Improvement of dynamics calculation code

DSE for Accelerator Driven System

5th International Workshop on the Utilization and Reliability of High Power Proton Accelerators

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I. Introduction

Development of Accelerator Driven System (ADS)

- An ADS has been developed to transmute high level waste which includes such as MA (Minor Actinide) and LLFP (Long-Lived Fission Products).
- The ADS has following characters:
  - High transmutation efficiency than Critical reactor.
  - High inherent safety and flexibility of core loading on designing etc.

![Fig. Concept of Accelerator Drive System](image)
II. DSE code system

To study ADS dynamics, DSE code system has been developed

DSE (Dynamics calculation code system for Sub-critical system for External neutron source)

- **DSE can treat both changes of**
  - the accelerator parameters
    - (beam intensity, energy, diameter, injection position etc.) and
  - the reactor parameters
    - (coolant flow, reactor power, temperature, density etc.)

- **This code can calculate both static and dynamics calculations for neutronics and thermal-hydraulics**

- **DSE calculates**
  - the neutron flux, the adjoint flux, the dynamics parameter, the external neutron source and
  - the thermal power, the coolant temperature and the fuel temperature etc.
Concept of DSE code system

**Input data**
Core geometry, composition
Source change event etc.

**Reactors part**

- **JENDL-3.3 Calculation by SRAC**
- **Convert cross section for DSE**
- **3-dimensional Neutronics calculation**
- **Thermal-hydraulics calculation**

**High energy part**

- **Proton and Neutron Calculation by PHITS**
- **Database for spallation neutron**

**Event parameters**
(Accelerator and reactor parameters)

**External neutron source**

**Feedback of Fuel temperature**

**Recalculation neutron source**
(when event occurred)
DSE code system

DSE has three functions for neutronics calculation

- **DSE-C**: Diffusion code (CITATION)
  - Low change of neutron flux events (startup, shutdown and restart etc.)
- **DSE-T**: Transport code (THREEDANT)
  - Wide range dynamics events
- **DSE-M**: Monte Carlo code
  - Reference calculation with high accuracy

DSE has been verified for

- The static neutronics calculation by comparing with other codes
- The dynamic neutronics calculation by comparing with theoretical value and other codes
- The thermal-hydraulics calculation by comparing with the benchmark problem

Development of DSE-M and its application
Development of DSE-M

DSE-M has adopted the GMVP code

- General Purpose Monte Carlo Code for Neutron and Photon Transport Calculations based on Multigroup Methods developed by JAEA

- DSE-M can solve
  - the exact treatments of neutron transport, angular dependence and geometry description
  - the adjoint calculation function, the calculation of the dynamics parameters

- The effect of the calculation error by the Monte Carlo calculation is examined
  - In the static calculation, the maximum error is about 1.4% in neutron flux
  - The error of dynamics calculation is about 1.0% in core power (if the history is enough)
  - The calculation error of the Monte Carlo to the dynamics calculation is a little

- DSE-M has a problem for calculation time
  - The static calculation of 5 million histories spends about 20 hours
  - The dynamics case of 40sec event spends about 3 days

We consider that DSE-M is effective for the reference calculation
III. Application of DSE-M

Calculation of beam variation is performed by using
- Assembly model
- Fuel pin model

The fuel pin model is used to define the fuel pin in the assembly

Fig. fine geometry model
III. Application of DSE-M

Beam variation events

- Reference case
  - The proton beam is injected to the center of the core with the diameter of 1cm

- Beam diameter case
  - The beam diameter is changed from 1 to 40cm

- Beam shape case
  - The beam diameter of y-axis is changed from 1 to 13cm while the diameter of x-axis is fixed to 26cm

- Beam injection position case
  - The beam injection position is changed from 0 to 24cm, i.e. the beam moves from the center to the peripheral of the target

Fig. Conceptual for beam variation events
III. Application of DSE-M

Beam variation events

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![Conceptual diagram for beam variation events](image)

