# Overview of Progress on Water Cooled Ceramic Breeder Blanket in Japan

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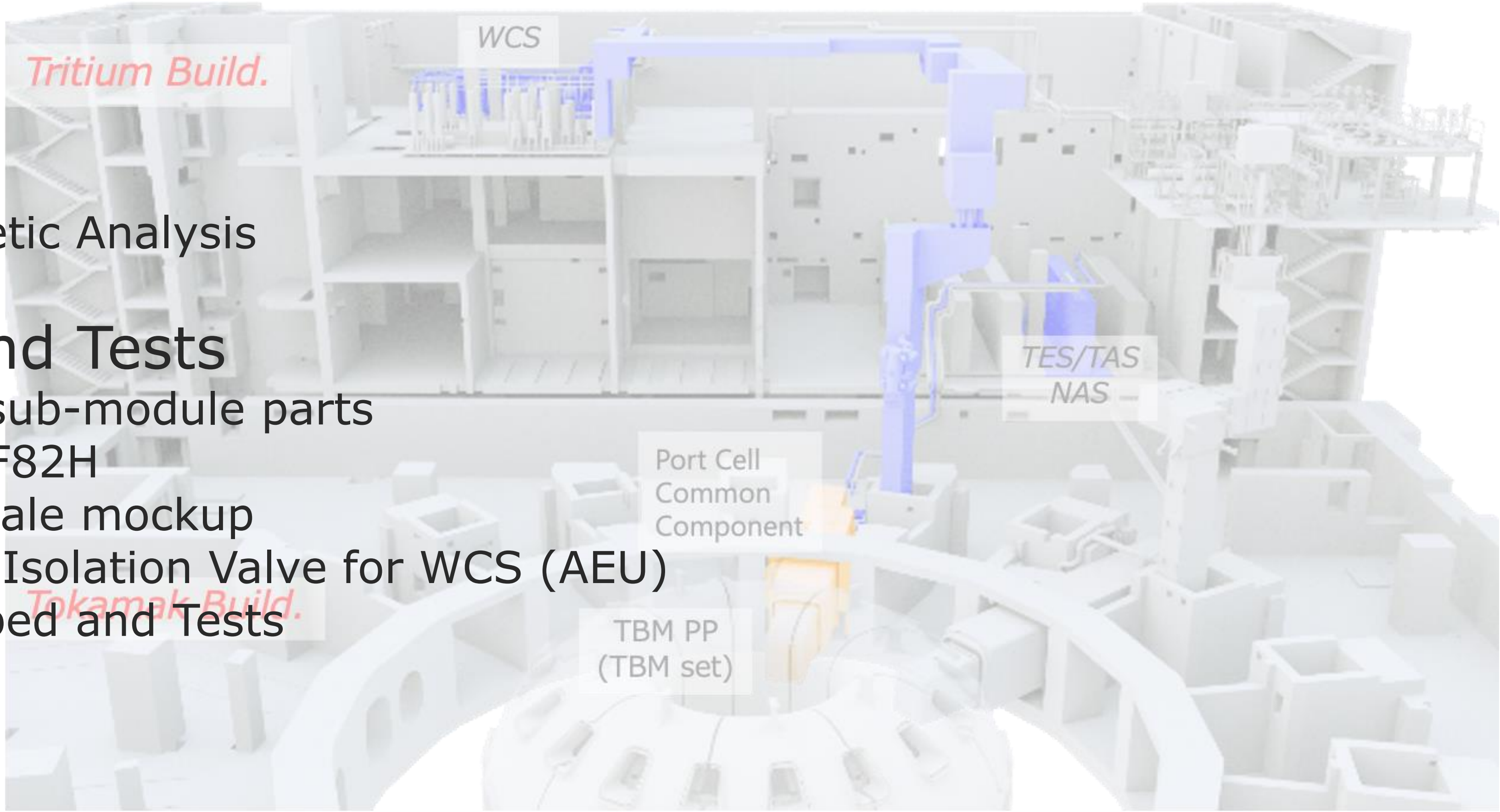


# Introduction

- Water Cooled Ceramic Breeder (WCCB) blanket is the primary concept of tritium breeding blanket for Japanese nuclear fusion reactor.

- ITER-TBM program is the first opportunity for testing breeding blanket under a real fusion environment.

- After the conceptual design approval in 2016, there were drastic changes such as
  - ➢ TBM structure changes from box to cylinder and
  - ➢ the port reduction from three to two.

- Preliminary design of WCCB TBS is still ongoing, and
  - the preliminary design status assessment has been done the end of 2022.
  - Blanket Test Facility completed in Rokkasho Fusion Institute in 2021, and main four experimental apparatus related high pressure and temperature water were installed in 2022.

➔ Progress of WCCB blanket in Japan will be introduced.

# Testing objectives of TBM for DEMO

Technical Readiness Level ■ *achieved,* ■ *major progress with important findings,* ■ *partly initiated*

| TRL | System TRL | JA-BB system status & targets |
|---|---|---|
| Level 1 | Basic principles | Consist the system with the least challenges |
| Level 2 | Technology concept | Selection of WCCB system |
| Level 3 | Proof of concept | **Tritium breeding/recovery demo in FNS@JAEA**<br>Cylindrical design using Bellylide block features |
| Level 4 | Validation in a laboratory environment | Validation of submodule elements at **the blanket test facility @ QST Rokkasho** |
| Level 5 | Partial system validation in a relevant environment | Irradiation test on the structural elements (miniature model) at fission reactor, etc.<br>Submodule/module test at blanket test facility etc. |
| Level 6 | Prototype demo in a relevant environment | **Verify BB design in TBM non-DT operation**<br>Irradiation test on elements (at Reactors, FNS etc.) |
| Level 7 | Prototype demo in an operational environment | **Verify BB design in TBM in DT operation**<br>Irradiation test on a submodule at fusion neutron source followed by PIEs |
| Level 8 | Test and demonstration | BB operation in DEMO Phase 1 (Pulse) |
| Level 9 | Proven in operation | BB operation in DEMO Phase 2 (Steady state) |

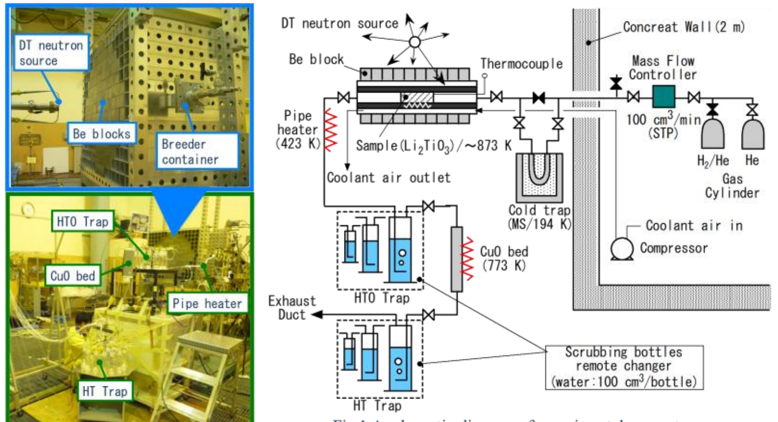
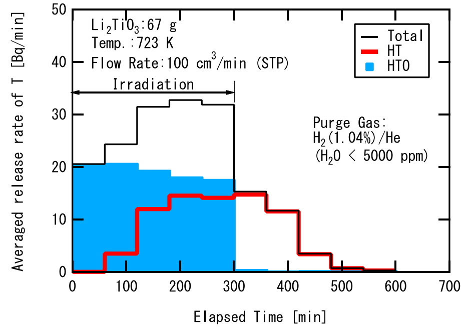



Fig.1 A schematic diagram of experimental apparatus.




