AW-19-4866
Enclosure 4

Enclosure 4:

Submittal of Presentation Material for Partially Closed Meeting with the U.S. Nuclear Regulatory Commission on February 28, 2019 to Discuss the Status of the Westinghouse EnCore® Accident Tolerant Fuel Program
(Non-Proprietary)

February 2019

EnCore® Accident Tolerant Fuel Coated Cladding

February 28, 2019

Westinghouse

Introductions and Purpose

- Introductions

- Purpose
  - Provide detailed overview of both near-term and long-term qualification and licensing plans for coated cladding
  - Review available data and future testing plans
  - Review impact of coated cladding on key analytical areas

  - Obtain NRC alignment or feedback on the approach

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Agenda

- Regulatory Requirements
- Licensing Plan
- Description of Coated Cladding
- Qualification Data
- Impact on Approved Analytical Methods
- Summary

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Agenda

- **Regulatory Requirements**
  - ✓ Applicable Regulations and NRC Guidance
  - ✓ Phenomena Important to Safety
  - ✓ NRC Interim Staff Guidance
  - ✓ Path to Compliance
- Licensing Plan
- Description of Coated Cladding
- Qualification Data
- Impact on Approved Analytical Methods
- Summary

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Applicable Regulations and NRC Guidance

- General Design Criteria (GDC) 10 states:
  - "The reactor core and associated coolant, control, and protection systems shall be designed with the 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."
- To meet GDC 10, the guidance of Standard Review Plan (SRP), NUREG-0800, Section 4.2, "Fuel System Design" will be utilized to demonstrate that
  - The fuel system is not damaged as a result of normal operation and anticipated operational occurrences (AOOs)
  - Fuel system damage is never so severe as to prevent control rod insertion when it is required
  - The number of fuel rod failures is not underestimated for postulated accidents
  - Coolability is always maintained

Phenomena Important to Safety

- EPRI Gap Analysis
  - No new phenomena were identified
  - Current fuel design limits can appropriately address the effects of coated cladding within design process
  - Technical gaps will be addressed (e.g., coating adherence)
- Westinghouse internal gap analysis ongoing
  - Focused review of Westinghouse coating technology will be finalized prior to topical report submittal
- NRC PIRT Activity expected completion in May/June 2019
  - Westinghouse will review and ensure it considers any items not already identified in the preceding activities

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NRC Interim Staff Guidance

- NRC Interim Staff Guidance (ISG) activity is planned for completion at end of 2019
  - Westinghouse will closely monitor the development of the ISG
  - Westinghouse will support the ISG by providing technology-specific information
  - Westinghouse will ensure the licensing actions will demonstrate compliance with the clarifications of the ISG

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Path to Compliance

- In order to demonstrate compliance with the regulatory requirements
  - Provide data to establish material properties and in-core behavior
  - Identify any performance boundaries for coated cladding
  - Demonstrate capability to accurately model coated cladding properties to confirm satisfaction of fuel system safety criteria
    - Assess impact of the phenomena important to safety

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Agenda

- Regulatory Requirements
- **Licensing Plan**
  - ✓ Coated Cladding Licensing Plan
  - ✓ [ ]^{d,e} Topical Report Submittal Plan
  - ✓ Regulatory Interactions
  - ✓ Timeline of Key Activities
  - ✓ Summary of Near and Long-Term Plans
- Description of Coated Cladding
- Qualification Data
- Impact on Approved Analytical Methods
- Summary

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Coated Cladding Licensing Plan

d,e

[ ]d,e Topical Report Submittal Plan (1 of 2)

d,e

[ ]d,e Topical Report Submittal Plan (2 of 2)

d,e

Regulatory Interactions

- To support overall timeline for [ ]^{d,e} submittal
  - Multiple meetings prior to submittal: additional technical exchange or informational audit meetings will be scheduled as needed

- To ensure coherence between pre-submittal and post-submittal activities
  - Requesting that a reviewer be identified prior to submittal
  - Feedback received in meetings held prior to submittal will be applicable to the submitted topical report

