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JSFR Design Study and R&D Progress in the FaCT Project

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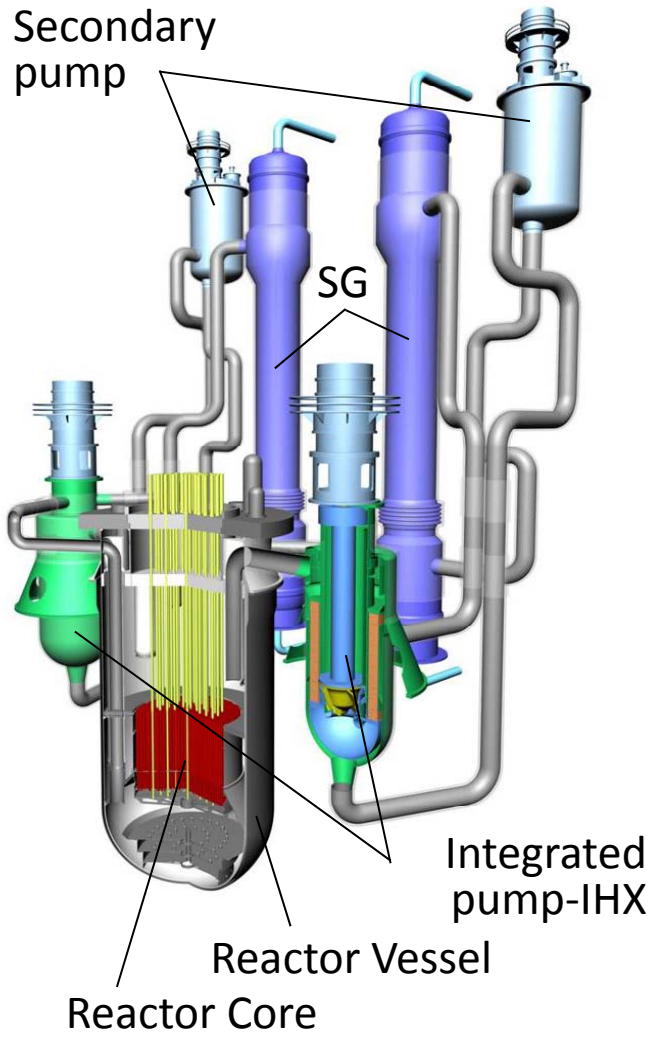
Contents

1. *Introduction*
2. *Progress of works*
   - ✓ *Two-loop cooling system*
   - ✓ *Compact reactor system*
   - ✓ *Double-walled straight tube SG*
   - ✓ *Fuel handling system*
3. *Current status of discussion on innovative technologies*
4. *Steps for demonstration toward commercialization*

Japan Sodium-cooled Fast Reactor (JSFR)



Items	Specifications
Output	3,570MWt / 1,500MWe
Number of loops	2
Primary sodium temperature	550 /395 degree C
Secondary sodium temperature	520 / 335 degree C
Main steam temperature and pressure	497 degree C 19.2 MPa
Feed water temperature	240 degree C
Plant efficiency	Approx. 42%
Fuel type	TRU-MOX
Breeding ratio	Break even ~ 1.2
Cycle length	26 months or less, 4 batches

Innovative technologies in JSFR

Plant constituent parts	Innovative Technologies
Core and Fuel	(1) High burn-up fuel with ODS cladding material
	(2) Safety enhancement technologies; Passive shutdown system and re-criticality free core
Reactor System	(3) Compact reactor vessel
Cooling System	(4) Two-loop cooling system of large diameter piping made of Modified 9Cr-1Mo steel
	(5) Integrated pump-IHX component
	(6) More highly reliable SG with double-walled straight tube
DHRS	(7) Capability of natural circulation for decay heat removal
BOP	(8) Simplified fuel handling system
Reactor Building	(9) CV made of steel plate reinforced concrete (SCCV)
	(10) Advanced seismic isolation system for SFR

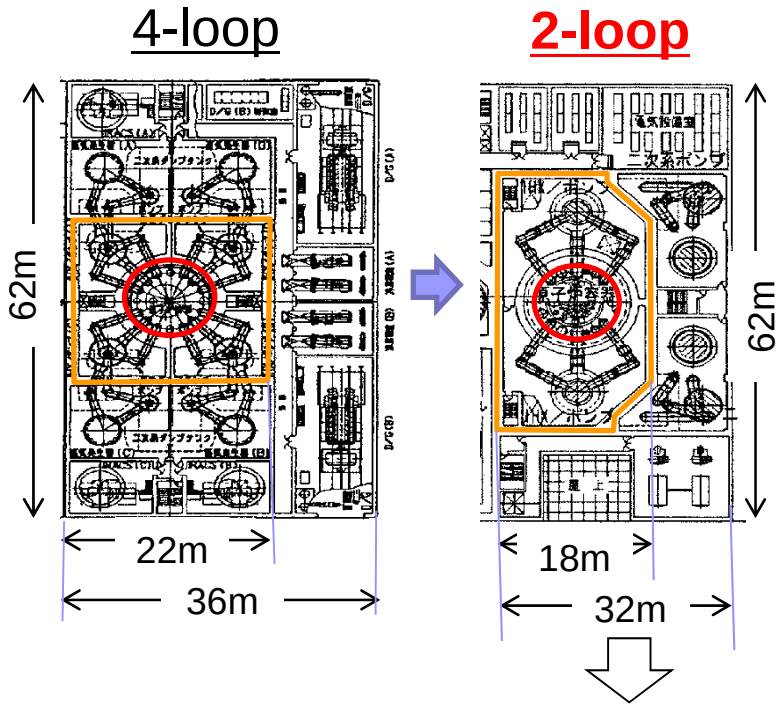
Two-loop cooling system concept

Two-loop cooling system

to enhance scale merit, thereby reduction of construction cost of plant.

