Enclosure 3

2021 Westinghouse Fuel Performance Update Meeting Slide Package

(Non-Proprietary)

(215 pages Including Coversheet)

September 2021
Welcome and Regulatory Update

Anthony Schoedel
Manager, eVinci™ Licensing and Configuration Management
## Agenda

<table>
<thead>
<tr>
<th>Description</th>
<th>Start Time</th>
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<tr>
<td>Welcome &amp; Opening Remarks - Anthony Schoedel</td>
<td>8:30 AM</td>
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<tr>
<td>CE Reconstitution - Jeff Brown</td>
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<td>Machine Learning - Emre Tatli</td>
<td>9:10 AM</td>
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<tr>
<td>ATF – Kallie Metzger</td>
<td>9:40 AM</td>
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<tr>
<td>BREAK</td>
<td>10:40 AM</td>
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<td>PWR Codes/Methods, Innovations, HEHB – Cenk Guler</td>
<td>10:50 AM</td>
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<td>AXIOM - Andrew Atwood</td>
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<td>LUNCH</td>
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<td>PWR fuel performance – Jason Smith</td>
<td>1:20 PM</td>
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<td>BWR fuel performance – Uffe Bergmann &amp; Jean-Marie LeCorre</td>
<td>2:05 PM</td>
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<tr>
<td>BREAK</td>
<td>2:50 PM</td>
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<tr>
<td>PRIME – Brian Millare</td>
<td>3:00 PM</td>
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<td>Additive manufacturing – Dave Huegel</td>
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<tr>
<td>ADJOURN</td>
<td>4:30 PM</td>
</tr>
</tbody>
</table>
Show Respect For Others
Follow The Rules
Stop When Unsure
Promptly Report Problems
My Signature Is My Word
CE Fuel Assembly Reconstitution Topical Supplement (CENPD-289)
CE Reconstitution Topical (CENPD-289)

- CENPD-289 describes methodology for analysis of reconstituted Westinghouse fuel containing inert replacement rods in Combustion Engineering plants
- Submitted in response to GL 90-02 which required NRC approval for methods used to analyze core configurations containing “inert” rods
  - Conservatism of DNB methodology was a primary concern
- Similar submittals were made by other fuel vendors
CE Recon Topical
CE Reconstitution Topical
CE Reconstitution Topical

• Unresolved RAIs related to application of the CE Critical Heat Flux (CHF) correlation to configurations involving large numbers of inert rods resulted in the NRC SER giving approval to only Class A configurations
  – SER restriction was accepted by CE customers in order to perform recons in upcoming reloads
  – Was not a major concern at the time since rod swaps could be performed to meet Class A restrictions in most cases
• Note that the topical itself did not limit application to non-Class A requirements
CE16NGF Reconstitution Requirements

- Applicability of CENPD-289 to CE16NGF was approved in WCAP-16500-P-A
- The new features of CE16NGF supports relaxation of the SER limits for recon
CE Reconstitution Topical

• The CENPD-289 SER Restriction has resulted in several adverse consequences
  – It has resulted in the premature discharge of assemblies which has in some cases resulted in increased power peaking and core power tilts due to the asymmetric core redesign as well as fuel cost penalties
  – It has prevented implementation of fuel leaker risk reduction initiatives, such as placing inert rods in high risk locations adjacent to core shroud or in damaged grid cells as a protective measure
  – The rods swaps required to comply with current Class A constraints require that more rods be removed and reinserted resulting in an increased risk of fuel damage
• Elimination of this restriction would have direct operations, safety, and fuel cost benefits
CE Reconstitution Topical Revision

• To remedy this situation Westinghouse will submit a supplement to CENPD-289 for regulatory approval that will allow exemptions to the Class A restrictions, to relax restrictions on where inert rods can be placed in CE16NGF assemblies.

• Additional DNB test data will be presented to demonstrate conservatism of current CE16NGF CHF correlations for inert rod configurations and that mixing vanes reduce the CHF cold wall effect.

• Supplement would also utilize general conclusions from W-NSSS Recon topical WCAP-13060-P-A
  – CE16NGF has same rod and similar mixing vanes as the WEC RFA fuel described in WCAP-13060-P-A.

• Targeting submittal by July 2022.

• Waterford has indicated desire to be lead plant for this update.
Questions/Discussions?
DNB Predictive Modeling Using ML Technology

Emre Tatli

September 2021
Westinghouse VISION & VALUES

together
we advance technology & services to power a clean, carbon-free future.

- Customer Focus & Innovation
- Speed & Passion to Win
- Teamwork & Accountability

Safety • Quality • Integrity • Trust
Outline

• Background
  – Departure from Nucleate Boiling (DNB)
  – Machine Learning (ML)

• Application of ML to DNB Predictive Modeling
  – Process
  – Initial Results
Departure from Nuclear Boiling (DNB)

- DNB – PWR Specified Acceptable Fuel Design Limit (SAFDL) to prevent fuel cladding overheating
- DNB heat flux is also referred to as Critical Heat Flux (CHF)
- Margin to DNB is quantified as DNB Ratio (DNBR)
  \[ \text{DNBR} = \frac{\text{Predicted CHF}}{\text{Local Heat Flux}} = \frac{P}{M} \]
Recent Challenges in DNB Testing & Modeling

• [a,c]
  – Resolution of NSAL-14-5, “Lower Than Expected Critical Heat Flux Results Obtained During Departure from Nucleate Boiling Testing”
  – [a,c]a,b,c
DNB Correlation Development Process

- For PWR design applications, DNB predictive model is currently determined empirically based on test data for complicated fuel assembly component designs
  
  [a,c]
Machine Learning (ML) Tool Overview

- Current Westinghouse ML tool kit
  - [ ]
  - [ ]

- ML tool provides new capabilities for DNB modeling
  - [ ]
  - [ ]
  - [ ]
  - [ ]

- ML technology is being applied in Westinghouse in support of plant design and fuel manufacturing operations
ML-Based DNB Correlation Development

• Database [a,c]
  – Original tests [a,c]
  – New tests [a,c]

• Input parameters [a,c]
  – [a,c]
  – [a,c]

