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LTR-NRC-19-38

July 17, 2019

Subject: Transmittal of the Slide Presentations for the 2019 Westinghouse Fuel Performance Update Meeting (Proprietary / Non-Proprietary)

Enclosed are the proprietary and non-proprietary versions of the presentation package, "Slide Presentations for the 2019 Westinghouse Fuel Performance Update Meeting," for the meeting to be held on July 23, 24 and 25, 2019 at the Westinghouse Churchill Facility and Cranberry Headquarters. A meeting agenda is also included.

This submittal contains proprietary information of Westinghouse Electric Company LLC ("Westinghouse"). In conformance with the requirements of 10 CFR Section 2.390, as amended, of the Nuclear Regulatory Commission's ("Commission's") regulations, we are enclosing with this submittal an Application for Withholding Proprietary Information from Public Disclosure. The Affidavit sets forth the basis on which the information identified as proprietary may be withheld from public disclosure by the Commission.

Correspondence with respect to the proprietary aspects of the Application for Withholding or the Westinghouse Affidavit should reference AW-19-4918 and should be addressed to Camille T. Zozula, Manager, Infrastructure & Facilities Licensing, Westinghouse Electric Company, 1000 Westinghouse Drive, Suite 165, Cranberry Township, Pennsylvania 16066.

Korey L. Hosack, Manager
Product Line Regulatory Support

cc: Ekaterina Lenning
Dennis Morey

Enclosures:

(1) Affidavit, AW-19-4918
(2) Westinghouse Proprietary Information Notice and Copyright Notice
(3) Slide Presentations for the 2019 Westinghouse Fuel Performance Update Meeting (Proprietary)
(4) Slide Presentations for the 2019 Westinghouse Fuel Performance Update Meeting (Non-Proprietary)

AFFIDAVIT

COMMONWEALTH OF PENNSYLVANIA:

COUNTY OF BUTLER:

(1) I, Korey L. Hosack, have been specifically delegated and authorized to apply for withholding and execute this Affidavit on behalf of Westinghouse Electric Company LLC (Westinghouse).

(2) I am requesting the proprietary portions of LTR-NRC-19-38 be withheld from public disclosure under 10 CFR 2.390.

(3) I have personal knowledge of the criteria and procedures utilized by Westinghouse in designating information as a trade secret, privileged, or as confidential commercial or financial information.

(4) Pursuant to 10 CFR 2.390, the following is furnished for consideration by the Commission in determining whether the information sought to be withheld from public disclosure should be withheld.

(i) The information sought to be withheld from public disclosure is owned and has been held in confidence by Westinghouse and is not customarily disclosed to the public.

(ii) Public disclosure of this proprietary information is likely to cause substantial harm to the competitive position of Westinghouse because it would enhance the ability of competitors to provide similar technical evaluation justifications and licensing defense services for commercial power reactors without commensurate expenses. Also, public disclosure of the information would enable others to use the information to meet NRC requirements for licensing documentation without purchasing the right to use the information.

(5) Westinghouse has policies in place to identify proprietary information. Under that system, information is held in confidence if it falls in one or more of several types, the release of which might result in the loss of an existing or potential competitive advantage, as follows:

(a) The information reveals the distinguishing aspects of a process (or component, structure, tool, method, etc.) where prevention of its use by any of Westinghouse's competitors without license from Westinghouse constitutes a competitive economic advantage over other companies.

(b) It consists of supporting data, including test data, relative to a process (or component, structure, tool, method, etc.), the application of which data secures a competitive economic advantage (e.g., by optimization or improved marketability).

(c) Its use by a competitor would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing a similar product.

(d) It reveals cost or price information, production capacities, budget levels, or commercial strategies of Westinghouse, its customers or suppliers.

(e) It reveals aspects of past, present, or future Westinghouse or customer funded development plans and programs of potential commercial value to Westinghouse.

(f) It contains patentable ideas, for which patent protection may be desirable.

(6) The attached documents are bracketed and marked to indicate the bases for withholding. The justification for withholding is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (5)(a) through (f) of this Affidavit.

I declare that the averments of fact set forth in this Affidavit are true and correct to the best of my knowledge, information, and belief.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on: 20190217

Korey L. Hosack, Manager
Product Line Regulatory Support

PROPRIETARY INFORMATION NOTICE

Transmitted herewith are proprietary and non-proprietary versions of a document, furnished to the NRC in connection with requests for generic review and approval.

In order to conform to the requirements of 10 CFR 2.390 of the Commission's regulations concerning the protection of proprietary information so submitted to the NRC, the information which is proprietary in the proprietary versions is contained within brackets, and where the proprietary information has been deleted in the non-proprietary versions, only the brackets remain (the information that was contained within the brackets in the proprietary versions having been deleted). The justification for claiming the information so designated as proprietary is indicated in both versions by means of lower case letters (a) through (f) located as a superscript immediately following the brackets enclosing each item of information being identified as proprietary or in the margin opposite such information. These lower case letters refer to the types of information Westinghouse customarily holds in confidence identified in Sections (5)(a) through (5)(f) of the Affidavit accompanying this transmittal pursuant to 10 CFR 2.390(b)(1).

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LTR-NRC-19-38

Non-Proprietary Enclosure 4

Enclosure 4

Slide Presentations for the 2019 Westinghouse Fuel Performance Update Meeting

(Non-Proprietary)

July 2019

2019 Westinghouse Fuel Performance Update Meeting

Wednesday, July 24, 2019

8:30 am – 8:45 am	Welcome, Introductions, Licensing Update, Safety Brief
8:45 am – 9:45 am	PWR Fuel Performance Update
9:45 am – 10:15 am	Additive Manufacturing
10:15 am – 10:30 am	Break
10:30 am – 11:00 am	PWR Methods Update
11:00 am – 11:15 am	AP1000 Plant Startup Physics Test Summary
11:15 am – 11:30 am	Statistical Transient Methodology Update
11:30 am – 12:15 pm	Lunch
12:15 pm – 2:15 pm	Accident Tolerant Fuel Program Update
2:15 pm – 2:45 pm	High Enrichment and High Burnup Fuel Update
2:45 pm – 3:00 pm	Break
3:00 pm – 4:45 pm	BWR Fuel Performance and Methods Update
4:45 pm – 5:00 pm	Closing Comment and Feedback

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Westinghouse PWR Fuel Performance Update

Jeremy King
Director
Product Engineering

Westinghouse

Agenda

- **Changes in Performance Trends**
  - Improvements in Debris Mitigation
- Fuel Performance Update
  - Recent PIE Inspections
- [ ] a,c
- Summary

Changes in Performance Trends (PWR)

a,c

Fuel Reliability Improvement (FRI)

a,c

Agenda

- **Changing in Performance Trends**
  - **Improvements in Debris Mitigation**
- Fuel Performance Update
  - Recent PIE Inspections
- [ ] a,c
- Summary

Advanced Debris Protection Program

a,c

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Advanced PWR Debris Filter Bottom Nozzle Plan

a,c

Westinghouse

[ ] a,c

a,c

[ ] a,c Filter Concepts

a,c

Agenda

- Changing in Performance Trends
  - Improvements in Debris Mitigation
- **Fuel Performance Update**
  - **Recent PIE Inspections**
- [ ] a,c
- Summary

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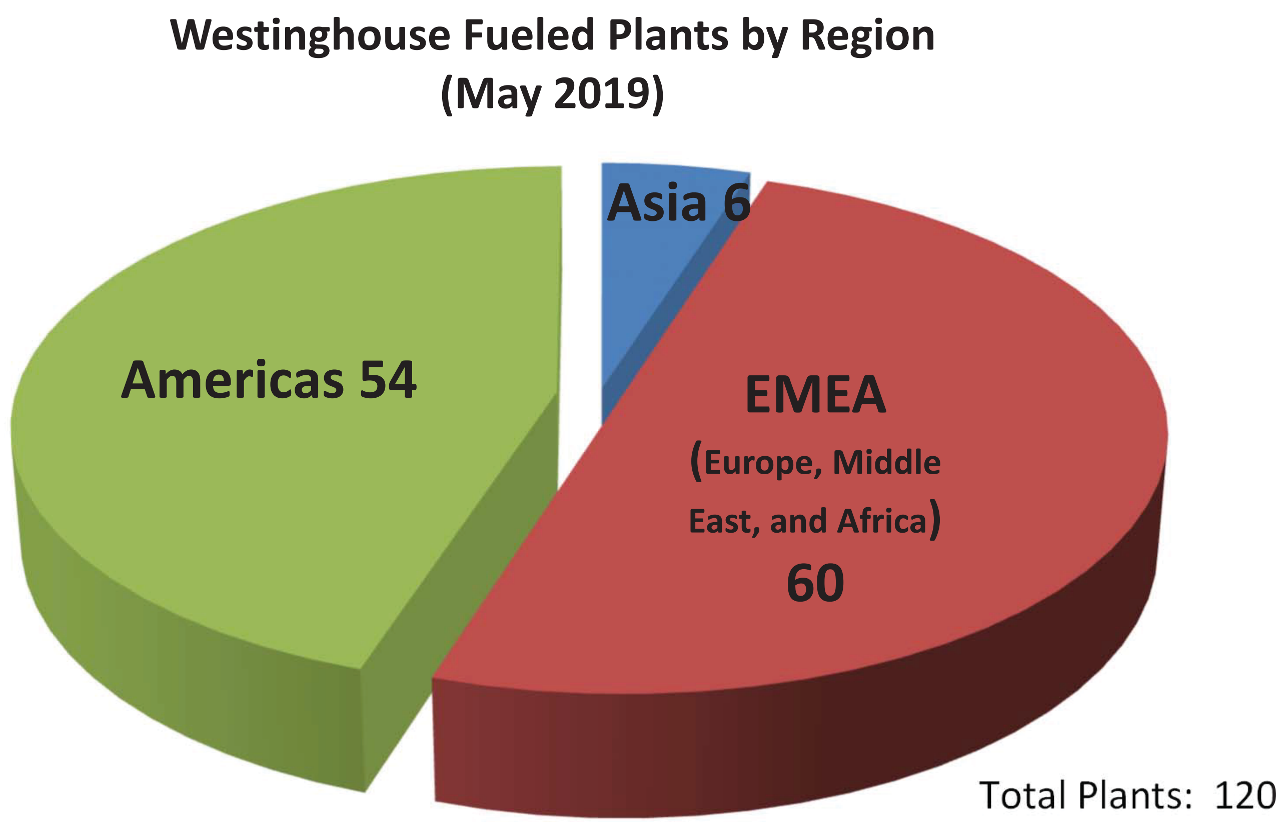
Westinghouse Fueled Plants by Region



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

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Nuclear Fuel Reliability Progress – June 2019

a,c

U.S. Nuclear Fuel Reliability Progress – June 2019

a,c

Westinghouse leads the U.S. industry due to our continuous improvement fuel reliability process and strong industry partnerships

Historical Performance of Westinghouse Fueled Plants

a,c

Majority of Westinghouse customers have operated 4 or more consecutive cycles leak free

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Leaking Plants, June 2019

[ ] a,c

a,c

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Historical Performance of Plants Currently Leaking June 2019

a,c

Agenda

- Changing in Performance Trends
  - Improvements in Debris Mitigation
- **Fuel Performance Update**
  - **Recent PIE Inspections**
- [ ] a,c
- Summary

[ ] a,c Leaking Rod Location

[ ] a,c

[ ] a,c Leaking Rod

a,c

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[ ] a,c Leaker Inspection

a,c

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[ ] a,c – Leaking Fuel Proposed Next Steps

a,c

Agenda

- Changing in Performance Trends
  - Improvements in Debris Mitigation
- Fuel Performance Update
  - Recent PIE Inspections
- [ ] a,c
- Summary

Process Description

a,c

Benefits

a,c

Early Development

a,c

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Current Program Status

a,c

Agenda

- Changing in Performance Trends
  - Improvements in Debris Mitigation
- Fuel Performance Update
  - Recent PIE Inspections
- [ ] a,c
- **Summary**

Summary

- Robust Westinghouse fuel designs performing well

[ ] a,c

- Goal is 100% leak-free performance through use of Westinghouse's FRI process to drive continuous improvement and strong partnership with industry

[ ] a,c

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Questions?

