topical Reports Overview** – R. Pederson
- 1:20 **PWR Fuel Seismic/LOCA Method** – B. Matthews
- 2:05 **Break**
- 2:15 **US PWR Advanced Methods** – K. Segard
- 3:15 **AREVA Program on Enhanced Accident Tolerant Fuel** – C. Lewis
- 4:15 **Wrap-up / Actions**
- 4:30 **Adjourn**

AREVA Inc. Regulatory Perspectives

Gary Peters
Director, Licensing and Regulatory Affairs

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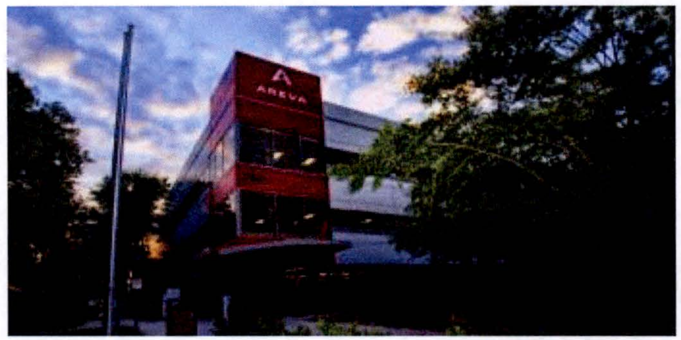
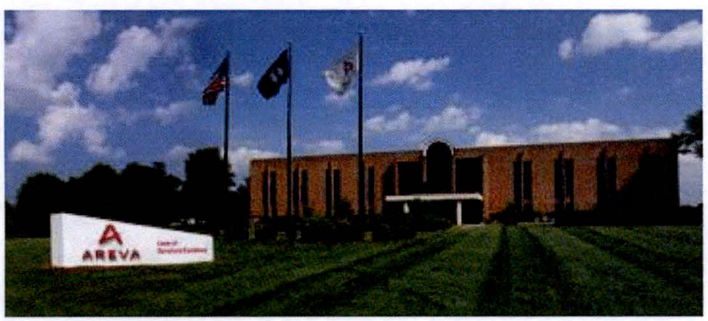
Our international presence

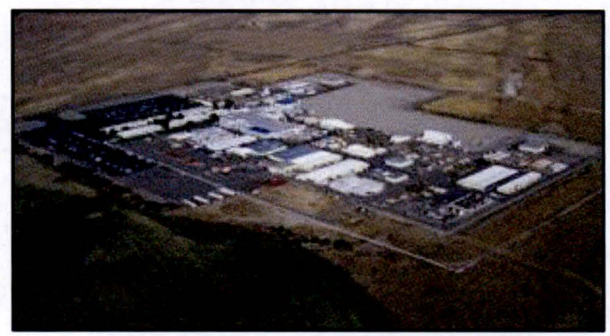
AREVA Inc.



Charlotte, NC –
North America
Headquarters

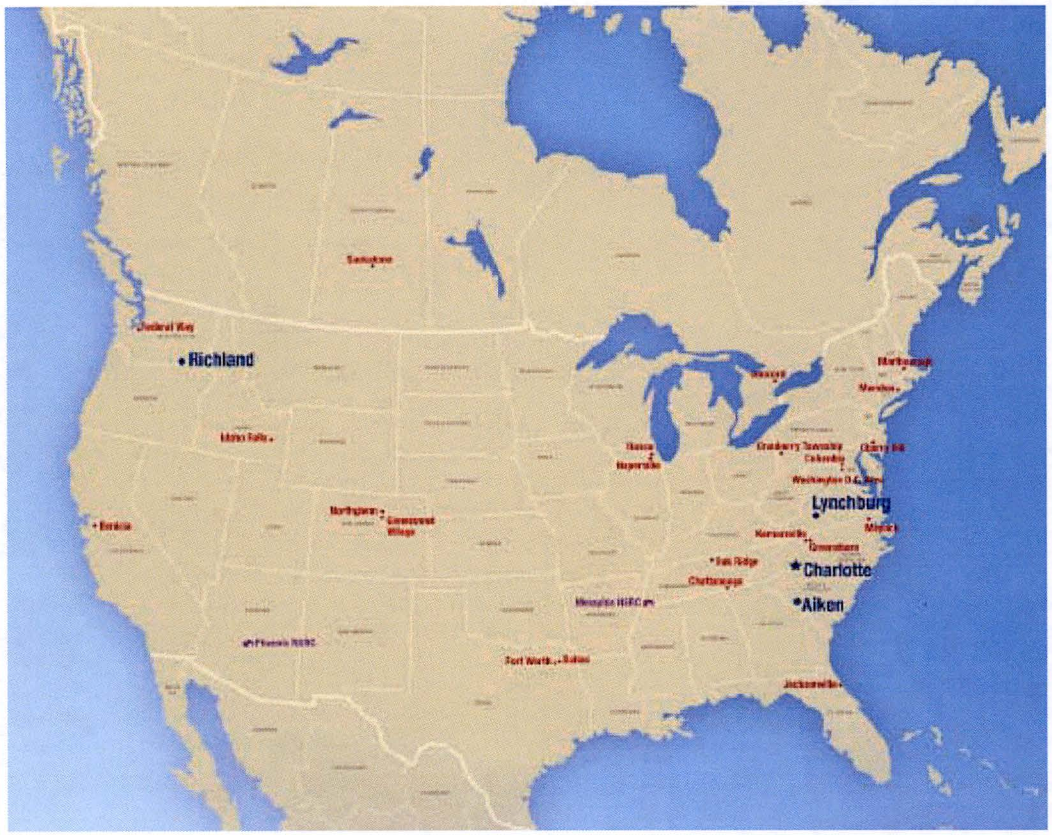


Lynchburg, Va.



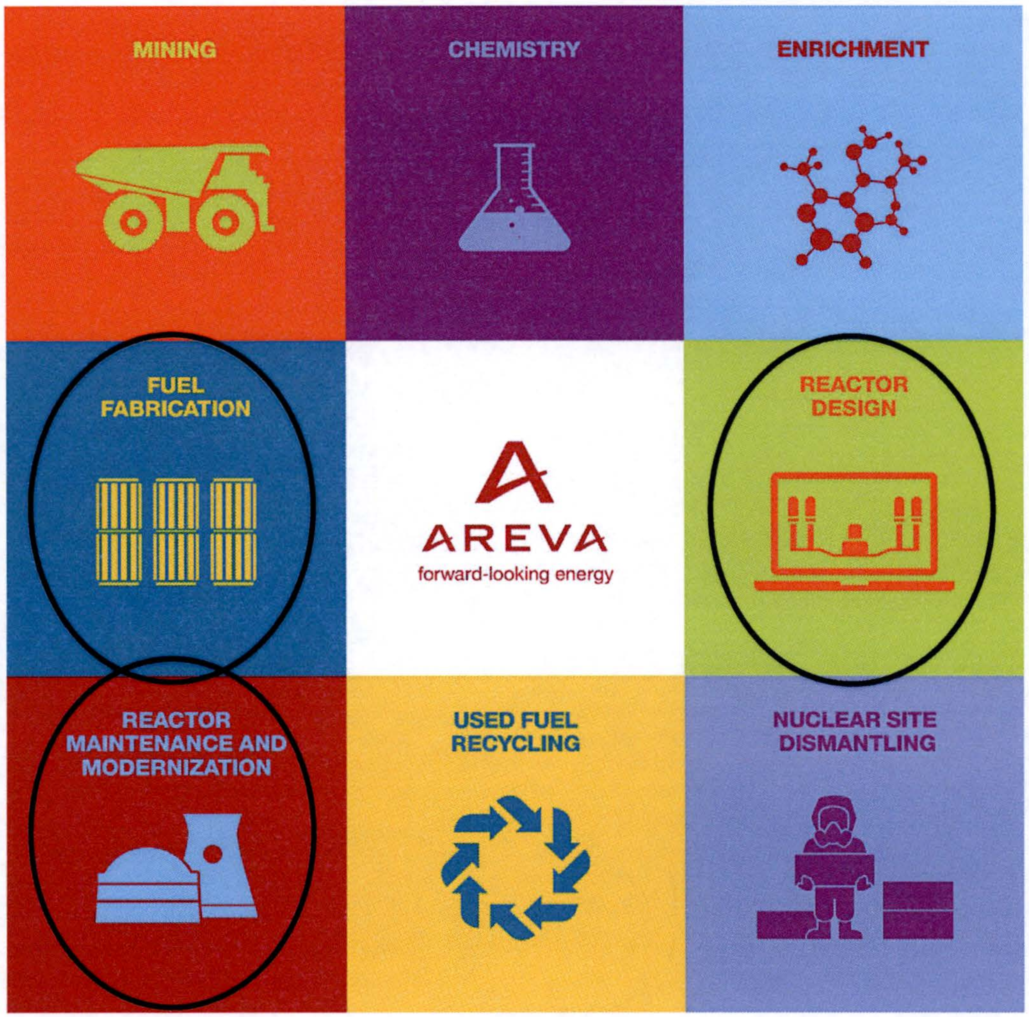
Richland, Wash.

AREVA is a Leader in North America



Nearly 4,100 employees committed to Operational Excellence in approximately 42 locations across North America

Our expertise

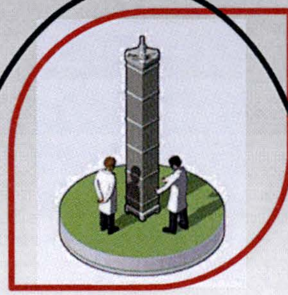


AREVA Inc. Business Capabilities

CORE BUSINESS

Mining
- Saskatchewan, Canada

Active sales presence in US



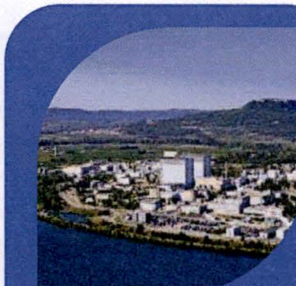
Front End
- Lynchburg, VA
- Richland, WA

Fuel in all U.S. Reactor Designs

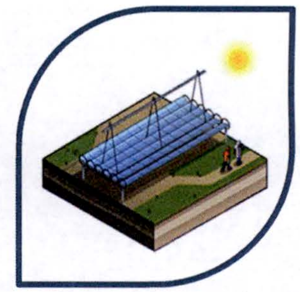
Reactors & Services
- Lynchburg, VA (Services)
- Charlotte, NC
- Marlborough, MA
- Fort Worth, TX
- Toronto, Canada

Key supplier of Services in U.S.

Back End
- Columbia, MD
- Charlotte, NC
- Aiken, SC
- San Onofre, CA



Leader in Dry Fuel Storage



Renewables
- Santa Clara, CA

Strategic Initiatives

US Fuel Product Implementation Plans

Robert S. Freeman
Vice President, U.S. Nuclear Fuels

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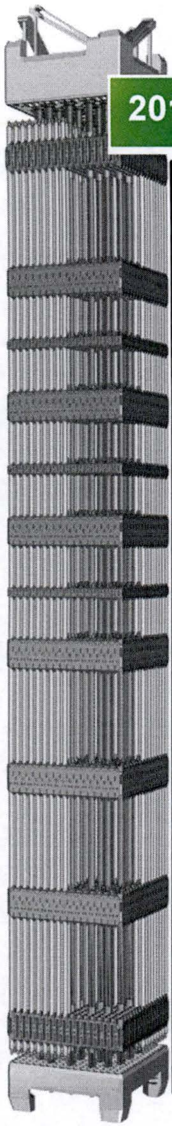
Objectives

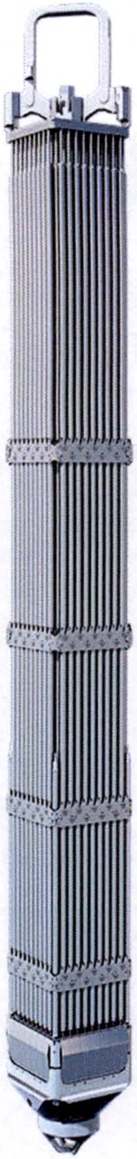
- Discuss AREVA's implementation plans for advanced fuel products
- Clarify need for alignment of NRC's topical report reviews with AREVA's priorities
- Emphasize need for efficient, timely NRC review of AREVA's topical reports

GAIA Go-To-Market in US



2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028

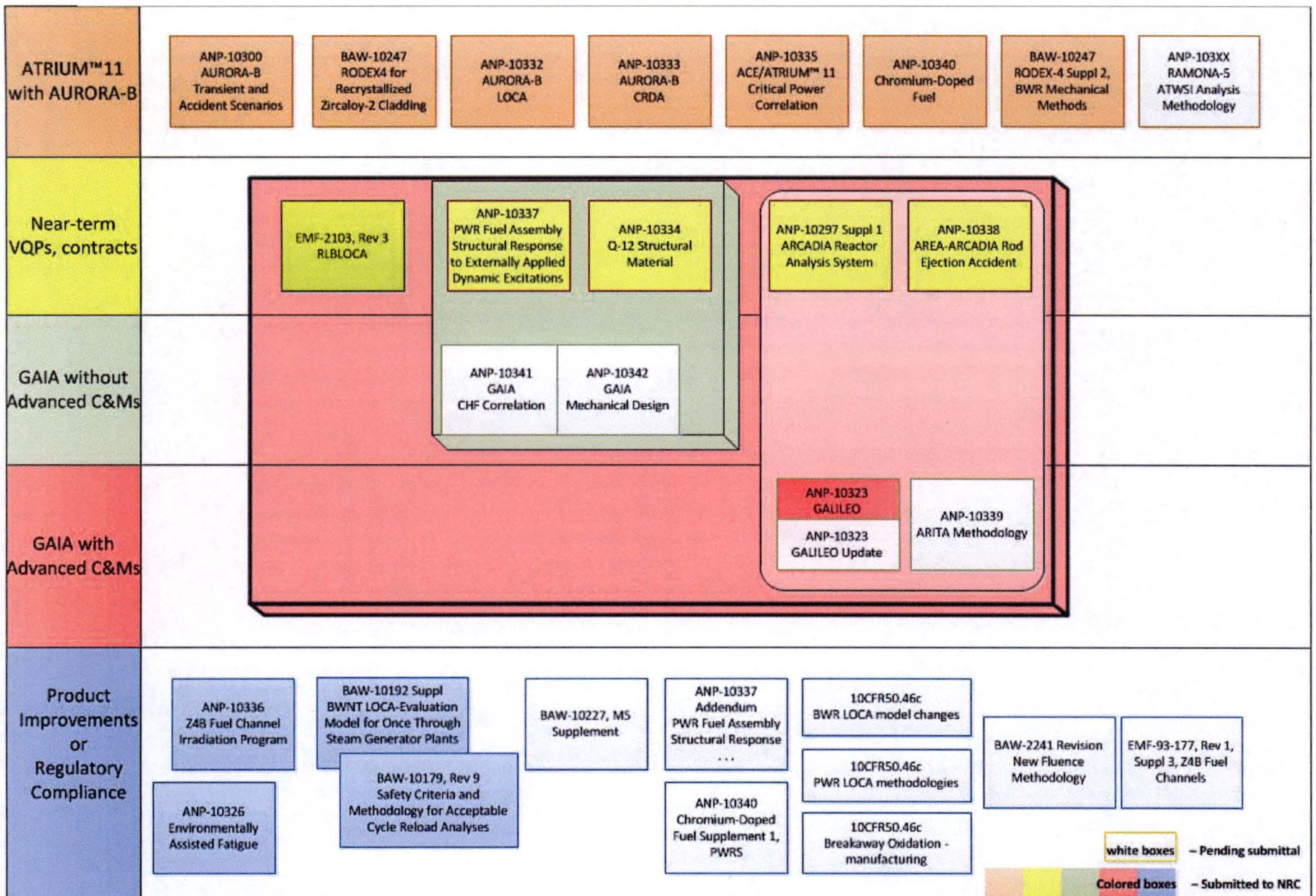
ATRIUM™ 11 Go-To-Market In US



2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028

Topical Reports

- **Priorities discussed during management review meetings remain unchanged.**



Summary/Conclusions

- AREVA recognizes the benefit of routine open/transparent dialogue with NRC
- Efficient, timely completion of NRC reviews is needed to support transitions to advanced fuel products and codes and methods.
- AREVA has clear priorities for NRC's review of topical reports

