ACTIVITIES ON ADS AT JAEA

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New Structure for ADS Development at JAEA: Midterm Plan

Description in “Midterm Plan” of JAEA

- Partitioning
  - New Extractant, Process Design, Laboratory Demonstration, ....

- Transmutation
  - General
    - Nuclear Data and Reactor Physics
    - Material Properties of MA and LLFP
  - FBR
    - Design, Fuel Irradiation, ....
  - ADS
    - Design
    - Accelerator
    - Spallation Target (Material, Thermal-hydraulics)
    - Lead-Bismuth Eutectic (LBE) Technology (Corrosion, Po Behavior, ..)
    - Dedicated MA Fuel

Scenario Study

Benefit of P&T on HLW Management
New Structure for ADS Development at JAEA: Directorates Concerning R&D on ADS

Nuclear Science and Engineering Directorate
- Director General: O. Oyamada
- Deputy Director General: T. Ogawa

- Division of Nuclear Data and Reactor Engineering
- Division of Fuels and Materials Engineering
- Division of Environment and Radiation Sciences
- Nuclear Applied Heat Technology Division

Quantum Beam Science Directorate
- Proton Accelerator Facility Development Unit

J-PARC Center

Advanced Nuclear System Research and Development Directorate

Research Co-ordination and Promotion Office

R&D on ADS
R&D on ADS fuel and materials
Development of J-PARC accelerators and facilities
Operation and maintenance of J-PARC
R&D on FBR cycle
Scenario Study: Characteristics of ADS and Possible Scenarios

- Two significant advantages of the dedicated transmutation strategy:
  1. It can accommodate various situations of the commercial power generation fuel cycle in an appropriate and flexible manner.
     - Suitable to the transient phase from LWR to FBR.
  2. MA can be confined into a small-scale dedicated fuel cycle.
     - Helpful for the deployment of the FBR.

- Taking these advantages into account, three typical situations of nuclear fuel cycle with the dedicated transmutation system can be assumed:
  a. LWR – ADS
  b. LWR – FBR – ADS
  c. FBR – ADS

- In this scenario study, the total capacity of the nuclear power generation is fixed at 58 GWe for all the situations.
Scenario Study:  
a. LWR-ADS

- “Pseudo Equilibrium State” with UO$_2$-LWR + MOX-LWR (58GWe)

MA can be managed in a very small dedicated fuel cycle.
Pu will be stored as MOX spent fuel and then used as FBR fuel.
Scenario Study:
b. Transient from LWR to FBR

"Transient Phase" with UO₂-LWR + MOX-FBR (58GWe)

α: Ratio of FBR deployment

Size of ADS cycle will not be affected by the situation of LWR and FBR cycles.
Scenario Study: c. FBR with ADS

“Symbiotic State” with FBR (58GWe):

- FBR and ADS co-exist **symbiotically and complementarily**.
- By adopting ADS and its dedicated transmutation cycle, MA can be confined and FBR cycle can be optimized from viewpoints of **reliability, safety and economy**.
- The scale of ADS cycle is about **1/30** of the commercial FBR cycle.
- The mass flow of the cycle will be about 13 t/y, which means about 50 kg/day of MA fuel will be enough to be fabricated.
Conceptual Design: Reference ADS

- Proton beam: 1.5 GeV
- Spallation target: Pb-Bi
- Coolant: Pb-Bi
- Max. $k_{eff} = 0.97$
- Thermal output: 800 MWt
- MA initial inventory: 2.5 t
- Fuel composition: $(\text{MA + Pu})\text{Nitride} + \text{ZrN}$
  - Initial loading:
    - Zone-1: Pu/HM = 30.0%
    - Zone-2: Pu/HM = 48.5%
- Transmutation rate: 10%MA / Year
- 600 EFPD, 1 batch
Engineering Feasibility:
Spallation Target and Beam Window

- 30 MW proton beam with 1.5 GeV causes heat deposition of 15.7 MW.

- Conditions and criteria for the beam window:
  - Inlet temp. : 300 °C
  - LBE flow: < 2 m/s
  - Temp. of outer surface: < 520 °C
  - Structural strength: Thermal stress, buckling, etc.

- The feasibility of the beam window was verified under the nominal operation conditions, but the effect of corrosion, irradiation and fabrication accuracy should be discussed.

- We should accumulate experience on LBE spallation target.
The increase in YS of irradiated specimens is within the fission neutron irradiated data band at lower dose. At higher dose, the increase in YS of JPCA-SA shows a tendency to exceed the upper bound the fission neutron irradiated data band.
Bend fatigue tests for SINQ irradiated specimens

No or little change of the fatigue life was observed for the irradiated JPCA-SA and 316F-SA specimens.
It is important to reduce the power peaking factor throughout the whole burn-up stage.

Power peaking will be the highest at EOC of the 2nd. cycle.

Two-zone core is adopted to reduce power peaking.

The hot spot pin will be about 600°C at EOC of the 2nd. cycle.

Efforts to reduce this temperature below 550°C are being continued:
- More detailed zoning
- Adjustment of inert matrix (ZrN) at every burnup stage
- Adoption of partial height fuel
- Adoption of reactivity adjustment rods, etc.

