Agenda and Slide Presentations for the 2017 Westinghouse Fuel Performance Update Meeting (Non-Proprietary)

August 2017

(203 pages attached)

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

Westinghouse Fuel Performance Update Meeting
(NRC Tour of CFFF)
Wednesday, August 9, 2017, CFFF Room 101

12:00 pm - 1:30 pm	Pre-Tour Activities: - Security Check-in - Welcome, Introduction, and Safety Brief - Review Agenda - CFFF Overview Presentation - Lunch - Suit-up for Tour (shoe protectors, other)
1:30 pm - 4:00 pm	Tour of CFFF: - Mezzanine - Mechanical Area - Test Lab - Scrubber Area
4:00 pm - 4:30 pm	Post-Tour Activities: - Return shoe protectors, other protection - Security Check-out

Westinghouse Fuel Performance Update Meeting
(NRC and Customers)
Thursday, August 10, 2017, CFFF Pavilion

8:30 am - 8:45 am	Welcome, Introduction, and Safety Brief
8:45 am - 9:00 am	Update on the S-1030 Scrubber Issue, and Security of Supply Efforts at the Columbia Fuel Fabrication Facility
9:00 am - 10:15 am	Pressurized Water Reactor (PWR) Fuel Performance Update
10:15 am - 10:30 am	BREAK
10:30 am - 11:15am	Westinghouse EnCore™ Accident Tolerant Fuel (ATF) Program
11:15 am - 11:45 am	Update on NSAL-14-5: Lower Than Expected Critical Heat Flux Results Obtained During Departure from Nucleate Boiling Testing and Future DNB & Transient Methods Development
11:45 am - 12:05 pm	Incremental High Burnup Extension Strategy
12:05 pm - 1:00 pm	LUNCH
1:00 pm - 1:30 pm	Additive Manufacturing (AM) Thimble Plugging Device
1:30 pm - 2:30 pm	Boiling Water Reactor (BWR) Fuel & Control Blade Performance Update
2:30 pm - 2:40 pm	BREAK
2:40 pm - 3:00 pm	Update on Cooling Deficiency Events at Leibstadt NPP (KKL)
3:00 pm - 3:40 pm	TRITON11™ Fuel Update
3:40 pm - 3:50 pm	BREAK
3:50 pm - 4:10 pm	Feedback on Presentations and Meeting
4:10 pm	Adjourn

Westinghouse Fuel Performance Update Meeting
(NRC)
Friday, August 11, 2017, CFFF Pavilion

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

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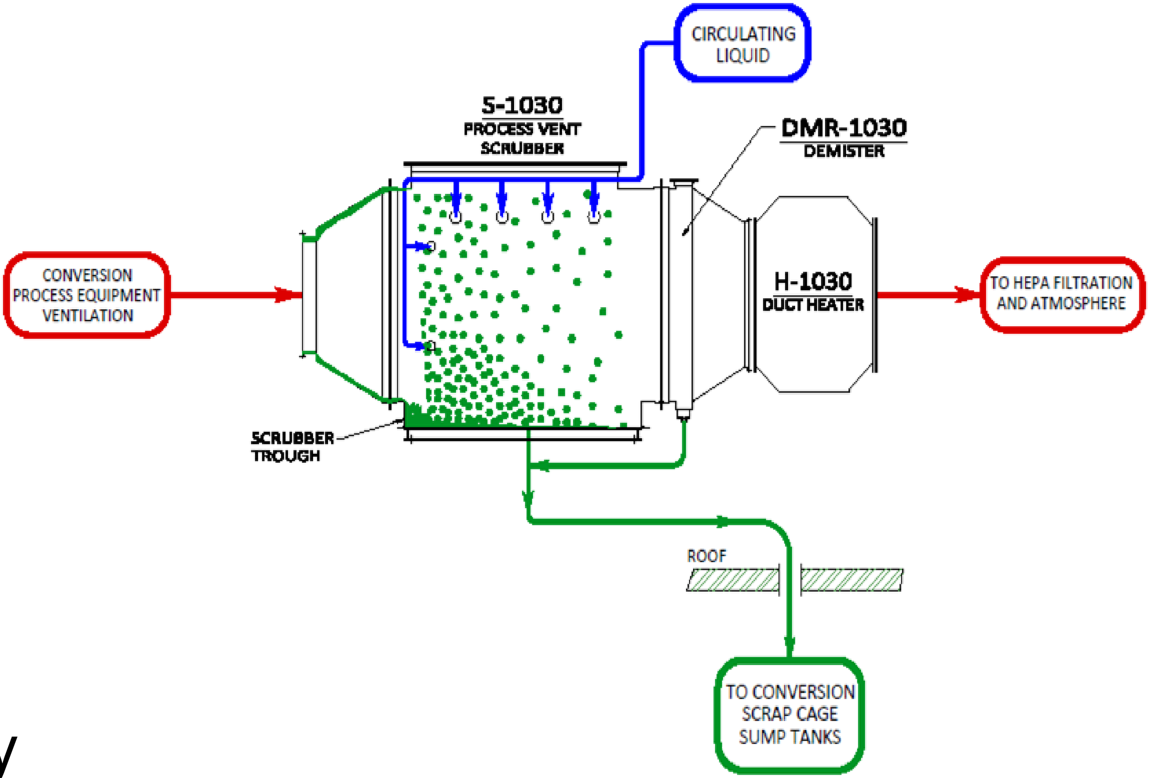
Update on the S-1030 Scrubber Issue, and Security of Supply Efforts at the Columbia Fuel Fabrication Facility

Michael Annacone
Vice President, Columbia Fuel Operations

Westinghouse

S-1030 Scrubber Summary

- Event Overview
- Root Cause Investigation Overview
- Confirmatory Action Letter/Plant Restart
- On-going Regulatory Interactions



Extensive corrective actions completed prior to restart

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S-1030 Scrubber Improvements

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- Extensive modifications completed to prevent material accumulation in the scrubber
- Rigorous inspection program:
  - Engagement with Criticality Safety
  - Documentation/evaluation of results
- Ventilation inspection program
- Additional actions are underway to sustain improvements

[ ]

New S-1030 controls are working to prevent accumulation in the scrubber.

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Nuclear Safety Culture

- Simplified NSC Traits
- Leadership alignment efforts
- Communications improvements
- NSC Training
- NSCMP
- Independent 3rd Party Assessment
- Oversight
- MRM
- Excellence plan – Management Systems

A healthy NSC is the foundation of our improvement efforts

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Excellence Plan Development

INPO 12-011; "A Strategic Framework for Significantly Improving Nuclear Plant Performance"

Sustainability Focus:

- **Leadership behaviors/alignment**
- **Program/process rigor**
- **Ability to self-identify/correct**
- **Oversight/Monitoring**
- **Industry Engagement**

Using a time tested, proven approach to bring about sustained improved performance

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CFFF Alternate Pellet Supply Update

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Questions

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Pressurized Water Reactor (PWR) Fuel Performance Update

Jeff Norrell, PhD
Director
Product Engineering

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Agenda

- Leak free plants
  - Nuclear fuel reliability progress
  - Historical trends
- Fuel reliability improvement process
- Update on recent Post Irradiation Exam (PIE) results
- **AXIOM**™ cladding update
- Summary

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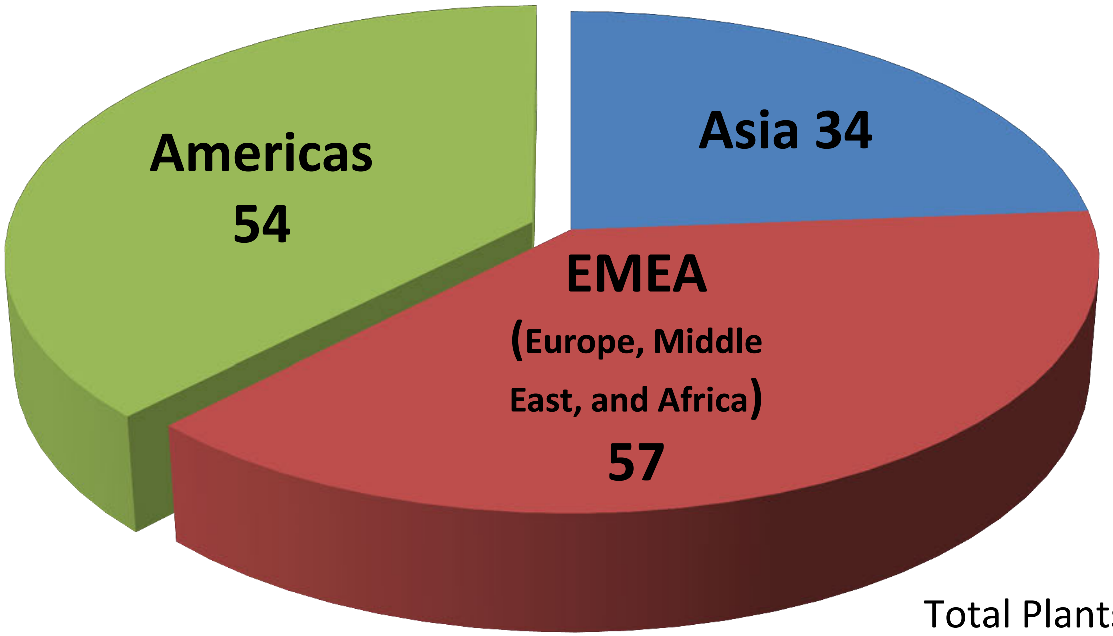
Westinghouse Fueled Plants by Region

