Advanced Irradiation Technology for LWR Fuel and Material

- Development of Mechanical Seal Structure for BOCA-

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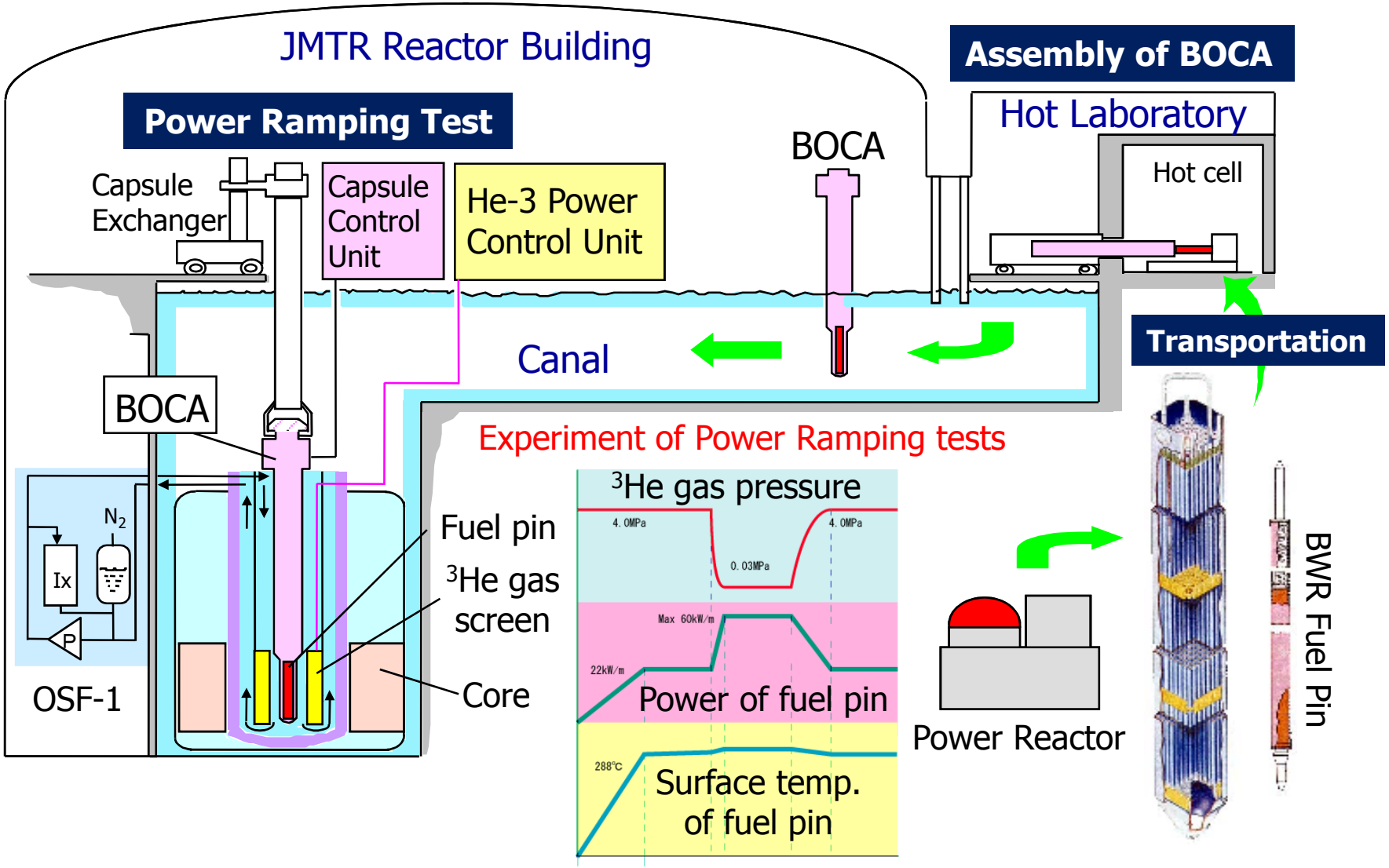
Introduction

Development of the BOCA (Boiling Water Capsule) has been carried out from a viewpoint of R&Ds for fuels of light-water reactor (LWR). Using the BOCA, it is possible to evaluate fuel behavior during power ramp tests by measurements of fuel center temperature, internal pressure, etc.

