Seismic Safety Margin Assessment of BWR Scrammability

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Hitachi-GE Nuclear Energy, Ltd.

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Contents

1-1. Introduction(Control Rod Insertion System)

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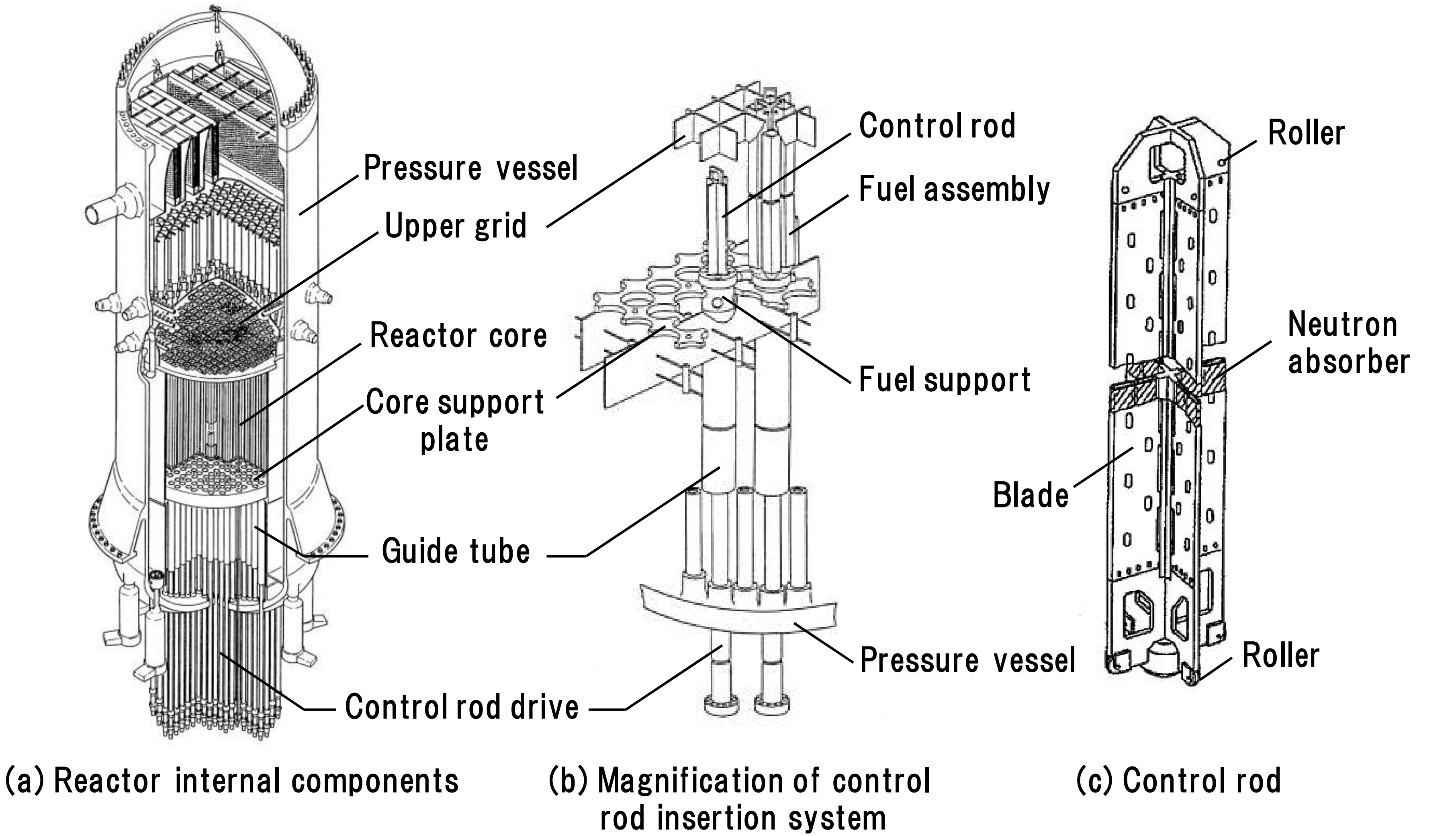


The estimation of the control rod insertability is one of the most important design tasks affecting the scrammability of the reactor under seismic events.

1-2. Introduction

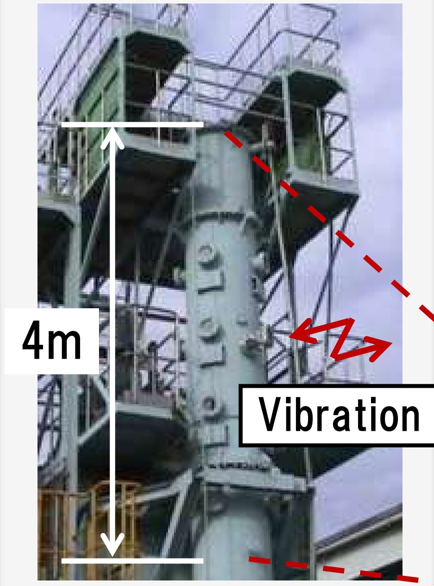
【Conventional estimation】

The insertion time of the control rod is conventionally estimated by vibration tests using sinusoidal input wave.

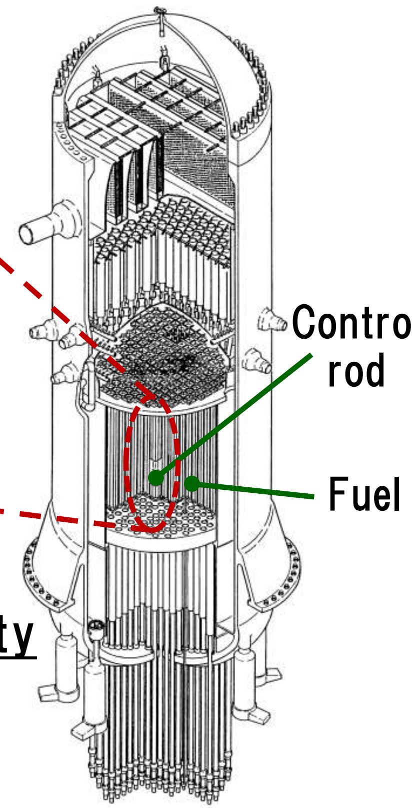
Difference between test condition and the real condition
- Temperature and pressure
- Input wave