BWR Operating Experience and Fuel Exams

Norman Garner
Technical Sales Manager

Rockville, MD
June 1–2, 2016

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BWR Operating Experience
Agenda

- **Objectives**
- **BWR Fuel Reliability Overview**
  - ATRIUM™ Load Chain Events
  - Fuel Rod Failure - 10 Year Rolling History
- **2015 Fuel Examination Campaigns**
  - ATRIUM™ 10XM Leads and Reloads
  - Z4B™ Lead Use Fuel Channels
- **Future Fuel Examination Campaigns**

BWR Operating Experience Objectives

- Provide a status update on the overall performance of AREVA's BWR fuel products
- Provide an overview of fuel examinations and results from 2015 campaigns
- Provide an overview of future fuel examination plans
- Engage in dialogue regarding NRC interests and priorities for BWR fuel surveillance

ATRIUM™ BWR Fuel
Load Chain Events – 2014/2015

[

]

Connecting Bolt Event
Root cause evaluation

Connecting Bolt Event
Remedial actions

[ ]

Water Channel Event
Fracture details

[ ]

Water Channel Event
Fracture evaluation

Water Channel Event
Root cause evaluation

ATRIUM™ Load Chain Events Conclusions

- Steps taken with respect to the connecting bolt event are sufficient to assure this failure mechanism will not recur

[ ]

- Remedial restrictions are practicable to assure no recurrence of the water channel event failure mode

[ ]

  - Specific type of cleaning should not be performed on ATRIUM™ fuel

BWR Fuel Reliability

General performance statistics

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AREVA is delivering on zero BWR fuel rod failure expectations

[ ]

2015 Post-irradiation Examinations (PIE)

ATRIUM™ 10XM Reloads and LTAs

Z4B™ Advanced Alloy Fuel Channels

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US BWR Fuel PIE 2015 Examinations

[ ]

4-Face Visual Examination
Appearance consistent with expectations

[ ]

Fuel Rod Visual Examination
Appearance consistent with expectations

[ ]

Assessment of Observations

Spacer Grid Shadow Corrosion Background

- **Close proximity of Ni-based alloys or stainless steel to Zircaloy can result in accelerated corrosion under irradiation in BWRs**
  - Shadow corrosion on fuel rods under spacer grids largely occurs early in life and is greatest at low to moderate void conditions (lower elevations)
  - Shadow corrosion behavior depends on various factors (e.g. cladding and surface condition, spacer type/material/design, water chemistry, operating conditions)

[ ]

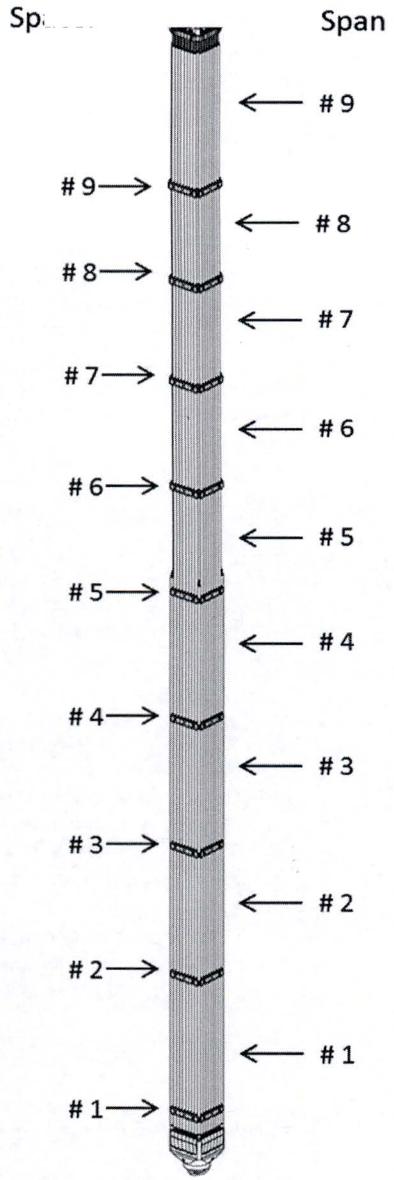
Spacer Grid Shadow Corrosion Campaign Scope

- Scope of poolside inspections included:

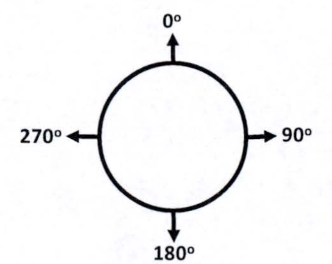
[ ]

*SSC: Spacer [Grid] Shadow Corrosion

Spacer Grid Shadow Corrosion Fuel Rod Selection



SIDE B



Fuel Rod Orientation for Examinations

Data for EPRI FRP SSC Program
Reference liftoff in span between grids

[ ]

Data for EPRI FRP SSC Program Liftoff 45° from spacer contact points

[ ]

Data for EPRI FRP SSC Program
Liftoff at spacer contact points

Shadow Corrosion Surveillance Observations & Next Steps

[

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US BWR Fuel PIE
2015 Examinations

ATRIUM™ 10XM LTA Exam

[ ]

Fuel Channel Surveillance
Z4B™ Alloy Lead Use Channels

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Fuel Channel Surveillance Z4B™ Alloy- continued

Fuel Channel Surveillance
Channel Coupon Removal

Z4B™ vs Zry-4 Fuel Channel Coupon Data

Z4B™ Fuel Channel Summary

2016-2020 Forecast for Post-irradiation Examinations (PIE)

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US BWR Fuel PIE Planning 5-year View

BWR Operating Experience Summary

Acronyms/Nomenclature

- BOL/EOL: Beginning-of-Life/End-of-Life
- BQ: Beta-Quench
- EFID: Effective Full Insertion Days- Fraction of full control blade insertion depth X number of days inserted
- EOC: End-of-Cycle
- EPRI FRP: Electric Power Research Institute Fuel Reliability Program
- HAZ: Heat affected zone (artifact of welding operations)
- IASCC: Irradiation Assisted Stress Corrosion Cracking
- IGSCC: Intergranular Stress Corrosion Cracking
- LTA: Lead Test Assembly
- LUC: Lead Use Channel
- OLNC: Online NobleChem, a trademark of GE Hitachi Nuclear Energy for platinum injection into the primary system
- PCI/MPS: Pellet-Clad Interaction/Missing Pellet Surface
- PIE: Post Irradiation Exam
- SSC: Spacer [Grid] Shadow Corrosion, local increase in cladding oxide in close proximity to Ni-alloy elements of spacer grids
- ULF-S: ULTRAFLOW™-S Alloy-718 spacer grid with CrN vapor deposition coating
- Z4B™: AREVA proprietary variation of Zircaloy-4 with iron and chromium above ASTM specification (developed under the working name of Zircaloy-BWR)

ATRIUM, FUELGUARD, ULTRAFLOW, and Z4B are trademarks of AREVA NP in the USA and other countries

ATRIUM™ 11 Irradiation Program & Poolside Inspection Results

Steven Cole
BWR Fuel Product Line Manager

Rockville, MD
June 1-2, 2016

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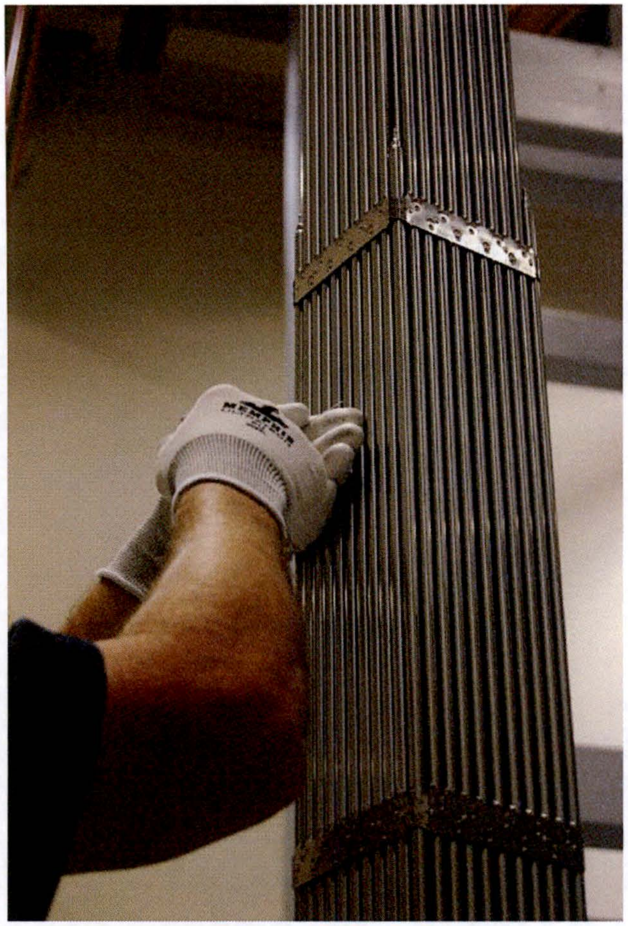
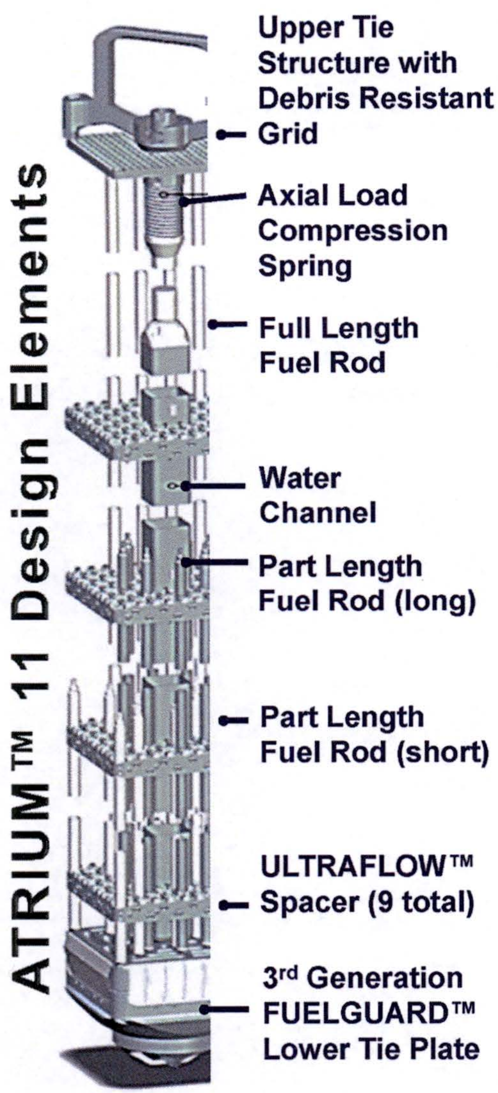
Objectives



ATRIUM™ 11 Fabrication, Richland WA

- Reiterate the purpose & safety advantages of the ATRIUM™ 11 fuel design
- Recap the new features of the ATRIUM™ 11
- Provide the current status of the ATRIUM™ 11 LTA program
- Share the ATRIUM™ 11 poolside irradiation results

Why ATRIUM™ 11?



- ~10 years ago, AREVA launched a development project to proactively address the industry need for superior BWR fuel safety and efficient reactor operation
- The new design had to address the known & anticipated failure mechanisms and increase design margins relative to the current (i.e., 10x10) designs
  - While simultaneously reducing fuel cycle costs
- Meeting these design objectives required combining high performing, proven technology with breakthrough innovation
- The 11x11 fuel rod array is the key breakthrough which led to meeting & surpassing the design objectives

The primary purpose of the ATRIUM™ 11 is to increase margins to design limits

ATRIUM™ 11 Fuel Rod Design

The ATRIUM™ 11 provides a comprehensive defense from the leading BWR fuel failure cause: debris fretting

- INPO Level 4 Event Report (March 17, 2016) was issued on the adverse trend in debris related fuel failures

The 3rd Generation FUELGUARD™ (3GFG) debris filter is standard on the ATRIUM™ 11

[

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ATRIUM™ 11 Fuel Channel

- Manufactured from Z4B™ material & beta-quenched for dimensional stability
  - Comprehensive protection against hydrogen & fluence induced bow

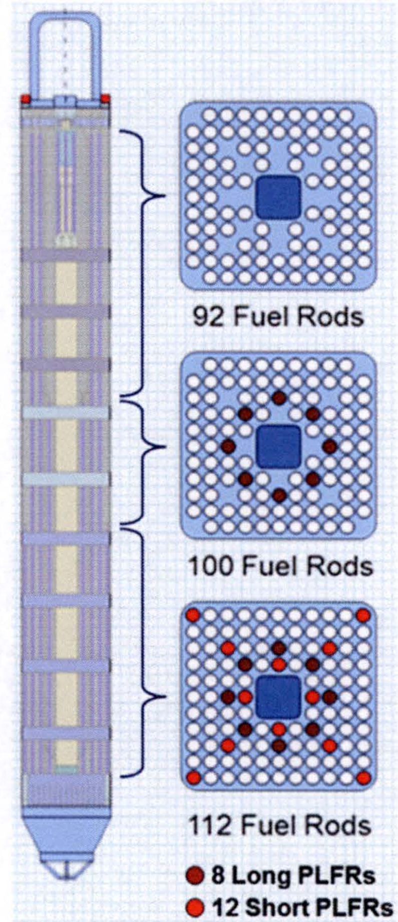
[ ]

The ATRIUM™ 11 fuel channel combines mechanical design features with Z4B™ BQ material to avoid fuel channel related safety risks and reliability issues

ATRIUM™ 11 Fuel Cycle Performance

- Cycle design simulations confirm that the ATRIUM™ 11 increases the calculated design margins for the transient and accident licensing analyses
  (Ref: "ATRIUM™ 11 – The Utilization of Reduced LHGR for Optimized BWR Operations" Topfuel 2013)
- The reduced LHGR allows for more flexible plant maneuvering, leading to improved capacity factors

[ ]



ATRIUM™ 11

The ATRIUM™ 11 improves operational flexibility, conserves uranium resources and can reduce spent fuel pool inventory

ATRIUM™ 11 LTA
Key Inspection Results

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The main ATRIUM™ 11 irradiation program consists of 40 LTAs operating across 5 reactors worldwide since 2012

[ ]

The ATRIUM™ 11 irradiation program is designed to fully demonstrate the product across the range of operating regimes & to provide EOL experience prior to the first US reload

Fuel Channel Visual Inspection

[ ]

- Excellent visual appearance with no unusual corrosion or mechanical anomaly

Fuel Rod Visual Inspection

- **No evidence of abnormal rod bow or performance issues**

ATRIUM™ 11 Fuel Rod Hot Cell Examination

[ ]

- **As in prior new fuel introductions, hot cell exams are used to substantiate poolside results**

Visual assessment of ATRIUM™ 11 ULTRAFLOW™ spacer grid

[ ]

- **Overall excellent visual appearance. No bent mixing vanes or damaged springs.**

ATRIUM™ 11 UTP inspection

[

]

[

]

- As expected visual appearance.
- No issues with removal or installation.