• Predictive model tested and evaluated in accordance with current practices and guidelines
  – NUREG-KM-0013 (Draft) reviewed
  – Available algorithms and optimization schemes explored
  – [a,c]
  – [a,c]

• Sensitivity check for Physics-Informed ML model
Data Description Table

<table>
<thead>
<tr>
<th>a,b,c</th>
</tr>
</thead>
<tbody>
<tr>
<td>a,c</td>
</tr>
<tr>
<td>a,b,c</td>
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</table>

LTR-NRC-21-26, Enclosure 3
Initial ML Model & Results

- [ ]_{a,c}
- [ ]_{a,c}
- [ ]_{a,c}
- [ ]_{a,c}
- [ ]_{a,c}
- [ ]_{a,c}
“PIML” Sensitivity Check

- Physics informed model sensitivity checks ensure CHF predictions consistent with physical behaviors
  - [a,c]
  - [a,c]
Summary

- ML is being applied to develop new DNB correlation [ ]

- Initial results are [ ]

- Work continues to improve the correlation development process through ML
QUESTIONS/COMMENTS?
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Westinghouse EnCore® Licensing Plans

Kallie Metzger, Ph.D.
ATF Technology
Presentation to NRC, September 22, 2021
Outline

Goal: Communicate the ongoing ATF strategy and anticipated licensing interactions

Agenda:
- Westinghouse EnCore® Fuel Program
- High Burnup Program Overview
- ADOPT™ Updates
- Coated Cladding Updates
- High Burnup Updates
- Topical Licensing Status
- Potential Technologies to Accelerate Development & Licensing
Westinghouse’s EnCore® Fuel Program

The EnCore® Fuel program is developing and commercializing advanced fuel products to improve safety and economic performance.

Advanced Cladding
- [Coated Zr Cladding]
- Silicon Carbide Cladding

Advanced Fuel
- ADOPT™ fuel pellets
- Advanced Pellet (UN)

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High Energy Fuel Product and Voice of the Customer

Right products at the right time to meet customer needs
2021 Goals and Accomplishments

- **Licensing**
  - Respond to RAIs for High Burnup to 68 GWd/MTU and ADOPT Topicals
  - Preparing input to Coated Cladding Topical
  - Preparing input to High Burnup Topical to \([\text{ ]}\)^a,c
  - Work on Alternative Licensing Methods and FFRD (EPRI CRAFT)
  - High Enrichment Limit Licensing Impact

- **LTR / LTA programs**
  - Fuel Assembly ATF LTA program
  - Move forward on other LTR / LTA programs

- **Data Needs**
  - Irradiated Fuel Shipment to ORNL (this is critical to supporting our schedule for obtaining data for topicals)
  - Work with Labs, Universities and Hot Cells on tests to support ATF and High Burnup
  - Work with EPRI CRAFT Fuel Performance and Testing Working Group

- **Methods**
  - Update methods and codes for high burnup implementation
  - Work with EPRI CRAFT Guidance and Analysis Working Group
  - Work on Accelerated Fuel Qualification, leveraging lower length scale modeling & use of wireless fuel sensors

- **Manufacturing**
  - Scale up for ADOPT pellet and Coated Cladding production
  - Address impact of enrichment > 5 wt% on manufacturing facilities, transport, on site storage and back end
ADOPT

WCAP-18482
ADOPT Overview

ADOPT Characteristics

- **ADOPT** (Advanced DOped Pellet Technology) fuel is a standard UO₂ fuel that has been doped with [a,c]
- The additives facilitate densification and diffusion during sintering resulting in a higher density and enlarged grain size compared to undoped UO₂.

ADOPT Market Interest

LTR-NRC-21-26, Enclosure 3
ADOPT – Forecasted Timeline
Coated Cladding
Coated Cladding Overview

• Coated Cladding Characteristics
  – Thin [ ]^{a,c} coating applied to fuel cladding
  – [ ]^{a,c} coated cladding will provide reduced corrosion, oxidation, improved ballooning/burst performance, and improved wear resistance.
  – Demonstration of manufacturability and performance [ ]^{a,c}

• Coated Cladding Market Interest
  [ ]^{d,e}
Lead Test Rod and Lead Test Assembly Programs

- **Byron 2**: inserted Spring 2019
  - Two 17x17 assemblies
  - 16 rods with Cold Spray [ a,c ]
  - Coated Cladding
    - 4 rods with ADOPT™ pellets
  - 4 rods with U₃Si₂ pellets in 12” segments
  - Poolside PIE completed October 2020
- **Doel Unit 4**: inserted Spring 2020
  - Four 17x17 RFA XL assemblies
  - 32 rods with Cold Spray [ a,c ]
  - Coated Cladding with UO₂
- **Other LTRs/LTAs planned for 2022 and 2023 incorporating Coated Cladding, ADOPT pellets**

- **Byron 2 LTAs**
  - As fabricated
  - After 1 cycle
    - Limited apparent crud accumulation (easily brushed off)
    - No significant oxidation
    - No deformation
    - No apparent wear
Coated Cladding – Forecasted Timeline
High Burnup

WCAP-18446-P
Industry Interest in improved Fuel Cycle Economics can be achieved with Higher Burnup and Longer Fuel Cycles

Step 1: Increase burnup limit to ~68 GWd/MTU
- Increase Burnup to 68 GWd/MTU
  - Submitted Incremental burnup topical report to NRC
  - Provides higher burnup benefits to customers sooner

Step 2: Increase burnup limit for entire core to [a,c with enrichment increase]
- Increase Burnup to [a,c]
  - Leverage advanced fuel products using >5% enrichment
  - DOE support for High Burnup / High Enrichment within the ATF program
  - Work with EPRI CRAFT program on Alternate Licensing Methods and consequences of fuel rod fragmentation and dispersal (FFRD)

Develop & deliver 24-month cycles to meet market demand by mid-2020’s
Step 1 – Incremental Burnup Increase
Rod Average Burnup Limit of 68 GWd/MTU