Establishing a more accurate estimation of the seismic scrammability

⇨ Combination between numerical analysis method and experimental method



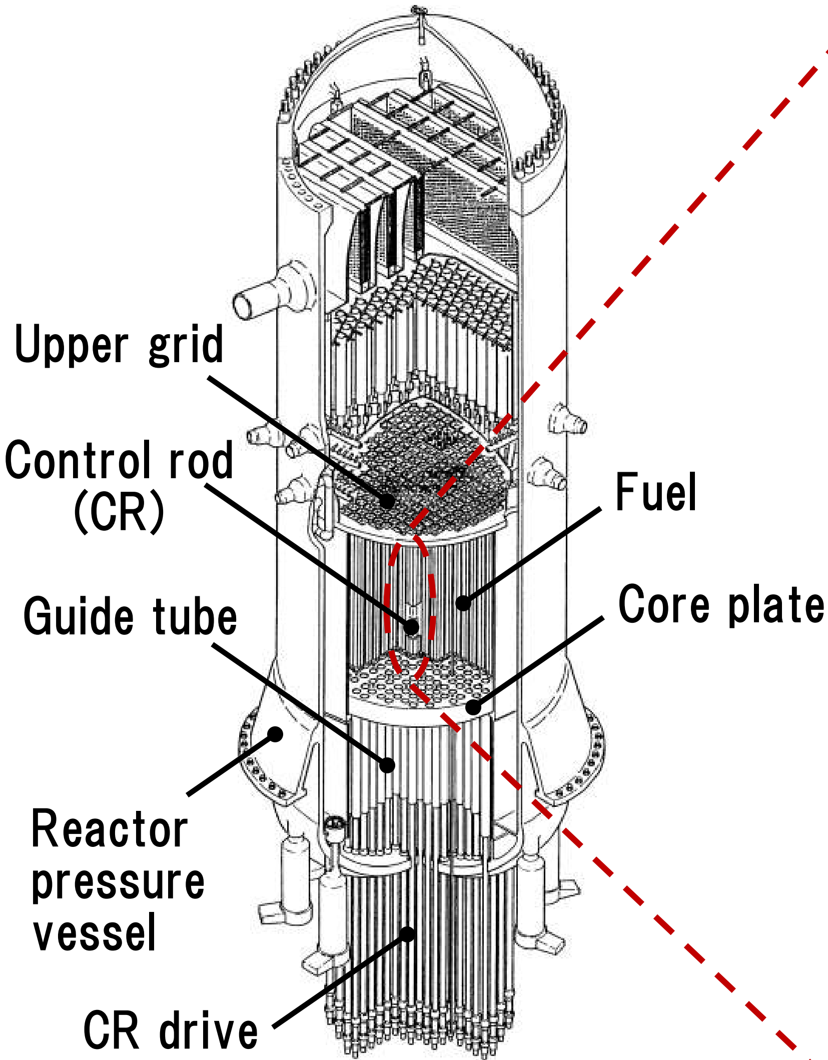
Vibration test



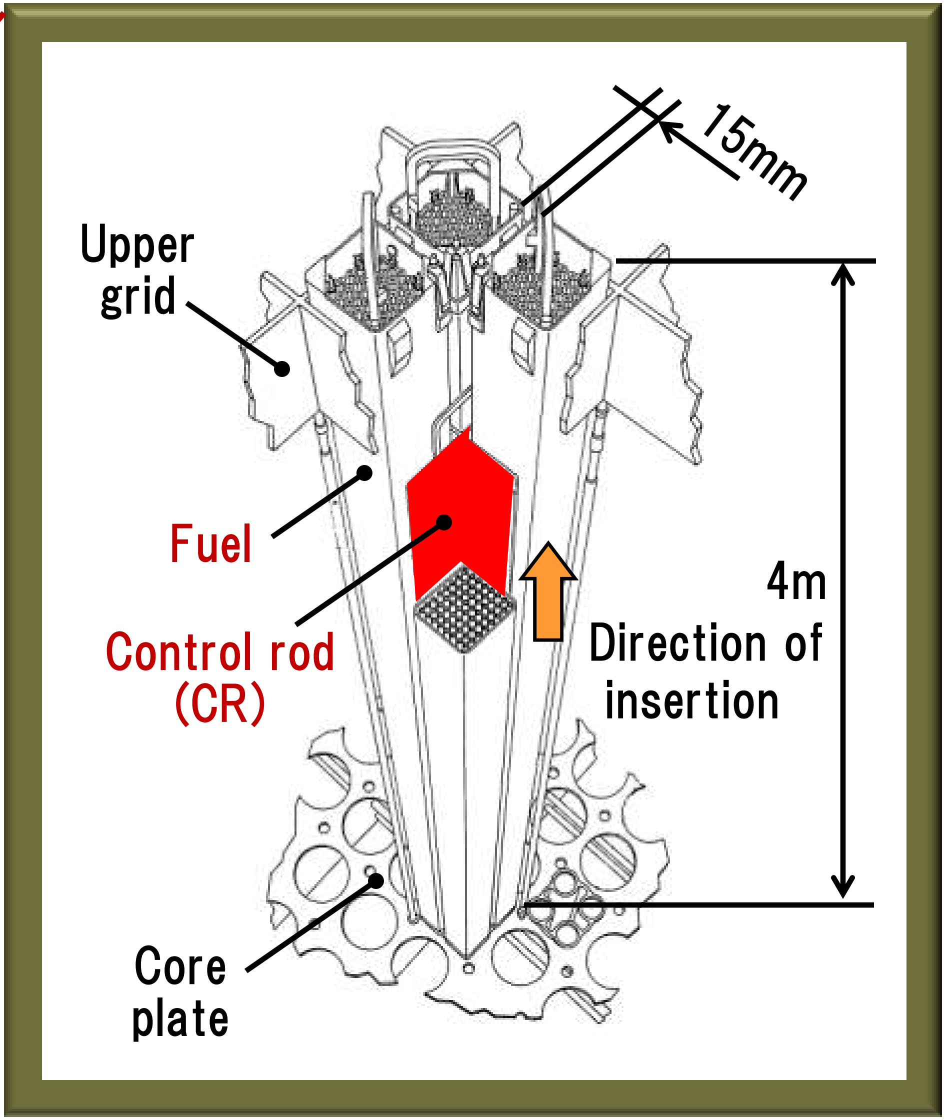
BWR

The following are main contents of this presentation
- Development of a numerical analysis technology
- Seismic safety margin of scrammability focused on the dependence of the insertion time on input seismic motion

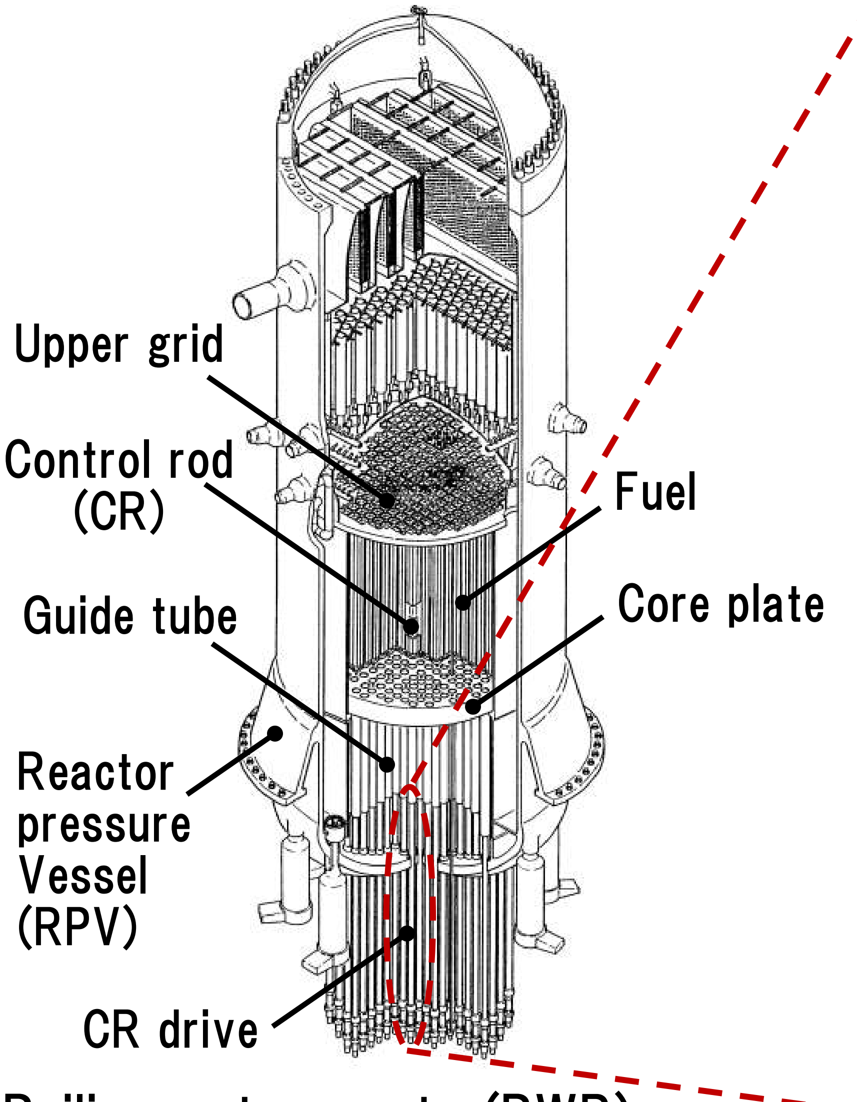
2-1. Control Rod Insertion Mechanism



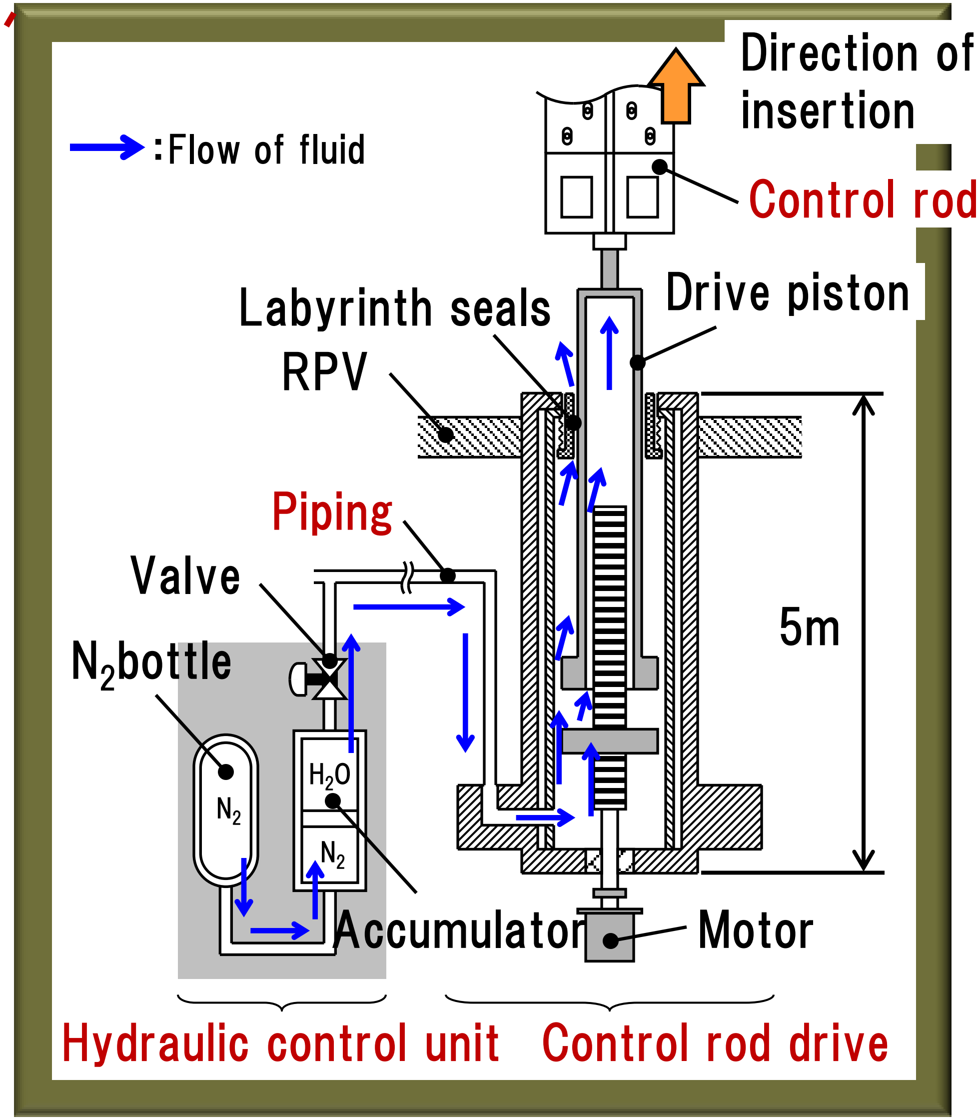
Boiling water reactor(BWR)



2-2. Control Rod Insertion Mechanism



Boiling water reactor(BWR)