3rd Generation FUELGUARD™ Visual Inspection

[ ]

Perfect mechanical integrity of all new features

ATRIUM™ 11 Fuel Rod Growth

ATRIUM™ 11 Fuel Rod Diameter Change

ATRIUM™ 11 Fuel Rod Corrosion

Shadow Corrosion Assessment

Summary

- The ATRIUM™ 11 was purposefully developed to improve safety and to avoid fuel operational issues
- The ATRIUM™ 11 main LTA program launched in 2012 is comprised of a group of 5 utilities hosting a total of 40 ATRIUM™ 11 lead assemblies
- The ATRIUM™ 11 LTA program comprehensively demonstrates the various design features across the range of expected operating regimes
- End of life data will be available prior to the initial ATRIUM™ 11 reload in the US
- Poolside measurements to-date confirm the expected ATRIUM™ 11 performance and demonstrate in-reactor serviceability
- AREVA together with our customers and the NRC are executing the plan to realize the ATRIUM™ 11 safety benefits and operational flexibility to be gained 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
- EOL: End of Life
- FA: Fuel Assembly
- HWC: Hydrogen Water Chemistry
- KWU: Kraftwerk Union (Germany)
- LHGR: Linear Heat Generation Rate
- LTA: Lead Test Assembly
- LTP: Lower Tie Plate
- 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
- SFP: Spent Fuel Pool
- UTP: Upper Tie Plate
- Z4B™: AREVA proprietary fuel channel material

BWR Topical Reports Overview

Ronda Pederson
Advisory Engineer
Fuel Regulatory Strategy

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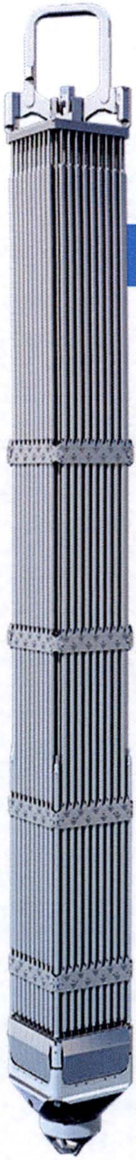
Objectives

- Discuss AREVA's implementation plans for advanced BWR fuel products, and supporting codes and methods
- Clarify need for alignment of NRC's topical report reviews with AREVA's priorities
- Emphasize need for efficient, timely NRC review of AREVA's topical reports

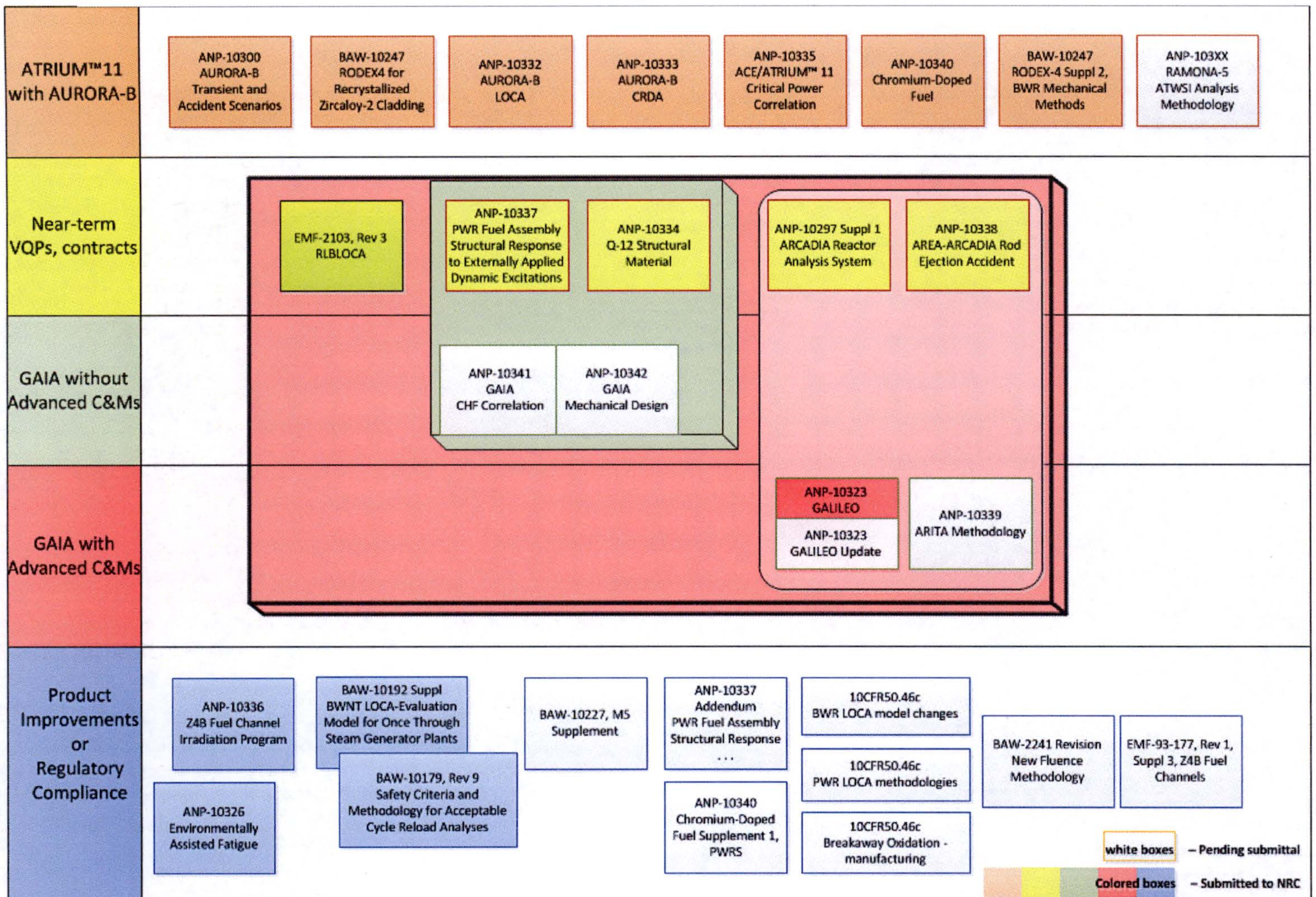


ATRIUM™ 11 Go-To-Market In US

2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028

Topical Reports

- **Priorities discussed during management review meetings remain unchanged.**

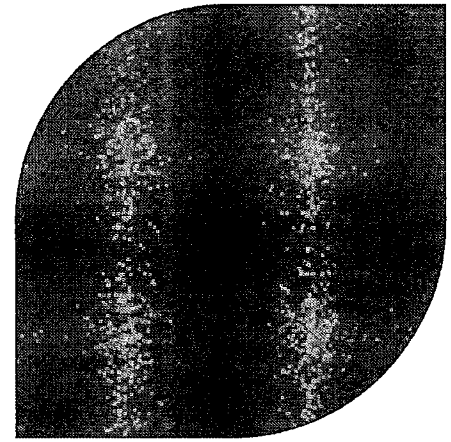


Summary/Conclusions

- AREVA recognizes the benefit of routine open/transparent dialogue with NRC

[ ]

- AREVA has clear priorities for NRC's review of topical reports



Update on BWR Advanced Engineering Methods

Kevin Quick
Supervisor
Thermal Hydraulic Codes and Methods

Rockville, MD
June 1–2, 2016

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Agenda

- ▶Objectives
- ▶AURORA-B Methodology Suite
  - ◇ Status and Schedule
  - ◇ LTR Review Progress
  - ◇ Summary
- ▶ATWSi Methodology to support extended flow window licensing
- ▶Additional BWR LTR Submittals
- ▶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

Background

- **Based on NRC feedback**
  - New methods development based on state of the art codes
  - Codes are based on first principles minimizing use of empirical formulations
- **New methods allow AREVA to**
  - Improve safety with better analytical tools
  - Transition from legacy methods
  - Improve modeling of phenomena with more explicit tools

New Methods Code Suite

AUREA-B Methodology Suite

AURORA-B Status

- Three AREVA BWR methodologies have been submitted to the NRC
  - AOO...... Draft SER expected in July
  - LOCA.... Not yet Accepted; NRC Active Status?
  - CRDA.... Accepted for review; NRC Active Status?
- Approval of these methodologies is required to address proposed changes in regulatory requirements

[ ]

Codes and Methods Schedule

Implementation Planning

[ ]

AURORA-B AOO Review Reaching Resolution

[ ]

AURORA-B Summary/Conclusions

ATWSi Methodology

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ATWSi Methodology

- A recent plant specific ATWSi methodology has been utilized by AREVA to support MELLLA+ operation

[ ]

ATWSi Methodology

Additional BWR LTR Submittals

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Chromium Doped Fuel

- ANP-10340, submitted on April 29th, addresses the incorporation of Chromia-Doped fuel properties in RODEX4. The LTR describes:
  - Cr_2O_3-doped material property database and the required changes to the standard RODEX4 fuel properties
  - Cr_2O_3-doped irradiation database including both steady-state data and ramp tests for code benchmarking
  - Benchmarking of RODEX4 against the database and updating of relevant licensing codes
  - Assessment of the impact of Cr_2O_3-doped UO_2 properties on licensing evaluations

[ ]

BWR Mechanical Design

- BAW-10247P-A Supplement 2P, submitted on April 29th, introduces improvements to AREVA's BWR fuel mechanical methods based on recent data

[ ]

Enhanced Option III

[ ]

Summary

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Summary

- AREVA has listened to NRC guidance and is investing in the advancement of codes and methodologies
- Advances in codes and methods are accompanied by a robust validation process
- Advances include capabilities to address proposed changes in regulations and provide greater flexibility to meet future needs
- Advanced codes and methods provide licensees with accurate and safe assessments of margins to fuel design limits, transients and accidents

PWR Fuel Designs and Operating Experience

Brian Friend
Advisory Engineer
Fuel Reliability and Performance

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PWR Fuel Designs and Operating Experience - Agenda

- Objectives
- Current Reload Fuel Products
  - HTP™ Design Overview and Status
  - Reliability and Recent Performance
  - Future Examination Campaigns
- AGORA® 5AI
  - Design Overview and European Operating Experience
  - Surry LFA Program
- GAIA™ Next Generation Fuel
  - Design Overview and European Operating Experience
  - Shearon Harris LFA Program

PWR Fuel Designs and Operating Experience - Objectives

- Familiarize the NRC Staff with AREVA's key PWR design features.
- Provide a status update on the overall performance of AREVA's PWR fuel designs.
- Provide an overview of PWR fuel examinations and results of recent surveillance campaigns.
- Provide an overview of future examination plans.

PWR Fuel Designs and Operating Experience – Objectives (cont.)

- Provide a status on the implementation of the next generation of PWR fuel design - GAIA™.
- Familiarize the NRC Staff with AREVA's Lead Fuel Assembly programs involving GAIA™ and AGORA® 5A-I.
- Engage in dialogue regarding NRC interests and priorities for PWR fuel surveillance.

HTP™ PWR Fuel
Extensive Operating Experience

- **Over 18,700 HTP™ assemblies irradiated in 50 cores worldwide**
  - **Arrays from 14x14 to 18x18**
  - **In reactors from various vendors – CE, Framatome, Westinghouse, Siemens and B&W**

[ ]

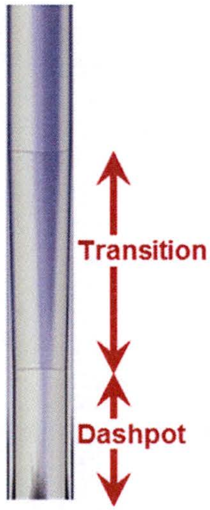
HTP™ PWR Fuel Proven Features

▶ M5® Fuel Rod Cladding

- Significant reduction is oxidation and hydrogen pickup (compared to Zircaloy-4)
- Supports high burnup design criteria for RIA and LOCA fuel performance with low hydrogen pickup
- Over 20 years of experience (15 in the U.S.)