Technical issues:

- Piping made of Mod.9Cr-1Mo Steel
  - Consideration of Type-IV damage of welded joint
  - Fabrication method of seamless pipes with large diameter and thin wall thickness
- Evaluation of flow-induced vibration caused by high velocity coolant flow
- Ultrasonic flowmeter system as safety grade instrument applicable to large diameter piping



Amount of commodity of NSSS: 16% less

Applicability of modified 9Cr-1Mo steel to hot-leg pipe of primary circuit

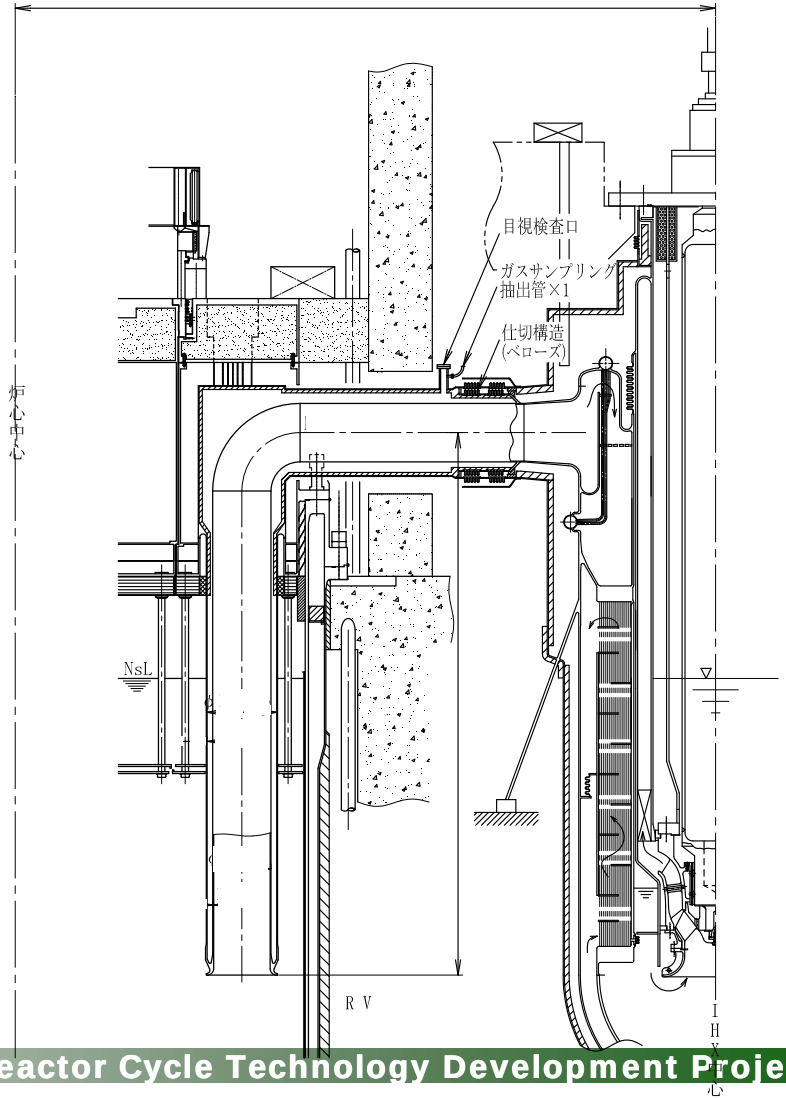
Design of Hot-leg Pipe of Primary Circuit

- ✓ Concrete structure in design was proposed.
- ✓ The allowable stress of modified 9Cr-1Mo steel was provisionally set up taking “Type-IV” damage into account.

Hot-leg Specification

- Diameter : 50B (ca.1.3m)
- Thickness : ca.16mm
- Material : Modified 9Cr-1Mo Steel (ASME P91)
- Temperature : 550 degree C
- Flow rate : 3.2 x 10^4 t/h

The Hot-leg piping design was established with assuming reduction in creep strength of welded joint by Type-IV damage.



Two-loop cooling system Summary

- The reduction in creep strength by Type-IV damage was taken into account in the hot-leg piping design of primary cooling system by setting up the provisional allowable stress.
- Fabrication method of pipes with large diameter and thin wall thickness has been investigating.
- Evaluation of flow-induced vibration was carried out using pressure fluctuation data obtained by the test which simulated piping in the JSFR design. As a result, feasibility of JSFR piping was confirmed.
- Basic specification of ultrasonic flowmeter system was established. Prospect for the expected performance was obtained by experimental study.

