OECD Halden Reactor Project

ATF experiments overview

4th Meeting of the Expert Group on Accident Tolerant Fuels for LWRs
PSI, Switzerland, September 17-18, 2015

Scott Holcombe (for Rudi Van Nieuwenhove)
Corrosion, creep and growth behaviour of ATF claddings

- Determine ATF cladding performance under normal PWR operating conditions
- Cladding corrosion determined via interim inspections (visual and eddy current) and PIE
- Cladding dimensional changes determined during interim and PIE (profilometry)
- Limited options for in-pile instrumentation
- Use of segmented rods as in IFA-708/785 to increase size of test matrix
- Option to start with smaller than standard fuel-clad gap to promote early PCMI
- Fuel pellet enrichment (to be made at Kjeller) to produce ALHR ~25-30 kW/m
ATF cladding test – proposed materials

- Candidate claddings proposed by HRP participants so far:
  - **CEA**
    - low tin Zry-4 with ~5-15 µm chromium coating (optimized PVD process)
    - 2 variants - different coating thickness and microstructure
  - **KAERI**
    - Zry-4 with ~80 µm chromium coating (3D laser process)
    - Surfaced modified Zry-4 (laser beam irradiation with ODS treatment)
  - **IFE**
    - Zry-4 with ~2-4 µm CrN coating (PVD – commercially available) as shown in IFA-774
  - **ORNL**
    - Modern Fe-Cr-Al ferritic alloys
    - 2 alloy composition variants
  - **EPRI**
    - PVD coated Mo thin-walled tube
    - 4 variants: Mo-LCAC (pure Mo) and Mo-ODS with a coating of Zry or FeCrAl
# ATF cladding test - test matrix under discussion

<table>
<thead>
<tr>
<th>Segment</th>
<th>CEA</th>
<th>KAERI</th>
<th>IFE</th>
<th>ORNL</th>
<th>EPRI</th>
<th>REF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rod 1</td>
<td>Rod 2</td>
<td>Rod 3</td>
<td>Rod 4</td>
<td>Rod 5</td>
<td>Rod 6</td>
<td></td>
</tr>
<tr>
<td>Top*</td>
<td>~5 μm Cr</td>
<td>~80 μm Cr</td>
<td>CrN</td>
<td>Mo-LCAC FeCrAl</td>
<td>Zry-4</td>
<td></td>
</tr>
<tr>
<td>Top-mid</td>
<td>~15 μm Cr</td>
<td>ODS</td>
<td>FeCrAl-2</td>
<td>Mo-LCAC Zry</td>
<td>Zry-4</td>
<td></td>
</tr>
<tr>
<td>Bot-mid</td>
<td>~5 μm Cr</td>
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</tbody>
</table>

* possibility to unload and replace segment mid-way for destructive PIE

NOTE: would require re-fabrication
ATF cladding test - test plan

• To be discussed and decided upon by HPG during 2015 with irradiation planned to start 2016

• Prototypic PWR conditions for ~5 years with target ~45 MWd/kg or 4-5 dpa

• Interim inspections after cycles 1, 3, 5, 7, 9:
  • cladding appearance (visual / photos)
  • oxide thickness and defect detection (where possible with eddy current technique)
  • dimensional changes (profilometry)

• PIE (can also be performed on segments unloaded e.g. mid-way*):
  • oxide thickness and morphology, hydrides (optical metallography and limited SEM)
  • HT oxidation (hot-cell LOCA) testing
  • recommend additional PIE and testing at participant labs (TEM, EPMA, mech. props, RIA ...)

• Specific objectives include:
  • Checking for any coolant-clad/coating interaction issues
  • Effect of irradiation on clad/coating microstructure and remaining HT oxidation resistance
  • Effect of PCMI on clad/coating integrity

* requires disassembly & subsequent re-fabrication with replacement segment
A long-term fuel irradiation experiment is planned to study the thermo-mechanical and FGR behaviour of enhanced performance fuels.

Candidate fuels proposed by HRP participants:

- Additive fuel aimed at retaining fission gas products in the pellets during transients/accidents and/or imparting higher thermal conductivity (KAERI)
- UN fuel with USi (SSM/KTH)
- Fuel as disks (high BU accumulation rate) for future PIE (cooperation with EPRI – NFIR) e.g. v.small/v.large GS, USi, UN, AlSi-UO2

Discussion and decision by HPG during 2015/2016 with irradiation starting 2017
Long-term irradiation of additive / ATF fuels – test plan

- Plan to use a test rig with 6 fuel rod positions (like IFA-716)
- Irradiation under HBWR conditions for ~5 years from zero to ~45 MWd/kg
- Fuel rods with small BOL fuel-clad gap (PCMI) and 3 instruments per rod
  - **Thermocouple**: fuel centre-line temperature (thermal conductivity)
  - **Pressure bellows**: fuel densification & swelling then FGR
  - **Fuel stack length**: direct fuel densification & swelling
- Specific objectives include:
  - How does micro-cell UO$_2$ fuel compare to UO$_2$ for thermo-mechanical and FGR?
  - Does micro-cell UO$_2$ fuel retain fission products during transients?
  - How does UN/USi compare to UO$_2$ for PCMI and dimension stability (swelling)?
  - “PIE behaviours” of fuel variants at high burn-up: thermal conductivity, microstructural changes, fission gas, fragmentation ........ (ref: IFA-649)
- Recommendation to plan for extensive PIE and testing also at participant labs
Thanks for your attention!