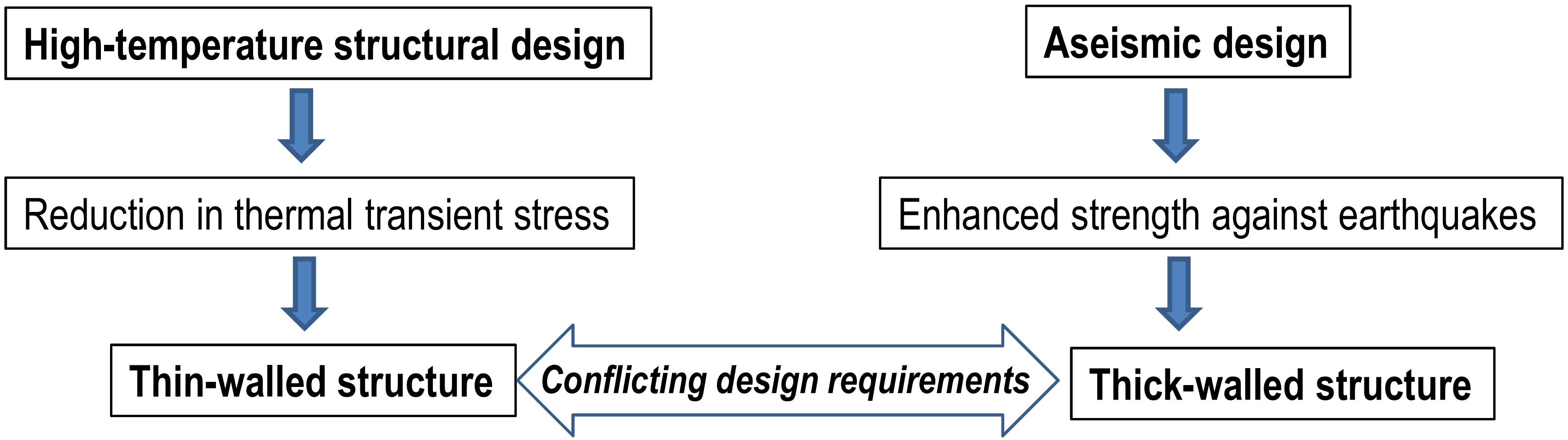
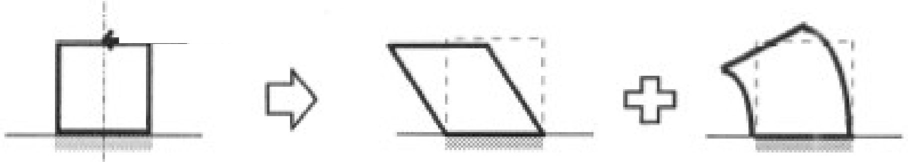
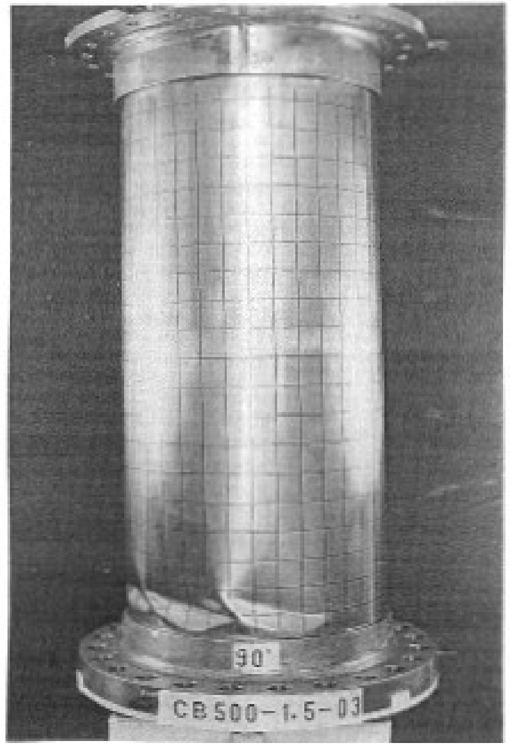
# 1.4 Aseismic Design of Thin-Walled Structures




Ref: Fast Reactor System Design, Naoto Kasahara Ed., Springer.

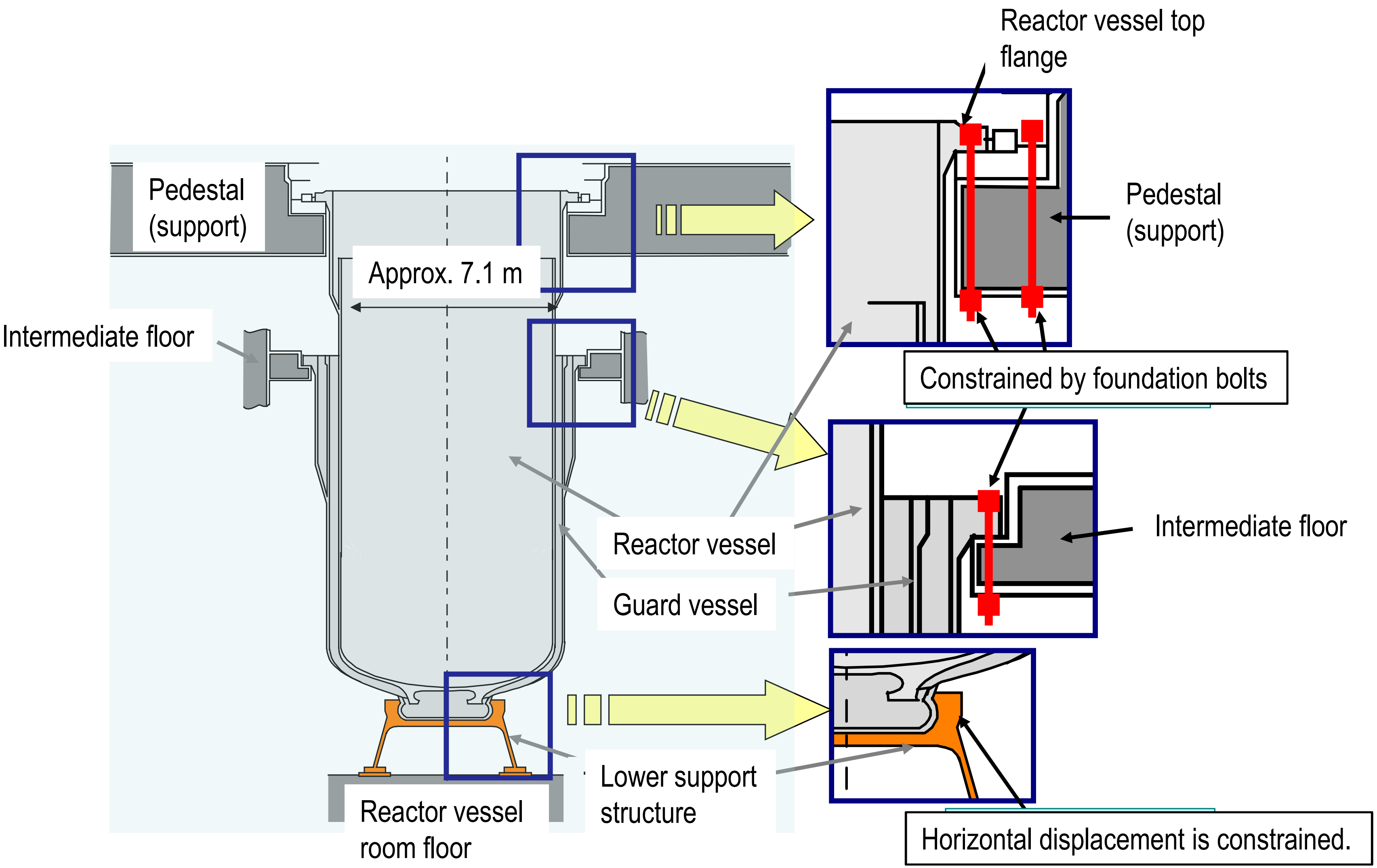
# *Buckling of cylindrical shell subject to shear-bending load*