Compact reactor system concept

Pursue compact design of RV by adopting innovative technologies

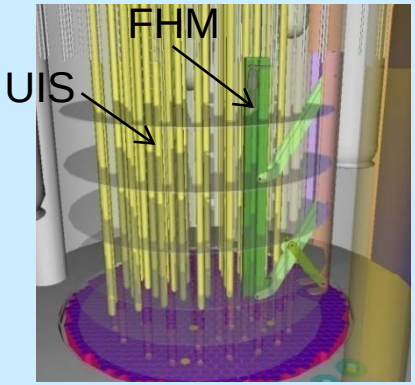
Advanced Fuel Handling System

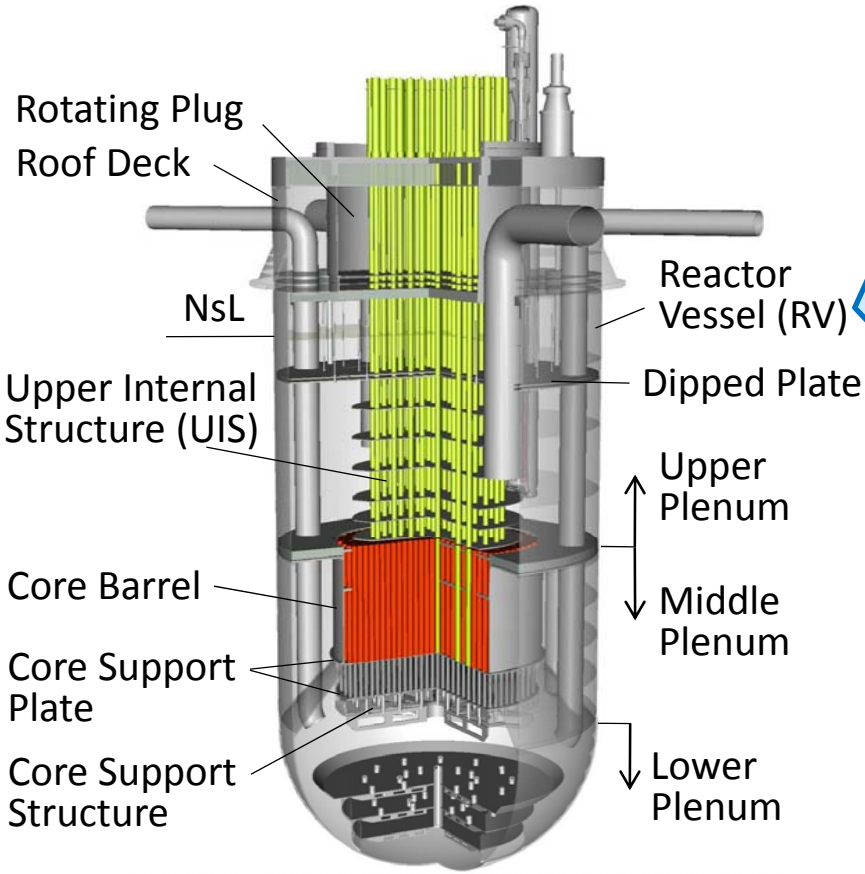
- *Fuel handling machine with pantograph arms*
- *UIS : No outer cover and with a Slit*

[Technical Issues]

→ *Gas entrainment*

→ *Vortex-induced cavitations, etc.*





Reactor System Concept

Hot Vessel Concept

- *RV wall suppressing wall-cooling layer*

[Technical Issues]

→ *Ensuring structural integrity against;*

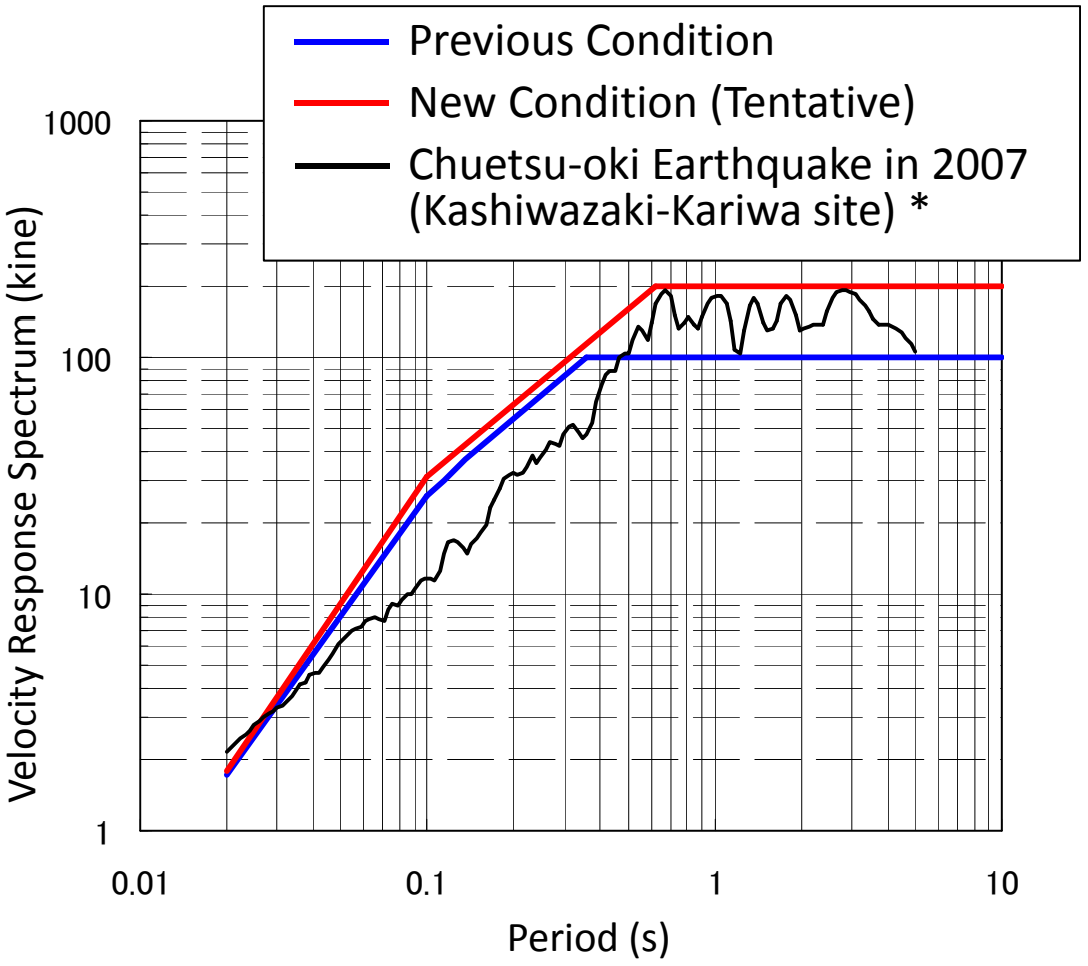
- *Thermal stress in plant transient, and*
- *Seismic force of severe earthquake*

