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FBR produces more fissile plutonium from non-fissile uranium than they consume while generating power. FBR enables to secure domestic energy sources for centuries. The FBR technology realizes long-term and sustainable energy supply and is the essential national benefit of Japan.

**I. Significance of FBR development**

**Efficient use of uranium resources - securing stable energy supply**

- FBR produces more fissile plutonium from non-fissile uranium than they consume while generating power. FBR enables to secure domestic energy sources for centuries.
- The FBR technology realizes long-term and sustainable energy supply and is the essential national benefit of Japan.

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**What is Fast Breeder Reactor?**

- **Fast:** Fast neutron
- **Breeder:** Produce more fuel than they consume while generating power

(Convert Uranium-235 into Plutonium-239)

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Centuries utilization of Uranium
Accumulative uranium demand (Worldwide) (×10^4 ton)

- JAEA established Medium Nuclear Power Generation Scenario considering goals of Asian regions (especially in China and India) for expanding of nuclear power use
- Increasing use of nuclear power generation will make international competitions of securing uranium resources harder at the end of 21st century

- FBR cycle development for the future is critical worldwide in terms of energy security
- A country which commercializes FBR cycle at an early stage will be freed from competition for access to uranium resources

Change of accumulative uranium demand (FBR deployment and once through by LWR) *2

*1 Uranium 2009: Resources, Production and Demand (2010)
*2 Estimation by JAEA, Medium Nuclear Power Generation Scenario
FBRs Contribute to environmental burden reduction

Aiming to reduce the environmental burden

Reduction of environmental burdens due to high level waste

FBRs have a potential to burnup radioactive materials efficiently in the reactors. FBRs reduce management burdens on high level waste.

- Reduction in the amount of actinides and the heat generated due to recovery of MA, etc.
- Higher thermal efficiency of FBR
- Relaxed limit of heat generated during vitrification due to reduction in the amount of heat-generating FP production

- Increase in FP content due to higher volume reduction
- Increase in FP content in vitrified waste due to separation of heat-generating FPs and recovery of platinum-group FPs

Focus on the challenges of nuclear energy

Long-term contribution to reducing CO₂ emissions

Nuclear energy generation produces very low levels of CO₂ compared to others. FBRs realize long term use of nuclear energy and contribute to global warming reduction.

*Note*

1. CO₂ emissions intensity is calculated from all energy consumed in mining, plant construction, fuel transports, refining, plant operations and maintenance, etc. as well as burning of fuel.
2. Data for nuclear power includes reprocessing of spent fuel in Japan (now under construction). MOX fuel use in thermal reactors (assuming recycling once) and disposal of high level radioactive waste.
### II. Fast Reactor Commercialization and Monju

**Responsible organization**

- Commercial FBR (1500MWe)
- Demonstration FBR (500-750MWe)

**To be realized in 2025**

- Commercial scale adoption from 2050

**Announcement of**

- Reactor and cycle facilities to commercialize and the relevant demonstration facility concept designs

**JAEA**

- Restarted commissioning in May 2010
- Demonstration of reliability as a power plant
- Establishment of Na handling technology

- First criticality in 1977

**Monju, prototype FBR (280MWe)**

**Joyo, experimental FBR**

**Commercialization R&D (FaCT)**

- for innovative technologies and design study on commercial reactors
# Japan Sodium-cooled Fast Reactor (J SFR)

<table>
<thead>
<tr>
<th>Items</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>3,530MWt / 1,500MWe</td>
</tr>
<tr>
<td>Number of loops</td>
<td>2</td>
</tr>
<tr>
<td>Primary sodium temperature (Reactor vessel inlet / outlet)</td>
<td>550 / 395 degree C</td>
</tr>
<tr>
<td>Secondary sodium temperature (IHX inlet / outlet)</td>
<td>520 / 335 degree C</td>
</tr>
<tr>
<td>Main steam temperature and pressure</td>
<td>497 degree C / 18.7 MPa</td>
</tr>
<tr>
<td>Feed water temperature</td>
<td>240 degree C</td>
</tr>
<tr>
<td>Plant efficiency</td>
<td>Approx. 42%</td>
</tr>
<tr>
<td>Fuel type</td>
<td>TRU-MOX</td>
</tr>
<tr>
<td>Burn-up</td>
<td>150,000MWd/t (Reactor core average)</td>
</tr>
<tr>
<td>Breeding ratio</td>
<td>Break even (1.03) ~ 1.2</td>
</tr>
<tr>
<td>Cycle length</td>
<td>18-26 months</td>
</tr>
<tr>
<td>Number of refueling batches</td>
<td>4 batches</td>
</tr>
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</table>
Significance of Monju development