Kawamura et al., Fusion Eng. Des. 87 (2012) 1253

Evaluation of the impacts of electromagnetic load along with the qualification of analysis method

Validation of design criteria and codes considering irradiation effects

*H.TANIGAWA et al., DEMO Breeding Blanket R&D in Japan, SOFE2023*

# Blanket Design ~TBM Set Design~

- The design updated from the manufacturing point of view. W. Guan et al., Fusion Eng. Des. 190 (2023) 113637.

- U-shape tubes (breeder packing) with 5 thin coolant tubes (inside 1 and outside 4)
  - 5 thin coolant tubes were removed
  - Breeder in U-shape tube was replaced by cooling water

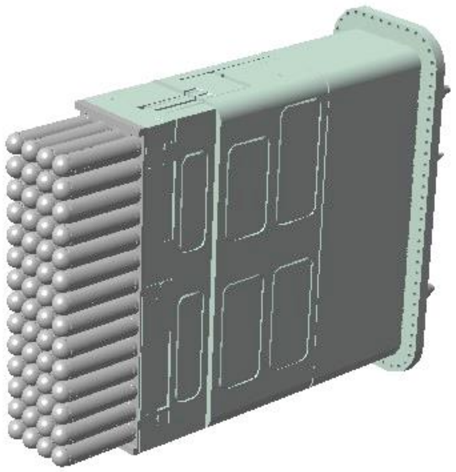


Fig.1 WCCB TBM set

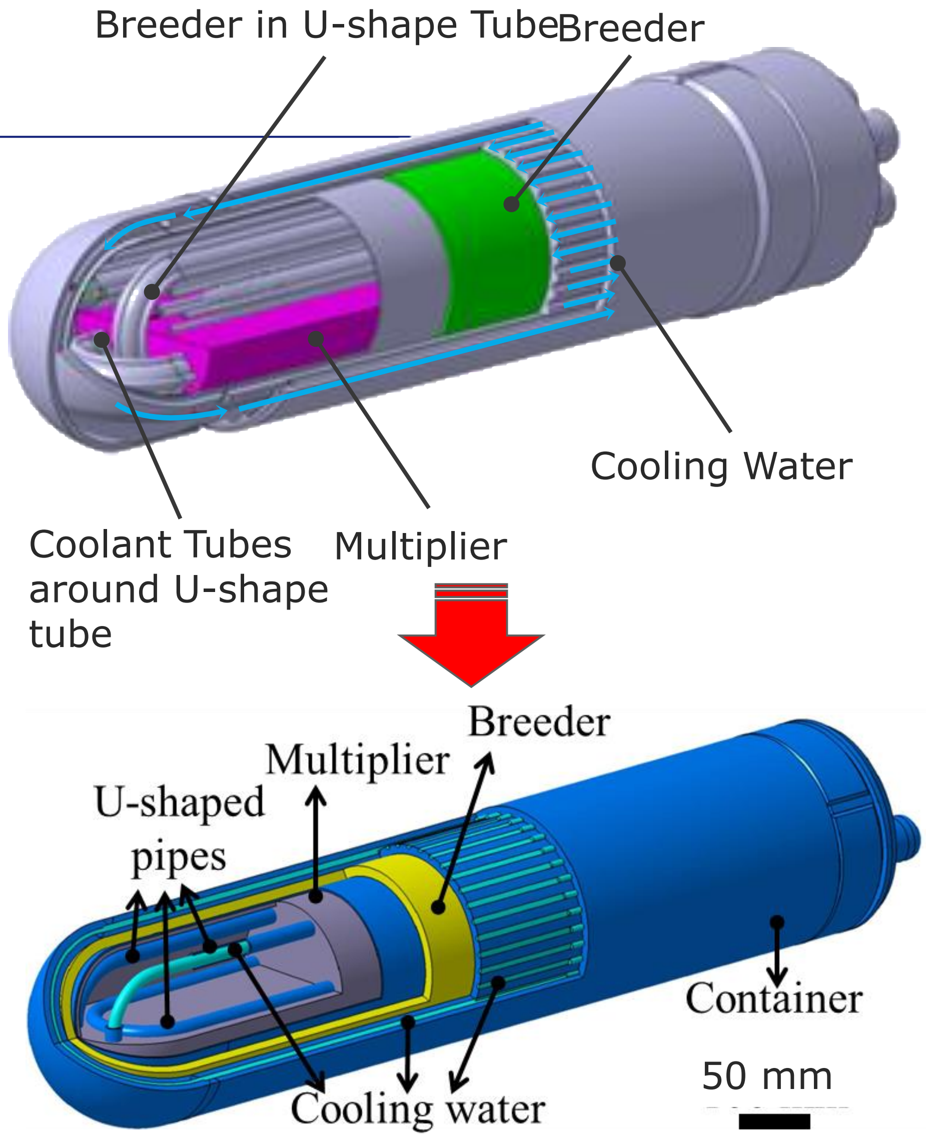



Fig.2 CAD model of TBM submodule, previous design (T), recent design(B).

# Progress of Electromagnetic Analysis

Electromagnetic (EM) force is one of stress acted TBM, and it should estimate accurately for TBM integrity assessment.

- TBM is made of magnetic material, so...
  - Lorentz force (LF) acts when disruption occurs.
  - Maxwell force always acts TBM during normal operation.

Effect of Be pebble bed electrical resistivity on EM force was investigated. W. Guan et al., SOFE2023, D-345.

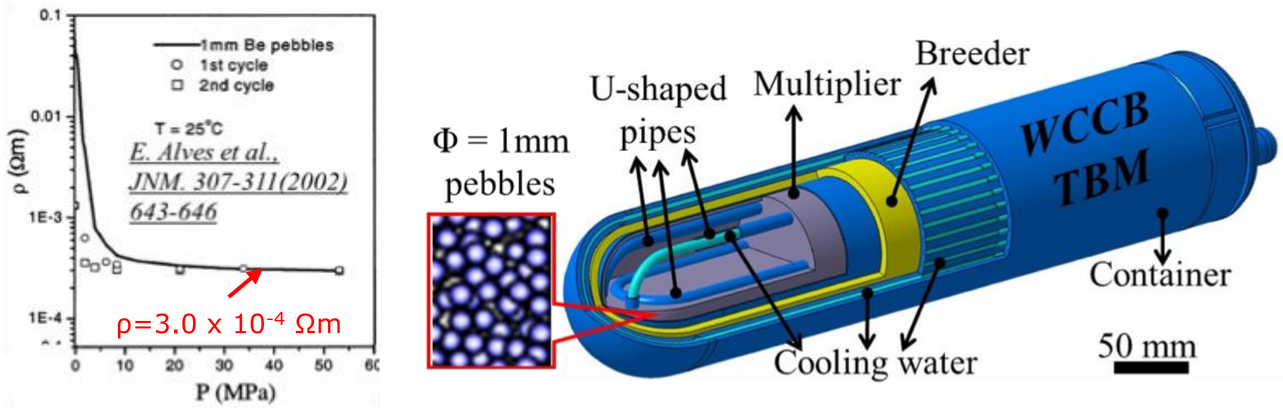



Fig. 3 Electrical resistivity of Be pebble (1 mmφ) bed.

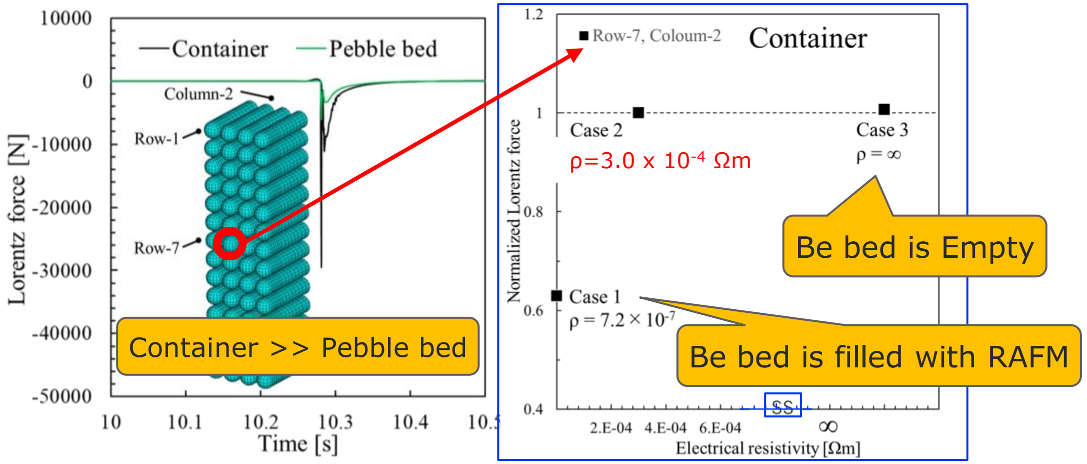



Fig. 4 Comparison of LF between container and Be bed (L), and LFs with various electrical resistivity (R).