Additive Manufacturing

David Huegel
Fellow Engineer
Structures, Fuel Assembly Design and Testing

Westinghouse

Overview

- Additive Manufacturing at Westinghouse
- Additive Manufacturing Development at Westinghouse
- Westinghouse Developed AM Nuclear Fuel Components
- Westinghouse AM Tooling Development
- Designing with AM at Westinghouse
- Additive Manufacturing Development Partnering with Industry/Academia
- Q&A

Additive Manufacturing at Westinghouse

Advanced Manufacturing Program Objectives

- **Improve industry competitiveness, through the development and implementation of advanced manufacturing (AM) technologies**
  - Drive cost reductions in manufacturing
  - Enable new products and services that provide innovative customer solutions
  - Leverage external funding sources and collaborative development

TPD – DMLS

RVI Quickloc Upper Support Assembly – PM-HIP

Passive Hydrogen Igniter Concepts - BJAM

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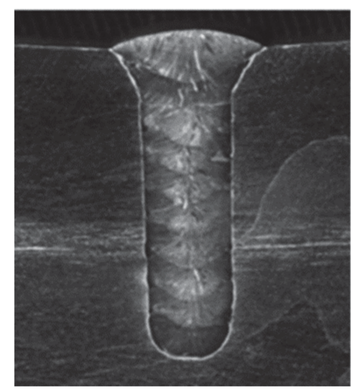
Upper Bearing Housing – AM Sand Casting Mold



Hot Wire Laser Weld

Additive Manufacturing at Westinghouse

- Additive Manufacturing will have a big impact in Nuclear:
  - Cost Effect
  - Improve Performance and Reliability
  - Improve Delivery and Schedule
- Westinghouse is fully invested in the AM technology:
  - Performed mechanical tests on 3D parts (with and without radiation effects)
  - Utilizing 3D printing for tooling for manufacturing
  - Implement a 3D AM part in reactor to gain experience
  - Building/designing numerous parts with AM for eventual employment in a nuclear reactor (grids, nozzles, etc.)

Our Goal is for AM to Help Transform the Nuclear Industry

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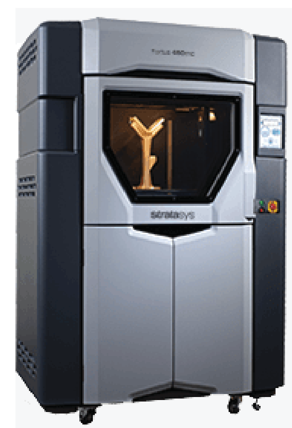
Additive Manufacturing – Westinghouse Equipment

- Additively Manufactured (3D Printed) Metal Parts
  - Currently printing in:
    - Alloy 718
    - Stainless Steel Type 316L
    - Stainless Steel 17-4 PH
    - Stainless Steel MS-1
  - Build volume 250mm x 250mm x 325mm (9.85 x 9.85 x 12.8 in)
- Additively Manufactured (3D Printed) Plastic Parts

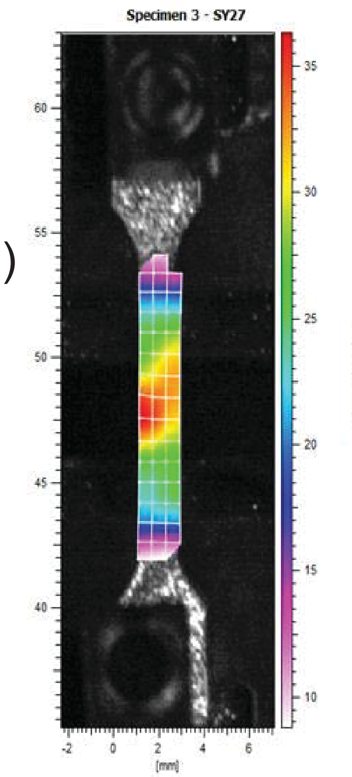
- CFFF installed a high quality Fortus 450 polymer FDM printer.
- Build volume 406mm x 355mm x 406 mm (16 x 14 x 16in)
- Variety of ABS and Nylon materials

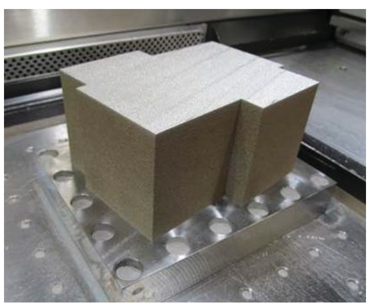


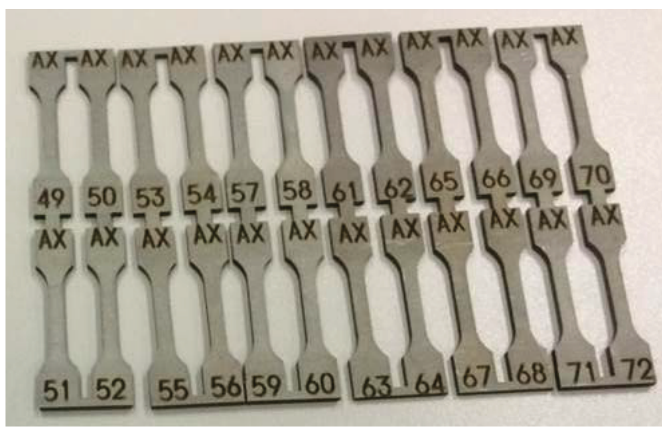
Additive Manufacturing Development at Westinghouse

AM Materials Development

- **Currently the nuclear industry has limited irradiation performance information for AM materials**
- **Westinghouse has funded material development and irradiation performance testing for 316L SS, Ni Alloy 718 and Zr**
  - Produced AM block and micro-tensile test specimens
  - Irradiating materials in MIT's test reactor (Oct. 2014 → 2018)
  - Completing post-irradiation examination (PIE) at Westinghouse Churchill laboratory (316 and 718 completed, Zr PIE DOE funded)
  - AM 316L irradiation performance consistent with wrought







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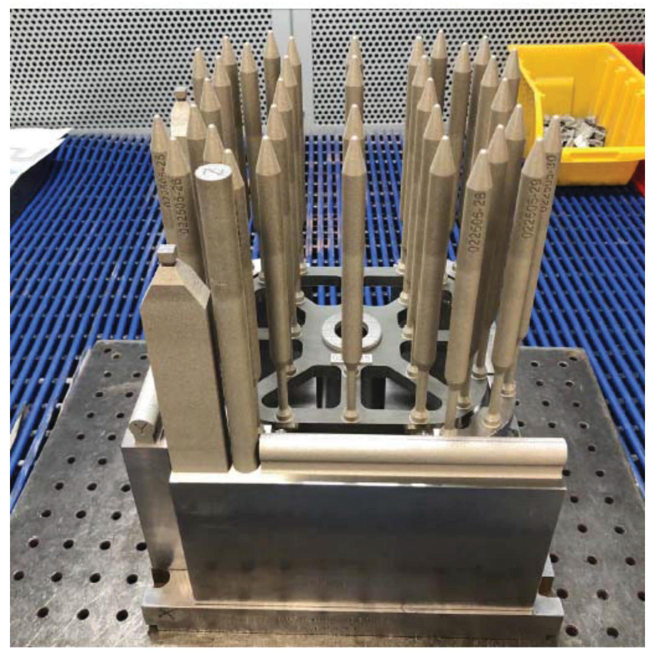
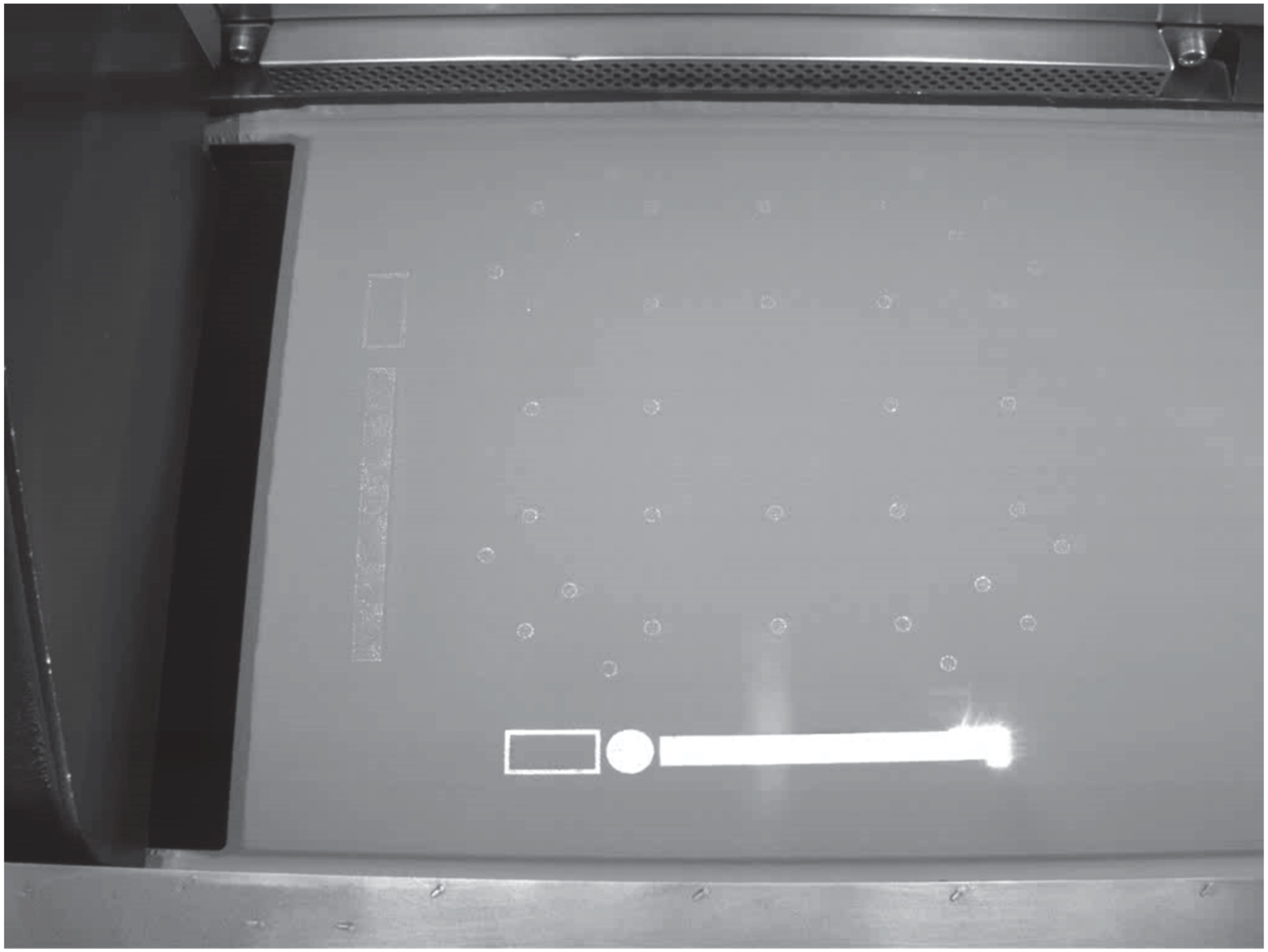
Reactor Ready Component Project

- Advanced Manufacturing Kaizen – Dec 2014
  - Thimble Plugging Device (TPD) selected as the first AM Fuels component to be place in a commercial reactor
  - Low Risk Component, moderate complexity
- Completed manufacturing qualification and production pieces
- Working with utility partner to complete licensing evaluation
- Targeting spring 2020 delivery



Reactor Ready Component Project



Licensing & Industry Partnerships

- Pursuing the licensing of the AM TPD using the 50.59 screening process.
  - Same form, fit, and function as conventional design.
- Coordinating with the NRC to use AM TPD component as candidate applicant using the recently issued NRC AM Action Plan process. Held meeting with NRC May 28th.
- Provided regular updates on AM initiatives at annual Westinghouse-NRC Fuel Performance Update meetings
- Member of the NEI Roadmap development Task Team
- Support the development of AM ASME code cases

Westinghouse is working with key organizations to help bring AM to Nuclear

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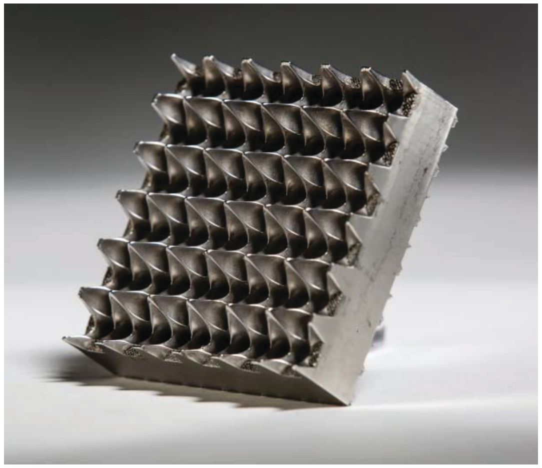
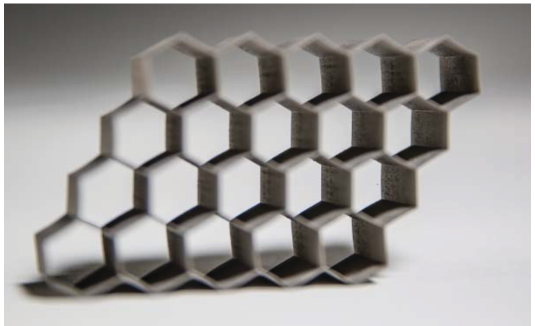
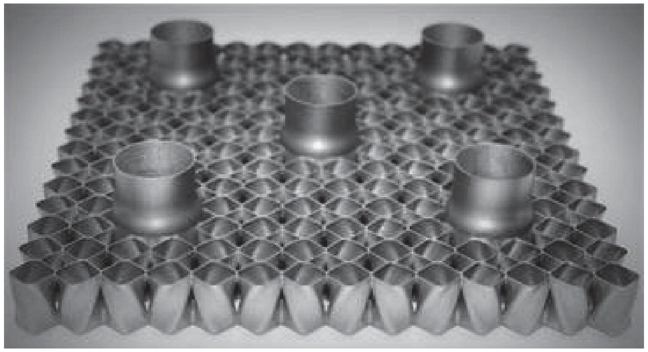
Westinghouse Developed AM Nuclear Fuel Components

