Accident Tolerant Fuel R&D status in China

Nuclear Fuel R&D Center
China General Nuclear Power Corporation (CGN)

3-5 March, 2015
Third meeting of OECD/NEA EGATFL, Paris
Contents

1. ATF development programs in China
2. ATF research facilities in CGN
3. Updated research activities
4. Summary
1. ATF development programs in China

- **Research on key technology of ATF**, *National Science and Technology Major Project, funded by Chinese government.*
  - Led by CGN, over 10 domestic organizations participate in.
  - Five sub-projects were included.
1. ATF development programs in China

- **Research on base properties of ATF, the Strategic Research Project of CGN.**
  - Financial supported by CGN, over 10 research group members in the project.
  - Four sub-projects are included.

1. Metrics
   - Scoping tests
   - Concept design

2. Advanced ODS alloys cladding
   - SiC cladding
   - Surface modification Zr cladding

3. Enhanced UO₂ pellets
   - FCM pellets

4. Simulation irradiation test and performance analysis
1. ATF development programs in China

**ATF R&D Strategy**

- ✔ Rodlets irradiation finished
- ✔ LTR/LTA ready

- ✔ Rodlets ready
- ✔ Rodlets irradiation (research reactor)

2015

- ✔ ATF general technology study
- ✔ Advanced cladding & fuel development

2017

- ✔ Cladding & fuel fabrication (lab-scale)
- ✔ Performance analysis & assessment
- ✔ Cladding samples ready for irradiation

2019

- ✔ Cladding & Fuel fabrication (trial)
- ✔ Fuel samples ready for irradiation

2021

- ✔ Rodlets irradiation finished
- ✔ LTR/LTA ready

2024
Contents

1. ATF development programs in China
2. ATF research facilities in CGN
3. Updated research activities
4. Summary
2. ATF research facilities in CGN

- **Research facilities of CGN**

  - Large-scale Hydraulic Test Facility
  - Integral Scale Hydraulic Test Facility, ISHY
  - Large thermal hydraulic test facility, LATHY
  - Seismic Effect Test Facility
2. ATF research facilities in CGN

- Research facilities of CGN

- New fuel assembly mechanical and hydraulic test facilities

- Material mechanical test machine

- LOCA high temperature oxidation and quenching simulation test facility
2. ATF research facilities in CGN

- Research facilities of CGN

Materials internal pressure creep and fatigue test facilities

XRD

SEM

XRD
2. ATF research facilities in CGN

- Research equipments of CGN-CAEP Joint Laboratory

- FEI TITAN TEM

- Pulsed laser sputtering deposit system

- Ion beam deposit system
2. ATF research facilities in CGN

- The new laboratory of CGN in Shenzhen is under construction

CGN would launch the experiments as following at the end of 2016:

<table>
<thead>
<tr>
<th>Research Facility</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials mechanical test</td>
<td>• strength, creep and fatigue</td>
</tr>
<tr>
<td>Materials corrosion test</td>
<td>• static and dynamic coolant corrosion</td>
</tr>
<tr>
<td>Materials oxidation test</td>
<td>• high temperature steam oxidation</td>
</tr>
<tr>
<td>LOCA simulating test</td>
<td>• high temperature steam oxidation and quenching</td>
</tr>
<tr>
<td>RIA simulating test</td>
<td>• high speed temperature and pressure increasing</td>
</tr>
<tr>
<td>Materials microstructure analyzing</td>
<td>• analysis with TEM, SEM and so on</td>
</tr>
<tr>
<td>Thermo physics property analyzing</td>
<td>• thermal expansion, heat conductivity and so on</td>
</tr>
</tbody>
</table>
Contents

1. ATF development programs in China
2. ATF research facilities in CGN
3. Updated research activities
4. Summary
3. Updated research activities

- ODS-FeCrAl cladding development

- ODS steels ingot and tube fabricated in China
  Supplied by University of Science and Technology Beijing

- TEM photo of ODS steels microstructure
  Supplied by University of Science and Technology Beijing

- The ODS-alloy powder is manufactured by mechanical alloying (MA)

- The ingot is manufactured by hot isostatic pressing
3. Updated research activities

- ODS-FeCrAl cladding development

- The corrosion of ODS-steel and other steel in water, 600°C, 25MPa
  Supplied by University of Science and Technology Beijing

- The mechanical properties of ODS-FeCrAl at RT and 700°C
  Supplied by University of Science and Technology Beijing

- The corrosion samples of ODS-steel
  Supplied by University of Science and Technology Beijing
3. Updated research activities

- SiC ceramic cladding development

- SiC/SiC<sub>f</sub> composite tube
  Supplied by Northwestern Polytechnical University