On the other hand, an instrumentation device for fuel center temperature and FP gas pressure is welded to the fuel specimens installed into the BOCA. The negative point for the instrumentation device is the cost performance.

Therefore, the mechanical seal structure for a new BOCA, which connects instrumentation devices with fuel specimens, has been proposed for reduction of fabrication cost and radioactive wastes.

Outline of Irradiation Tests for LWR Fuels



Object and Configuration of Irradiation Facility

The irradiation facility was developed for power ramping and boiling transition tests on light-water reactor (LWR) fuels. This facility consists of shroud irradiation unit (OSF-1), capsule control unit, and He-3 power control unit. Fuel specimens installed in BOCA are irradiated in the facility.

Object for irradiation tests

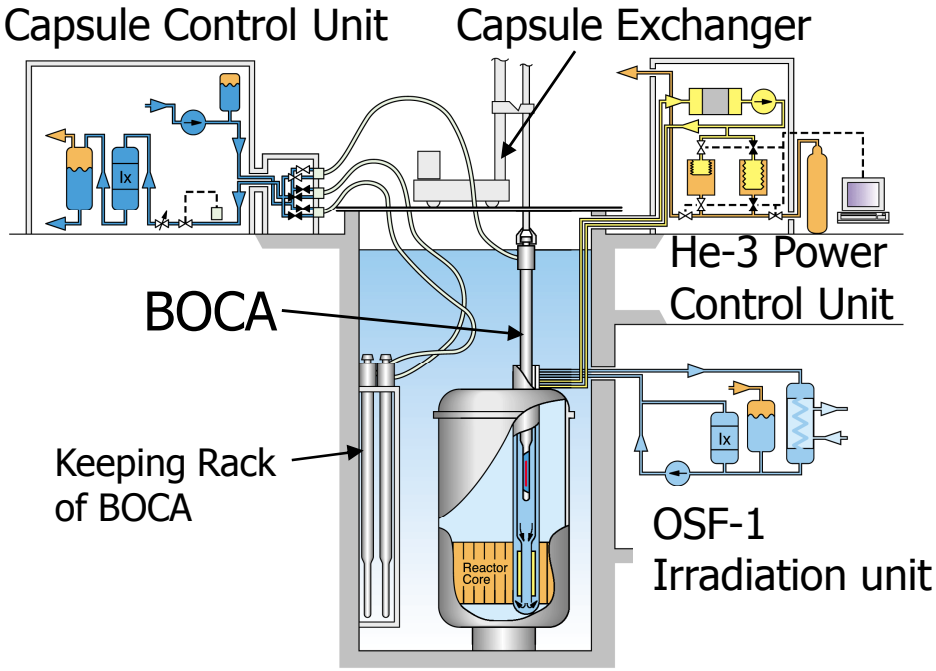
[Fuel Safety Research]

1) Verification of analysis code for fuel behavior.
2) Evaluation of pellet-and-clad interaction.
3) Evaluation of fission product gas release.

[High Burn-up Study of BWR Fuel]

