EATF Status – Chromium Coated Cladding

Jerald Holm, Kiran Nimishakavi, Jacki Stevens

Rockville MD, February 27, 2019
AGENDA

• Introduction and background
• Failure Modes & Effects Analysis and Design Review Summary
• Test program
• Models
• Topical Report outline
• Next steps
Introduction and Background
EATF Solution
Cr-Coated Cladding / Chromia-doped Pellets

Base M5 Cladding
• No change to M5 properties or dimensions

Cr-coating
• 10-20 µm
• Does not change base M5
• Improved oxidation resistance
• Improved wear resistance
• Reduced LOCA rupture

Chromia-doped UO₂ pellets
• BWR licensing approved
• Improved fission gas retention
• Improved fragmentation behavior
• Improved PCI performance
Overview of Plan

- Base Topical Reports for Advanced Methods
  - ANP-10323P, Revision 1, “GALILEO Fuel Rod Thermal-Mechanical Methodology for Pressurized Water Reactors”
  - ANP-10339P, “ARITA - ARCADIA/RELAP-Integrated Transient Analysis Methodology”
  - Topical report for implementation of GALILEO in W&CE LOCA methodologies (SBLOCA and RLBLOCA)
- Extension to Advanced Products (Cr-Cr EATF Solution)
  - Chromia-doped pellet topical report supplement (ANP-10340P) report to extend material properties to PWR methodologies
  - BAW-10227 supplement to incorporate chromium-coated cladding (addressing base methods)
Advanced Products - EATF
Cr-Coated Cladding Topical Report

Purpose
- Implement Chromium coated cladding properties into PWR codes and methods
- Supplement to BAW-10227P, Revision 2

Scope Detail
- Chromium coated M5 cladding
  - Define new properties / models for Cr-coated cladding
  - Disposition M5 properties where applicable
- Implementation of Cr-coated cladding in
  - GALILEO
  - LOCA Methodologies
  - ARITA / AREA Methodologies
- Address failure mechanisms and surveillance plans
- Appropriate sample problems for Cr-coated cladding addressed
Background

- BAW-10227PA, Revision 0 approved February 2000
- BAW-10227PA, Revision 1 approved June 2003
  - Extended burnup to 62 GWd/mtU
- BAW-10227, Supplement 1P “Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel”
  - Extend the range of applicability of models and correlations
  - Submitted May 2017
- BAW-10227, Revision 2 “Evaluation of Advanced Cladding and Structural Material (M5) in PWR Reactor Fuel”
  - Update of M5 properties
- BAW-10227, Supplement 2P “Incorporation of Chromium Coated Cladding Properties
Recent Results
Beginning of Proprietary Information
Recent Results - Corrosion
Recent Results - Beyond Eutectic Temperature
Failure Modes & Effects Analysis and Design Review
FMEA

- Objective: Identify all possible risks of failures in a design
  - Conducted on October 16th, 2018 per US Fuel administrative procedure
- Risk Priority Number (RPN) rankings were determined for each Failure Mode based on Severity, Occurrence and Detection
  - Final RPN could range from 1 to 1000
  - 1 is very low risk and 1000 is high risk
- Team identified
- FMEA exercise yielded RPNs ranging from

Design Review

- Objective: Review the technical status of Cr-coated cladding and ensure all the requirements and constraints are completely identified
  - Conducted on November 13th, 2018 per US Fuel administrative procedure

- Bounding Assumptions
  - Coating and Manufacturing processes will produce cladding which meets the design requirements

- [ ]

- Industrialization aspects, contractual needs, etc. are out of scope of this design review

- Board made [ ]

<table>
<thead>
<tr>
<th>Cross-functional team:</th>
<th>Materials, Neutronics, Severe Accident, Regulatory Affairs, Physical Vapor</th>
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<tbody>
<tr>
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<td>Thermal-Mechanics, Thermal-Hydraulics, Mechanical Design, RCS Chemistry, Deposition Expert</td>
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<td>Fuel Reliability, LOCA/non-LOCA, Radiological, RIA</td>
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<tr>
<td>Source</td>
<td>Potential Failure Mode</td>
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FMEA and Design Review - Key Findings (1/9)
Coating Technique to Improve Adherence