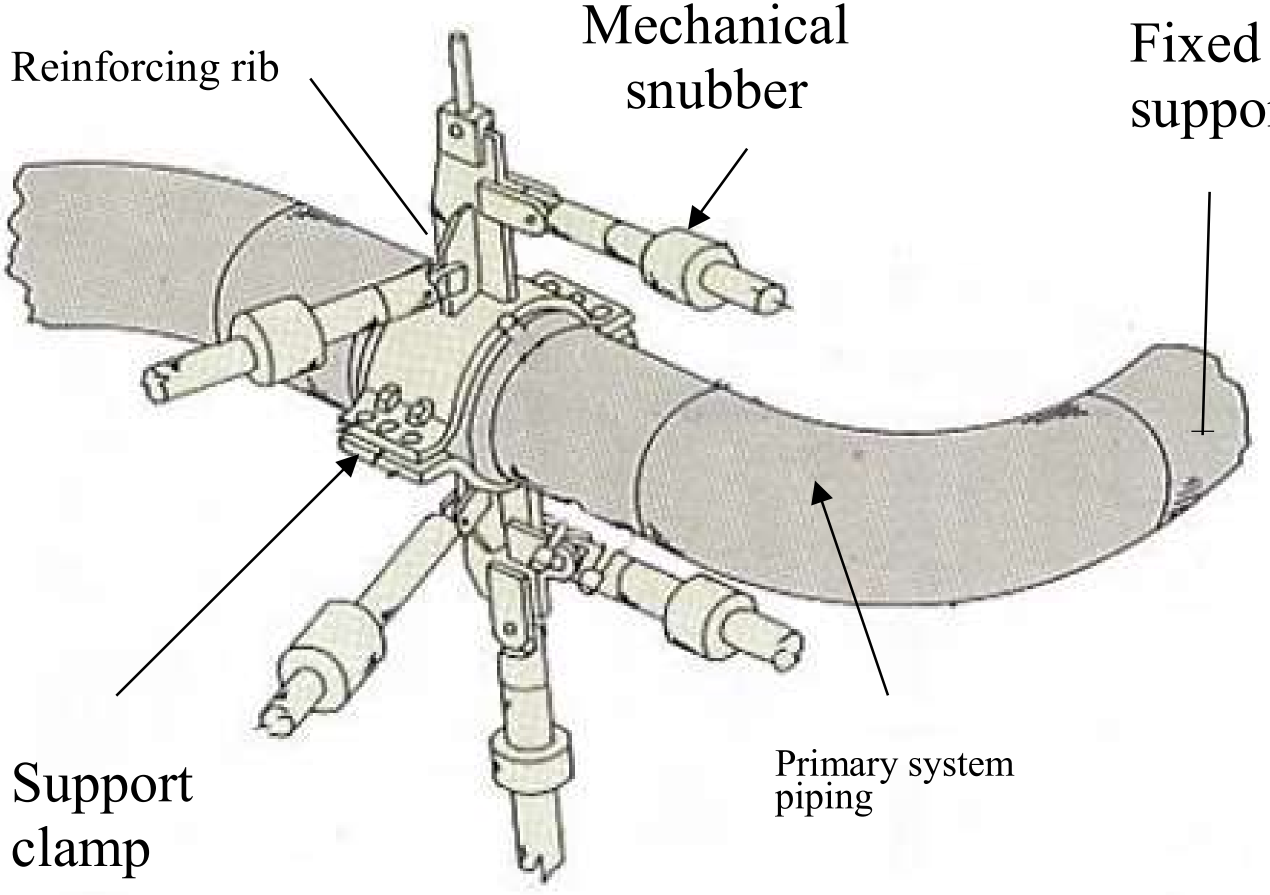

Shear Buckling

Bending Buckling




# Method of Supporting Reactor Vessel

# *Piping Supports to Prevent Vibration while allowing Thermal Expansion*



# *Seismic Tolerance of Equipment and Piping*

- According to the recent experiences in nuclear power plants in Japan, the seismic tolerance is extremely high, if proper quality assurance (design, manufacture, assembly, inspection) is carried out for equipment and piping.

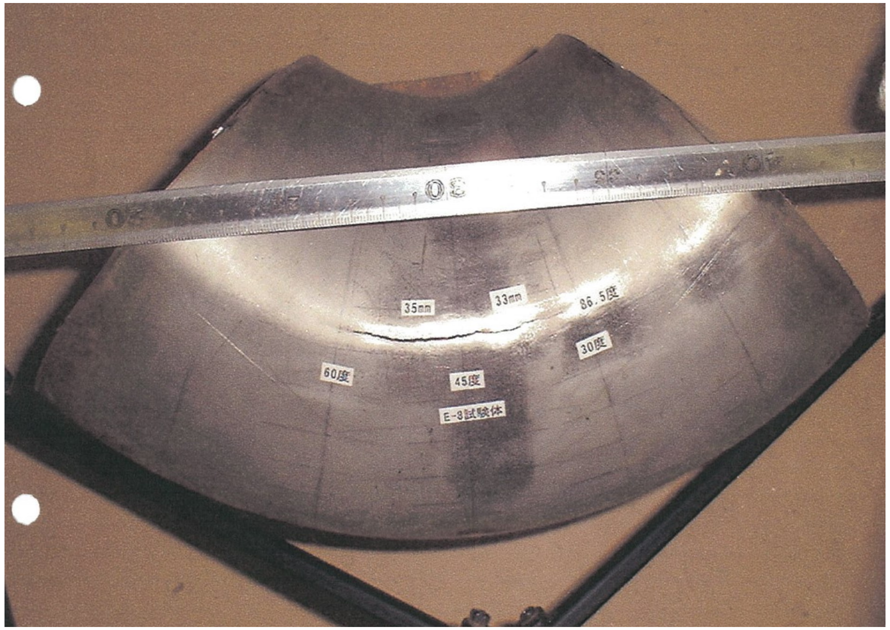
# ***Failure mode of piping under seismic loading***

**Recent Studies have shown;**

- *The failure mode of LWR piping subject to the reversing dynamic loads is not plastic collapse but fatigue or ratchet fatigue.*
- ***Extremely high level seismic test using FR piping exhibited identical failure mode.***

# *Structural integrity of FR piping subject to excessive seismic load*

***The failure mode of FR piping subject to excessive earthquake motion is through-wall fatigue cracking.***




**Thin-walled piping after vibration test simulating severe earthquake load**

# *Seismic Loading Tests for FR Piping*

Kasahara,N., Sato,T. and Blahoianu,A., “Contribution to Safety Enhancement for BDBE in Structure and Material Fields,” Proceedings of the ASME 2018 Pressure Vessels & Piping Conference , PVP2018-84353, July 15-20, 2018 , Prague, Czech Republic.
Nakamura,I. and Kasahara,N., “Improved Model Tests to Investigate the Failure Modes of Pipes under Beyond Design Basis Earthquakes,” Proceedings of the ASME 2018 Pressure Vessels & Piping Conference , PVP2018-8442, July 15-20, 2018 , Prague, Czech Republic.
Watakabe, T., Tsukimori, K., Otani, A., Moriizumi, M., and Kaneko, N., "Study on Strength of Thin-walled Tee Pipe for Fast Breeder Reactors under Seismic Loading", Proc. of PVP2014, PVP2014-28619.
Watakabe, Y., Tsukimori, K., Kitamura, S., and Morishita, M., "Ultimate Strength of a Thin Wall Elbow for Sodium Cooled Fast Reactors Under Seismic Loads", Journal of Pressure Vessel Technology, 138, pp. 021801-1-021801-10.