After the accident at the Fukushima Daiichi nuclear power plant, the world challenges of securing energy resources and preventing further global warming remain to be important ⇒ Japan needs long-term and sustainable stable energy security without depending on resources from other countries

FBR is a technology that Japan with scarce resources has developed over half a century as a state policy in public-private cooperation as a technology of high potential in order to tackle these problems

Monju has an important role to provide essential technical information for designs of demonstration reactor and commercial reactor, and operation maintenance as Japan’s prototype reactor toward commercialization of FBR

Evaluation of design technology
Accumulation of operation experiences
Sodium maintenance technology
Designs of demonstration reactor and commercial reactor, operation maintenance
The goal of Monju

Operating schedule

<table>
<thead>
<tr>
<th>Commissioning</th>
<th>Regular Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSTs (40% CT, Power Rising Test)</td>
<td>1st – 5th Cycle Operation</td>
</tr>
</tbody>
</table>

Plant status

<table>
<thead>
<tr>
<th>Initial core breeding</th>
<th>High burnup core (irradiation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commissioning and adjustment / initial failure</td>
<td>Random failure / Aging failure</td>
</tr>
</tbody>
</table>

Major results

<table>
<thead>
<tr>
<th>Safety demonstration during SBO</th>
<th>Demonstration of long-lived nuclides burnup [MA burnup]</th>
</tr>
</thead>
<tbody>
<tr>
<td>[Demonstration of practical fuel]</td>
<td>(R&amp;D for reduction of HLW)</td>
</tr>
<tr>
<td>(Core cooling by natural circulation)</td>
<td>[Demonstration of practical fuel]</td>
</tr>
<tr>
<td>(R&amp;D for maximum use of uranium)</td>
<td>High-burnup fuel</td>
</tr>
<tr>
<td>(Aimed for 2-3 times more than LWR fuel)</td>
<td></td>
</tr>
</tbody>
</table>

Other results

<table>
<thead>
<tr>
<th>Complete a prototype as a FBR power plant</th>
<th>High-burnup fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Performance confirmation such as 100% power test (Feasibility confirmation of power generation system)</td>
<td>High-burnup fuel (Aimed for 2-3 times more than LWR fuel)</td>
</tr>
<tr>
<td>- Confirmation of initial core (Criticality, reactor physics characteristics etc)</td>
<td>- Confirmation of aging characteristics of generating system due to long term full power operation</td>
</tr>
<tr>
<td>- Establishment of maintenance management technology through equipment inspection/failure correspondance experience (Maintenance program etc)</td>
<td>- Development and establishment of advanced maintenance technology (inspection technology etc) of loop-type reactor</td>
</tr>
<tr>
<td>- Improvement and upgrading of inspection technology of loop-type reactor (reactor inspection etc)</td>
<td>- Demonstration of MA transmutation (GACID)</td>
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<tr>
<td>- International collaboration (Tests participation of foreign researchers)</td>
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Reliability demonstration as a power plant

Establishment of Na handling technology

International human resource development

Establishment of maintenance management technology through equipment inspection/failure correspondance experience (Maintenance program etc)
### Core Confirmation Test results applied to FBR design study

#### Acquisition of reactor physics data

- Feature of the core: Most of fuels were irradiated or fabricated about 15 years ago.
  - \( \rightarrow \) Increased Americium-241 content: \( \sim1.5 \) wt% / MH
- Acquisition of world’s valuable data of reactor core which contains approx. 1.5wt% of americium 241 for reactor physics study toward commercialization.

\[ \Rightarrow \text{Core characteristics have been analyzed by JAEA method prepared for DFBR.} \]

Results of calculation show higher accuracy compared to the design criteria for DFBR.

#### Difference between analytical value and actual measured value

- **Criticality**: \( \pm 0.6\% \)
- **Control rod worth**: \( \pm 6\% \)
- **Doppler coefficient**: \( \pm 15\% \)

\[ \begin{align*}
\circ : & \text{JENDL-3.3} \\
\square : & \text{JENDL-4.0}
\end{align*} \]

**Note:** The analysis data in the chart is evaluated by calculation. Critical experiment correction is not included.

#### Utilization of data and offering results

- Conducting detailed evaluation and verifying the affectivity of the latest nuclear data, JENDL-4.0 on americium 241 etc. Releasing the results at international conferences and in academic journals.
The findings to be obtained from the future System Start-up Tests (SSTs);  
- Natural circulation test,  
- Plant trip transient test, etc.