Power density of two-zone core (axial position: center)
**Engineering Feasibility:**

*Static Test - Low Oxygen Concentration*

- SX(18Cr-19Ni-5Si)
- 316SS
- Pure iron
- 2.25Cr-1Mo
- 430SS
- 410SS
- JPCA(14Cr-16Ni-2Mo)
- Mod.9Cr-1Mo
- F82H(8Cr-2W)

**Corrosion Depth (mm/y):**

- **316SS**
  - 316SS shows deep corrosion
  - 100µm

- **2.25Cr-1Mo steel shows grain boundary corrosion**
  - 20µm

**Conditions:**

- 550 °C, O₂: 3x10⁻⁹wt%, 3000h

- **Oxide**

- **Grain boundary corrosion**
The reactor physics parameters are very influential for the optimization of core design.

Uncertainty of reactor physics parameters was estimated on the basis of the sensitivity of nuclear data and the error files evaluated for JENDL-3.3.

Large uncertainty was found in $k_{eff}$ and burnup reactivity.

The capture reaction of Am-241 has significant effect.
Reliability: Acceptable Beam Trip Frequency

- Thermal stress caused by beam trip is estimated to know acceptable frequency of beam trip.
  1. Beam window
  2. Inner barrel
  3. Reactor vessel

- The influence of the beam trip to the power generation system is also estimated.
Reliability: Thermal Shock on Beam Window

- Beam window:
  - $450\text{mm}^\phi$, $2\text{mm}$, 9Cr-1Mo steel,
  - beam power: 30 MW
- Beam trip will cause max. 179 MPa thermal stress 0.5 sec. after the beam trip.
- This thermal stress is much lower than a criteria to prevent buckling failure.
- The acceptable number of this thermal shock: about $10^5$
- Several beam trips per an hour is acceptable for 2 years (about 15,000 hours)
- It should be noted that this estimation is based on the material data without radiation damage.

![Temperature of beam window at beam trip transient](image)

**Graph:**
- Temperature (°C) vs. Time after beam trip (s)
- Restart
- max. 82°C

**Graph legend:**
- Inner surface
- Outer surface
- Coolant
- Temperature difference

**Table:**

<table>
<thead>
<tr>
<th>Time after beam trip (s)</th>
<th>Inner surface</th>
<th>Outer surface</th>
<th>Coolant</th>
<th>Temperature difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>80</td>
<td>100</td>
<td>60</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>120</td>
<td>140</td>
<td>80</td>
<td>40</td>
</tr>
<tr>
<td>3</td>
<td>180</td>
<td>200</td>
<td>120</td>
<td>80</td>
</tr>
<tr>
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<td>7</td>
<td>420</td>
<td>440</td>
<td>280</td>
<td>160</td>
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<td>8</td>
<td>480</td>
<td>500</td>
<td>320</td>
<td>180</td>
</tr>
<tr>
<td>9</td>
<td>540</td>
<td>560</td>
<td>360</td>
<td>200</td>
</tr>
<tr>
<td>10</td>
<td>600</td>
<td>620</td>
<td>400</td>
<td>220</td>
</tr>
</tbody>
</table>
Reliability: Thermal Shock on Inner Barrel

- Inner barrel: 3cm³, 9Cr-1Mo steel
- Beam trip will cause max. 130 MPa thermal stress 24 sec. after the beam trip.
- The stress range will be 260 MPa considering the following restart transient.
- The acceptable number of this thermal shock: about 10⁴
- 250 trips per year is acceptable for 40 years.

Temperature and stress of inner barrel at beam trip transient:

Temperature (°C)

Stress (N/mm²)

max. 130N/mm² at 24s
Reliability: Thermal Shock on Reactor Vessel

- Reactor vessel: 5cm, 9Cr-1Mo steel
- Temperature difference between inner and outer surface will cause 113 MPa thermal stress just before beam restart (400 s).
- Additionally, the formation of the temperature stratification and the LBE level lowering by thermal shrinkage will also cause 109 MPa.
- In total, the stress range will be 270 MPa considering the following restart.
- The acceptable number of this thermal shock: about $10^4$
- 250 trips per year is acceptable for 40 years.
Reliability: Behavior of Electric Power Generation System

- Saturated steam cycle with steam drums enables us to continue power generation in case of short beam trip.

![Graph showing temperature and power output over time]

- Beam trip for 400 s

- Electric Power

- Core outlet temperature

- Core inlet temperature
Reliability: Summary of Criteria

Three criteria depending on the beam trip duration $T$

<table>
<thead>
<tr>
<th>Beam trip duration $T$</th>
<th>Acceptable frequency</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T &lt; 1$ sec.</td>
<td>$10^5 / 2$ year</td>
<td>Beam window life time</td>
</tr>
<tr>
<td></td>
<td>(50,000 / y)</td>
<td></td>
</tr>
<tr>
<td>1 sec. &lt; $T &lt; 5$ min.</td>
<td>$10^4 / 40$ year</td>
<td>Fatigue failure of reactor structure</td>
</tr>
<tr>
<td></td>
<td>(250 / y)</td>
<td></td>
</tr>
<tr>
<td>$T &gt; 5$ min.</td>
<td>Once a week</td>
<td>System availability</td>
</tr>
<tr>
<td></td>
<td>(50 / y)</td>
<td></td>
</tr>
</tbody>
</table>
Reliability:
Strategy to Reduce Beam Trip Frequency

SINQ and LANSCE experiences show 1 or 2 orders of frequency reduction might be necessary to meet the criteria.