• Applicable to current fuel products and current enrichments
• Demonstrate fuel designs can meet design criteria under extended burnup planned fuel cycles
• Address science behind rule changes for:
  – LOCA (Proposed 50.46c)
  – RIA (RG 1.236)
Step 2 – Increase rod burnup limit to [a, c] and enrichment to > 5 wt%  

- Continue to expand database for high burnup fuel
- Demonstrate fuel designs can meet criteria with higher enrichment under extended burnup planned fuel cycles  
  - Leverage advanced fuel products
- Address fuel fragmentation, relocation and dispersal (FFRD)
- Address impact of enrichment > 5 wt% on manufacturing facilities, transport, on site storage and back end

Step 2, Westinghouse has a dedicated, multidiscipline team focused on this effort
Incremental High Burnup ~68 GWd/MTU – Forecasted Timeline
Licensing Status of Submitted Topicals
ATF Milestones
Novel Approaches May Accelerate Development & Licensing
High Energy Fuel & PWR Core Methods for Fuel Performance Update Meeting

Cenk Güler
Manager, High Energy Fuel Technology
September 2021

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Outline

• Customer Interest in High Energy Fuel (HEF)
• High Energy Fuel Product
• HEF Roadmap
• Topicals
  
  d,e

• High Burnup Topical Content
Customer Interest in HEF
High Energy Fuel Product

Right products at the right time to meet customer needs
Industry Interest in improved Fuel Cycle Economics can be achieved with Higher Burnup and Longer Fuel Cycles

**Step 1: Increase burnup limit for rods in peripheral assemblies to ~68 GWd/MTU**

- Increase Burnup to 68 GWd/MTU
  - Submitted Incremental burnup topical report to NRC
  - Provides higher burnup benefits to customers sooner

- Increase Burnup to [ ]
  - Leverage advanced fuel products using >5% enrichment
  - DOE support for High Burnup / High Enrichment within the ATF program
  - Work with EPRI CRAFT program on Alternate Licensing Methods and consequences of fuel rod fragmentation and dispersal (FFRD)

Develop & deliver 24-month cycles to meet market demand by mid-2020’s
High Enrichment Lead Assembly Fabrication and Licensing
Overall High Energy Fuel Roadmap
Paragon 2 and Nexus Topicals

- WCAP-16045 Addendum 2 “Updated NEXUS Cross-Section Methodology”
- WCAP-18443 “Qualification of the Two-Dimensional Transport Code PARAGON2”

- We appreciated the timely review process for both topicals by the NRC

- These methods are going to allow Westinghouse to model >5% enrichment and High Burnup conditions to support future ATF programs across the industry
Fuel Performance Topical
FSLOCA™ Evaluation Methodology
High Burnup Topical Report
Plans for Consequence Assessment of Fuel Dispersal
High Burnup Topical Report
RIA Criteria (RG 1.236)

• Reactivity Insertion Accident (RIA) also referred to as Control Rod Ejection (RE) or CEA Ejection accidents

• New RIA criteria issued as Regulatory Guide (RG) 1.236 in June 2020

• Westinghouse is implementing RG 1.236 for High Energy Fuel (HEF)
  – ADOPT fuel pellets (WCAP-18482-P)
  – AXIOM cladding (WCAP-18546-P)
  – Incremental burnup to 68K (WCAP-18446-P)
  – Coated cladding (TBD)
  – Lead Test Rods / Assemblies (LTR/LTA) for rod average burnup to [ ]

LTR-NRC-21-26, Enclosure 3
High Burnup Topical Report
RG 1.236 and New Fuel Product Features

• All criteria in RG 1.236 applicable [\textsuperscript{a,c}]

• [\textsuperscript{a,c}] Pellet-Clad Mechanical Interaction (PCMI) failure threshold

• Implement RG 1.236 for incremental burnup fuel
  - [\textsuperscript{a,c}]
High Burnup Topical Report
RIA Criteria and High Burnup LTR/LTA

• Applicability of RG 1.236 currently limited to rod average burnup of 68 GWd/MTU

• Conservative approach being taken in high burnup LTR/LTA evaluation and core loading plan
  – All RG 1.236 failure thresholds and criteria to be met
  – Confirm [ ]
    • [ ]
    • [ ]
  – [ ]
High Burnup Topical Report
RAVE Methodology

• **RAVE™** methodology documented in WCAP-16259-P-A
  - Applicable to [a,c]
  - Methodology based on coupled multi-physics code system containing USNRC-approved computer codes, such as
    • RETRAN for system transient
    • ANC(K) for 3D neutronic kinetics
    • VIPRE-W for reactor core thermal-hydraulics

• [a,c]
  - Simplified **RAVE** process is referred to as "SAVE"
High Burnup Topical Report
New SAVE Applications

• Simplified **RAVE** process (SAVE) is considered for new applications [ ]

  – [ ]
  – [ ]
  – [ ]

• New applications planned to be included [ ]
FPUM 2021 Technical Update:
Westinghouse AXIOM® Cladding for Use in Pressurized Water Reactor Fuel

September 22, 2021
Introductions and Agenda

• Purpose of the Meeting
• Overview of AXIOM® Cladding
• Licensing Plans
• Summary
Purpose of the Meeting

• Touch base on present review status and progress

• Obtain NRC input and feedback on the licensing topical report submitted for **AXIOM** cladding material in early 2021
Agenda

• Purpose of the Meeting
• Overview of AXIOM Cladding
  – AXIOM in Review
  – Background and History
• Licensing Plans
• Summary
AXIOM in Review

- **AXIOM** cladding: Next generation of robust zirconium alloy targeting very high fuel duties
  - Build on the successes of ZIRLO® and Optimized ZIRLO™ cladding to target increasingly challenging fuel management practices
  - Designed to exhibit improved corrosion resistance, lower hydrogen pick-up, and lower creep and growth
  - Further reduction of Sn, modification of pRXA as well as addition of other alloying elements to improve specific properties

Table 1-1 The nominal chemical composition (%) of AXIOM with ZIRLO and Optimized ZIRLO cladding