- LF acted to container is much larger than Be bed.
- Employing electrical resistivity of $3.0 \times 10^{-4}$ Ωm is conservative enough .

- Using magnetic material under strong magnetic field is unique case of fusion environment.
- There are various commercial code for Maxwell Force calculation, but their results are not agreed.
- Experimental confirmation might be necessary.

# DEMO blanket design

## DEMO blanket

- Honeycomb container fabricated by HIP method
- Mixed breeder/multiplier pebbles

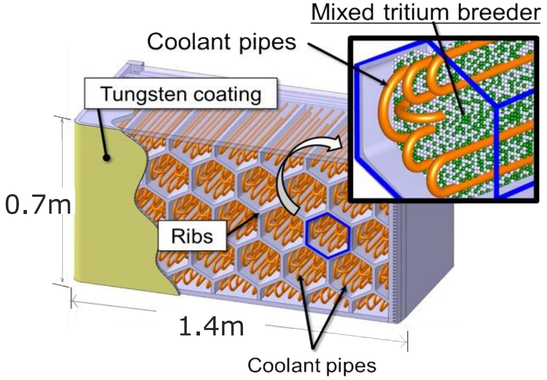



Fig.5 DEMO Blanket with Honeycomb structure.

## ITER-WCCB TBM (w/o W as PFM)

- Cylindrical container fabricated without HIP method
- Breeder/multiplier pebbles packed separately

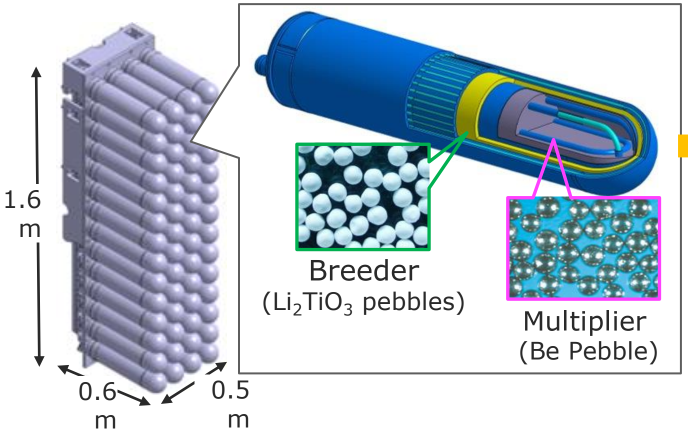



Fig.6 WCCB TBM (Cylindrical) .

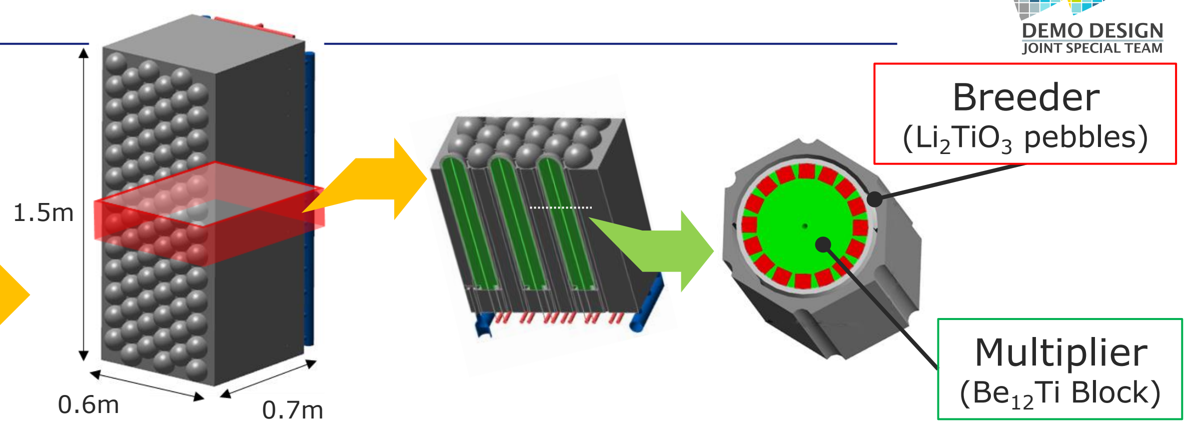



Fig.7 DEMO Blanket with Cylindrical structure

- Cylindrical container coated with W
- Pebble breeder/ Block multiplier

Beryllide ($Be_{12}Ti$, $Be_{12}V$) was developed to minimize the risk of Be-water reaction.
Using Beryllide as a block is optimal in obtaining high TBR and simplifying the structure.

- Be ratio : $Be_{12}Ti$ block > Be pebble bed
- Thermal conductivity : $Be_{12}Ti$ block >> Be pebble bed
  - Beryllide block works as heat transfer parts leads to simplified structure.

# Demo blanket design (Beryllide block)

## A case of gear-shaped beryllide block design

*Someya et al., FEC2021*

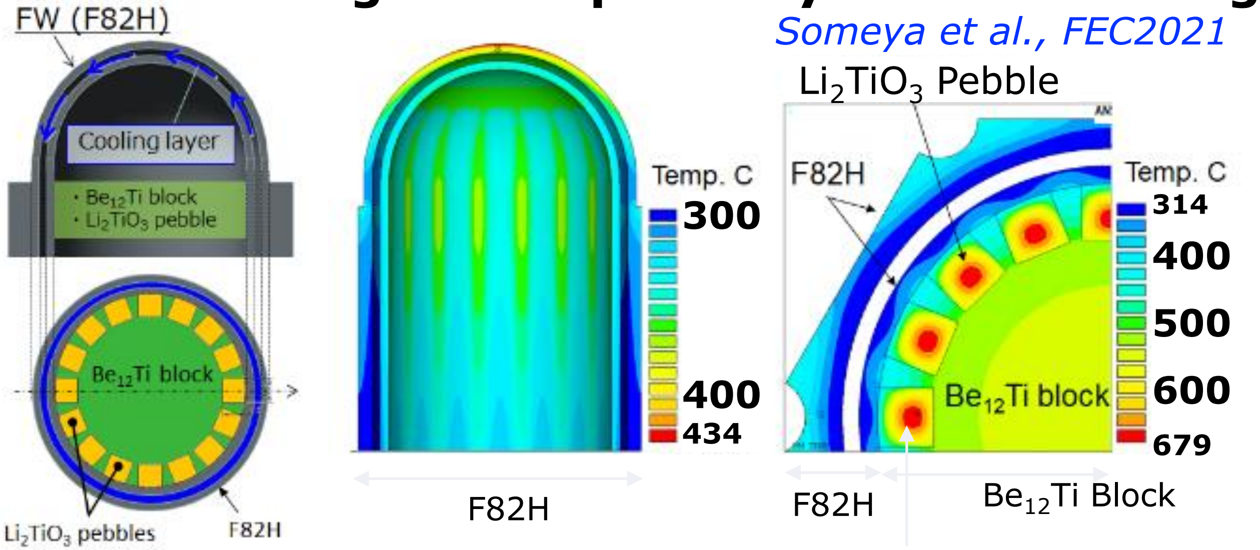



Fig.8 Temperature distribution of DEMO blanket submodule.