# ASME Code Section III Division I-NB

- *Criteria of piping design codes were based on the thought that failure mode under high level earthquake loads was plastic collapse.*
- *NB-3656 Consideration of Level D service Limits (b);*

  ***In the pipe subjected to the reversing dynamic load satisfying D / t <40 using the specified ductile material, the allowable value of the primary stress limit of Level D was expanded 1.5 times (3Sm → 4.5Sm).***

# *2. Component Design of FR*

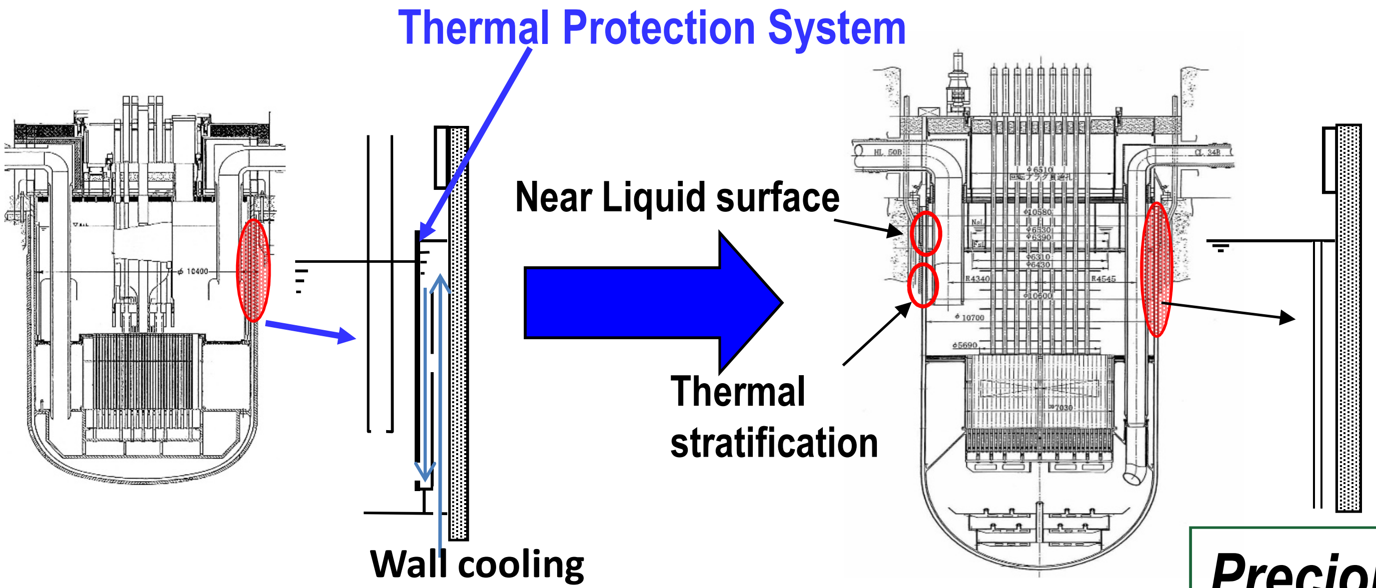
## *2.1 Measures for Mitigation of Thermal Load*

●Since the constraints for structural design greatly affect plant construction cost, measures to actively mitigate loads are taken to remove them.

●Typical examples are presented.