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Micro-structure</th>
<th>Nb (%)</th>
<th>Sn (%)</th>
<th>Fe (%)</th>
<th>Cu (%)</th>
<th>V (%)</th>
<th>Zr (%)</th>
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<tr>
<td>ZIRLO</td>
<td>SRA</td>
<td>1</td>
<td>1</td>
<td>0.1</td>
<td>-</td>
<td>-</td>
<td>Bal.</td>
</tr>
<tr>
<td>Optimized ZIRLO</td>
<td>pRXA</td>
<td>1</td>
<td>0.67</td>
<td>0.1</td>
<td>-</td>
<td>-</td>
<td>Bal.</td>
</tr>
<tr>
<td>AXIOM</td>
<td>pRXA</td>
<td>0.7</td>
<td>0.35</td>
<td>0.1</td>
<td>0.12</td>
<td>0.25</td>
<td>Bal.</td>
</tr>
</tbody>
</table>

SRA: Stress-relief annealed  
pRXA: Partially-recrystallized annealed
Background and History

- Material research and optimization for AXIOM cladding development began in 2000, with four major variants identified for further in-reactor testing.
- Poolside and hotcell PIE data from various lead test rod programs as well as extensive out-reactor characterization program.
- The final AXIOM cladding composition was selected in 2015 based on best overall performance to ensure that all operating requirements were considered.
- Production size ingot with the final AXIOM composition has been melted and the fabrication processes including the tube and assembly fabrications have been qualified.
- Eight full AXIOM Lead Use Assemblies are currently being irradiated at Millstone now in their 3rd cycle of operation.

AXIOM is progressing through licensing and looking forward to region implementation.
Agenda

• Purpose of the Meeting
• Overview of AXIOM Cladding
• Licensing Plans
  – Applicable Regulations and NRC Guidance
  – Path to Compliance
  – Timeline of Key Activities
• Summary
Applicable Regulations and NRC Guidance

**AXIOM** cladding will be generically applicable to current regulatory requirements

- General Design Criteria (GDC) provide the minimum design requirements for LWRs
  - GDC 10: “The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.”
  - GDC 2 as it relates to seismic design of structures, systems and components
  - GDCs 25, 26, 27, and 28 concerning reactivity control systems to ensure fuel design limits are met and capability to cool the core is maintained
  - GDC 35 as it relates to core cooling such that fuel and clad damage would not interfere with cooling and clad metal-water reaction is limited to negligible amounts
- 10 CFR 50.46 as it relates to cooling performance
Applicable Regulations and NRC Guidance (Continued)

- To demonstrate generic applicability, the guidance of Standard Review Plan (SRP), NUREG-0800, has been utilized
  - SRP Section 4.2, “Fuel System Design”
  - SRP Section 4.3, “Nuclear Design”
  - SRP Section 4.4, “Thermal and Hydraulic Design”
  - SRP Chapter 6.2.1, “Containment Functional Design”
  - SRP Chapter 15, “Transient and Accident Analysis”

- Pertinent Regulatory Guides (RG) also used
  - RG 1.236, Reactivity Initiated Accident (RIA) criteria
Path to Compliance

• The submitted topical WCAP-18546-P
  – Provides data demonstrating material properties and in-core behavior
  – Identifies performance boundaries for AXIOM cladding
  – Demonstrates capability to accurately model cladding properties to confirm satisfaction of fuel system safety criteria

• The overall topical approach to demonstrating regulatory compliance is similar to existing NRC-approved zirconium alloys (i.e., ZIRLO and Optimized ZIRLO cladding)
Timeline of Key Activities

- Insertion of first region

Spring 2025
Agenda

• Purpose of the Meeting
• Introduction of AXIOM Cladding
• Licensing Plans
• Summary
Summary and Alignment Strategy

- Coordination of resources with the NRC through heads-up approach via this meeting

We appreciate your time and consideration today.
Westinghouse PWR Fuel Performance Update

September 2021

Jason Smith, Manager
Product Performance Engineering

Fuel Performance info – Charles Haselden
Debris Mitigation info – Michael Conner
Agenda

• Fuel Performance Update

• Changing in Performance Trends
  – Improvements in Debris Mitigation

• [ ] a,c Leaker Investigation

• [ ] a,c Leaker Investigation

• Summary
Westinghouse Fueled Plants by Region

Westinghouse Fueled Plants by Region (August 2021)

- Americas: 49
- Asia: 6
- EMEA (Europe, Middle East, and Africa): 60

Total Plants: **115**

**Global Fuel Reliability Process Required to Achieve and Maintain 100% Leak-Free, Issue-Free Fuel**
Nuclear Fuel Reliability Improvement Progress As Of August 31, 2021
Historical Performance of Westinghouse Fueled Plants
Leaking Plants, August 31, 2021 worldwide
Historical Performance of Plants Currently Leaking
As of August 31, 2021
Historical Trend in Number of Leaking Fuel Rods
Agenda

• Fuel Performance Update
• Changing in Performance Trends  
  – Improvements in Debris Mitigation
• [ ] \( a,c \) Leaker Investigation
• [ ] \( a,c \) Leaker Investigation
• Summary
Changing in Performance Trends (PWR)
Advanced Debris Protection Program
PWR Filter Improvements:
1. Advanced Debris Filter Bottom Nozzle (ADFBN)
Nozzle Skirt Design Details
Final ADFBN – Design Criteria Met
Debris Test Details
FACTS-DS Test Results
PWR Filter Improvements:
2. Additive Manufactured Bottom Nozzle (AM BN)
AM BN Filter:
AM BN Primary Design Criteria are met
Debris Filtering Test: AM BN
Agenda

• Fuel Performance Update
• Changing in Performance Trends
  – Improvements in Debris Mitigation
• [                  ] a,c Leaker Investigation
• [                               ] a,c Leaker Investigation
• Summary
W 14x14 Fleet Fuel Performance Status
a,c Outage Prep
[ ]^{a,c} Fuel Failure Contingency Measures
Agenda

- Fuel Performance Update
- Changing in Performance Trends
  - Improvements in Debris Mitigation
- [ a,c Leaker Investigation
- [ ] a,c Leaker Investigation
- Summary
Agenda

• Fuel Performance Update
• Changing in Performance Trends
  – Improvements in Debris Mitigation
• [ ] \(^{a,c}\) Leaker Investigation
• [ ] \(^{a,c}\) Leaker Investigation
• Summary
Summary

• Robust Westinghouse fuel designs performing well

• Goal is 100% leak free performance through use of Fuel Reliability Improvement (FRI) process to drive continuous improvement and strong partnership with industry
Questions?
BWR Fuel Performance Update

Uffe Bergmann
Jean-Marie Le Corre
Westinghouse VISION & VALUES

together
we advance technology & services to power a clean, carbon-free future.

