Enhance the Collaboration in R&D in Fast Reactor and the Capabilities of CEFR towards Deployment of INES

Presented by Yang Yong

China fast reactor research centre, China Institute of Atomic Energy
Deputy director of reactor core research division
China
13810357055@163.com
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Current status and Challenges

China is the world's economic engine and also is the largest energy consumption country (22.4% in 2013);

China’s energy is 85% self-sufficient;

China’s per capital energy consumption is about the world average;

China’s energy is heavily relying on coal (67.5% in 2013).
China's energy demand expected to grow by 2% annually over the next 20 yrs.
China's energy policy

“National Plan for Coping with Climate Change”

to guarantee the realization of the target of cutting the carbon emission intensity by 40 to 45 percent by 2020 from the 2005 level.
China's energy policy

The development of nuclear power is a good choice for China to achieve sustainable energy development

★ An important mean for China to carry out the international commitment of reducing carbon emission

★ A realistic choice for China to optimize energy structure and ensure energy security

★ An important way for China to fuel domestic demand and boost the economic development

★ A major aspect for China to promote innovation and technology and upgrade the equipment manufacturing industry
China's nuclear power plan

Positive policy.

In 2020, the total capacity of nuclear power will be up to 40GWe and 18GWe will be under construction.

Percentage will be raised from 1.5% in 2005 to 4% in 2020.

A. The strategy study of INES in China
What’s the next?

——A study of INES in China

- PWR rise to 200GWe in 2050
- FBR capacity begins from 2030~2035
- The first step of FR is the breed reactor without MA transmutation, all the plutonium produced by PWR and FBR was used to support to the new FBR plant.
- The second step of FR is the fast transmutation reactor, with the uranium, plutonium and MA fuel recycle together after 2050.
FR Technology strategy of China

“three-step” strategy for development of FR technology in China.

✓ The China Experimental Fast Reactor (CEFR) (65MWt / 20MWe)
✓ The China demonstration Fast Reactor (CFR600) (about 600MWe)  2023?
✓ The China commercial Fast Reactor (1000~1200 MWe)  2030~2035?

<table>
<thead>
<tr>
<th>Electric Power</th>
<th>CEFR</th>
<th>CFR</th>
<th>CFR+</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 MW</td>
<td>600 MW</td>
<td>1000~1200 MW</td>
<td></td>
</tr>
<tr>
<td>Coolant</td>
<td>Na</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary Loop Type</td>
<td>pool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel Type</td>
<td>UO₂ / MOX</td>
<td>MOX / Metal</td>
<td>Metal</td>
</tr>
<tr>
<td>Cladding Material</td>
<td>Cr-Ni SS</td>
<td>Cr-Ni SS / ODS</td>
<td>Cr-Ni SS / ODS</td>
</tr>
<tr>
<td>Core Outlet Temperature</td>
<td>530℃</td>
<td>550~500℃</td>
<td>500℃</td>
</tr>
<tr>
<td>Fuel Linear Power</td>
<td>430W/cm</td>
<td>480 / 450 W/cm</td>
<td>450W/cm</td>
</tr>
<tr>
<td>Burnup</td>
<td>60~100MWd / kg</td>
<td>100~120MWd / kg</td>
<td>120-150MWd / kg</td>
</tr>
<tr>
<td>Fuel Operation</td>
<td>straight pull manipulator with double plug</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spent Fuel Storage</td>
<td>one cycle storage in the core and spent fuel storage water pool</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Engineered Safety Features

- Active Shutdown System
- Passive Residual Heat Removal

A. The strategy study of INES in China
B. Key technologies of sodium fast reactor towards INES

- **sustainability**
  - The higher BR fast reactor core design, especially including metal fuel technologies technology
  - The shortly reprocessing time of FBR spent fuel, especially including pyroprocessing technology.
key technologies of sodium fast reactor towards INES

- **Safety**
  - Passive reactor shut down system. The hydraulics control rod could prevent the ULOF effectively. But the reliability should be improved.
  - Preventing sodium fire in the fast reactor.
  - The passive reactor decay heat remove system.
  - Reducing the source term under severe accident
B. Key technologies of sodium fast reactor towards INES

- Environment friendship
  - MA transmutation in fast reactor. MA recycled with Pu and RU together.
  - Advanced FBR spent fuel reprocessing technology with the higher partition coefficient and shorter recycle time.
Some expectation of collaboration in R&D in fast reactor

The CFR600 is under studied. And how does the CFR600 support the commercial FBR plant. The following key technologies R&D should be taken:

✓ Fast reactor metal fuel R&D
✓ The test of cladding material with higher irradiation resistance
✓ Passive DHRS with nature convection R&D and verification
✓ The R&D of negative sodium vacuum reactivity effect
✓ MA transmutation technologies.
**The main parameters of CEFR**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Thermal power</td>
<td>65 MW</td>
</tr>
<tr>
<td>Experimental Electric Power</td>
<td>20MW</td>
</tr>
<tr>
<td>Fuel</td>
<td>UO$_2$ or MOX</td>
</tr>
<tr>
<td>Fuel SA/Control rods SA</td>
<td>81 / 8</td>
</tr>
<tr>
<td>Equivalent Reactor Core Diameter</td>
<td>600mm</td>
</tr>
<tr>
<td>Core Height</td>
<td>450mm</td>
</tr>
<tr>
<td>Maximum Neutron Flux Rate</td>
<td>$3.2 \times 10^{15} / 3.5 \times 10^{15}$</td>
</tr>
<tr>
<td>Maximum Fuel Burnup</td>
<td>60000MWd/t</td>
</tr>
<tr>
<td>Core Inlet/Outlet Temperature.</td>
<td>360 / 530°C</td>
</tr>
<tr>
<td>Core flow rate</td>
<td>301kg/s</td>
</tr>
</tbody>
</table>