→ *Manufacturing of RV*

- *Large-size ring-shaped forging*
  - *for no welding line at highly stressed parts*

Seismic design

- *Chuetsu-oki earthquake occurred in 2007.*
- *The earthquake condition for the JSFR design was reviewed and modified to be severer.*
- *The new condition is an envelope for most earthquake conditions of Japanese NPP sites except Hamaoka site.*
- *The adequateness of the new condition will be reviewed based on results of back-check on earthquake resistance of the existing NPPs in Japan.*



* HP of Nuclear Safety Commission of Japan, http://www.nsc.go.jp/

Current status of seismic design for JSFR

Design Measures for Improvement of Seismic Resistance

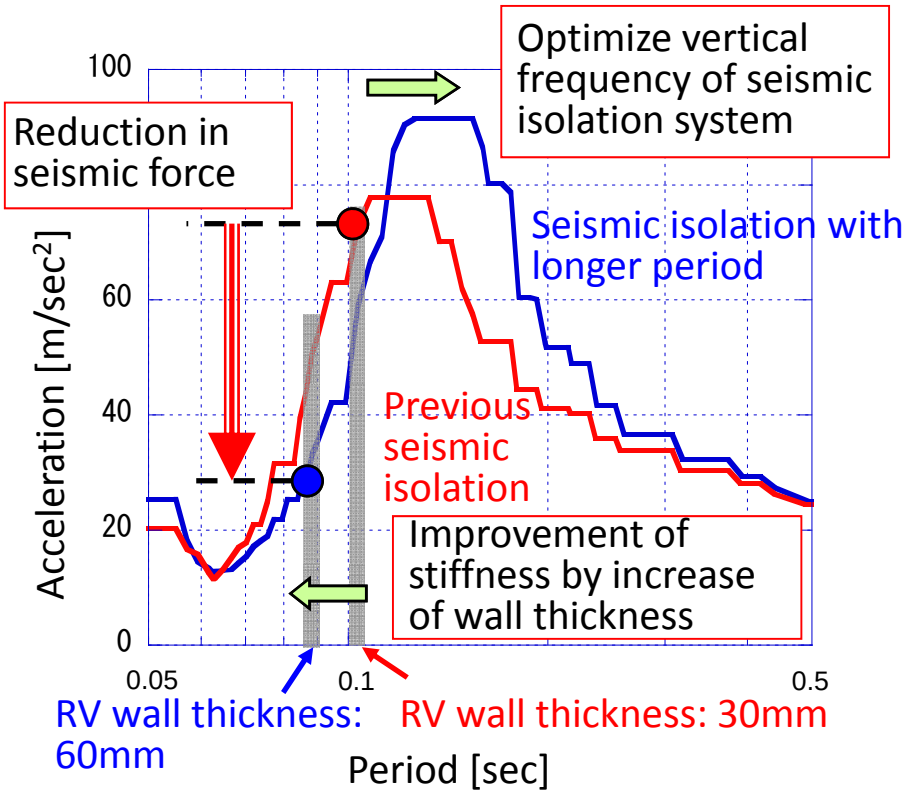
RV wall thickness of 30mm is not feasible under the new seismic condition.

- *Improve stiffness by increase of wall thickness of RV*
- *Optimize specification of seismic isolation system for SFR*

Seismic Evaluation Results (1,500MWe JSFR)

Conditions		
Seismic isolation system	Previous	Optimized
RV wall thickness (mm)	60	60
Results		
Buckling of RV	O	O
Fuel sub-assembly jump-up	X	O
Reactivity insertion	O	O

