Recent progress on micro-cell UO$_2$ pellets

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Korea Atomic Energy Research Institute (KAERI)

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ATF Pellet Program in KAERI

- **Mid-term technology: Micro-cell UO$_2$ pellets**
  - Enhance retention capability of volatile fission products (Cs, I) → Reduced radioactivity release to the environment
  - Use existing infrastructure, experience and expertise to the maximum extent possible

- **Long-term technology: High uranium density pellets**
  - Develop innovative fuel pellets with uranium nitride (UN) composite
  - Increase uranium density & thermal conductivity → Increased discharge burnup (economy) and lower fuel temperature (safety)
Micro-cell UO₂ Pellet

- Objective: To enhance the retention capability of volatile fission products (Cs, I) during accident and normal conditions
- How: To provide many chemical and/or physical barriers (micro-cells) within UO₂ pellet that prevents volatile fission products being released to pellet outside
- Cell wall: Ceramic or metallic material
Micro-cell pellets: Fabrication Feasibility

- Ceramic wall: Si-based oxides, 1~2vol%
- Metallic wall: Refractory metals (Cr, Mo, Nb, alloys), ~5vol%

**Ceramic Micro-cell pellets**
- Mixing
- Eutectic
- Sintering
- Grain size: ~100μm
- Density: ~97%TD

**Metallic Micro-cell pellets**
- Coating
- Pressing
- Sintering
- Granule size: ~350μm
- Density: ~96.5%TD
Micro-cell pellets: Performance Feasibility

- Cs capture test (ceramic micro-cell)

- Thermal conductivity (metallic micro-cell)

Thermal conductivity of metallic micro-cell pellets increased by ~100%
Micro-cell pellets: Performance Feasibility

- **Steam oxidation test**
  - As polished
  - After 72h oxidation

  - UO₂
  - Metallic Micro-cell
  - Ceramic Micro-cell

- **Resintering test**

- **Thermal shock test**

  - UO₂
  - Metallic Ceramic
Metallic-cell: Cell geometry optimizing

Cell geometry on thermal conductivity

- Effect of aspect ratio

\[ AR = \frac{b}{a} \]

- Effect of cell size

Radial direction cell size \( r \) (\( \mu m \))

- Fixed metal volume
- Fixed aspect ratio

Analysis tool

KAERI / LWR Fuel Technology Division
Performance Assessment Plans

- Properties under normal operating condition
  - Thermal & mechanical properties: Thermal conductivity, Melting Temperature, Creep, Toughness, Heat capacity, etc.
  - Chemical properties: Water corrosion, oxidation, FPs retention, Cladding reaction, long-term stability

- Behavior under accident condition
  - Oxidation behavior under high temperature high pressure steam
  - Dimensional integrity at accident conditions
  - Compatibility with ATF claddings
  - Etc.

- Manufacturability, Reproducibility of pellets, ...

- Several test apparatuses are being equipped.

- Neutronics, Fuel cycle economy, ...
Fuel Cycle Economy

- Fuel cycle economy would be reduced
  - Wall volume ⇒ Low U loading, Neutron absorption by metallic wall

<table>
<thead>
<tr>
<th>Property</th>
<th>Cell Volume (additives)</th>
<th>U density (g/cm³) (4% porosity)</th>
<th>U density (g/cm³) (2% porosity)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UO₂</td>
<td>0</td>
<td>9.27</td>
<td>9.46</td>
</tr>
<tr>
<td>Ceramic micro-cell UO₂</td>
<td>1~2%</td>
<td>9.08</td>
<td>9.27~9.37</td>
</tr>
<tr>
<td>Metallic micro-cell UO₂</td>
<td>5%</td>
<td>8.81</td>
<td>[8.99, 9.17]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(reduced gap size 80⇒40µm)</td>
</tr>
</tbody>
</table>

- Partly compensable
  - Ceramic microcell UO₂ (soft pellets, reduced PCI)
    ⇒ Increasing the pellet density or decreasing the gap distance.
  - Metallic microcell UO₂ (cold pellets, reduced thermal expansion)
    ⇒ Increasing the pellet density & decreasing the gap distance
    ⇒ Metal alloy with reduced neutron capture cross-section
Irradiation Test Plan (1/2)

- **HANARO program**
  - 4 kinds ceramic + 2 kinds metallic micro-cell pellets
  - Target burnup: 20 GWD/MTU
  - Stability of wall and pellet, Cs capture ability
  - Irradiation period: two years
  - Pending due to overhaul
Halden reactor test: Cooperation with “Thor energy”

- Two ATF rods with instrumentation.
- **Rod 1**: Metallic microcell pellet + Surface modified Zr cladding
- **Rod 2**: Ceramic microcell pellet + Surface modified Zr cladding
- Irradiation period: 2015.06 ~ 2017.05 (Estimated burnup: 25GWD/MTU)

Halden reactor test: Halden Reactor Project (HRP)

- ATF Pellets were proposed as candidates for test
- Ceramic & Metallic microcell pellets are proposed
- Irradiation period: 2017 ~
Thank you for your kind attention!