- Customer Focus & Innovation
- Speed & Passion to Win
- Teamwork & Accountability
- Safety • Quality • Integrity • Trust
Outline

• Leaker Statistics

• Novel Method for Prediction of Localized Zinc-Rich Crud at Leibstadt NPP (KKL)
  1) Background on Core Flow Conditions in BWR/6 Plants
  2) Background on KKL Crud Event 2012-2016 (reviewed by NRC as part of D5 CPR Correlation Topical Report)
  3) MEFISTO-T Code Upgrade: New Models of Annular Two-Phase Flow and Localized Crud Deposition in BWR Fuel Bundles
  4) Validation of MEFISTO-T against Crud Inspections at KKL
  5) References
Leaker Statistics

Uffe Bergmann
BWR Primary Failure Statistics
10X10 BWR Fuel Designs using liner cladding
Core Flow Conditions in BWR/6 Plants

Uffe Bergmann
Flow Paths in Plants with Cross Beams under Core Support Plate

Quarter-core symmetry assumed in loading pattern
  • Sets of 4 symmetrical fuel assemblies (FAs) loaded:
    1 FA in SEO1, 2 FAs in SEO2 and 1 FA in SEO3
• Accounted for uneven hydraulic resistances due to tighter flow paths at SEO2 and SEO3 (see table)
  – Established current SEO pressure loss coefficients (PLCs) based on testing in \[a,c\]
  – 1% reduction in CPR margin (for limiting FA in SEO3)
  – Did not account for the presence of flow vortices at SEO3 (and SEO2)
16-Bundle Experiments

- To better characterize the flow conditions in a square beam section below the core support plate, and the influence on fuel assembly inlet flow, performed a series of full-scale 16-bundle experiments.
Observation of Twin Vortices at SEO3
Supporting CFD Studies

- Vortex development comprehensively studied by CFD simulations
- Phenomenon reported by [a,c]

Many independent CFD studies confirmed twin vortices and flow reduction at SEO3
KKL Gamma Scanning 2018

• Final evidence of reduced flow resulting from the existence of twin vortices came from a specifically tailored Ba-140 gamma-scanning campaign performed in 2018 by Westinghouse at KKL – 16 SEO quartets (1 FA in SEO1, 2 FAs in SEO2 and 1 FA in SEO3) measured

• The flow measured (indirectly via the resulting fuel assembly power) was approximately 15% lower in SEO3 as compared to SEO1 (facing no support beams), in full agreement with the 16-bundle experiments

• Results confirmed that twin-vortices are present essentially all the time at SEO3
• The existence of twin vortices at SEO3 and the consequences in terms of reduced fuel assembly flow were
  - Pressure loss coefficient at SEO3 must be increased by a factor 1.9 (see table)
  - Results in a flow reduction of ~15%
  - Recommended interim action:
    5% CPR margin penalty for operating BWR/6 plants

LTR-NRC-21-26, Enclosure 3
KKL Crud Event (2012-2016)
Uffe Bergmann
Background on KKL Crud Event (2012-2016)

- **Main basis**
  - Around 300 inspected fuel assemblies from many cycles
  - 48 observed marks
  - Hot cell examination of 3 affected rods
  - 16-bundle experiments
  - KKL gamma scanning
Background on KKL Crud Event (2012-2016)

- Main observations
  - Localized V-shaped marks extending below upper spacers (7 & 8)
  - Next-to-corner rods only and oriented towards channel and opening above 1/3 corner rod
  - Fresh SVEA-96 Optima2 fuel only
  - Limited to Cycles 28-32
    - Coincides with increase in zinc injection
  - SEO3 mainly (few SEO2, no SEO1)
  - Zinc-rich crud (ZnO, Zn$_2$SiO$_4$), 100-200 µm, no significant cladding oxidation
Background on KKL Crud Event (2012-2016)

• Refined understanding of crud deposition mechanism with MEFISTO-T code
MEFISTO-T Code Upgrade:
New Models of Annular Two-Phase Flow and Localized Crud Deposition in BWR Fuel Bundles

*Patent no. PCT/EP2021/057715*

Jean-Marie Le Corre
BWR Coolant Conditions and Crud

**Keywords:** Disturbance waves, Liquid base film

**Reference:**
- Laboratory of Nuclear Energy Systems ETHZ
- The Red Laboratory

**Key Concepts:**
- Stable film dryout (CPR=1)
- Thin liquid film
- Thick liquid film
- Nucleation
- Convection
- Heat transfer

**Illustration:**
- Diagram showing coolant flow and crud formation
- Images of crud marks
- Graphs illustrating liquid film thickness and nucleation

**Diagram Notes:**
- Fuel inlet and outlet
- BWR operation
- "Normal" crud
- Localized crud

**References:**
- LTR-NRC-21-26, Enclosure 3
Crud Deposition Mechanisms

- Coolant impurity concentration > precipitation limit
- Compound-dependent (e.g. ~100 ppb for Zn$_2$SiO$_4$)
- Reached through local evaporation

Evaporation

<table>
<thead>
<tr>
<th>Fuel inlet</th>
<th>Fuel outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Convection</td>
<td>BWR Operation</td>
</tr>
<tr>
<td>Nucleation</td>
<td>Thick liquid film</td>
</tr>
<tr>
<td>Slug Flow</td>
<td>Annular Flow</td>
</tr>
<tr>
<td>Single-phase Liquid</td>
<td>Heat</td>
</tr>
</tbody>
</table>

"Normal" crude

Localized crud

LTR-NRC-21-26, Enclosure 3
Impurity Concentration Model (1)

