Non-Destructive and Destructive Testing for the 25 Sister Rods in the High Burnup Spent Fuel Data Project

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The U.S. Department of Energy Used Fuel Disposition (UFD) program was initiated to support removal of commercial SNF from utility sites. Mission: To identify alternatives and conduct scientific research and technology development to enable storage, transportation and disposal of spent nuclear fuel and wastes generated by existing and future nuclear fuel cycles.

Overall DOE goals include:
- Improve the overall integration of storage as part of the waste management system;
- Prepare for the large-scale transportation of spent nuclear fuel (SNF);

In support of these goals, near-term Storage and Transportation objectives include:
- Support the high-burnup (HBU) spent fuel full-scale storage data project;
- Develop understanding of how temperature and pressure affect cladding integrity in high-burnup SNF;
- Predictive modeling;
- Experimentation;
- Characterize external loadings on SNF during normal conditions of transport.
Assembly average discharge burnups have steadily increased since the first reactor came online

- However, there is a scarcity of publically available data on high burnup SNF properties

- In the U.S., typical SNF average assembly burnup has plateaued just above 45 GWd/MTU, and typical peak rod burnups are near 58 GW/MTU

- Per NEI (2012), dry storage of HBU fuel (>45 GWd/MTU) began in the last decade
  - Maine Yankee, beginning 2003, up to 49.5 GWd/MTU
  - Robinson, beginning 2005, up to 56.9 GWd/MTU
  - Oconee, beginning 2006, up to 55 GWd/MTU
  - Surry and North Anna, beginning 2007, up to 56.1 GWd/MTU
The US High Burnup SNF Data Project will experimentally define the effects of long-term storage and transportation on HBU SNF

- Cask to be loaded with HBU SNF in 2017 and opened in 2027 or later
- The project is led by EPRI and supported by DOE
- Information to be collected for the project includes:
  - Initial condition of as-irradiated HBU fuel rods prior to drying, transfer and storage
  - Impacts of drying, transfer, and storage on HBU fuel rods
  - Mechanical properties of HBU and dry-stored fuel rods
  - Effects of expected handling and transportation loads on the composite fuel system
  - Respirable release fractions from HBU fuel

The table below shows the characteristics of each cask basket cell:

<table>
<thead>
<tr>
<th>Cell ID / cask instrument (TC Lance)</th>
<th>Assembly identifier</th>
<th>Cladding material, assembly average burnup</th>
<th>Initial enrichment, cycles operated, cooling time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 6T0</td>
<td>Zirlo, 54.2 GWd</td>
<td>4.25%, 3cy, 11yr</td>
<td></td>
</tr>
<tr>
<td>2 (TC Lance)</td>
<td>30A</td>
<td>M5, 52.0 GWd</td>
<td></td>
</tr>
<tr>
<td>3 (TC Lance)</td>
<td>22B</td>
<td>M5, 51.2 GWd</td>
<td></td>
</tr>
<tr>
<td>4 6F2</td>
<td>Zirlo, 51.9 GWd</td>
<td>4.25%, 3cy, 13yr</td>
<td></td>
</tr>
<tr>
<td>5 3F6</td>
<td>Zirlo, 52.1 GWd</td>
<td>4.25%, 3cy, 13yr</td>
<td></td>
</tr>
<tr>
<td>6 (TC Lance)</td>
<td>30A</td>
<td>M5, 52.0 GWd</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>22B</td>
<td>M5, 51.2 GWd</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>20B</td>
<td>M5, 50.5 GWd</td>
<td></td>
</tr>
<tr>
<td>9 9K6</td>
<td>Zirlo, 53.3 GWd</td>
<td>4.25%, 3cy, 5yr</td>
<td></td>
</tr>
<tr>
<td>10 5D5</td>
<td>Zirlo, 55.5 GWd</td>
<td>4.2%, 3cy, 17yr</td>
<td></td>
</tr>
<tr>
<td>11 Vent Port</td>
<td>5D6</td>
<td>Zirlo, 54.6 GWd 4.2%, 3cy, 17yr</td>
<td></td>
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<tr>
<td>12</td>
<td>26B</td>
<td>M5, 51.0 GWd</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>F40</td>
<td>Zirc-4, 50.6 GWd 5.92%, 3cy, 30yr</td>
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<tr>
<td>14 (TC Lance)</td>
<td>57A</td>
<td>M5, 52.2 GWd</td>
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<tr>
<td>15</td>
<td>30B</td>
<td>M5, 50.6 GWd</td>
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<tr>
<td>16</td>
<td>3K4</td>
<td>M5, 51.8 GWd</td>
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</tr>
<tr>
<td>17</td>
<td>5K7</td>
<td>M5, 53.3 GWd 4.55%, 3cy, 8yr</td>
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<tr>
<td>18</td>
<td>50B</td>
<td>M5, 50.9 GWd 4.45%, 3cy, 5yr</td>
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<tr>
<td>19 (TC Lance)</td>
<td>3U9</td>
<td>Zirlo, 53.1 GWd 4.45%, 3cy, 10yr</td>
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<tr>
<td>20</td>
<td>4A4</td>
<td>w-Sn Zr-4, 50 GW 4.0%, 2cy, 22yr</td>
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<tr>
<td>21</td>
<td>15B</td>
<td>M5, 51.0 GWd 4.45%, 3cy, 5y</td>
<td></td>
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<tr>
<td>22</td>
<td>6K4</td>
<td>M5, 51.9 GWd 4.55%, 3cy, 8 yr</td>
<td></td>
</tr>
<tr>
<td>23 (TC Lance)</td>
<td>3U4</td>
<td>Zirlo, 52.9 GWd 4.45%, 3cy, 10yr</td>
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<tr>
<td>24</td>
<td>56B</td>
<td>M5, 51.0 GWd 4.45%, 3cy, 5yr</td>
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</tr>
<tr>
<td>25</td>
<td>54B</td>
<td>M5, 51.3 GWd 4.45%, 3cy, 5yr</td>
<td></td>
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<tr>
<td>26</td>
<td>6V0</td>
<td>M5, 53.5 GWd 4.4%, 3cy, 8yr</td>
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<tr>
<td>27</td>
<td>(TC Lance)</td>
<td>ST9</td>
<td></td>
</tr>
<tr>
<td>28 (TC Lance)</td>
<td>3U6</td>
<td>Zirlo, 53.0 GWd 4.45%, 3cy, 10yr</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>4V4</td>
<td>M5, 51.2 GWd 4.40%, 3cy, 8yr</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>5K1</td>
<td>M5, 53.0 GWd 4.55%, 3cy, 8yr</td>
<td></td>
</tr>
<tr>
<td>31 (TC Lance)</td>
<td>Zirlo, 54.9 GWd</td>
<td>4.25%, 3cy, 11yr</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>4F1</td>
<td>Zirlo, 52.3 GWd 4.25%, 3cy, 13yr</td>
<td></td>
</tr>
</tbody>
</table>

Each square represents a cask basket cell, with the cell identifier in the upper left corner and the identifying characteristics of the fuel assembly:
- Cell ID / cask instrument (TC Lance)
- Assembly identifier
- Cladding material, assembly average burnup
- Initial enrichment, cycles operated, cooling time.

Red outline = cask fuel assemblies with rods considered to be sisters to one or more of the 25 sister rods
Orange outline = sister rod direct donor assemblies
Twenty-five sister rods will be examined to provide a comparison point for the post-storage condition of the project cask rods

- Sister rods were received at ORNL in January 2016
- A sister or sister rod has similar characteristics to rods loaded into the project cask because they were extracted from assemblies with the same design and similar operating histories (symmetric partners) or from specific assemblies to be stored in the project cask
- Twenty-five 17×17 HBU rods from 7 commercial SNF assemblies operated at Dominion’s North Anna Reactor will be examined
  - 9 M5™ rods
  - 12 Zirlo® rods
  - 2 low tin Zr-4 rods
  - 2 Zircaloy-4 rods
The Post-Irradiation Examination (PIE) Program Will Be Conducted at ORNL’s Irradiated Fuels Examination Laboratory (IFEL)