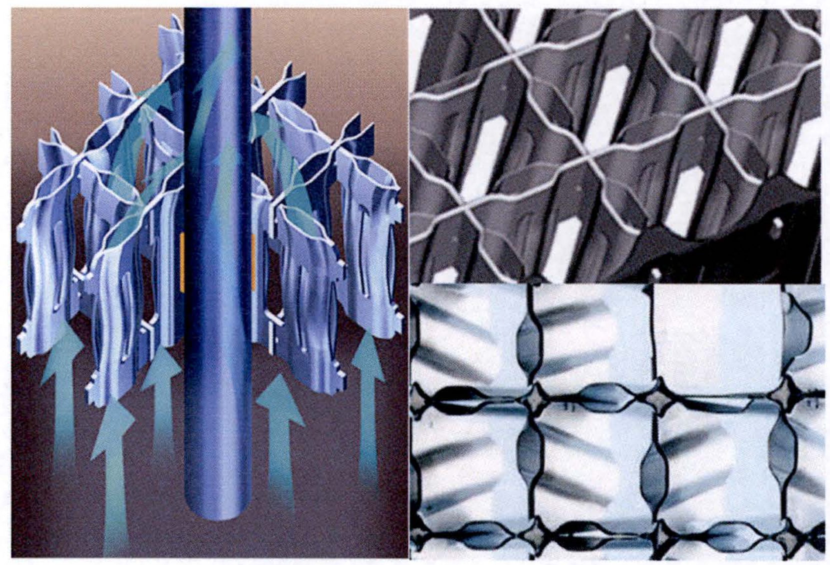
HTP™ PWR Fuel Proven Features

- **MONOBLOC™ Guide Tube**



- **FUELGUARD™ Bottom Nozzle**

- **Spacer grid designs with exceptional GTRF performance in challenging flow conditions**



AREVA U.S. PWR Reloads B&W Plants

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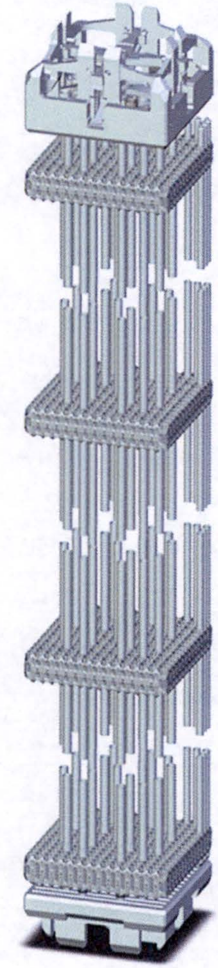

» **Transition to the Mark-B-HTP™ fuel design has been effective in eliminating GTRF failures in challenging flow environments.**

AREVA U.S. PWR Reloads
CE Plants

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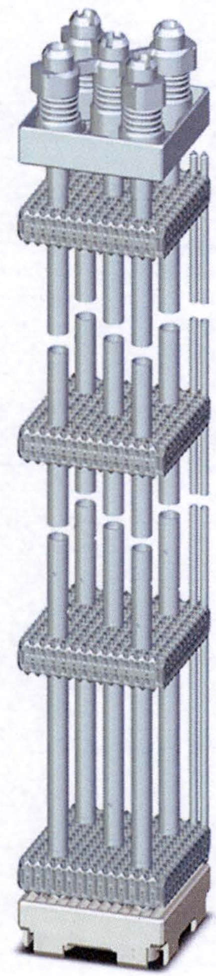
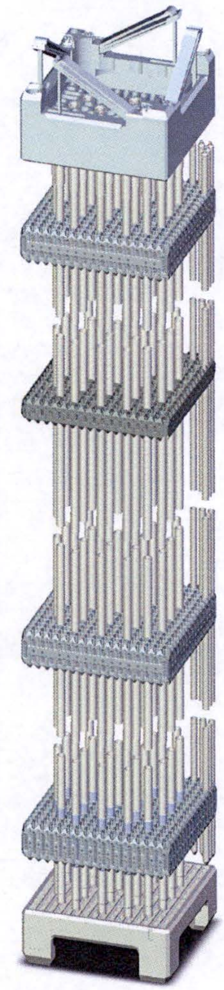


HTP™ designs continue to have excellent fuel performance in challenging flow conditions.

AREVA U.S. PWR Reloads Westinghouse Plants

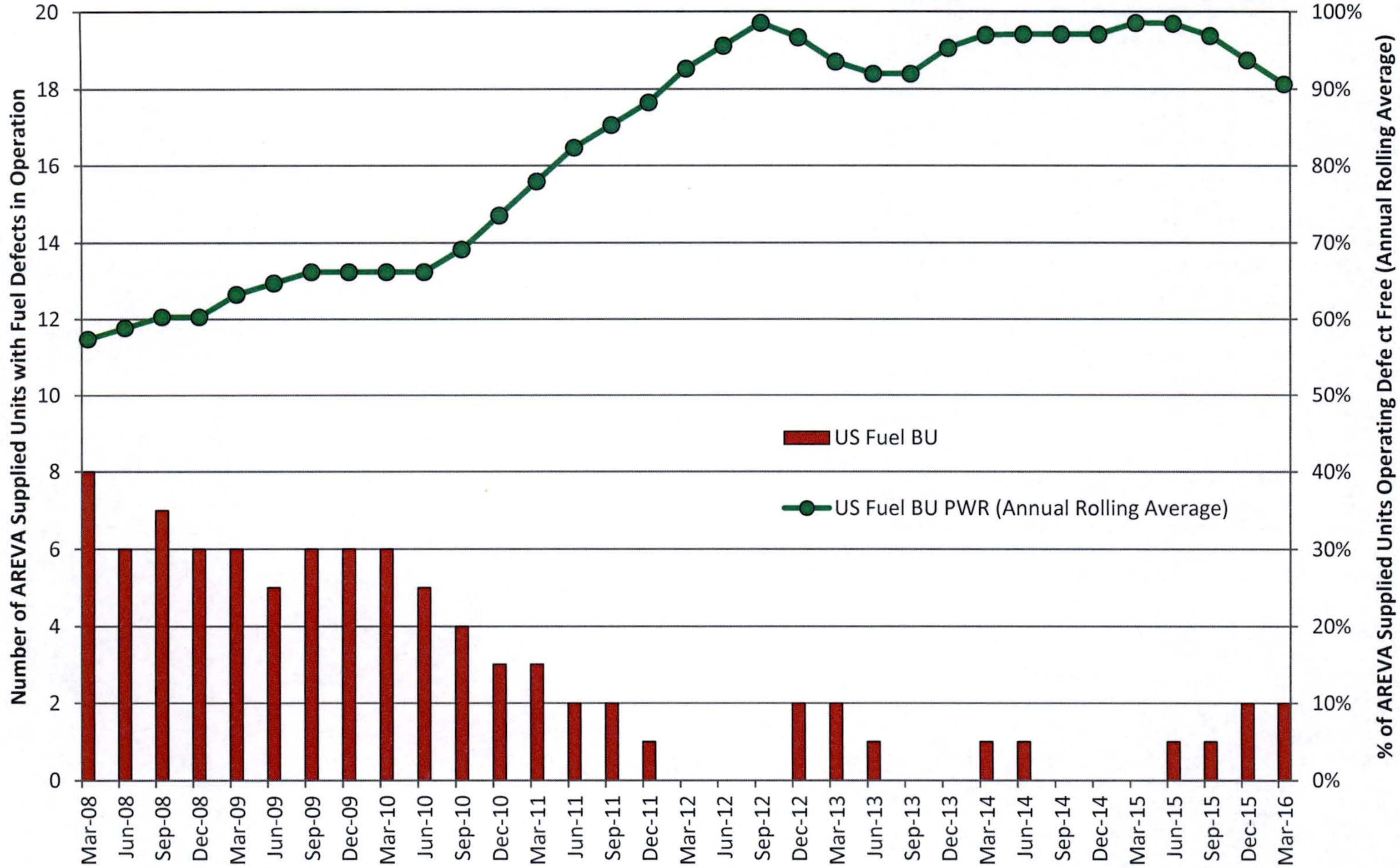


[ ]

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

PWR Fuel Reliability Status

- Currently two units are operating with failures



PWR Fuel Reliability Historical Perspective

[ ]

No fuel failures discharged in 2015.
Recent failures are in legacy designs.

Recent Surveillance Campaigns

Fuel Assembly Distortion Management (Grid Damage)

- With implementation of Adv. W17-HTP™ (two cycles), improvements in fuel assembly distortion have resulted in less grid damage.

[ ]

- No fuel scheduled for reinsertion was discharged due to grid damage.

Fuel Assembly Distortion Management (In-core Drag)

[

]

Significant improvement after first cycle.

Fuel Assembly Distortion Management (In-core Drag)

[ ]

Continued improvement in distortion with HTP™ implementation.

HTP Implementation
Grid width

[

]

The grid width behaviour of the Sequoyah-2 W17-HTP™ lies within the expected range of the experience feedback

HTP Implementation
FA Length

[ ]

The assembly growth behaviour of the Sequoyah-2 Adv. W17-HTP™ with M5® fuel rods is similar to the W17-HTP™ design with Zry-4 fuel rods

Mark-B HTP HDS Cracking Visuals

[

]

- Since heat treatment process controls implemented in 2008 to favourably control the cooling rate, no spring damage has been observed.

Mark-B-HTP Verification
Fuel Assembly Length

[ ]

The assembly length behaviour of the Oconee-2 Mark-B-HTP™ lies within the expected range of the experience feedback

B&W Baffle Interaction Continued Surveillance of Wear

No changes in frequency and severity

B&W Baffle Interaction
Pre-emptive Reconstitution

[ ]

Moving to a pre-emptive instead of re-active response

Upcoming PWR Fuel Surveillance Campaigns through 2018

AGORA® 5A-I
Fuel Assembly Attributes

[ ]

Q12™ Alloy Structural Material

- The Quaternary Alloy Q12™ consists of Zr with additions of Nb, Sn, and Fe
  - Tin improves irradiation-induced creep resistance
  - Iron helps sustain corrosion resistance
- Mechanical properties and material properties are similar to M5® and Zry-4
- Q12™ MONOBLOC™ guide tubes are manufactured by pilgering
- The final heat treatment leads to a stable fully-recrystallized material condition

Q12™ Alloy Experience Base

Plant	Lattice	Year Inserted	Quantity of Assembly	Q12™ GT	Q12™ Grid
D21	18x18	2011	12	√	√
		2013	8	√	√
D20	18x18	2010	4	√	
		2012	4	√	√
D18	18x18	2010	4	√	
D26	17x17	2012	2	√	
B42		2015	8	√	
D80	17x17	2013	68	√	
		2015	68	√	
D61		2014	56	√	
		2015	64	√	
D35	16x16	2012	4	√	√
D14	16x16	2012	4	√	√
D25	15x15	2012	4	√	
D24	15x15	2013	2	√	√

Since 2010, AREVA has irradiated 312 fuel assemblies with Q12™ (34 with both guide tubes and grids).

AGORA® 5A
Operating Experience

Plant	Cycle / Year Delivered	# FAs Delivered	Failed Rods
D9	28 / 2010	68	None
	29 / 2011	68	None
	30 / 2013	56	None
	31 / 2014	68	None
	Total	**260**	**Max Burnup 51 GWd/mtU Three 18 month cycles**
D25	32 / 2007	32	None
	33 / 2008	36	None
	34 / 2010	32	None
	35 / 2012	28	None
	36 / 2012	8 AGORA® 5A-I LFAs	None
	37 / 2013	24	None
	Total	**160**	**Max Burnup 61 GWd/mtU Five 12 month cycles**

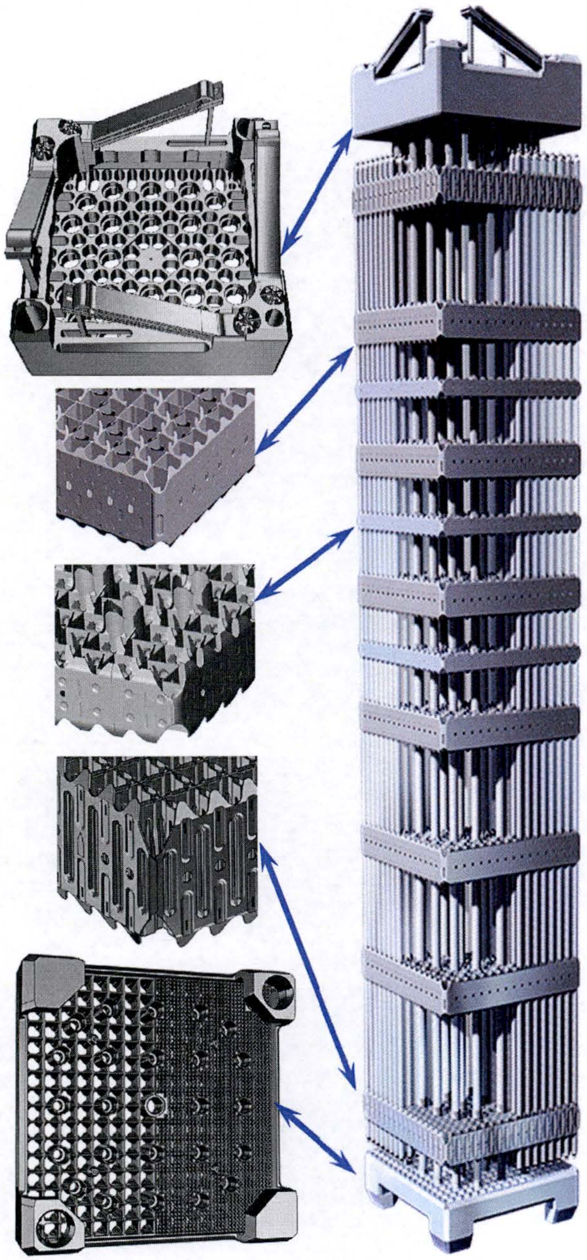
AGORA® 5A-I LTAs

- 8 LFAs 2016 delivery (cycle 28)
- Poolside Surveillance

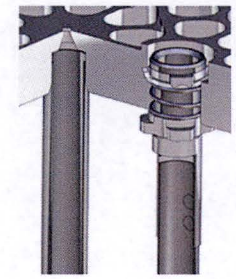
[ ]

Builds on worldwide experience with successful operation of a proven design

GAIA: Next Generation Fuel Assembly 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**
- **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 Grids

- **GAIA structural grid**
  - Combines proven experience of mixing vane with line contact

[ ]

- **IGM (Intermediate GAIA Mixer)**
  - Based on proven experience of the AFA design

GAIA
GRIP™ Bottom Nozzle

- Combines flow stability of FUELGUARD™ with low ΔP of TRAPPER®
- Flow stabilization – CFD evaluations confirmed by testing (Laser Doppler)
- High anti-debris efficiency

[ ]

[ ]

- Bullet nose interface with fuel rod protects against rod vibration and reduces trailing edge turbulence

GAIA - European LFA experience
Assembly Growth

[ ]

The growth behaviour of the GAIA LFAs lies within the expected range of the experience feedback

GAIA LFAs

▶8 LTAs inserted in 2015 at Shearon Harris,

▶Poolside Confirmatory Surveillance

[ ]

Next Generation Product – combines innovation with proven design

Summary/Conclusions

- HTP continues to be successful in addressing conditions adverse to fuel performance.
- All U.S. customers are in the process of implementing advanced cladding (M5®) with low oxidation, growth, and hydrogen pickup.
- AREVA's commitment to resolving conditions adverse to fuel reliability remain evident.
- AREVA is implementing next generation products based on improvements of successful and effective design features.
- AREVA's active PIE program continues to validate the successful performance of AREVA fuel products.