Westinghouse Fueled Plants by Region (June 2017)



Total Plants: 145

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

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Worldwide Map of Westinghouse-fueled Power Plants

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Boiling Water Reactors (BWRs)

Nuclear Fuel Reliability Progress – June 2017

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Historical Performance of Westinghouse Fueled Plants

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Driving to Flawless Fuel Through Design – Current Status

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Driving to Flawless Fuel Through Design – Challenges

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Driving to Flawless Fuel Through Design – Activities

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[ ]

Agenda

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

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Fuel Reliability Improvement Process

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Fuel Reliability Improvement Process

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Fuel Reliability Improvement Process

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Agenda

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- **AXIOM**™ cladding update
- Summary

Recent PIE Results: [ ] a,c

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Recent PIE Results: [ ] a,c

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Inspection Results: [ ]a,c

[ ]a,c

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Recent PIE Results: [ ] a,c

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Recent PIE Results: [ ] a,c

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Recent PIE Results: [ ]a,c

[ ]a,c

Agenda

- Leak free plants
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- **AXIOM™** cladding update
- Summary

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AXIOM Cladding Overview

- AXIOM High Performance Developmental Fuel Cladding Material builds on successes of **Optimized ZIRLO™** High Performance Fuel Cladding Material a,c

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- Westinghouse has selected final AXIOM cladding composition
  - Based on extensive PIE database of poolside and hot-cell results from various irradiation programs as well as out-of-reactor testing.
- AXIOM alloy demonstrated
  - Significant performance improvement including in-reactor corrosion, hydrogen pick-up, dimensional stability as well as post irradiation ductility a,c

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- Full AXIOM clad LTA demonstrations currently ongoing to provide additional support for licensing and commercial introduction of AXIOM alloy a,c

[ ]

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Update on AXIOM Clad Lead Test Assemblies

- AXIOM Clad LTAs for [ ] a,c
  - Eight fuel assemblies will be produced with all fuel rods clad in AXIOM tubing [ ] a,c
  - Full size ingot of AXIOM material has been produced and tubing fabrication was completed earlier this year
  - [ ] a,c LTA exemption request has been approved by NRC
    - Westinghouse appreciates the NRC's review efforts for [ ] a,c licensing request
  - These LTAs will demonstrate performance benefits of AXIOM clad materials in representative operating conditions [ ] a,c
- Lead Test Rods at [ ] a,c
  - AXIOM clad Lead Test Rods have been fabricated and delivered to [ ] a,c
    - Planned to operate for single annual cycle to provide fuel rod creep data to validate expected creep data in fuel rod applications
  - Information supplements existing data on irradiation creep obtained from Vogtle Creep and Growth program for AXIOM cladding

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AXIOM Cladding Development Program Timeline

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Agenda

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  - Nuclear fuel reliability progress
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Summary

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Questions?

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Westinghouse **EnCore™**
Accident Tolerant Fuel (ATF) Program

Javier Romero
Principal Engineer
Global Accident Tolerant Fuel Technology

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Outline

- Westinghouse technologies for ATF
  - Chromium-coated zirconium cladding
  - Uranium silicide (U_3Si_2) fuel pellets
  - Silicon carbide (SiC) cladding
- Data acquisition
  - Out-of-pile testing of cladding
  - In-pile testing of cladding and U_3Si_2 fuel pellets
- Licensing approach for LTRs/LTAs
- Summary

LTR: Lead Test Rod
LTA: Lead Test Assembly

Westinghouse ATF Technologies

Chromium-coated Zirconium Cladding
Uranium Silicide (U_3Si_2) Fuel Pellets
Silicon Carbide (SiC) Cladding

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Chromium-coated Zirconium Cladding

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Chromium-coated Zirconium Cladding – Benefits

- Reduced oxidation during normal operation
  - Longer life and increased margins allow use of higher density fuels
- Improved corrosion resistance in steam and air at high temperature
  - Reduced exothermic reaction energy
  - During and beyond design basis conditions
  - Increased loss-off-coolant accident (LOCA) peak cladding temperature
  - Improved reactivity initiated accident (RIA) deposition limits
- Drastic reduction in hydrogen generation and pickup
  - Benefits for draft 10 CFR 50.46c rule
  - Potential for higher transient strain limit
  - Reduced embrittlement in dry storage
- Enhanced resistance to wear (debris, grid-to-rod or rod-to-grid)

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Chromium-coated Zirconium Cladding – Performance

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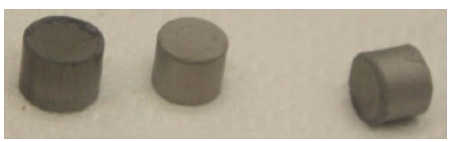
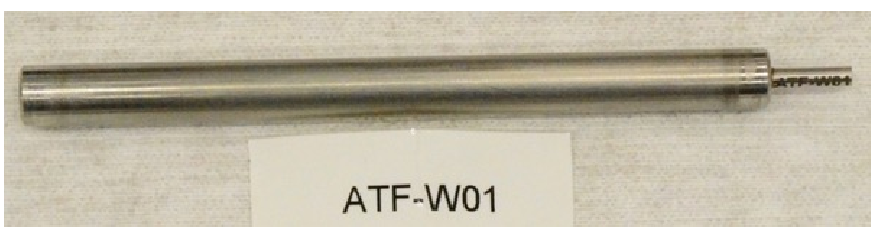
Uranium Silicide Fuel Pellets

Increased uranium density and higher thermal conductivity

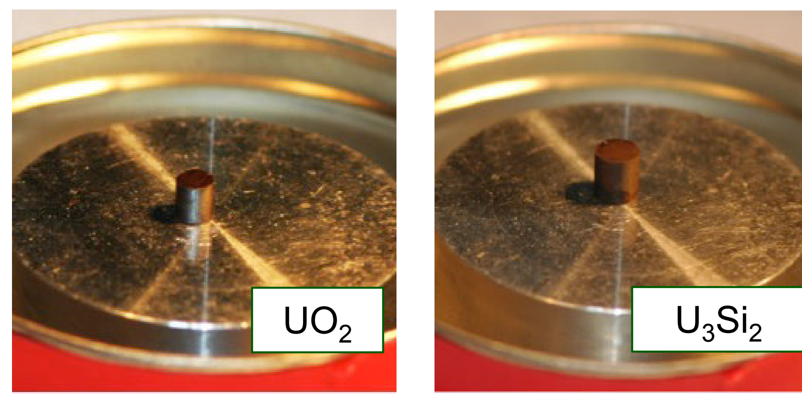
	UO_2	U_3Si_2
Uranium Density (g/cm^3)	9.68	11.3
Thermal Conductivity (W/m-K)	5-2 (300-2000°C)	9-20 (300-1200°C)

Fabrication





Testing



Corrosion testing in water at 300°C (50 hours)
No measurable weight change or evolution in appearance

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NATIONAL NUCLEAR LABORATORY

INL Idaho National Laboratory

Los Alamos NATIONAL LABORATORY EST. 1943

Uranium Silicide Fuel Pellets - Benefits

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Silicon Carbide Cladding - Benefits

- No ballooning and bursting
  - Retention of tensile strength up to 1700ºC
  - Slow degradation above 1700ºC
- Eliminate oxidation driven temperature spikes
  - Slow reaction with steam to >1700ºC
- Drastic reduction of hydrogen generation
- Maintain integrity under most severe beyond design basis accident conditions
- Improved economics for normal operation
  - Reasonably small cross section for thermal neutrons
- Predictable irradiation behavior
  - Swelling is small (<2%) and predictable

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GENERAL ATOMICS

Data Acquisition

Out-of-pile Testing of Cladding
In-pile Testing of Cladding and U_3Si_2 fuel pellets

Out-of-Pile Testing of Cladding

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Ultra-High Temperature Testing

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Ultra-High Temperature Testing - Results

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EnCore™ cladding technologies maintain integrity in accident conditions

In-pile Testing – Overall Status

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U_3Si_2 Fuel Irradiated in ATR

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In-pile Testing – Innovation on Data Acquisition

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Technologies now being developed and tested by Westinghouse

Licensing Approach for LTRs/LTAs

Coated Cladding
U_3Si_2 Pellets
SiC Cladding

LTR/LTA Licensing Approach - Coated Cladding

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LTR/LTA Licensing Approach – U_3Si_2 Pellets

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LTR/LTA Licensing Approach – SiC Cladding

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LTR/LTA Licensing – Additional Considerations