# *Realization of Compact Reactor Vessel for JSFR*

## Elimination of Thermal Protection System



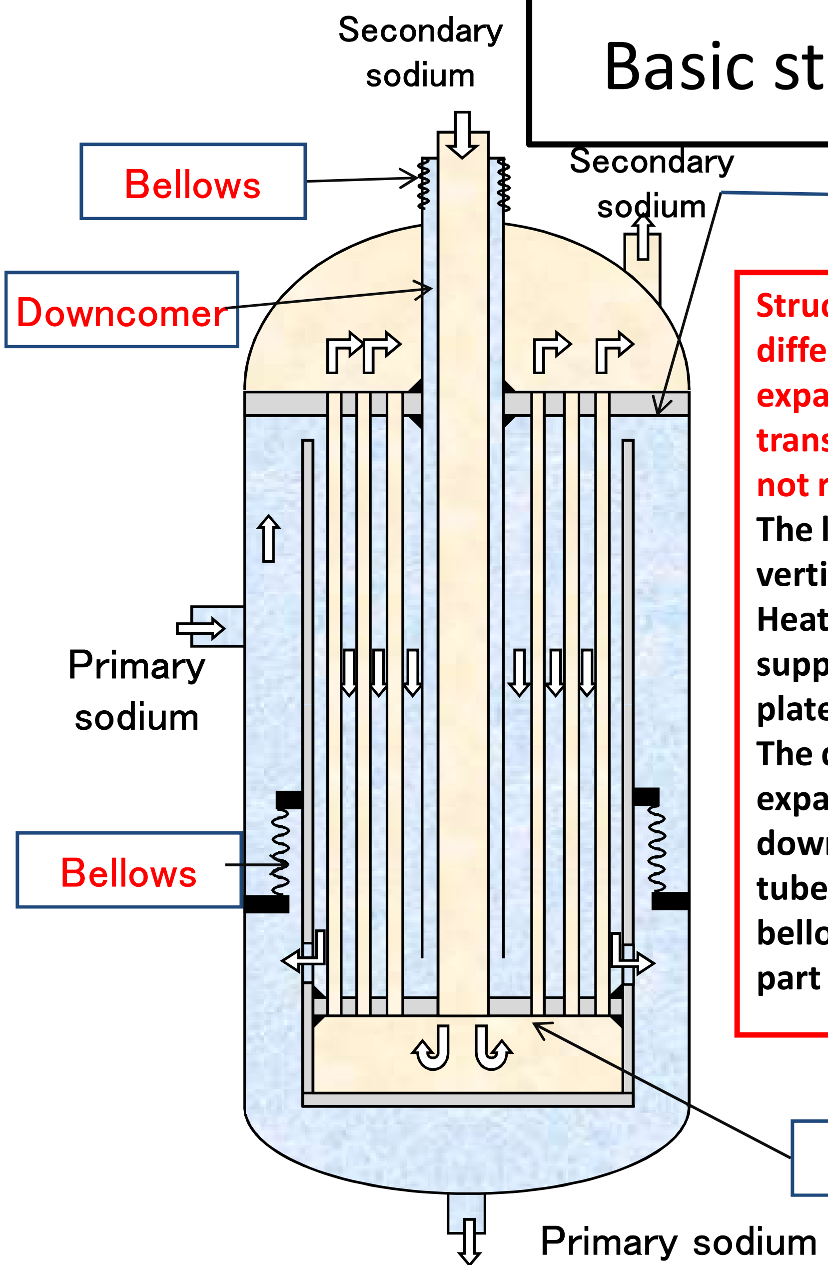

JSFR

***Precious evaluation of structural integrity against thermal loadings***

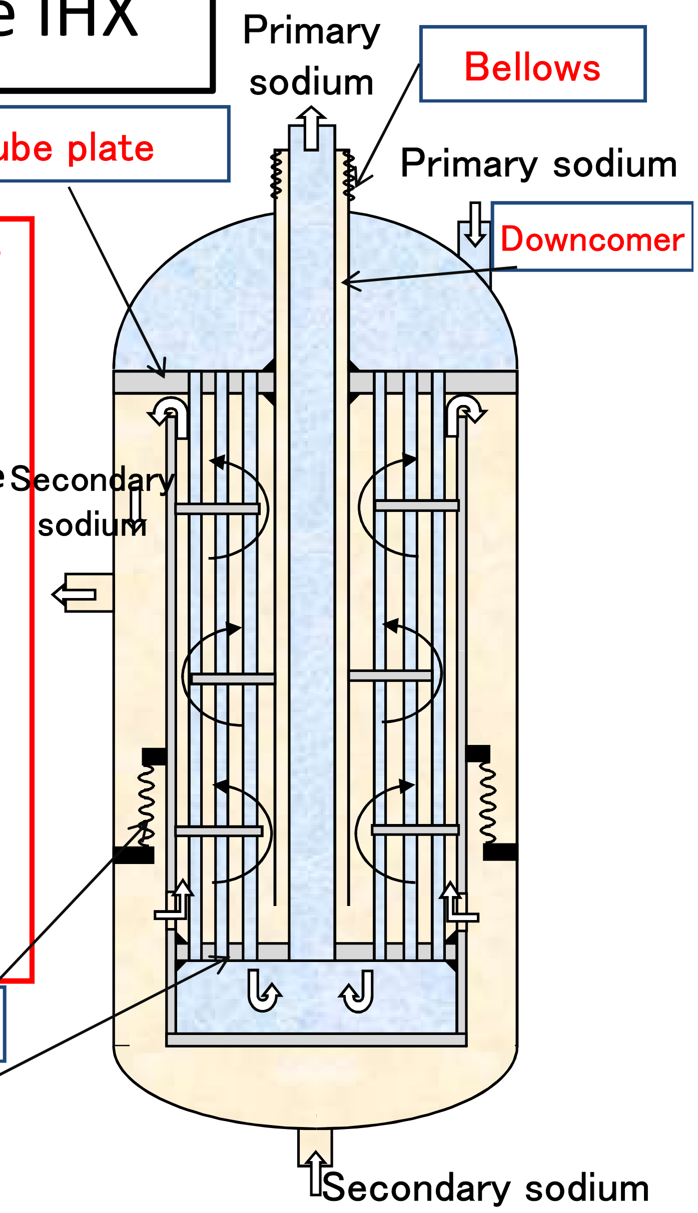
# Basic structure of the IHX

**Structure concept in which the difference in thermal expansion between heat transfer tubes and the shell is not restricted.**

**The lower tube plate can move vertically (float).**
**Heat transfer tubes are supported at the upper tube plate.**
**The difference in thermal expansion between the downcomer and heat transfer tubes is absorbed by the bellows located in the upper part of the downcomer.**