Acronyms/Nomenclature

▶ B&W	Babcock and Wilcox
▶ CFD	Computational Fluid Dynamics
▶ CE	Combustion Engineering
▶ DNB	Departure from Nucleate Boiling
▶ FA	Fuel Assembly
▶ FR	Fuel Rod
▶ GT	Guide Tube
▶ GTRF	Grid-to-Rod Fretting
▶ HDS	Hold-down Spring
▶ IFM	Intermediate Flow Mixer
▶ IGM	Intermediate GAIA Mixer
▶ LFA	Lead Fuel Assembly
▶ LOCA	Loss of Coolant Accident
▶ LTL	Lower Tolerance Limit
▶ NRC	Nuclear Regulatory Commission
▶ OCO	Oconee
▶ PIE	Post Irradiation Examination
▶ PWR	Pressurized Water Reactor
▶ RIA	Reactivity Insertion Accident
▶ RCCA	Rod Cluster Control Assembly
▶ SS	Stainless Steel
▶ SSR	Stainless Steel Rod
▶ TMI	Three Mile Island
▶ UTL	Upper Tolerance Limit
▶ Zry-4	Zircaloy-4 alloy

Update of AREVA Activities and Plans Related to 10 CFR 50.46c

Lisa Gerken
Principal Engineer
W&CE LOCA Analysis

June 2, 2016

AREVA

Agenda

- ▶Rule Status: High Level Overview
- ▶Submittal Plans
- ▶Breakaway Oxidation Testing
- ▶AREVA Activities and Schedule

Rule Status

- **Rule Package under Commission Review:**
  - SECY-16-0033: Rule Language and Statements of Consideration
- **Supporting information, not for Commission approval:**
  - Regulatory Guide (RG) 1.222: Measuring Breakaway Oxidation Behavior
  - RG 1.223: Determining Post-Quench Ductility
  - RG 1.224: Establishing Analytical Limits for Zirconium-Alloy Cladding Material
  - RG 1.229: Risk-Informed Approach for Addressing the Effects of Debris on Post Accident Long-Term Core Cooling – To be provided to Commission in June 2016
- **First required industry action: Licensee submittal of implementation plan – within 6 months, requires vendor coordination**

Submittal Plans

- ▶ **AREVA plans for submittal content: Unchanged from 2015**

[ ]

Breakaway Oxidation Testing

▶BrOx Testing Status

- **Equipment procured; Fully meets the specifications of RG 1.222**
- **Currently concluding internal device validation and qualification program**
  - Including round robin tests with CEA
  - Demonstrates well controlled temperature and humidity
  - Results consistent with previous test results and CEA

AREVA Activities and Schedule

- **NRC and Licensee Schedule**
  - **10 CFR 50.46c Effective Date: Unknown**
  - **Licensee implementation plan: Effective Date +6 months**
  - **Final licensee compliance demonstration submittal: Effective Date +60 months**
  - **Final compliance demonstration approval: Effective Date +84 months**

[ ]

Summary

- NRC and AREVA have a mutual interest in supporting the 10 CFR 50.46c project goals and schedule
- AREVA will:
  - Provide customers with cost and time efficient solutions
  - Work with customers to develop their implementation plans
  - Support early and frequent interactions with the NRC
- AREVA requests that the NRC:
  - Continue to communicate the 50.46c activity needs and schedule to key players and management levels of the utility
  - Keep open lines of communication between the NRC and AREVA to provide update on status and any new developments
  - Develop a streamlined Topical Report review process and schedule with AREVA to ensure the overall compliance requirements can be met

PWR Topical Reports Overview

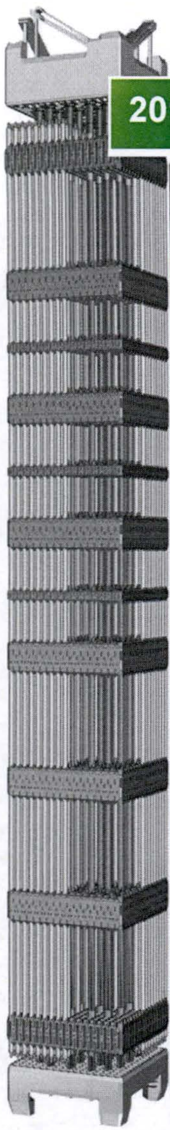
Ronda Pederson
Advisory Engineer
Fuel Regulatory Strategy

AREVA

Objectives

- Discuss AREVA's implementation plans for PWR advanced fuel products and codes and methods
- Emphasize need for efficient, timely NRC review of AREVA's topical reports

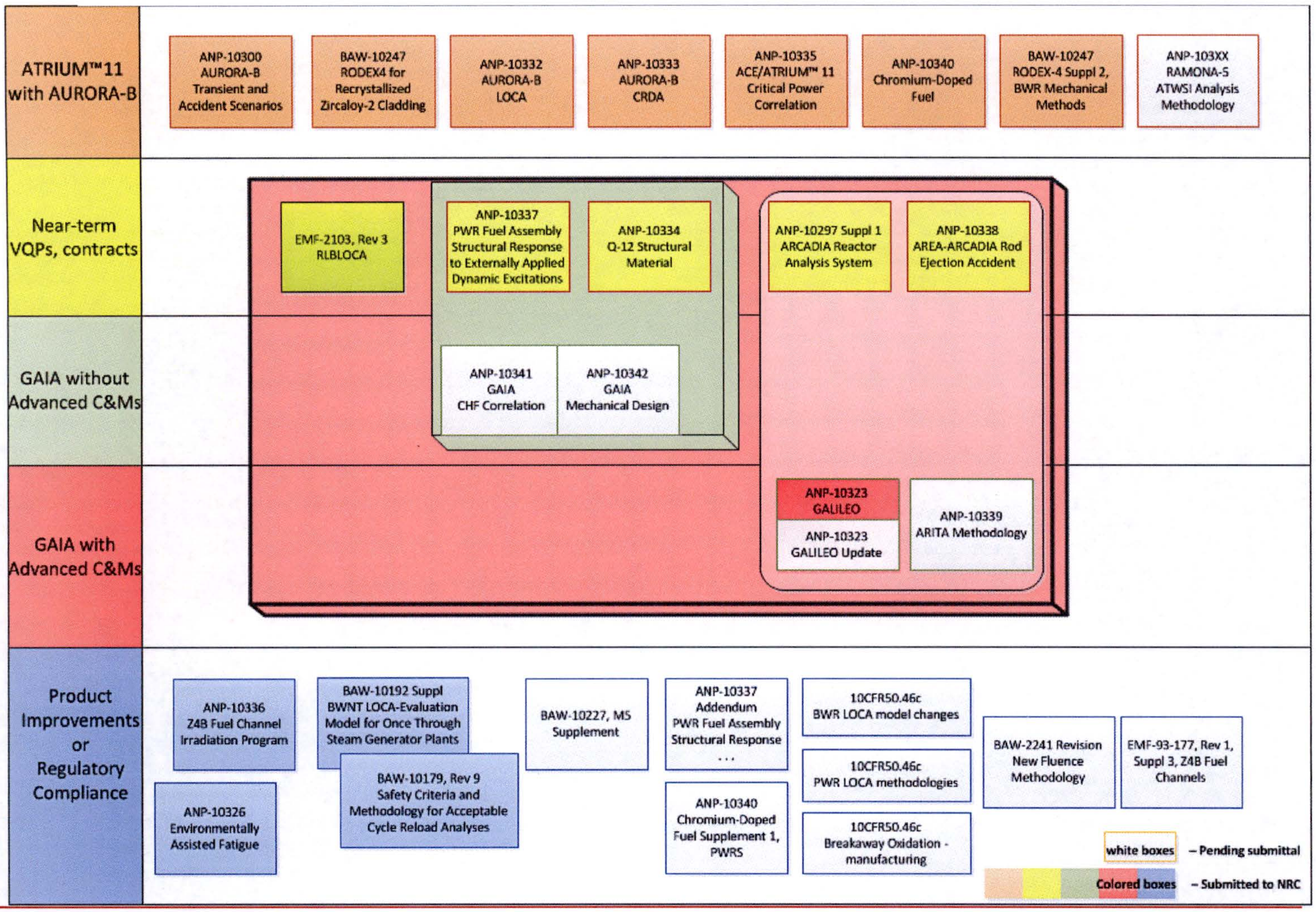
GAIA Go-To-Market in US



2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028

Topical Reports

Priorities discussed during management review meetings remain unchanged.



Summary/Conclusions

- ▶AREVA recognizes the benefit of routine open/transparent dialogue with NRC
- ▶Efficient, timely completion of NRC reviews is needed to support transitions to advanced fuel products and codes and methods.
- ▶AREVA has clear priorities for NRC's review of topical reports

PWR Fuel Seismic/LOCA Method

Brett Matthews
Supervisor
Fuel Mechanics

AREVA

Objectives

- Provide an update on AREVA's current and future activities associated with fuel seismic and LOCA methodology

Status of AREVA Seismic/LOCA Methodology

- AREVA's "seismic" methodology is moving!
- BAW-10133 → ANP-10337
- ANP-10337 submitted in August 2015
- Working for approval no later than [ ]
- Why are we moving?
  - Address industry issues
    - IN 2012-09: Irradiation Effects on Spacer Grid Crush Strength
    - Damping
    - LOOP
    - GT Stress Allowables
  - Capture the progress made during review of US EPR DC
  - Usability. . .streamline and consolidate old topical content

ANP-10337 sets a new standard and builds a robust platform for future methodology

Status of AREVA Seismic/LOCA Methodology

▶ Highlights of ANP-10337:

- ◇ 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)

Status of AREVA Seismic/LOCA Methodology

- **In the interim, AREVA is applying content from ANP-10337. . .**
  - **Methods applied and approved for St. Lucie Unit 2 fuel transition**
    - Main issues from ANP-10337 are addressed and summarized in LAR and corresponding RAI responses
  - **Methods are currently being applied to . . .**

[ ]

Beyond ANP-10337

- AREVA plans to use ANP-10337 as a platform to build new products and methods
- Two examples to build upon ANP-10337 are:
  - GAIA fuel design

[ ]

GAIA Spacer Grid Behavior

[ ]

New Testing Protocols

[ ]

New Testing Protocols

New Testing Protocols

Summary

- AREVA is proactively addressing emerging issues
- AREVA is investing in products and methods beyond ANP-10337
- AREVA requests full NRC support in the review of ANP-10337
- AREVA requests a push for a modernization of staff guidance in the area of seismic/LOCA methodology

Acronyms/Nomenclature

- BOL Beginning Of Life
- EOL End Of Life
- GT Guide Tube
- LOCA Loss-Of-Coolant Accident
- LOOP Loss-Of-Offsite Power

US PWR Advanced Methods

Kevin Segard
Supervisor, PWR Methods and Licensing
AREVA Expert

Rockville, MD
June 1–2, 2016

AREVA

Agenda

- Objectives
- Introduction
- ARCADIA® Code System
- GALILEO™ Fuel Performance Code
- AREA™ Rod Ejection Methodology
- ARITA™ Non-LOCA Methodology
- Summary

Objectives

- Provide a status update on
  - ARCADIA® Supplement
  - GALILEO™
  - AREA™
  - ARITA™
- Provide an overview on methodology development
- Obtain NRC feedback

Background

- **Based on NRC feedback**
  - **New methods development based on state of the art codes**
  - **Codes are based on first principles minimizing use of empirical formulations**
- **New methods allow AREVA to**
  - **Improve safety with better analytical tools**
  - **Replace legacy methods**
  - **Improve modeling of phenomena with more explicit tools**

New Methods Code Suite

▶Codes

- ◇ APOLLO2-A – Assembly lattice code
- ◇ ARTEMIS™ – 3D core simulator code
- ◇ COBRA-FLX™ – Core thermal-hydraulics code
- ◇ GALILEO™ – Fuel thermal-mechanical code
- ◇ S-RELAP5 – System thermal-hydraulics code

(APOLLO2-A, ARTEMIS™, COBRA-FLX™ } ARCADIA®)

▶Code Status

- ◇ ARCADIA® codes received NRC approval in 2013
  - Supplement 1 submitted to NRC in June 2015
- ◇ GALILEO™ Currently under review

ARCADIA®
Supplement

AREVA

ARCADIA® Background

- Approved 2013
- Consists of
  - ANP-10297PA "ARCADIA®"
  - ANP-10331PA "COBRA-FLX™"
- ANP-10297P Supplement 1 submitted June 2015
  - Comparisons to MOX identified code modification beneficial to UO_2 cores
  - Improved MEDIAN power reconstruction technique for power distributions
  - Addition of a spacer grid model
  - Improved treatment of transients
  - Improvements to ^{147m}Pm branching ratio
  - Upscatter in U and Pu isotopes
- Under NRC review
  - Audit for understanding held April 28 – 29, 2016

ARCADIA®
Supplement Purpose

- ▶ Address code enhancements
- ▶ Additional core benchmarks
  - ◇ Enriched Reprocessed Uranium cycles
  - ◇ Cold critical boron comparisons
- ▶ Additional transient benchmarks
  - ◇ SPERT III E-Core rod ejection
- ▶ Extension of MEDIAN process to Rh and fission detectors
- ▶ Uncertainty definitions
  - ◇ Total Rod Worth
  - ◇ ITC/MTC

Lattice Calculations

- ▶Pm branching ratio and U, Pu upscatter intended to adjust reactivity behavior

[ ]

APOLLO2-A Experimental Validation

- ▶Critical Experiments:
  - ◇ B&W
  - ◇ CAMELEON (Gad)
  - ◇ EPICURE-MOX
  - ◇ EPICURE-UOX
  - ◇ Kritz-KWU (Pu)
  - ◇ Kritz-KWU (U)
- ▶Additional Validations
  - ◇ Fission rate measurements
  - ◇ Spent fuel isotopics

▶Re-analysis of benchmark data (criteria established in ANP-10297PA)

◇ HZP Physics Testing

• ARO CBC	±50 ppm (or ±500 pcm equivalent)
• Individual rod worth	±15% (±100 pcm for low worth banks)
• Total rod worth	±10%
• ITC	±2 pcm/°F

◇ Core Follow Data

• Boron Concentrations	±50 ppm (or ±500 pcm equivalent)
• Core RPD	RMS*100 < 5.0 (absolute difference)
• Axial Power distribution	RMS*100 < 5.0 (absolute difference)

ARTEMIS™
HZP Physics Testing Results

[ ]

ARTEMIS™
HFP CBC Results

ARCADIA®
Range of Applicability

▶Capable of modeling

- Diverse plant types (core size and configuration)
- Diverse lattice types (enrichment, and BP loadings)
- Diverse cycle lengths

Plant Type	Core Size	Fuel	# of Cycles	Lattice	Burnable Absorbers	Control Rod Absorbers	Detectors
W	157	UO_2	14	17x17	Pyrex, WABA, IFBA, Gd	Hf, AIC	TIP
W	157	UO_2	1	17x17	Pyrex + Gd	AIC	TIP
CE	217	UO_2	9	14x14	Gd	B_4C	SPND
S	177	UO_2	5	15x15	Gd	AIC	AMS
S	193	UO_2	5	18x18	Gd	AIC	AMS
W	193	UO_2	3	17x17	B_4C, B_4C + Gd	AIC	TIP
W	193	UO_2	3	17x17	B_4C, B_4C + Gd	AIC	TIP
B&W	177	UO_2	7	15x15	B_4C, B_4C + Gd, Gd	AIC	SPND
W	157	UO_2	5	15x15	Gd (up to 10 wt%)	AIC	TIP
W	157	ERU	6	17x17	None	AIC	TIP
Total Number of Cycles			58				

ARTEMIS™ Qualification Criteria

▶Established in ANP-10297P Supplement 1

◈ HZP Physics Testing

- ARO CBC ±50 ppm (or ±500 pcm equivalent)
- Individual rod worth ±15% (±100 pcm for low worth banks)

[ ]