3-1. Development of Numerical Analysis Model

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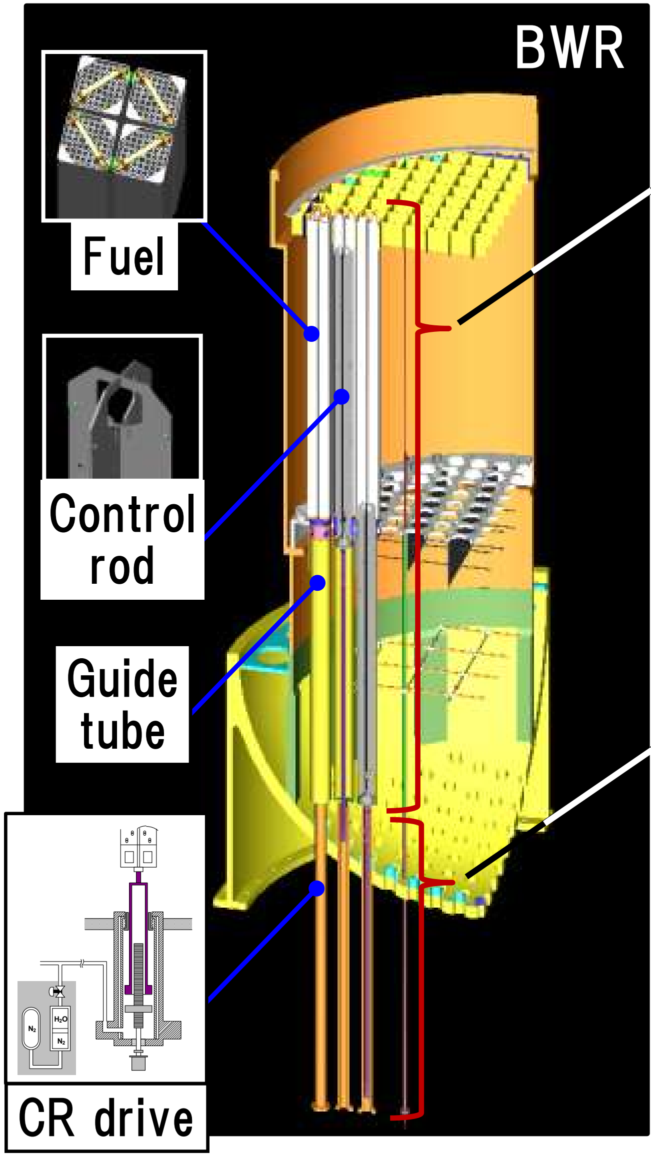
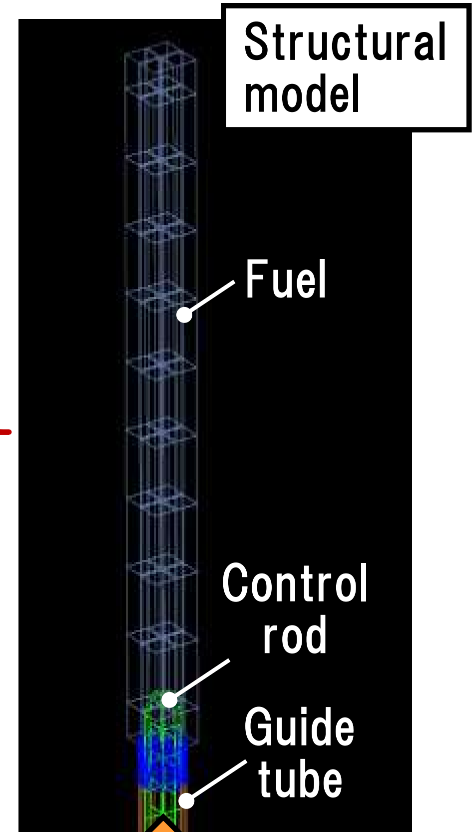


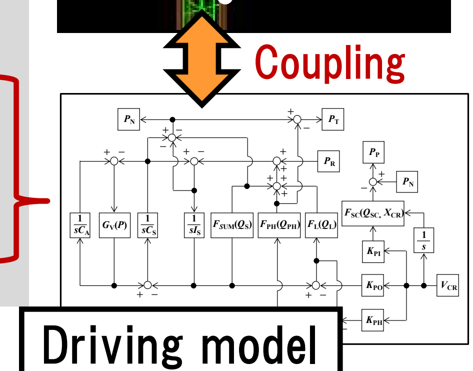
Structural system

- **Vibration・Contact analysis**
  - ・Fuel
  - ・Control rod
  - ・Guide tube
- **Fluid-structural analysis**
  - ・Fuels in water

CR driving system

- **Hydraulic circuit analysis**
  - ・Hydraulic control unit
  - ・Control rod drive
  - ・Piping





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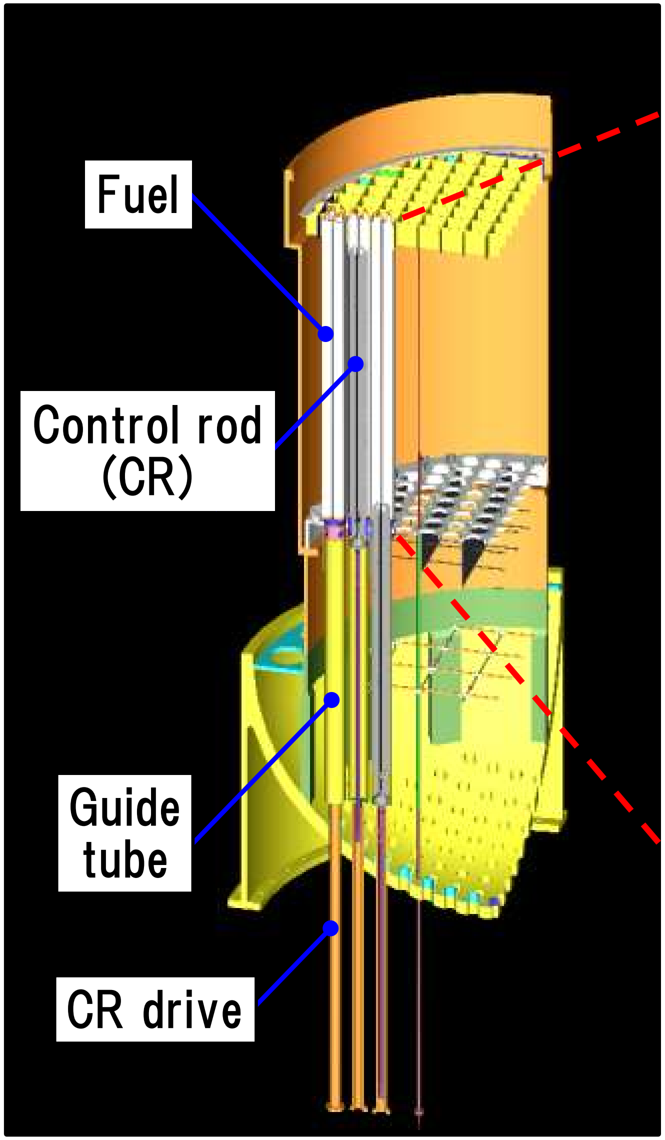
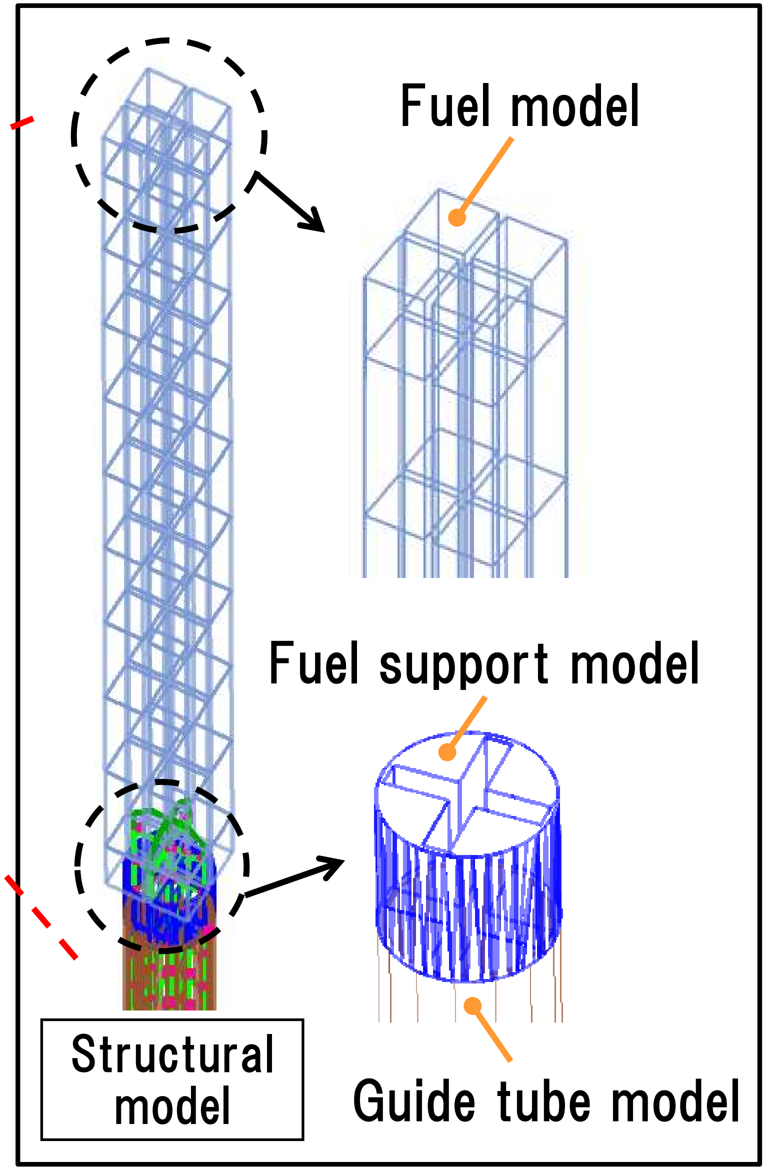
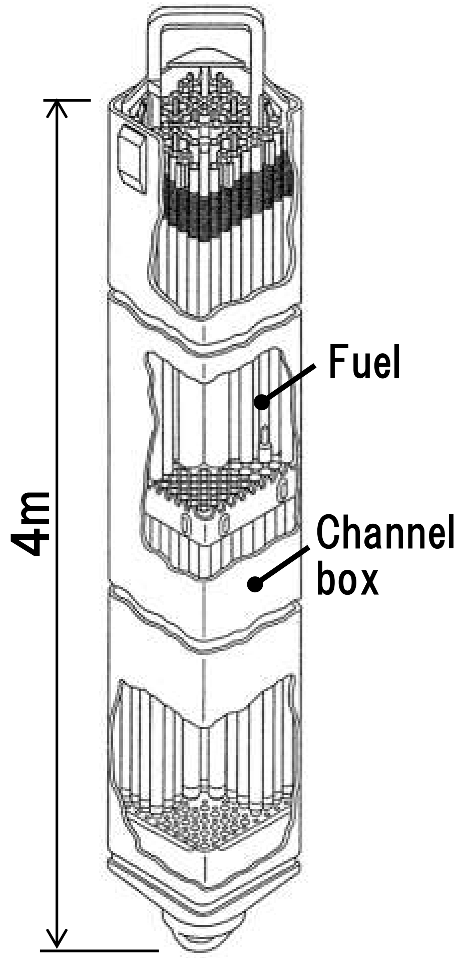
3-2. Structural model (1)