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LTR/LTA Licensing – Manufacturing and Transport

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Summary

Summary

- Westinghouse **EnCore**™ Fuel products
  - Chromium-coated zirconium cladding
  - U_3Si_2 fuel pellets
  - SiC cladding
- Promising capabilities to achieve full safety benefits
- Ongoing testing program in preparation for LTRs/LTAs
- Licensing actions for LTRs/LTAs ongoing
  - Both on 10 CFR Part 50 and Part 70
  - Including active engagement with the NRC

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EnCore™ Fuel

We're changing nuclear energy … again

Westinghouse

Update on NSAL-14-5: Lower Than Expected Critical Heat Flux Results Obtained During Departure from Nucleate Boiling Testing

and Future DNB & Transient Methods Development

Zeses Karoutas

Chief Engineer

Fuel Engineering and Safety Analysis

Outline

- Update for DNB Issue Described in NSAL-14-5
- Planned CHF Testing for 17x17 OFA/IFM
- Thermal-Hydraulic Statistical DNB Program Status
- Statistical Transient Methodology
- Summary

Update for DNB Issue Described in NSAL-14-5

- Lower than expected CHF results were found during data analysis
  - Non-conservatism observed for WRB-1, WRB-2, WRB-2M and WNG-1 DNB correlations with new RFA without IFM test data
  - Almost all existing plant analyses were impacted but were unaffected due to analyses not reaching high quality conditions

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17x17 RFA without IFM Data: WRB-2M with New ODEN Data

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Trend in Data was not Obvious from Previous Tests at Columbia University (HTRF)

WNG-2 Correlation Under Development

- WNG-2 correlation database to include new tests
  - Expanded WNG-1 database for correlation development
  - Additional tests for validation

[ ]a,c

- Original WNG-1 correlation form in WCAP-16766-P-A modified

- Preliminary WNG-2 correlation currently under testing
  - To be applicable to high temperature testing conditions
  - Designed to be applicable to all Westinghouse 17x17 RFA and NGF fuel designs

Preliminary WNG-2 Correlation – Measured to Predicted CHF

[ ]a,c

Planned CHF Testing for 17x17 OFA/IFM

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When deciding to take an action that may result in impacts to customers: communicate the plan, reasoning, potential impacts, and the plans/efforts to minimize potential impacts

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Discovery of Need for Additional Testing for 17x17 OFA/IFM Geometry

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Discovery of Need for Additional Testing for 17x17 OFA/IFM Geometry

[ ]a,c

Safety/Operability Significance

[ ]a,c

Testing and Data Analysis

[ ]a,c

Plan Forward

[ ]a,c

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Thermal-Hydraulic Statistical DNB Program Status

Zeses Karoutas

Thermal-Hydraulic Statistical DNB Program Status

- Statistical DNB program consolidates existing methods for process simplification and more accurate solution

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- Consolidated method referred to as WTDP:
  - Westinghouse Thermal Design Procedure

- WTDP method similar to those approved and used for CE-NSSS plant applications

[ ]a,c

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T-H Statistical DNB Program Status (continued)

- No change to existing design interfaces and criteria

[ ]a,c

- Applications to W-NSSS currently using RTDP (Revised Thermal Design Procedure)

[ ]a,c

- Applications to CE-NSSS currently using SCU (Statistical Combination of Uncertainties)

[ ]a,c

WTDP applications and planned topical report submittal

Statistical Transient Methodology

Zeses Karoutas

STM - Methodology Overview

- Statistical Transient Methodology (STM)
  - Statistical combination of uncertainties for non-LOCA events that do not currently apply statistical approach
  - Method uses [ ]a,c
    - Will provide basis for sampling of selected initial condition uncertainties
    - Remainder continue to be bounded
  - Will utilize current code models
  - Applicability
    - Limited to events that use deterministic approach
    - Method code independent, applicable to both LOFTRAN and RETRAN
    - Initial method development focused on Westinghouse legacy PWRs (no **AP1000®** or CE plant designs)
      - Potential to extend method through future submittals

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STM - Methodology Overview

- Initial development is focused on [ ]a,c Chapter 15 non-LOCA safety analysis events

[ ]a,c

- Criterion
  - Statistical Statement to bound the 95th percentile with 95% confidence
  - Statistical statement will be compared to the current acceptance criterion for the event (margin to pressurizer overfill or margin to hot leg saturation).

Method change limited to uncertainty treatment

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STM - Methodology Overview

- Initial Condition Uncertainties Currently Investigating

[ ]a,c

- Other Event Specific Uncertainties under consideration such as [ ]a,c

- Project Plan
  - Developing topical report (WCAP)
    - Topical report will include
      - statistical basis,
      - justification for sampled inputs
      - sample analysis

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Summary

- DNB Testing and Correlations
  - Preliminary WNG-2 correlation addresses DNB issue for 17x17 RFA fuel and also 17x17 NGF and 16x16 NGF
  - Plan to submit topical or supplements for WNG-2 in [ ]a,c
  - 5x5 DNB tests planned next [ ]a,c for comparisons to WRB-2 correlation
  - Westinghouse recommends plants which use the WRB-2 correlation take no action until test results are available and analyzed by [ ]a,c
- T-H Statistical DNB - plan to submit in [ ]a,c
- Statistic Transient Methodology - plan to submit in a few years

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Westinghouse is focused on making improvements in DNB & Transient areas

Acronyms

CHF - Critical Heat Flux (DNB)	**Typ - Typical cell**
DNB - Departure from Nucleate Boiling (CHF)	**V+ - Vantage Plus, (OFA)**
IFM - Intermediate Flow Mixing Vane	**V5H - Vantage 5 Hybrid**
NGF - Next Generation Fuel	**WNG-1 - PWR DNB Correlation**
OFA- Optimized Fuel Assembly, (V+)	**WRB-1 - PWR DNB Correlation**
RFA - Robust Fuel Assembly	**WRB-2 - PWR DNB Correlation**
Thm - Thimble cell	**WRB-2M - PWR DNB Correlation**

Incremental High Burnup Extension Strategy

Zeses Karoutas
Chief Engineer, Fuel Engineering and Safety Analysis

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Agenda

- Industry Motivation
- Industry Trends for High Burnup
- Key Concern for High Burnup
- Industry Proposal for an Incremental Burnup Extension
- LOCA Analysis Considerations for High Burnup
- Cladding Database Supporting Extension
- Licensing Approaches
- Summary

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Industry Motivation

- Industry core designs are frequently constrained by the lead burnup limit so an increase in limit is expected to decrease reload batch size and result in more efficient fuel utilization
- 18 and 24 month cycle designs could be made more efficient if lead rod burnup limit is increased
- EPRI received positive industry feedback at the February 2017 Core-tac meeting on an incremental burnup extension

Improved fuel cycle economics help support Nuclear Promise

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Industry Trends for High burnup

- Fuel cycles being evaluated for high burnup generally fall into two categories
  - Mostly peripheral and center assembly fuel burnup extension – reduce constraints on fuel cycle designs ≤ 65 GWd/MTU peak rod burnup
  - Higher energy cycles with high burnup fuel in interior burnups approaching 70 GWd/MTU.

- For the first category fuel rods in peripheral and center assemblies have low power for rods that may exceed 62 GWd/MTU

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Key Concern for High Burnup
Fuel Fragmentation Relocation and Dispersal (FFRD)

- At high burnups, fuel pellets have increased fission gas loading and the rim region is highly porous. Under high temperatures fuel can fragment into fine particles.
- If cladding temperatures during a LOCA become high enough, cladding ballooning and rupture can occur
  - Fuel fragments can relocate from above, into the ballooned region (increases local linear heat rates)
  - Fuel fragment expulsion out of the burst region has been observed in some high burnup tests ("dispersal")
- NUREG-2121 discusses experimental observations in detail
- SECY-15-0148 contains justification for not including FFRD in 10 CFR 50.46c rulemaking

NRC expects that FFRD be addressed for high burnup

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Industry Proposal for an Incremental Burnup Extension

- For rods in fuel assemblies which exceed peak rod burnup of 62 GWd/MTU demonstrate these rods do not burst
- Although key fuel performance models have not been approved for > 62 GWd/MTU, benchmarking data demonstrates that models are applicable up to 70 GWd/MTU.
- It is expected that peak rod burnups will be less than or near 65 GWd/MTU
- Demonstrate that all methods and hardware satisfy design criteria for the small incremental burnup extension
- Address all key criteria from SRP 4.2
- Prepare licensing submittal

Limited extended burnup can maintain safety margins

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LOCA Analysis Considerations for High Burnup Overview

- Westinghouse realistic LOCA methods account for fuel relocation into the burst region, when burst is predicted to occur
- Basic methods for evaluating the conditions necessary for cladding rupture were previously established by Westinghouse, and are recognized in NUREG-2121
- Analytical methods can be used for more robust prediction of cladding rupture

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LOCA Analysis Considerations for High Burnup Preliminary Studies, 3-Loop PWR