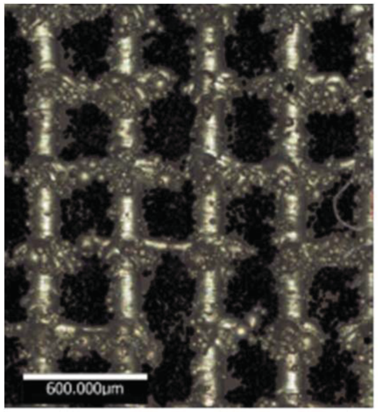
Fuel Structures

- Improved flow characteristics are a possibility with AM resulting in better heat transfer from fuel rods to reactor coolant for better efficiencies
- Stronger, more efficient support of fuel rods with better mixing characteristics









Items requiring further investigation:

- Corrosion characteristics in PWR and BWR chemistries
- Mechanical strengths of small features

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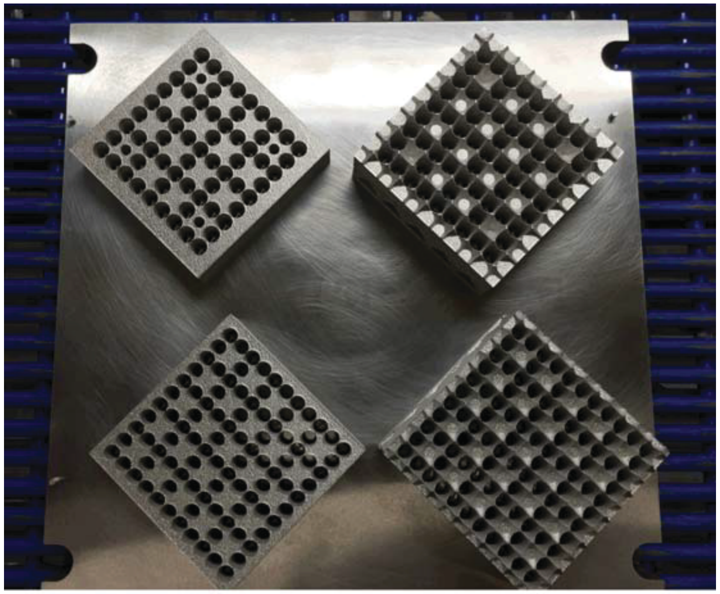
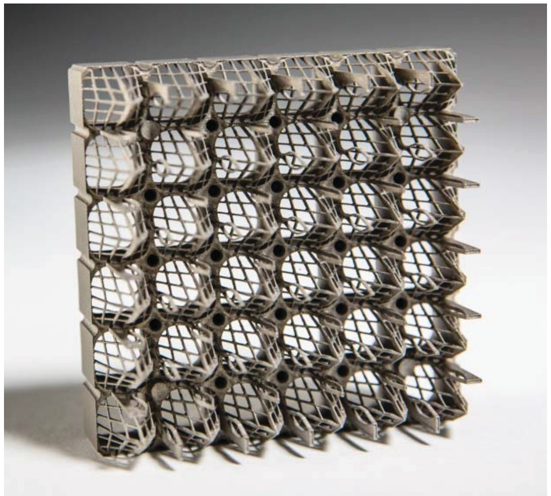
Fuel Bottom Nozzle

- Goal: Reduced pressure drop and improved debris filtration
- Multiple complex designs enabled by AM
- Polymer based bottom nozzles created for prototype flow testing
- ADFBN Projects for both PWR and BWR application - see photos and next slide



- Innovation Project: PWR Fuel Bottom Nozzle Advanced Design Through Multi-Physics Topology Optimization and Design for Additive Manufacturing



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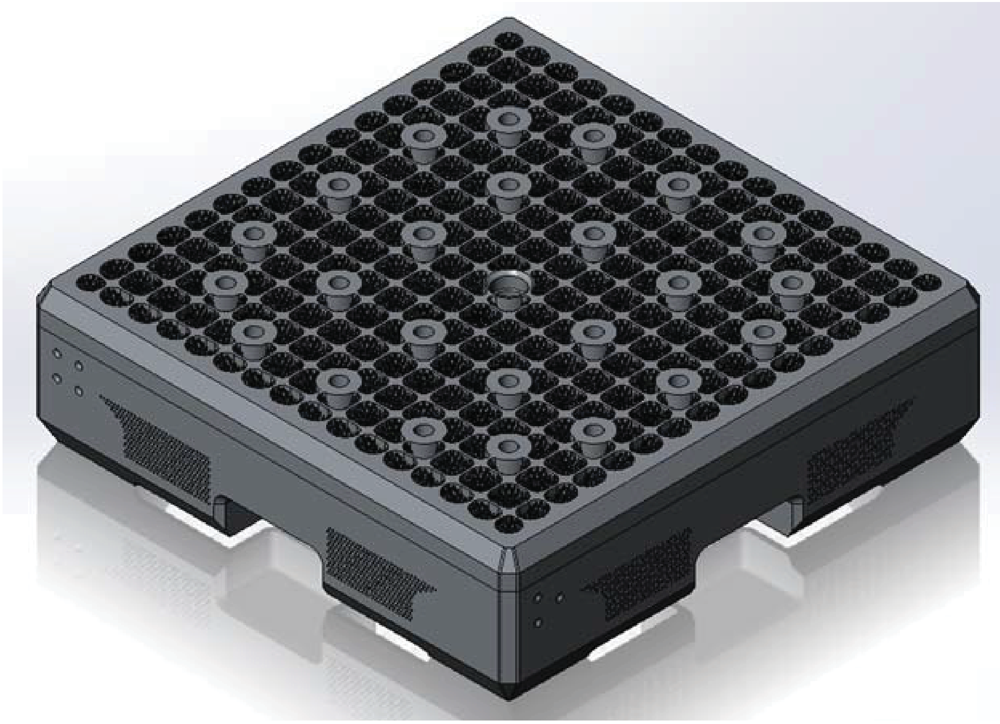
Fuel Bottom Nozzle

- Full size AM produced Bottom Nozzle
  - Reduced pressure drop
  - Improved Filtering capability



- Pursuing the licensing of Lead Test Assembly AM Bottom Nozzles (4 to 8) using the 50.59 screening process.

- Coordinating with the NRC to ensure approach is acceptable.

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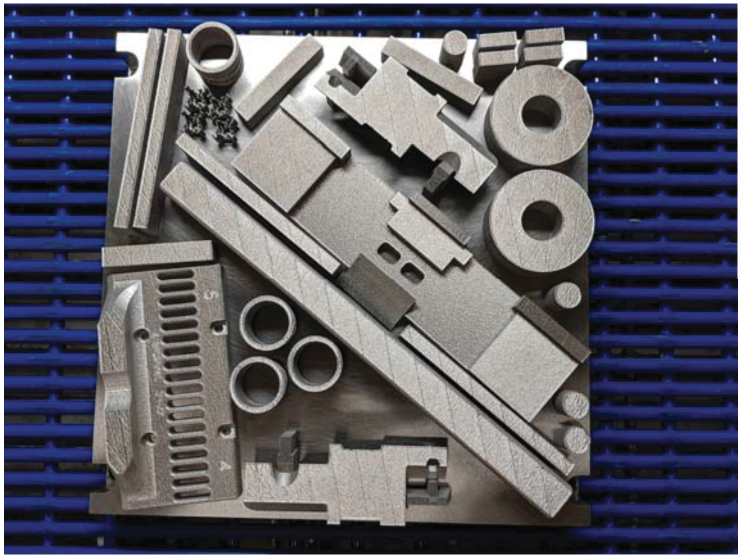
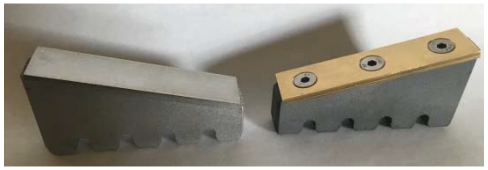
Westinghouse AM
Tooling Development

Tooling for Fuel Manufacturing

- Immediate benefit from tooling applications helping to lower the costs and improve performance
- Improved safety for operators
- More ergonomic designs resulting in less fatigue injuries

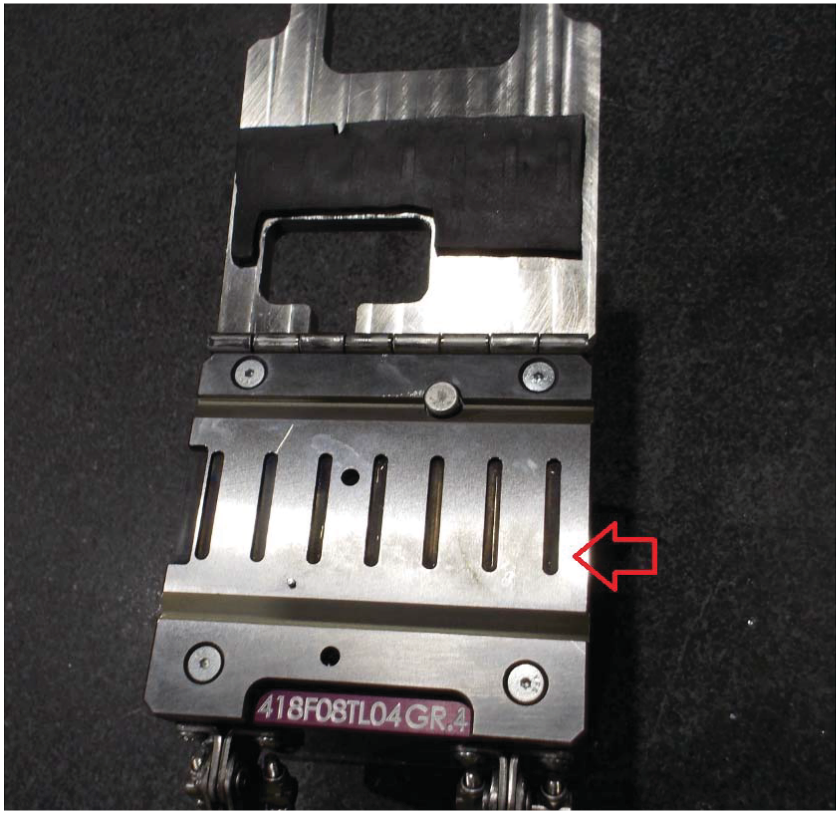




Designing with AM at Westinghouse

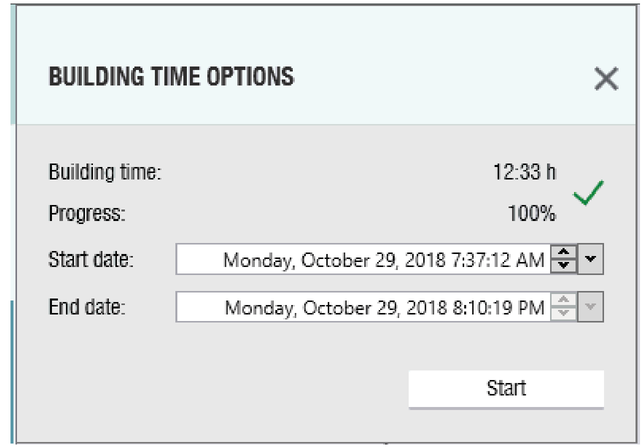
Strap Marking Plate

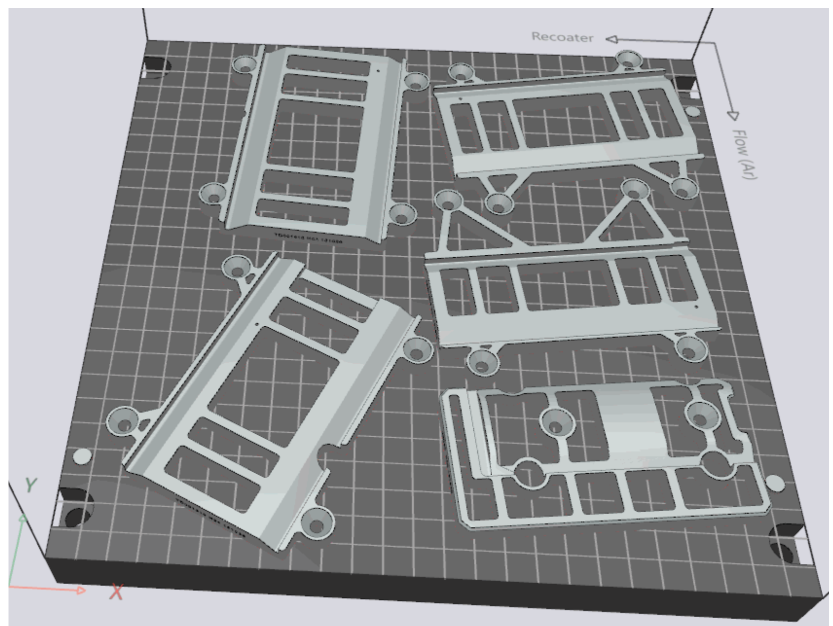
- Strap plates are used to support the grid's outer strap during the serial number etching process and are unique to each outer strap design (some grids use the same outer strap configuration). There are approximately 50 different plates at the CFFF.