Fuel assemblies

3-3. Structural model (2)

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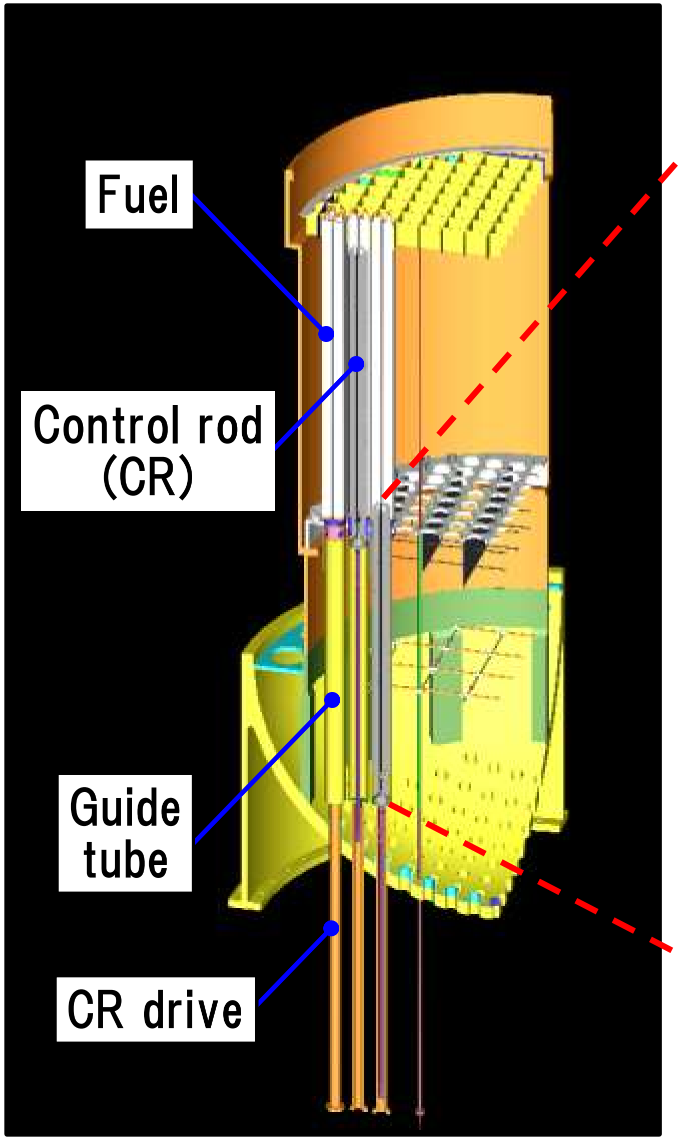

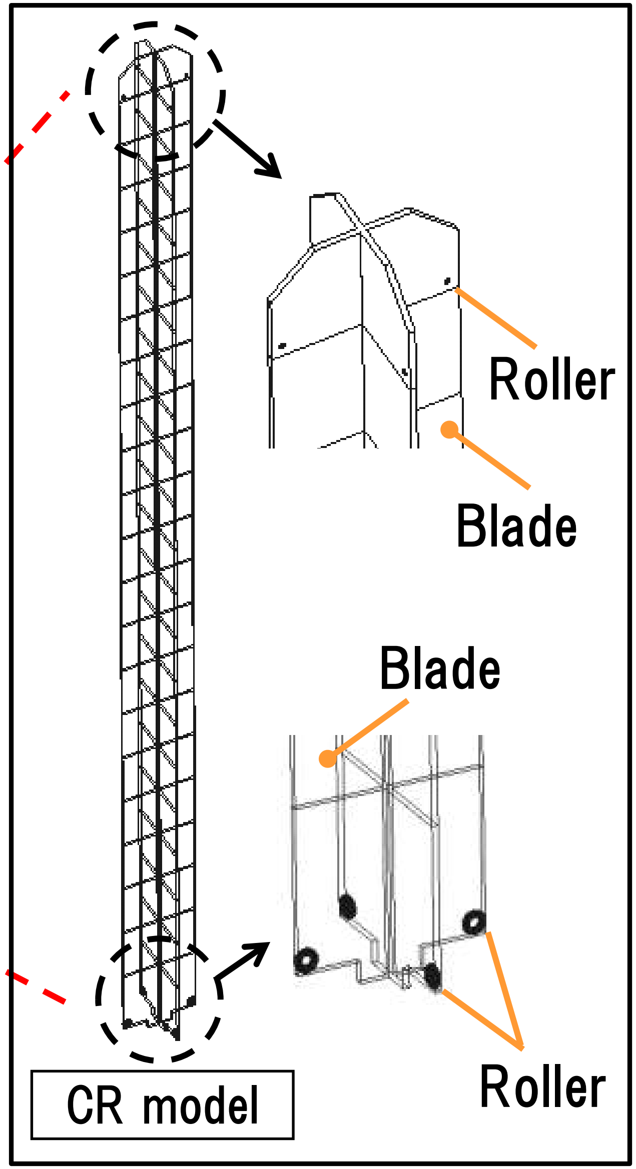

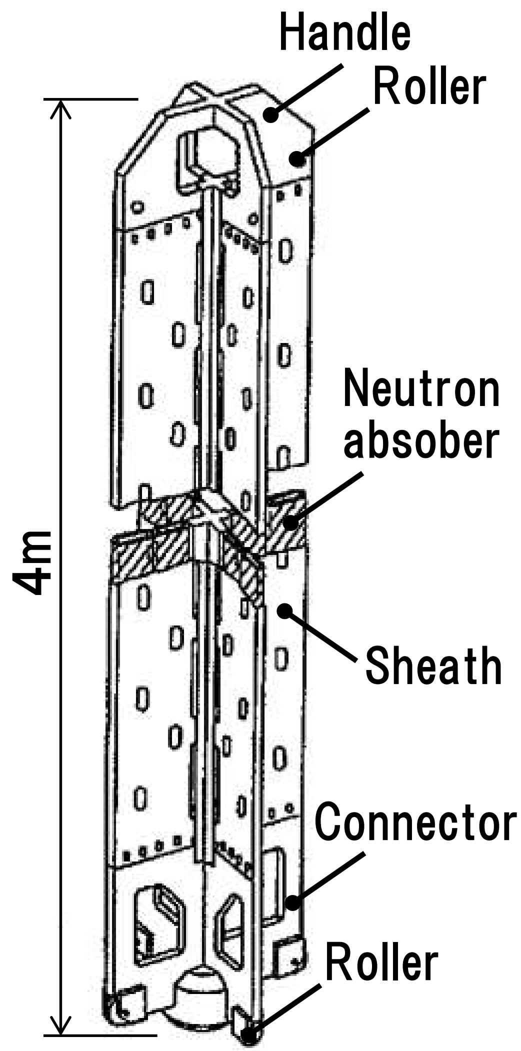

Control rod

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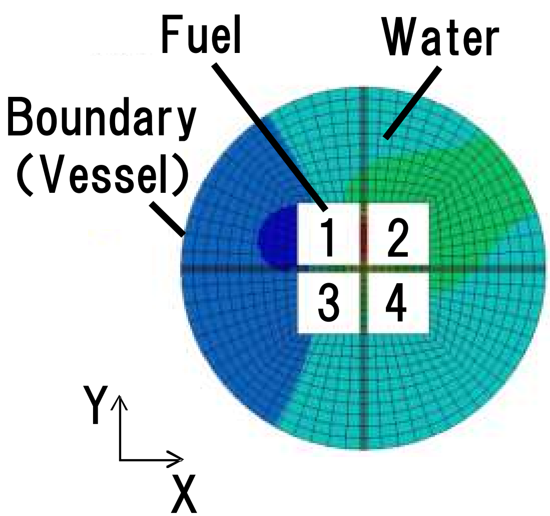
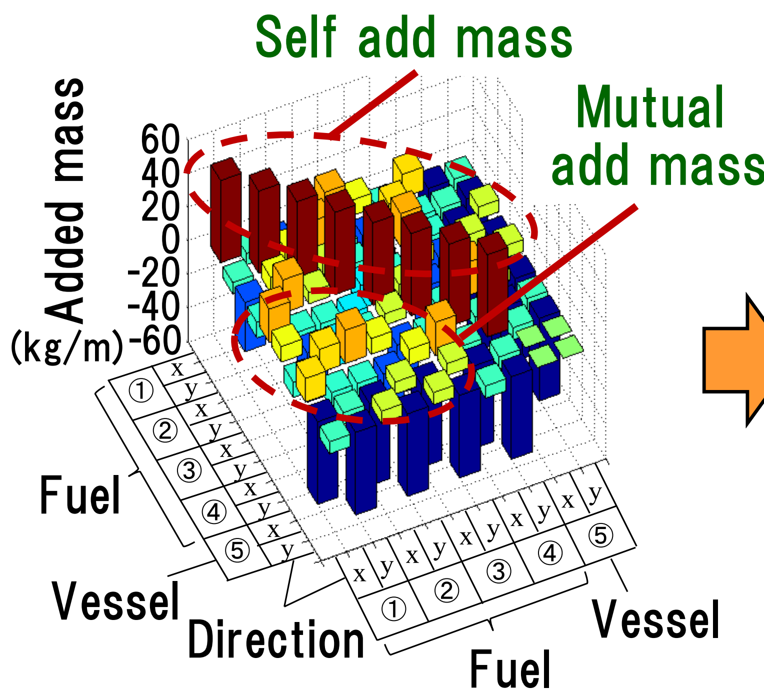
Added mass for fuel in water

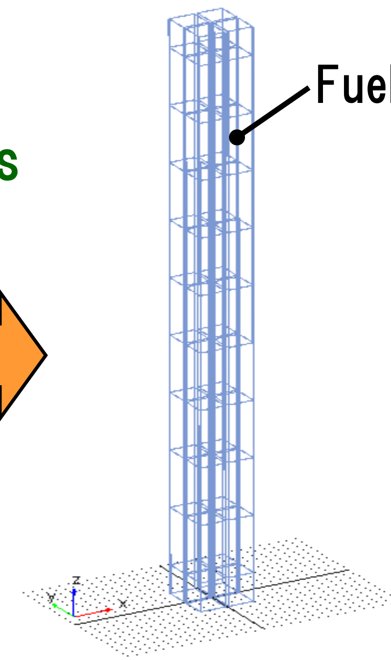
【Modeling】
⇒Potential flow
⇒Stationary fluid, Small deformation