◈ Core Follow Data

- Boron Concentrations ±50 ppm (or ±500 pcm equivalent)
- Core RPD RMS*100 < 5.0 (absolute difference)
- Axial Power distribution RMS*100 < 5.0 (absolute difference)

▶Analysis of PWR using Er burnable absorbers

◈ Preliminary results are within the criteria specified above

ARCADIA® Summary

- ▶Established criteria are met
- ▶Expected improvements to results were achieved
- ▶Justification has been provided of the update process defined in ANP-10297PA

GALILEO™

AREVA

Next-Generation Fuel Rod Performance Code: GALILEO™

- **Improved fuel rod modeling**
  - Capable of modelling PWR and BWR fuel (Zirc-4, M5®, CWSRA and RXA Zirc-2 cladding materials and UO_2, UO_2-Gd_2O_3, and MOX pellet materials)
  - Benefits from the modeling of latest observed phenomena, including fuel thermal conductivity reduction with burnup and high burnup effects
- **Extensive calibration and validation Database**

[ ]

- **Modern statistical methodology**
  - Methodology is based on the approved RODEX4 methodology
- **Ready for future industry needs**
  - Support rod burnup of [ ]
  - Support high duty cores resulting from Extended Power Uprates (EPUs)

GALILEO™ addresses all recent NRC concerns on legacy fuel rod performance codes

arge Validation Database Covering Entire Burnup Range of Interest

[ ]

All Models Benefits from Large Calibration Database

[ ]

GALILEO™ Timeline

- GALILEO™ topical report was submitted for NRC approval in August 2013 and accepted by the Staff for review in March 2014
  - BAW-10323P, "Fuel Rod Thermal-Mechanical Methodology for Boiling Water Reactors and Pressurized Water Reactors"
  - Initial draft of RAIs was received in April 2015
  - Final RAIs issued in April 2016 after positive interactions between NRC, PNNL, and AREVA
- AREVA revised the scope of requested approval to exclude review for applicability to MOX and BWR by letter dated November 23, 2015
  - Approval now requested only for PWR fuel (Zircaloy-4, M5®, UO2, and Gd2O3) irradiated in B&W, CE and Westinghouse reactors
- AREVA has resolved the code convergence issues discovered after submittal of the topical report
  - Resolution required changes to key models (fuel cracking, fission gas release, and gaseous swelling)
  - Code is currently being re-calibrated and validated
- Updated topical report will be submitted in [ ]
- Preparation of RAI responses will resume after updated topical report is submitted to the NRC

AREA™ - ARCADIA®
Rod Ejection Analysis Methodology

AREVA

AREA™ Introduction

- Current rod ejection methods at AREVA use point kinetics or r-z kinetics
- AREA™ is a 3D kinetics approach
  - ARTEMIS™ is the 3D kinetics engine

[ ]

  - Manual or automatic coupling to RELAP5 used to perform system pressure calculation
- AREA™ designed to address changes in regulatory requirements
- AREA™ submitted for review in October 2015

AREA™ Features

▸Features of the AREA™ transient models

[ ]

- Power level and cycle burnup are treated (not just the four corners)
- Parameter biasing performed to ensure a conservative model
- Oxidation and Hydrogen pick-up limits established using GALILEO™

» **Method uses a 3D kinetics approach to remove excess conservatism in the analysis while providing a more accurate assessment of the event**

AREA™ Limiting Pin

▶Limiting Pin Determination

- **Peak pin ≠ limiting pin**
- **Burnup limits will determine limiting pin**
  - Worst combination of oxide thickness and Δcal/g
- **Energy deposited in higher burnup pins can be significant**
- **ARCADIA® Code System provides a significant improvement in determining the deposited energy**

Treatment of burnup limits provides a more robust analysis for Rod Ejection

AREA™ Enthalpy Rise

[ ]

AREA™ Fuel Temperature

[ ]

AREA™ DNBR

[ ]

AREA™ Summary

- Method developed to meet current and proposed NRC RIA requirements
- Method uses a 3D kinetics approach to remove excess conservatism in the analysis while providing a more accurate assessment of the event
- The AREA™ Method ensures safe plant operation while anticipating future regulation changes

[ ]

ARITA™ - ARCADIA®/RELAP Integrated Transient Analysis

AREVA

ARITA™ Structure

Topical report addresses

- Phenomena Identification and Ranking Table
- Assessment Matrix Table
- Range of applicability
- W and CE setpoints
- Mixed core treatment
- Non-LOCA events divided in SAFDL and non-SAFDL
- DNB propagation
- Power Distribution Control

ARITA™ Non-LOCA Event Analysis

- **Events supporting SAFDLs**
  - 3D transient ARTEMIS™ coupled to S-RELAP5

[ ]

  - FCM analysis performed with GALILEO™
- **Non-SAFDL event analysis**
  - 0D (point kinetics) S-RELAP5 using ARTEMIS™ neutronic data
  - DNB and FCM not considered

Method uses a 3D kinetics approach to remove excess conservatism in the analysis while providing a more accurate assessment of the event

ARITA™ 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**

[

]

ARITA™ Summary

- Incorporates the coupling of ARTEMIS™ and S-RELAP5 creating a 3D transient model for SAFDL events
- Standalone S-RELAP5 modeling with ARTEMIS™ neutronics inputs for non-SAFDL events
- Event analyses based on PIRT evaluation
- Topical will incorporate a treatment for mixing in various regions of the vessel
- Many aspects for modeling of a PWR are considered and implemented

Summary

Summary

- AREVA has listened to the NRC and is advancing both codes and methodologies
- Advances in codes are consistent with changes in regulations while flexible to meet future needs
- Advanced Codes and Methods provide utilities operational flexibility
- Advanced methods provide an accurate and safe assessment of Non-LOCA events

AREVA Program on Enhanced Accident Tolerant Fuel

Chris Lewis
Sr. Project Manager
AREVA Fuels

AREVA

Agenda/Objectives

▸Agenda

- DOE Program Background
- AREVA EATF Concepts
  - Cr-Coated M5™ with Cr_2O_3-Doped UO_2 Pellets
  - SiC-SiC Sandwich Cladding
  - Molybdenum Based Alloy Cladding
- AREVA Phase 2 Roadmap

▸Objectives

- Develop an understanding of the drivers of this effort and goals
- Get an introduction to the AREVA EATF concepts
- Present a high level roadmap of future activities

DOE Background

Congressional Directions

U.S. DEPARTMENT OF
ENERGY
Nuclear Energy

Senate Guidance Regarding Accident Tolerant Fuel

- **In the Consolidated Appropriations Act, 2012, Conference Report 112-75, the Department of Energy, Office of Nuclear Energy was:**
  - Directed "to give priority to developing enhanced fuels and cladding for light water reactors to improve safety in the event of accidents in the reactor or spent fuel pools,"
  - Urged " that special technical emphasis and funding priority be given to activities aimed at the development and near-term qualification of meltdown-resistant, accident-tolerant nuclear fuels that would enhance the safety of present and future generations of Light Water Reactors,
  - And requested "to report to the Committee, within 90 days of enactment of this act, on its plan for development of meltdown resistant fuels leading to reactor testing and utilization by 2020."

Definition of EATF

U.S. DEPARTMENT OF **ENERGY**
Nuclear Energy

Definition and Challenge

Definition of Fuels with Enhanced Accident Tolerance

Fuels with enhanced accident tolerance are those that, in comparison with the standard UO_2 – Zircaloy system currently used by the nuclear industry, can tolerate loss of active cooling in the reactor core for a considerably longer time period (depending on the LWR system and accident scenario) while maintaining or improving the fuel performance during normal operations, operational transients, as well as design-basis and beyond design-basis events.

10-year Goal
Insert a LTA/LTR into an operating commercial reactor

Attributes of EATF

U.S. DEPARTMENT OF
ENERGY
Nuclear Energy

Major Attributes to Address

Improved Reaction Kinetics with Steam
- -Heat of oxidation
- -Oxidation rate

Slower Hydrogen Generation Rate
- -Hydrogen bubble
- -Hydrogen explosion
- -Hydrogen embrittlement of the clad

High temperature during loss of active cooling

Improved Fuel Properties
- -Lower operating temperatures
- -Clad internal oxidation
- -Fuel relocation / dispersion
- -Fuel melting

Improved Cladding Properties
- -Clad fracture
- -Geometric stability
- -Thermal shock resistance
- -Melting of the cladding

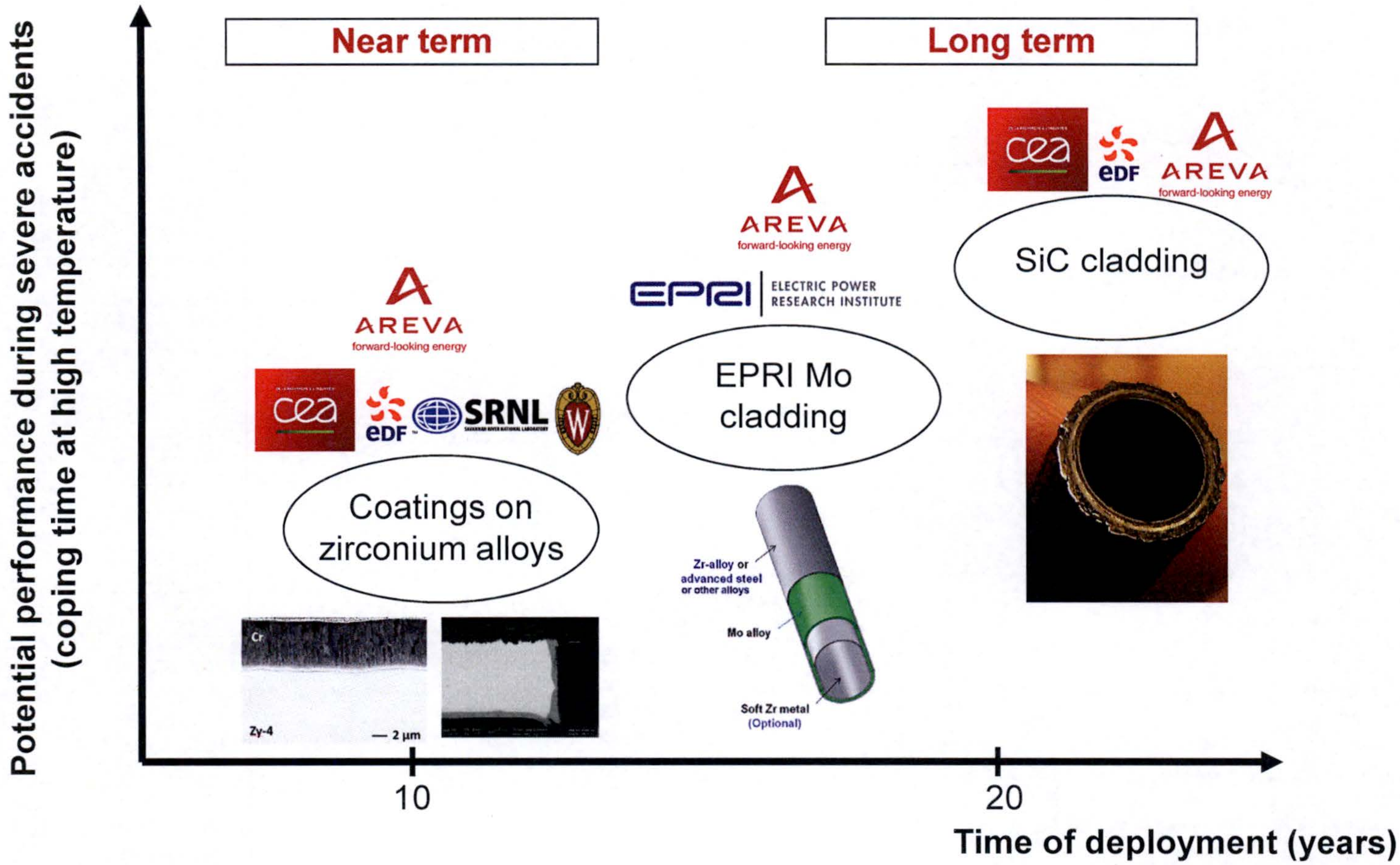
Enhanced Retention of Fission Products
- -Gaseous fission products
- -Solid/liquid fission products

Based on these safety-related issues, metrics for quantifying the enhancements in accident tolerance must be developed in conjunction with the safety features of a given LWR design and based on specific accident scenarios.

AREVA EATF Concepts

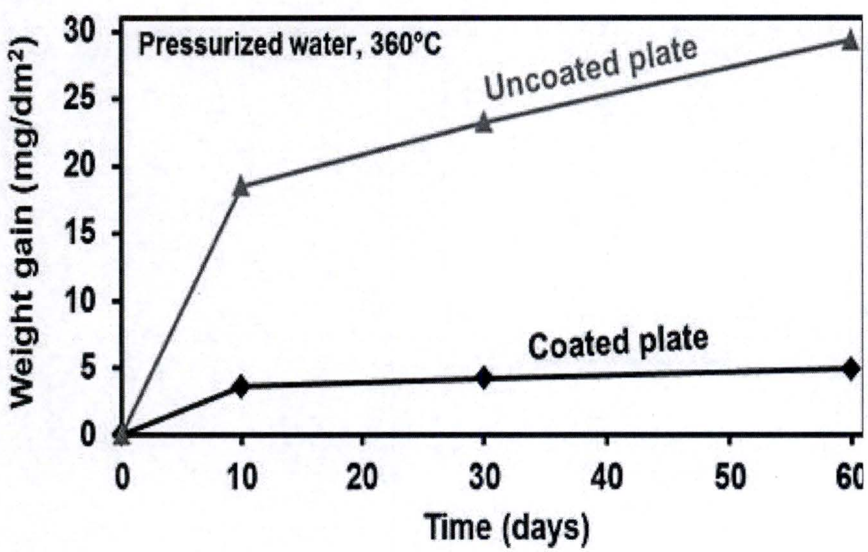
AREVA

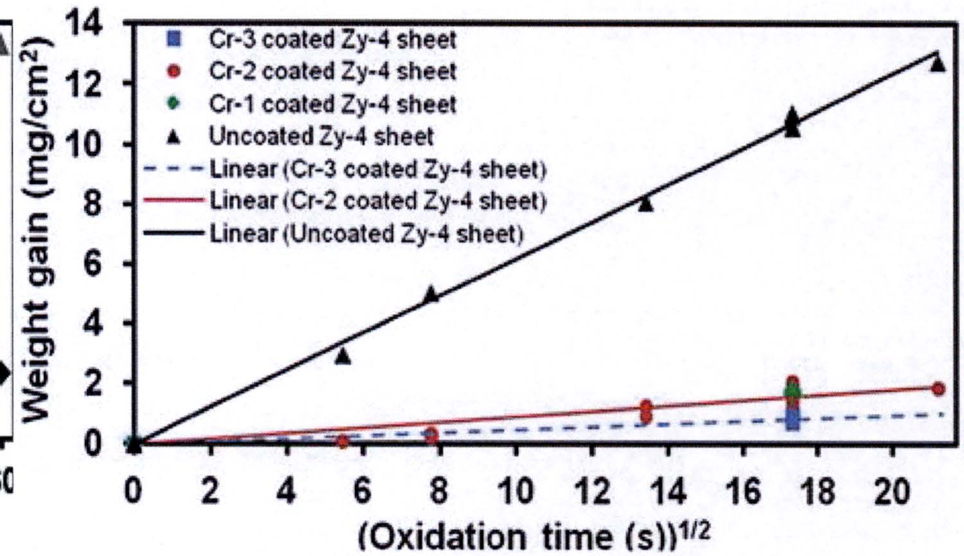
AREVA's Global Scope for EATF



Cr-Coated Zr-4/M5TM Cladding

- Based on current Zr-4 or M5™ fuel rod cladding configurations
  - Chromium coatings on the order of 5-15 µm
  - Applied with Physical Vapor Deposition (PVD) coating process
- Provides improved PWR water and high temperature steam oxidation kinetics