Strap Marking Plate – Additively Manufactured

- The plate was redesigned using benefits from the AM process. By removing material that isn't required for support or to locate with the mounting block, the build time was reduced (<13 hours for 5 different designs).





Lower AM cost = minimum material required

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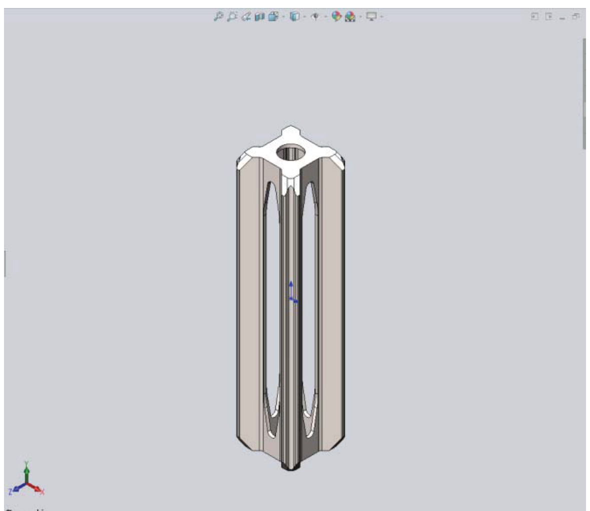
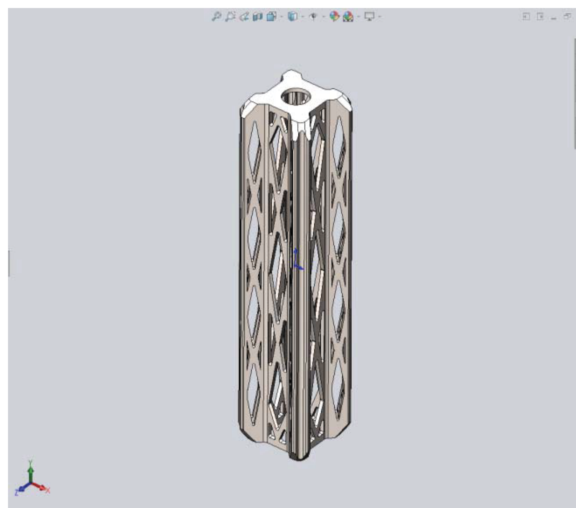
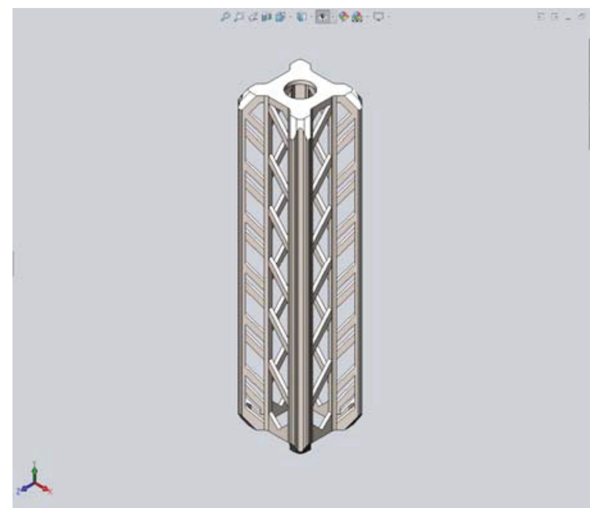
Strap Alignment Pins

- The strap alignment pins as shown below have gone through a number of design iterations to improve build times, increase part life and minimize weight.







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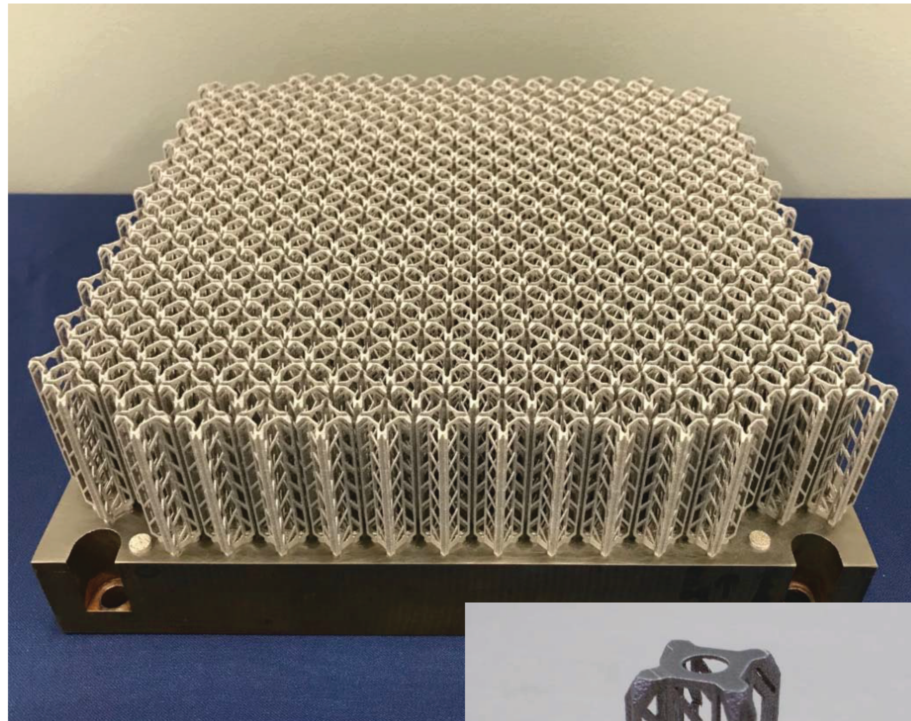
Strap Alignment Pins

- A complete set can be made on one build plate, or parts can be mismatched as required. After they are printed, they are removed from the build plate using EDM and then bead blasted/ vibratory polished to improve surface finish.



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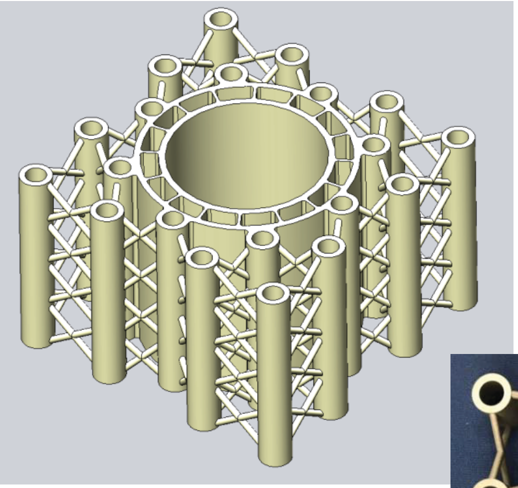
RCCA Spider Envelope Gage

- This gage is used to measure the locations of the RCCA spider fingers after welding/brazing. Because of the gage weighs (~60 lbs) inspectors are at risk of injury during movement of the gage. As a result, a "Greenbook" issue was opened and the redesign was investigated using the AM process.

RCCA Spider Envelope Gage

- Using the AM technology which can easily minimize the required material and maintain the gage function and stability, this gage was redesigned to a total weight of less than 10 lbs. Test builds verified the gage functionality and stability.



Gage in the "as-built" configuration

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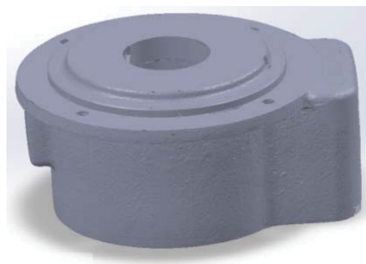
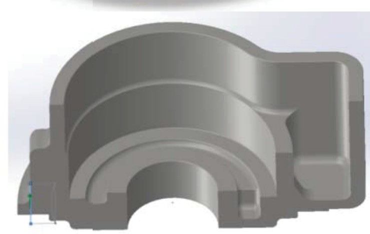
Westinghouse Non-Proprietary Class 3

Binder Jetting for Replacement Castings

Utilizing Reverse Engineering Process for Replacement Parts

Laser scanning → 3D modeling → AM sand molds → traditional casting





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Additive Manufacturing Development Partnering with Industry/Academia

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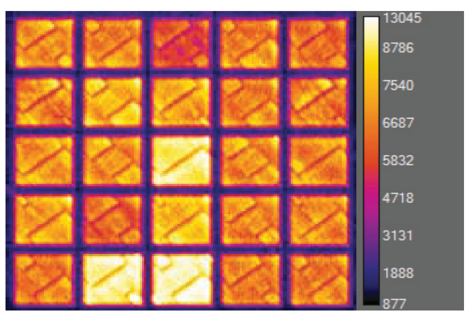
Additive Manufacturing – Current Projects

- Department of Energy – *DE-FOA-0001281* - NEET-1- "**Integrated Computational Materials Engineering (ICME) and In-situ Process Monitoring for Rapid Qualification of Components Made by Laser-Based Powder Bed Additive Manufacturing (AM) Processes for Nuclear Structural and Pressure Boundary Applications**"
  - Project Lead Principal Investigator(PI) is EPRI
  - Project Co-PI's – ORNL, Rolls Royce, and WEC
  - Initiated in fiscal year 2016 - third year of a three year project
  - WEC is a sub-awardee from EPRI
  - $1.75M Award



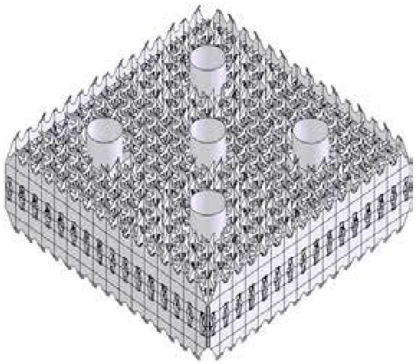
Qualification of AM Components

Additive Manufacturing – Current Projects

- Department of Energy – *DE-FOA-0001858* – ARPA-E

"ADDITIVE MANUFACTURING OF SPACER GRIDS FOR NUCLEAR REACTORS"

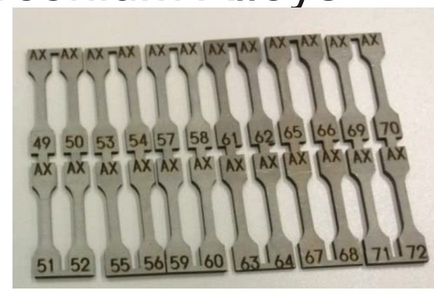
- Project Lead Principal Investigator(PI) is CMU (Carnegie Melon University)
- Project Co-PI – WEC
- Expected to be initiated in fiscal year 2019
- WEC is a sub-awardee from CMU
- $1.25M Award

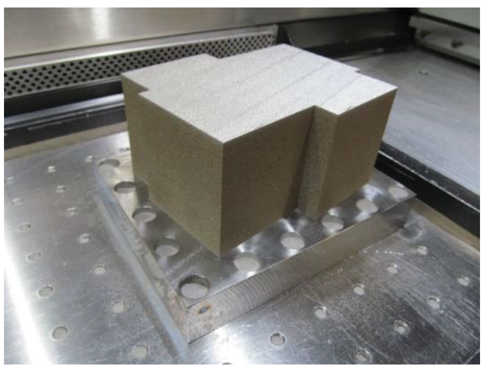


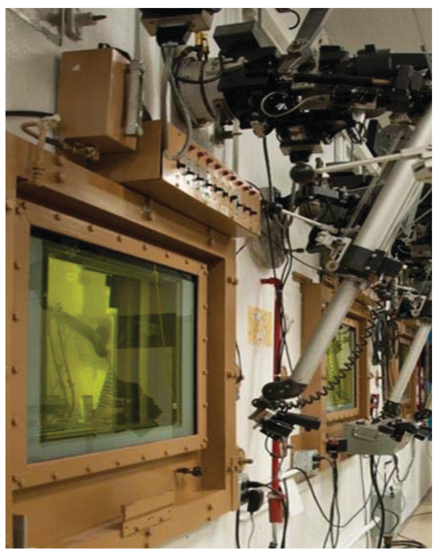
Exploring Advanced Reactor Components

Additive Manufacturing – Current Projects

- Department of Energy – DE-FOA-0001515 - NSUF-2: Nuclear Science User Facilities Access Only - Radiation Effects on Zirconium Alloys Produced by Powder Bed Fusion Additive
  - Project Leads – William Cleary and Peng Xu
  - Initiated in fiscal year 2018 – 3 year program
  - $1M Award