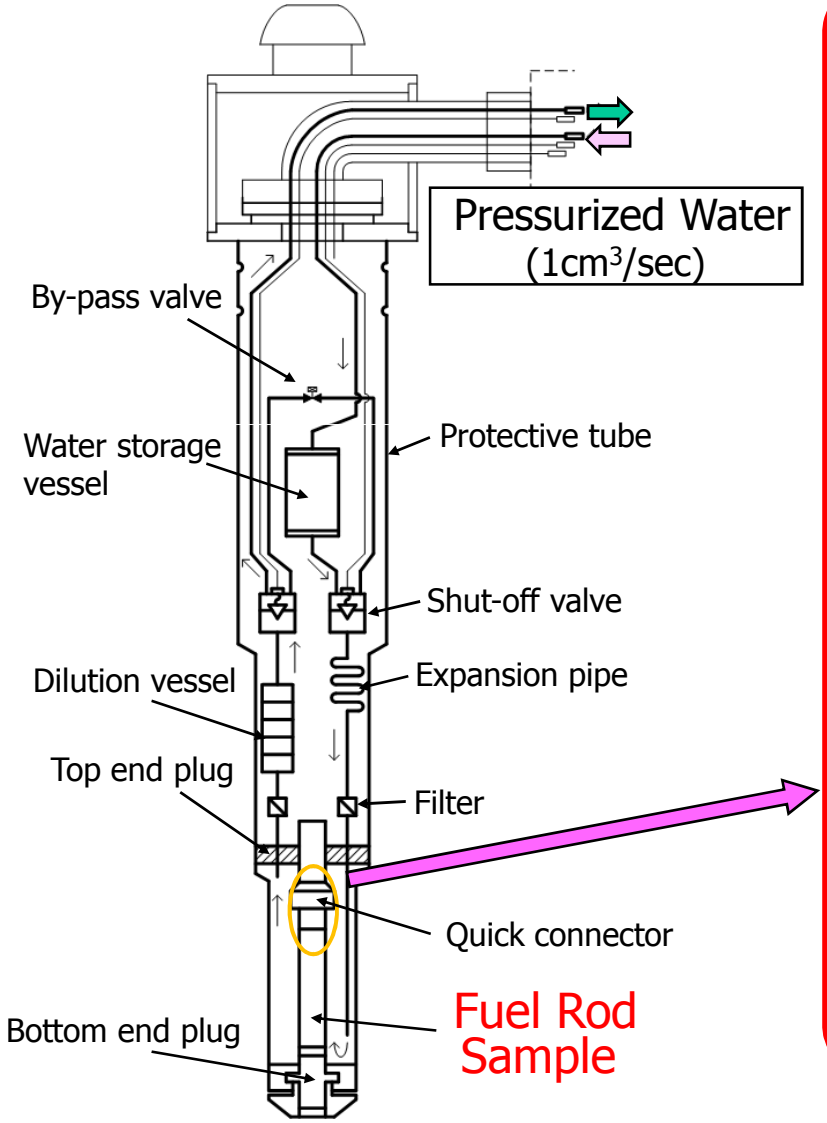
1) Soundness Evaluation of Fuel elements.
2) Determination of fuel damage threshold.

Configuration of Facility



Development of Instrumentation Devices for BOCA

Configuration of BOCA



Instrumentation for Fuel Rod

Development of Connector

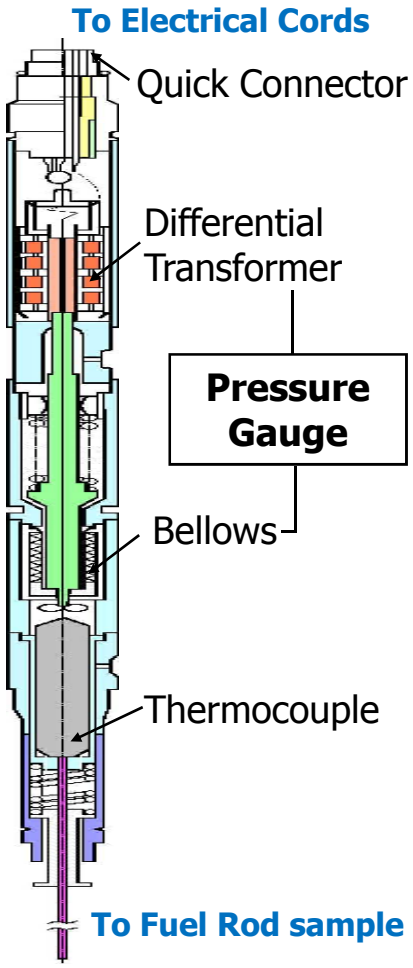
9 electrical cords can be connected by the developed quick connector.

Development of FP gas pressure gauge

Gas pressure can be measured in the range from 0 to 5MPa.

Development of thermocouples

Temperature up to 1900°C can be measured by W/Re thermocouple for the fuel behavior.