Three strategies for reduction:
1. Reduction of the beam trip duration down to 1 sec.
2. Reduction of frequency for relatively long beam trip
3. Mitigation of the criteria by design consideration and detailed transient analysis.

Detailed analysis on the causes of the beam trips is underway to explore the realistic solutions for Strategy-1 and 2.
## Cost: Preliminary Estimation

### Preliminary Estimation of ADS Cost (billion Japanese Yen = $10^9$ JY)

<table>
<thead>
<tr>
<th>Items</th>
<th>Construction</th>
<th>Operation and maintenance</th>
<th>Decommissioning</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADS-reactor</td>
<td>150</td>
<td>240&lt;sup&gt;a)&lt;/sup&gt;</td>
<td>12&lt;sup&gt;b)&lt;/sup&gt;</td>
<td>402</td>
</tr>
<tr>
<td>ADS-accelerator</td>
<td>76</td>
<td>122&lt;sup&gt;a)&lt;/sup&gt;</td>
<td>6&lt;sup&gt;b)&lt;/sup&gt;</td>
<td>204</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>226</strong></td>
<td><strong>362</strong></td>
<td><strong>18</strong></td>
<td><strong>606</strong></td>
</tr>
</tbody>
</table>

<sup>a)</sup> 4% of construction cost per year.  
<sup>b)</sup> 8% of construction cost

### ADS Cycle Cost ($10^9$ JY)

<table>
<thead>
<tr>
<th>Items</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 units of ADS</td>
<td>2450</td>
</tr>
<tr>
<td>Partitioning process</td>
<td>570</td>
</tr>
<tr>
<td>MA fuel fabrication</td>
<td>520</td>
</tr>
<tr>
<td>MA fuel reprocessing</td>
<td>450</td>
</tr>
<tr>
<td>Profit by ADS electric power</td>
<td>-750</td>
</tr>
<tr>
<td>Reduction of number of repository sites</td>
<td>-1900</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1340</strong></td>
</tr>
</tbody>
</table>

- Balance: 0.12 ~ 0.13 JY/kWh  
  (discount rate: 0%)
- About 2-3% increase of the electricity cost in Japan.
- Cost of ADS is the most influential.
Current Status of J-PARC Project: Site Plan

Sept. 15, 2005

Hadron Experimental Facility
Material and Life Science Facility
Neutrino

50 GeV

3 GeV

Site for Transmutation Experimental Facility
LINAC
Current Status of J-PARC Project: LINAC Klystron Gallery

Aug. 1, 2006
Current Status of J-PARC Project: LINAC Beam Line

June 22, 2006
**Current Status of J-PARC Project: Transmutation Experimental Facility**

1. Transmutation Experimental Facility (TEF): **Phase-2 Program**.
2. TEF consists of the Transmutation Physics Experimental Facility (TEF-P) and the ADS Target Test Facility (TEF-T).
3. Because of the budget shortage, **step by step construction** will be necessary.
The project team is calling for the Preliminary Letters Of Intent (Pre-LOI) for TEF.

Purposes:
- To know which groups have an interest in this activity.
- To reflect the proposals on the specifications and layout of the TEF.
- To establish an appropriate collaboration scheme between J-PARC and the anticipated outside users.

Up to now, we received about 30 proposals on
- Reactor physics for ADS
- Experiments using MA for both FR and ADS
- High energy particle behavior
- MA cross section measurement using pulsed spallation source
- Engineering feasibility of LBE spallation target, etc.

We are still accepting proposals, so please do not hesitate to contact us.
Step-by-step Approach for ADS and Importance of International Collaboration

- ADS Transmutation Plant
  800MWt, Pb-Bi Target/Coolant
  Transmute 250kg of MA annually

- Experimental ADS
  30 - 100MWt, Pb-Bi Target/Coolant

- Transmutation Experimental Facility
  Pb-Bi Target with 200kW beam
  Physics experiments at low power

It is important to share a common roadmap in international community
Concluding Remarks

- The new organization JAEA continues the R&D efforts on the ADS.
- Scenario study shows the flexible nature of ADS to manage MA, and one of ultimate options would be FBR-ADS symbiotic state.
- The engineering feasibility of ADS is being studied on beam window and core performance.
- The reliability of ADS, especially for beam trip transient, is also being studied and the strategy to enhance the reliability is being discussed.
- The preliminary cost estimation shows that about 2-3% of cost increase would be expected to introduce P&T technology with ADS.
- The TEF of J-PARC Project is waiting for the approval, and the Pre-LOI is now being called for.