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LOCA Analysis Considerations for High Burnup Preliminary Studies, 4-Loop PWR

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LOCA Analysis Considerations for High Burnup Key Uncertainties

- Burst Temperature
  - Uncertainty directly impacts burst prediction
- Fuel Performance Data
  - Fuel temperature and rod internal pressure uncertainties have impact on burst prediction
  - Simulations use data with overly conservative power history
- Application of LOCA Models Beyond Approved Burnup
  - Additional justification may be required
  - Simulations conservatively run with nominal+2σ decay heat

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Structural and Fuel Performance Considerations

- Fuel rod peak oxide thickness as a function of burnup
- Fuel rod growth as a function of fast fluence
- Fuel Assembly Growth as a function of burnup
- Will use PAD5 to justify current safety setpoints for incremental high burnup extension

Fuel rod peak oxide thickness as a function of burnup

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Sufficient well behaved oxide data at high burnup is available

Fuel rod growth as a function of fast fluence

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Sufficient well behaved fuel rod growth data at high burnup is available

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Fuel Assembly Growth as a function of burnup

[ ]a,c

Sufficient well behaved fuel assembly growth data at high burnup is available

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Licensing Approaches

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Licensing Approaches and Schedule to be discussed with Customers

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Summary

- Two step process in transition to higher burnups provides value to utilities without impacting safety.
- FFRD issues are addressed by limiting fuel rod power at burnups > 62 GWd/MTU to prevent burst.
- Current cladding and ZIRLO® structural material are sufficient to support the small burnup extension
- Prepare and submit licensing document

Additive Manufacturing (AM) Thimble Plugging Device

David Huegel

Fuel Product Engineer

Additive Manufacturing (AM): Overview

- Westinghouse AM Objective
- Additive Manufacturing Process Benefits
- Examples of Westinghouse Prototypes
- Westinghouse AM Material Testing Performed to Date
- Westinghouse AM Thimble Plugging Device
- Westinghouse AM Thimble Plugging Device Testing
- Schedule for AM Thimble Plugging Device
- Summary

AM: Objective

- Westinghouse is focused on using the AM process in order to produce high quality/ high performance fuel component/ products for use in commercial nuclear reactors.
- Westinghouse has performed significant testing, designing, prototype building, verifying design characteristics, validating material properties, etc. to ensure that the process if fully understood and thus can be used for producing high quality/ high performance fuel components for use in commercial reactors.

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AM: Benefits

AM process is being developed within Westinghouse to improve products and to enhance product performance.

1. AM provides design freedom allowing complex geometries to support existing and next generation plant component designs not easily produced with existing technologies.
2. Allows for advanced designs to improve fuel and reactor performance.
3. Fast prototyping, mockups, fixtures, tooling, etc. to support advanced design development as well as manufacturing support.

AM: Benefits (continued)

AM process is being developed within Westinghouse to improve products and to enhance product performance.

4. Help minimize defects by reducing/eliminating manual processes as components are manufactured in a single build.
5. Improved material lead-time and properties (custom chemistry, isotropic mechanical properties, improved machinability, improved inspectability, etc.).

Advanced Designs Obtainable

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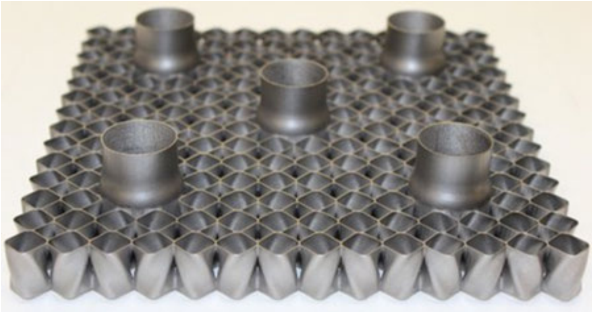
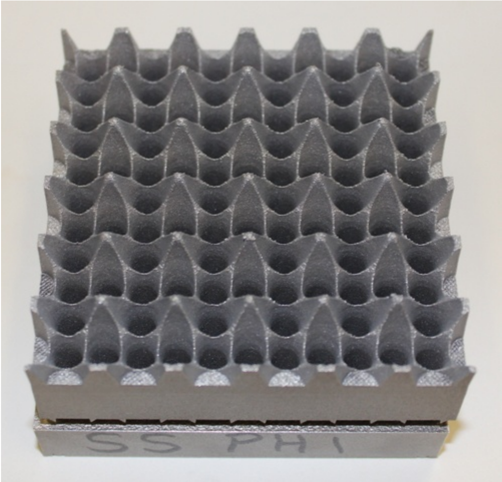
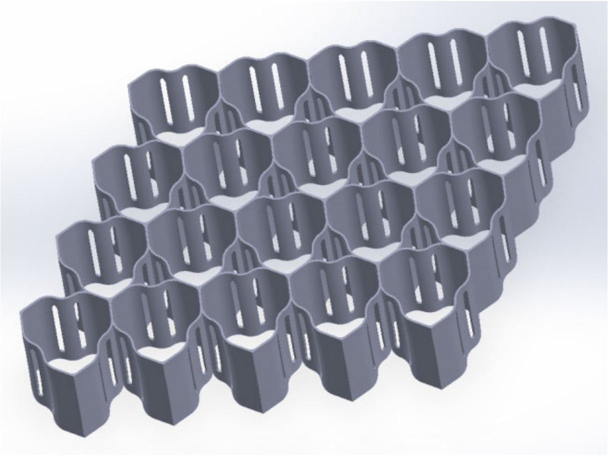
AM: Conceptual Models

Numerous Conceptual Models have been developed (and created and tested) by Westinghouse

- Tubular grid
- “Egg Crate” Bottom Nozzle
- Debris filtering bottom nozzles
- Advanced spacer grids







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AM: Westinghouse AM Material Testing

Westinghouse has spent significant time and resources over the last 5+ years developing AM technology for the placement of a fuel component in a commercial reactor:

Evaluation of Material Mechanical Properties:
Tensile specimens were created for the purposes of testing the mechanical properties of the AM material such as:

- Ultimate Tensile Strength (UTS)
- Yield Strength (YS)
- Young's Modulus
- Ductility

AM mechanical properties validated to be the consistent with conventional Stainless Steel (SS)

AM: Westinghouse AM Material Testing (continued)

Irradiation of AM produced tensile specimens:

- Miniature AM produced tensile specimens were irradiated in the MIT test reactor with conditions (temperatures, pressures, boron concentrations, etc.) comparable to that of a commercial Pressurizer Water Reactor (PWR) reactor.
- Initial testing of un-irradiated and irradiated tensile specimens demonstrated AM material behaves similarly to wrought / cast materials.

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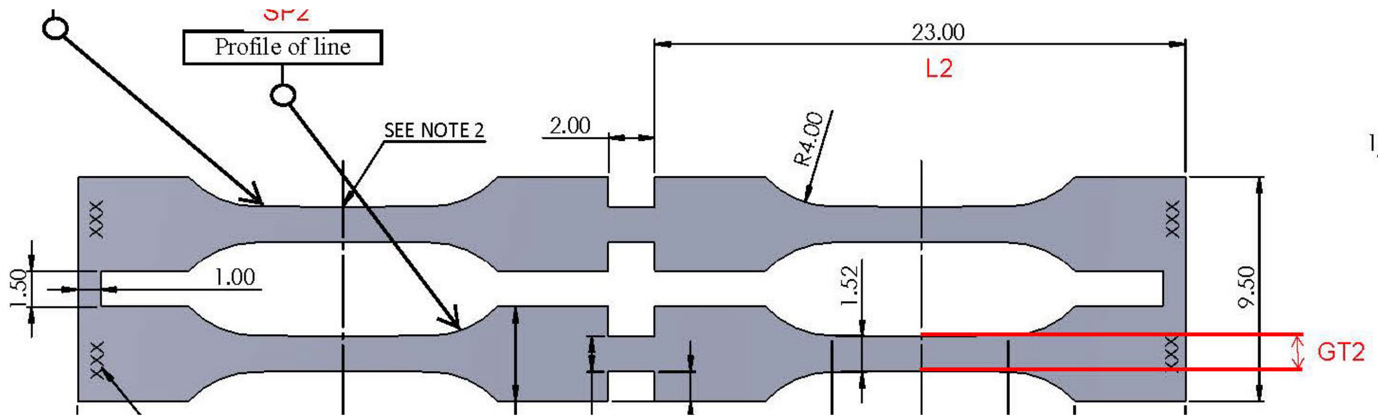
AM: Westinghouse Testing - Irradiation of AM Specimens

- Miniature AM 316L and Alloy 718 tensile specimens irradiated to ~ 0.8 dpa (displacements per atom) in MIT reactor
- Very high near contact radiation dose rates of ~ 100-400 R/hr
- Group of four (4) tensile specimens shown below:



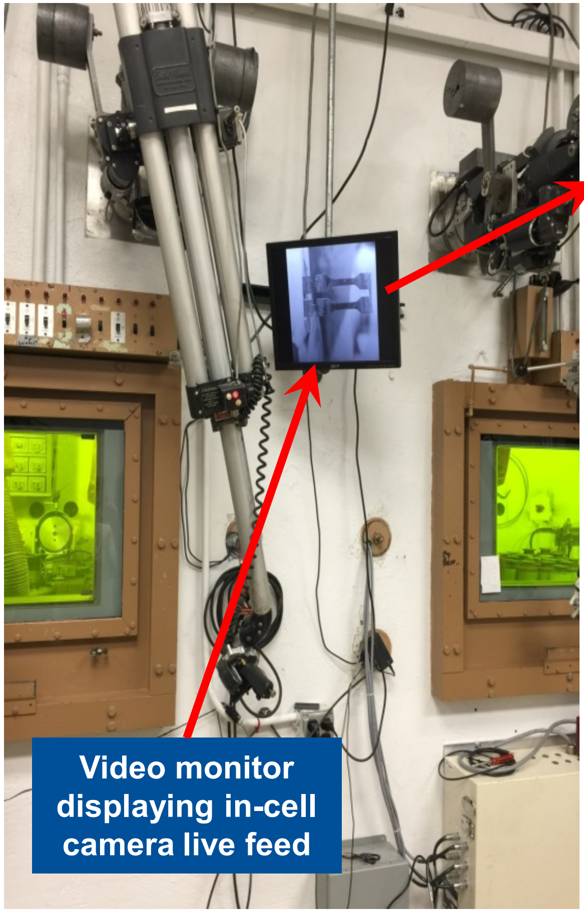
Westinghouse

AM: Westinghouse Testing - Irradiation of AM Specimens

- Unirradiated and irradiated tensile testing of AM 316 SS and Alloy 718 materials inside WEC hot cell.

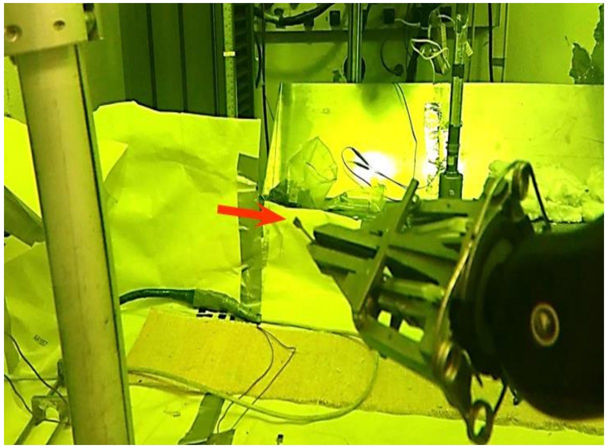
- Room Temp and elevated Temp (i.e., 572°F) tensile testing of ~50 AM 316SS specimens and ~50 AM Alloy 718 specimens.

- Extensive unirradiated and irradiated materials evaluations completed.



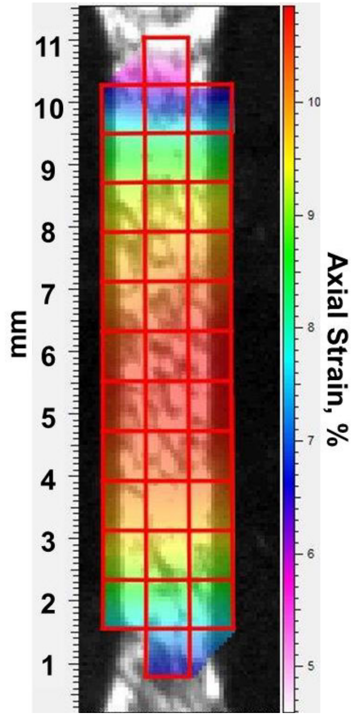
Video monitor displaying in-cell camera live feed

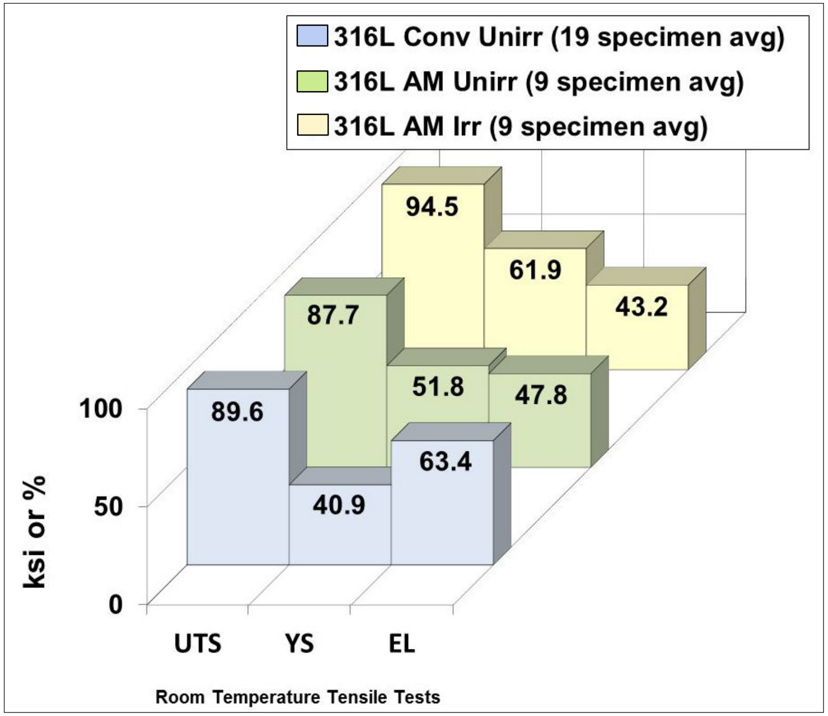
Intact irradiated quad held with hot cell grips prior to separation into 4 individual miniature tensile specimens



AM: Westinghouse Testing - AM 316 SS Performance

Irradiated AM Specimen SX51





~ 100 tensile specimens successfully tested remotely inside WEC hot cell

AM 316L Properties validated to be consistent with conventional SS

!! AM Alloy 718 specimens showed similar consistency with conventional Alloy 718 properties !!

Westinghouse

AM: Westinghouse AM Material Testing (continued)

Autoclave Testing of AM Austenitic Stainless Steel, Type 316L:

- Corrosion testing was performed on AM austenitic stainless steel, Type 316L and also Nickel Alloy 718 for 30 days in a flowing water autoclave at simulated pressurized water reactor primary temperature, pressure and chemistry conditions.
- The morphology and thickness of the resulting oxide was characterized using a Focused Ion Beam and Scanning Electron Microscopy.
- It was concluded that the relative corrosion rates of conventional and AM alloys are similar. The base material manufacturing method (AM or conventional) did not influence the corrosion rates.

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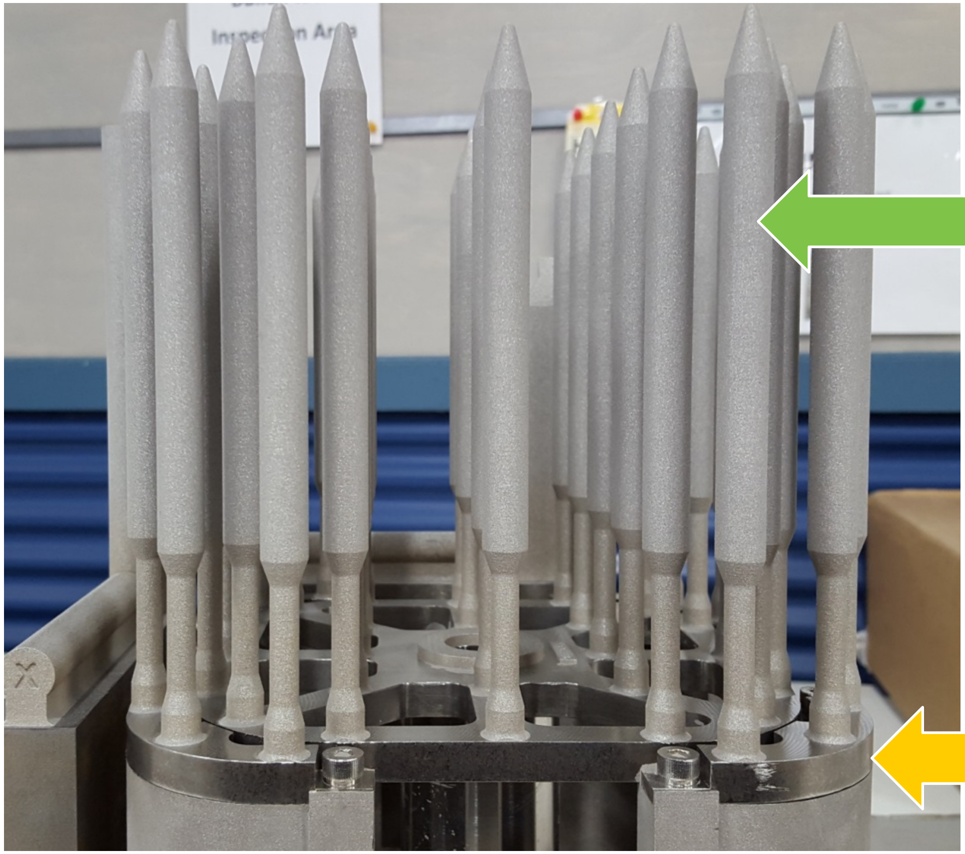
AM: Thimble Plugging Device

- **The first Westinghouse AM Fuel Assembly component will be a Thimble Plugging Device (TPD) placed in a commercial reactor in 2018**.
  - Final design of the AM TPD is a combination of wrought 304 SS (used on existing TPD) and AM 316L SS.
  - AM TPD is equivalent in Form, Fit and Function as existing TPD.
  - AM TPD is considered “low” risk as the AM TPD is contained in Guide Thimble Tubes at the top of fuel assembly.
  - One or two TPDs to be manufactured this Fall 2017.
  - TPDs to be delivered with the fuel in Spring of 2018.