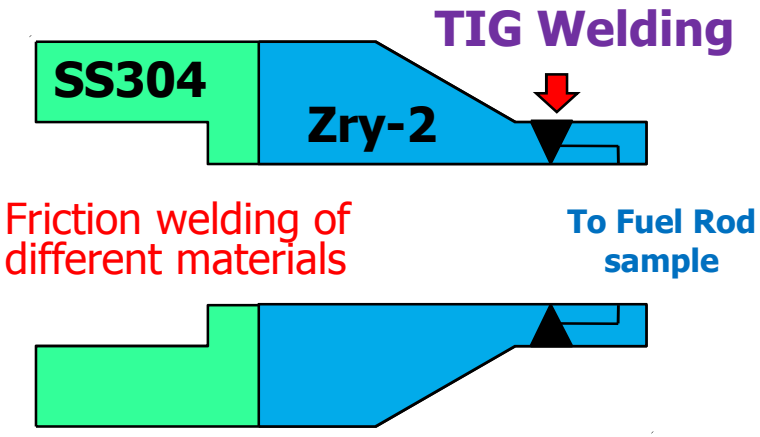


Comparison between Welding and Mechanical Seal

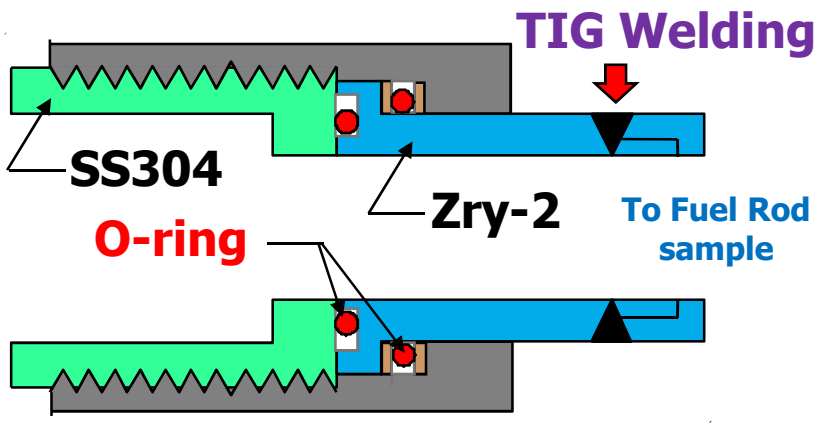
An instrumentation device is welded to the fuel specimens installed into the BOCA. The mechanical seal structure is proposed for;

(1) Re-instrumentation of FP gas pressure gauge after irradiation test,
(2) Reduction of radioactive wastes,
(3) Cost reduction of fabrication and wastes.

Welding structure



Mechanical seal structure



[R&D items for mechanical seal structure]

(1) Structual design for continual connections
(2) Mitigation of thermal expansion for connection of different materials

Flow for Mechanical Seal Structure Development

Design of Mechanical Seal Structure

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Trial Fabrication

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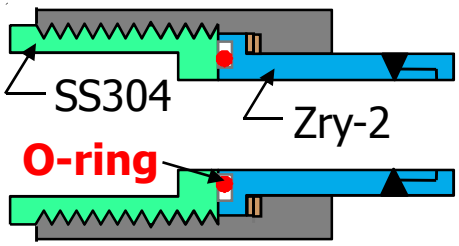
Characterization

[Adoption of mechanical seal with O-ring]

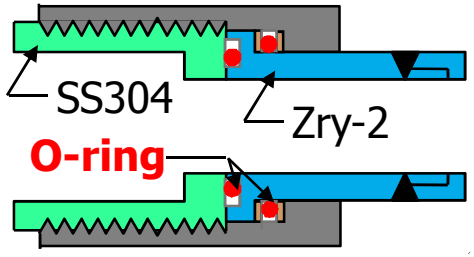
(1) Simple and downsizing structure
(2) Cost reduction
(3) Utilization under extensive condition

[Type 1]



O-ring : 1 point

[Type 2]