O: Success, X: Failure

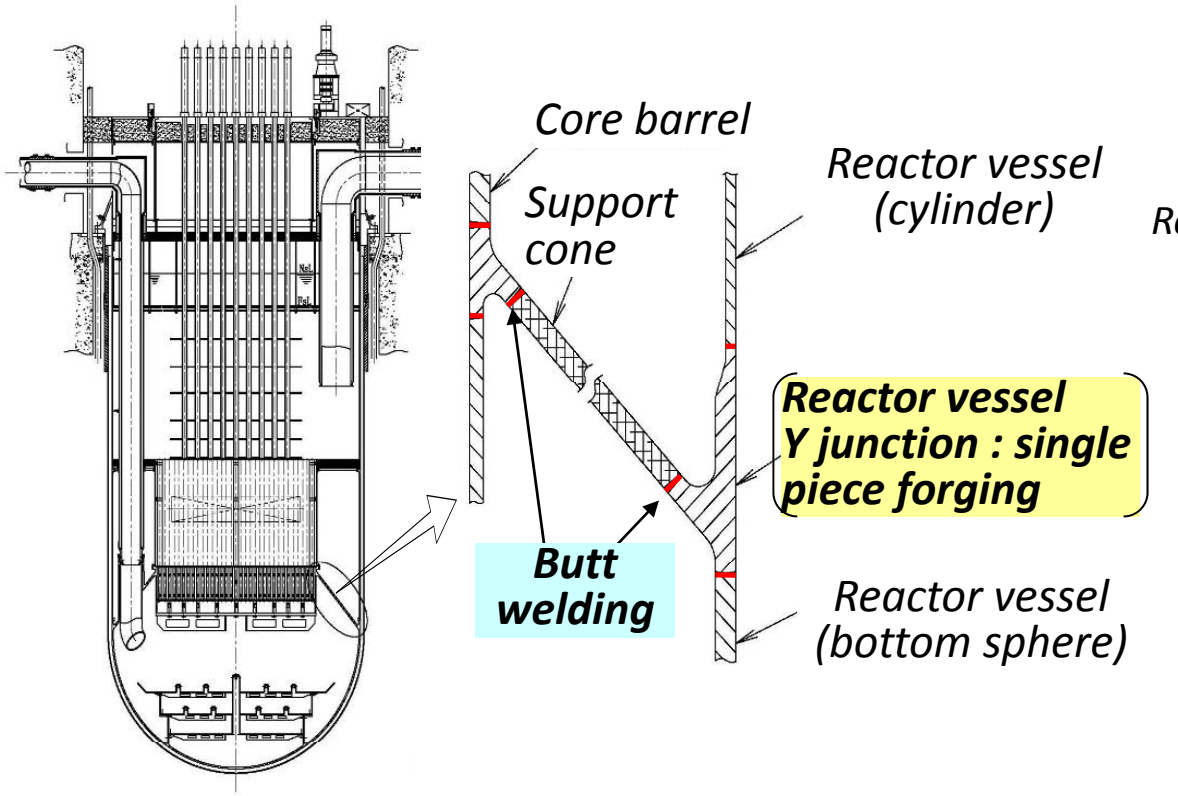


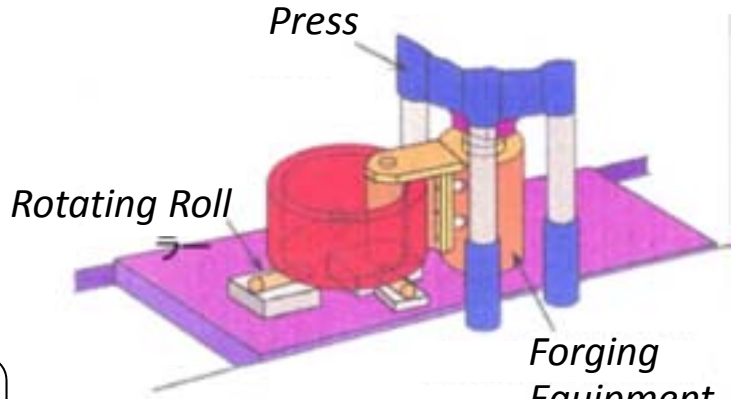
Floor Response at Setting Position of RV in Vertical Direction using new seismic condition

Concept of reduction in seismic force

Application of single-piece forging

– Investigation to apply and produce a large-size single-piece forging –





By use of single-piece forging,

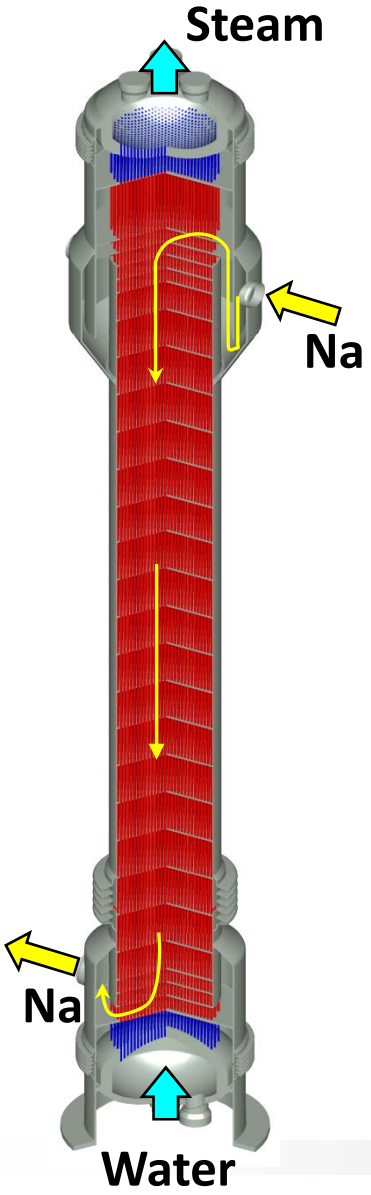
- *Reliable butt welding can be applied.*
- *It is easy to access to a weld line for inspection.*

Presentation by JSW in 8th Advisory Committee on R&D, 17 March 2009, Japan Atomic Energy Commission, http://www.aec.go.jp/

Compact reactor system Summary

- Compact reactor system was assessed from technical point of view. As a result, it has potential to be realized in a commercial reactor.
- RV wall thickness and specification of seismic isolation system were optimized to respond to a severer seismic condition.
- R&D on innovative technologies has progressing steadily, e.g., thermal hydraulics issues in upper plenum, fabrication issues of forging.
- Design options will be also investigated to extend a design margin against seismic resistance, e.g., RV with wall-cooling layer, improvement of seismic isolation.