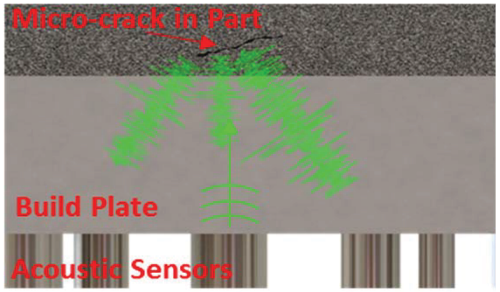


First of a Kind Research in AM Zirconium Alloys

Westinghouse

Additive Manufacturing – Current Projects

- **Department of Energy –Two small projects with Argonne National Lab**
  - Funding Opportunity Announcement DE-FOA-0001772 – NEET-1 Advanced Methods for Manufacturing (Awarded)
    - CFA-18-15141: Pulsed Thermal Tomography Nondestructive Examination of Additively Manufactured Reactor Materials and Components
  - Funding Opportunity Announcement DE-FOA-0001 – NEET-1.2 Quality Control Techniques and Qualification Methodologies (Selected for full application)
    - In Situ Quality Control of Additively Manufactured Metallic Nuclear Components using the Ultrasound-Based SMART Platform



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Developing key supporting technologies

Q & A

Westinghouse Fuel Performance Update Meeting

PWR Methods Update

Yixing Sung
Fellow Engineer
PWR Core Methods

Westinghouse

Agenda

- Westinghouse Thermal Design Procedure (WTDP) Topical
- Improved NEXUS Cross-Section Representation Methodology
- Qualification of the Two-Dimensional Transport Code PARAGON2
- Reactivity Initiated Accident (RIA) Update

Westinghouse Thermal Design Procedure (WTDP) Topical Report WCAP-18240

Technical Overview

- One topical report which consolidates existing approved methods for all PWRs would facilitate future analysis work and review activities
  - Calculations of DNBR limits for Condition I and II events
  - Statistical rods-in-DNB evaluations for non-LOCA Condition III and IV events in support of radiological consequence analyses

- Applicable to all PWR designs

Westinghouse

Technical Overview

- WTDP based on existing CE-PWR statistical methods enhanced with VIPRE-W code
- Maintains full compliance with current regulatory requirements and guidelines
- Compatible with current design interfaces and complementary with Westinghouse advanced technologies

Current Status

- Topical report WCAP-18240-P submitted in August 2018
- NRC review followed a new and improved process (TIGER)
  - Technical audit conducted in April 2019
  - RAI's issued in May 2019
- Westinghouse provided response to RAI's in July 2019
- Draft SER anticipated by December 2019

Updated NEXUS Cross-Section Methodology
WCAP-16045 Addendum 2

Westinghouse

Technical Overview

- New NEXUS cross-section methodology (XSR) keeps basic concept of current ANC cross-section methodology
  - [
  -

  ]a,c
- Instead of using [

  ]a,c

Technical Overview

- [
-
-

]a,c

Current Status

- Pre-submittal meeting held April 29^{th}, 2019
- Topical report WCAP-16045 Addendum 2 submitted in June 2019 as planned
- NRC expected to begin Topical Report review shortly
- Westinghouse welcomes an early audit in order to facilitate expedited review
- Final SER anticipated in 2020

Westinghouse

Qualification of the Two-Dimensional Transport Code PARAGON2

WCAP-18443

Technical Overview

- PARAGON1 is a lattice physics code that provides the basic cross-sections for the core neutronics code
- PARAGON2 is a replacement for the PHOENIX-P and PARAGON1 codes as a standalone application or a data supplier for nodal codes (such as ANC) for PWR core design applications.
  - No interface changes are required for existing codes packages that use lattice codes
  - All PWR licensed methodologies remain applicable when using PARAGON2
  - Current uncertainties for safety analysis and Tech Spec surveillance remain applicable

Westinghouse

Technical Overview

- The PARAGON2 neutronics lattice physics code was developed to improve the accuracy of current core design code systems, NEXUS/ANC, and APA

[ ] a,c

The methodology and models implemented in PARAGON2 require licensing.

Westinghouse

Technical Overview

- For all plant types, PARAGON2 is intended to:

[ ] a,c

  - Improve ANC and BEACON™ code predictions
  - Consistently improve predictions for all fuel types (from 14x14 to 17x17)

Westinghouse

Technical Overview

a,c

Major changes are in energy variable treatment

Current Status

- Topical Report Pre-submittal meeting with NRC on June 27, 2019
- Topical Report to be submitted September 2019
- Final SER anticipated in 2020

Westinghouse

Reactivity Initiated Accident (RIA) Update

NRC Criterion Next Revision for Public Comment

- Awaiting NRC next revision for public comment such that Westinghouse can review and provide feedback
  - Will continue to work with PWR Owners Group and NEI on providing feedback

Westinghouse

AP1000® Plant Startup Physics Test Summary

James Boyle
Manager
New Reactor Technology

Westinghouse

Agenda

- Overview of Advanced First Core employed by the **AP1000** Pressurized Water Reactor (PWR) fleet
- Sanmen Unit 1 Plant Startup Timeline (2018)
- Selected Physics Test Results Summaries
  - Low Power Physics Testing (LPPT)
- Examples of Successful BEACON™ System Use in Support of Plant Acceptance Testing (PAT) and First-Plant-Only-Tests (FPOT)

Westinghouse

AP1000 PWR Advanced First Core

- Tungsten Gray Rod Cluster Assemblies to facilitate the MSHIM™ operation and control strategy
- Radially zoned fuel enrichments
- Reduced enrichment axial blankets
- Combinations of burnable absorbers (both IFBA and WABA) within fuel assemblies
- Natural uranium fuel assemblies on core periphery
- Vanadium fixed incore detectors for BEACON system online monitoring

[ ]a,b,c

Multiple first-of-a-kind elements and feature combinations in comparison to past initial cycle and reload core designs

Westinghouse

Sanmen Unit 1 Plant Startup Timeline (2018)

25-Apr	Began Initial Fuel Loading (IFL)
21-Jun	Achieved Initial Criticality
25-Jun	Entered MODE 1 (>5% rated thermal power, RTP)
30-Jun	Initial Grid Synchronization
14-Aug	Reached Stable 100% RTP Conditions
30-Sep	End of Performance Testing (EOPT)
11-Oct	Signed Acceptance Certificate (Full Commercialization)

Program completed in just over 5 months (158 days from IFL to EOPT)

Westinghouse

Physics Test Results – LPPT

- All results from the four startups were very consistent and well within review and acceptance criteria.
  - Total Rod Worth **measured vs. predicted (M−P) within 1%**
    - *Confirms rod worth uncertainty/reactor shutdown capability*
  - Individual bank worths **M−P within 50 pcm**
    - *Provides initial insights regarding the core power distribution*
  - Critical boron concentration **M−P within 20 ppm**
    - *Confirms the core reactivity balance*
  - Temperature coefficient **M−P ≈ 1.0 pcm/°C**
    - *Demonstrates proper reactivity control capability*

Provides confidence that the nuclear design accurately reflects the as-built reactor

Westinghouse

Individual Bank Worth Axial Results Profile

[ ]a,b,c

BEACON System Use in Support of PAT & FPOT

- Several tests heavily relied on BEACON system simulation and proper rod control functionality via the MSHIM operating strategy. Some of the most significant efforts included:
  - (FPOT) Control Rod Misalignment
    - Recovery from unplanned xenon oscillation
  - (FPOT) Load Follow Demonstration
    - Confirmed the capability to perform load follow operation

Successful results provide further confidence in Westinghouse codes/tools and the MSHIM Operating Strategy

Westinghouse

Control Rod Misalignment FPOT

- While attempting to establish the test initial conditions, an axial xenon oscillation was triggered [ ] a,c
- The customer cited the BEACON Monitor Xenon Mode View as a very useful recovery tool to stabilize the plant.

[ ] a,b,c

Westinghouse

Load Follow Demonstration FPOT

- Westinghouse partnered with the customer to ensure test performance would not lose AFD control or require a boron change (either of which would invalidate the test).
- BEACON Analysis Load Swing Function was used to simulate and refine initial conditions and the test procedure.

[ ] a,b,c

Statistical Transient Methodology (STM) – Status Update

Alan Macdonald
Principal Engineer
Transient Analysis

Westinghouse

The purpose of this presentation is to provide an update on the status of the STM development program

What is STM?

STM Results

What are our plans?

Why do something different?

- 1980s
  - Statistical method introduced to address non-LOCA departure from nucleate boiling (DNB) acceptance criteria
    - Improved thermal design procedure
    - Revised thermal design procedure
- 1990s
  - Statistical methods introduced to address LOCA acceptance criteria
    - ASTRUM methodology
- 2010s
  - Improved methods developed to address LOCA acceptance criteria
- Current
  - Improved methods developed to address DNB acceptance criteria
    - Westinghouse Thermal Design Procedure
  - Statistical method developed to address other non-LOCA acceptance criteria Statistical Transient Method (STM)

The STM has been developed to allow for the statistical treatment of uncertainties for safety analysis events that currently use a bounding approach

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Method finalized for a select subset of events described in Chapter 15 of the Standard Review Plan

[ ]a,c

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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] similar to recent safety analysis applications
  - Utilizes current code models
  - Applicability
    - Limited to events that use deterministic approach
    - Method code independent, applicable to both LOFTRAN and RETRAN
    - Current method addresses Westinghouse legacy PWRs
      - Potential to extend method through future submittals to Combustion Engineering and other plant designs
- Criterion
  - Statistical statement to bound the 95th percentile with 95% confidence
  - Statistical statement will be compared to the current acceptance criterion for the event

The uncertainty elements sampled depend on the event

[ ] a,c

[ ] a,c

Sample STM Results – [ ] a,c

[ ] a,c

[ ] a,c

Sample STM Results – [ ]a,c

[ ]a,c

[ ] a,c

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Sample STM Results – [ ] a,c

[ ] a,c

Convolution of uncertainties generated [ ] a,c of margin

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STM – Licensing Plan

[ ] a,c

[ ] a,c

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EnCore® Accident Tolerant Fuel (ATF)

Zeses Karoutas
Chief Engineer
Innovation, Technology & Exploration

Westinghouse

Agenda

- Westinghouse EnCore fuel program
- Lead Test Rod (LTR) programs
- State of near-term and advanced technologies
- Licensing framework for EnCore ATF technologies
- Summary

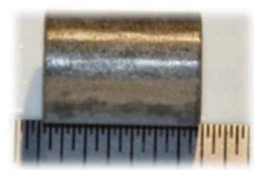
EnCore Fuel Program

Benefit	Cr-Coated Cladding ADOPT™ Fuel	Cr-Coated Cladding U_3Si_2 Fuel	SiC Cladding U_3Si_2 Fuel
Pellet Uranium Loading	Some / Potential Benefit	Large Benefit	Large Benefit
Fuel Utilization	Some / Potential Benefit	Large Benefit	Large Benefit
Debris and Grid-to-rod Fretting	Large Benefit	Large Benefit	Large Benefit
High Burnup	Large Benefit	Large Benefit	Large Benefit
Load Follow / Flexibility	Some / Potential Benefit	Large Benefit	Large Benefit
LOCA / DBA Margin	Some / Potential Benefit	Some / Potential Benefit	Large Benefit
DNB Margin	Some / Potential Benefit	Some / Potential Benefit	Large Benefit
Hydrogen Generation	Some / Potential Benefit	Some / Potential Benefit	Large Benefit
BDBA Operator Response Times	Some / Potential Benefit	Some / Potential Benefit	Large Benefit


Chromium-coated Cladding


SiC Cladding


ADOPT™ Fuel


U_3Si_2 Fuel

LOCA: Loss of Coolant Accident
DBA: Design Basis Accident
DNB: Departure from Nucleate Boiling
BDBA: Beyond Design Basis Accident

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Legend:
- Some / Potential Benefit (yellow)
- Large Benefit (green)

