Post Irradiation Examinations of High Performance Research Reactor Fuels

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INTRODUCTION

• Purpose of post irradiation examinations
• Current fuel development situation
• Requirements for fuel qualification
• Scope of post irradiation examinations
• Recent examinations and results
• Future work and advancements
End Goal- Fuel Qualification

- There is not an NRC defined process for Research and Test Reactor Fuel Qualification
- Most recent precedent is NUREG-1313 (1988)
  - Safety Evaluation Report for generic acceptance of U3Si2 fuel
- IAEA Guide NF-T-5.2
  - Good Practices for Qualification of High Density Low Enriched Uranium Research Reactor Fuels
- Other
  - USHPRR Fuel requirements document
  - Base Fuel Qualification Plan
**USHPRR Fuel System**

- Dispersion fuel system limitations lead to required monolithic fuel system.
- Significant change from existing fuel system presents new challenges for fuel qualification.
- Recent improvements in technology allow for improved data acquisition.
- New fuel system may require new examinations or techniques.
### Fuel Performance Requirements

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<th>Mechanical Integrity</th>
<th>Geometric Stability</th>
<th>Stable and Predictable Behavior</th>
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<tr>
<td><em>Ensure no delamination during normal operation and anticipated transients</em></td>
<td><em>Geometry is maintained during normal operation and anticipated transients</em></td>
<td>• Fuel performance shall be known and predictable</td>
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<td><em>Mechanical response of the fuel meat, cladding, and interlayers is established</em></td>
<td><em>Irradiation–induced degradation of properties does not lead to conditions that result in loss of cool-ability</em></td>
<td>• Fuel swelling is within a stable regime</td>
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<td><em>Plate movement caused by pressure differential does not compromise ability to cool the fuel</em></td>
<td>• Irradiation behavior on scale-up is predictable</td>
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<td>• U-Mo corrosion behavior after breach is known</td>
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Post Irradiation Examinations

- In Canal Examinations
- Element Disassembly / Visual Examinations
- Neutron Radiography
- Gamma Scanning
- Immersion Density
- Profilometry
- Eddy Current Testing (oxide thickness)
- Metallography
- Blister Testing
- Mechanical Testing
In-Canal Examinations

• Visual examination of capsules/elements
• Irradiation test vehicle disassembly
• Individual plate visual examination
• Ultrasonic testing to determine plate thickness/swelling
• Ultrasonic testing to determine delamination/void formation in plate
• Channel gap thickness measurements
In-Canal Examinations: Thickness measurements

After 35 days

After 77 days

After 133 days
In-Canal Examinations

Example in-canal channel probe data (AFIP-7)

- Pre irradiation
- After 1st cycle
- After 2nd cycle
(Y-scale in inches)
Disassembly / Visual Examinations

- Visual inspection of capsules and plates to identify defects/failures
- Identify geometric stability and cladding corrosion
Neutron Radiography

- Nondestructive way to examine fuel inside of cladding prior to sectioning
- Locate defects (cracking), identify fuel relocation (swelling, creep), perform dimensional analysis of fuel zone
- Identify mechanical integrity/stability of the fuel
**Gamma Scanning**

- Obtain fission product profile across plate surfaces
- Used for validation of calculated power profile using MCNP
- Power comparison between plates
- Identify any fission product relocation
- Confirmation of mechanical integrity of the fuel foil
Profilometry

- Localized fuel swelling values
- Quantify edge and peaking effects
- Investigate size effects and fission rate on swelling
- Validate geometric stability and quantify predictability of behavior
**Immersion Density**

- Pre-irradiation vs post-irradiation immersion density yields whole plate fuel swelling
- Eliminates localized effects that result from mini-plates
- Demonstrates fuel stability and predictable behavior
Eddy Current Testing (oxide thickness)

- Measurement of aluminum-hydroxide layer that forms on the plate surface.
- ASTM standard for eddy current testing used
- Excessive oxide growth can lead to plate surface corrosion
- Thicker layers can drastically influence fuel temperature
- Oxide thickness required to interpret fuel performance
- Validated using metallography
Metallography

- Observations of fuel swelling and fission gas morphology
- Interaction layer growth quantification
- Confirm mechanical integrity of the fuel foil
- Identify failure mechanisms
- 5x-750x magnification
Metallography

L1P754 – Mid Plane (8E+21 fissions/cc)
Blister Testing

- The blister test evaluates the maximum research reactor fuel use temperature and associated safety margins.
- The method has been used for 40+ years.
- Testing is conducted on irradiated fuel plates in HFEF.
  - Fuel plates heated and held at temperature.
  - Plates are then withdrawn from the furnace and inspected for blisters.
  - If no blisters are detected, the temperature is increased and the plate is retested.
- The test temperature at which the first blisters are seen is defined as the blister threshold temperature.
- The appearance of a blister is associated with fission gas release.
Future/Developing Technology

• Mechanical testing of irradiated fuel foils (4 point bend tests)
• 3D tomography of fuel elements using neutron radiography
• Blister testing of full sized fuel plates
• Handling of new geometries
• Bond strength measurements
• Residual stress measurements
• Advanced in-canal techniques
Future/Developing Technology

- New Measurement bench currently in qualification stage
- Capable of handling both full sized plates as well as shaped plates
- Measures both fuel plate thickness and oxide thickness simultaneously
- Developed in conjunction with SCK-CEN
Summary

• Individual post irradiation examination results provide feedback into demonstrating the mechanical integrity, geometric stability, and stable and predictable behavior of the fuel

• Comparison of behaviors observed over a range of fabrication parameters, irradiation conditions, and geometries provides confidence in the fuels performance

• Compilation of all fuel performance metrics will feed fuel down-selection as well as fuel qualification requirements