Pressure distribution under acceleration motion of CR

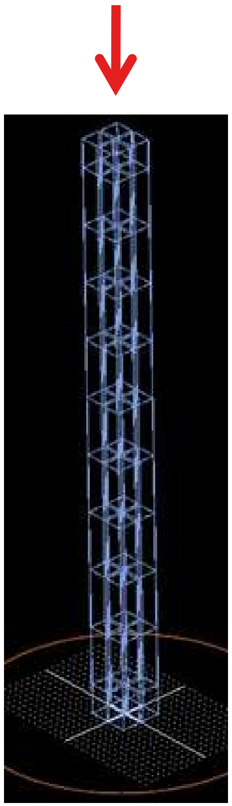


Added mass matrix

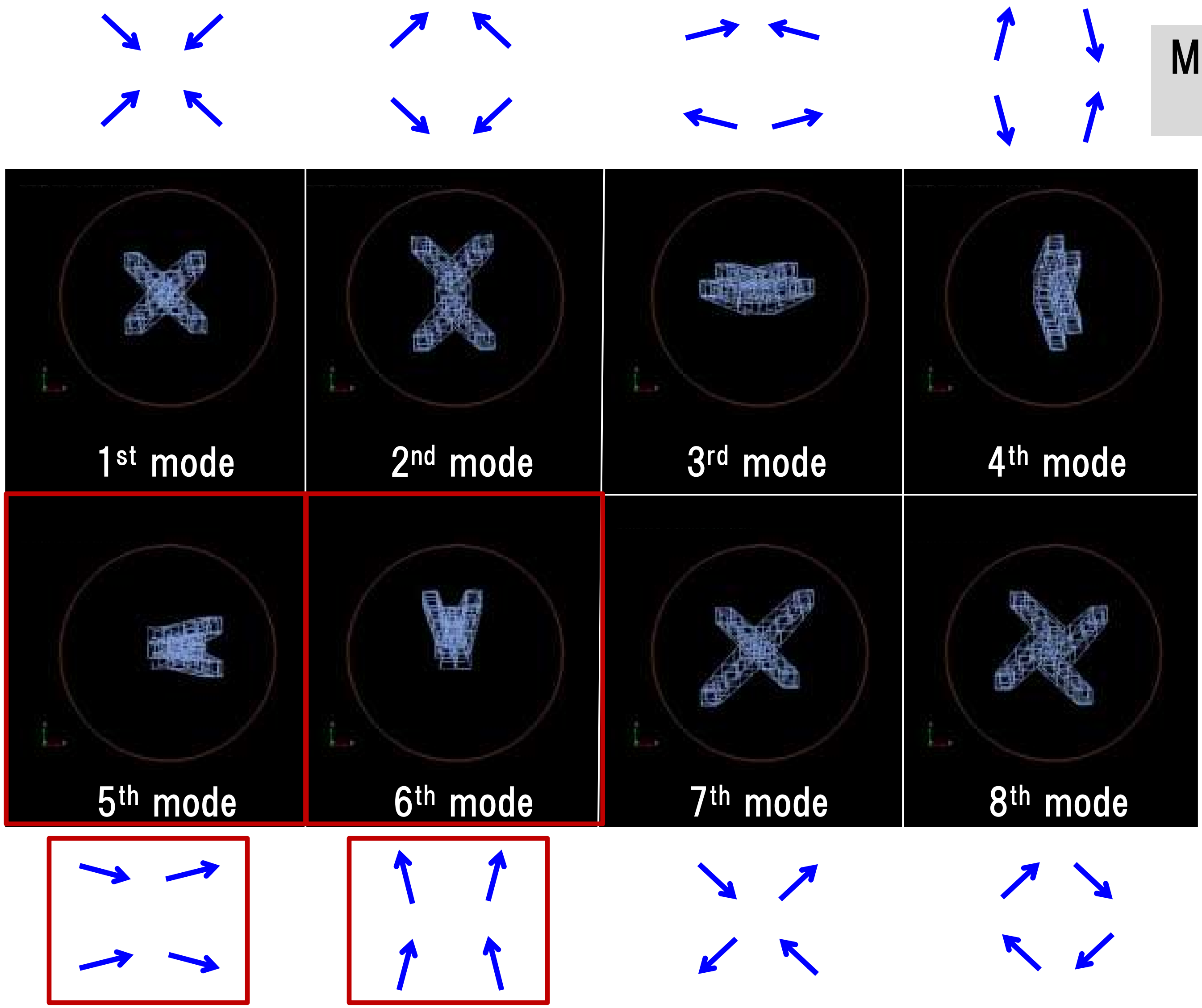


Fuel model

Mode vector (image)



Fuel model



Mode Shape

3-6. CR Driving Model

Inertance of working fluid in piping

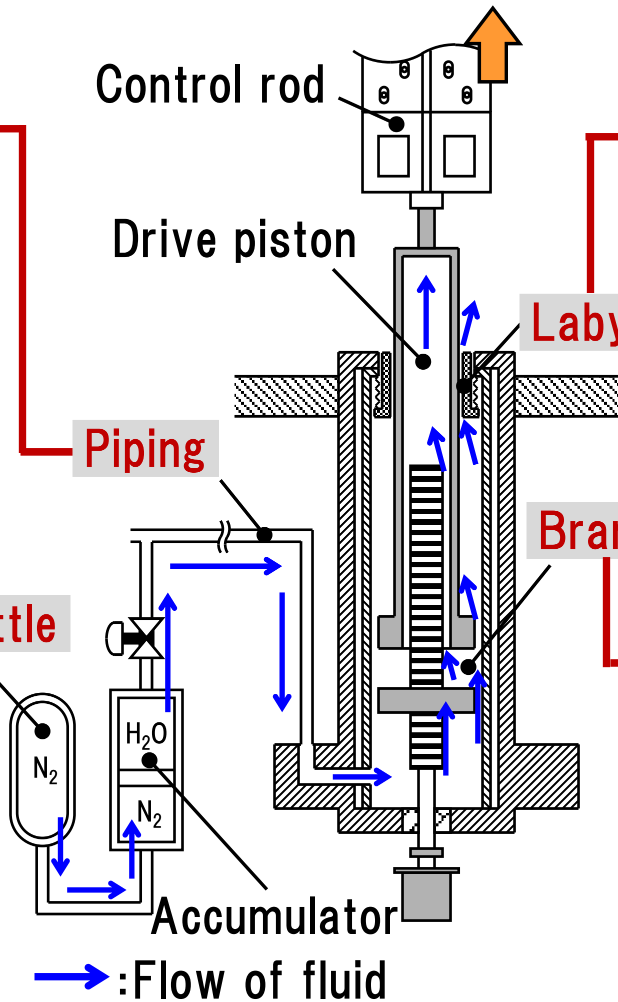
$$\Delta P = \frac{\rho_w L}{A}\frac{dQ}{dt} \equiv I\frac{dQ}{dt}$$

P : Pressure, Q : Flow
ρ_w : Density
A : Area
L : Length of piping
I : Inertance

Capacitance of N_2 gas

$$Q = \frac{V}{nP}\frac{dP}{dt} \equiv C\frac{dP}{dt}$$

V : Volume
n : Polytropic index
C : Capacitance



Control rod driving system

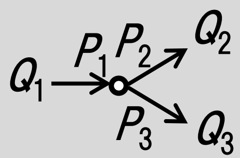
Pressure loss

$$\Delta P = \frac{1}{2}\rho_w R\left(\frac{Q}{A}\right)^2$$

R : Pressure loss coefficient

Constraint condition

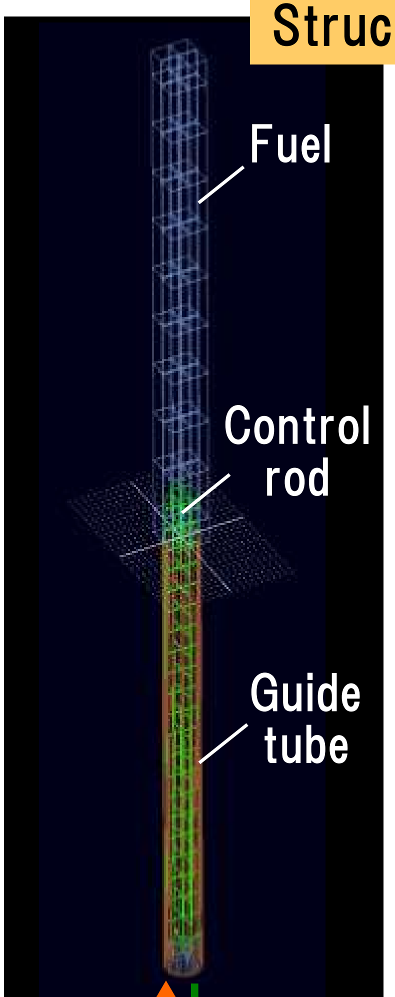
$$P_1 = P_2 = P_3$$
$$Q_1 + Q_2 + Q_3 = 0$$



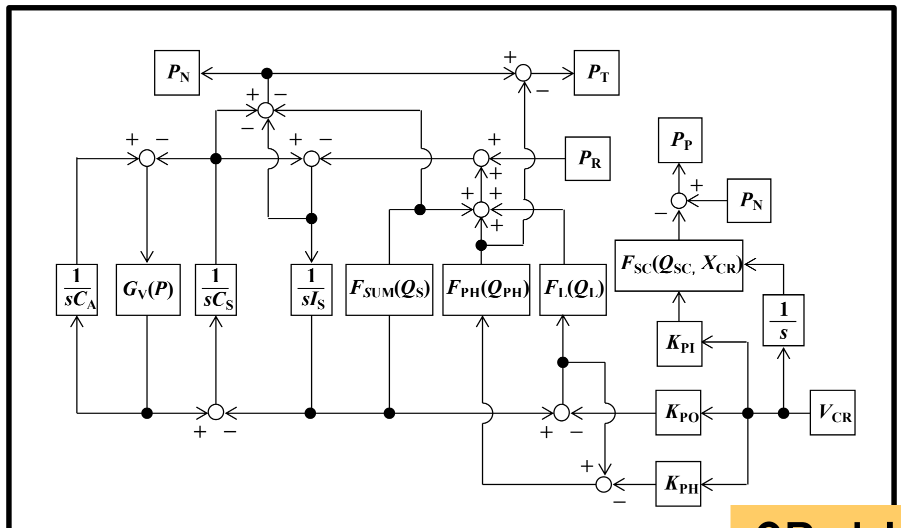
【Research supervision】
Mutoh Lab. Waseda Univ.