EnCore Fuel Technology Anticipated Roadmap

[ ]d,e

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Lead Test Rod Programs – Byron Unit 2

- Two 17x17 OFA fuel assemblies
  - 16 rods with chromium-coated cladding
    - 4 rods with ADOPT pellets
  - 4 rods with U_3Si_2 pellets in short segments
    - One ~12 inch segment in each rod
- Completed all design, licensing and delivery
  - Effective interaction with the NRC for approval of LAR

[ ]b,c

NRC Nuclear Regulatory Commission
LAR: Licensing Amendment Request

Westinghouse

EnCore® fuel LTRs delivered
Featuring three out of four technologies

Lead Test Rod Programs – Byron Unit 2

- Assemblies operating since April 2019

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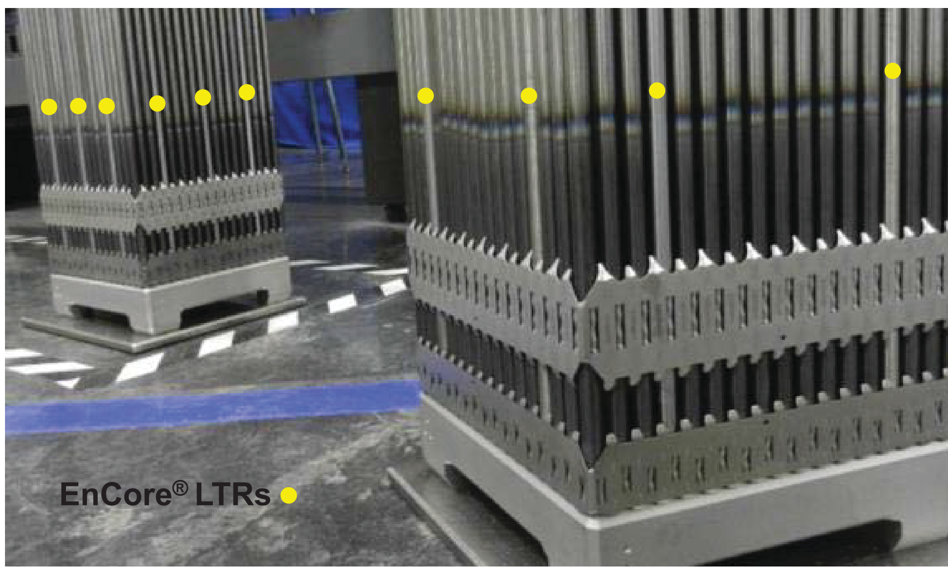
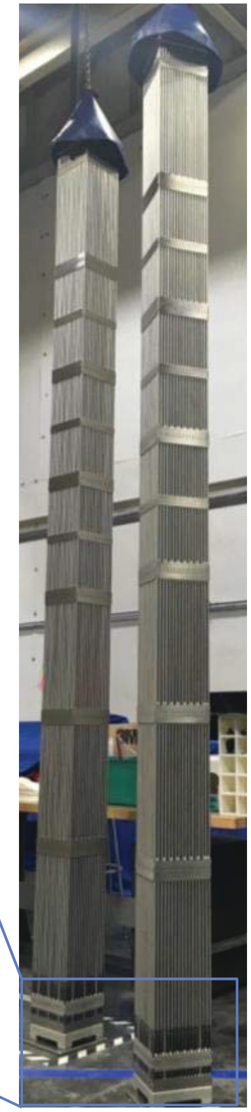




Lead Test Rod Programs – [ ]d,e

[ ]d,e

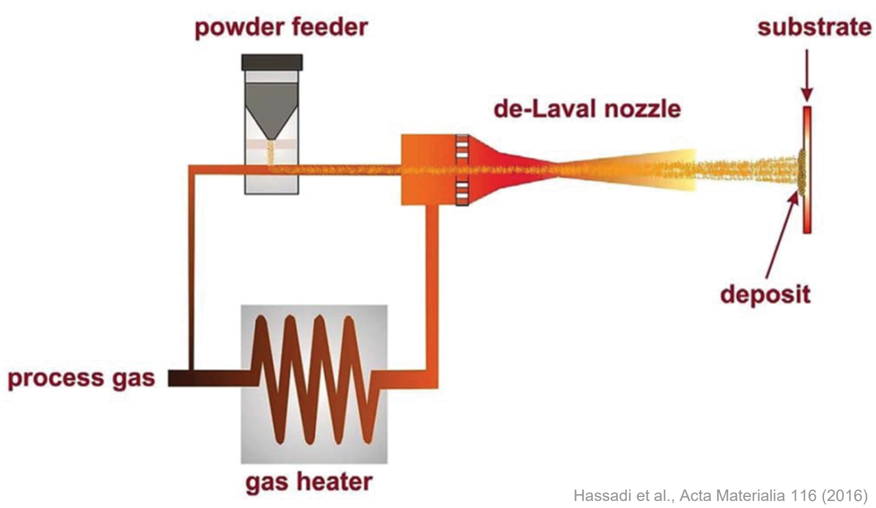
Near-term Technologies

Chromium-coated Cladding

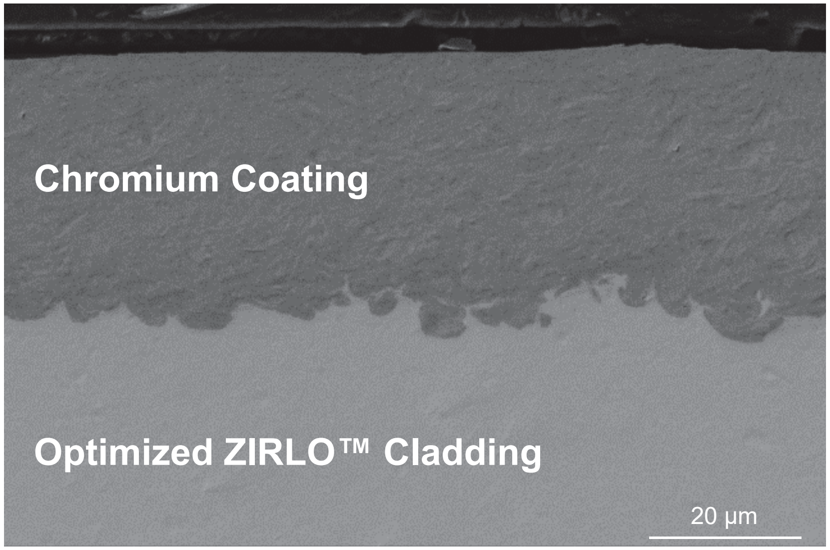
ADOPT Fuel

Chromium-coated Cladding

- Thin adherent and dense chromium layer
- Substrate cladding unchanged
- Cold spray as deposition technology



Hassadi et al., Acta Materialia 116 (2016)



As-fabricated Chromium-coated Zirconium Cladding

Chromium-coated Cladding – Status

[ ]b,c

Preparing licensing framework for first region in the US by 2023

Westinghouse

Chromium-coated Cladding – Irradiation Experience

[ ]b,c

Chromium-coated Cladding – Manufacturing (1)

- Coating and polishing of full length tubes qualified

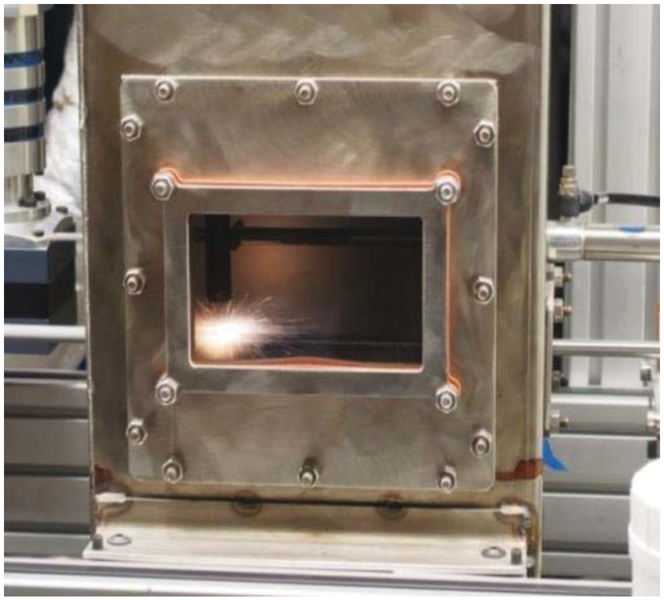
[ ] b,c

Advancing manufacturing processes for industrial scale-up

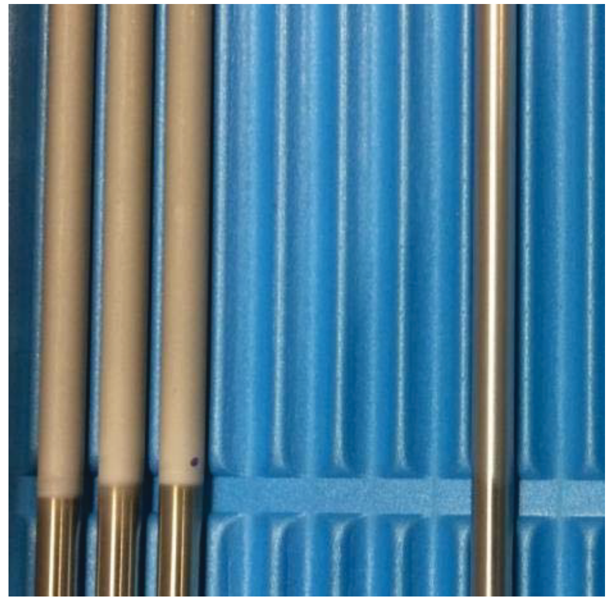
Chromium-coated Cladding – Manufacturing (2)

b,c

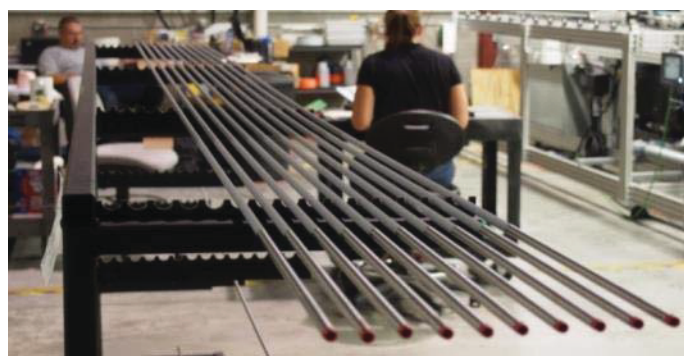
Chromium-coated Cladding – Manufacturing (3)



Cold Spray of Full Length Tube



Coated Tubes Before and After Polishing



Batches of Coated Tubes

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Coated Cladding Improvement – [ ]b,c

[ ]b,c

ADOPT™ Fuel – Benefits

- Higher density
  - Up to 10 kg additional uranium per assembly
- Lower transient fission gas release
- Better oxidation resistance (in presence of air and water)
- Increased PCI margins at high temperatures
  - Higher fuel creep rate to mitigate PCMI (softer pellet)

[ ] b,c

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PCI: Pellet-Cladding Interaction
PCMI: Pellet-Cladding Mechanical Interaction

ADOPT™ Fuel – Status

- Manufacturing capability ready

[ ] b,c

ADOPT fuel is a mature technology ready for delivery

Development of Advanced Technologies

U_3Si_2 and Other Advanced Pellets

SiC Cladding

Multi-scale Modeling

In-rod Sensors

Westinghouse

Material Property Benefits and Limitations of U_3Si_2

+ High uranium density
  - Pure U_3Si_2 has 17% higher U density than UO_2
  - Enables longer cycles or lower enrichments to support current cycle lengths
  - Stays within current enrichment limit (<5%)

+ High thermal conductivity
  - Lower fuel centerline temperature
  - Lower fission gas release

- Low melting point (1665°C compared to 2800°C for UO_2)

[ ] b,c

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U_3Si_2 and [ ]d,e

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Westinghouse

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Westinghouse

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Advanced Pellets – Moving Forward

[ ] b,c

Silicon Carbide Cladding – Benefits

- Fuel cycle cost
  - Lower cross-section than coated Zr
    - Effect of lower thermal conductivity under evaluation
  - Eliminates fretting wear risk
    - Rod-to-grid wear needs evaluation
  - Higher rod internal pressure margins
  - Longer burnups and fuel cycle length
  - Enables flex power operation
- Best accident tolerance
  - No ballooning or burst
    - SiC retain strength up to 1750°C
    - Minimum fuel dispersal
  - May tolerate fuel melting
  - Best oxidation resistance in steam over 1900°C
    - May have saved TMI-2 and Fukushima reactors