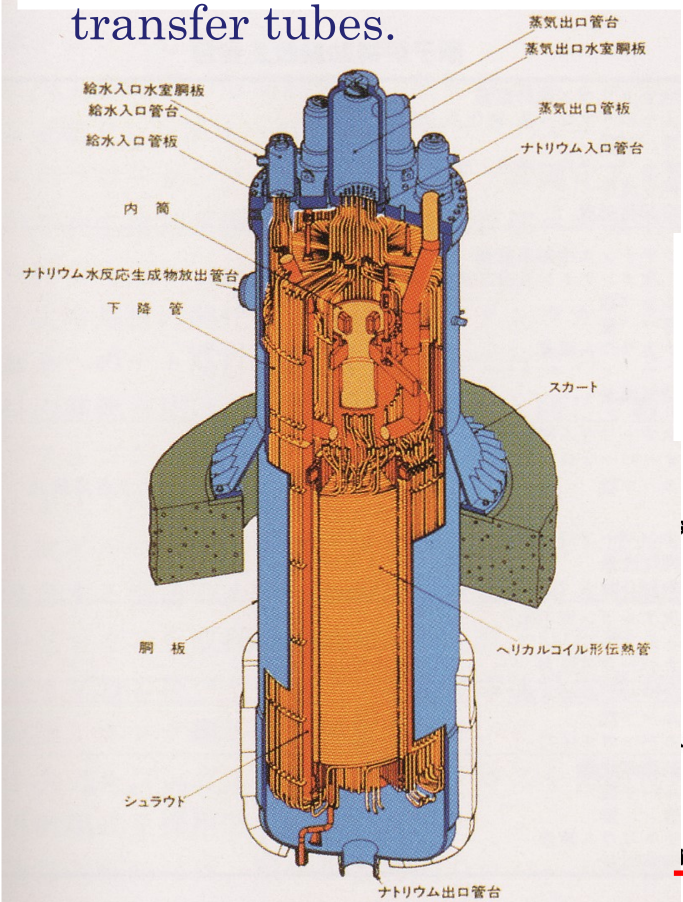

**Case in which the primary sodium flows outside the heat transfer tubes**



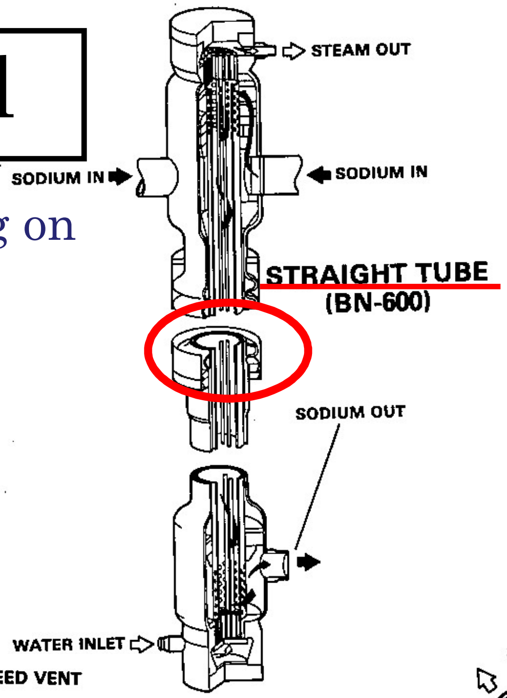

**Case in which the primary sodium flows inside the heat transfer tubes**

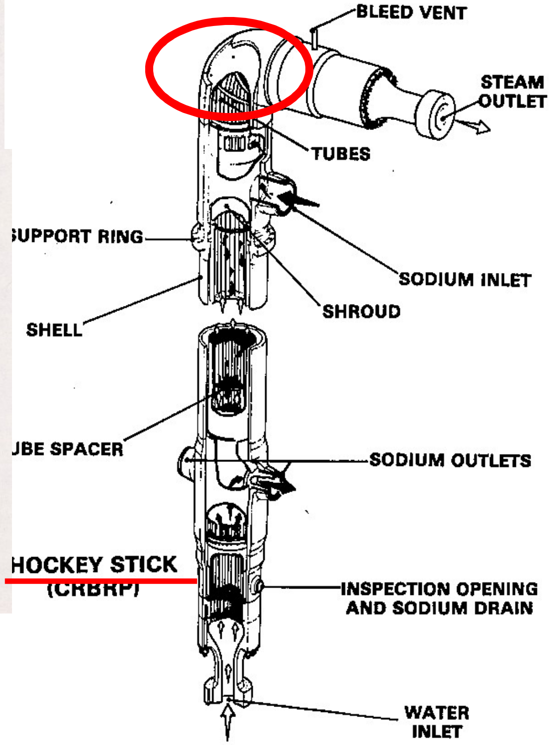
# Steam generator model

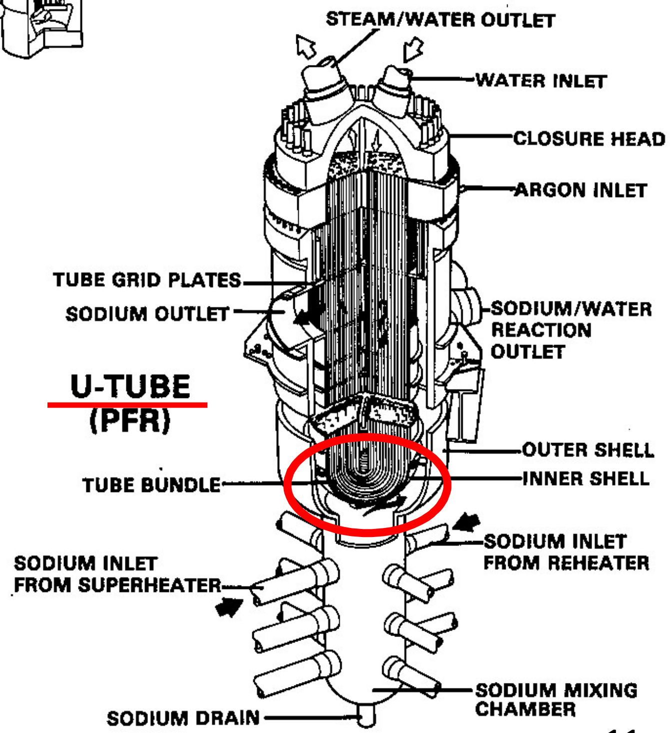
✓The basic structure is determined depending on the method of absorbing the difference in thermal expansion between shell and heat transfer tubes.




Evaporator for Monju



# *2.2 Measures for Mitigation of Seismic Loads*

## *- SEISMIC ISOLATION -*

1. **Fast reactors; high-temperature and low pressure system results in relatively flexible and thin-walled components and pipes.**
2. **Seismic isolation is especially effective to these plants.**
3. **The vertical component of EQ load is NOT negligible.**
4. **Both enhanced safety and economy can be expected by mitigation of 3D EQ load.**

→**3D Seismic Isolation System is effective to FR**

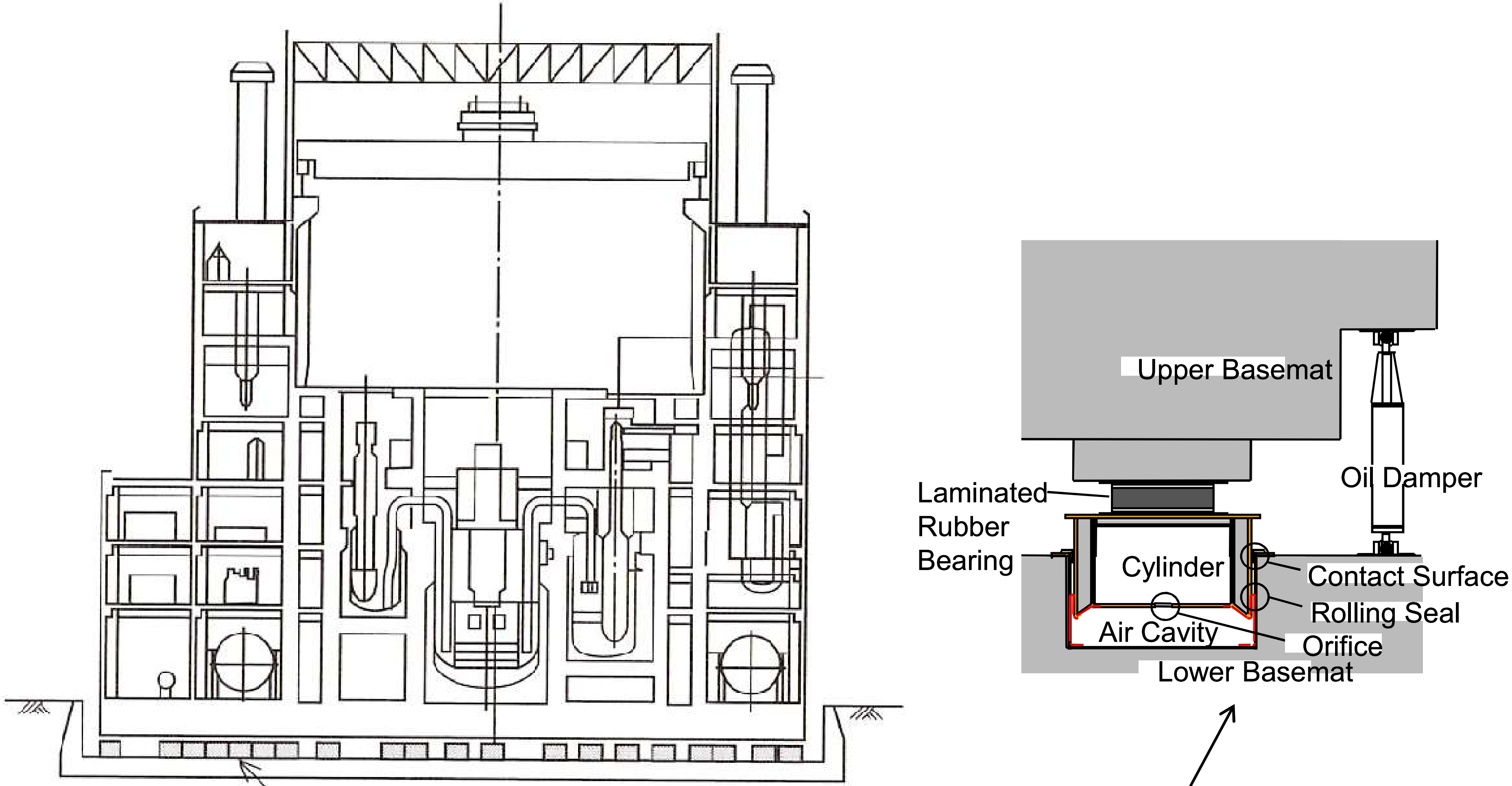
# ***Requirements to Seismic Isolation***

<u>From the component :</u>

- Suppress reactivity insertion,
  Avoid uplift of fuel assembly,
- Avoid reactor vessel buckling
- Suppress relative displacement of piping

<u>From the 3D isolation building :</u>

- Suppress amplification of vertical acceleration
- Avoid uplift of isolation devices
- Reduce horizontal acceleration



