Recent studies on first generation indigenous Zr-2.5Nb pressure tube after 15.3 HOY

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Pressure tube operation in reactor

- Temperature
- Stress
- Corrosion
- Radiation damage

Changes in
- Dimension
- Microstructure
- Heq content
- Mechanical properties
Old Hot Cell
1974

New Hot Cell
2015

Hot Labs at PIED, BARC
Low Active Lab

Hot Labs at PIED, BARC
Steps followed for PIE of Pressure tube

Non destructive testing
  - Visual
  - Gamma scanning
    - Diameter measurement
    - Flaw detection
  - Ultrasonic testing

Destructive testing
  - Heq content
  - Hydride distribution
  - Oxide thickness
  - Fracture toughness
  - DHC velocity

Irradiated Zr-2.5Nb PT

Metallography
Diameter and Heq along the length of the Pressure tube after 15 HOY of reactor operation

Diameter and thickness

Schematic flux and temperature

Heq content
Hydride morphology at rolled joint and in main body region
Test specimen preparation

Trepanning of 30 mm dia. Disc coupons inside hotcell or at WWA

Drilling and notching to get DCT specimen

Zircaloy wire welding
Fracture toughness study on irradiated Indian Zr-2.5Nb pressure tube

Low Active Lab

Fracture toughness test set-up
Load-displacement plots

Fracture toughness at different temperatures
Fracture surface of the fracture toughness tested specimens
Comparison of fracture toughness of two different tubes: Q10 (15 HOY) and S7 (8 HOY)
Fissure density relatively more in S-7 compared to Q-10 pressure tube.

SZW relatively smaller in S-7 compared to Q-10 pressure tube.

<table>
<thead>
<tr>
<th>Pressure tube</th>
<th>Niobium (wt%)</th>
<th>Oxygen (ppm)</th>
<th>Chlorine (ppm)</th>
<th>Phosphorus (ppm)</th>
<th>Hydrogen (ppm)</th>
<th>Carbon (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-7</td>
<td>2.71</td>
<td>1019</td>
<td>1.37</td>
<td>12.83</td>
<td>11.9</td>
<td>244</td>
</tr>
<tr>
<td>Q-10</td>
<td>2.79</td>
<td>882</td>
<td>1.21</td>
<td>7.97</td>
<td>7.45</td>
<td>25.1</td>
</tr>
</tbody>
</table>
Application of fracture toughness test results

\[ K_q = \sigma \sqrt{\Pi a} f(a/W) \], where \( \sigma \) is stress and \( 2a \) is crack length.
Delayed hydride crack growth study on irradiated Indian Zr-2.5Nb pressure tube
<table>
<thead>
<tr>
<th>Material condition</th>
<th>Temp. (°C)</th>
<th>DHC Velocity (mm/hr)</th>
<th>Time for crack to grow from 18 mm to 55 mm (hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unirradiated</td>
<td>200</td>
<td>0.02</td>
<td>925</td>
</tr>
<tr>
<td>Irradiated</td>
<td>200</td>
<td>0.16</td>
<td>116</td>
</tr>
</tbody>
</table>
Application of fracture toughness and dhc velocity data

Time available to take action = \frac{(CCL-L)}{2V}
ORT = \frac{(CCL - LSC)}{(2 \times DHCV)}

If we assume LSC as 5 times thickness (3.6 mm) of PT, then using the experimental output for 200°C:

ORT = \frac{(55 - 18) \text{ mm}}{(2 \times 0.16 \text{ mm/hour})} = 116 \text{ hours}

But if the DHC grows at reactor operating condition i.e at 250°C then though the toughness is more or less same as that of 200°C, the available ORT will become:

ORT = \frac{(55 - 18) \text{ mm}}{(2 \times 0.45 \text{ mm/hour})} = 41 \text{ hours}
The fracture toughness parameters for irradiated Zr-2.5Nb pressure tube have been evaluated, using disk compact tension specimens, at different test temperatures.

The fracture toughness is quite low at 25°C, however the toughness improves at temperatures of 150°C and above.

Critical pressure and critical crack length values have been evaluated using these data to show adequate safety margins at operating conditions.

DHCV in irradiated pressure tube was found to be around 2 to 4 times than that in as-fabricated pressure tube in the operating temperature range.
All colleagues of PIED, BARC

Thank you!

Organizers

All of you