Facility Includes:

- 3 Large Multi-Purpose Cells
- 2 Large Service Cells
- 4’ x 6’ Special Purpose Cell
- SEM Shielded Cubicle
- IMGA Shielded Cubicle
- 24 Storage Wells
- Hot Lab with Hoods

Comprehensive Facility for Post-Irradiation Examination of Nuclear Fuels
ORNL Hot Cells Are Highly Flexible and Support Non-Destructive Examination (NDE) of Full-Length Rods, Heater Testing, and Destructive Testing
The 25 Full Length Sister Rods Were Shipped to ORNL in the NAC-LWT Cask and Were Unloaded into the IFEL East Hot Cell

1. An air pallet/skid system is used to align and mate the cask to the East Hot Cell.
2. A grapple arm pulls the fuel canister part way into the cell.
3. Manipulators remove the fuel canister lid and slide the fuel rods into the storage box.
Nondestructive examinations (NDEs) will begin in October 2016 using the ORNL Advanced Diagnostics and Evaluation Platform (ADEPT)

• NDE will include:
  – Visual inspection
  – Gamma scans
  – Fuel rod overall length
  – Eddy current
  – Profilometry
  – Rod surface temperature
The ADEPT Set-Up Allows ORNL to Efficiently Examine Full Length Rods and Prepare Smaller Samples for Destructive PIE

Full Length Fuel Rod PIE Capabilities

• Automated High-Volume Digital Photography
• 1D Gamma Ray Scanning
• Axial Measurements accurate to .25 mm
• Radial Measurements accurate to 0.5 degree
• Eddy Current Gross Clad Inspection
• Rod Surface Temperature Measurements
• Fuel Rod Plenum Pressure (4% Accuracy)
• Fuel Rod Plenum Volume (6% Accuracy)
• Fission Gas Isotopic Determination
• Precision Cutting Saw for Accurate Sample Lengths
• Electronic Data Transfer
• Storage for 26 Full Length Fuel Rods (also have 1 MOX rod)
Destructive examinations (DEs) will follow the NDE and will include a variety of testing to benchmark the pre-storage condition of the HBU SNF

- Destructive examinations (DEs) will begin with rod puncture, gas sampling, and rod segmentation
- As each rod is punctured, rod internal pressure (RIP) will be measured
  - Pressure will be measured as a function of time as an indication of free communication through the pellet stack
  - Fission gas constituents, moles of each gas present, and rod free volume will be determined
  - The gas sample will be analyzed for the major fission gas isotopes
- Some of the 25 sister rods may be held in reserve for later use
- Some of the rods or rod segments will be heat treated to simulate cask drying conditions
Mechanical testing to be performed is still being specified, with several complimentary and overlapping tests being considered

• Proposed tests are being evaluated and prioritized and may include:
  – Fueled segments
    • Optical examinations, including metallography (MET) and scanning electron microscopy (SEM)
    • Spiral notch torsion toughness (SNTT)
    • Cyclic reversible bending fatigue (CIRFT)
    • Four-point bending
    • Ring compression testing
  – Defueled cladding
    • Clad hydrogen analysis (hot extraction method)
    • Tube tensile (axial) and burst testing
    • Ring compression testing
    • Expanded plug wedge testing
    • Hardness testing
Summary

• The High Burnup SNF Data Project will experimentally define the effects of long-term storage and transportation on HBU SNF. The project cask will be:
  – Loaded in 2017
  – Unloaded and examined in 2027 or later

• Twenty-five pre-storage “sister” rods will be examined to provide a benchmark for comparison with the cask rods

• The sister rods have been received at ORNL and NDE work to begin in CY2016

• All NDE will be performed in ORNL’s IFEL hot cell facility

• Destructive examinations will follow using a variety of test methods to characterize the performance/mechanical properties of the cladding and composite fuel rod

• Similar examinations to be performed on the cask rods

• This approach is expected to support extended dry storage and subsequent transport of commercial SNF

Help close the technical gaps to extended dry storage
Mechanical & thermal property data is needed for proprietary cladding alloys at high burnup