O-ring : 2 points

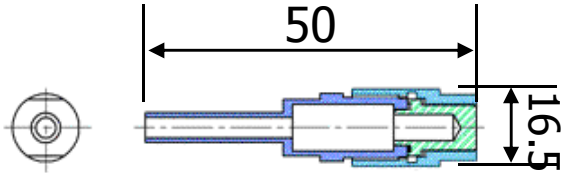
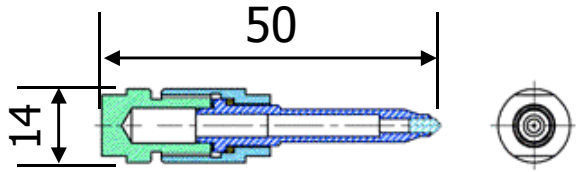
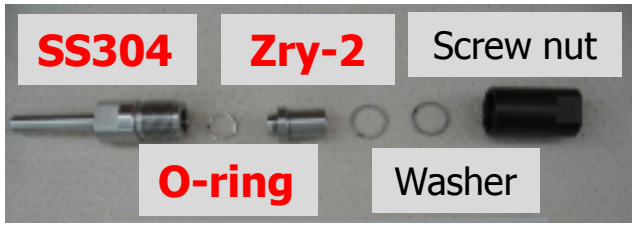
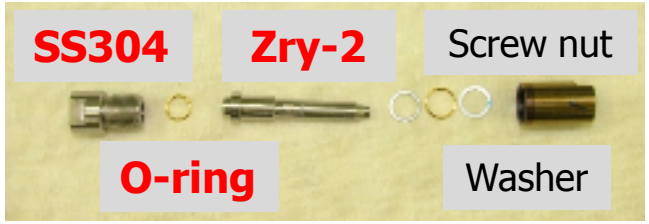
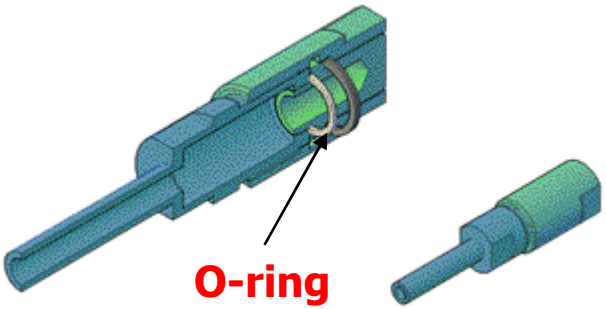
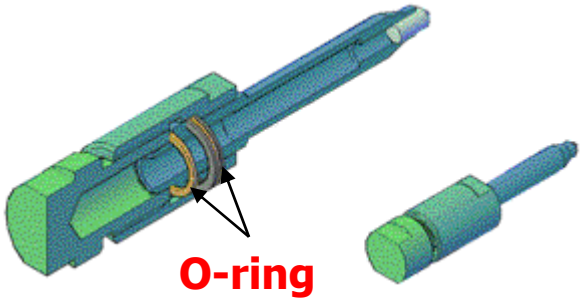
[Specification of O-ring]

(1) Inconel 600 tube (ϕ0.89mm) coated with Au (40μm)
(2) O-ring size : ϕ8.8mm^{OD}
(3) Temperature range : -270 – 700°C

[Test Items]

(1) Pressure Test at 10MPa
(2) He leakage test
(3) Thermal Cycle Tests at the condition of high temperature and pressure

Trial Fabrication of Mechanical Seal Structure

	Type 1	Type 2
Section (mm)		
Photograph		
3D Section		

Selection of Optimum Compression Forces

Three kinds of compression forces were tested on the mechanical seal structures. Pressure test and helium leakage test were carried out for selection of compression forces.

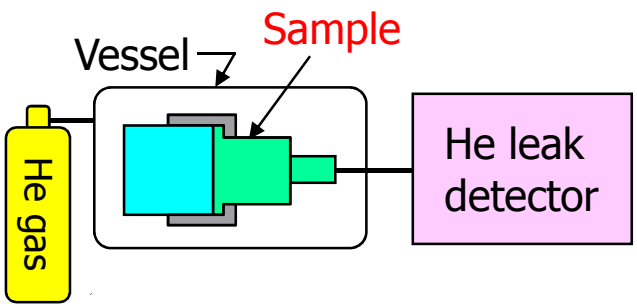
Condition of compression forces

Compression Force : 1.37kN/cm, 1.72kN/cm (standard*), 2.06kN/cm

* : Standard is recommended as compression force of this O-ring.