AM Thimble Plugging Device
“Low” Risk Component

Westinghouse

AM: TPD Hybrid Design



316L Stainless Steel AM rodlets grown on Stainless Steel Wrought 304 base plate

Wrought 304 Stainless Steel base plate

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AM: Westinghouse AM TPD Testing

Mechanical Testing of Existing and AM TPDs:

- Mechanical testing was performed for the existing and the AM TPDs. This testing included axial pull tests, lateral bending tests and baseplate weld integrity tests.

- An Instron machine was used for the testing as shown in the enclosed figure (axial pull testing shown).

- The performance of the AM TPD was consistent with the existing TPD and in addition, the AM TPDs satisfied all of the TPD mechanical design criteria.

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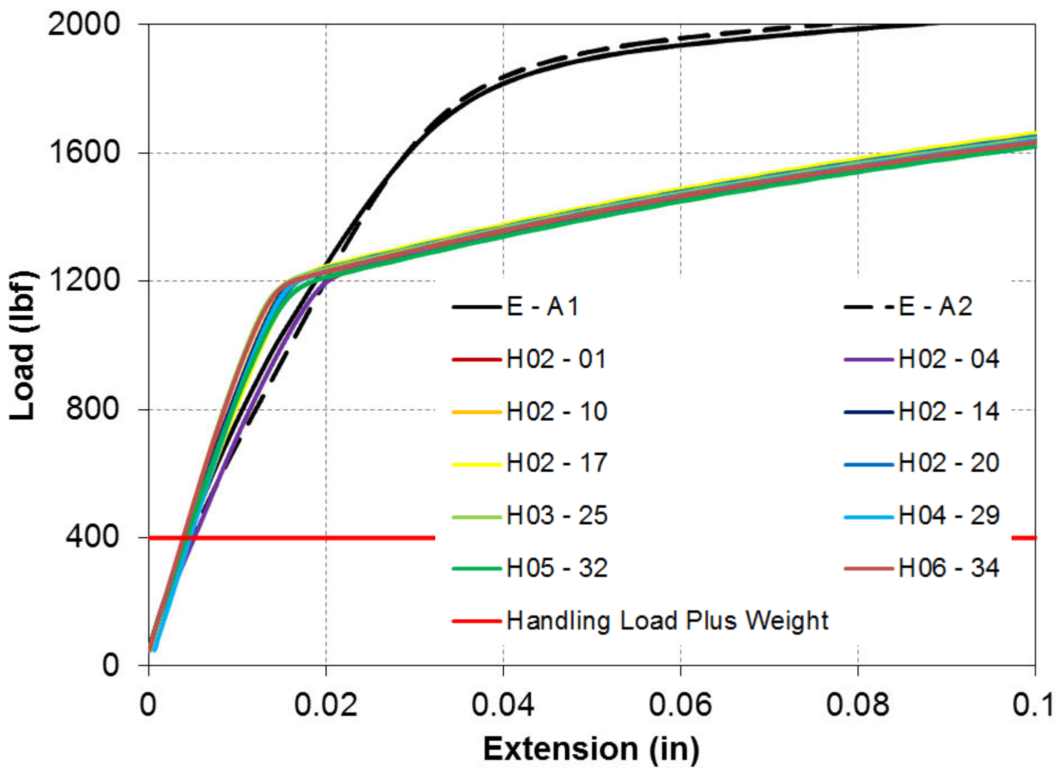
AM: Westinghouse AM TPD Testing

Mechanical Testing of Existing and AM TPDs:

- The existing and AM TPD Rodlets were demonstrated to have more than sufficient strength to meet the core component handling load requirement of 400 lbs.



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AM: Westinghouse AM TPD T&H Evaluation

T&H Evaluation of the AM TPDs:

- The TPDs are used to reduce the core bypass flow by impeding the flow in the guide thimble tubes and thereby increasing the flow in the core for heat removal.

- Specific Thermal Hydraulic calculations were performed for the AM TPD and it was demonstrated that all of the thermal hydraulic design criteria, including the design core bypass flow, were satisfied.

Westinghouse

AM: Schedule

Task	Date
Design & Manufacturability Review (Participation from 2 utility customers)	Complete
Irradiation of Small AM Tensile specimens in MIT reactor	Complete
Numerous AM prototype parts produced	On Going
Significant testing of AM properties by W	Complete
Testing of TPD	On Going
Perform 50.59 Assessment (working with specific utilities)	September 2017
Design Closeout Review	September 2017
TPD production (1 to 3)	Late 2017
First TPDs inserted in Commercial Reactor (On-going discussions with two utility customers)	Spring 2018
Post-Irradiation Exam (PIEs) will be performed on TPDs	Future

Westinghouse

AM: Summary

- Westinghouse has invested significant time and effort thoroughly evaluating the Additively Manufactured process for application to fuel components for a commercial reactor.
- Material and Mechanical Property Testing has concluded that AM Properties are consistent with conventional.
- First Thimble Plugging Device LTAs (1 or 2) are to be inserted in 2018 in a commercial reactor.
- Westinghouse continues to test other AM materials such as Zircaloy based metals for use in commercial reactor components.

Boiling Water Reactor (BWR) Fuel and Control Blade Performance Update

Jeremy King
BWR Fuel Product Manager

Outline

- Delivery statistics
- Performed Inspections 2016
- **HiFi™** Cladding Update
- Control Rod Blade Inspections 2016
- Summary

Delivery Statistics Europe Up to End of 2016

a,c

Delivery Statistics US Up to End of 2016 (cont'd)

a,c

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Outline

- Delivery statistics
- **Performed Inspections 2016**
- **HiFi**^{TM} Cladding Update
- Control Rod Blade Inspections 2016
- Summary

Performed Inspections 2016

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Inspection in [ ]a,c

[ ]a,c

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Inspection SVEA-96 Optima3 in [ ]a,c

[ ]a,c

Inspection SVEA-96 Optima3 in [ ]a,c

a,c

Inspection SVEA-96 Optima2 in [ ]a,c

[ ]a,c

Inspection SVEA-96 Optima2 in [ ]a,c

[ ]a,c

[ ]a,c - **Low Tin ZIRLO** Channel, 47 MWd/kgU

(Operated with a deeply inserted control blade during C34, third cycle of operation)

a,c

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[ ]a,c - SVEA-96 Optima3 LUA, BU ~28 MWd/kg U Visual Inspection **Low Tin ZIRLO** Channel

(2 cycles with instrumentation tube)

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[ ]a,c Low Tin ZIRLO Channels

[ ]a,c

SVEA-96 Optima3 Fuel Repair Campaign in [ ]a,c

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Optima3 - Fuel Repair Campaign

[ ]a,c

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Inspection of the Leaking Fuel Assembly in [ ]a,c

[ ]a,c

Westinghouse

Inspection of the Leaking Fuel Assembly in [ ]a,c

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Inspection in [ ]a,c

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SVEA-96 Optima3 – End of Life Inspection [ ]a,c (6 cycles)

[ ]a,c

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SVEA-96 Optima3 – End of Life Inspection [ ]a,c (6 cycles) (cont'd)

a,c

SVEA-96 Optima3 – End of Life Inspection [ ]a,c (6 cycles) (cont'd)

[ ]a,c

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SVEA-96 Optima3 – End of Life Inspection [ ]a,c (6 cycles) (cont'd)

[ ]a,c

Outline

- Delivery statistics
- Performed Inspections 2016
- **HiFi^{TM} Cladding Update**
- Control Rod Blade Inspections 2016
- Summary

Inspection in [ ]a,c

a,c

HiFi Cladding Background

- Starting in the mid-1980s Japanese industry and government identified and supported development of low hydrogen pickup claddings. This led to **HiFi** cladding from NFI.
- **HiFi** cladding will be introduced in Japan with 10x10 fuel. Post-Fukushima **HiFi** cladding introduction to 9x9 fuel is also under discussion with Japanese customers.
- All elements apart from iron are within the Zry-2 specification.