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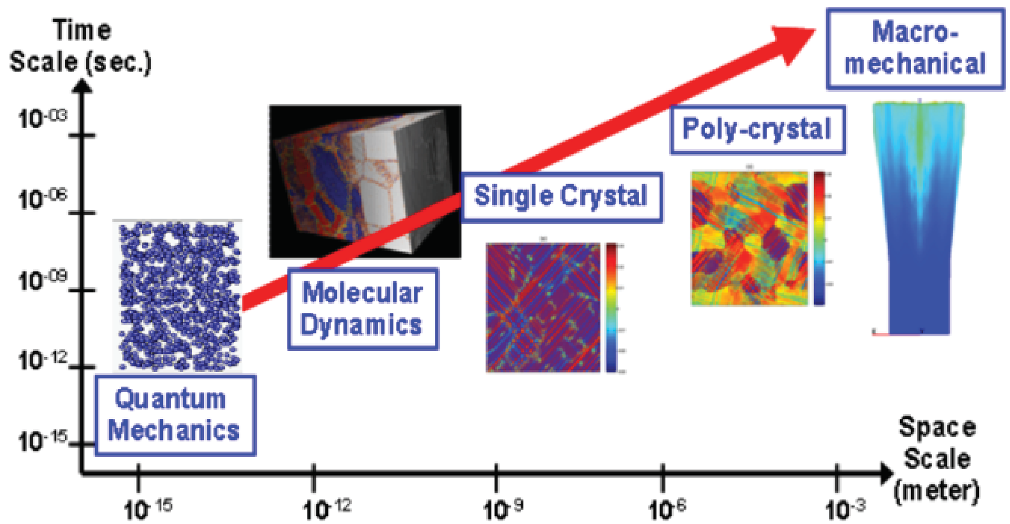
GENERAL ATOMICS

SiC Cladding – Systematic Evaluation

b,c

Atomistic Modeling – Description

- Use of computational models to mimic the behavior of a complex system by considering its atoms
- A range of methods modeling atoms in various larger systems (molecules, crystals, etc.)
- Atomistic modeling is a part of small-scale modeling



https://www.researchgate.net

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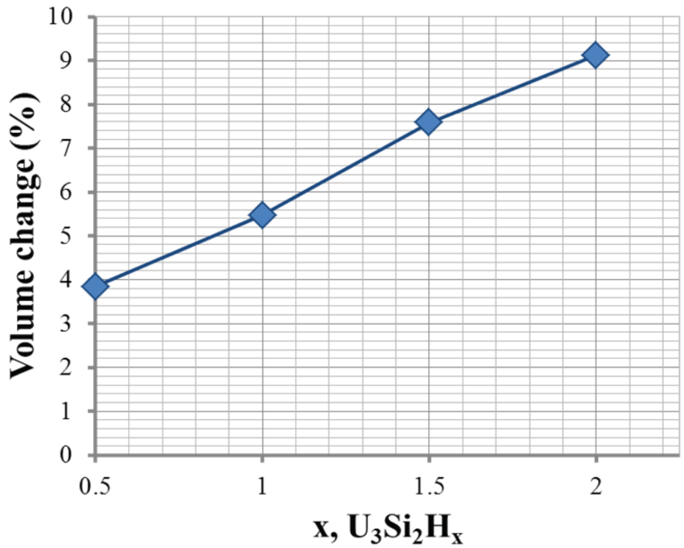
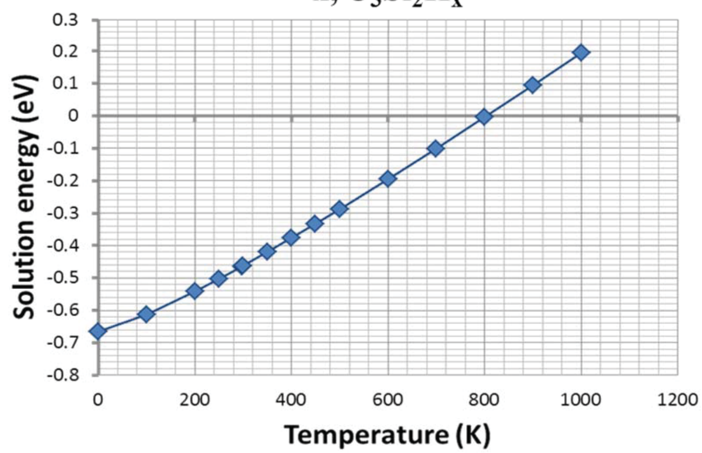
Atomistic Modeling – Application





Middleburgh et al. (2018)

- U_3Si_2 was experimentally observed to absorb H and have a volume increase
- Atomistic modeling
  - showed where the H atoms were staying
  - allowed calculation of volume change
  - Reproduced the release temperature

An unexpected experimental result was explained, with potential engineering applications

Advanced Modeling Applications

- Assist in understanding experimental results
  - Mechanistic treatment of experimental data points
  - Help to derive FRD models (to be validated on experiments)
- Materials screening
  - Prediction of material behavior
  - Rare or not yet commercially available materials accessible
- Design of experiments
  - Ensure selected conditions highlight phenomena of interest
  - Evaluate behaviors in extreme conditions (i.e. high burnup)

FRD: Fuel Rod Design

Atomistic and multi-scale modeling enables accelerated development of new materials

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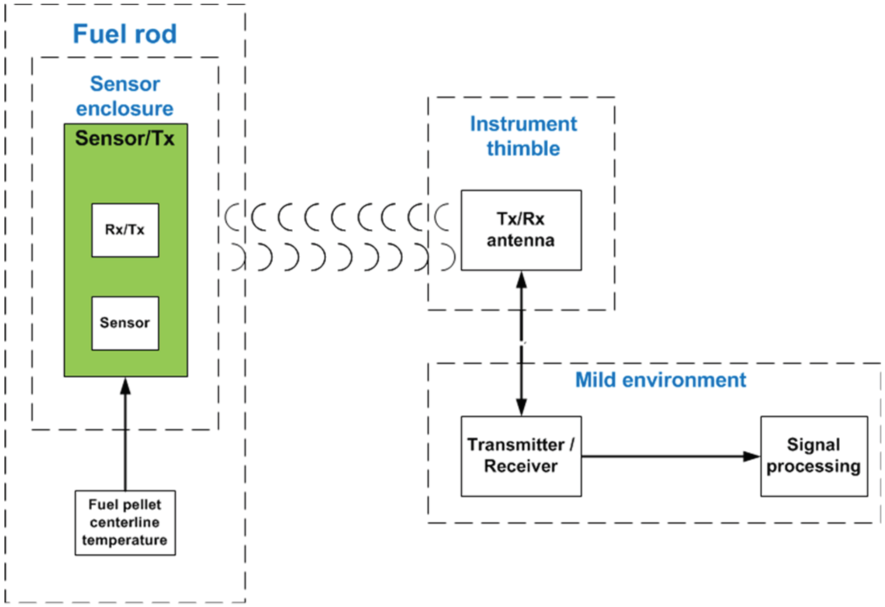
In-rod Sensors

- Wireless sensor inside the fuel rod transmitting real-time data
  - Centerline temperature, fuel elongation and internal pressure
- Sensor and reference circuits operating at different frequencies.
  - Resolve in the frequency domain



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In-rod Sensors - Testing

[ ] b,c

Irradiation Test Results (MITR)

b,c

Licensing Framework for EnCore ATF Technologies

Licensing Framework – Chromium-coated Cladding

- Preparing licensing submittal for US NRC
  - Targeting submittal of topical report by [ ]d,e
- Phenomena Identification and Ranking Table (PIRT)
  - Westinghouse was observer in PIRT led by NRC
  - [ ]d,e
- Following development of Interim Staff Guidance (ISG)

[ ]d,e

2019 Topical Report Submittal Plan (1)

[ ]d,e

2019 Topical Report Submittal Plan (2)

[ ]d,e

Licensing Framework – ADOPT™ Fuel (1)

[ ]d,e

Licensing Framework – ADOPT™ Fuel (2)

[ ] d,e

Partnerships and Collaboration

US Department of Energy (DOE) program
Frame Cooperation Agreement (FCA) with ENUSA
CARAT
UK Nuclear Innovation Program
NEI/EPRI evaluation of benefits

DOE Program

- Westinghouse received a $93.6M award
  - From October 2018 to January 2021

[ ] d,e

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U.S. DEPARTMENT OF ENERGY

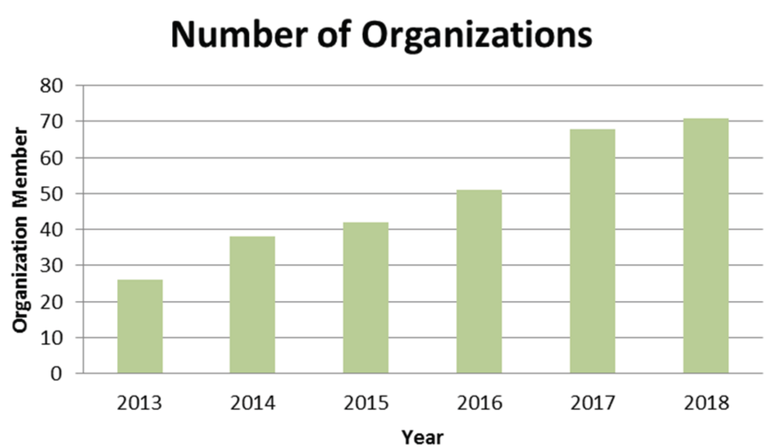
Westinghouse Non-Proprietary Class 3

[ ]d,e

[ ]d,e

CARAT

- Collaboration for Advanced Research on ATF
- Fosters collaboration and partnership, led by Westinghouse
- Industry, universities and research institutions worldwide
  - Coordination with global activities (OECD-NEA)
- Fundamental research on ATF technologies
  - Exponential increase in impact of R&D funding
- Recent meetings with wide participation
  - Prague September 2018
  - Cambridge March 2019



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[ ]b,c

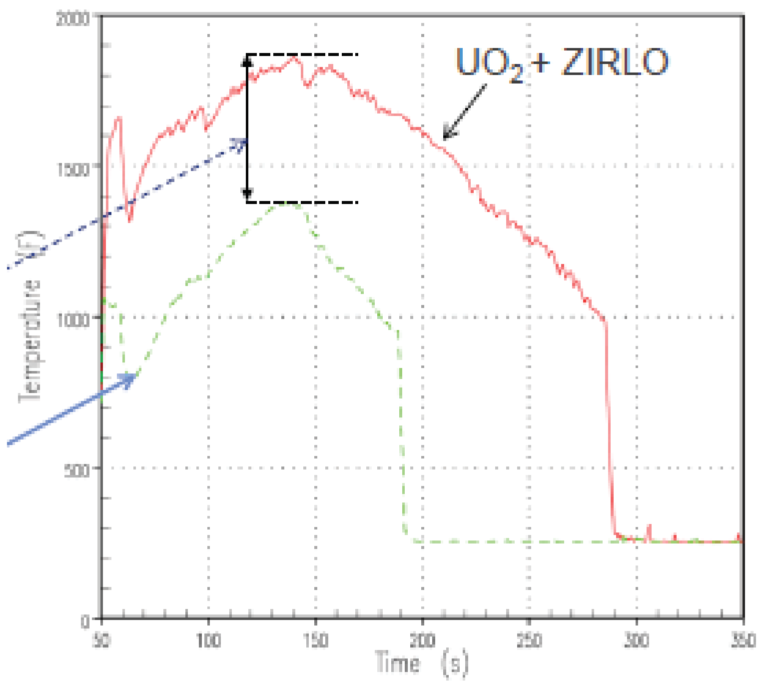
NEI/EPRI – Evaluation of Benefits

- Reports on evaluation of benefits issued by NEI and EPRI
- Performance of ATF under BDBA, DBA and AOO
- Capable of preventing core damage in severe accidents
  - If coupled with simple operator mitigating actions
- Benefits in DNB and LOCA scenarios

Peak Cladding Temperature (PCT) in Large Break LOCA (LBLOCA)

~280 ºF PCT margin

Coated Cladding + U_3Si_2 pellet



AOO: Anticipated Operational Occurrences

Summary

- EnCore® fuel technologies supporting industry demand

[ ] d,e

- Continuous improvement of technologies
  - Manufacturing optimization for near-term technologies
  - Product performance improvement for advanced technologies
- Preparation of licensing framework continues
  - Constant communication with NRC

[ ] d,e

EnCore® Fuel

We're changing nuclear energy ... again

Westinghouse

High Burnup / High Enrichment Activities

Zeses Karoutas, Chief Engineer
Innovation, Technology & Exploration

Jeff Norrell, Director
Global Product Management

Westinghouse

Agenda

- Burnup Extension Program
  - [ ]a,c
- High Burnup/Enrichment "Pilot Plant" Initiative

Burnup Extension Program

- Step 1: Increase burnup limit for rods which do not rupture to [ ]a,c
  - Preliminary technical exchange with NRC held on 6/27/19
  - Submittal by [ ] a,c
- Step 2: Increase burnup limit for entire core to [ ] a,c
  - Approval targeted by [ ] a,c