Test procedure

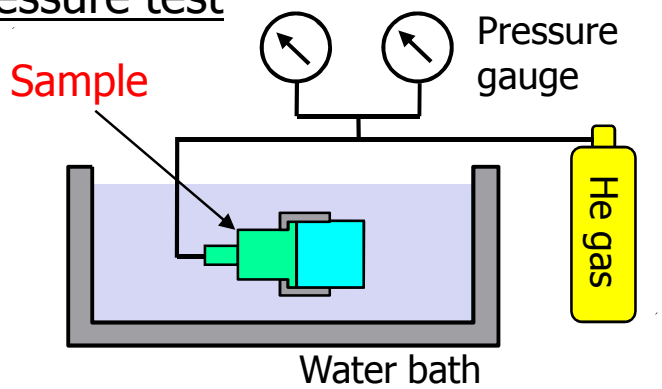
He leakage test



Test condition : Room Temp.

Acceptance : $<1\times10^{-9}$ Pa·m^3/s

Pressure test



Test condition : Room Temp.
10MPa

Acceptance : No bubble

Results of Optimum Compression Forces

Seal structure	Compression force (kN/cm)	Pressure test	He leakage test ($Pa \cdot m^3/sec$)	Result
Type 1	1.37	No bubbles	3.5×10^{-11}	Acceptance
	1.72	No bubbles	6.6×10^{-11}	Acceptance
	2.06	No bubbles	6.8×10^{-11}	Acceptance
Type 2	1.72	No bubbles	2.8×10^{-10}	Acceptance

In pressure and helium leak tests in trail fabrication, two kinds of mechanical seal structures were good results.

Procedure of Thermal Cycle Test

Thermal cycle tests of two kinds of mechanical seal structures were carried out during high temperature and pressure of BOCA condition.

Test Flow

He leakage test

Test condition
: Room Temp.
Acceptance
: $<1\times10^{-9}$ Pa·m³/s

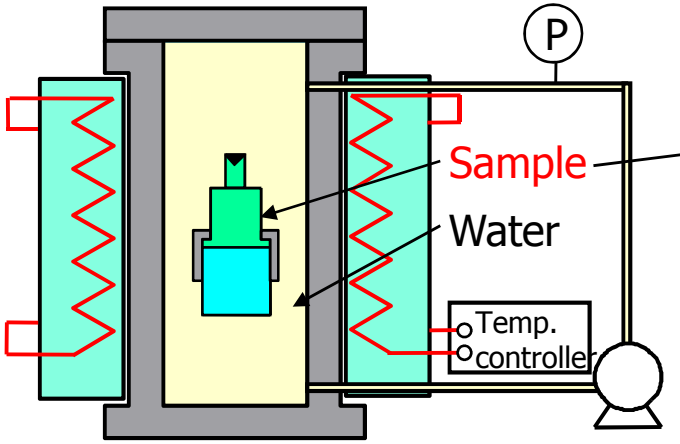
Thermal cycle test

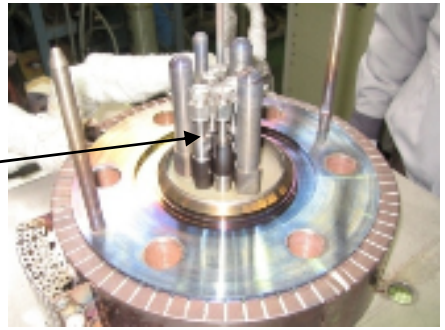
He leakage test

Test condition
: Room Temp.
Acceptance
: $<1\times10^{-9}$ Pa·m³/s

Observation after dismantlement

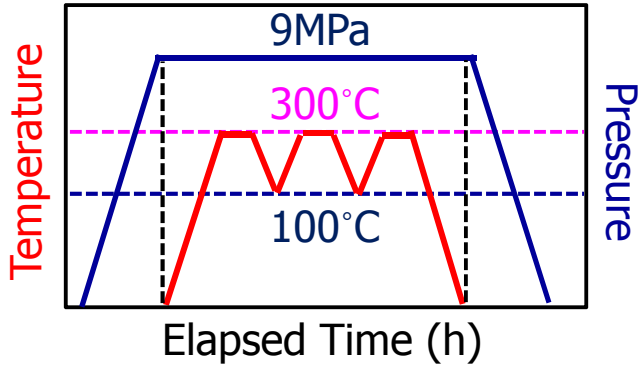
Configuration of thermal cycle test device