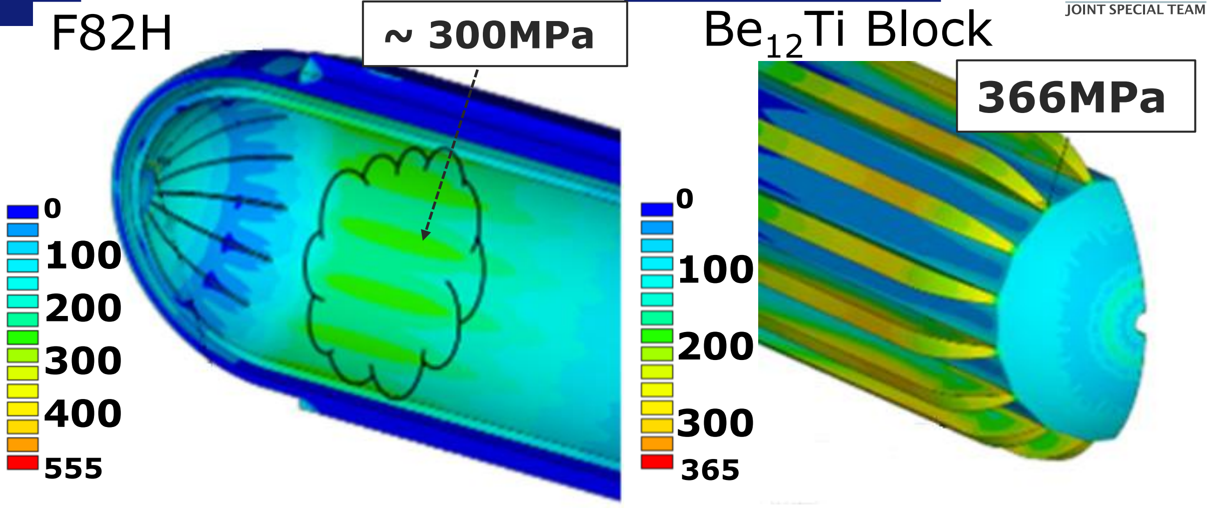



Fig.9 Stress distribution on DEMO blanket submodule.

- F82H: Sm 177MPa @300℃ (3Sm: 531 MPa)
- $Be_{12}Ti$ : Compressive fracture stress >2.5 GPa @RT-600℃

➔ The primary and secondary stress <u>for the container</u> were below the allowable stresses

➔ The stress for the beryllide block was found to be below the high-temperature compressive failure stress .

- Local TBR = 1.21
- F82H＜434℃　$Li_2TiO_3$＜679℃　$Be_{12}Ti$＜546℃
  (F82H＜550℃)　($Li_2TiO_3$＜900℃)　($Be_{12}Ti$＜1000℃)

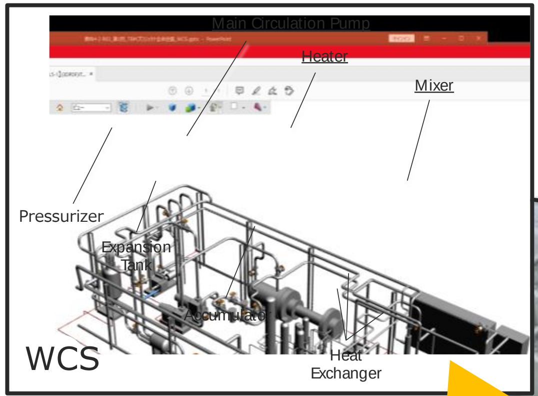
➔ Tritium breeding ratio (TBR) is expected to excess 1.19 (target)

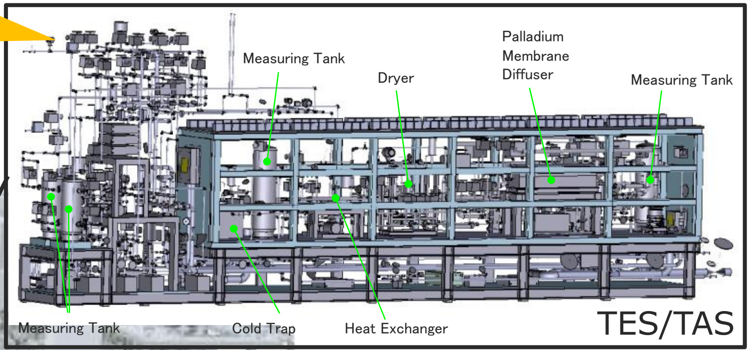
➔ All temperature are expected to be lower than the maximum allowable temperature during steady-state operation.

WCCB TBM team start investigation for employing Beryllide block for TBM.