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Coating Microstructure and Cr/Zr Interface
Testing – Coating Adherence
<table>
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Follow-Up Action
FMEA and Design Review - Key Findings (3/9)

Potential Failure Mode
FMEA and Design Review - Key Findings (3/9)

Follow-up Action
FMEA and Design Review - Key Findings (4/9)

Potential Failure Mode
FMEA and Design Review - Key Findings (4/9)

Follow-up Action
FMEA and Design Review - Key Findings (5/9)

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FMEA and Design Review - Key Findings (6/9)

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### FMEA and Design Review - Key Findings (7/9)

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FMEA and Design Review - Key Findings (8/9)

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FMEA and Design Review - Key Findings (9/9)

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FMEA and Design Review - Summary

- Review boards identified the need for additional test data to update/verify the applicability of current performance models.
- Test Program has been revised and reprioritized based on recommendation from FMEA and Design Review Boards.
- No new phenomenon or failure mode was identified for the Cr-coated cladding.
- All recommendations shall be addressed in a timely manner and monitored to completion.
IN-PILE TESTING
Cr-clad Irradiation Program

- ATR - 2018
  Cr-Cr₂O₃ Fuel pins

- HALDEN - 2017
  Cr-UO₂ Fuel pins

- ANO - 2019
  Full-length LTRs

- ORNL - 2019
  Unfueled Cr-clad samples

- Vogtle - 2019
  Full-length LTRs

- Calvert Cliffs - 2021
  Cr-Cr₂O₃ Full Assembly (LTAs)

- OSIRIS - 2015
  Unfueled Cr-clad samples

- Gösgen - 2016 & 2019
  Cr-clad samples - (2016)
  Full Length LTRs (2019)

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Cr-Coated Clad Irradiation Program
Cr-Coated Clad Irradiation Program
OSIRIS and Halden Irradiation
Cr-Coated Clad Irradiation Program
Visual Inspection of Cr-Coated Segments
IMAGO Irradiation - Schedule
Cr-Coated Clad Irradiation Program
ATR and TREAT - Irradiation and Testing
ATR Irradiation - Schedule
Cr-Coated Clad Irradiation Program
HFIR Irradiation Schedule
Cr-Coated Clad Irradiation Program
Testing Program – Summary (1/3)
Testing Program – Summary (2/3)
Models
Models Summary (1/3)

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## Models Summary (2/3)

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Models Summary (3/3)

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<td>EATF Status – Chromium Coated Cladding, February 27, 2019</td>
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Topical Report Outline
**Topical Report Outline**

- Each section of BAW-10227 R2 will be evaluated:

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<td>10.0 Oxidation and Hydrogen Pick up During Normal Operation</td>
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<td>15.0 Update Process</td>
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<td>16.0 References</td>
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- Added sections for Cr-Coated M5:

  - 5.0 Additional Failure Modes
  - 13.0 Codes and Methods Update
  - 14.1 Planned Test Irradiations
Acronyms

- ATF – Accident Tolerant Fuel
- ATR – Advanced Test Reactor
- BU – Burnup
- BWR – Boiling Water Reactor
- CE – Combustion Engineering
- CEA – The French Alternative Energies and Atomic Energy Commission
- EATF – Enhanced Accident Tolerant Fuel
- EOL – End of Life
- FMEA – Failure Modes and Effects Analysis
- HT – High Temperature
- LOCA – Loss of Coolant Accident

- LTA – Lead Test Assembly
- LTR – Lead Test Rod
- NRC – U.S. Nuclear Regulatory Commission
- PCI – Pellet Cladding Interaction
- PIE – Post Irradiation Examination
- PQD – Post Quench Ductility
- PVD – Physical Vapor Deposition
- PWR – pressurized Water Reactor
- RAI – Request for Additional Information
- RPN – Risk Priority Number
- TBD – To Be Determined
- W – Westinghouse
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