Alloying elements used today in High Fe Zr-based alloys (ex. Alloy-2 and **HiFi** cladding):

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3rd Cycle Inspection in [ ]a,c

[ ]a,c

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Inspection in [ ]a,c

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Inspection in [ ]a,c

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First Cycle **HiFi** Cladding Inspection in [ ]a,c

[ ]a,c

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Outline

- Delivery statistics
- Performed Inspections 2016
- HiFi™ Cladding Update
- **Control Rod Blade Inspections 2016**
- Summary

CR 99 Surveillance – Nordic Plants

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[ ]a,c CR 99 3rd Generation Inspections 2013

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[ ]a,c CR 99 3rd Generation Inspections 2015

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CR 99 Experience Summary

- CR 99 3rd generation has shown flawless performance in US reactors for 10 years. Operation to NEOL continues.

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[ ]

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Outline

- Delivery statistics
- Performed Inspections 2016
- **HiFi**™ Cladding Update
- Control Rod Blade Inspections 2016
- **Summary**

Summary

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Update on Cooling Deficiency Events at Leibstadt NPP (KKL)

Jeremy King
BWR Fuel Product Manager

Discovery

a,c

Fuel Leaker: [ ]a,c

[ ]a,c

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Inspection Results

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Categorizing the Indications

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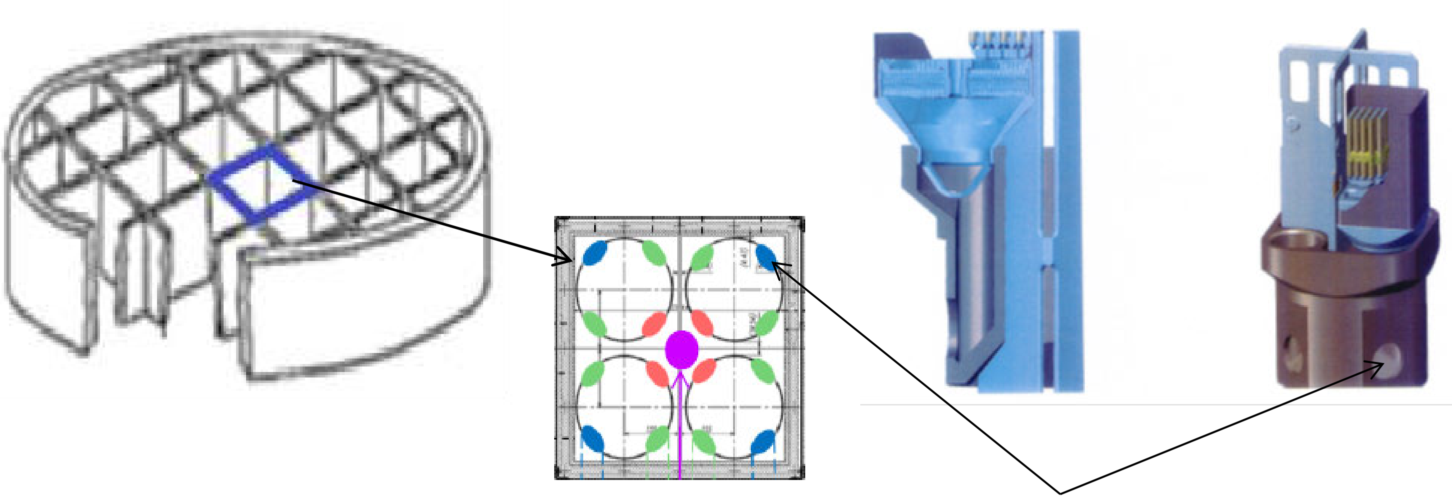
BWR/6 Fuel Support Piece Design



Fuel Support Piece orifice at cross-beam

Evaluation of inspections

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Data Evaluation

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a,c

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a,c

US Patent Application 2003/0185334 A1 - Toshiba proposed vortex control solutions

CORE INLET STRUCTURE FOR COOLANT

Inventors: **Toshihiro Fujii**, Yokohama-Shi (JP); **Shiho Fujita**, Yokohama-Shi (JP); **Akira Mototani**, Yokohama-Shi (JP); **Hideo Komita**, Yokohama-Shi (JP); **Miyuki Akiba**, Tokyo (JP); **Tadashi Narabayashi**, Yokohama-Shi (JP); **Masaru Ukai**, Yokohama-Shi (JP); **Shinichi Morooka**, Tokyo (JP); **Tetsuzo Yamamoto**, Yokosuka-Shi (JP); **Ryoma Kato**, Yokohama-Shi (JP)

Correspondence Address:
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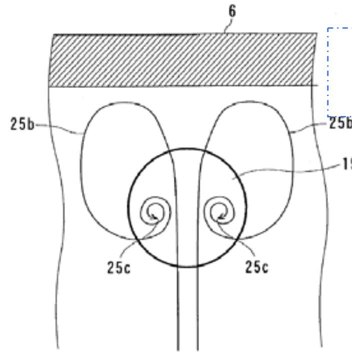
1940 DUKE STREET
ALEXANDRIA, VA 22314 (US)

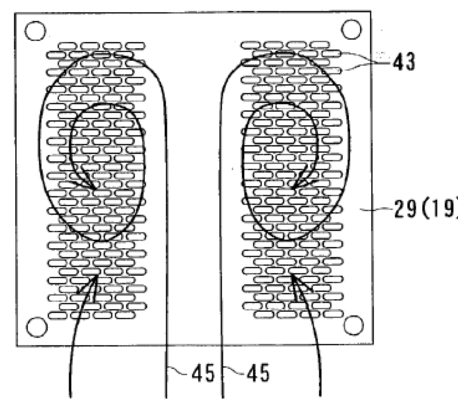
Assignee: **Kabushiki Kaisha Toshiba**, Tokyo (JP)

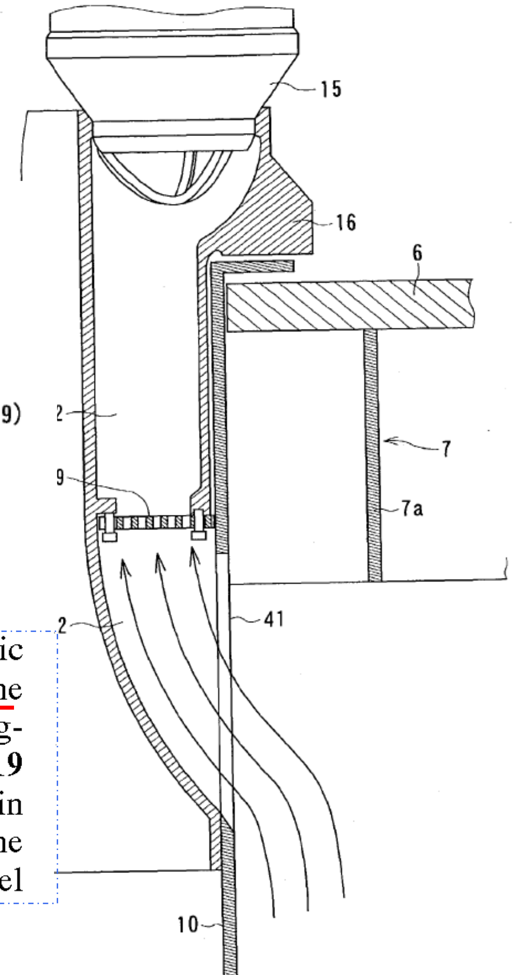
Appl. No.: **10/403,283**

Filed: **Apr. 1, 2003**



vortex control means for controlling vortex of the coolant flowing into the inlet orifice formed to the fuel support





orifice **19** is changed. Further, in the case of the symmetric twin vortex, the conditions or states of these vortexes of the vortex largely change in elapsing of time. The large changing of passage pressure loss factor at the inlet orifice **19** caused by the condition changing of the symmetric twin vortex makes it difficult to adjust the inlet orifice **19** for the proper flow rate of the coolant flowing the respective fuel

US Patent Application 2016/0379722 A1 - GEH proposed re-design of Fuel Support Piece

SYSTEMS AND METHODS FOR INCREASED STABILITY NUCLEAR FUEL CASTINGS

Applicant: **GE-HITACHI NUCLEAR ENERGY AMERICAS LLC**, Wilmington, NC (US)

Inventors: **Francis T. Bolger**, Wilmington, NC (US); **Wayne Marquino**, Wilmington, NC (US); **Charles L. Heck**, Wilmington, NC (US); **Randall H. Jacobs**, Wilmington, NC (US)

Appl. No.: **14/754,645**

Filed: **Jun. 29, 2015**

thereby combating pressure shock waves and resulting self-reinforcing flow oscillations following a flow disruption.