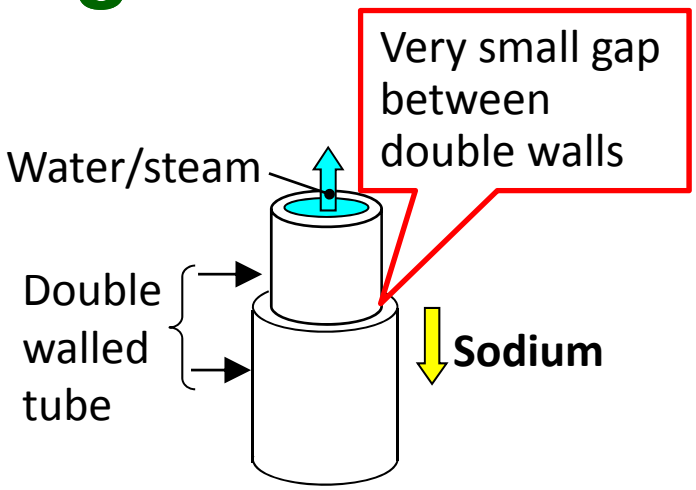
Double walled straight tube SG concept



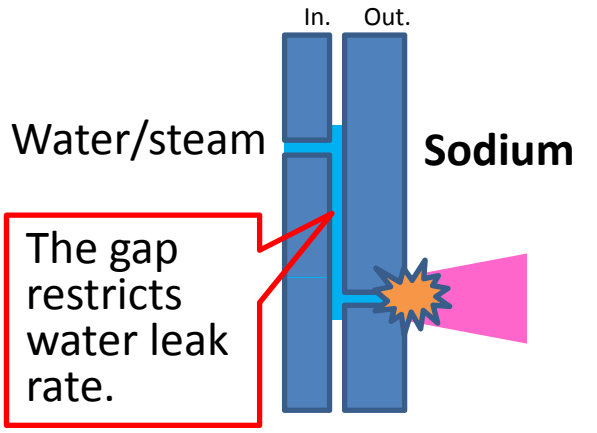
1. Large heat transfer capacity
   - Scale merit for lower construction cost
   - 750MWe/unit fitted for JSFR two-loop cooling system concept
2. High reliability on sodium-water boundary
   - Lower possibility of water leak event
   - Higher availability for economic performance
3. Mitigation function of sodium-water reaction
   - For property protection against tube failure propagation in case of water leak event

Ideas for tube design

1. Large heat transfer capacity
   - Long straight tube (L_{eff}=29m) for higher thermal efficiency
   - Straight tube SG for lower fabrication cost
2. High reliability on sodium-water boundary
   - Double walled tube
     - Cold worked DW tube for independent boundaries
   - Independent ISI
     - ECT for inner tube + UT for outer tube
3. Mitigation function of sodium-water reaction
   - Restriction of water leak rate with double walled tube
     - Very small gap between double walls



【Double walled tube concept】



【Mitigation function concept】

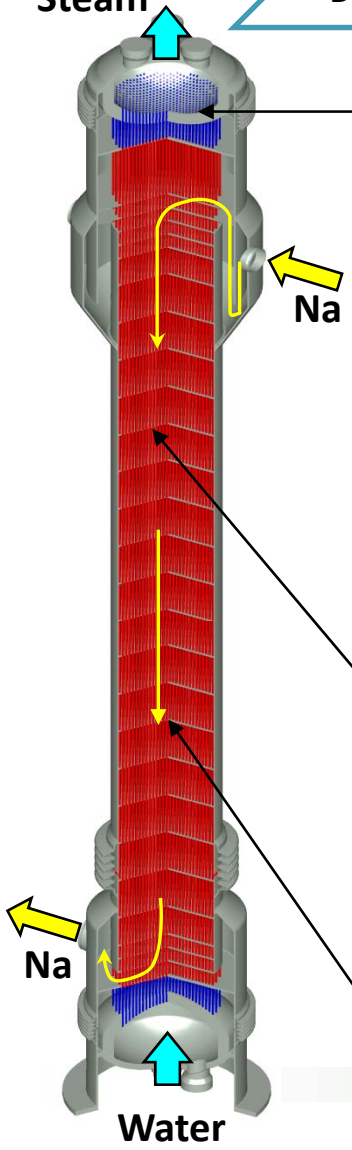
Development plan

- ・Parts fabrication test
- ・Design method dev.

→ ・Structure tests
・Elemental tests

→ ・Structure fab. test
・10MW-Sodium test

→ Demonstration test (50MW)



1. T91 parts and structure

Target: Fabrication in commercial facilities
- Test fabrication in commercial condition
- Collaboration with material suppliers, fabricators, etc.