3-7. Control Rod Scrammability Analysis Model

Structural model (using Multi-Body dynamics)



Hi-SCRAM Ver.2.0

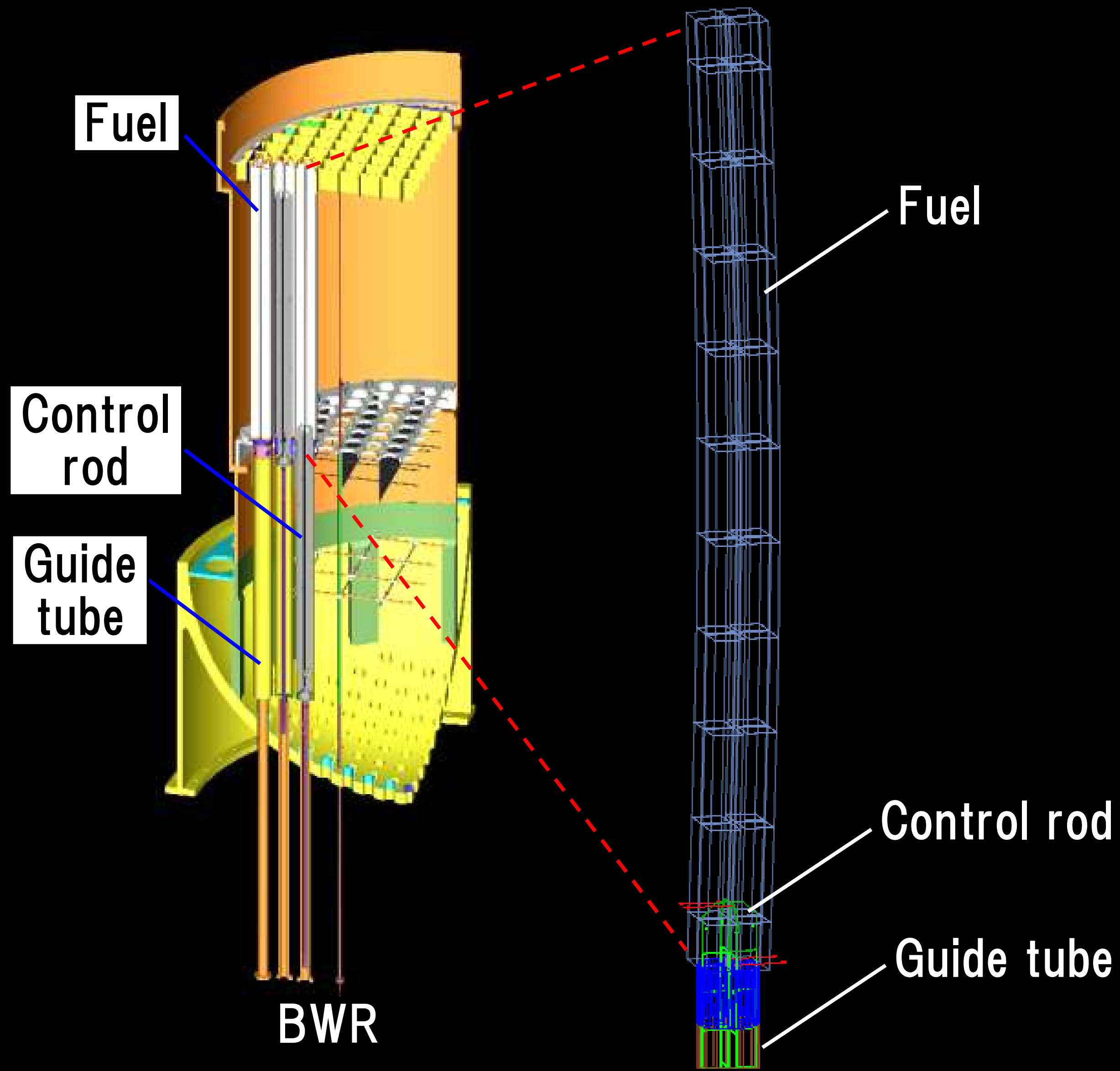


CR driving model

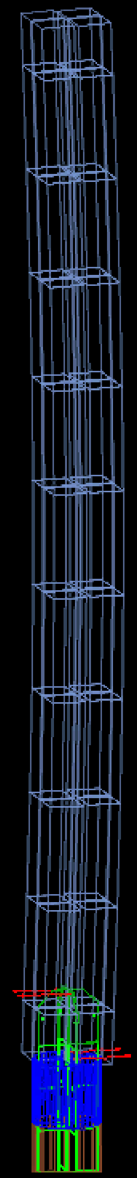
CR velocity[m/s]

Driving force[N]