D. Capabilities of CEFR towards INES
The irradiation parameter of CEFR

For the closed nuclear fuel cycle, a main purpose of CEFR is to test the fast reactor technologies and to demonstrate the fast reactor power plant. So there is not some special test channel in CEFR, but it provides 251 positions, which can be used for the irradiation test (cooled by forced circulation), including 81 fuel subassemblies, 1 neutron source subassembly and 169 SS subassemblies, beside of 8 control rod subassemblies. All the irradiation test targets must be put into a special test subassembly, which has the same shape with fuel subassembly.

<table>
<thead>
<tr>
<th>Position</th>
<th>Neutron flux, $1 / (\text{cm}^2\cdot\text{s})$</th>
<th>Max irradiation damage, Dpa/80EFPDs</th>
</tr>
</thead>
<tbody>
<tr>
<td>The very center</td>
<td>$3.2 \times 10^{15}$</td>
<td>8.6</td>
</tr>
<tr>
<td>$2^{nd}$ round</td>
<td>$3.2 \times 10^{15}$</td>
<td>9.3</td>
</tr>
<tr>
<td>$6^{th}$ round</td>
<td>$2.3 \times 10^{15}$</td>
<td>6.4</td>
</tr>
<tr>
<td>$7^{th}$ round</td>
<td>$1.9 \times 10^{15}$</td>
<td>4.5</td>
</tr>
<tr>
<td>$8^{th}$ round</td>
<td>$1.5 \times 10^{15}$</td>
<td>2.6</td>
</tr>
<tr>
<td>$9^{th}$ round</td>
<td>$7.1 \times 10^{14}$</td>
<td>0.8</td>
</tr>
<tr>
<td>$10^{th}$ round</td>
<td>$4.4 \times 10^{14}$</td>
<td>0.5</td>
</tr>
<tr>
<td>$11^{th}$ round</td>
<td>$3.1 \times 10^{14}$</td>
<td>0.3</td>
</tr>
<tr>
<td>$13^{th}$ round</td>
<td>$1.4 \times 10^{14}$</td>
<td>0.2</td>
</tr>
<tr>
<td>$15^{th}$ round</td>
<td>$2.9 \times 10^{13}$</td>
<td>0.04</td>
</tr>
</tbody>
</table>
High temperature sodium static test facility (SSTF)

SSTF is one of the serials test out-of-core facilities for studying the compatibility of SFR structural materials with high temperature sodium.

Max. temp.: 800°C;
Cover gas: Argon;
Oxygen in sodium: 10 ppm;
Carbon in sodium: 10 ppm.
High temperature sodium thermal convection test loop (STCTL)

STCTL is a quite important out-of-core loop which mainly used for studying the corrosion behaviour of SFR structural materials in the flowing sodium.

Total electric power: ~ 85 kW;
Gross capacity: ~ 0.125 m³;
Temperature of hot-leg: 550-650°C;
Temperature of cold-leg: 350-450°C;
Max. temperature difference: 250°C;
Flow rate in main circuit: 1.2 m³/h;
Flow rate in by-pass: 0.22-0.125 m³/h;
Pressure: 0.03-0.06 MPa;
Oxygen in sodium: 10-20 ppm.
Fuel-Cladding chemical interaction out-of-pile test facility (FCCITF)

FCCITF which is mainly used to simulate the interaction between SFR fuel cladding material with the fuel elements by out-of-pile simulation tests, while it could also serve for simulating chemical interactions between the control rod element B₄C pellets and the cladding of control sub-assembly.

Test temperature (maximum): 900°C; Oxygen buffer: Cr/Cr₂O₃ & Ni/NiO; Cs, Te and Se mixture: simulating fission product.
The materials analysis laboratory (MAL)

The materials analysis lab consists of electron microscopy lab and mechanical test lab which is located in the area of CEFR site.

The mechanical test lab includes a 300J pendulum impact machines, several tensile test machines and a bunch of creep testing machines. Some machines are located in a semi-hot cell which could perform mechanical tests on irradiated samples.
Some irradiation plan of CEFR

To support the China demonstration fast reactor, the following irradiation tests would be put in practice:

- MOX fuel irradiation test
- Cladding material irradiation test
- The UO$_2$ fuel with 5% MA transmutation test
Some expectation of collaboration of test in CEFR

CEFR is a platform to support the deployment of INES, it should be made fully used in the FR R&D, sharing the capability by collaboration:

✓ Fast reactor new fuel R&D irradiation test
✓ Cladding material irradiation test
✓ The more MA transmutation irradiation test
✓ Isotope production irradiation.
Thanks for your attention