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Burnup to [ ]a,c

- Lower power assemblies
  - No cladding burst under LOCA / RE accident conditions
- Current fuel products
  - **ZIRLO**® cladding / **Optimized ZIRLO**™ cladding
  - UO_2 fuel pellets
- Average rod burnup limit of [

  ] a,c
- Limit on assembly and rod power for assemblies as a function of burnup
- Implementation will require plant specific analyses

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Burnup to [ ]a,c

- Customers have expressed interest to higher rod burnups [ ]a,c and longer cycles for the entire core
- Need higher enrichment > 5 w/o to achieve these burnups economically
- Will work together with EPRI on the research to achieve higher burnup, and others to obtain data; INL, Studsvik, etc
- Will leverage as much as possible the work performed for German plants to achieve higher rod burnup [ ]a,c
- Advanced fuel technology will help achieve the higher rod burnup

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Submit High Burnup Topical [ ]a,c

High Burnup/High Enrichment Efforts

- "Pilot Plant" concept stems from Nuclear Strategic Issues Advisory Committee (NSIAC) interest in accelerating loading of ATF
- ATF features can be leveraged to enable high burnup/high enrichment fuel management strategy options
- High burnup/enrichment can result in fuel cost benefit
- Potential back-end storage benefit (reduced number of assemblies requiring storage)
- Promotes industry adoption of ATF technologies

Westinghouse is actively evaluating technical options and licensing strategies

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"Pilot Plant" Initiative

- Current strategy/goals:

[ ]a,c

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Closing

- ATF, High Burnup, High Enrichment programs are industry priority
- Viable paths exist to implement
- Challenges are recognized and can be managed effectively
- Frequent, open communication and collaboration will be needed for success

Westinghouse BWR Fuel Performance and Methods Update

Michael Boone

Product Manager

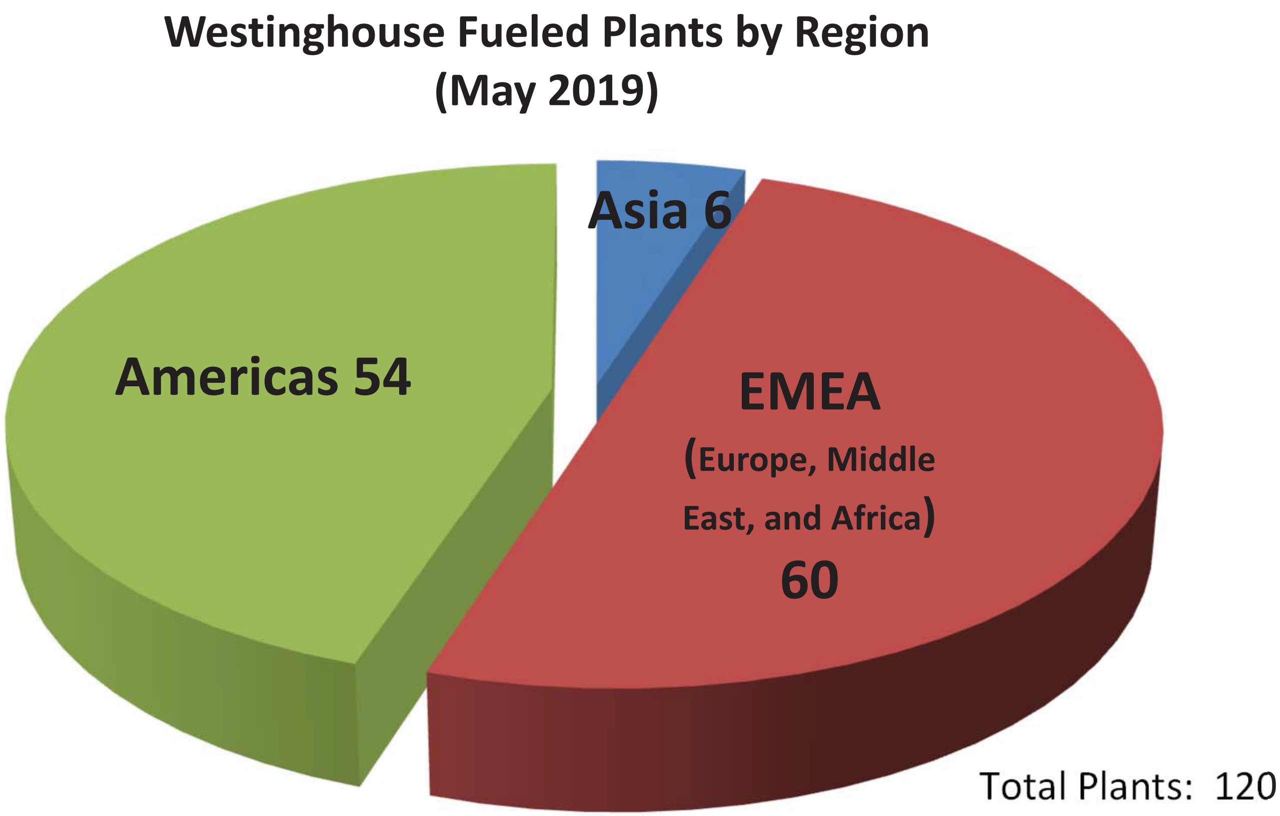
USBWR and EnCore® Fuel

Westinghouse

Outline

- **BWR Fuel Performance Overview**
  - [ ]a,c
- Debris Leaker Elimination Initiative
- **TRITON11**TM Fuel Development
- BWR Channel Performance
- Control Rod Blade Update
- BWR Methods Update

Westinghouse Fueled Plants by Region



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

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BWR Primary Failure Statistics
10X10 BWR Fuel Designs using liner cladding

a,c

BWR Global Nuclear Fuel Reliability Progress – May 2019

a,c

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BWR EMEA Nuclear Fuel Reliability Progress – May 2019

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PCI protection: Westinghouse Zr-Sn Liner Experience

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Recent Westinghouse BWR Leakers

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Westinghouse BWR Leaker Causes

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Summary

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QUESTIONS?

Outline

- BWR Fuel Performance Overview
  - [ ]a,c
- Debris Leaker Elimination Initiative
- TRITON11™ Fuel Development
- BWR Channel Performance
- Control Rod Blade Update
- BWR Methods Update

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Summary

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Development of Improved BWR Fuel Debris Filter

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Remaining Challenge for Westinghouse BWR Fuel: Eliminate Debris Fretting Leakers

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Improved BWR Debris Filter Testing Methodology

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Benchmark Testing of TripleWave+ (TW+)

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Westinghouse Non-Proprietary Class 3

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Further Improvements of BWR Fuel Debris Filter

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BWR Coated Cladding Initiative

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Summary

- Debris Fretting Leaker Elimination project is ongoing and is highly prioritized

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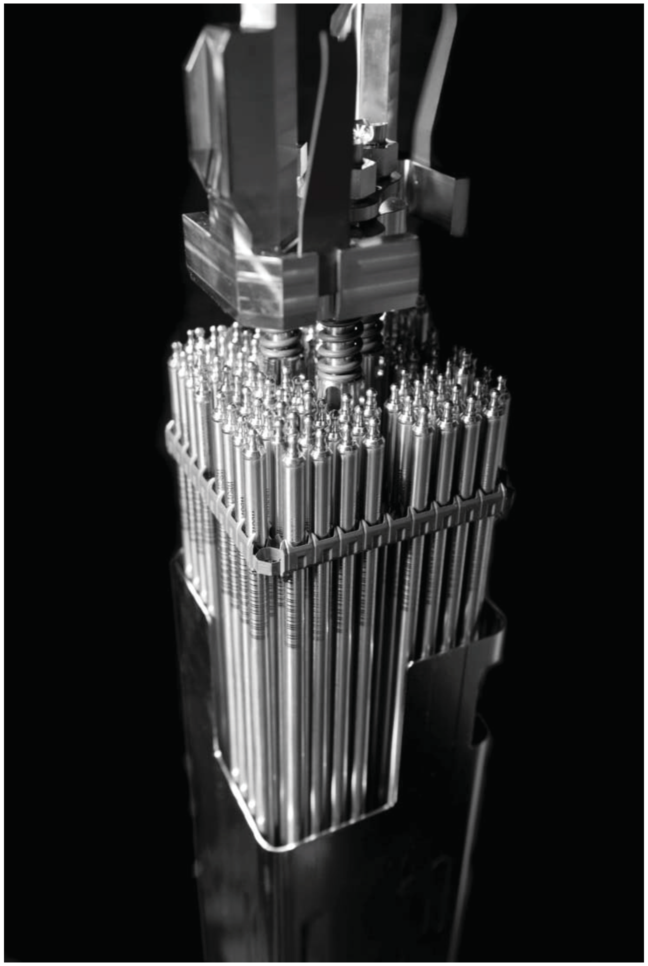
TRITON11 Westinghouse 11x11 BWR Fuel Design



Next Generation BWR Fuel with

- ***Superior Fuel Economy***
- ***Robust Mechanical Design***
- ***Uncompromised Reliability***
- ***High-Performing Materials***
- ***State of the Art Methods***

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TRITON11 Superior Fuel Economy

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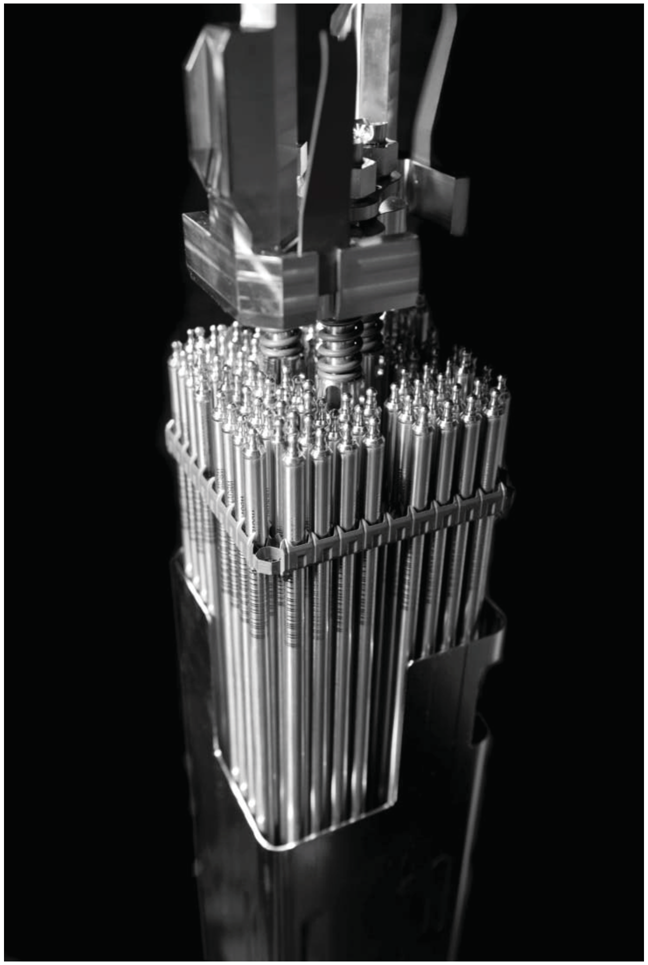

TRITON11 – Robust Mechanical Design

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TRITON11 Innovation Overview

The greatest W-BWR fuel development leap since early 1980's

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TRITON11 Innovation Overview

The greatest W-BWR fuel development leap since early 1980's

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Assembly of the 1st commercial TRITON11 Fuel Bundle complete [ ] a,c

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Inspection in [ ] a,c

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[ ] a,c Channel Performance Visual Inspection

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Performance of Low-Tin ZIRLO Channels
Channel Bow

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Performance of Low-Tin ZIRLO Channels
Channel Bow

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Performance of Low-Tin ZIRLO Channels
Channel Bow

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Performance of Low-Tin ZIRLO Channels Growth

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Westinghouse Deliveries of Low Tin ZIRLO BWR Channels

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Performance of Low-Tin ZIRLO Channels
Channel Bow

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High Performance Control Rod, CR 99/CR 99+

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Main Objective – Safety and Reliability

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Mid-duty Control Rod CR 82M-1

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Control Rod Deliveries

In Total Since First CRBs in 1970 (Dec 2018)

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Control Rod Deliveries by Type (Dec 2018)

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CR 99/CR 99+ Deliveries (Dec 2018)

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Control Rod Deliveries (Dec 2018)

Distribution per Type and Country

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Westinghouse BWR Methodology USNRC-licensed package

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BWR Methods – US NRC Licensing Status

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BWR Methods – US NRC Licensing Status (cont.)

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BWR Methods – US NRC Licensing Status (cont.)

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Status of Development Projects

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USNRC Licensing Topical Reports - in support of TRITON11, [ ] a,c

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Westinghouse Non-Proprietary Class 3

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