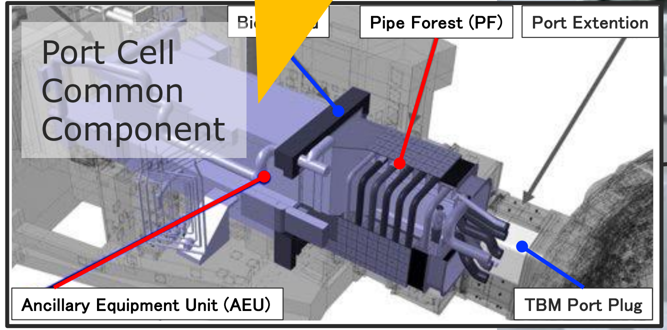
# Trial manufacturing and Tests

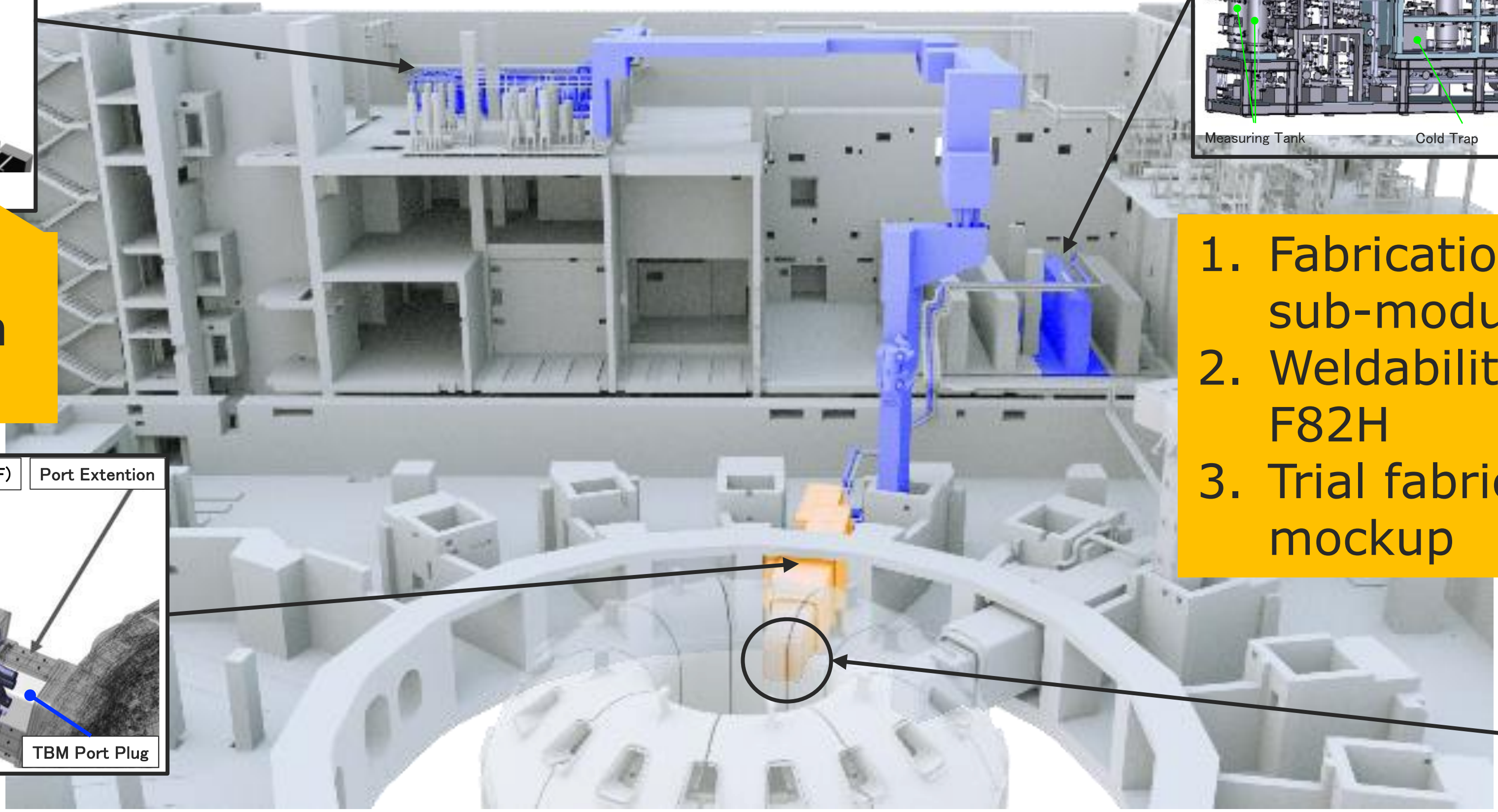
5. Trial manufacturing of ZrCo bed




4. Fabrication of Pneumatic Isolation Valve for WCS



1. Fabrication of F82H and sub-module parts
2. Weldability validation of F82H
3. Trial fabrication full-scale mockup

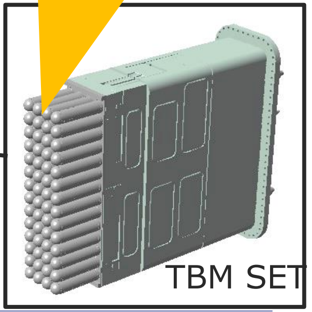



Fig.10 WCCB TBS in ITER

# 1. Fabrication of F82H and sub-module parts

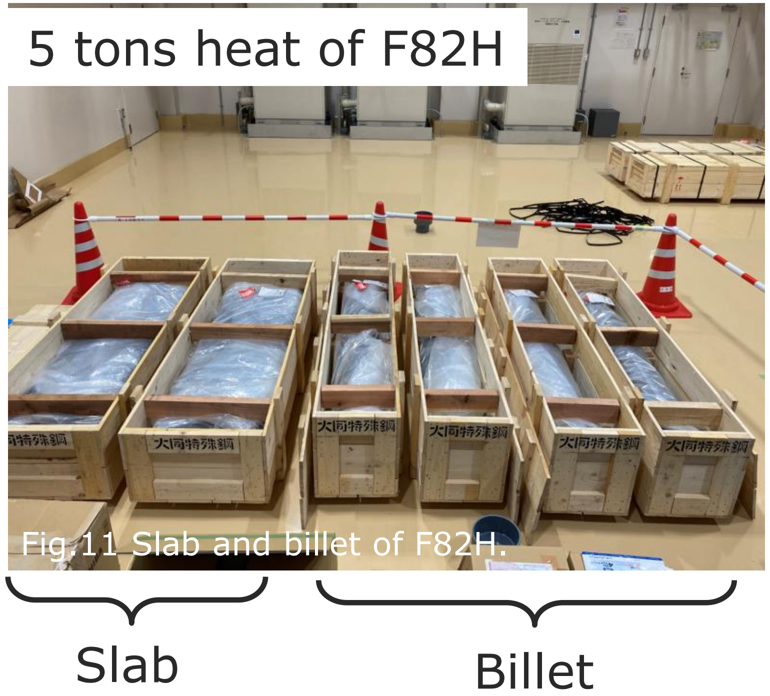



Fig.11 Slab and billet of F82H.

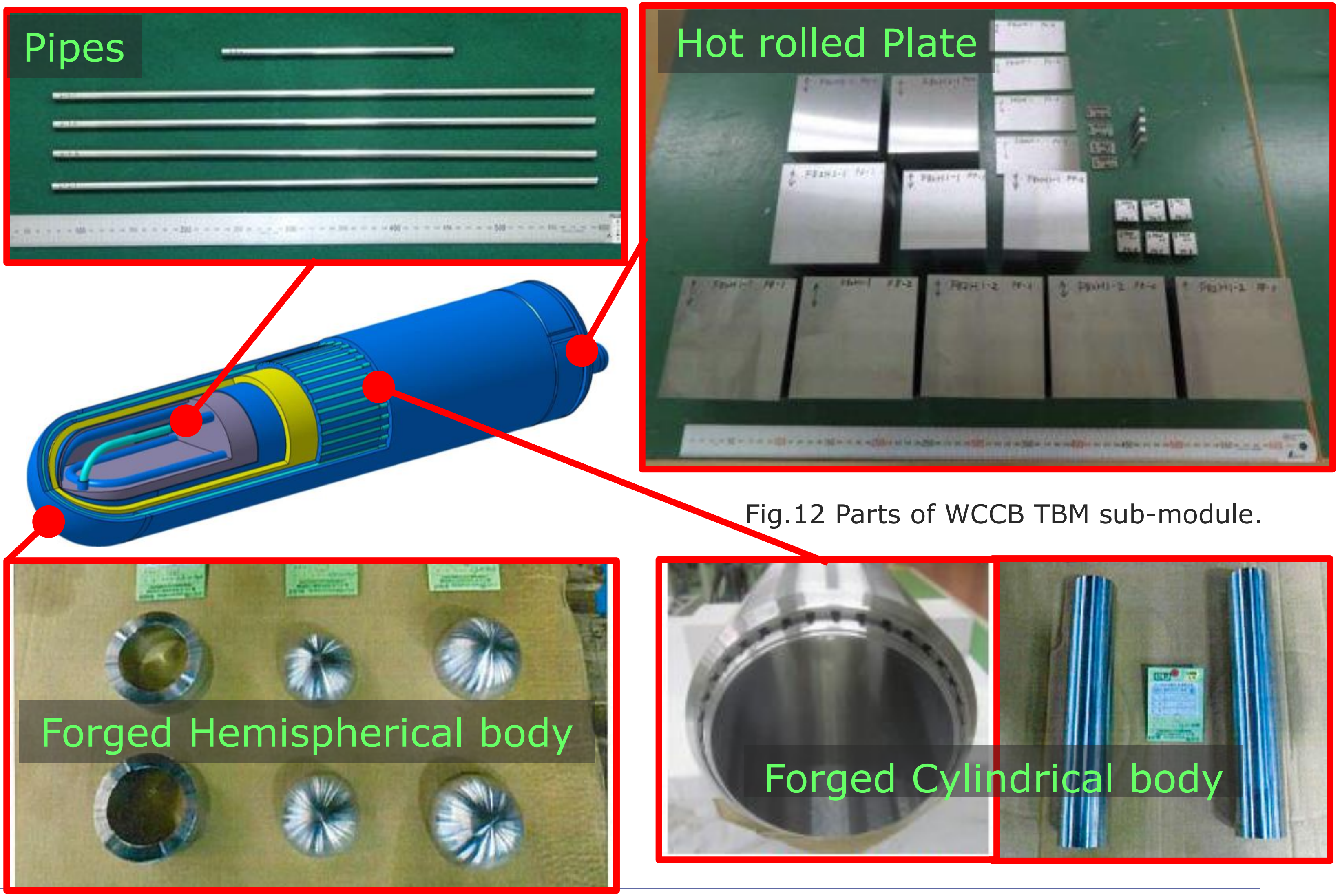



Fig.12 Parts of WCCB TBM sub-module.

- Reduced Activation Ferritic Martensitic steel, F82H, of 5 tons was fabricated.
- Several parts of submodule were also fabricated by use of that.