Control Rod Scrammability Analysis Result

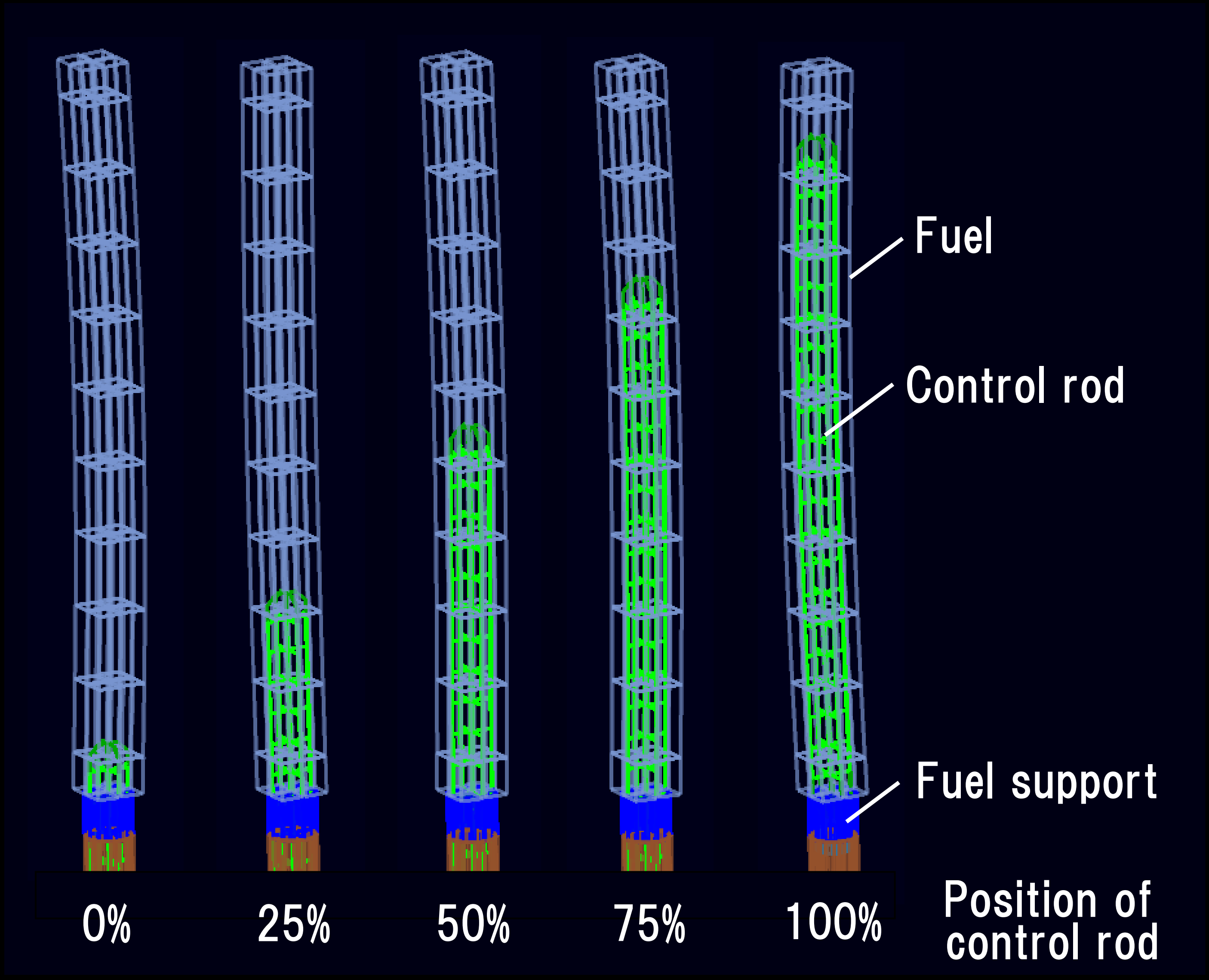


Last_Run Time= 2.4950 Frame=0500



Control Rod Scrammability Analysis Result

⇒Behavior of control rod insertion



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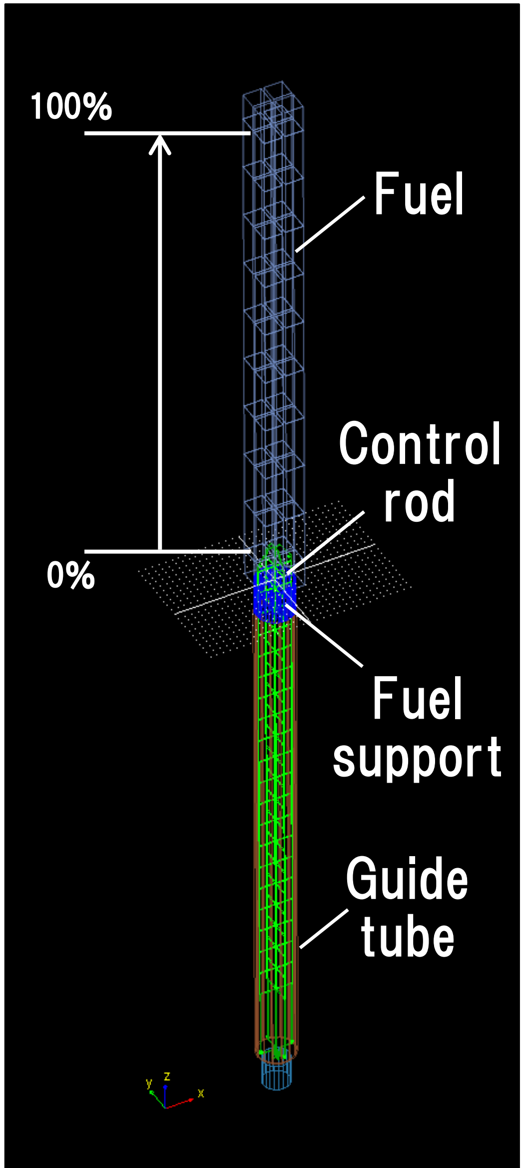
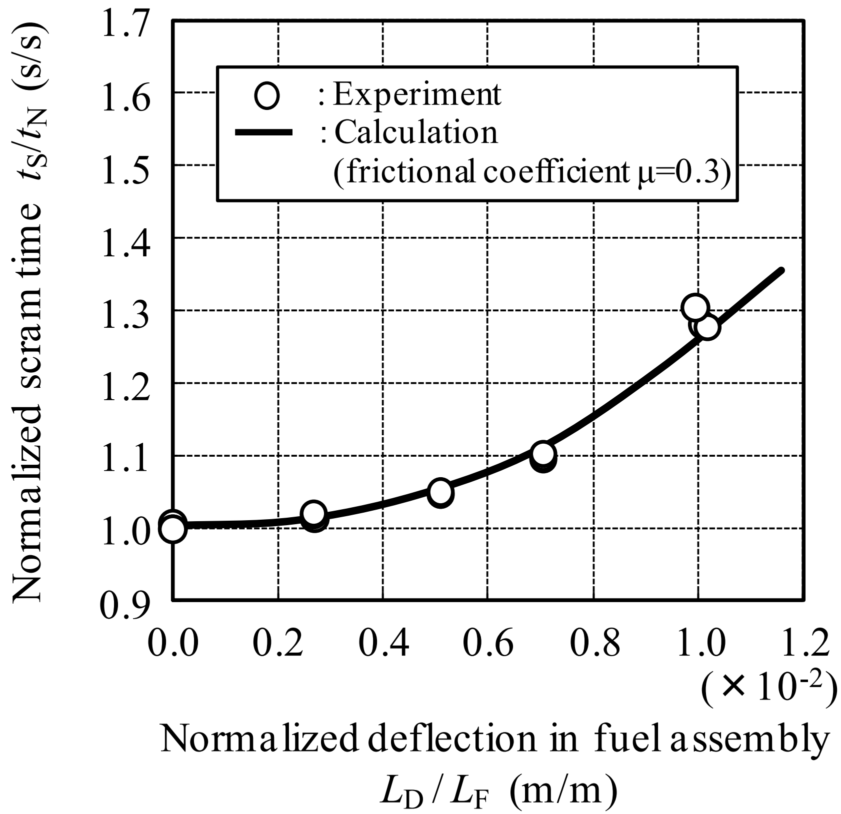


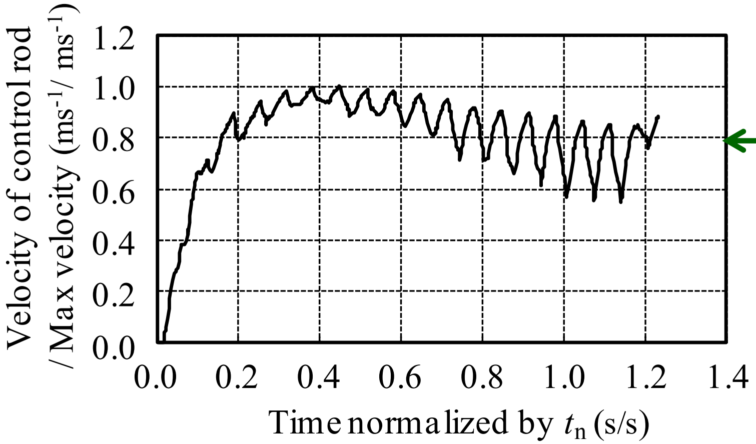
The comparison between analytical results and experimental results



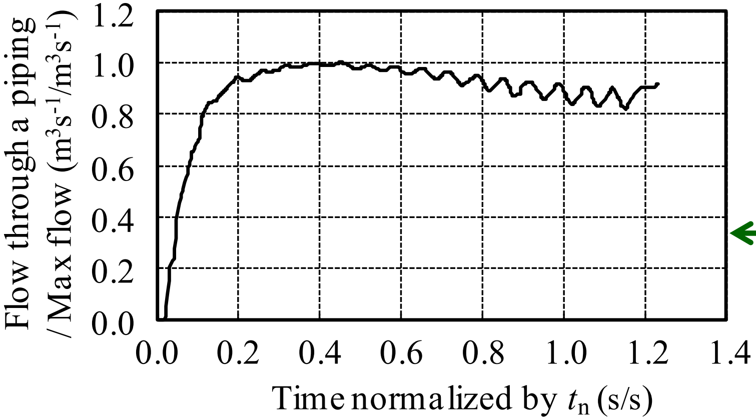
Scram time with deflection in fuel assembly (Input wave : sinusoidal)

※ t_s:Scram time, t_N:Scram time(Non-Seismic excitation) L_D:Deflection in fuel, L_F:Length of fuel

4-2.Control Rod Scrammability Analysis Result



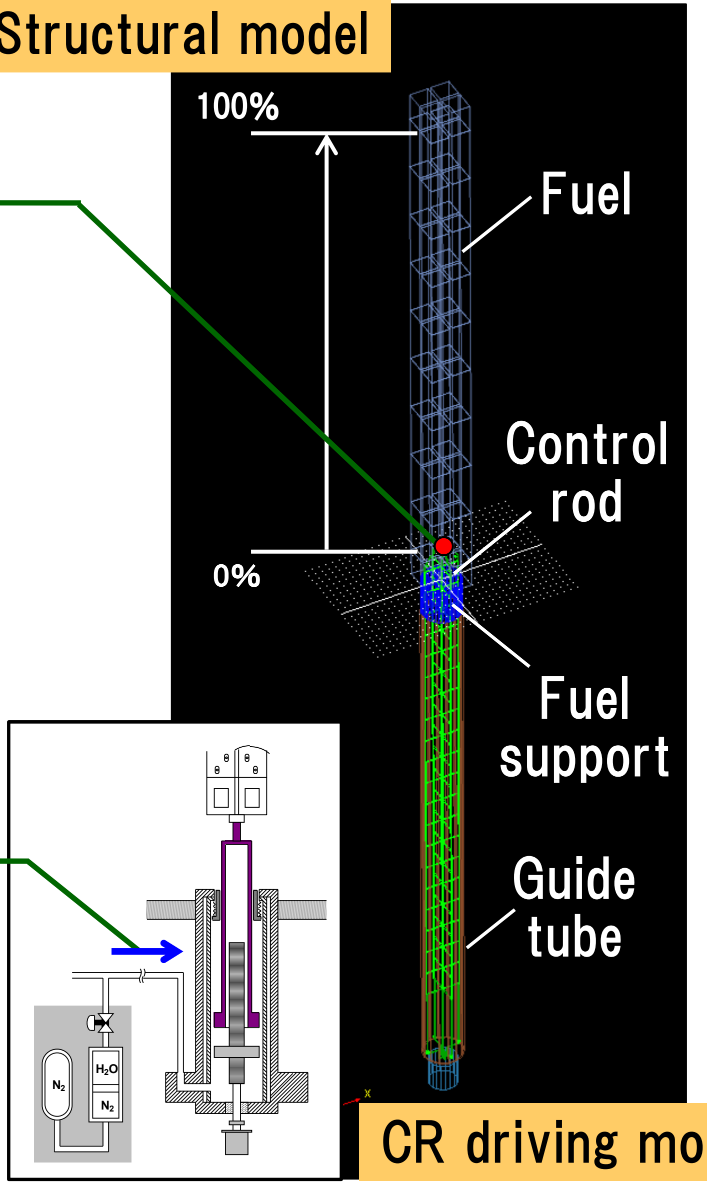
Time history of control rod velocity



Time history of flow through a piping

※ t_N:Scram time(Non-Seismic excitation)