- Three layers SiC/SiC tube
  Inner tube is manufactured by CVD
  The fiber layer is densified by CVI

- SiC fibers
  Supplied by Xiamen University
3. Updated research activities

- Mo-alloy cladding development

The microstructure and mechanical properties of NS-Mo

Supplied by Xi'an Jiaotong University

<table>
<thead>
<tr>
<th>Alloys</th>
<th>Properties</th>
<th>1,000 °C</th>
<th>1,200 °C</th>
<th>1,300 °C</th>
<th>1,400 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tensile strength (MPa)/elongation (%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CP-Mo</td>
<td></td>
<td>120/8.6*</td>
<td>102/6.4</td>
<td>88/7.2</td>
<td>72/5.8</td>
</tr>
<tr>
<td>ODS-Mo</td>
<td></td>
<td>382/10.7*</td>
<td>205/8.7</td>
<td>184/11.4</td>
<td>167/9.6</td>
</tr>
<tr>
<td>NS-Mo</td>
<td></td>
<td>368/23.7*</td>
<td>224/28.8</td>
<td>211/25.4</td>
<td>185/22.7</td>
</tr>
<tr>
<td>TZM-Mo (ref. 17)</td>
<td></td>
<td>520/3.6</td>
<td>414/5.6</td>
<td>-</td>
<td>172/26</td>
</tr>
<tr>
<td>LCAC-Mo (ref. 17)</td>
<td></td>
<td>260/2.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ODS-Mo (ref. 17)</td>
<td></td>
<td>313/4.9</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Measured at 1,050 °C.
3. Updated research activities

- ATF conceptual design and preliminary analysis
  - LOCA performance

CGN & Xi’an Jiaotong University

**Cladding temp.**

**Fuel temp.**

![Graph showing cladding temperature over time for different materials](image1)

![Graph showing in-core hydrogen generation over time for different materials](image2)

![Graph showing in-core CO generation over time for different materials](image3)
3. Updated research activities

- ATF conceptual design and preliminary analysis

  **SBO performance**

<table>
<thead>
<tr>
<th>Event</th>
<th>UO$_2$-Zr</th>
<th>FCM-SiC</th>
<th>U$_3$Si$_2$-SiC</th>
<th>UO$_2$+BeO-FeCrAl$^a$</th>
<th>UO$_2$+BeO-FeCrAl$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cladding temp. to 1477K</td>
<td>8716.0*</td>
<td>9982.0</td>
<td>9756.0</td>
<td>9925.0</td>
<td>9811.0</td>
</tr>
<tr>
<td>Cladding temp. to 1672K</td>
<td>8907.0</td>
<td>11074.0</td>
<td>10887.0</td>
<td>11048.0*</td>
<td>10843.0*</td>
</tr>
<tr>
<td>Pellet temp. to 1938K</td>
<td>8987.0</td>
<td>17194.0</td>
<td>16916.0*</td>
<td>17269.0</td>
<td>16744.0</td>
</tr>
<tr>
<td>Pellet temp. to 2818K</td>
<td>8987.0</td>
<td>&gt;19000.0*</td>
<td>&gt;19000.0</td>
<td>&gt;19000.0</td>
<td>&gt;19000.0</td>
</tr>
</tbody>
</table>

*failure time

| Cladding temp. to 1477K| 8716.0*   | 9982.0  | 9756.0         | 9925.0                 | 9811.0                 |
| Cladding temp. to 1672K| 8907.0    | 11074.0 | 10887.0        | 11048.0*               | 10843.0*               |
| Pellet temp. to 1938K  | 8987.0    | 17194.0 | 16916.0*       | 17269.0                | 16744.0                |
| Pellet temp. to 2818K  | 8987.0    | >19000.0*| >19000.0       | >19000.0               | >19000.0               |

The first failure ATF system (UO$_2$+BeO-FeCrAl$^b$) is 2000s later than the standard UO$_2$-Zr system.

---

The first failure ATF system (UO$_2$+BeO-FeCrAl$^b$) is 2000s later than the standard UO$_2$-Zr system.
Contents

1. ATF development programs in China
2. ATF research facilities in CGN
3. Updated research activities
4. Summary
4. Summary

- ATF R&D projects have been approved and formally launched by China government and CGN, the funding is over 400 million RMB (60 million US dollar).

- Existing research facilities and abilities in CGN and Chinese ATF research groups will contribute to the implementation of ATF R&D activities, and much more advanced facilities are under construction or in plan.

- The research group has obtained some achievements on ODS-steel, SiC/SiC cladding, ATF conceptual design and preliminary analysis.
Thank you for your attention