**Verification of Analytical Method for Decay Heat Removal by Natural Circulation**

**System start-up tests (SSTs);**

- Natural circulation test,  
- Plant trip transient test, etc.

**Natural Circulation Analysis Model of JSFR**

- Non-dimensional number describing heat transfer;  
  \[ \text{Pe}_{\text{Monju}} \approx \frac{4}{5} \text{Pe}_{\text{JSFR}} \]
- Scaled experiments enable to predict natural circulation of JSFR;  
  \( \{ \text{Pe}_W > \text{Pe}_{\text{Monju}} > \text{Pe}_{\text{Na}} \} \)
  \( \text{Pe}_W; 1/10 \) scaled water experiment  
  \( \text{Pe}_{\text{Na}}; 1/5 \) scaled sodium experiment
### III. International Collaboration using Monju

- Expectation on Monju is considered to be significant because the other operable FBR prototype reactor in the Western countries, i.e. Phenix of France was shut down in 2009.

- Monju is actively offering prototype plant data to the world, which is important for FBR development. Extensive and detailed test data obtained from Monju will be an international benchmark of FR thermal hydraulics. Monju will make a contribution to validate the analysis codes for design/ safety assessment for each country.

- Monju can contribute as a place to perform irradiation tests to acquire FBR fuel and material irradiation data critical for FBR development. Monju will also make a contribution by providing education and training critical for improving technical level of FBR engineers and researchers.
Objective: To improve numerical analysis technology to accurately predict post-trip thermal stratification inside the upper plenum of reactor vessel after, which is a common issue among various types of sodium-cooled fast reactors.

Inside the upper plenum of actual reactor vessel, acquisition of thermal stratification data produced an unprecedented result in the world (turbine trip test in a state of 40% operation, on 1995 December).

Participating countries/organizations:
IAEA, USA (ANL), France (CEA), Russia (IPPE), India (IGCAR), China (CIAE), Korea (KAERI), Japan (UF, JAEA)
Expected results

» Extensive and detailed test data obtained from Monju will be an international benchmark of FR thermal hydraulics. Monju will make a contribution to validate the analysis codes for design/safety assessment for each country.

» Transient data obtained from the 100% output test of the system start up tests of Monju makes thermal high-accuracy stratification and structure evaluation possible for future reactors.
International collaboration using Monju [2]

- Establish analysis codes developed in each country based on the design data of Monju
- Utilize for FBR design

France (CEA)

CATHARE (CEA)

Monju

(Exchange of views: Reaffirm Monju based on the data obtained from 35-year-operation of Phenix → Reflect the results in operation of Monju)

Korea (KAERI)

Super-COPD (JAEA)

Offering of test results

- Provide information on plant specification and characteristics

Phénix

Temperature change in the reactor outlet due to plant trip
Purpose:
Demonstration of a major candidate fuel for commercial FBRs: Minor-Actinide (MA) bearing fuel (also referred to as “TRU Fuel”) making use of “Monju” and “Joyo”

GACID Overall Schedule

**Step-1**
Pin irradiation of Np/Am bearing fuel

**Step-2**
Pin irradiation of Np/Am/Cm bearing fuel

**Step-3**
Subassembly irradiation of Np/Am/Cm bearing fuel

- Possibility demonstration of total MA recycle using transmutation in FBRs
- A phased approach in 3 steps
- SFR project in the Generation-4 International Forum
The BRC’s final report to the Secretary of Energy
(issued on January 26, 2012)

- New comprehensive strategy for back-end management of nuclear fuel cycle in the U. S.

- The BRC report includes eight key elements:
  (1 – 6, 8 omitted)

7. Support for continued U.S. innovation in nuclear energy technology and for workforce development.
History and Development Plans of FR Cycle in the World
Ⅳ. Conclusion

1. After the accident at the Fukushima Daiichi nuclear power plant, the world challenges of securing energy resources and preventing global warming remain to be important. Securing long-term and stable supplies of energy is essential.

2. FBR realizes long-term and sustainable energy supply. The technology is the essential national benefit of Japan.

3. Monju, as the Japanese prototype reactor for the purpose of FBR commercialization, has an important role to provide indispensable technical information for design, operation and maintenance of demonstration and commercialized FBRs.

4. Data obtained from Monju is an international benchmark and contributes to validate the analysis codes for each country. Monju also can make a contribution as a place for irradiation tests to acquire FBR fuel and material irradiation data and as a place for education and training improve technical level.