Tube sheet fab. test (50t)

Tube fab. test(ϕ20.4×t1.7)

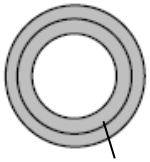
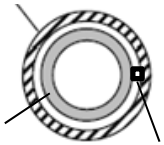
2. Thermo-hydraulics

Target: Design optimization in thermo-hydraulic
- ~2010: Evaluation without sodium test
  - Water-steam 2 phase flow model development with electric heated tube test
  - Sodium flow model development with water test
- 2011~: Verification & demonstration with sodium test
  - 10MW Sodium test for structure and code verification
  - 50MW Sodium test for Demonstration

3. Sodium-water reaction

Target: Evaluation by mechanistic model
- Elemental tests for mechanistic modeling

Alternative ideas for tube design

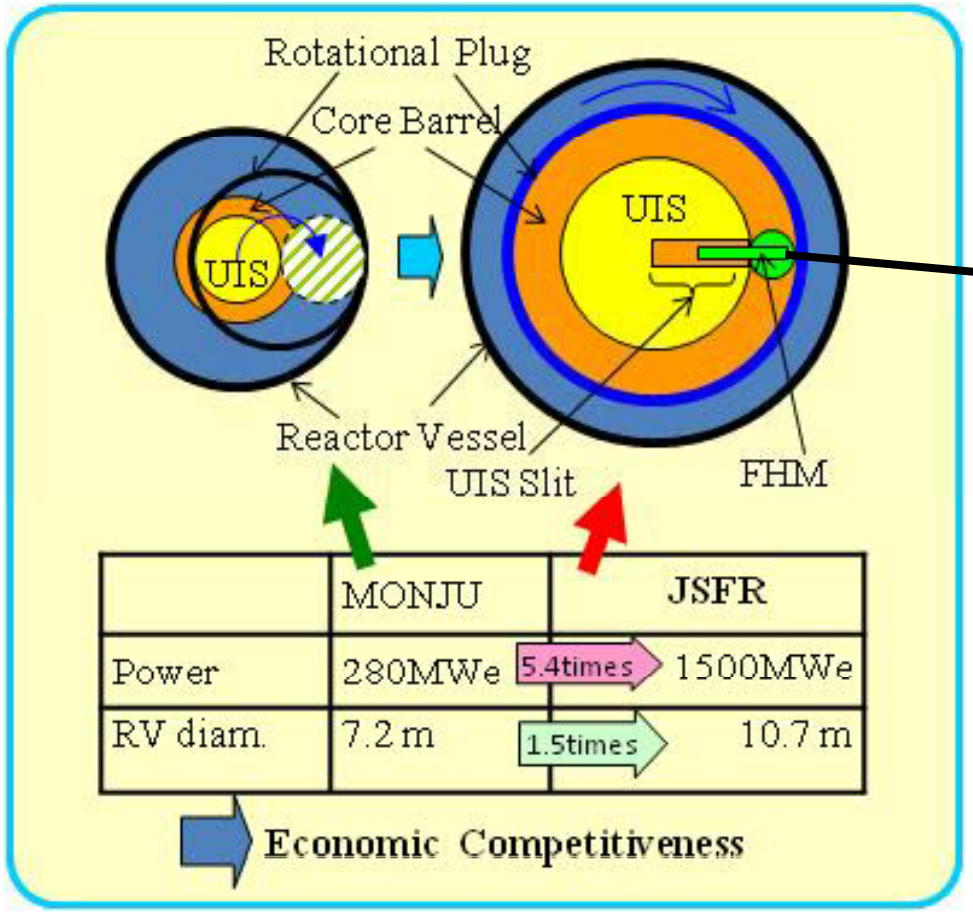
	(1) T91 double walled tube	(2) T91 tube with anti-wastage guard tube	(3) T91 tube with anti-wastage clad
Tube	 T91double walled tube	Wastage resistant tube  T91 tube Spiral rib	Wastage resistant cladding  T91 tube
Failure propagation	Non	Non	Non
Plugged tubes	<2 tubes	<8tubes	<8 tubes
Tubes*	1.00	1.00	1.08
Weight*	1.00	1.33	1.40
Welding jointed tube	•non	•Yes	•Yes
Issues	•Double walled tube •Tube-sheet	•Inspection method for guard tubes •Wastage behavior on the guard tube	•Structural integrity of tube and cladding

＊：ratio vs. Double walled tube SG

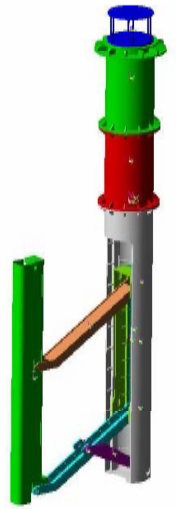
Double walled straight tube SG Summary

- Conceptual design of double walled straight tube SG has been established.
- Parts fabrication tests and elemental experiments have been performed.
  - Double walled tube, tube sheet, CSEJ, tube-tube sheet joint
- Thermo-hydraulic design code for long straight tube SG has been established.
  - Water-steam 2 phase flow model development with electric heated tube test
  - Sodium flow model development with water test
- Sodium test plan is fixed and test facility is under construction.

