Progress of ITER TF coil fabrication in Japan

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National Institutes for Quantum and Radiological Science and Technology(QST)

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Outline

1. Introduction
2. Progress of Double-Pancake (DP) and Winding Pack (WP) fabrication
3. Progress of Coil case (CC) fabrication
4. Assembly of WP with CC
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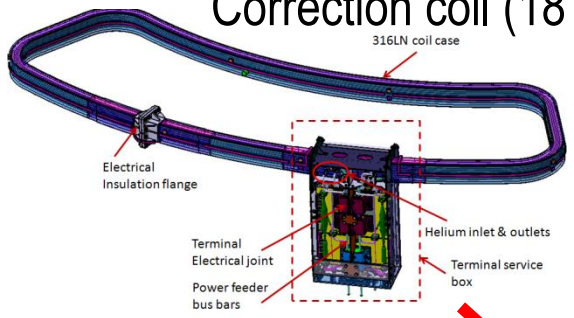
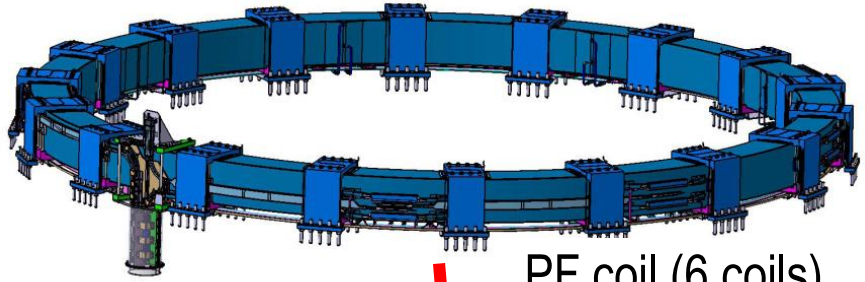
ITER Magnet System

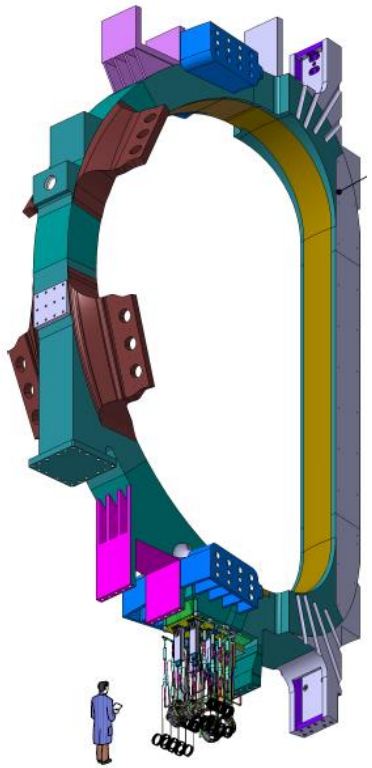
Correction coil (18 coils)

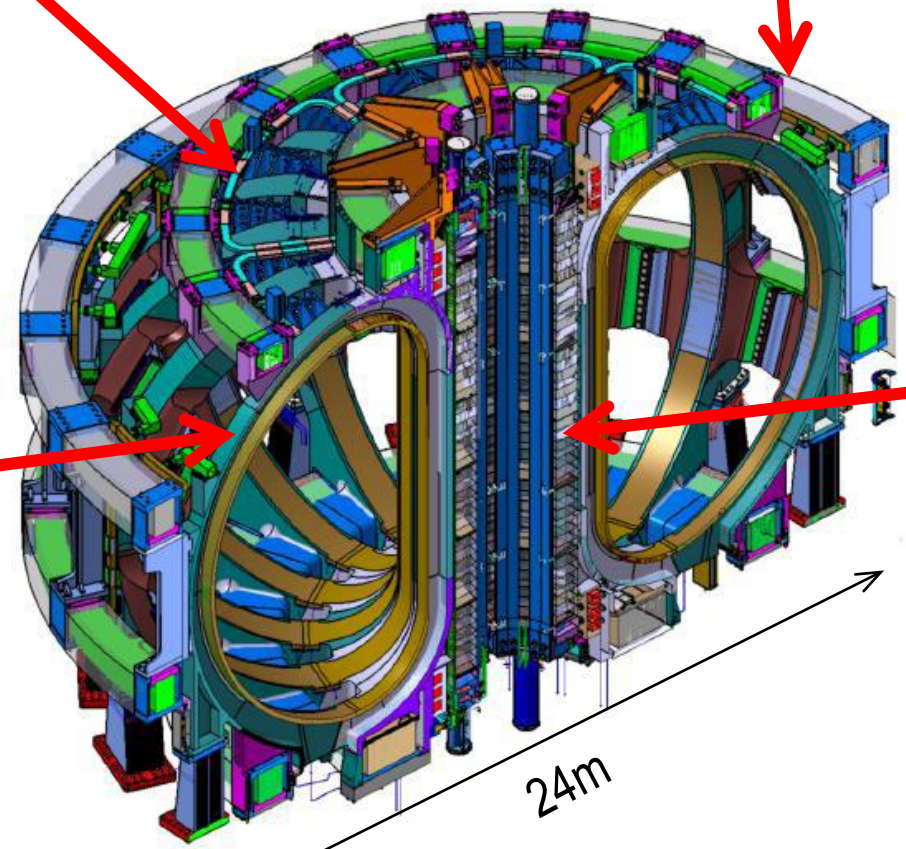


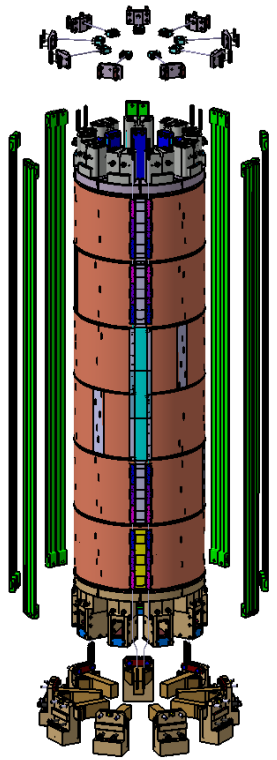


PF coil (6 coils)

TF coil (18 coils)

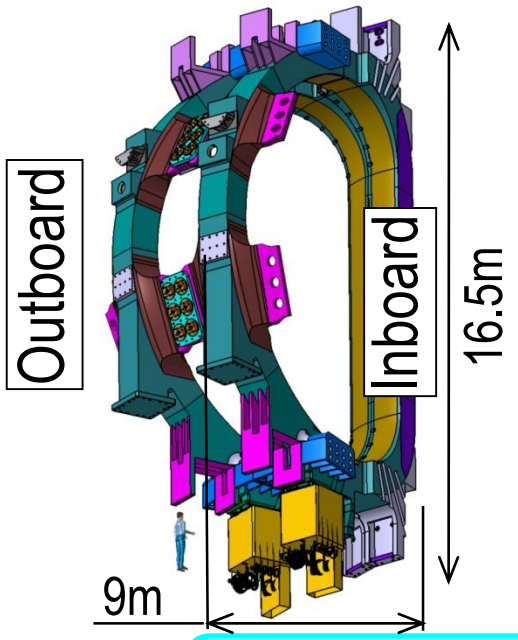




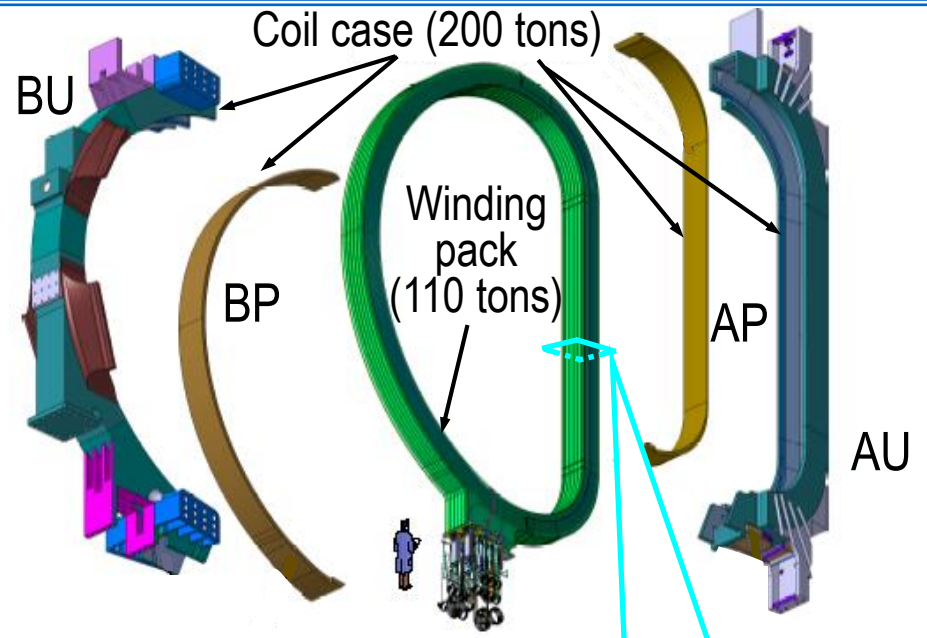


CS (6 modules)