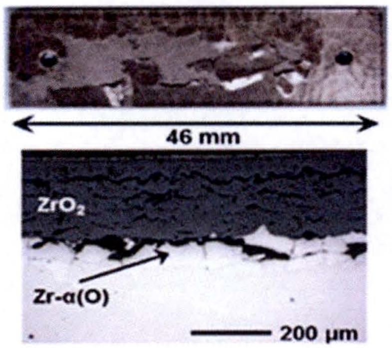


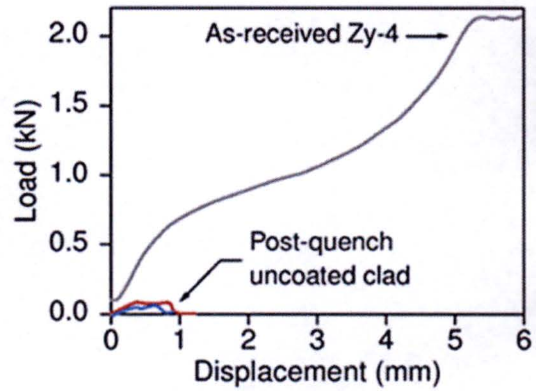
Cr-Coated Zr-4/M5™ Cladding

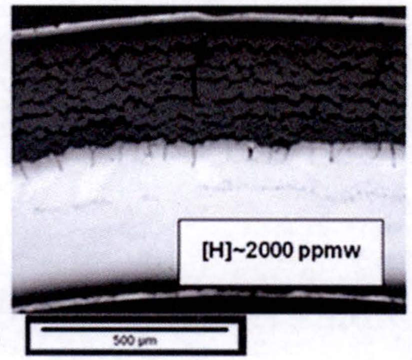
- Improved Beyond Design Basis Accident (BDBA) Performance (Ductility)

Comparison of uncoated and chromium coated Zircaloy-4 (Zy-4) samples after exposure to 1000 °C steam for 15000s by metallographic cross-section and post-quench mechanical behavior.

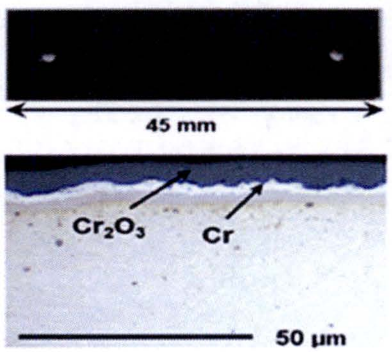
Uncoated Zy-4

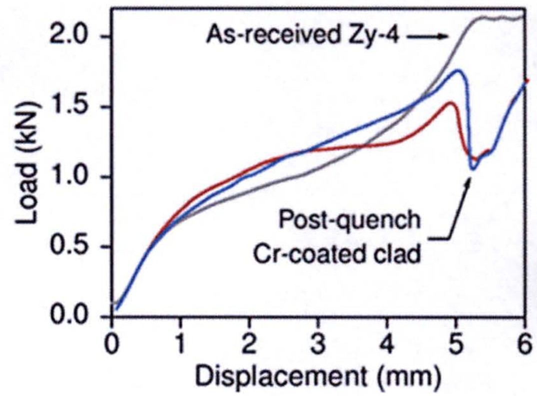


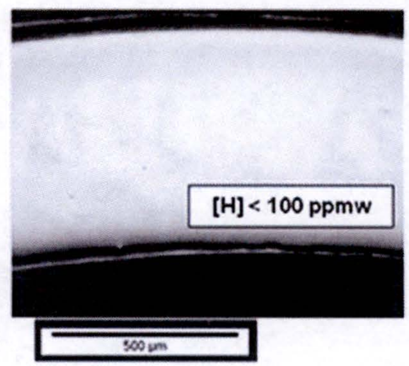




Cr-Coated Zy-4



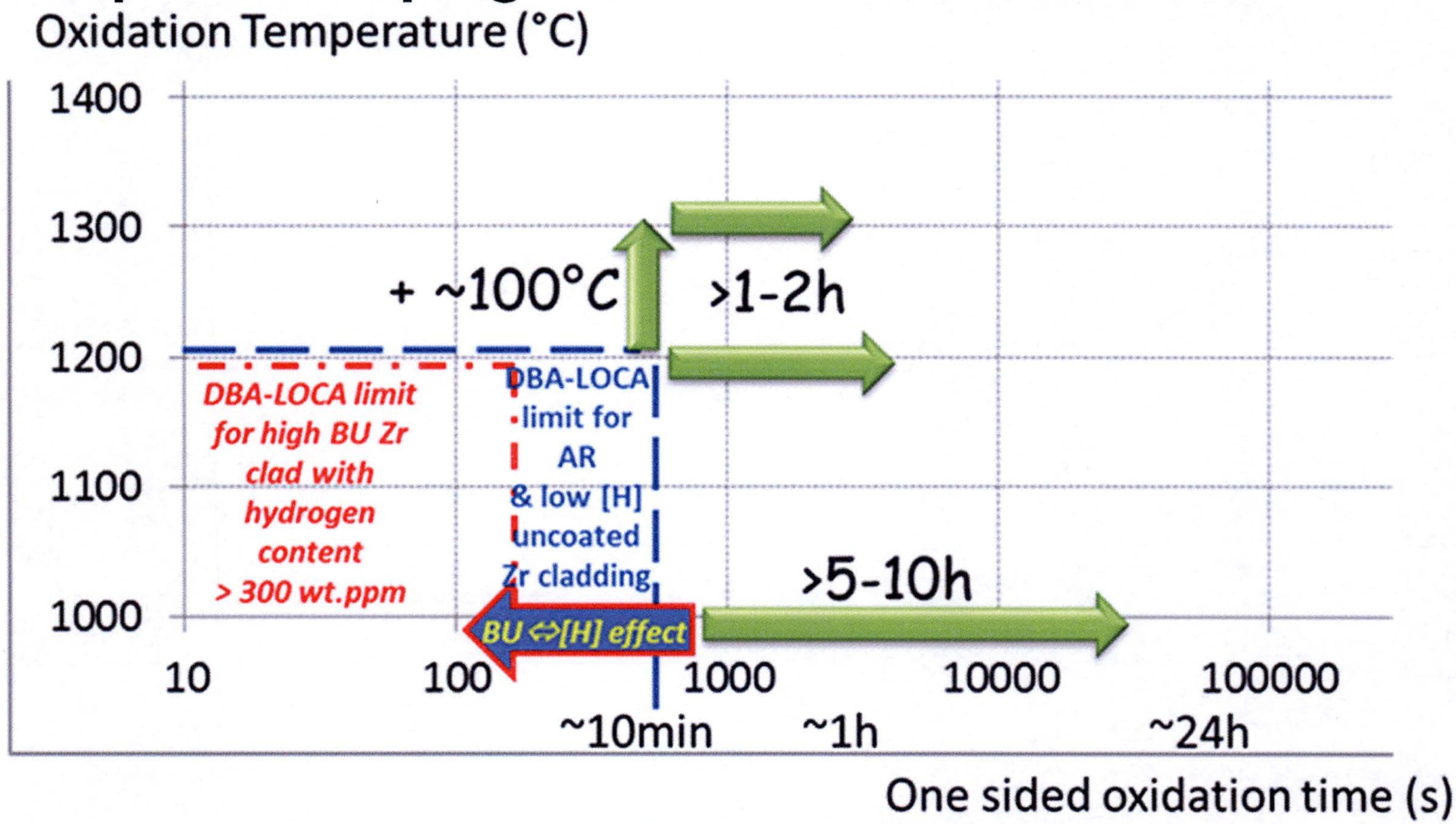




Cr-Coated Zr-4/M5^{TM} Cladding

Cr-Coated Zr-4/M5^{TM} Cladding

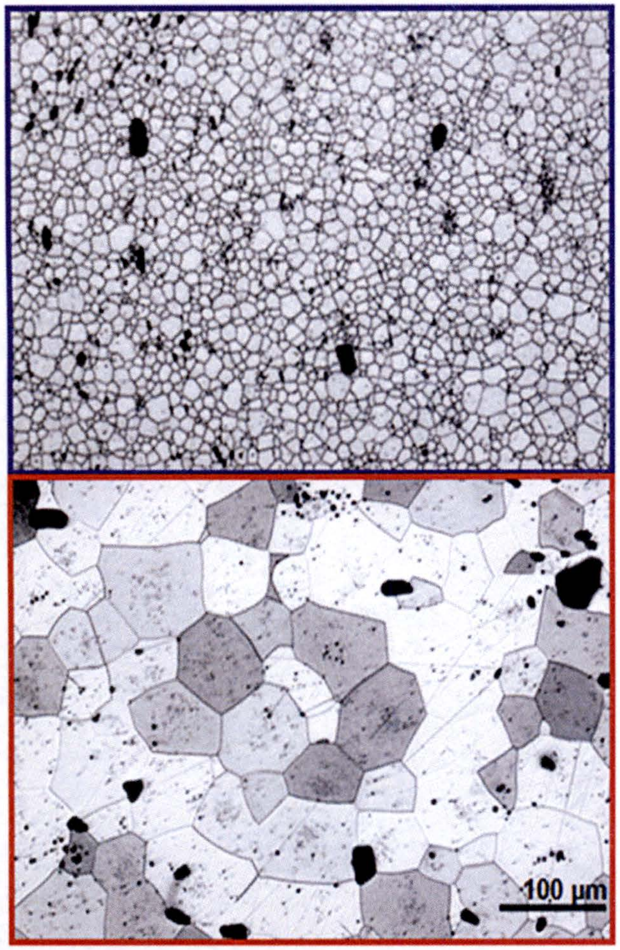
▶ Improved Coping Time for Severe Accidents



Potential gains in coping time due to the chromium coating

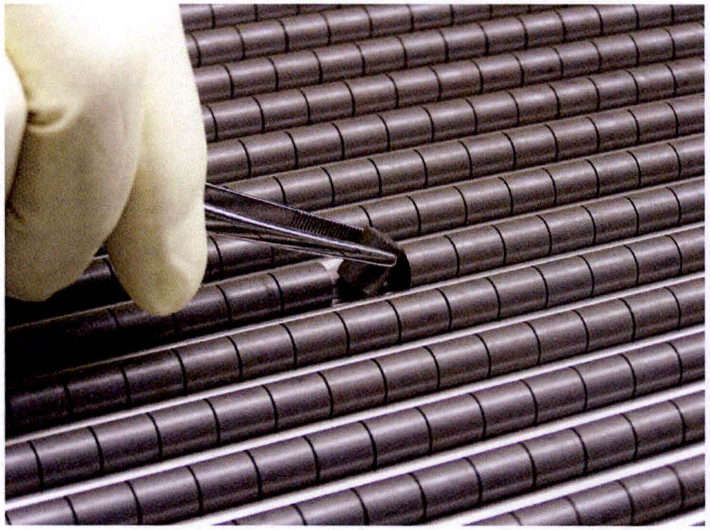
Cr_2O_3 Doped UO_2 Pellets

Standard UO_2: ~12 µm



Cr_2O_3-doped UO_2 : 60 µm

- UO_2 pellet doped with up to 0.16 w/o Cr_2O_3
  - Provides for large grain, viscoplastic microstructure
  - Enhanced densification (>96 %TD)
  - Improved washout behavior
  - Reduced susceptibility to chipping

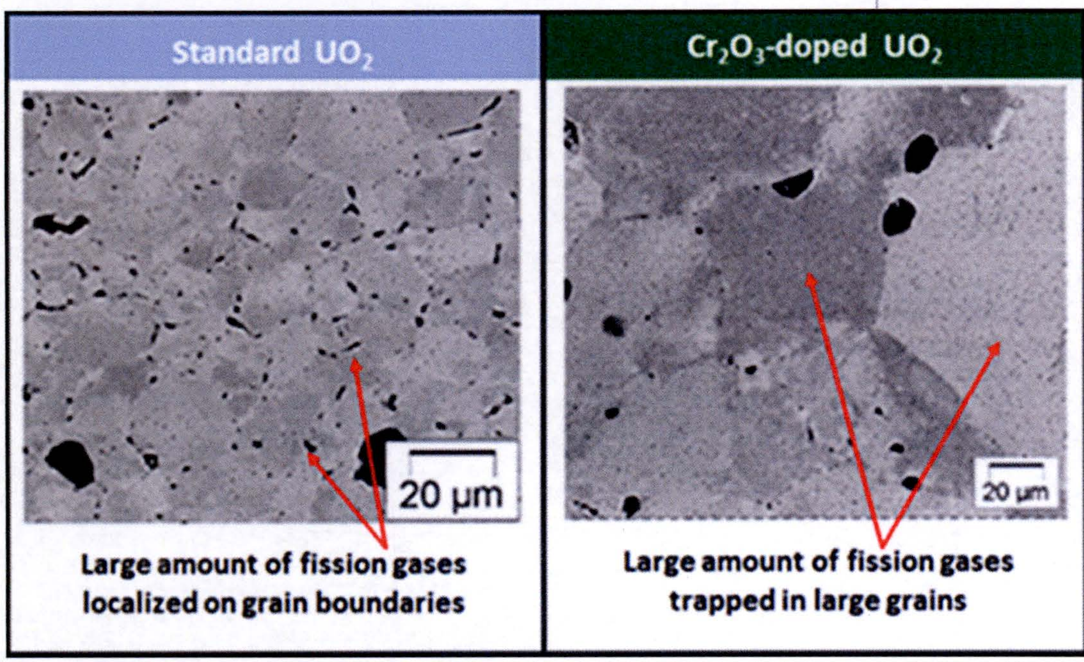


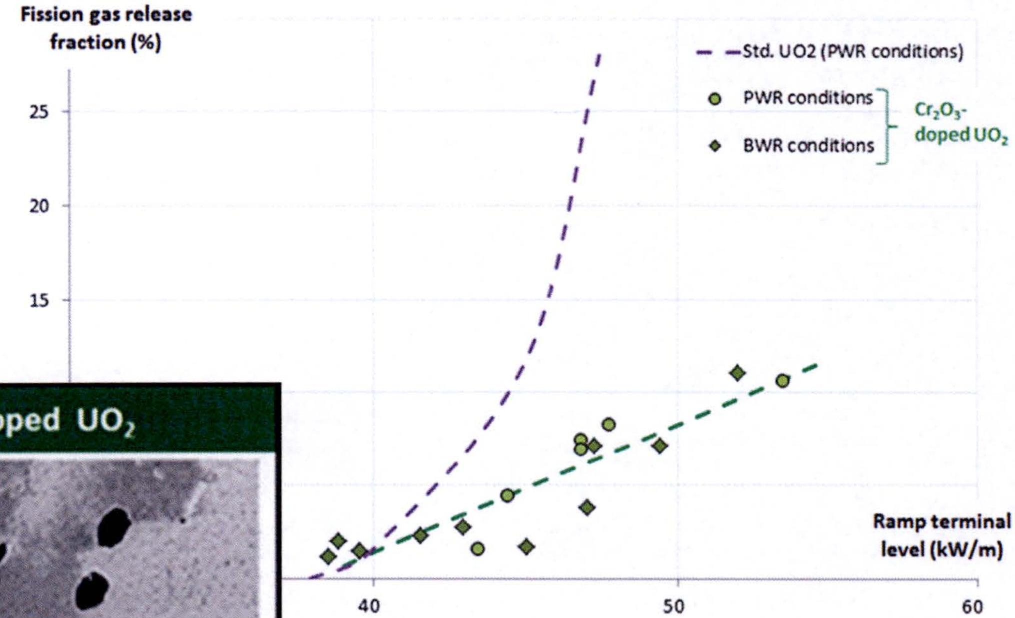
Cr_2O_3 Doped UO_2 Pellets

Cr_2O_3 Doped UO_2 Pellets

- **Improved Fission Gas Retention**

Fission gas distribution in conventional and Cr2O3 doped UO2 fuel irradiated to a burnup of approximately 62 GWd/tU