Westinghouse seeks proactive interaction with NRC review staff leading up to topical report submittal

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Timeline of Key Activities

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Summary of Near and Long-Term Plans

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LTR: Lead Test Rod
LOCA: Loss of Coolant Accident
PCT: Peak Cladding Temperature
DNB: Departure from Nucleate Boiling

Agenda

- Regulatory Requirements
- Licensing Plan
- **Description of Coated Cladding**
  - ✓ Material Specification
  - ✓ Manufacturing
- Qualification Data
- Impact on Approved Analytical Methods
- Summary

Description of Chromium-coated Cladding

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

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Specification of Chromium-coated Cladding

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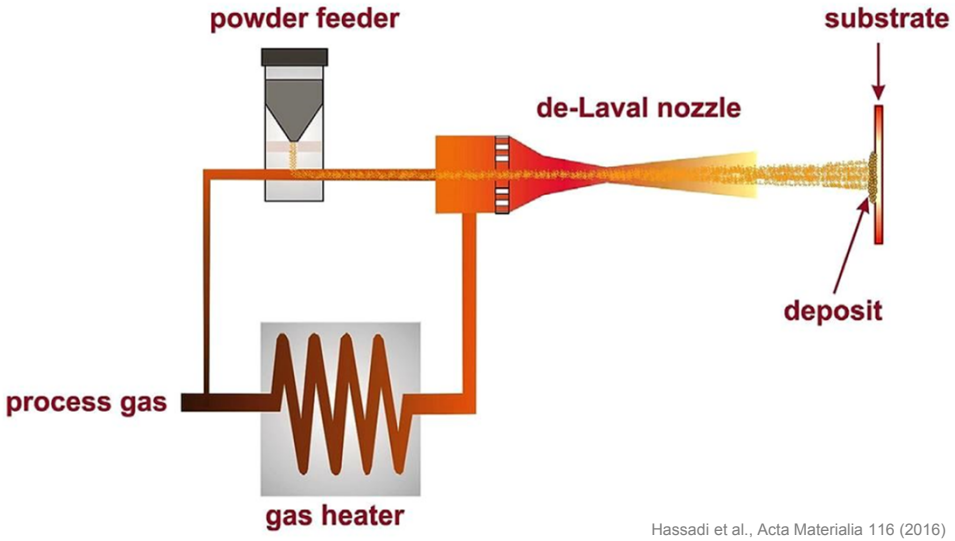
*Specifications for Lead Test Rods

Cold Spray Process



Hassadi et al., Acta Materialia 116 (2016)

- Powder particles propelled to high velocities by a gas
- Particles do not melt and deposition occurs in solid state
  - No need for vacuum or inert environment
  - No substrate preparation required
  - Facilitates manufacturing scalability

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Manufacturing

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Manufacturing processes for chromium-coated LTRs qualified