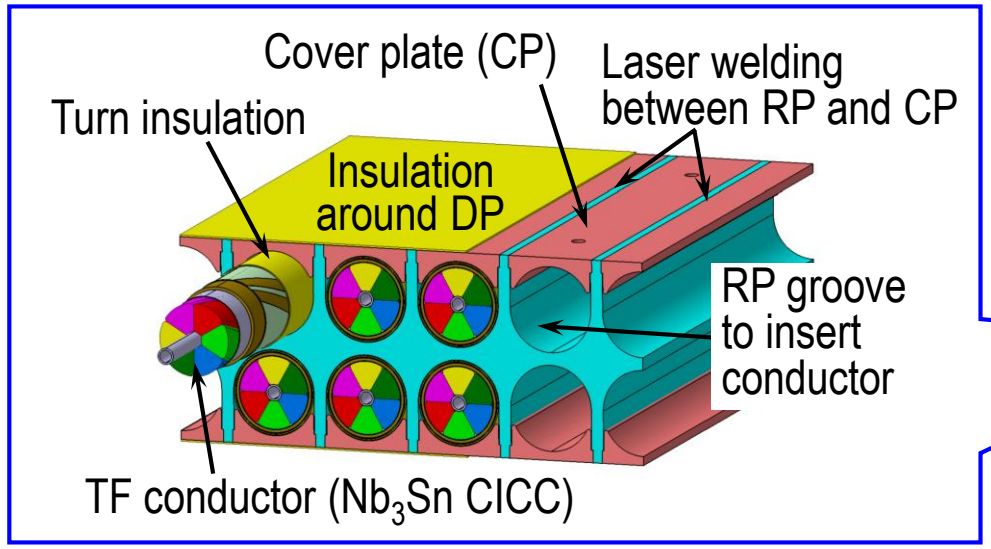
ITER TF Coil

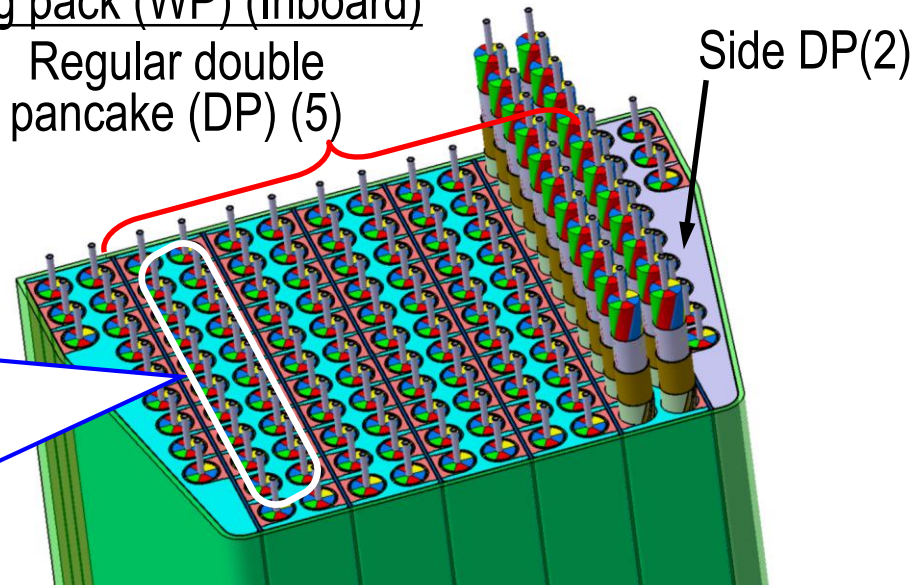


Nominal field = 11.8T
Nominal current = 68kA



Cross-sectional view of a TF winding pack (WP) (Inboard)

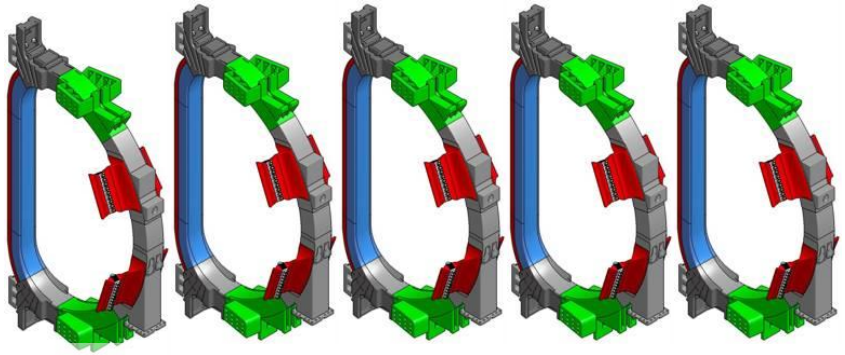




Scheme of TF coil procurement in Japan

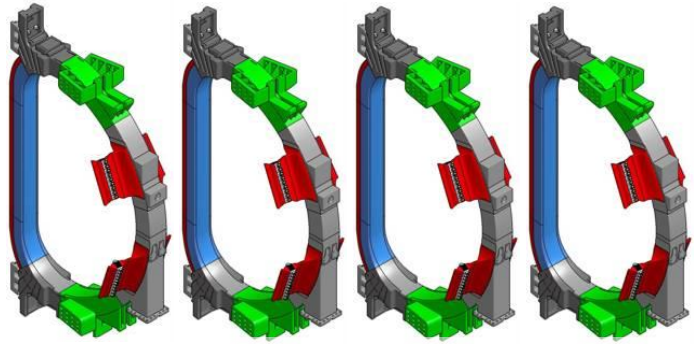
QST(JADA)

MHI with Melco & HHI



5 JA TF coils

Toshiba (TSB)

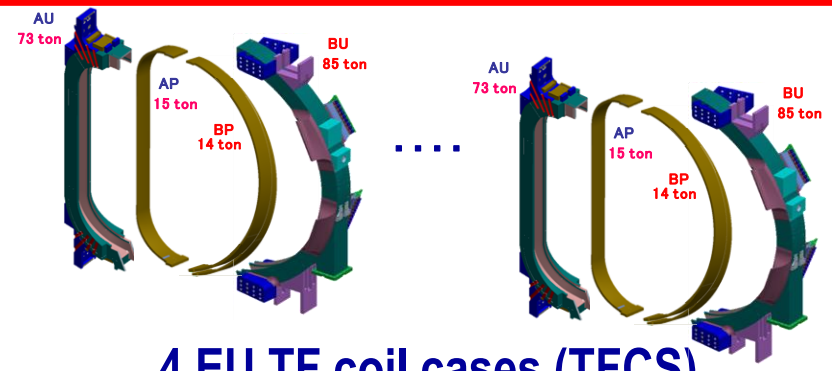


4 JA TF coils

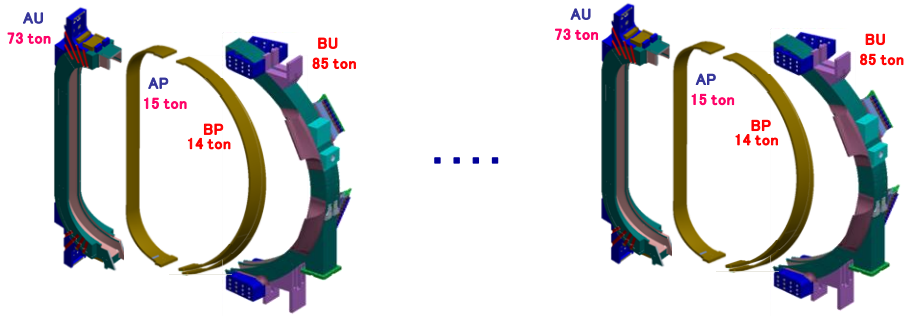
9 JA TF coils

10 EU TF coil cases

HHI with MHI



4 EU TF coil cases (TFCS)



6 EU TFCSs

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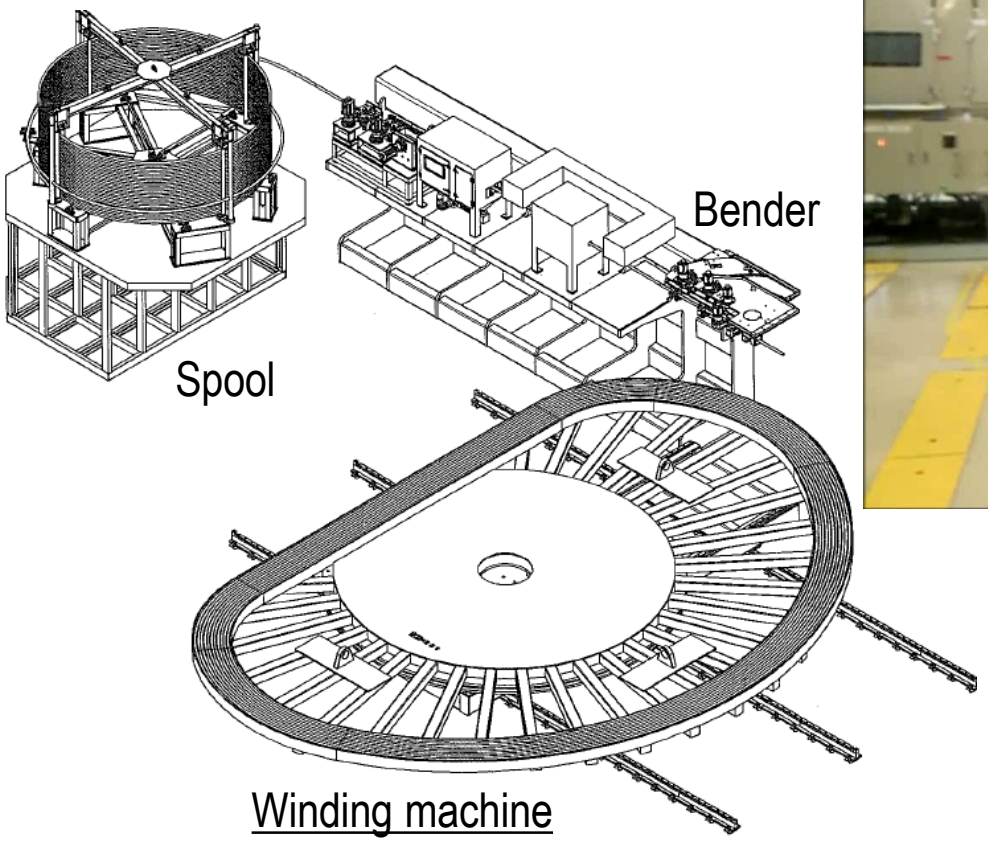
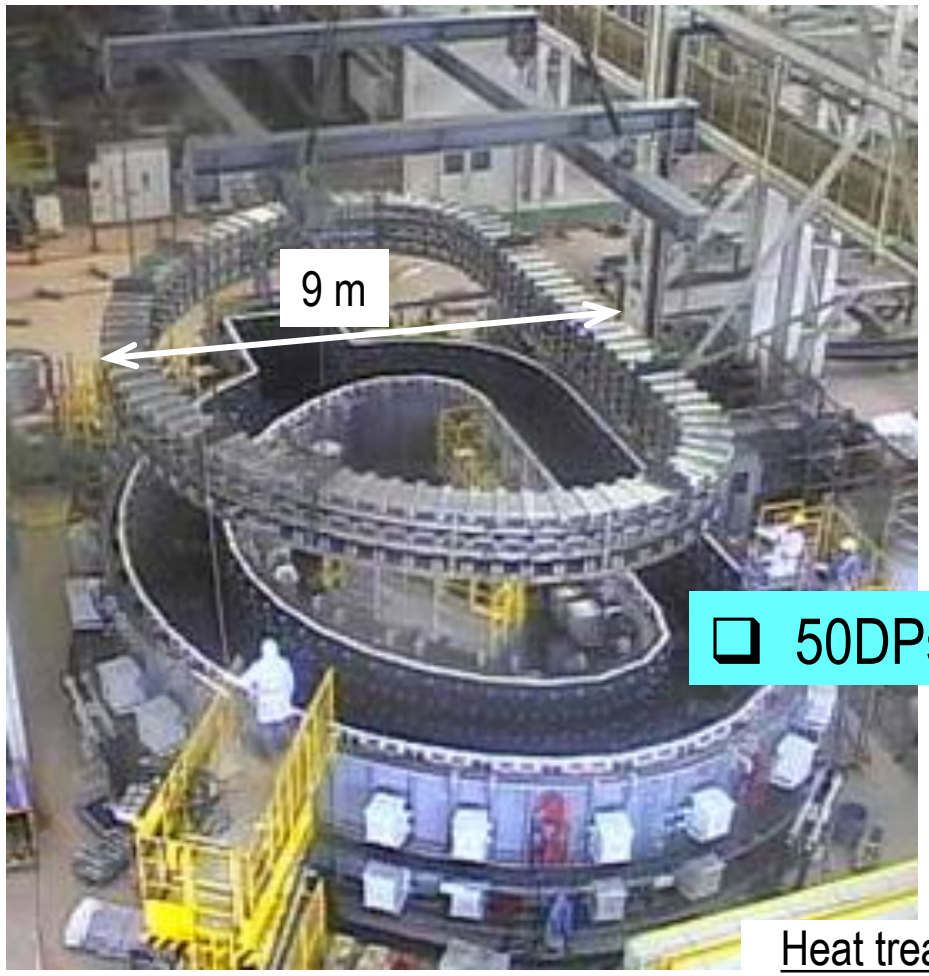
DP fabrication - 1) DP Winding