# 2. Weldability validation of F82H

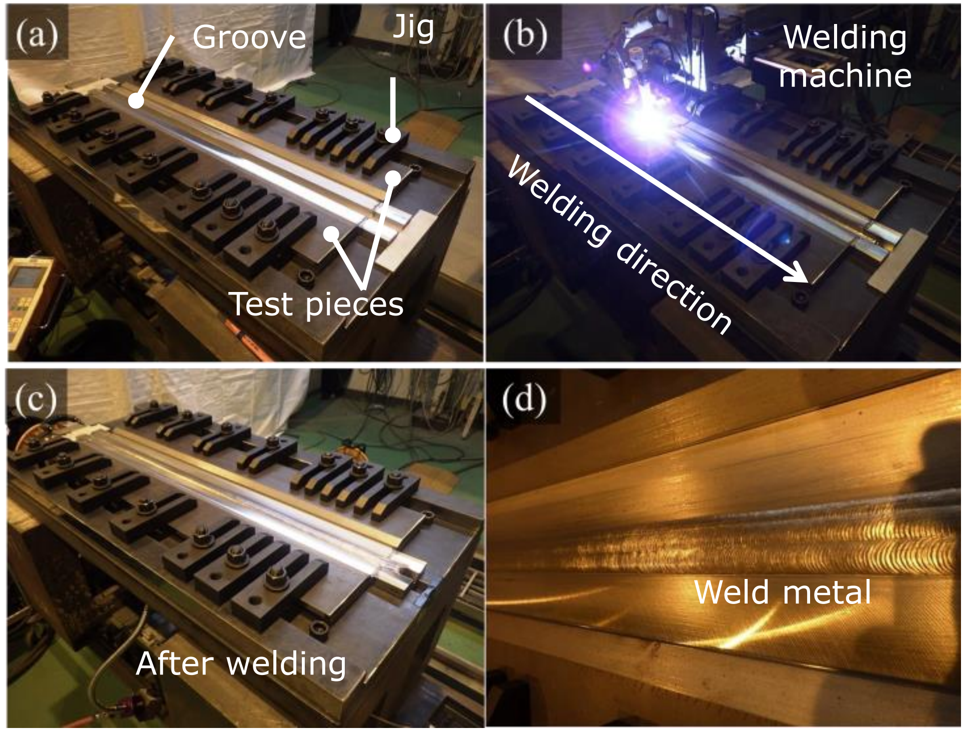



Fig.13 TIG weld process

- Tungsten Inert Gas Arc Welding of F82H has been done in the presence of the third-party witness.
- Test coupons were prepared for weldability validation.

Table 1 Requirements for weld F82H.

| | Evaluation item | Requirement (Regulation / Construction codes) |
|---|---|---|
| NDT | VT | 1. Crack (hot / cold), pore, shrink etc.. / **(ISO 17637)** |
| | PT | 1. Crack (hot / cold), porosity, lack of fusion, slag inclusion, undercut etc.. / **(ISO 23277)** |
| | RT | 1. Crack (hot / cold), porosity, lack of fusion, slag inclusion, undercut etc.. / **(ISO 10675)** |
| DT | Chemical analyses | 1. Sample is taken from longitudinal tensile specimen and outside the dilution area. / **(RCC-MRx Edition 2015)** |
| | Metallographic examination | 1. Clearly reveal the fusion line, HAZ and build up of the runs. / **(ISO 15614)**<br>2. Clearly reveal a complete transverse section of the weld. / **(RCC-MRx Edition 2015)** |
| | Bending test | 1. Not reveal any one single flaw > 3 mm in any direction. / **(ISO 15614)** |
| | Hardness test | 1. Not exceed 300 HV. / **(ISO 15614)** |
| | Tensile test | 1. Transverse direction: not less than parent metal. / **(ISO 15614)**<br>2. Longitudinal direction (RT): not exceed 800 MPa in UTS and YS, at least 20% in TE. / **(RCC-MRx Edition 2015, ISO 15614)**<br>3. Longitudinal direction (elevated temperature): at least equal to base metal in UTS and YS. / **(RCC-MRx Edition 2015, ISO 15614)** |
| | Charpy test | 1. Not less than 100 J. / **(ESPN)**<br>2. Not less than 70% of minimum average value of base metal. / **(RCC-MRx Edition 2015, ISO 15614)** |

- TIG welded F82H was evaluated following regulations and construction codes.
- The weldability of F82H could be validated.

The detail will be presenting on Thursday (ps3−21 by GUAN).

# 3. Trial manufacture of Full-Scale mockup

Full scale mockup has been manufactured to identify issues on the manufacturing.

- TIG welds were applied.
- Full-penetration was achieved at the pressure boundaries.
- Most of joints satisfied requirement.

➔ Welding Procedure Specification have been developed for the manufacturing.

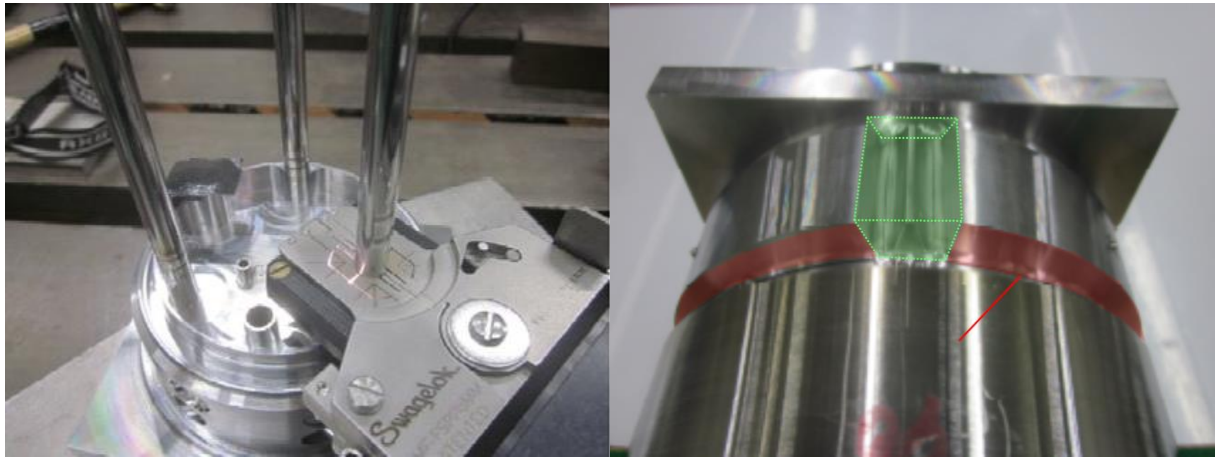



Fig.14 F82H TIG welding between U-shaped pipe and coolant manifold (L), and weld joints at the manifold (R).

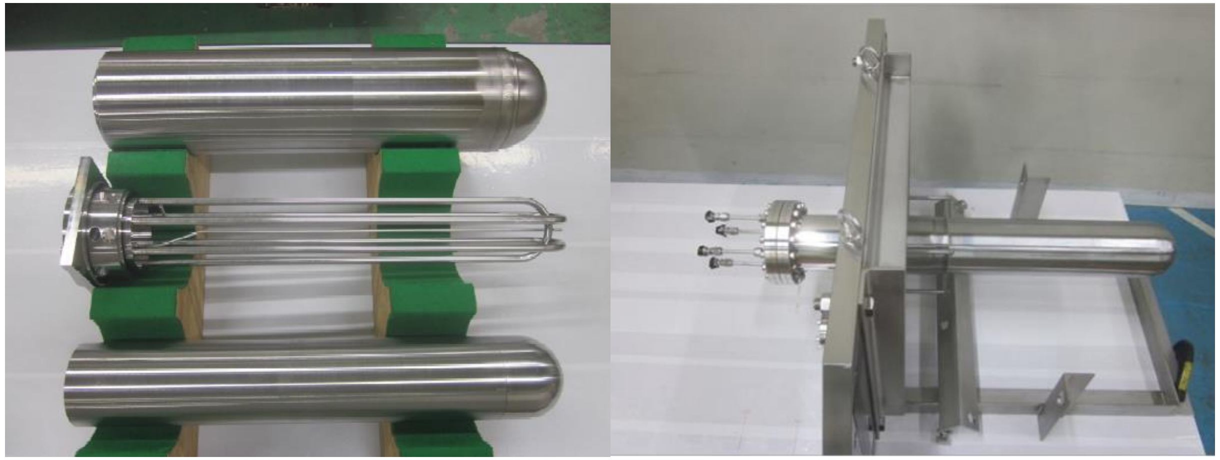


Fig.15 WCCB-TBM sub-module

➔ The weld joints that are hardly inspected was identified

➔ Tolerance due to assembly and welding distortion can be controlled by the dimension of parts.