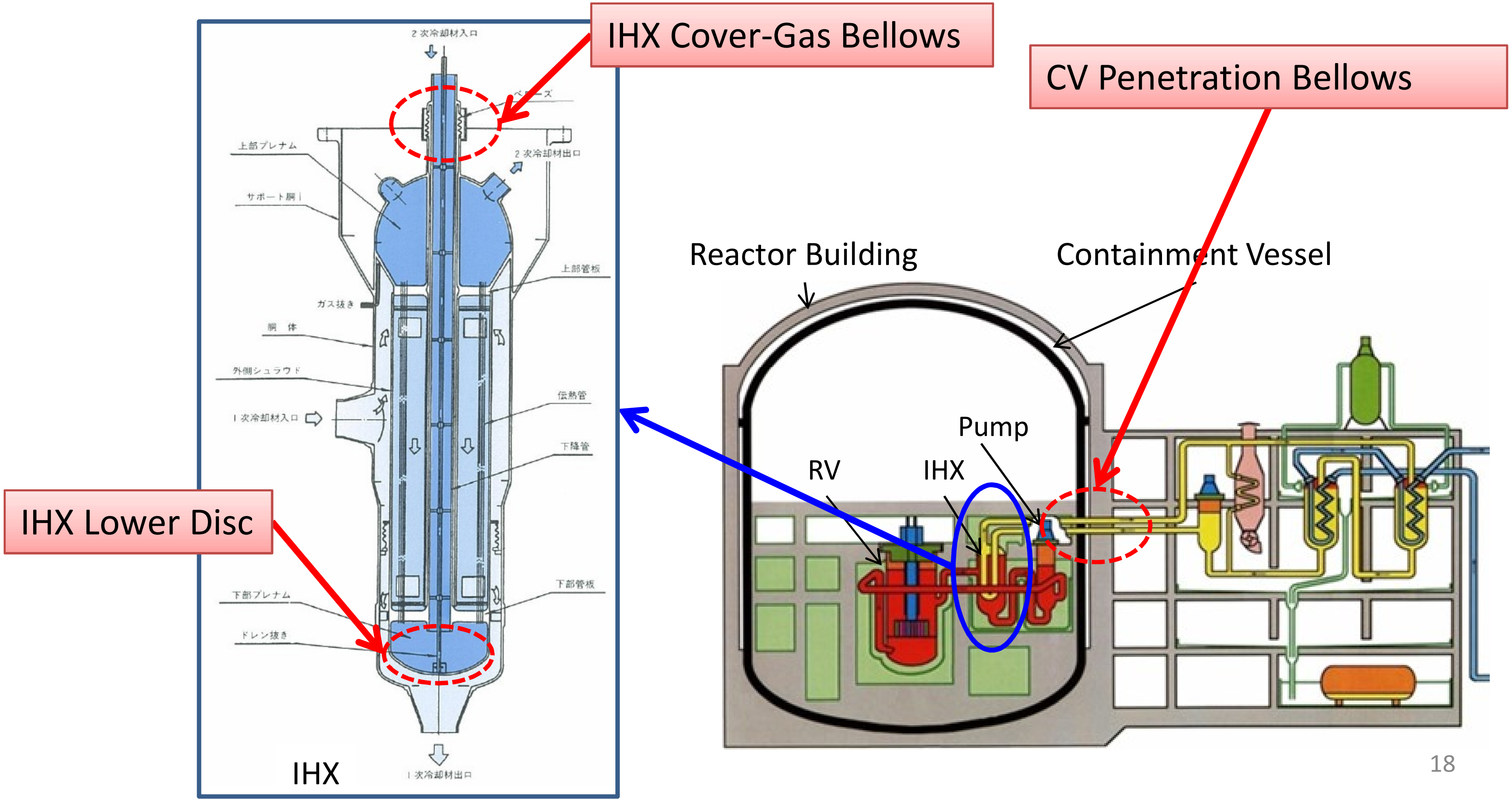

**3-D base-isolated building equipment**
**(e.g., combination of laminated rubber and air spring)**

# Fig 3-D base-isolated building structure

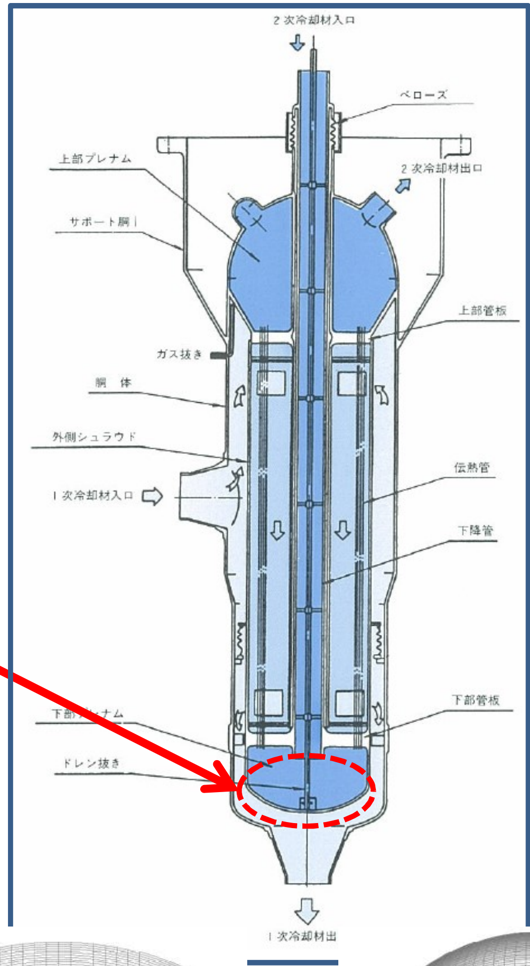
## *2.3 Integrity of the Structure under Severe Accident*

1. **During a severe accident, the function of containment is primary concern. Severe accident condition might exceed the maximum design pressure.**
2. **Tests and analyses were conducted to demonstrate the maximum pressure that the boundary function can maintain.**

# *Containment Boundaries Specific to FR*



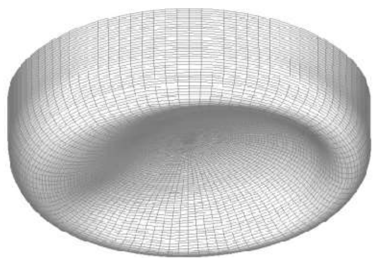
# 【Test】

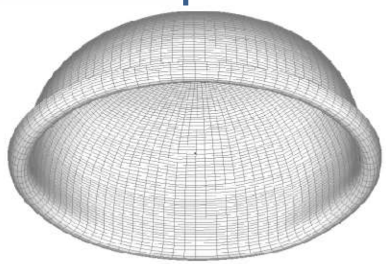

# 【Analysis】

Initial Configuration

Buckling (6.01MPa)

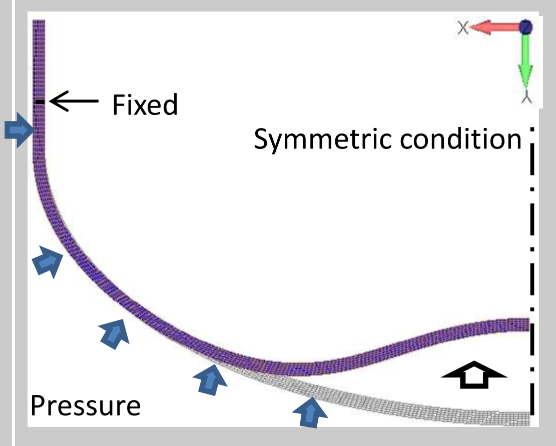


Progress of distortion (6.04MPa)