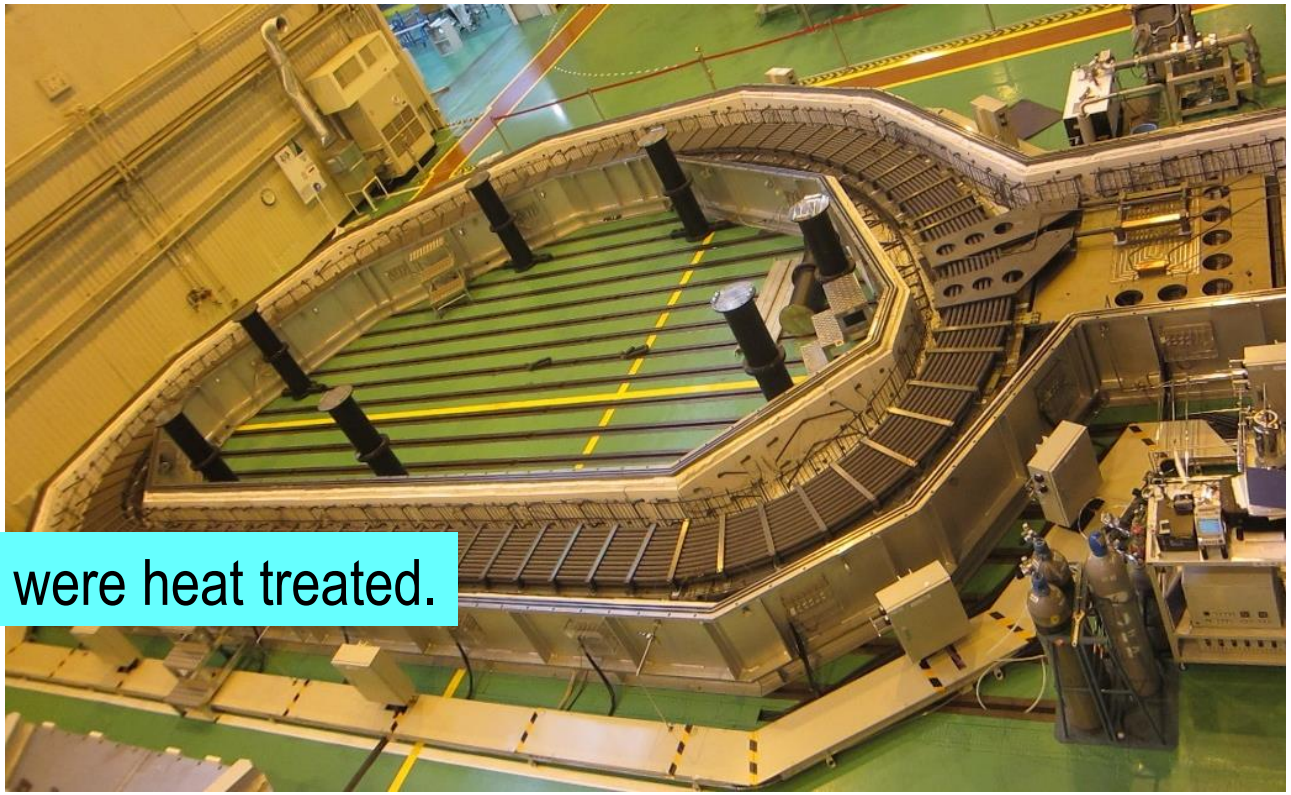
TF conductor:
CN, JA, KO



❑ Winding of 55 DPs were completed.

2) DP Heat treatment



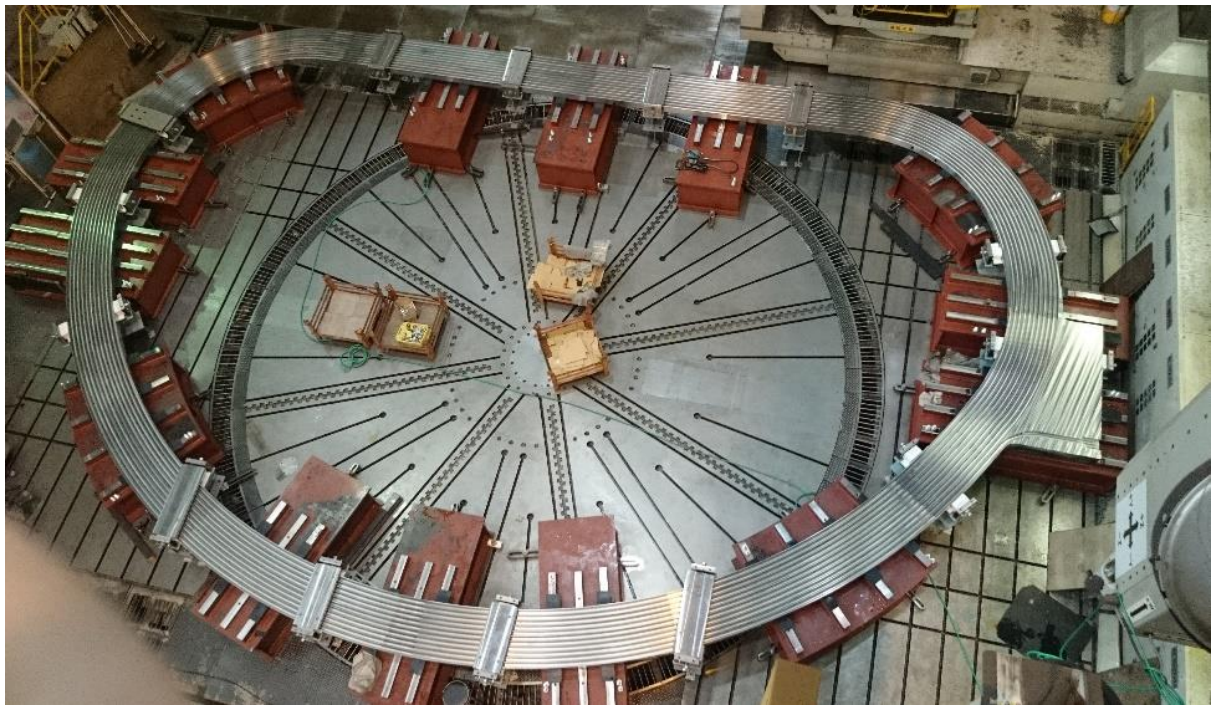


❑ 50DPs were heat treated.

Heat treatment (650°C, >100h)

3) RP fabrication

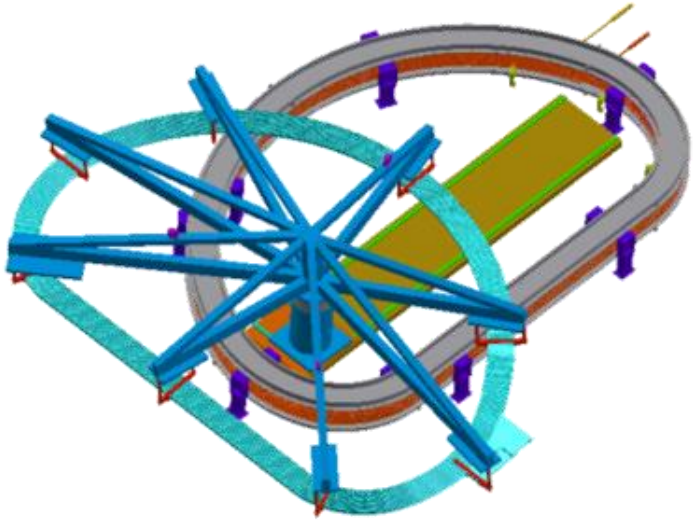
RP made by MHI



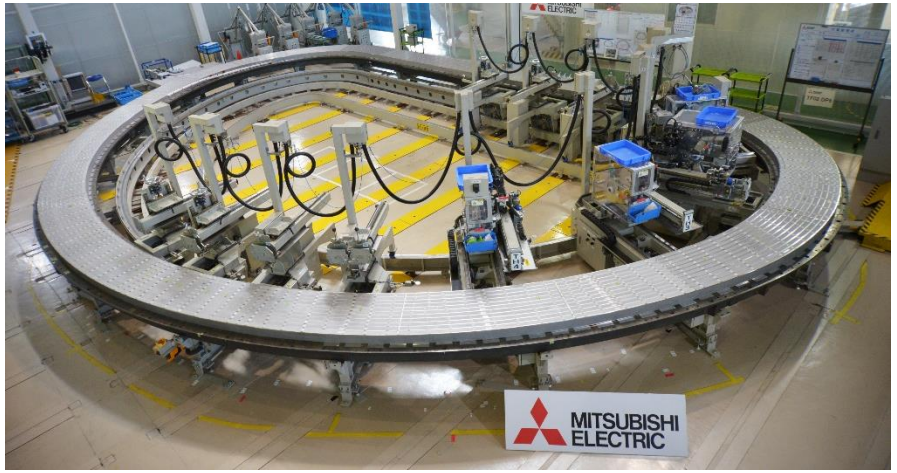
RP made by TSB

❑ 54RPs were completed.

