Nuclear data needs for transmutation system

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  - Benefit and role of Partitioning and Transmutation
  - Accelerator-Driven System (ADS) for minor actinide (MA) transmutation

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  - Benchmark calculation in IAEA-CRP
  - Uncertainty analysis utilizing covariance data of nuclear data for calculation results

- Summary
Benefits of P&T on Management of High-Level Radioactive Wastes (HLW):

- Reduction of long-term radiological toxicity
- Reduction of dose for future inhabitants
- Reduction of amount of HLW
- Reduction of repository size
- Recovery of valuable materials from wastes, and so on.

To mitigate difficulties caused by long-term nature of radioactivity

To extend capacity of a repository

Steady implementation of High Level Waste (HLW) disposal is one of the most important issues even though we select to reduce dependency on nuclear energy.

Partitioning and Transmutation (P&T) will be a key technology to reduce the environmental burden of HLW.
**Purpose: MA transmutation**

- Proton beam: 1.5GeV ~20MW
- Spallation target: LBE
- Coolant: LBE
- Subcriticality: $k_{eff} = 0.97$
- 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

Allowable maximum $k$-eff for ADS

- High $k$-eff value implies low proton beam current and small power peaking, but risk of approaching criticality under accidental conditions will increase.

- **The subcriticality must be set to adequate level considering accidental insertion of reactivity and uncertainties for calculation and measured reactivity.**

<table>
<thead>
<tr>
<th>Accidental insertion reactivity</th>
<th>$%\Delta k/k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam tube filled with Pb-Bi$^{1)}$</td>
<td>0.32</td>
</tr>
<tr>
<td>Unusual temperature rise of coolant Pb-Bi$^{2)}$</td>
<td>0.69</td>
</tr>
<tr>
<td>Uncertainty for measurement$^{3)}$</td>
<td>0.50</td>
</tr>
<tr>
<td>Uncertainty for calculation</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2.51</strong></td>
</tr>
</tbody>
</table>

1) Pb-Bi entry to the vacuum beam tube by failure of the beam window
2) Coolant temperature rise of 1000K in only fuel region by coast down
3) Accuracy of $\beta_{\text{eff}}$ influences directly


Allowable maximum $k$-eff was set at **0.97**
To survey current status of neutronics design accuracy for ADS, benchmark calculations were performed in framework of IAEA-CRP. Benchmark problem was based on the ADS design proposed by JAEA.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Code</th>
<th>Library</th>
</tr>
</thead>
<tbody>
<tr>
<td>JAEA (Japan)</td>
<td>PHITS, NMTC or MCNPX (MC code for proton and neutron &gt;20MeV) SLAROM (Cross section code) TWODANT (Deterministic neutron transport code) ORIGEN (Burn-up code)</td>
<td>JENDL-3.3 JENDL-4.0 JENDL-3.2 ENDF/B-VI JEFF-3.0</td>
</tr>
<tr>
<td>CIEMAT (Spain)</td>
<td>EVOLCODE2 (MCNPX-based burnup code)</td>
<td>JEFF-3.0 (JEFF-3.1) a) (ENDF/B-VI) a)</td>
</tr>
<tr>
<td>KIT (Germany)</td>
<td>High energy particles are not analyzed. C4P, ZMIX (Cross section code) DANTSYS (Deterministic neutron transport code) TRAIN (Burn-up code)</td>
<td>ENDF/B-VII JEFF-3.1</td>
</tr>
</tbody>
</table>

a) Library in parenthesis is only for the beginning of cycle (BOC).
About 2% discrepancies in k-eff were found among the different nuclear data libraries in a IAEA-CRP benchmark proposed to survey current status of calculation accuracy of ADS by JAEA.


Calculated results for IAEC-CRP benchmark proposed by JAEA (Burnup calculation for the first burnup cycle of 600 EFPD with 800MWth ADS)
Current status of neutronics design of ADS (2/2)

- Identification of typical contributors for the differences among the calculated $k_{\text{eff}}$ values with different nuclear data library, JENDL-4.0 ENDF/B-VII, and JEFF-3.1

- Δkeff due to library exchange of single nuclide from JENDL-4 to ENDF/B-VII or JEFF-3.1 estimated by MCNPX.

The cause of the difference between the calculation results with JENDL-4.0 and JENDL-3.3 are the cross section of Am-241, Pb-206, and Pb-207.

**Fig.** Nuclide-wise contribution for the difference between calculated $k_{\text{eff}}$ with JENDL-4.0 and 3.3

**Table** Reaction-wise contributions for the difference between calculated $k_{\text{eff}}$ with JENDL-4.0 and 3.3

<table>
<thead>
<tr>
<th></th>
<th>fis</th>
<th>$\nu$</th>
<th>cap</th>
<th>inl</th>
<th>el</th>
<th>$\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{241}\text{Am}$</td>
<td>76</td>
<td>208</td>
<td>255</td>
<td>293</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>$^{206}\text{Pb}$</td>
<td></td>
<td></td>
<td>-34</td>
<td>674</td>
<td>3</td>
<td>-5</td>
</tr>
<tr>
<td>$^{207}\text{Pb}$</td>
<td></td>
<td></td>
<td>-14</td>
<td>560</td>
<td>14</td>
<td>-4</td>
</tr>
</tbody>
</table>

Summary of IAEA-CRP benchmark

- Small difference between participants (codes) with same library.
- $k$-effective disperse from 0.98 to 1.0 at BOC and 0.93 to 0.96 at EOC.

To design an ADS is very difficult, if estimated $k$-effective changes 2 to 3 %dk.

Uncertainty should be evaluated.
Uncertainty evaluation results for k-eff

Total uncertainty: **1.04%Δk**

- The uncertainty for k-eff of 1% is smaller than the result of IAEA benchmark activity (2-3%).

**Fig.** Nuclear- and reaction-wise Breakdown of criticality uncertainty

**LBE**

**Iron**

**Nitrogen**

- **Pb, Fe-56**
  - Inelastic scattering
- **N-15**
  - Elastic scattering

- **MA, Pu**
  - Capture cross section
  - Fission spectrum
  - Fission cross section
\textbf{\textsuperscript{241}Am capture cross section}

- **Sensitivity coefficients**

- **Covariance data (1\sigma S.D.)**

- **Energy breakdown of uncertainties**

**Fig. \textsuperscript{241}Am capture cross section**

Nuclear-data evaluation in this region (\textit{From \textasciitilde 1 keV to 1 MeV}) affects the uncertainties in the integral parameters!
**206Pb inelastic cross section**

- **Sensitivity coefficients**
- **Covariance data (1σ S.D.)**
- **Energy breakdown of uncertainties**

**Fig.** $^{206}$Pb inelastic scattering cross section

Nuclear-data evaluation in this region (From threshold to ~3MeV) affects the uncertainties in the integral parameters of the ADS.
The current status of nuclear data is not so satisfactory for the neutronics design of ADS as MA transmutation system.

- The benchmark results for the neutronics parameters of ADS showed that there were large differences among the calculated parameters with different nuclear data libraries. For example, the differences for the calculated k-eff values were approximately 3%.

Improvement of nuclear data, not only for MA and Pu but also other nuclide (Pb, N-15), is significantly necessary for transmutation system.

In order to meet the requirements for the nuclear data to improve the design accuracy, continuous effort including not only differential experiments but also the integral experiments are important issue.