- Goal: Quantify local (near wall) impurity concentration
- Physical model: Impurity conservation in liquid coolant
- Simple approach (1-D)
  - Based on e.g. POLCA7 TH output
  - Mixed liquid: $C_{Liquid} = \frac{1}{1-x}$
  - Insufficient approach ($C_{Liquid} \approx 2$)
- CFD approach
  - High spatial resolution
  - Complex models, high run time
  - Simplification of physical processes (mass exchange between fields)
Impurity Concentration Model (2)

- New proposed approach
  - MEFISTO-T sub-channel analysis code
    - 124 interconnected channels per assembly
    - Steam, film & drop fields separation (3-field)
    - Mechanistic CPR prediction based on film dryout
    - Presented to NRC during past topical report reviews
  - Missing information
    - Wave characteristics (e.g. frequency)
    - Base film characteristics (mass flow)
  - New models development
    - Base film & wave fields separation (4-field)
    - Base film dynamic evaporation model between waves
    - Multi-field coupled dissolved impurity transport equations
    - Calibration and validation under relevant BWR core operating conditions
Impurity Concentration Model (3)

- Transport of dissolved impurities
  - Mass impurity conservation in all liquid fields
  - Capture spacer effect (dilution) and part-length rods

- Dynamic base film between waves
  - During wave time period
    - Base film mass evaporation (local heat flux)
    - Impurity concentration increases before being quenched by next wave

  - **Base film concentration at end of wave cycle is the figure of merit**
Validation of MEFISTO-T against Crud Inspections at KKL

Uffe Bergmann
Considered Precipitation Limits

- Limits defined in terms of calculated maximum local zinc concentration in base film
  - Lower limit where crud deposition has been observed: **75 ppb**
  - Average (best-estimate) limit based on logistic regression analysis: **100 ppb**
- Historical reactor water zinc concentrations in KKL and concentration factors needed to reach the 75 ppb lower limit:

<table>
<thead>
<tr>
<th>Cycle</th>
<th>Zinc concentration at core inlet (ppb)</th>
<th>Reference concentration factor limit (75 ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 – 25</td>
<td>6</td>
<td>12.5</td>
</tr>
<tr>
<td>26</td>
<td>3</td>
<td>25.0</td>
</tr>
<tr>
<td>27</td>
<td>4</td>
<td>18.8</td>
</tr>
<tr>
<td>28</td>
<td>8</td>
<td>9.4</td>
</tr>
<tr>
<td>29 – 35</td>
<td>10</td>
<td>7.5</td>
</tr>
</tbody>
</table>
MEFISTO-T Simulation Example

- Crud predicted by evaporation of base film between disturbance waves
- Crud is correctly predicted at SEO3 core positions, during second half of first cycle, on next-to-corner rods, below Spacers 7 and 8, and in direction towards fuel channel
Summary of Results for Selected Cycles

MEFISTO-T can separate populations of affected/unaffected assemblies to a satisfactory extent (small overlap)
New Design Criterion for SVEA-96 Optima3™ Fuel

- All affected assemblies in Cycles 28-32 have maximum local zinc concentration greater than 75 ppb
- The following design criterion is being used at KKL

\[
\text{Maximum impurity concentration factor} < 7.5 \times \frac{10 \text{ ppb}}{\text{zinc concentration [ppb]}}
\]

Conservatively bounding approach
Tailored Nuclear Designs of Optima3 for Crud Mitigation

- The 75 ppb acceptance criterion can be fulfilled by optimizing the U-235 enrichment in the next-to-corner rods during the nuclear design process
  - An axially graded design with lower enrichment in the top segment is most efficient
  - Impact on average enrichment (burnup capability) is acceptable
- Example below is relevant to KKL conditions (12-month cycle)
  - Optima3 generally has lower concentration factors in 24-month cycles due to further depletion of next-to-corner rods when power swings to top of core
Applicability to other BWR Fuel Designs and Plants

- New MEFISTO-T four-field model for crud prediction includes local (fuel design independent) empirical correlations that have been calibrated against equilibrium steam/water experiments in tube and annuli at conditions relevant of BWR operation.
- MEFISTO-T was successfully validated against KKL crud inspection database for BWR fuel bundles (Optima2).
- MEFISTO-T may be applied to any fuel assembly design and operating condition in any BWR plant, provided that certain input data are made available:
  - Fuel assembly geometrical information
  - Fuel assembly boundary conditions (from 3D nodal code)
  - Coolant chemistry data

MEFISTO-T is applicable for prediction of margin to crud deposition in any BWR fuel design and plant.
References

Uffe Bergmann and Jean-Marie Le Corre
Future Publications

  - High level model description and application to KKL
  - Detailed description of disturbance wave model
  - Detailed description of impurity transport model
  - Characteristics of KKL crud
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2021 Fuel Performance Update Meeting

PRIME™ Fuel Assembly Features

Brian Millare
Technical Lead

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Topics

• Scope and Schedule
• Design Overview / Verification
• Licensing
• Summary
Scope and Schedule

• Scope
  
  – Integration of Advanced Fuel Assembly Features
    • 17 Optimized Fuel Assembly (OFA)
    • 17 Robust Fuel Assembly
    • 15 Upgrade Fuel Assembly
Scope and Schedule

Improved Fuel Performance; Licensing effort will be discussed later
First region of PRIME 17OFA fuel by end of 2021. 17RFA and 15 Upgrade are ongoing.
## Design Overview / Verification

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Feature</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>15x15</td>
<td>Mid and IFM Grids</td>
<td>ZIRLO®</td>
</tr>
<tr>
<td></td>
<td>Dashpot</td>
<td>Tube-in-Tube</td>
</tr>
<tr>
<td></td>
<td>Bottom Nozzle</td>
<td>mDFBN</td>
</tr>
<tr>
<td>17OFA</td>
<td>Mid and IFM Grids</td>
<td>ZIRLO</td>
</tr>
<tr>
<td></td>
<td>Dashpot</td>
<td>Swaged</td>
</tr>
<tr>
<td></td>
<td>Bottom Nozzle</td>
<td>SDFBN</td>
</tr>
<tr>
<td>17RFA</td>
<td>Mid and IFM Grids</td>
<td>ZIRLO</td>
</tr>
<tr>
<td></td>
<td>Dashpot</td>
<td>Swaged</td>
</tr>
<tr>
<td></td>
<td>Bottom Nozzle</td>
<td>SDFBN</td>
</tr>
</tbody>
</table>
• Mechanical testing complete
• Analyses are ongoing
• Other analyses are still ongoing for 17RFA and 15Upg
Design Overview / Verification – PRIME Bottom Nozzle
Design Overview / Verification – Reinforced Dashpot

- Mechanical testing completed
- Analyses are ongoing for 17RFA and 15Upg
Licensing

• New fuel designs require NRC approval to ensure that the licensing requirements in Section 4.2 of the Standard Review Plan are met.

