Transmutation Experimental Facility for Research and Development of Accelerator-Driven System (ADS) in JAEA

Kazufumi Tsujimoto
Research Group for Nuclear Transmutation System
Japan Atomic Energy Agency (JAEA)

IGORR 2014 / IAEA TM on enhanced utilization of zero power and subcritical assemblies, Bariloche, Argentina, 17-21, Nov. 2014
Contents

- Introduction
  - Background and motivation for new experimental study

- FCA (Fast Critical Assembly)

- TEF-P (Transmutation Physics Experimental Facility) in J-PARC project
  - General configuration
  - Conceptual design
  - R&T
  - Construction schedule

- Conclusion
Partitioning and Transmutation (P&T) technology is expected to be effective in mitigating the burden of the HLW disposal by reducing the radiological toxicity and heat generation.

JAEA has been studying this technology for more than 20 years.

**Homogeneous cycle**

**Double-Strata (ADS)**

- MA is homogeneously mixed to FBR fuel with small amount up to 5 wt.%.  
- MA transmutation is performed in all electricity generating FBR plant.

- Dedicated (second) transmutation fuel cycle with Accelerator-Driven System (ADS) is added to commercial fuel cycle.
**Purpose: MA transmutation**

- Proton beam: 1.5GeV ~20MW
- Spallation target: LBE
- Coolant: LBE
- Subcriticality: $k_{\text{eff}} = 0.97$
- Thermal output: 800MWt
- Core height: 1000mm
- Core diameter: 2440 mm
- Fuel inventory: 4.2t (MA:2.5t)
- Fuel composition:
  - (MA + Pu)N+ZrN (Mono-nitride)
  - Inner: 70%MA+30%Pu
  - Outer: 54%MA+42%Pu
- Transmutation rate:
  - 250kg(MA) / 300EFPD
About 2% discrepancies in k-eff were found among the different nuclear data in a IAEA-CRP benchmark proposed to survey current status of calculation accuracy of ADS by JAEA.

Nuclear data validation by integral experiment is essential.

**Fig.** Calculated results for IAEC-CRP benchmark proposed by JAEA (Burnup calculation for the first burnup cycle of 600 EFPD with 800MWth ADS)
Validation by integral experiments

- The current status of nuclear data is not so satisfactory for the neutronics design of ADS as MA transmutation system.
  - Validation of nuclear data, not only for MA and Pu but also other nuclide (Pb, N-15), is significantly necessary by using integral experimental data. There are a few or no integral experimental data for these nuclides.

- Mock-up experiments using large amount of MA and Pu (U-free) and subcritical core with spallation target in the fast neutron system are a necessary step to realize the ADS for MA transmutation.
  - Validation of neutronics characteristics, such as k-eff, reaction rate, etc.
  - Validation of safety parameters, such as void reactivity, Doppler reactivity, delayed neutron fraction, etc.
  - Validation of characteristics for subcritical core with spallation neutron, such as power distribution, subcriticality measurement, etc.
Type: Horizontal split-table type
For loading: they are separated
For operation: they are brought together

Structure: Square tube matrix
Tube: 55mm square x 1300mm long
Number of tubes: 51 rows x 51 columns
(2.8m x 2.8m)

Power: 2kW (maximum)

Cooling: Air circulation
(for removal of Pu decay heat)

Control/Safety Rods: Fuel drawers
(to avoid singularities in flux distributions near C/R)

Operation: 1967-
FCA (Fast Critical Assembly) in JAEA (2/2)

Large flexibility for fuel composition and core geometry

- Reactor materials: 2”-2” with different thickness (1/16”, 1/8”, 1/4”)
  - Fuel:
    - Enriched (HEU, LEU) Uranium metal
    - Natural Uranium metal
    - Plutonium metal in SS container
  - Other plates:
    - Solid Na, Al$_2$O$_3$, AlN, Graphite, Polystyrene, SS, B$_4$C, etc.

- Loading: Hand-loading
  Reactor material plates are packed into drawers by hand.
  Drawers are loaded in desired pattern into each half assembly.
Necessity of new critical assembly

- FCA is the only fast critical assembly of split-table type in operation. It has various unique features.
  - Large flexibility in composition, large flexibility in geometry, great variety of neutron spectrum, etc.

- However, it is difficult to upgrade for the new demand based on the new regulation.

New experimental facility

- Horizontal split-table type
  - to utilize core materials of FCA,
  - to minimize cost and risk of R&D for new facility by utilizing experience of FCA, and
  - to take over the experiences and functions of FCA.

- New functions
  - Proton beam injection and
  - Large amount of MA in kg-order
Zero power critical assembly (max. 500W) operated in both critical and sub-critical.