JSFR fuel handling system concept



- Compact in-vessel fuel handling with a slit UIS and **pantograph FHM**



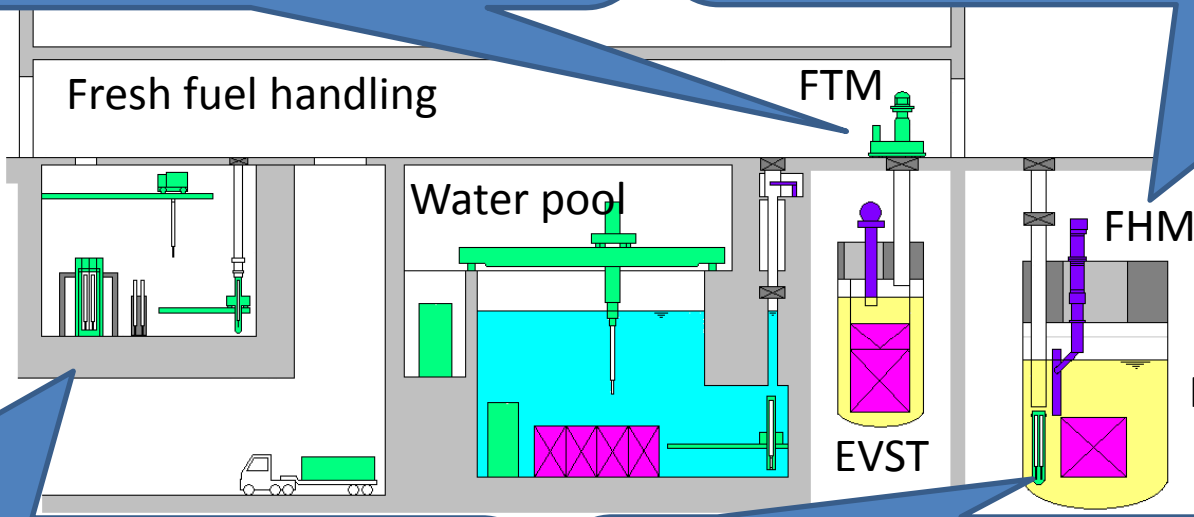
Pantograph Fuel handling machine (FHM)

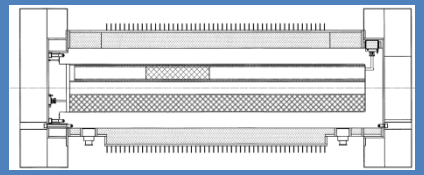
- Short plant outage (30 min per subassembly → **Transportation pot with two-subassembly positions**
- Simple fuel handling system (**Dry cleaning**)
- MA bearing fuel storage and handling (Fresh fuel decay heat up to 3kW → Fresh fuel shipping cask)

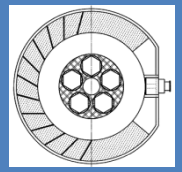
JSFR fuel handling system : R&D

Dry cleaning
Cleaning test with full-scale pin bundle mockup
✓ residual sodium is under 0.75% of the requirement.

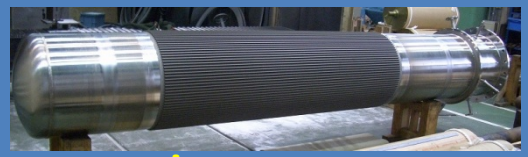
Pantograph FHM
Full-scale mockup test in the air
✓ positioning within 1mm
✓ seismic proof
✓ accident manage







Fresh fuel shipping cask
✓ 1 to 3kW/SA (1 to 5 accommodation)



Transportation pot
radiation heat transport experiment with full-scale pot experiment
✓ radiation (20kW) + argon gas blow (25kW)

JSFR Fuel handling system Summary

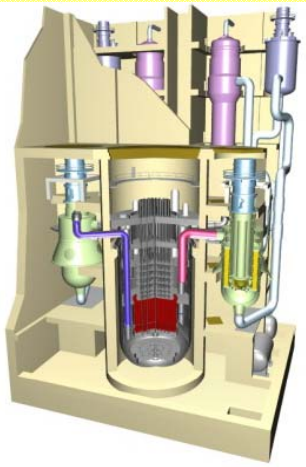
- FHM performance including positioning accuracy, arm speed and stiffness for subassembly charge/discharge operation has been demonstrated using a full-scale FHM mockup.
- The FHM seismic analysis model has been improved based on the mockup data and the analysis method has been validated by vibration tests.
- The seismic analysis showed that there is no interaction between UIS and FHM under the design base seismic condition.
- Performance of the dry cleaning method has been demonstrated by sodium tests with a mockup tube bundle of the JSFR fuel subassembly with an inner duct.
- Radiation heat removal capability of the JSFR fuel transportation pot has been evaluated by a full-scale mockup test. Radiation heat removal capability has been evaluated at least 20kW.
- A concept of the fresh fuel shipping cask for minor actinide bearing fuel transportation has been provided. And cooling and shielding capability have been confirmed using numerical analyses.

Adopted*

** Recommendation of JAEA and MHI/MFBR*

- Advanced Seismic Isolation System for SFR
- Safety Enhancement Technologies (SASS, Re-criticality Free Core)
- Two-loop Cooling System of Large Diameter Piping made of Mod.9Cr-1Mo Steel
- Integrated Pump-IHX Component
- DHRS by Natural Circulation
- Simplified Fuel Handling System
- CV made of Steel Plate Reinforced Concrete

JSFR



"Road to Commercialization"

Background of necessity of study on alternatives

Under discussion

- Compact Reactor System
- High Burn-up Fuel with ODS Cladding Material
- Higher Reliable SG with Double-walled Straight Tube

- Measure to enhance the design margin for seismic reliability *(ex. Cold vessel; (Hot Vessel at present))*
- Shortage of time to irradiation tests *(ex. Consideration of alternative material as needed)*
- *Fabrication capability of full scale double-walled straight tube(ex. Other tube idea for anti-wastage)*

- Process of R&D on Innovative technology and steps for demonstration of reactor technology toward the commercial FBR -