[0017] The inventors have recognized that existing flow structures in nuclear cores that create desired flow direction may have relatively high instability in the instance of thermo-hydraulic perturbation, such as when the inlet temperature or pumped flow is reduced. Boiling two-phase flow

[0018] However, the inventors have recognized that increasing pressure loss in the fuel support casting to correct such oscillations with an inlet orifice may detrimentally increase overall pressure loss, and reduce flow through the fuel assembly. To overcome these newly-recognized problems as well as others, the inventors have developed systems

[0022] Example embodiment fuel support casting **148** may further include a lower opening **194** that is relatively less or non-orificed. For example, lower opening **194** may be

seating in openings **190/290**. It is further possible to retrofit existing fuel castings as example embodiment fuel castings by extending a lower portion to form longer internal flow passages **196** and potentially further remove or relocate a side-entry orifice in such existing castings. In such a retrofit, a lower opening for may be drilled in a control rod guide tube to accommodate longer flow passages.

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Westinghouse Root Cause Analysis

Root Cause (RC) & Apparent Cause (AC)

a,c

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Understanding the failure mechanism

a,c

NRC Audit SVEA-96 Optima3 / D5 (April 21st-23rd)

a,c

Summary

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TRITON11™ Fuel
Design Verification and Manufacturing

Jeremy King
BWR Fuel Product Manager

Westinghouse

Outline

a,c

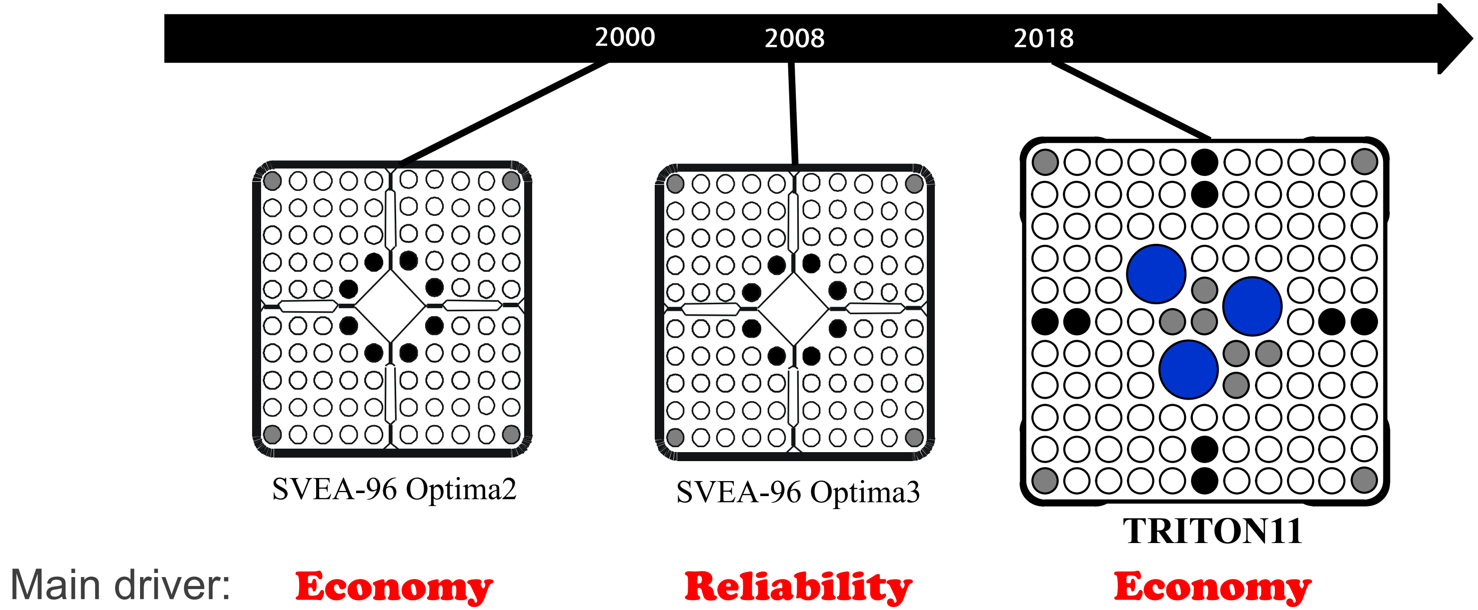
- Project Overview and Schedule
- Design Overview
- Status of Verification Testing
- Manufacturing
- Summary

Westinghouse 11x11 BWR **TRITON11™** Fuel Design

a,c

Westinghouse BWR fuel Evolution

- Main driver for **TRITON11** fuel development is improving fuel economy
- High fuel reliability is provided through long evolution of robust materials and proven mechanical design solutions
  - Important reliability features of SVEA-96 **Optima3^{TM}** fuel are maintained



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TRITON11 Fuel Design - Project Status

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TRITON11 Fuel – High Level Schedule

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Design Overview
&
Status of Verification Testing

Superior Fuel Economy

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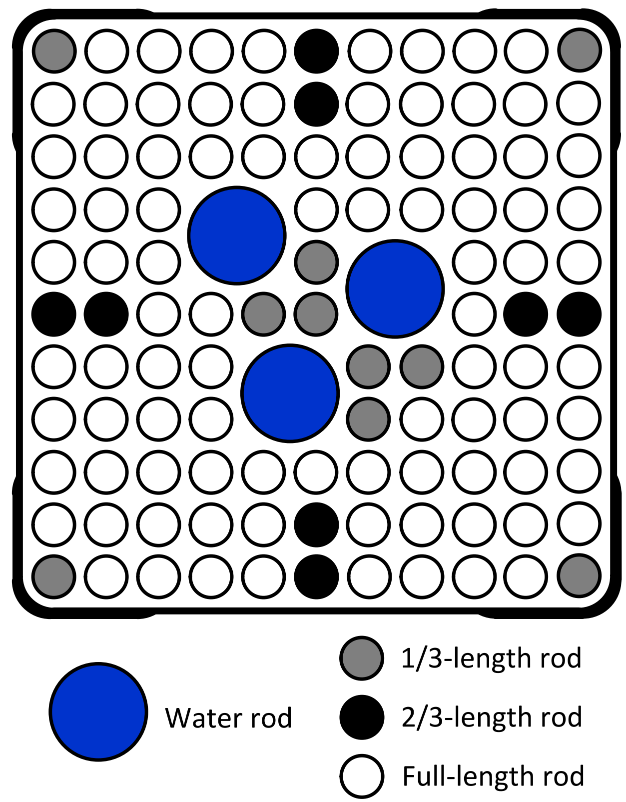

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Robust Mechanical Design

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Robust Mechanical Design

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Robust Mechanical Design

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High-performance Materials

a,c

Uncompromised Reliability

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Design Verification - FRIGG Test

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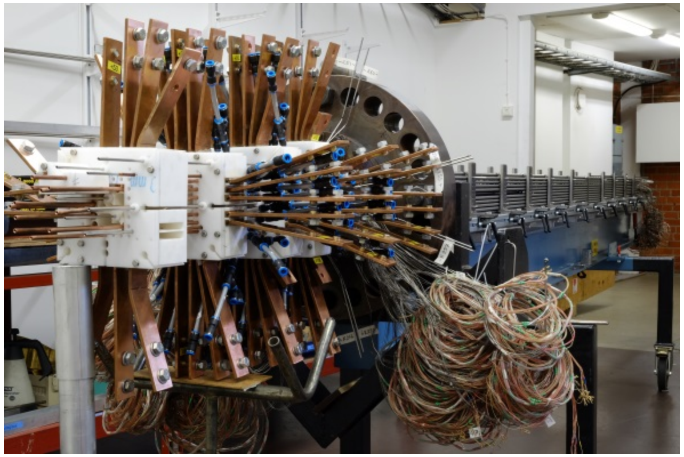

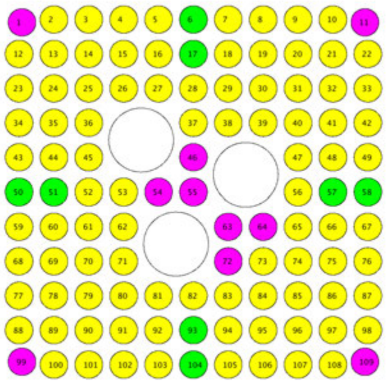

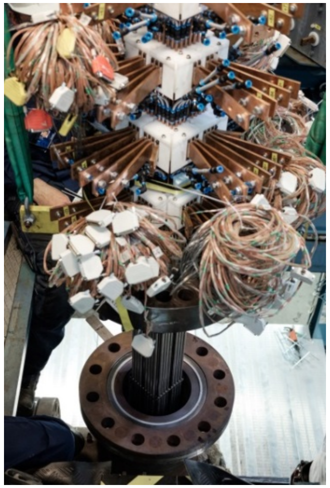

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Design Verification - FRIGG Test

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Design Verification - BURE Test

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Westinghouse

Design Verification - BURE Test

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Manufacturing

TRITON11 Fuel Fabrication Preparedness
LTA Status

a,c

TRITON11 Grid Production

a,c

TRITON11 Fuel Rod Loading

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TRITON11 Fuel Channel Manufacturing

a,c

TRITON11 Water Rod

a,c

TRITON11 Fuel Rods

a,c

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TRITON11 Fuel Design Verification and Manufacturing Summary

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