• Changes to existing fuel mechanical designs can be implemented without NRC approval provided they meet the criteria in the Westinghouse Fuel Criteria Evaluation Process (FCEP) (WCAP-12488-A).
  – Requires sending a letter to the NRC addressing the criteria
  – Can then be implemented by licensees via 10 CFR 50.59 provided no technical specification (TS) changes are needed and the 50.59 review concludes that prior NRC review and approval is not required
Licensing

• Based on past precedent and previous FCEP submittals, all PRIME features are anticipated to meet the NRC-approved design criteria in WCAP-12488-A.

• Advanced Debris Filter Bottom Nozzle licensed via FCEP (2020)
Utility Licensing

• Once the FCEP notification letter has been issued to the NRC, the current plan is to implement the **PRIME** fuel features at plants under 10 CFR 50.59 (provided no TS changes are needed and the 50.59 review concludes that prior NRC review and approval is not required).

• There are many instances within the UFSARs that discuss the components being changed as part of the **PRIME** fuel features. To fully incorporate **PRIME** fuel features into the licensing basis, the appropriate updates are required to the plant’s UFSAR.
  – These changes can typically be made within the allowance of 10 CFR 50.59
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Additive Manufacturing
at Westinghouse

2021 Fuel Performance Update Meeting

David Huegel
September 2021
Overview

• AM at Westinghouse
• AM Development at Westinghouse
• First AM Nuclear Fuel Component Installed in Commercial Reactor
• Westinghouse Developed AM Nuclear Fuel Components
• Westinghouse AM Tooling Development
• Powder Metallurgy (PM) Hot Isostatic Pressing (HIP) Development
• AM Development Partnering with Industry/ Academia
• Q&A
Additive Manufacturing at Westinghouse
Advanced Manufacturing 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

Thimble Plugging Device
Direct Metal Laser Sintering

RVI Quickloc Upper Support Assembly
Powder Metallurgy and Hot Isostatic Pressing (PM-HIP)

Passive Hydrogen Igniter Concepts
Binder Jetting Additive Manufacturing

Tooling - AM Laser Powder Bed Fusion
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:
  – Continue to performed significant testing on 3D parts (with and without radiation effects)
  – Utilizing 3D printing for tooling for manufacturing
  – Implemented 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
Additive Manufacturing – Westinghouse Equipment

- Westinghouse owns one (1) EOS M 290 machine for printing in metal with access to additional machines at the same facility
  - Currently printing in:
    - Alloy 718
    - SS Types: 316L, 304, 17-4 PH and MS-1
    - Copper and Aluminum
  - 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

Westinghouse AM Equipment
Additive Manufacturing Development at Westinghouse
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
• **316L samples have been tested and evaluated for mechanical properties**
  - The absolute values for the AM material Ultimate Tensile Strength (UTS), 0.2% Offset Yield Strength (YS) and percent elongation (% EL) were as expected and consistent with conventional material
  - Tensile strengths, both UTS and YS increased with irradiation as expected
  - % EL went down with irradiation as expected
First AM Nuclear Fuel Component Installed in Commercial Reactor
First AM Component (TPD) Installed at Commercial Reactor

– AM Thimble Plugging Device (TPD) first AM fuels component successfully installed in a commercial reactor (Byron 1 March 2020)
  • Low Risk Component, moderate complexity
– Westinghouse met with NRC in May 2019 at the Westinghouse Rockville offices and discussed AM TPD in detail prior to installation.
  • Implemented using the 50.59 process
First AM Component (TPD) Installed at Commercial Reactor

- AM TPD was installed in Byron Unit 1 Cycle 24 in core location L11 which was predicted to have a FA power level of 1.179 at BOL and 1.003 at EOL (burnup of 24,500 MWd/MTU).

- The AM TPD will be/has been re-inserted into the core for Cycle 25 into a twice-burned fuel assembly in location E15.
AM Component (TPD) Inspection Summary

• During the recent cycle 25 outage, an inspection of the AM TPD was performed and included:
  – A drag test was performed on the AM TPD as it was removed from the fuel assembly and a load cell measured the force.
    • Ensure no spike in the drag force outside of standard forces.
  – A detailed visual inspection from numerous angles was then performed using a high-resolution camera positioned perpendicular to the AM TPD in order to view all rodlets.
    • Goal to observe no anomalies/defects/discolorations/distortions nor any physical damage to the AM TPD.
• The AM TPD was then re-inserted back into the core for a second cycle of irradiation.
Westinghouse Developed
AM Nuclear Fuel Components
AM Fuel Structures - Grids

- Improved flow characteristics are possible with AM resulting in better heat transfer from fuel rods to reactor coolant for better performance.
- Stronger, more efficient support of fuel rods with better mixing characteristics and less GTRF.