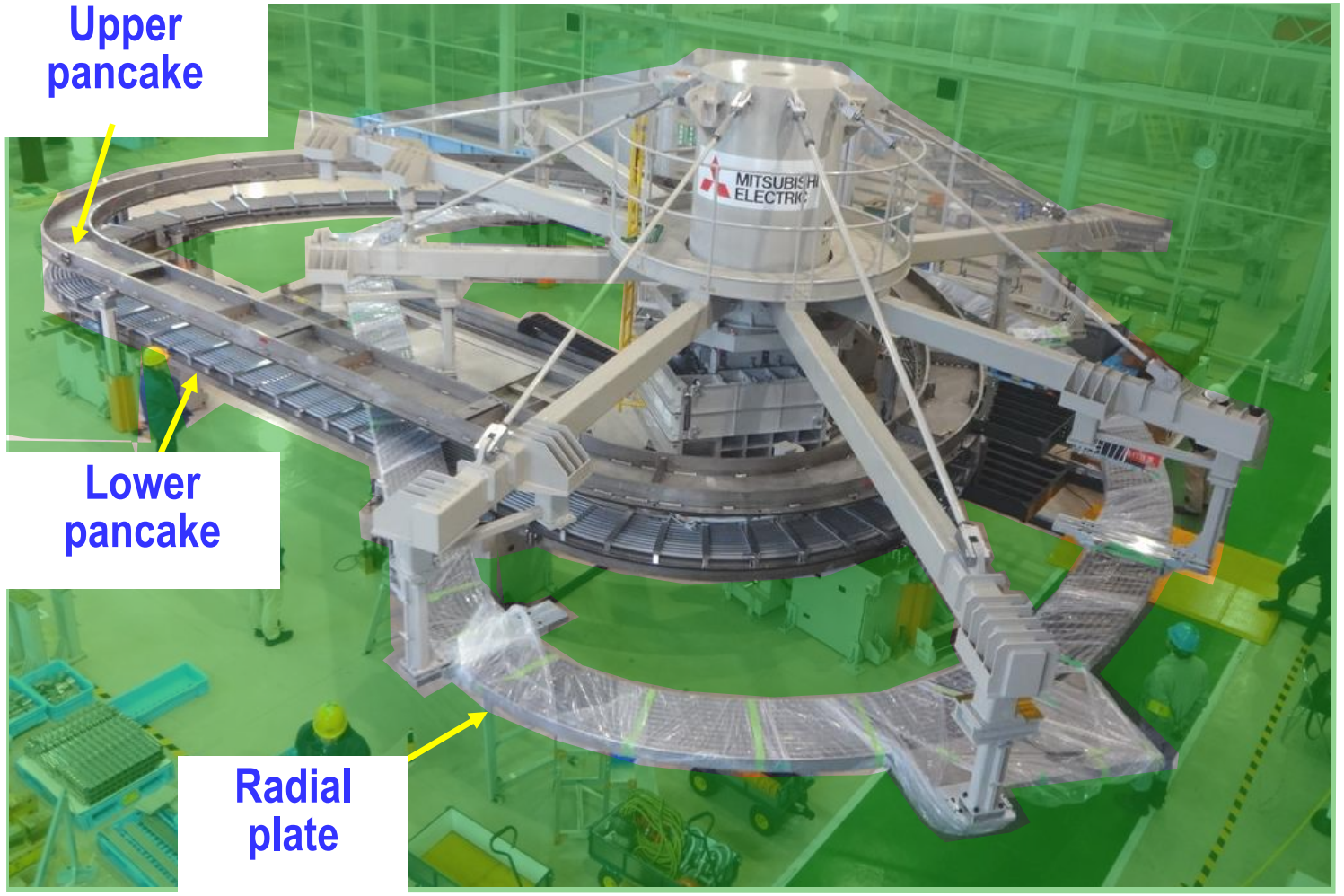
4) Transfer and turn insulation



Transfer of conductor into RP groove



Turn insulation



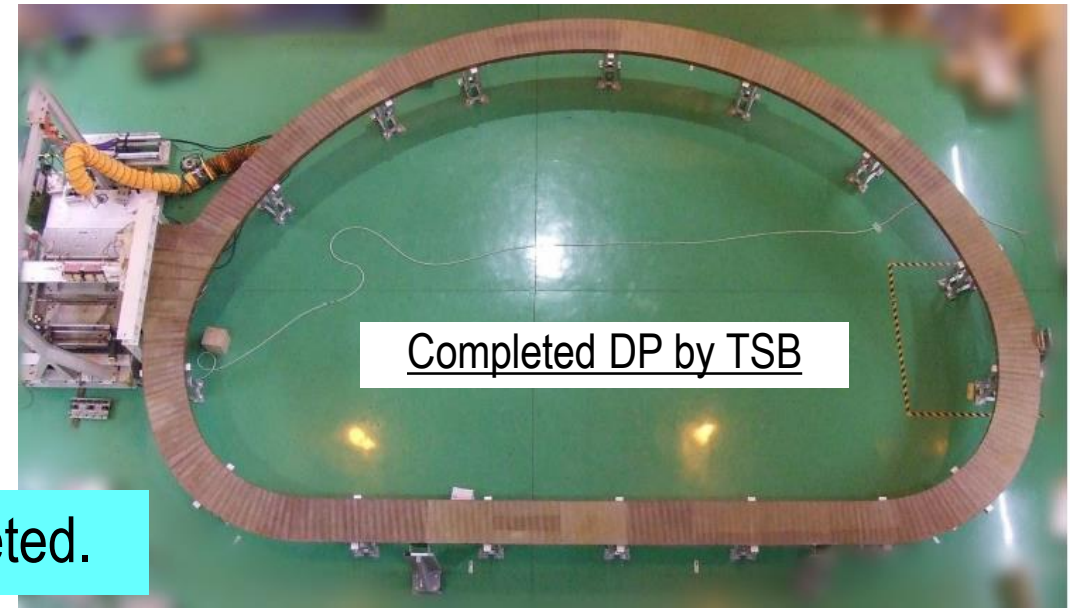
❑ Turn insulation of 48DPs were completed.

5) DP insulation, impregnation

DP insulation

Impregnation of DP

Completed DP by MHI



Completed DP by TSB

❑ 40DPs were completed.

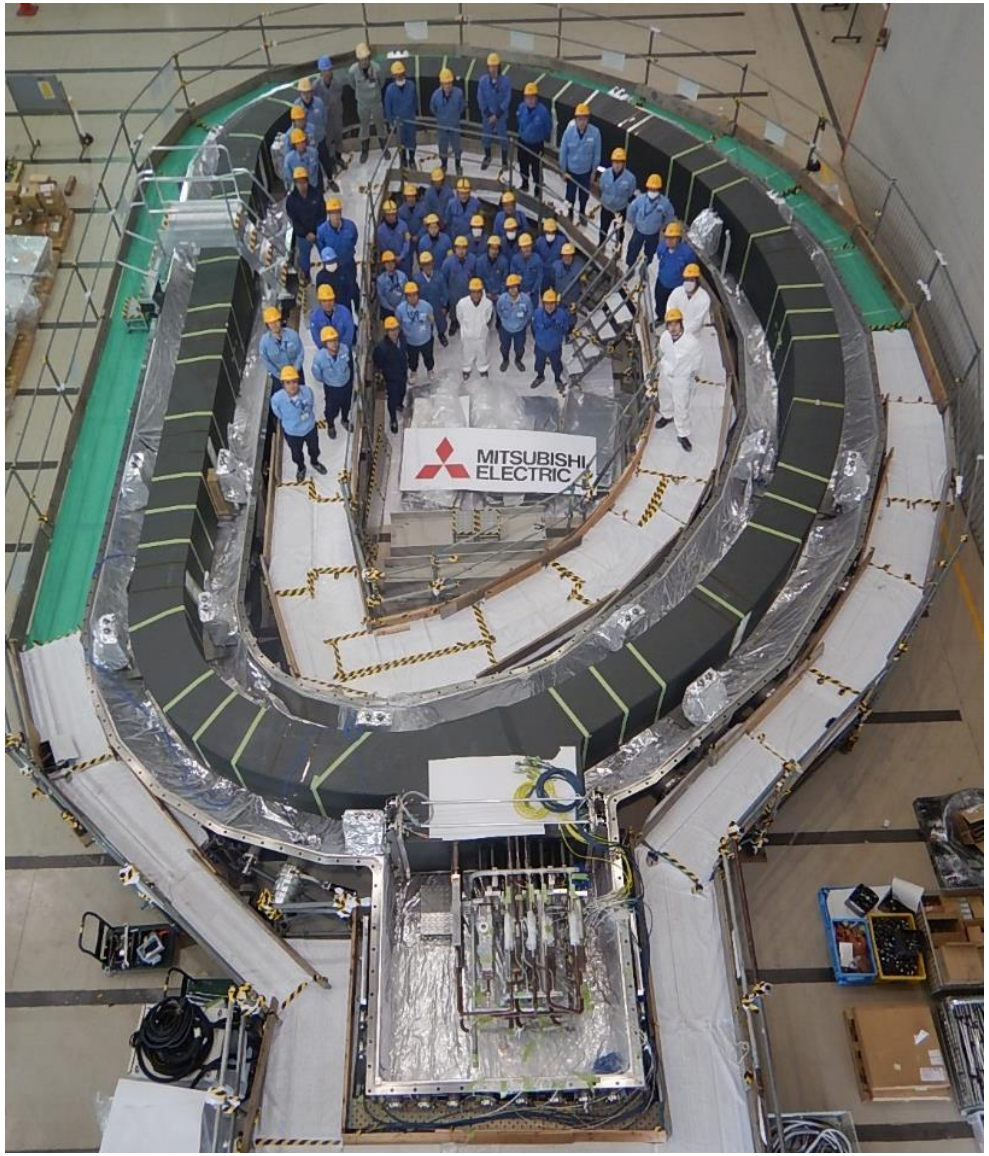
DP stacking and WP ground insulation

❑ 4 WP ground insulation completed

Completed WP

❑ 3WPs completed

Summary of DP and WP Fabrication



1st WP in Cold Test Chamber

TF#	Progress
TF12 (1st WP by MHI)	• Completed. • No He leak after cold test to apply thermal cycle to 80 K • No failure finally in electrical test after once repair of high voltage wire extrusion (Lesson and learn)
TF13 (2nd WP by MHI)	• Completed. • No He leak and no failure in electrical test after cold test.
TF08 (3rd WP by MHI)	• Completed • No He leak and no failure in electrical test .
TF10 (1st WP by TSB)	• Under preparation for WP impregnation.
TF16 (2nd WP by TSB)	• Under fabrication of DPs.
TF02 (4th WP by MHI)	• Under preparation for WP impregnation.
Others	• Under fabrication of DPs.