Photograph of sample setting

Test Condition



Pressure: 9 MPa
Temperature
: 100 – 300°C
Hold time
: 30min at 300°C
Thermal cycle
: 3 times

Results of Thermal Cycle Test

	Type 1	Type 2
Test sample	Compression force : 1.72kN/cm	Compression force : 1.72kN/cm
Characterization		
He leakage test before thermal cycle	1.1×10^{-10} Pa·m^3/s	2.3×10^{-10} Pa·m^3/sec
Thermal cycle test	Water leak	No water leak
He leakage test after thermal cycle	-	5.2×10^{-10} Pa·m^3/s
Result	Failure	Acceptance

Mechanical seal structure with two O-rings is good procedure for connection between fuel pin and instruments.

Conclusions

Design and trail fabrication of the mechanical seal structures were carried out and the results are as follows;

1) In pressure and helium leak tests in trail fabrication, two kinds of mechanical seal structures were good results.

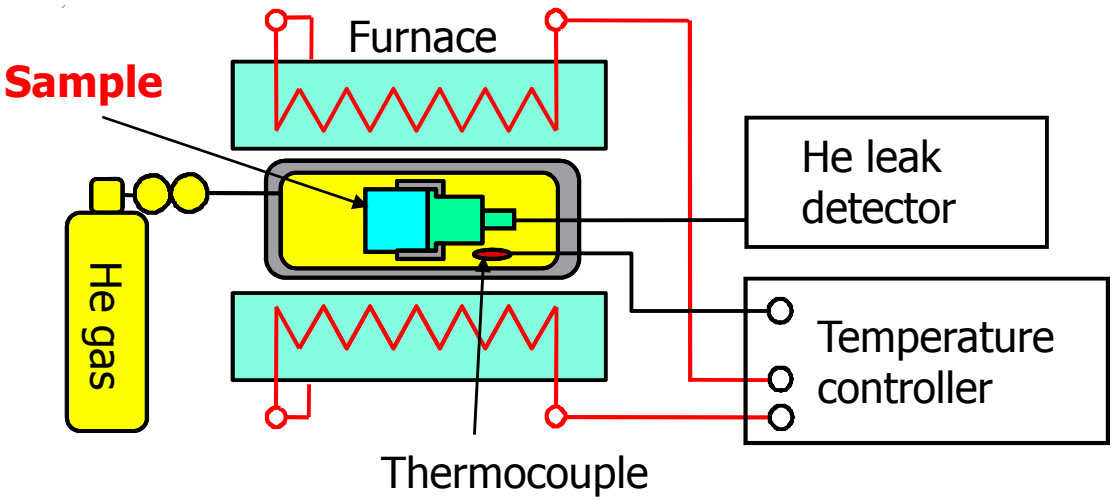
2) In Type 1 of mechanical seal structure, water leak was observed after the thermal cycle test. It seems that the screw nut was worked loose in this test because of the difference of thermal expansion.

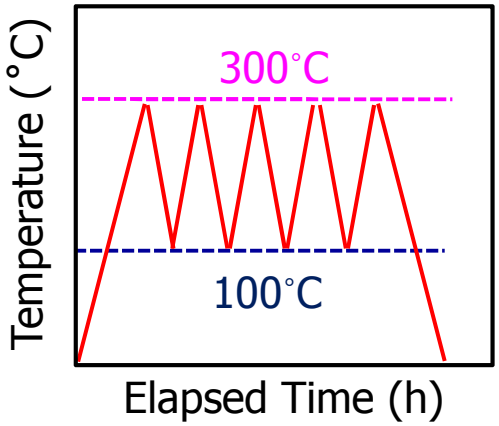
3) In Type 2 of mechanical seal structure, water leak was not observed by locking effect of two O-rings in thermal cycle test.

Mechanical seal structure with two O-rings is good procedure for connection between fuel pin and instruments for a new BOCA in JMTR.

Future Plan

1) Confirmation of leakage in thermal cycle test under the exact conditions in helium atmosphere.





2) Irradiation test of the mechanical seal structure in JMTR

- Irradiation condition
- Measurement items and procedures during irradiation test
- Design and fabrication of irradiation capsule
- PIE items