Manufacturing

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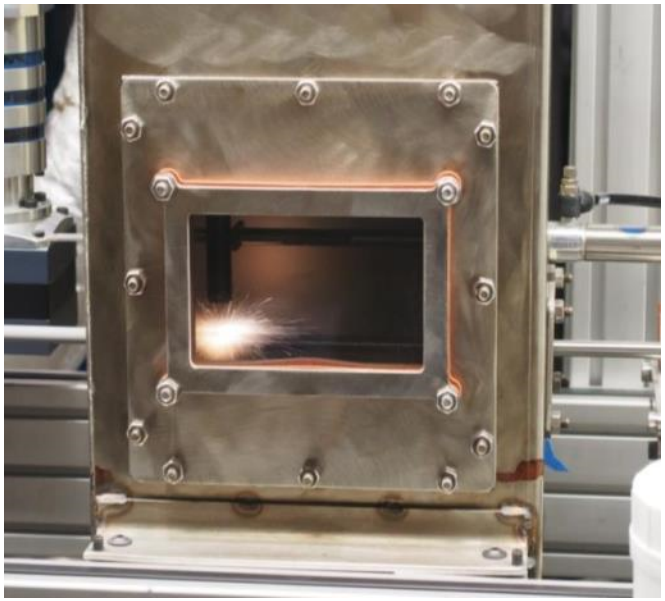
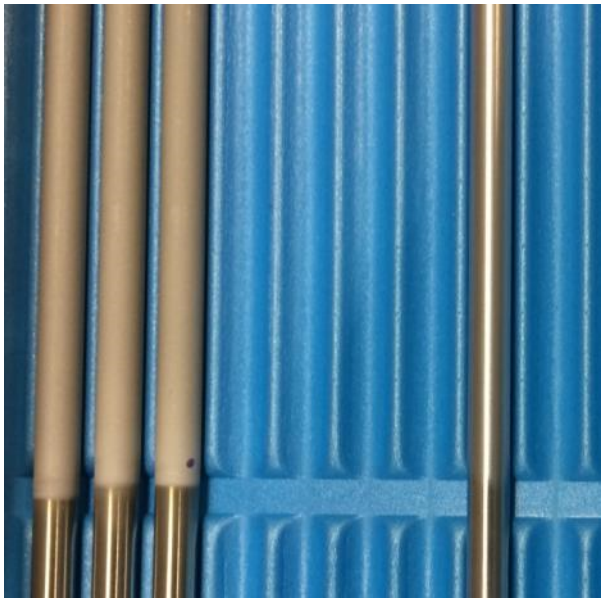
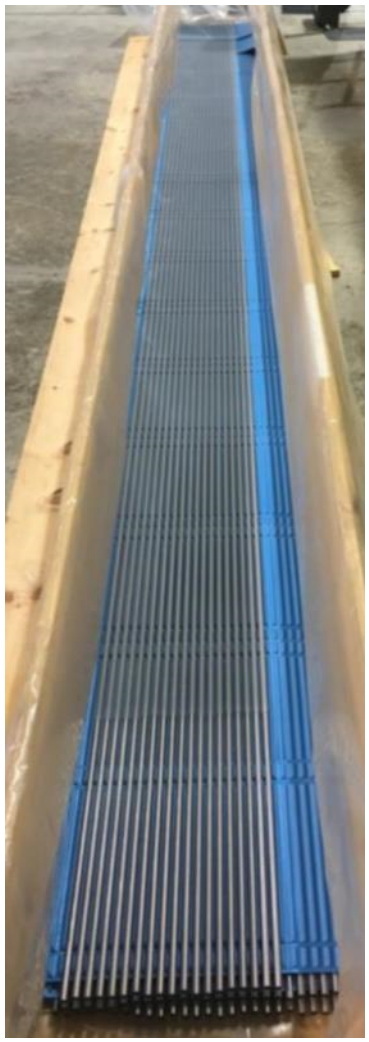
Manufacturing



Cold Spray of Full Length Tube



Coated Tubes Before and After Polishing



Batches of Coated Tubes

Agenda

- Regulatory Requirements
- Licensing Plan
- Description of Coated Cladding
- **Qualification Data**
  - ✓ Out-of-pile performance
  - ✓ In-reactor experience
- Impact on Approved Analytical Methods
- Summary

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Reduced Corrosion During Normal Operation

b,c

Coating maintains integrity and oxidation of coated surfaces is near zero

Reduced Corrosion During Normal Operation

b,c

Reduced High Temperature Oxidation

b,c

Reduced High Temperature Oxidation

b,c

Minimal oxidation and ductility retention with coatings during severe accident conditions

Improved Burst Behavior

b,c

Mechanical Performance

- Excellent adherence in all tests
- No observable spalling even at very high strain
- No effect on mechanical properties of the substrate
- Different stress conditions tested