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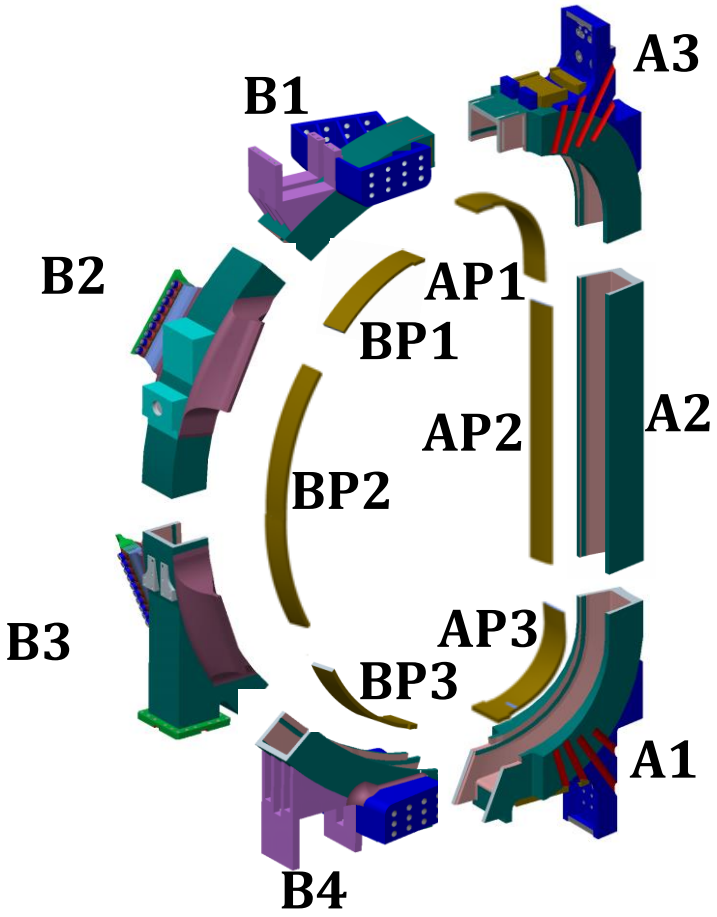
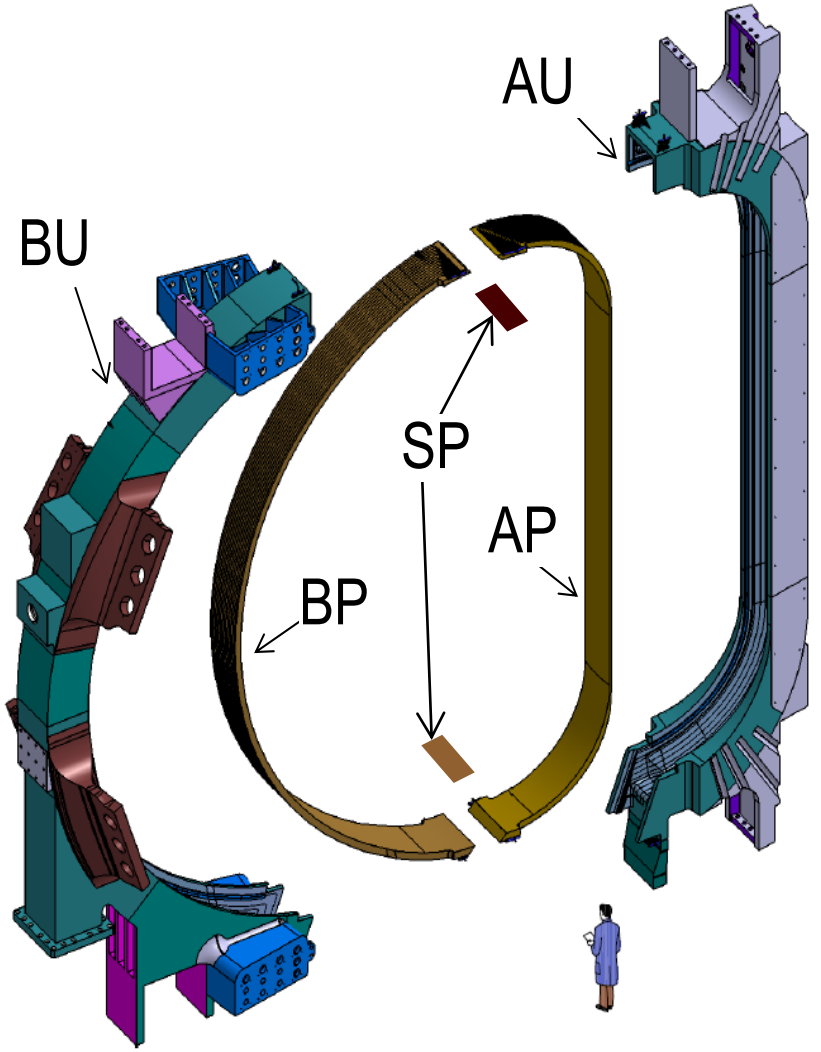
Coil Case Fabrication

- For manufacturability, coil case (CC) is fabricated in steps;
  1) fabricating basic segments, and
  2) welding basic segments together.

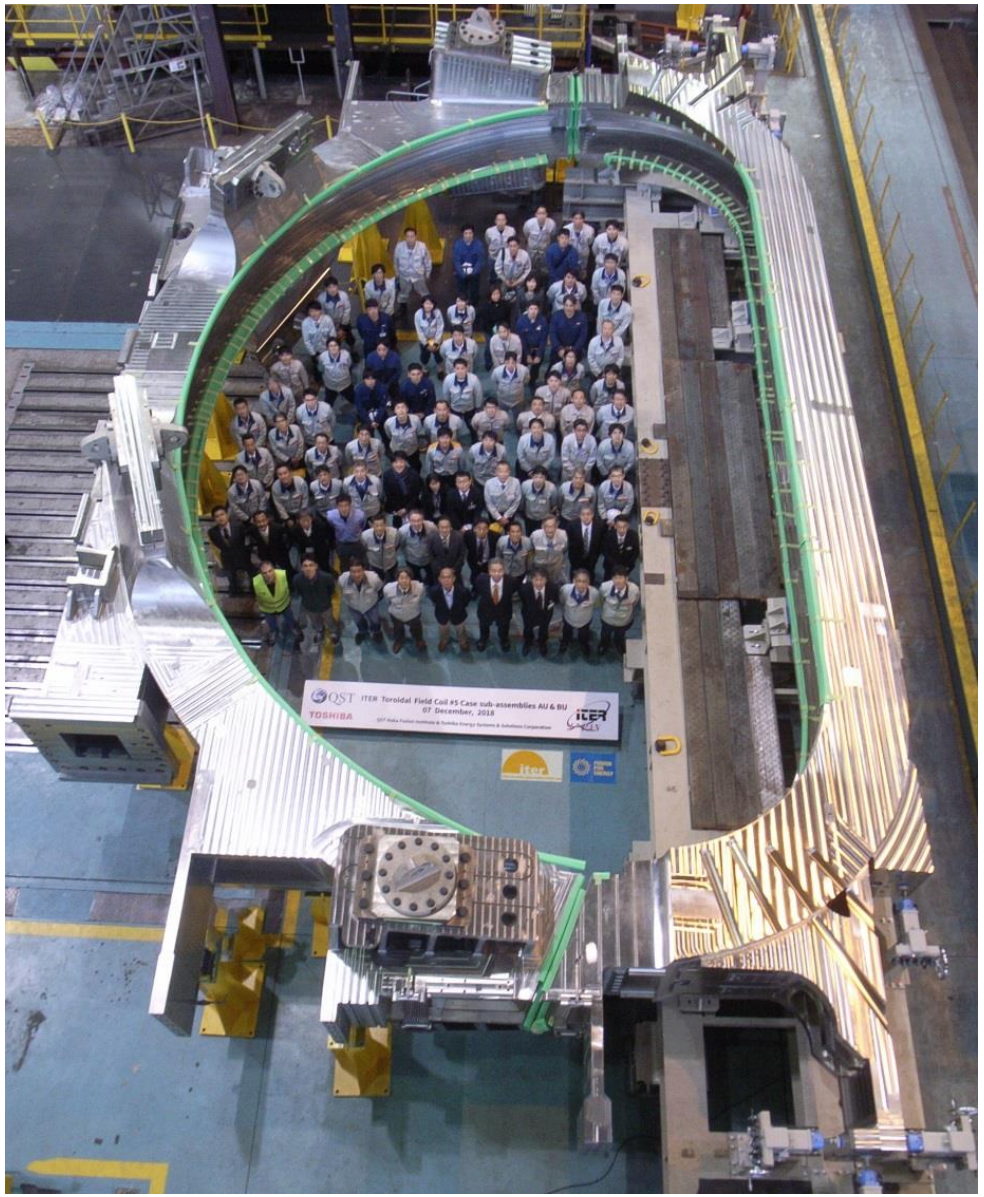


Basic segments



Sub-assemblies (TF coil case)

Summary of CC Fabrication



5th CC AU and BU (1st CC by TSB)

TFC	TF#	Progress
EU	TF09 (1st CC by HHI&MHI)	Completed & Delivered to EU.
EU	TF11 (2nd CC by HHI&MHI)	
JA	TF12 (3rd CC by MHI&HHI)	Completed.
JA	TF13 (4th CC by MHI&HHI)	
EU	TF05 (1st CC by TSB)	Completed & Delivered to EU.
EU	TF03 (2nd CC by TSB)	
JA	TF08 (5th CC by MHI&HHI)	Completed.
EU	TF06 (5th CC by HHI&MHI)	Completed.& Waiting for shipping
EU&JA	Others	Under fabrication

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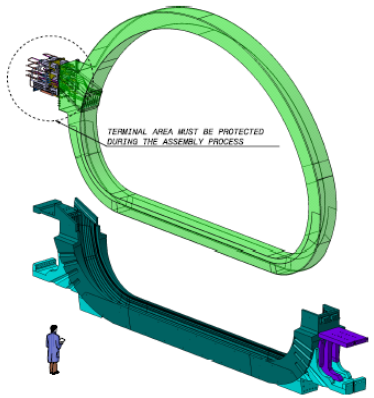
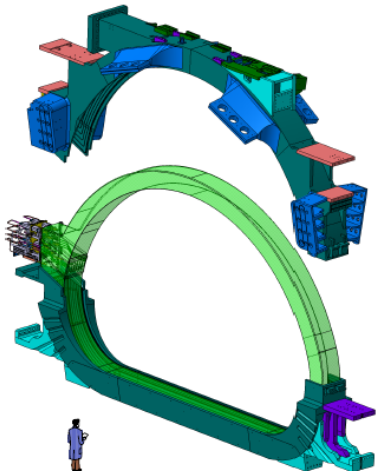
Brief procedure of assembly of WP into CC