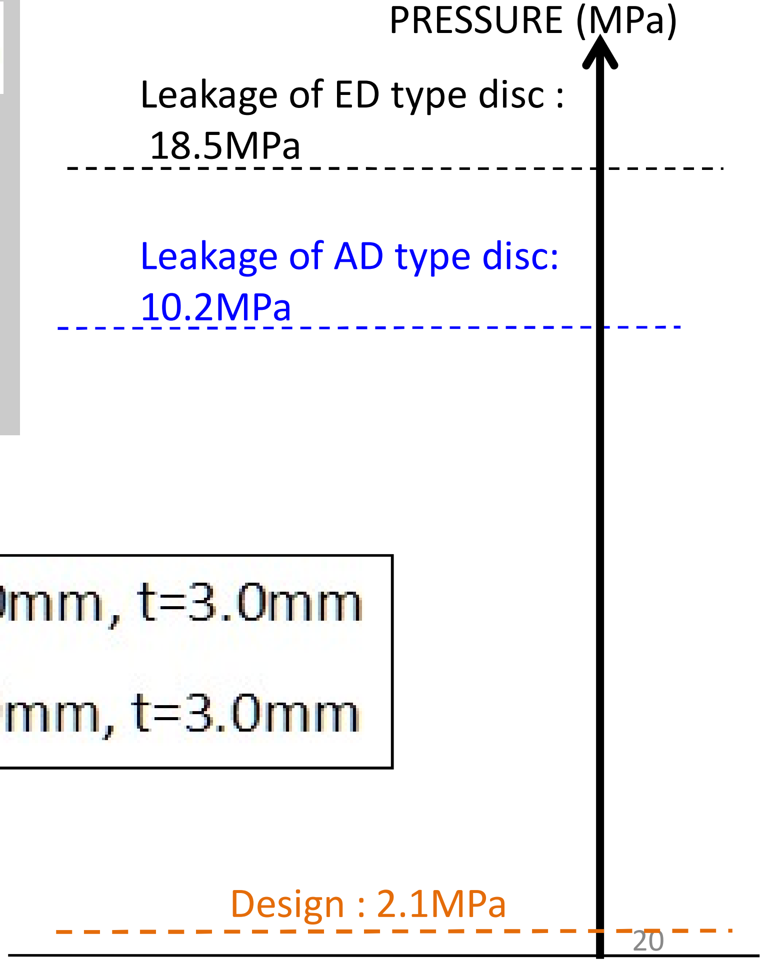


Final Configuration (6.95MPa)

# *Evaluation of Disc Failure*

| TEST | ANALYSIS |
|---|---|
|  |  |





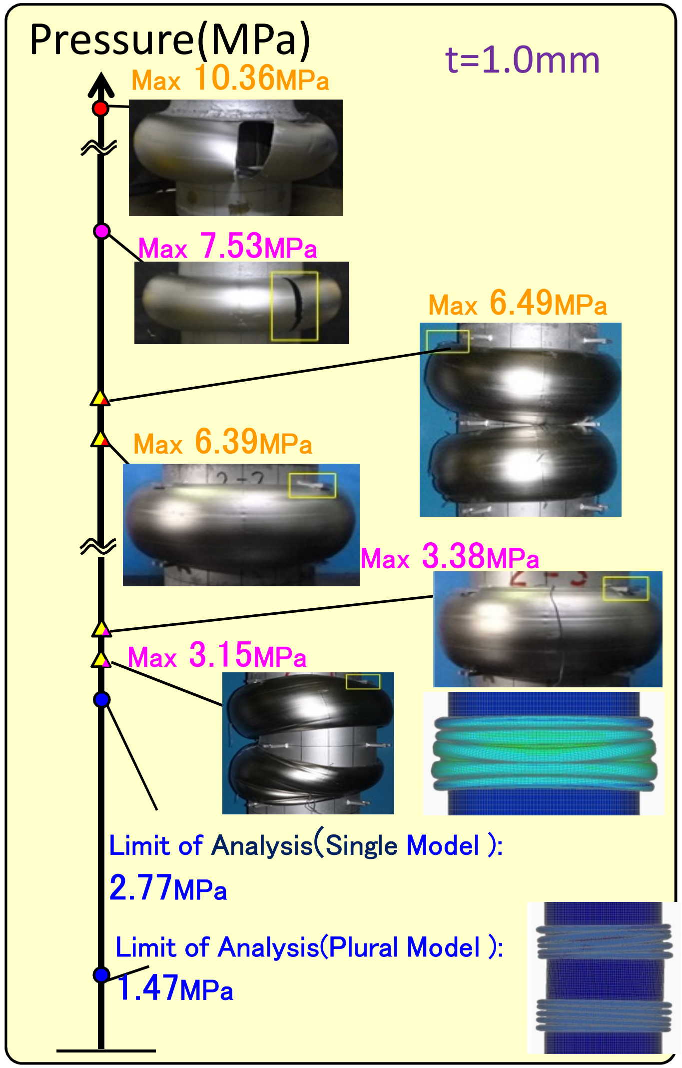


AD type,D=250mm, t=3.0mm

ED type,D=250mm, t=3.0mm

H. Yada et al., "Failure Mode of ED and AD Type Head Plates Subject to Convex Side Pressure," PVP2017-65226, Waikoloa, Hawaii, USA, July 16–20, 2017.

# Evaluation of Bellows Failure




M.Ando et al., “Experimental Demonstration of Failure Modes on Bellows Structures Subject to Internal Pressure,” PVP2017-65227, Waikoloa, Hawaii, USA, July 16–20, 2017.

# *3. Inspection and Maintenance*

- ***Basic Concept of FBR Inspection***

✓ **continuous monitoring and the periodic inspection**

✓ **to achieve the safety and stable operation of the nuclear power plants**

**- confirming integrity and functions, and**

**- improving reliability of the nuclear components and facilities.**

# *Features of FR System on In Service Inspection*

***1. Leak Before Break (LBB)***

**Since the sodium boundary material of FR is ductile austenitic stainless steel and the system pressure is low, the Leak Before Break (LBB) is possibly to be satisfied.**

***2. Leak Detection***

**It is possible to detect the leakage of coolant by monitoring the leakage of sodium using high sensitive leak detectors at a small leak stage.**

# *Concept of the LBB on FBRs*

**① Ductile Structural Material : Austenitic SS**
**② Low Pressure Boundary : Sodium Coolant**

＋

**③ In Service Inspection : Continuous Monitoring**

⇩

**Condition of Leak Before Break (LBB) is satisfied for FBRs.**

**[ISI of FBRs]**

**Continuous Monitoring is adopted as a main measure of the In-Service Inspection.**

- ✔**Sodium Leak Monitoring (SoLM)**
- ✔**Radioactive Ar gas Leak Monitoring (ArLM)**

**Periodic tests such as Visual Test (ViT) and Material Surveillance are also adopted complementary.**

# In Service Inspection Provisions for FBR Plants

**(Reference : IAEA TECDOC-1531)**

Primary vessel and internals (Demonstration or Prototype Reactors)

| Plant | Primary vessel and internals | |
|---|---|---|
| | Provision for routine ISI of primary vessel and internal structure | Provision for routine ISI of outer surface of primary vessel |
| Phenix (France) | - | - |
| SNR-300 (Germany) | - | - |
| PFBR (India) | USV, UGV, DM | AD, US, VI |
| Monju (Japan) | - | AD, VI |
| PFR (UK) | - | - |
| CRBRP (UAS) | - | TV |
| BN-350 (Russian Federation) | UGV | AD, Elcon |
| BN-600 (Russian Federation) | UGV | AD, Elcon |