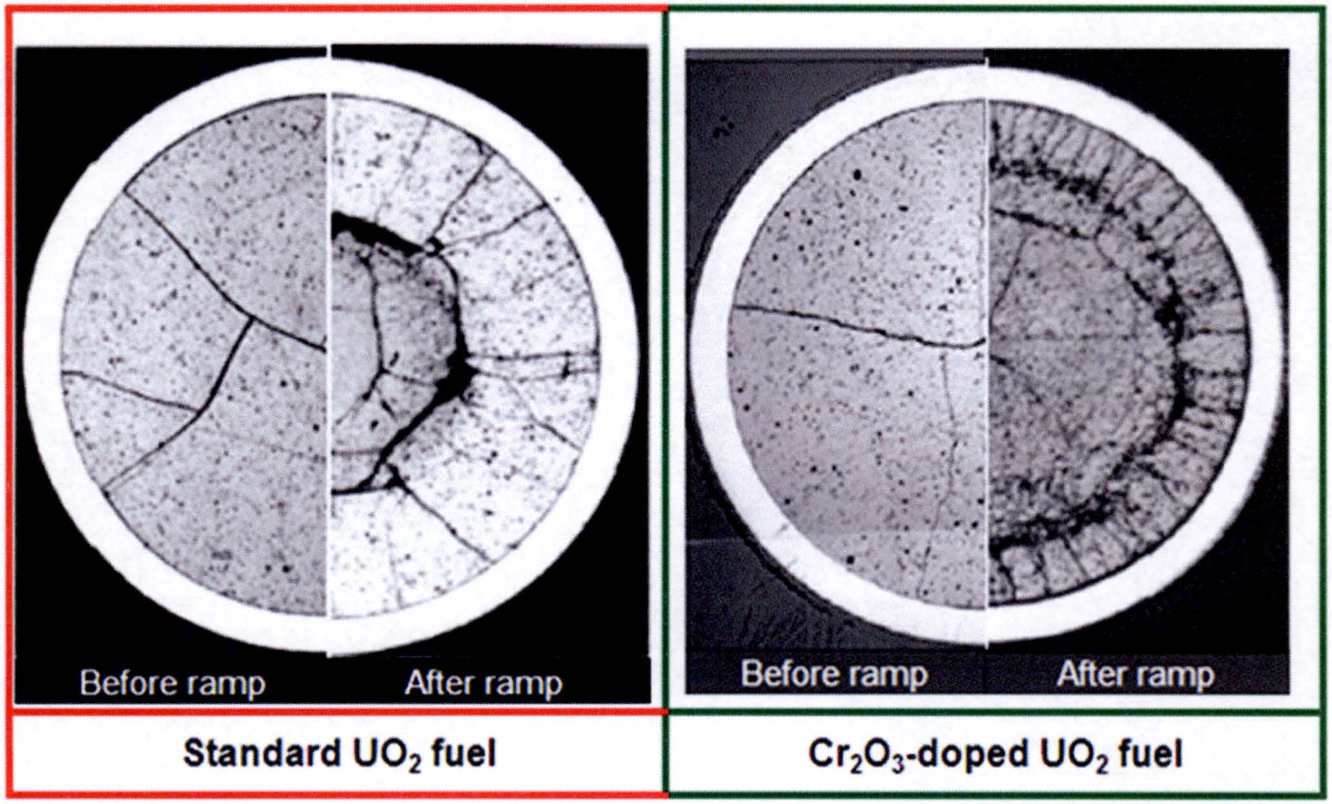




Fission gas release (FGR) kinetics in UO2 and Cr2O3 doped UO2 fuels in ramp testing conditions

Cr_2O_3 Doped UO_2 Pellets

- Improved PCI Performance that may also translate to improved accident performance

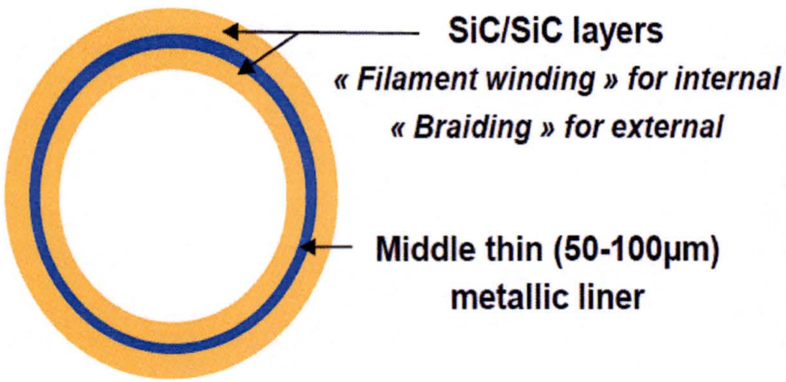


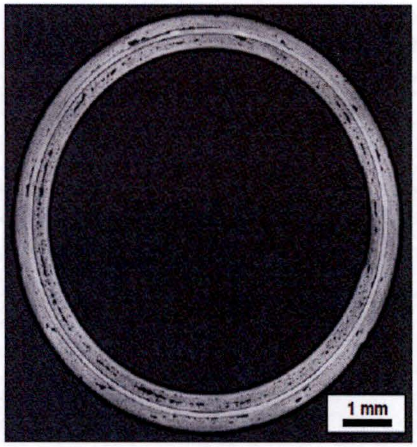
Post ramp ceramographs of Cr_2O_3 doped UO_2 fuel and the reference UO_2 fuel

SiC/SiC Sandwich Cladding

- **Concept under development through a Tripartite R&D program with CEA and EdF**

« SANDWICH » CLADDING: A SOLUTION TO LEAK-TIGHTNESS





Patent WO 2013/017621 A1

Candidate materials for liner selected on thermochemical and neutronic criteria : Ta, Nb (GFR)

Other benefits: liner protection, end-closure by welding

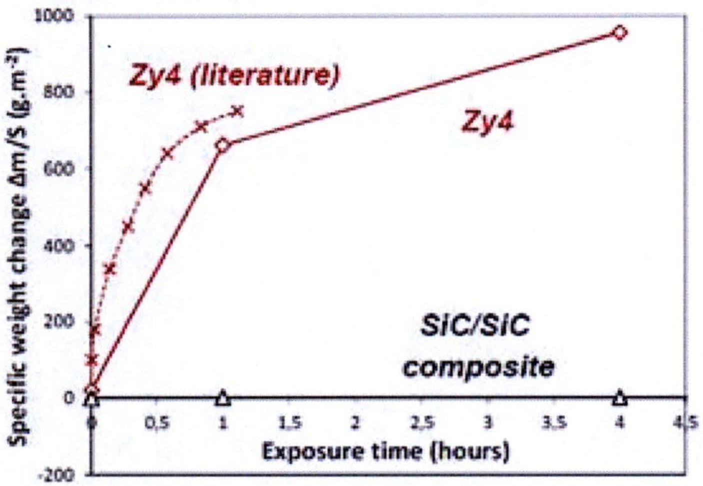
Development of "sandwich" cladding was driven by GEN IV nuclear systems **Transposition to LWR is achievable with the manufacturing process**

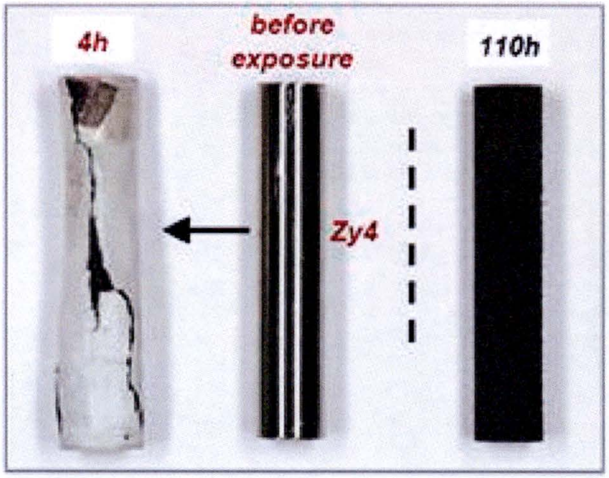
SiC/SiC Sandwich Cladding

Oxidation tests performed in LWR conditions (360° C) for up to 3500h and in accidental behavior in Air/H_2O (50/50) at 1200° C for 4-110h

Experiments on SiC/SiC tubes without liner and Zircaloy-4 clad segments as baseline material

COND C
1bar, 1200°C
Air/H2O (50/50)





SiC/SiC composite

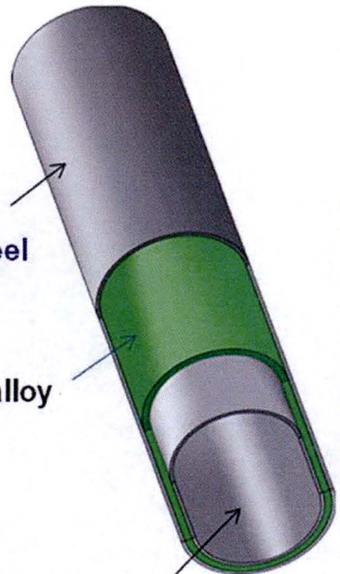
The oxidation kinetics are extremely slower than for Zr alloys !

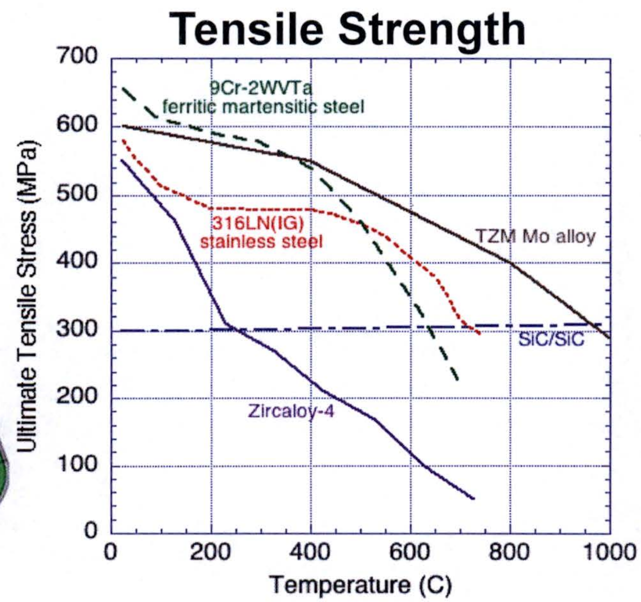
Confirmation of high potential for SiC/SiC

Main advantages:

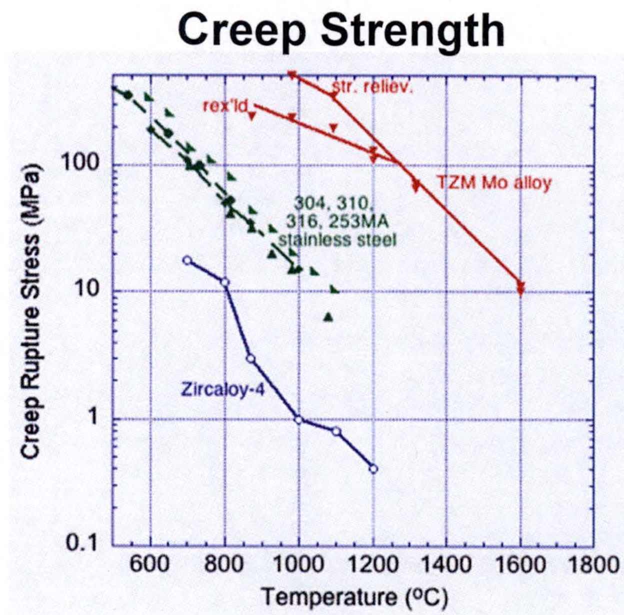
- Very low oxidation kinetics in high temperature steam and LWR conditions
- High strength at high temperatures
- High melting temperature

Molybdenum Cladding





B. Cheng, EPRI



- High melting temperature = 2623°C
- Good high temperature mechanical behavior
- High thermal conductivity

→ Preserves coolable geometry up to very high temperatures

EATF Phase 2 Roadmap

- **Current plan assumes submittal of an LAR for Cr-Coated cladding concept**
  - **Coating has no discernable impact on underlying Zr properties (apart from improved corrosion performance) – may lend itself favorably to a 50.59 review**

Phase 2 - Major EATF Tasks	Government Fiscal Year						
	2017	2018	2019	2020	2021	2022	2023+
Cr-Cr2O3 Concept							
Development & Characterization							
Safety Bases Development							
Economic Impact Assessment							
Manufacturing Integration							
Cr-Coating of Clad							
Cr_2O_3 Doping of Pellets							
Cr-Cr_2O_3 LFA Irradiation Program							
Host Utility 50.59 Evaluation							
Development of LAR							
NRC Interactions and Review of LAR							
Fabrication of LFAs							
Irradiation of LFAs (plus On-Site and Hot Cell PIE-◊)							◊ ◊
SiC-SiC Concept							
Development & Characterization							
Economic Impact Assessment							
Manufacturing Integration							

Near-Term Actions

▶ ACRS Subcommittee briefing on EATF	June 23, 2016
▶ Finalize EATF Phase 2 DOE funding	September 2016
◆ Establish final schedules	
▶ Set up next NRC EATF technical meeting	Early 2017