WP insertion

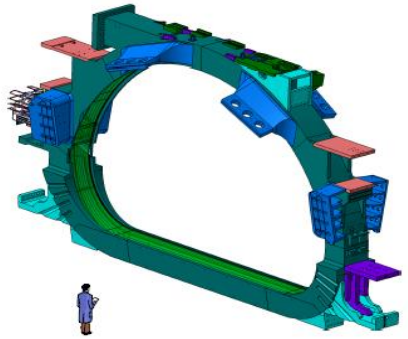


WP insertion into AU

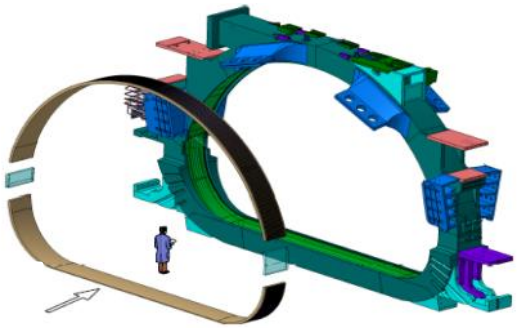


BU install on AU

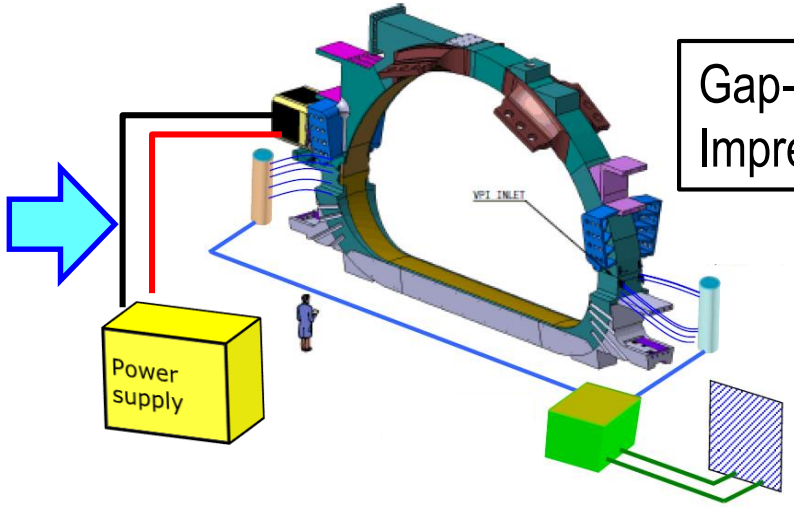
Closure welding



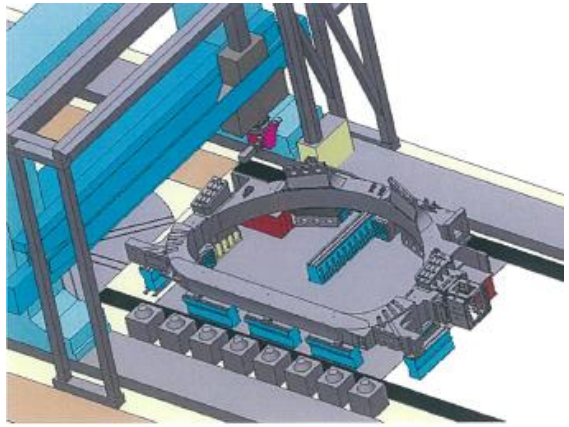
AU-BU welding



AU-AP&BU-BP welding
And AP-SP-BP welding



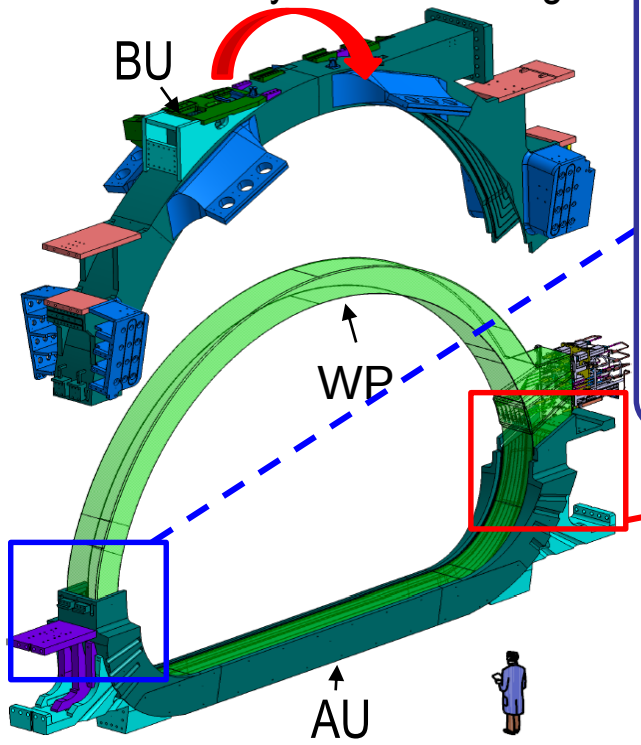
Gap-filling
Impregnation



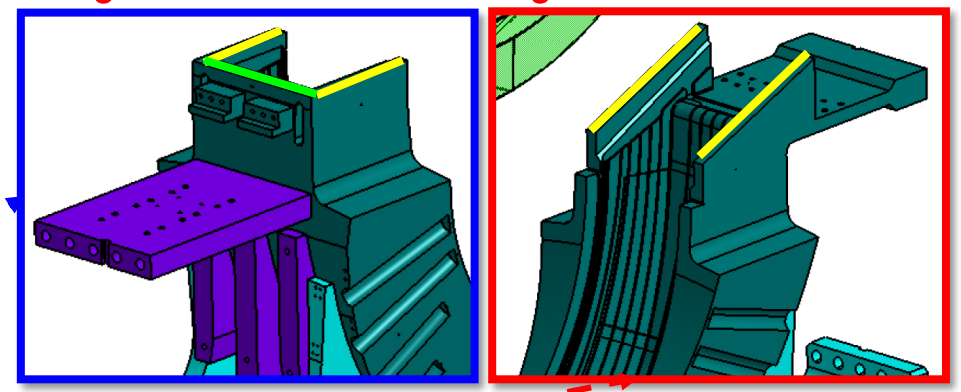
Final machining

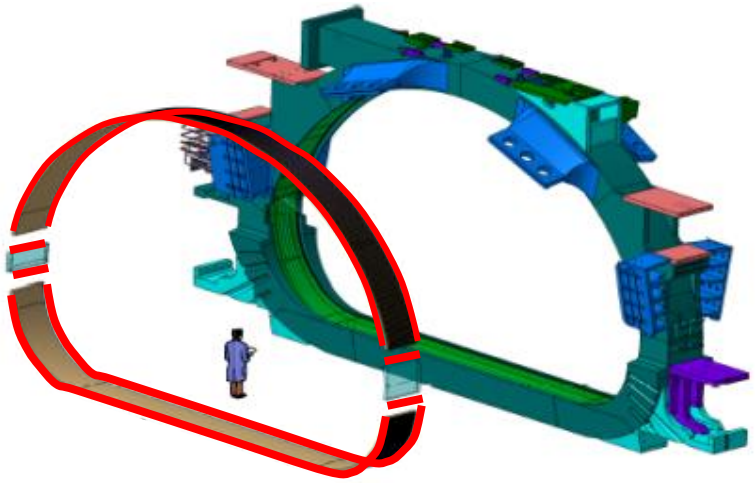
Challenges in assembly of WP into CC (1)

BU distortion by AU-BU welding



Tight tolerance of welding bevel < +/-**0.5mm**





- Large welding deformation by long and deep welding lines in closure weld
- Difficult to expect deformation

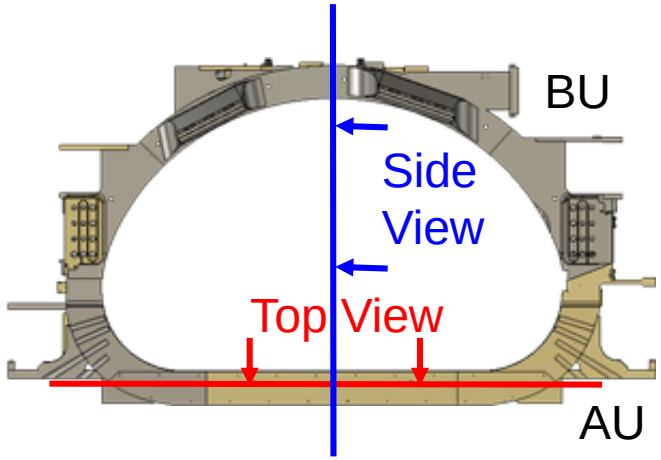
Target error field ≈10^{-5}

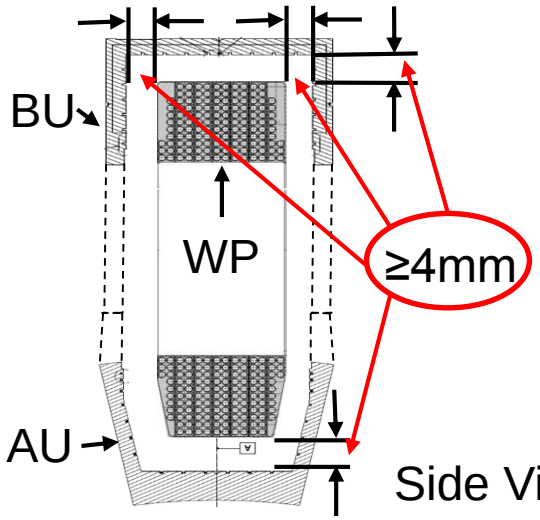
Target of positioning WP < ϕ2.6 mm at inboard

⇔

If WP is deformed by coupling with closure welding deformation of CC, WP (CCL) is deformed much.

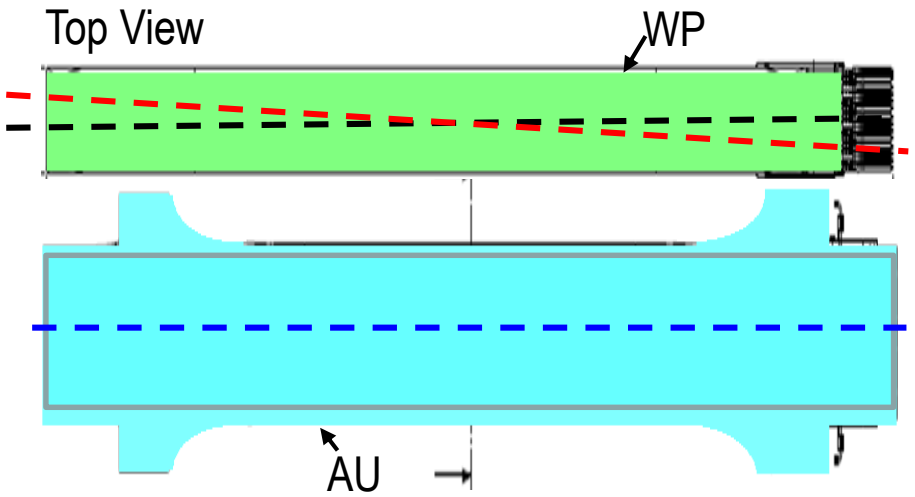
Challenges in assembly of WP into CC (2)





- Viscosity of gap-filling resin with filler
  8 Pas ➔ ≈40 Pas after 20 h

For impregnation with resin with 41% filler, 4 mm gap shall be kept with allowance of local 3 mm gap.



Center Line of WP profile

Least square approximation of CCL @ Straight portion

Reference Line of CC

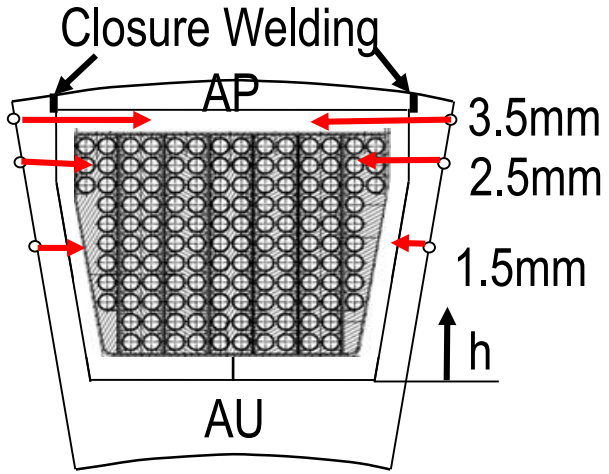
If large difference, alignment with 4mm gap is difficult.