Structural model



CR driving model

5-1. SSM assessment of BWR scramability

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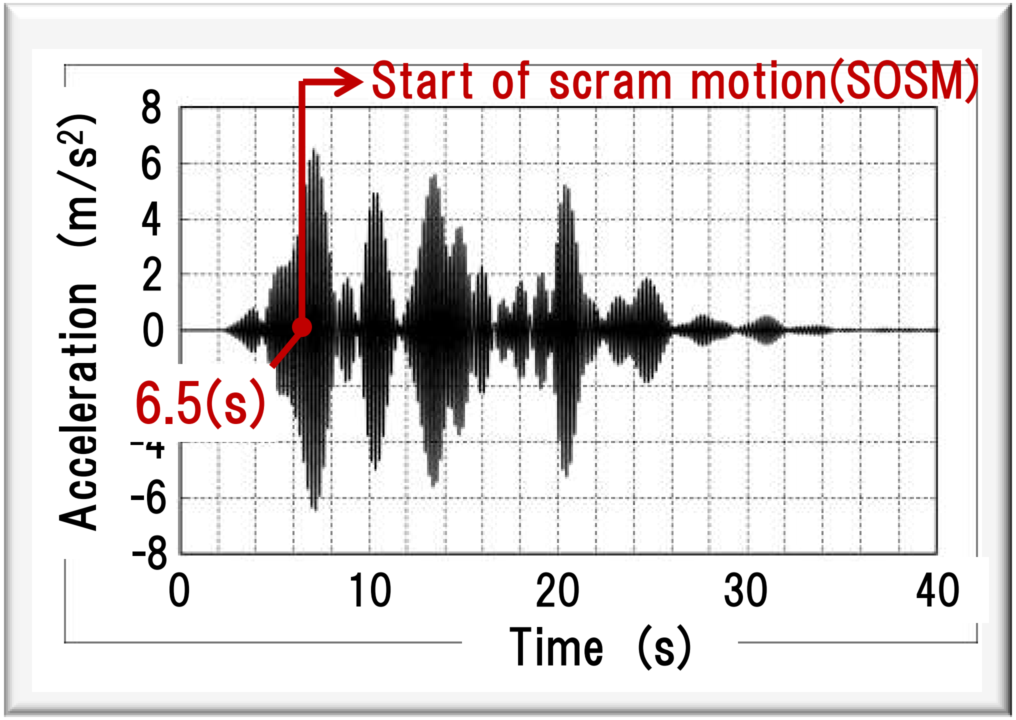
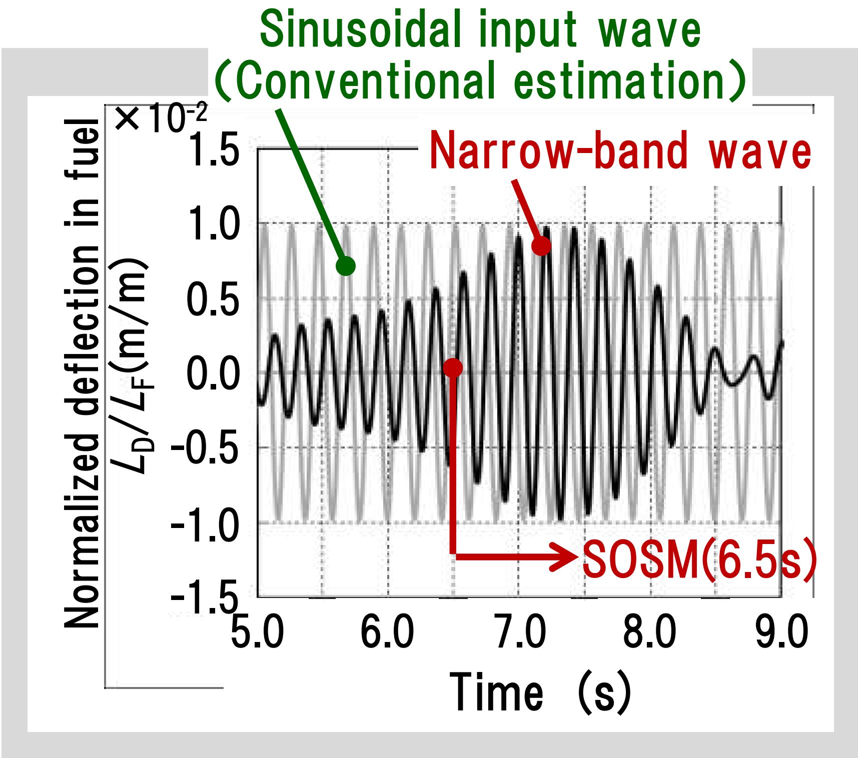
- Seismic safety margin of scrammability focused on the dependence of the insertion time on input seismic motion



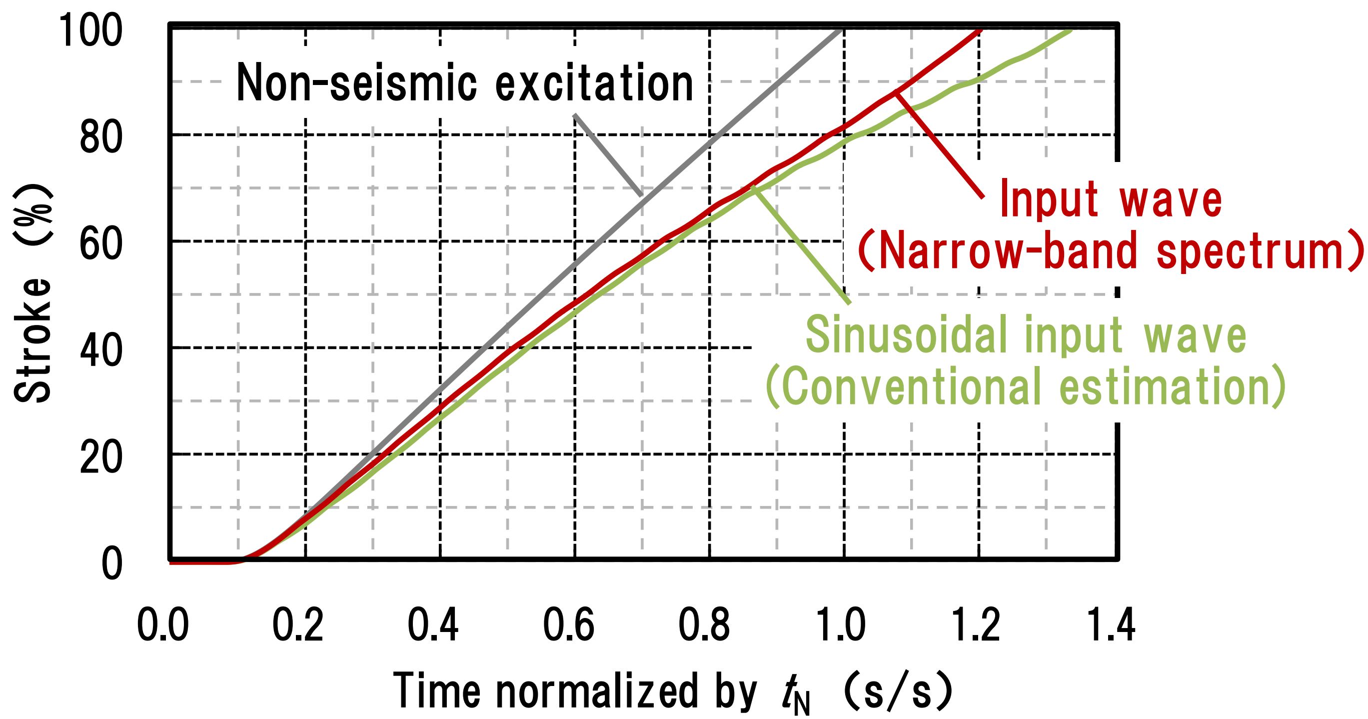
Time history of input wave
(Narrow-band spectrum(4.8Hz±10%))



Time history of deflection in fuel

※ L_D:Deflection in fuel, L_F:Length of fuel

5-2. SSM assessment of BWR scramability



※ Design reference time: 2.1 t_N

※ t_N: Scram time(Non-Seismic excitation)

This result suggests that the conventional estimation using sinusoidal input wave is more conservative than using seismic waves.

6. Summary

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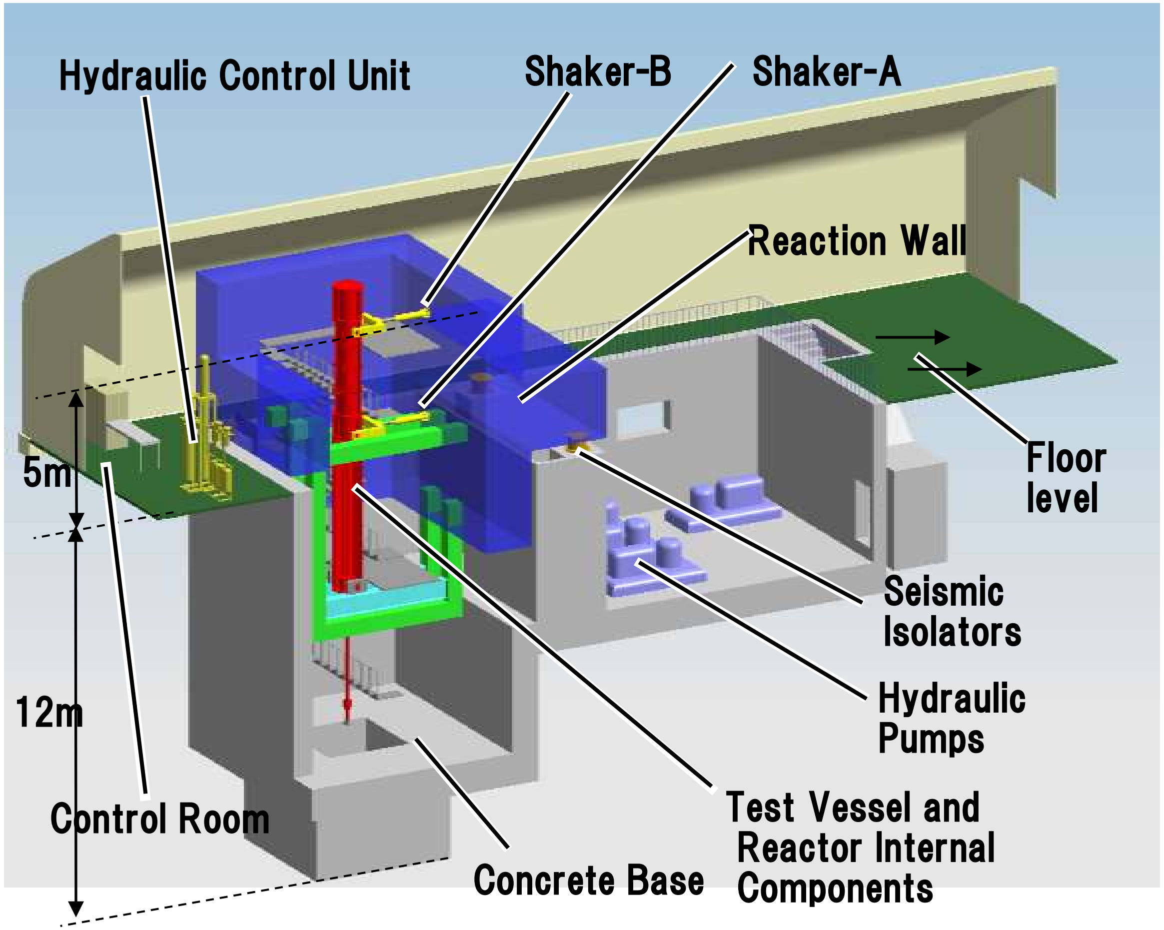
1. Hi-SCRAM can simulate the realistic insertion behavior of the control rod and predict the insertion time under seismic excitation.
2. The numerical analysis model provides good agreement with the insertion time of the control rod.
3. The conventional estimation using sinusoidal input wave includes the seismic safety margin.

Seismic Scramability Test Facility

Outline

Hitachi-GE Nuclear Energy, Ltd. developed the test facility for demonstration and evaluation of dynamic behavior of reactor internal components under seismic conditions.



Features

- Seismic scrammability test for all BWR type reactors can be performed.
- Horizontal excitation by two hydraulic shakers can demonstrate seismic response behavior.
- Seismic isolators are used for supporting the reaction wall in order to minimize the vibration influence to the surrounding areas.

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