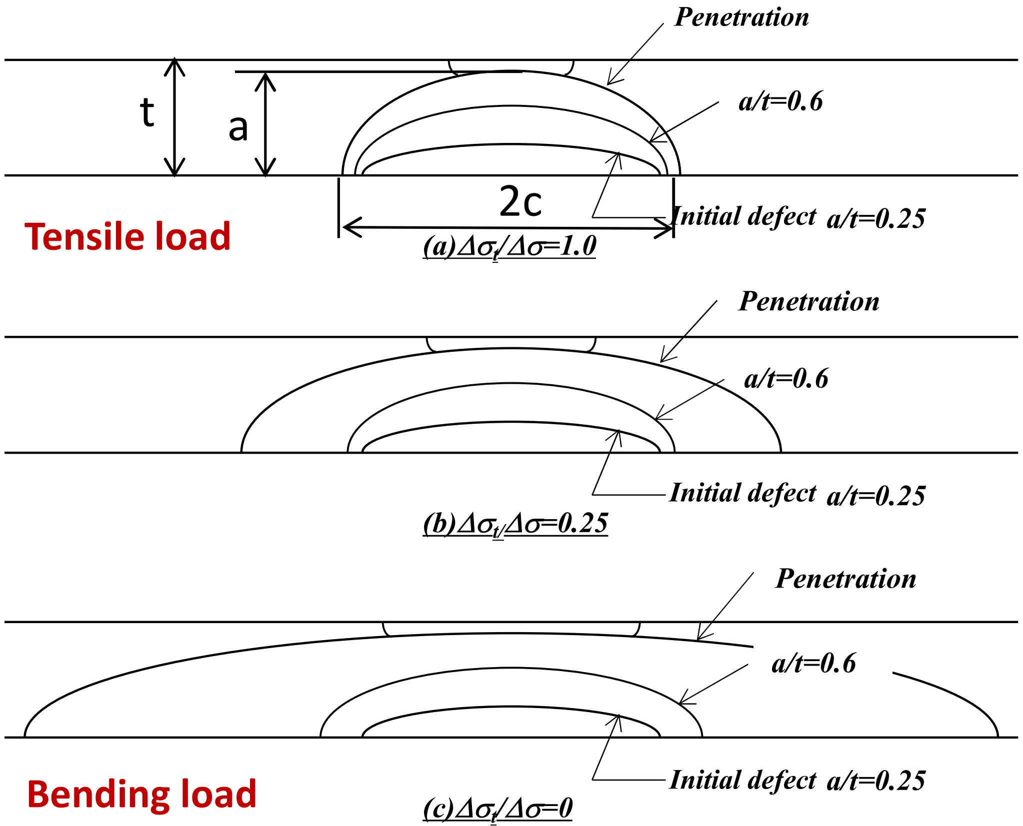
Primary vessel and internals (Commercial Size Reactors)

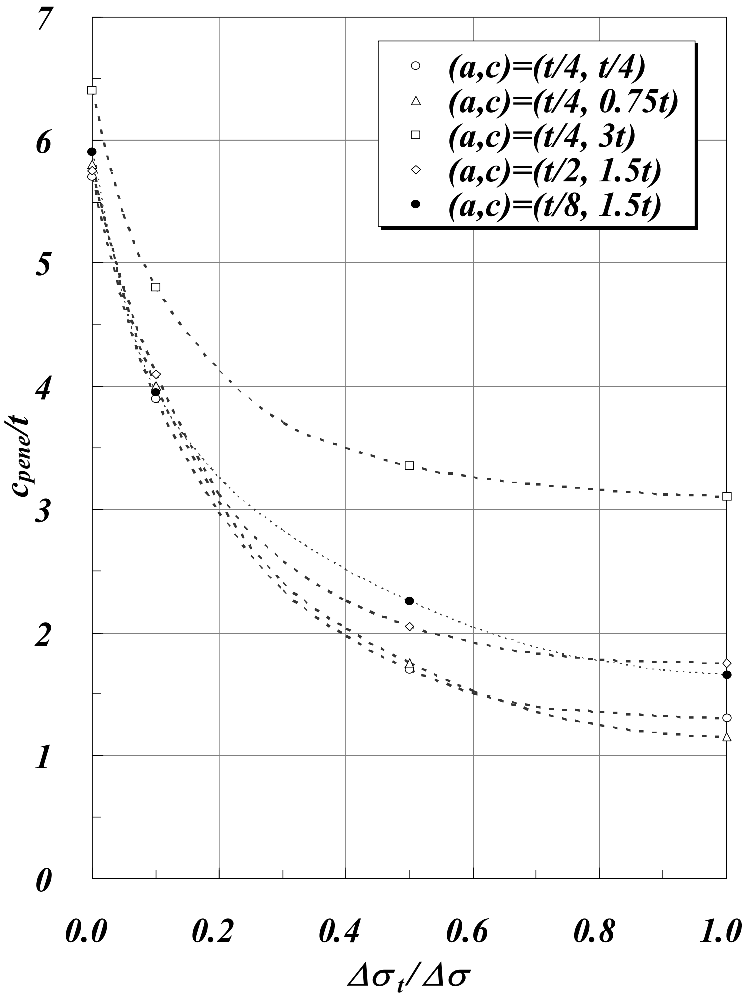
| Plant | Primary vessel and internals | |
|---|---|---|
| | Provision for routine ISI of primary vessel and internal structure | Provision for routine ISI of outer surface of primary vessel |
| Super-Phenix 1 (France) | USV*, UGV* | Elcon/VI*, US*, FV* |

USV - Under sodium viewing
UGV - Under gas viewing, e.g. optical periscope
DM - Displacement monitoring by ultrasonic detector
TV - Traced vehicle
FV - Free moving vehicle

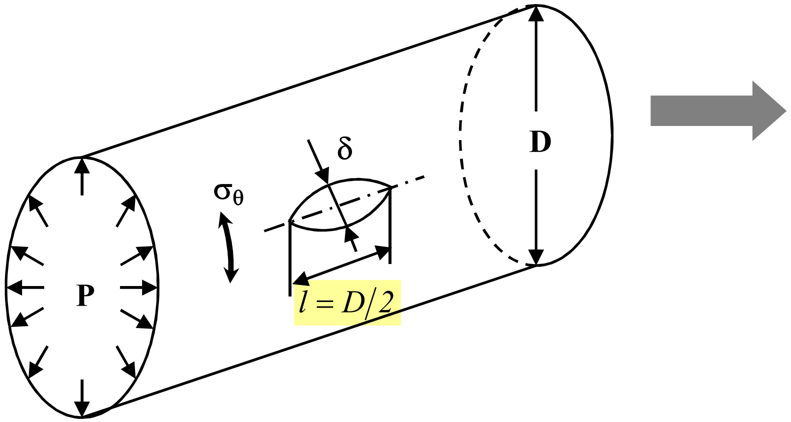
AD - Aerosol detection of primary vessel leak
VI - Visual inspection by optical equipment
Elcon - Electrical contact
US - Ultrasonic measurements

# Safety Related Issue
# - Postulation of crack length -



# *Safety Evaluation Issue - Postulation of leak path area under MONJU condition -*




- ***Postulation of Leak Path Area: Dt/4***

***(for safety evaluation)***

**Though wall crack length < D/2**
**D:Straight Pipe with Diameter**

**Opening  of the through crack < t/2**
**t:thickness**