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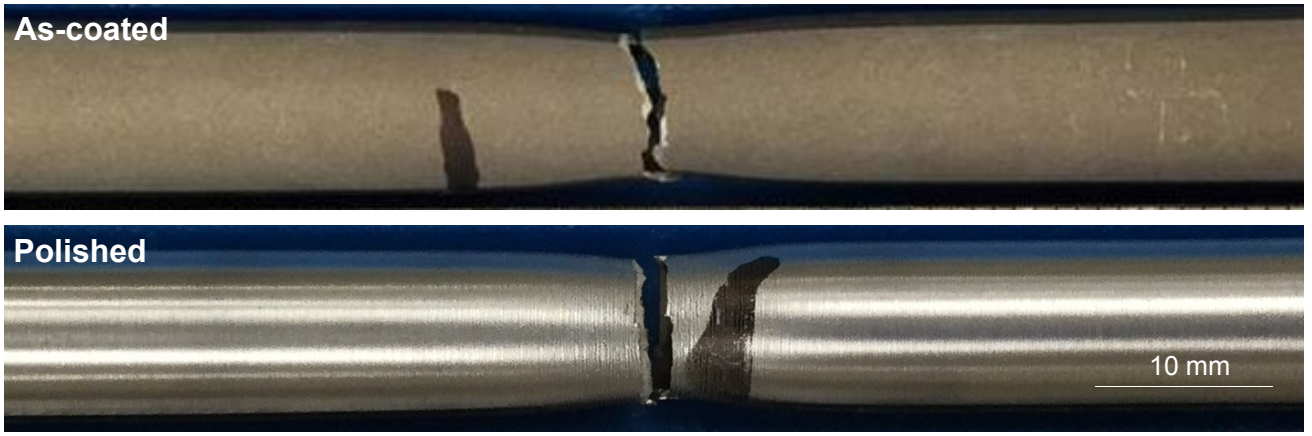
Mechanical Tests

b,c

Mechanical properties compare well with those of the substrate and meet specifications

Mechanical Tests



No observable spalling of coating even at high strain

Thermo-mechanical Tests

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No significant issues with thermo-mechanical behavior

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b,c

Rod Loading

b,c

Grid-to-rod Fretting (GTRF)

b,c

Defective Substrate and/or Defective Coating

b,c

Crud

- Tests conducted in WALT loop under PWR conditions
  - Including crud stimulants

[ ] b,c

WALT: Westinghouse Advanced Loop Tester

Departure from Nucleate Boiling

- Tests conducted in WALT loop

[ ] b,c

Agenda

- Regulatory Requirements
- Licensing Plan
- Description of Coated Cladding
- **Qualification Data**
  - ✓ Out-of-pile performance
    - Corrosion, thermo-mechanical, thermal-hydraulic, wear
  - ✓ In-reactor experience
- Impact on Approved Analytical Methods
- Summary

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Irradiation Experience

b,c

MITR-2

b,c

EPD: Effective Power Days

MITR-2 and -3

b,c

Agenda

- Regulatory Requirements
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- Description of Coated Cladding
- Qualification Data
- **Impact on Approved Analytical Methods**
  - ✓ Fuel Rod Design (FRD)
  - ✓ LOCA Accident Analysis
  - ✓ Other Analysis Areas
- Summary

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Impact on NRC-Approved Analytical Methods

b,c

Impact on Fuel Performance Models

b,c

No impact on the properties of the base cladding

Impact on Fuel Rod Design Criteria (1 of 2)

b,c

Coating largely improves FRD margin

Impact on Fuel Rod Design Criteria (2 of 2)

b,c

Fuel Rod Design

- PAD5 (WCAP-17642-P-A, Rev. 1)

[ ] b,c

LOCA Accident Analysis

b,c

Other Analysis Areas

b,c

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Summary

- Westinghouse has developed chromium-coated cladding, achieving insertion of LTRs in commercial reactors
- The addition of a chromium layer does not negatively affect the properties or performance of zirconium-based cladding under normal operations and shows significant improvements with respect to corrosion
- The coating also improves high-temperature behavior in accident conditions
- Westinghouse will justify implementation of chromium-coated cladding in the [ ][d,e] submittal

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