Fig. Conceptual for beam variation events

- a) reference case
- c) **Beam shape case**
III. Application of DSE-M

Beam variation events

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Fig. Conceptual for beam variation events
## Adopted ADS model in this study

### Table. Main parameter of reference ADS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power</td>
<td>800 [MWt]</td>
</tr>
<tr>
<td>Multiplication factor</td>
<td>0.95</td>
</tr>
<tr>
<td>Core height/diameter</td>
<td>1.00 / 2.50 [m]</td>
</tr>
<tr>
<td>Target height/diameter</td>
<td>1.50 / 0.5 [m]</td>
</tr>
<tr>
<td>Core fuel element</td>
<td>(MA+Pu)+ZrN</td>
</tr>
<tr>
<td>Target and Coolant material</td>
<td>Liquid Pb-Bi</td>
</tr>
<tr>
<td>Coolant temperature (in/out)</td>
<td>603 / 703 [K]</td>
</tr>
<tr>
<td>Coolant flow rate</td>
<td>$1.98 \times 10^8$ [kg/h]</td>
</tr>
<tr>
<td>Transmutation efficiency</td>
<td>250 [kgMA/year]</td>
</tr>
<tr>
<td>Proton beam energy</td>
<td>2.0 [GeV]</td>
</tr>
</tbody>
</table>

![Fig. ADS core design and calculation mesh](image)

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12 Neutron device engineering laboratory
Calculation for the variation of position (1)

Fig. Neutron flux distribution (assembly model)

It is confirmed that the peak of the neutron flux significantly increases at the position of core center.
Calculation for the variation of position (2)

The maximum peaking factor (MPF) is examined

\[ MPF = \frac{\text{maximum neutron flux at peak location}}{\text{average neutron flux of the core}} \]

When the beam injection position move from 0cm to 24cm, the MPF increases about 1.6 times larger

Fig. Calculation results for maximum peaking factor in assembly model
The fuel pin model is applied

- The MPF for the pin cell model is 6.7, while the MPF by the assembly model is 4.5

The MPF by fuel pin model increases about 1.6 times larger than that by assembly model

Neutron flux distribution is varied significantly with the change of beam injection position

Fig. Calculation results for maximum peaking factor in fuel pin model
For the variation of the core power

The dynamics calculation is examined by using DSE-M (by the assembly case)
When the beam injection position moves from 0cm to 24cm at 20sec,
- The thermal power quickly increased from 800 to 900MWt
- The fuel temperature increase was about 1800K after 20sec

The variation of the beam position has significant effect to thermal power and fuel temperature

Fig. Variation of thermal power

Fig. Variation of fuel temperature increase
IV. Summary and future works

- **DSE code system have been developed**
  - We developed the code which has three method of neutronics calculations
  - DSE-M can solve the exact treatments of neutron transport, angular dependence and geometry description, the adjoint calculation function, the calculation of the dynamics parameters
  - In the static and dynamics calculation, the effect of the calculation error of the Monte Carlo is a little

- **By using DSE-M, the calculation of the beam variation events was performed**
  - The diameter case and the shape case have a little effect
  - The Beam injection position case has significant effect to neutron flux, core power, fuel temperature
    - When the beam injection position moves from 0cm to 24cm,
      - The MPF for the pin cell model is 6.7
      - The thermal power quickly increased from 800 to 900MWt in the dynamics
      - The fuel temperature increase was about 1800K after 20sec in the dynamics
IV. Summary and future works

- The verification of DSE should be performed with the experiment data

- **We are searching the dynamics experiment data**

- Experiment conditions is required
  - Sub-critical core
  - Experiment of variation of neutron source
    - Insertion or withdrawal of fixed neutron source
    - Variation of Beam intensity by accelerator
  - Experiment of reactivity insertion
    - Insertion or withdrawal of the control rod
    - Control rod drop
  - Neutron counting by neutron detector
    - Several locations in core
    - Time dependent measurement