The detail will be presenting on Tuesday (PS2-38 by HIROSE).

# 4. Trial manufacture of Pneumatic Isolation Valve for WCS (AEU)

- A pneumatic isolation valve (fail close) has been made.
- Functional tests under vibration or magnetic field was carried out at Room Temperature.

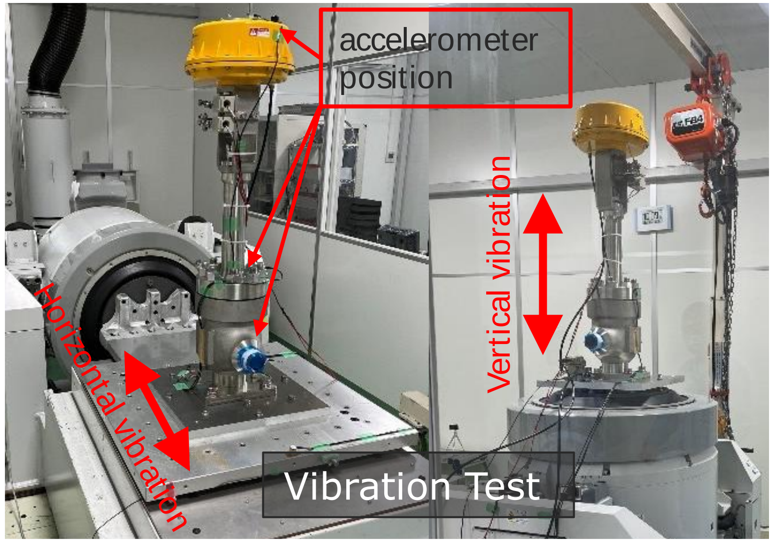



Fig.16 Isolation valve Fabricated for WCS.

- ☐ Open / close was confirmed during vibration.
- ☐ Natural frequency was evaluated.

➔ It took just 3 seconds to close even if coolant with 15.5 MPa was there.

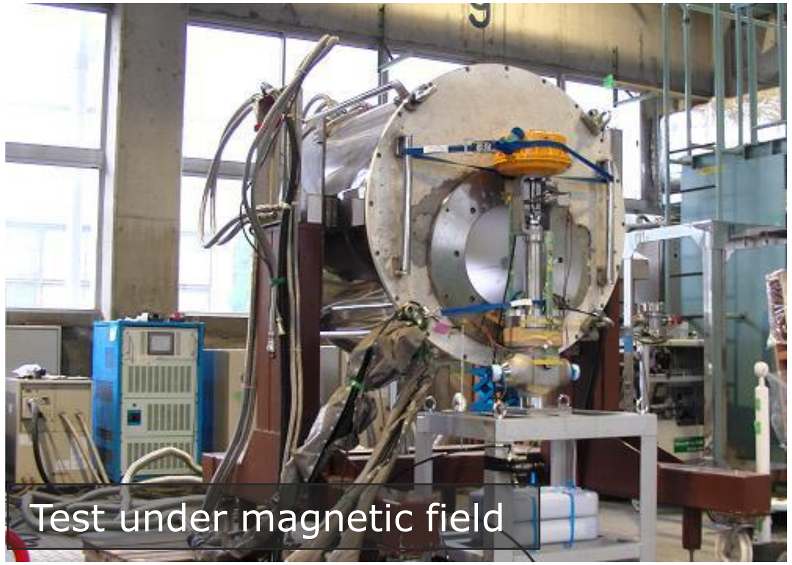



Fig.17 Operation test under magnetic field.

The valve has Inconel (magnetic mater.) parts.

【Magnetic field】

- 120~690 mT @ around equipment
- >290 mT @ Inconel spring
- 218mT @ PC#18(anticipated)

➔ The isolation valve operated, but the magnetic shield may be necessary for solenoid valves

# 5. Trial manufacture of ZrCo Bed

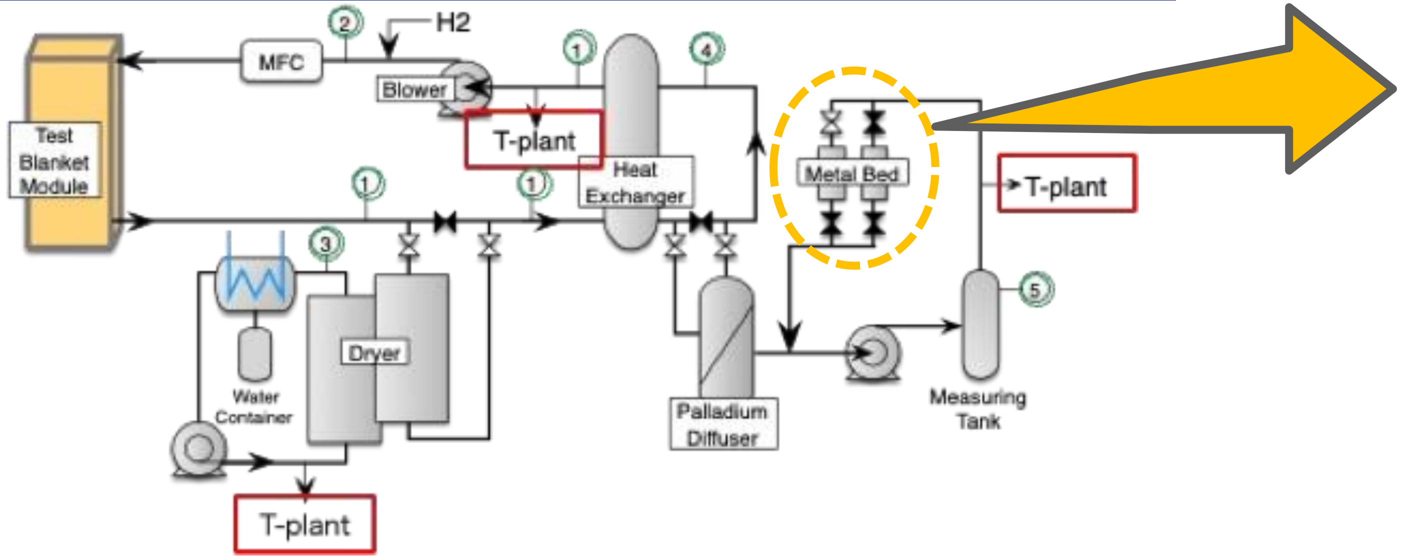
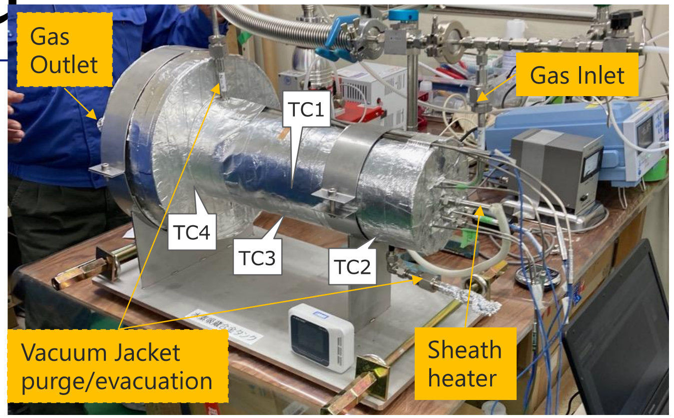
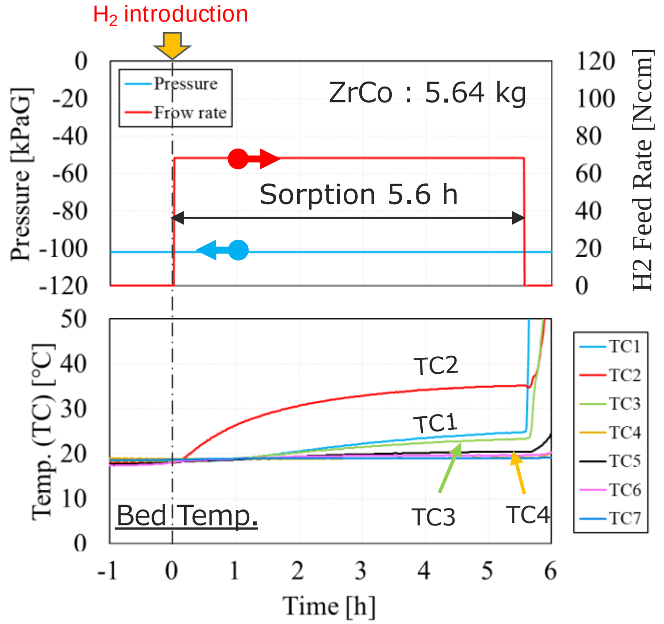