Items requiring further investigation:
- Corrosion characteristics in PWR chemistries
- Mechanical strength of small features
AM Fuel Bottom Nozzle

- **Goal**: Consistent/Reduced pressure drop and improved debris filtration
- Multiple complex designs enabled by AM
- Numerous polymer based bottom nozzles created for prototype flow testing
- AM BN (Design developed for PWR applications)

- **Innovation Projects**: PWR Fuel Bottom Nozzle Advanced Design Through Multi-Physics Topology Optimization (TO) for Design with Additive Manufacturing
VVER-440 AM Top Flow Plate

- Hexagonal Russian fuel design
- Plate printed in 304L SS
- Eliminates need for welding of pins
- Combines 7 pieces into 1
- Retains fuel rods in accident scenario
- Planned to be implemented on region basis in the Ukraine Rivne 2 plant in 2024
AM Fuel Bottom Nozzle

Full size AM produced Bottom Nozzle

- Equivalent pressure drop to existing bottom nozzle design
- All design and safety requirements satisfied
- Improved filtering ability
- All manufacturing interfaces satisfied
- No changes to basic BN envelop nor interfacing features; LCP pin "S" holes, thimble screw locations, instrumentation tube insert, etc.
AM Fuel Bottom Nozzle - Mesh Structural Testing

- Detailed Mechanical (and T&H) Testing of Fine Mesh Filter (Spire) Structure Performed.
  - Static loads applied to the fine mesh filter (spire) structure to determine strength
  - Dynamic Load testing also performed
AM Fuel Bottom Nozzle - Mesh Structural Testing

• Detailed Mechanical and T&H Testing of Fine Mesh Filter.
• Mechanical tests performed to ensure that the fine mesh filter (spire) does not fail during operation and become debris.
  – Static load testing (example shown to right) demonstrated significant fine mesh filter (spire) strength and margin to failure.
  – Ballistic testing performed - demonstrated "spire" will not fail when debris in flow field

• T&H testing:
  – Pressure drop - matches current bottom nozzle design
  – Debris filtering - significant improvement compared to current design
AM Fuel Bottom Nozzle - GSI-191

- The AM BN has a significantly different adapter plate as compared to existing bottom nozzle design for the purposes of providing improved filtering capability.
- Given that the filtering capability is improved, Westinghouse examined the potential impacts to the Generic Safety Issue (GSI) 191 sump issue.
- This included GSI-191 testing performed consistent with the testing that was performed in the topical report WCAP-17788 Volume 6, *Comprehensive Analysis and Test Program for GSI-191 (PA-SEE-1090) - Subscale Head Loss Test Program Report*. 
AM Fuel Bottom Nozzle - GSI-191

• To qualify the AM BN, subscale testing is being performed consistent with the subscale testing performed as documented in the topical report WCAP-17788 Volume 6.

• The first step was to repeat the existing testing with current bottom nozzle design to demonstrate that the subscale loop was performing as intended.

• Test loop schematic:
AM Fuel Bottom Nozzle - GSI-191

- Subscale test loop - cross section showing the core inlet geometry.
- Results for current bottom nozzle design will be compared to the topical report.
- AM bottom nozzle results are currently in progress.
AM Fuel Bottom Nozzle Licensing - LUAs

LUA Licensing Approach:
• Pursuing the licensing of Lead Use Assembly AM Bottom Nozzles (4 to 8) similar to used for AM TPD
• Following the NRC issued draft 50.59 guidance for AMTs (Subtask 2A)
• All design and safety criteria satisfied
AM Fuel Bottom Nozzle Licensing - Region

Region Implementation Approach:

• Westinghouse plans on utilizing the NRC approved Westinghouse Fuel Criteria Evaluation Process (FCEP) process (WCAP-12488-A)

• Following the NRC issued draft 50.59 guidance for AMTs (Subtask 2A)
In the draft NRC 50.59 guidance for AMTs (Subtask 2A), it is noted that:

"Since AMT fabrication involves a significant change to the material and manufacturing process when compared to traditional fabrication methods, an AMT item is not identical to the original and therefore should not be considered a like-for-like replacement."

"However, the licensee's technical evaluation process might include an equivalency evaluation to address the impact of the change in design, material and manufacturing on the ability of the AMT item to perform its intended design function."

"If there is no adverse impact on the design function, the AMT item may be considered "equivalent" to the original in its ability to perform its intended design function."
Westinghouse AM
Tooling Development
Tooling for Manufacturing

- **Immediate benefit from tooling applications**
  - Lower the costs and improve performance
- **Improved safety for operators**
  - Reduction of leak points
  - Two hands touch control
  - Ergonomic designs resulting in less fatigue injuries
AM Tooling - 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.
AM Tooling - 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.
AM Tooling - 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.
- Redesign of gage was implemented using the AM process.
AM Tooling - RCCA Spider Envelope Gage

- Using the AM technology, the required material was greatly minimized while maintaining gage functionality and stability.
- Redesigned gage total weight is less than 10 lbs.
- Test builds verified the gage functionality and stability.
Powder Metallurgy (PM)
Hot Isostatic Pressing (HIP)
Development
Hot Isostatic Pressing (HIP) Development Efforts

- **NEER Project (Innovate UK-funded): Completed in May 2018**
  - Focused on reusable tooling, HIP development and demonstration of nuclear components, and UK supply based development
  - Produced demonstration components
    - Reactor Vessel Internals (RVIs): Quickloc Upper Support Assembly
    - Control Rod Drive Mechanisms (CRDMs): Guide Funnel Extension
    - Valves: 4” Motor Operated Gate Valve Body

- **Producing Prototypes / Mockups for Next Generation Plants**

- **Completing Cost-Benefit Analysis for Reactor Coolant Loop Piping and Critical Components**
Additive Manufacturing Development
Partnering with Industry/Academia
Additive Manufacturing – Current Projects

  - Project Lead Principal Investigator(PI) is EPRI
  - Project Co-PI’s – ORNL, Rolls Royce, and WEC
  - Completed in early 2020 with ASME code case submission for 316L
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)
  - Initiated in 2019
  - Effort to demonstrate feasibility of additively manufacturing thin-walled components for reactor use.
  - Currently, thin-walled materials (Zirc based and Alloy 718) are commonly used in the manufacturing of grids.
Additive Manufacturing – Current Projects

  - Project Lead – William Cleary
  - Initiated in fiscal year 2018 – 3 year program
  - $1M Award
  - Demonstrating feasibility of AM zircaloy

First of a Kind Research in AM Zirconium Alloys
Additive Manufacturing – Current Projects

• Partnering with KNF to develop Zr-4 for Laser Powder Bed Fusion systems
• Utilizing two methods for making Zr-4 powder from 2” diameter bars
• Targeting spacer grids with a secondary medical devices market
• Challenges:
  – Reactivity of zircalloy powder
  – Yield rates of the powderization processes
Q & A