Proton beam with 400eV (max. 10W) from LINAC will be horizontally introduced.

MA-bearing fuel will be used by replacing central partial matrix tubes with pin-type assembly.

Transmutation Physics Experimental Facility (TEF-P)

Experiments in “critical mode”

ADS experiments in “subcritical with proton beam”

Stainless steel matrix
Coolant simulator (Pb, Na, etc.)

Plate-type fuel
Fuel drawer
Pin-type fuel

SUS lattice
Coolant simulator (Pb, Na)

Proton beam
Beam duct
Spallation target

MA pin fuel
Fuel drawer
Pin-type MA bearing fuel for TEF-P

- Partial mock-up experiments are planned to evaluate MA contributions in nuclear characteristics for MA transmutation systems, ADS and FBR.
- The partial mock-up region composed of pin-type fuels will be newly prepared and will be installed in the central region in TEF-P.
- MA pins are inserted in a coolant simulator (Calandria) which are inserted to core matrix made by stainless steel.

MA fuel (tentative)

<table>
<thead>
<tr>
<th>Composition:</th>
<th>Pu: Am=50:50</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pu = reactor grade</td>
<td>Am = Am-241</td>
</tr>
<tr>
<td>Chemical form:</td>
<td>oxide or nitride</td>
</tr>
<tr>
<td>Inert matrix:</td>
<td>MgO or ZrN with 50vol%</td>
</tr>
<tr>
<td>Geometry:</td>
<td>φ9mm, L300mm</td>
</tr>
<tr>
<td>Total mass:</td>
<td>~60kgTRU</td>
</tr>
</tbody>
</table>
Development of handling equipment

- Requires remote handling device to storage/transport/loading of MA fuel
- Basic functional tests for MA fuel loading device is planned to be performed in 2015
- Heat removal test in coolant simulator (Calandria) is prepared simultaneously
J-PARC (Japan Proton Accelerator Research Complex)
Transmutation Experimental Facility (TEF)

**Transmutation Physics Experimental Facility: TEF-P**

Purpose: To investigate physics properties of subcritical reactor with low power, and to accumulate operation experiences of ADS.

Licensing: Nuclear reactor: (Critical assembly)

Proton beam: 400MeV-10W

Thermal power: <500W

---

**ADS Target Test Facility: TEF-T**

Purpose: To research and develop a spallation target and related materials with high-power proton beam.

Licensing: Particle accelerator

Proton beam: 400MeV-250kW

Target: Lead-Bismuth Eutectic (LBE, Pb-Bi)

---

Critical Assembly

Multi-purpose Irradiation Area

Proton Beam

Pb-Bi Target
Phase-I construction of J-PARC was completed.

Phase-I facilities were in service until March 2011. Although there were significant damages by the earthquake, the operation was restarted in Dec. 2011.

The Transmutation Experimental Facility (TEF) is the main project in Phase-2 of J-PARC, however, it is still waiting for the approval of the Government.
Current Condition of Facility Site

Earthwork for future beam line connection

LINAC Building
### Time schedule of FCA and TEF-P (tentative)

<table>
<thead>
<tr>
<th>Fiscal Year</th>
<th>2013</th>
<th>14</th>
<th>15</th>
<th>16</th>
<th>17</th>
<th>18</th>
<th>19</th>
<th>2020</th>
<th>21</th>
<th>22</th>
<th>23</th>
<th>24</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Licensing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decommissioning</td>
<td>▼ re-start</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TEF-P</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Licensing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Uncertainties

- **Removal of HEU and Pu fuel from FCA**
  
  Removal and disposal plan of all HEU and separated plutonium from FCA was announced by Joint Statement by the Leaders of Japan and the United States on Contributions to Global Minimization of Nuclear Material (March 24, 2014)

- **Budget for the construction of TEF-P**
  
  Estimated cost of about 130 M$ has not yet approved by the Government.
Concluding remarks

  - “Nuclear power is an important base-load power source”
  - “GOJ will promote development of technologies for reducing the volume and harmfulness of radioactive waste in order to secure a wide range of options in the future.”

- JAEA has been conducting the R&D activities on P&T technology.

- New experimental facility, TEF, for R&D of P&T.
  - The technical challenges for ADS spread over wide range. Various basic R&D have been implemented, and new experimental facility, TEF, is proposed in the J-PARC project in JAEA.
  - TEF-P is planned as a critical assembly with MA bearing fuel and proton beam.
  - Time schedule for removal of FCA fuel (HEU & Pu) and construction of TEF-P is still uncertain, however, we will continue the experimental study using critical assembly with fast neutron field.
Thank you very much for your attention.