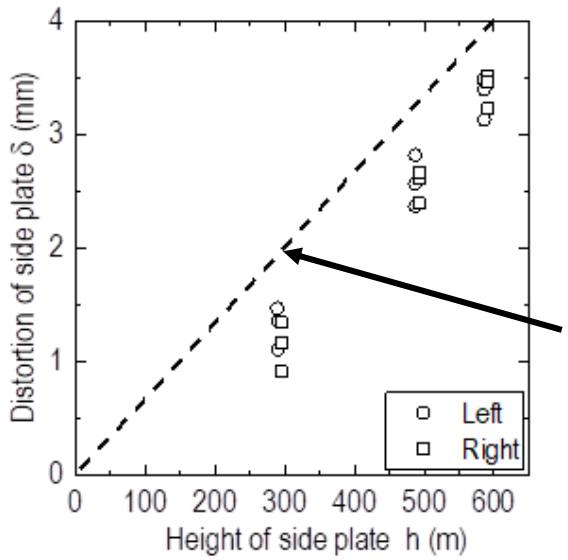
Detailed expectation of gap with proper alignment these axis before insertion of WP is necessary

Any remaining misalignment is corrected by shifting final machining axis.

Gap Analysis of WP and CC before WP insertion

Side Plate Distortion due to Closure Welding

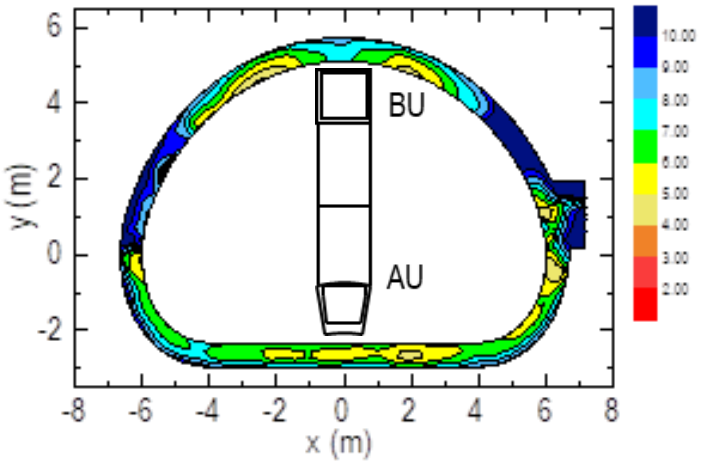




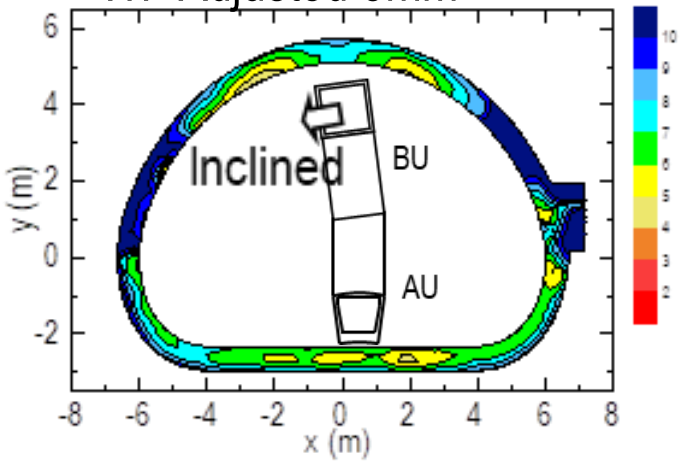
Side plate distortion value used for analysis

Gap Analysis

No BU Inclination



BU inclined 3mm and top of WP Adjusted 3mm

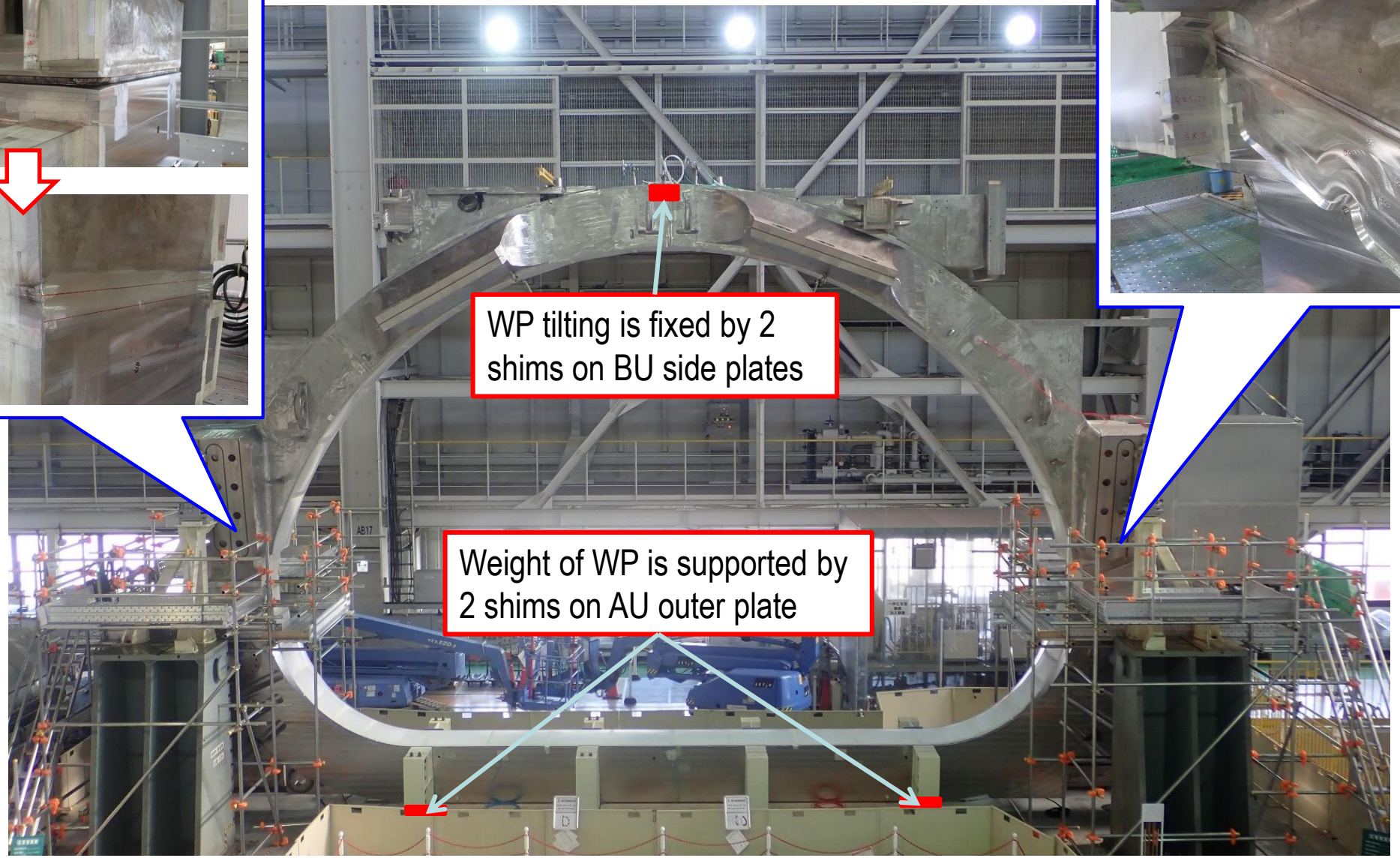


4mm gap can be achieved in both cases.

WP insertion into AU

BU assembly on AU

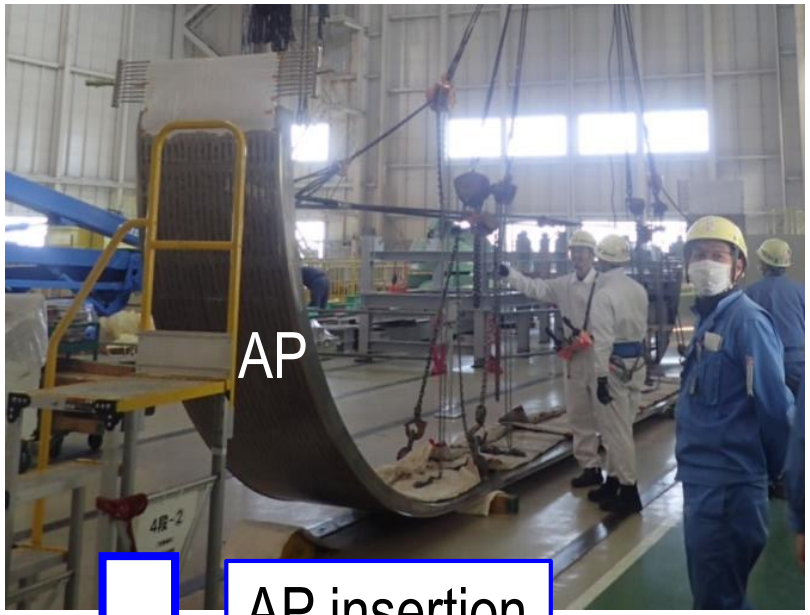
AU-BU welding



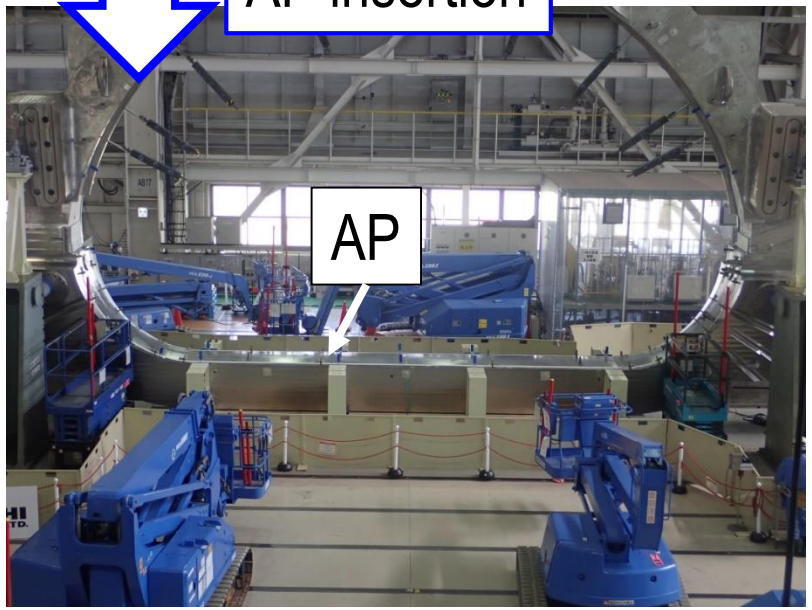
WP tilting is fixed by 2 shims on BU side plates