Fig.18 Schematic diagram of TES.




Mock-up of Temporary Storage Bed (weight : 40 kg)




- Temporary Storage Bed mockup was manufactured.
  - ZrCo of 5.64 kg was packed.
  - It has a vacuum jacket for thermal isolation.
  - Total weight was 40 kg per bed.
- $H_2$ sorption / desorption tests successfully completed.

➔ The storage bed also should be connected directly to the main loop.

Fig.19 Mockup of ZrCo bed (T) and its $H_2$ sorption test (B)

# Blanket Test Facility

- Blanket Test Facility completed in Rokkasho Fusion Institute of QST in June 2021.

- This facility..
  - is to be a base of breeding blanket development for nuclear fusion reactor in Japan.
  - has 7 laboratories.
  - has a control area for Beryllium, but not for radio isotope including Tritium.
  - has main 4 apparatus those are related to high temperature and pressure water.

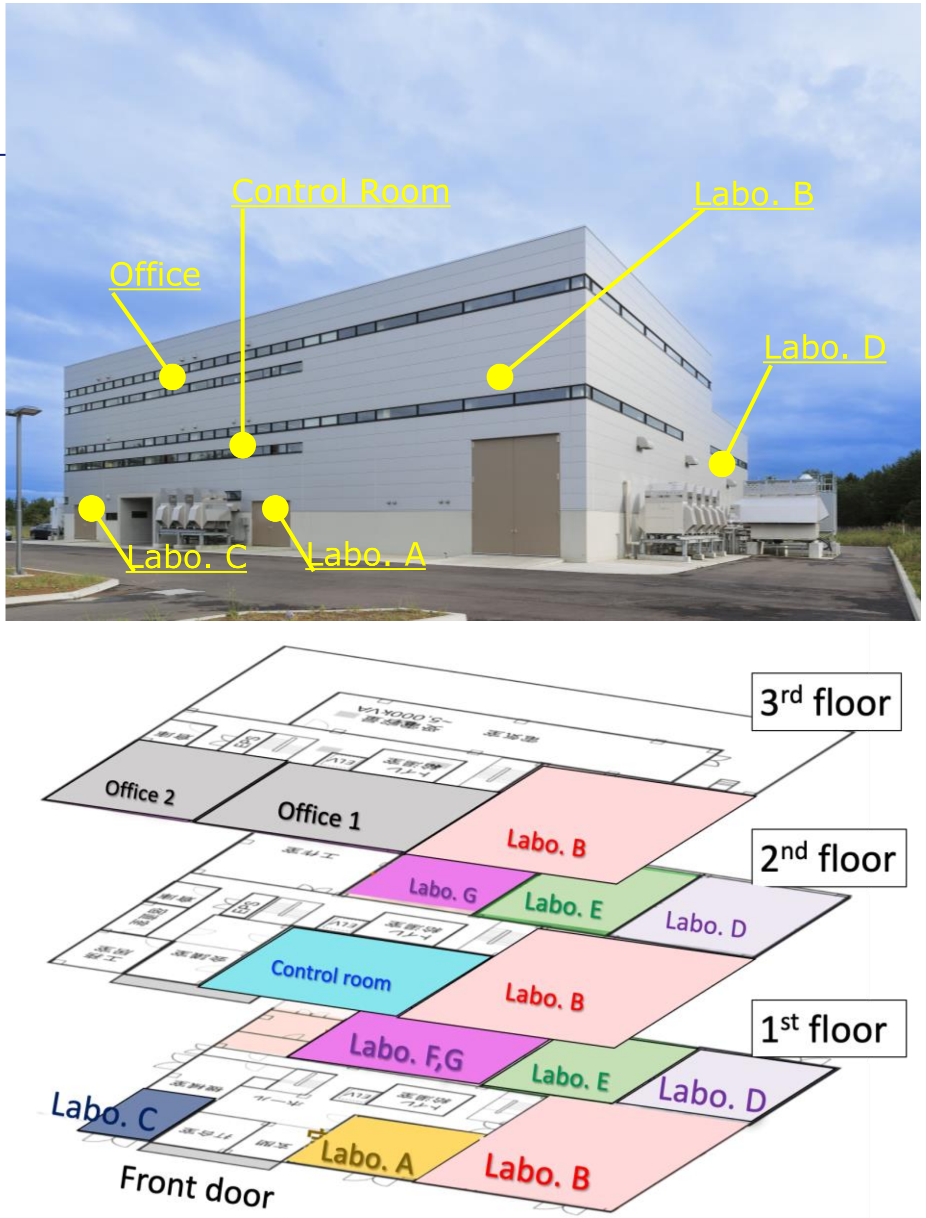



Fig. 20 Appearance of Blanket Test Facility (Top), and its floor layout (Bottom).

# Mockup Test with High Temperature and Pressure Water

The installation of main 4 apparatus completed in 2022.

1. High Heat Flux test
   - Calibration of IR thermo-camera is going on.
2. Flow Assisted Corrosion test
   - Pre-oxidation has completed.
   - ➔ The test for circular tubes will be done this fiscal year.
3. Coolant leakage propagation test
   - Commissioning is going on.
4. Be-water reaction rate measurement
   - The data acquisition almost completed.
   - ➔ The results will be presenting in ICFRM.

The detail will be presenting on Friday (PS4-19 by KATAGIRI).


Fig. 21 Main 4 apparatus

# Summary

- Water Cooled Ceramic Breeder (WCCB) blanket is the primary concept of tritium breeding blanket for Japanese nuclear fusion reactor.
  - Design on cylindrical blanket is on-going.
  - Maxwell force evaluation is quite important for the structural integrity assessment.
  - JA DEMO blanket design will employ Beryllide block. From the DEMO blanket mockup point of view, WCCB TBM design might also be introduced Beryllide block.
- Trial fabrication of mockup and tests were performed.
  - F82H and the parts made of that were fabricated.
  - Weldability of F82H was validated.
  - Welding Procedure Specification was developed.
  - Isolation valve and ZrCo bed were fabricated and tested.
- Test apparatus for physical mockup test featuring high pressure and temperature water were completed, and the tests using with them are ongoing.
- ITER-TBM program is essential for fusion DEMO program in Japan.

# Thank you for your attention!

Creation of Harmonious Diversity