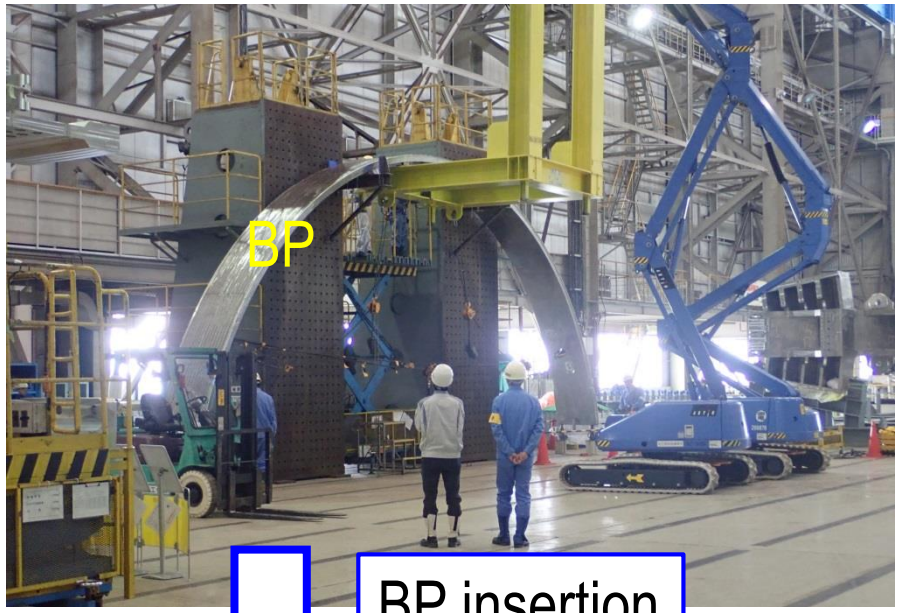
Weight of WP is supported by 2 shims on AU outer plate

AP and BP insertion

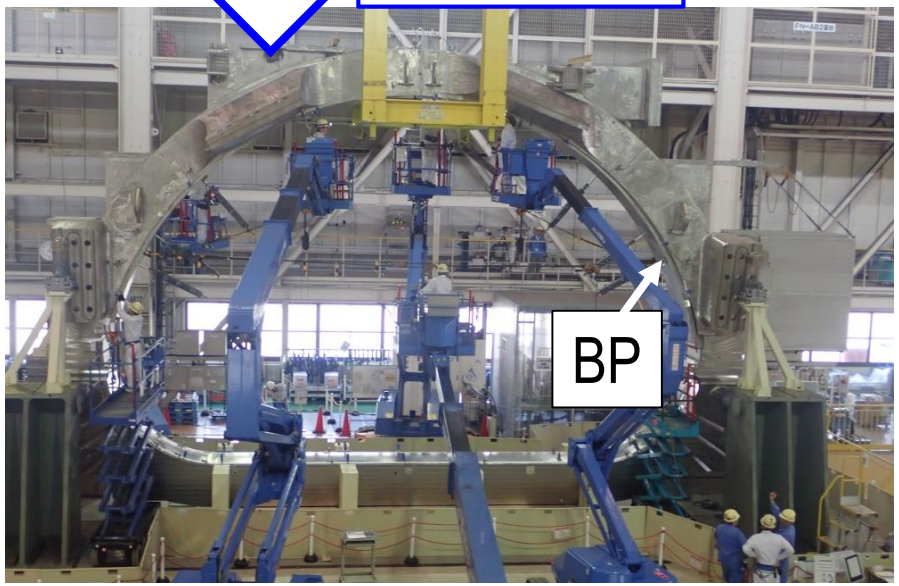


AP insertion

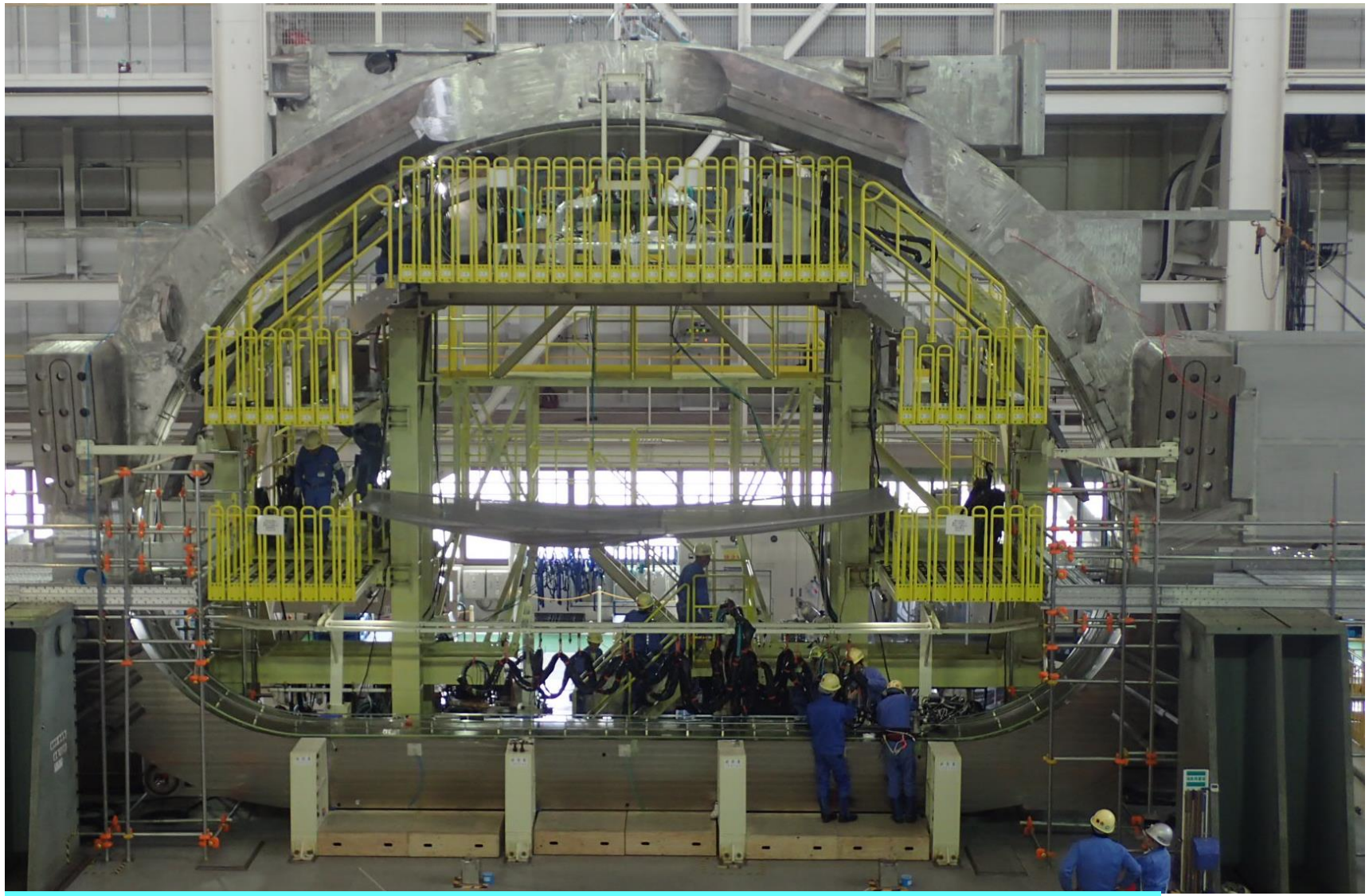




BP insertion

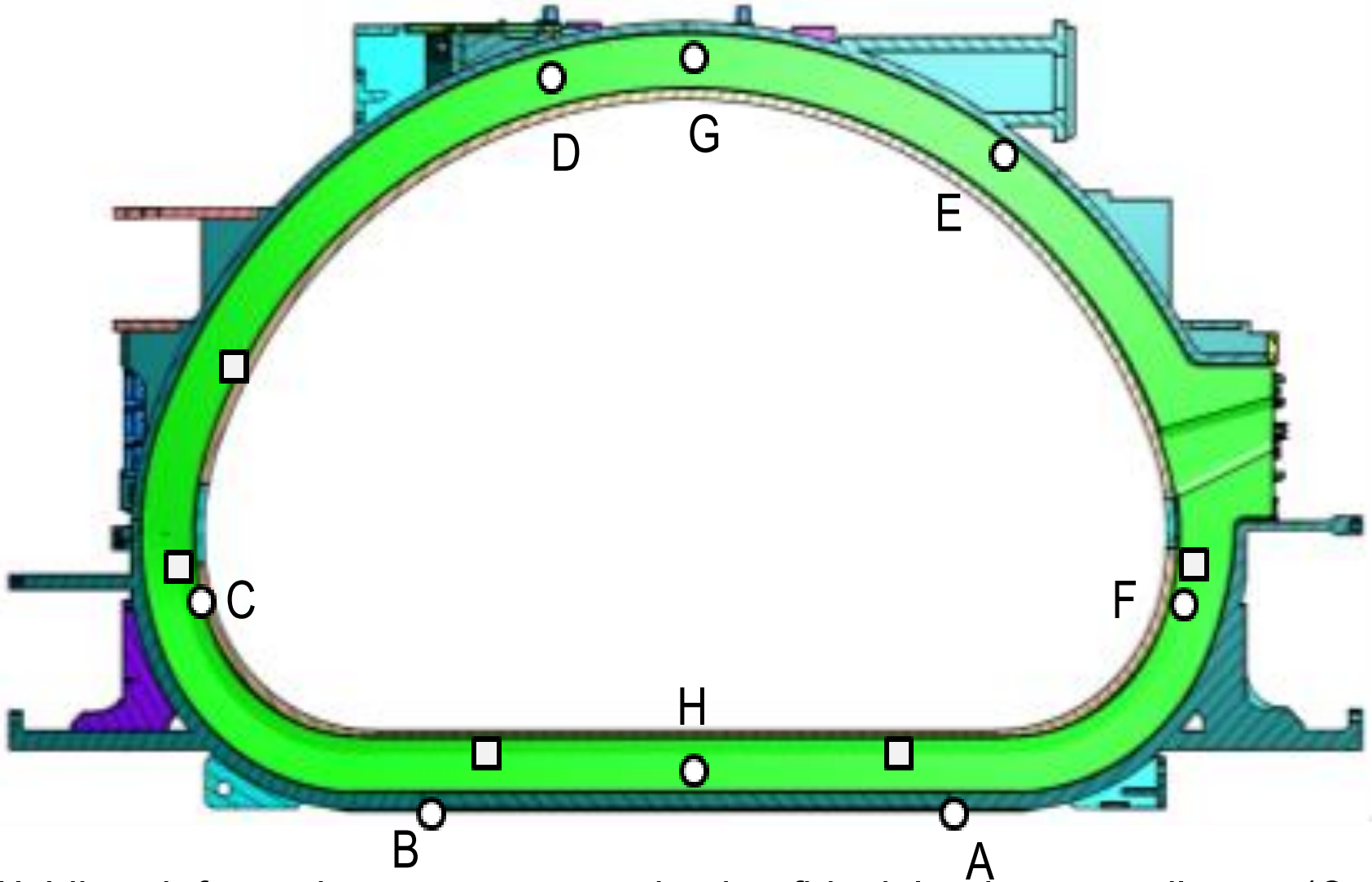


AU-AP and BU-BP, AP-SP-BP welding



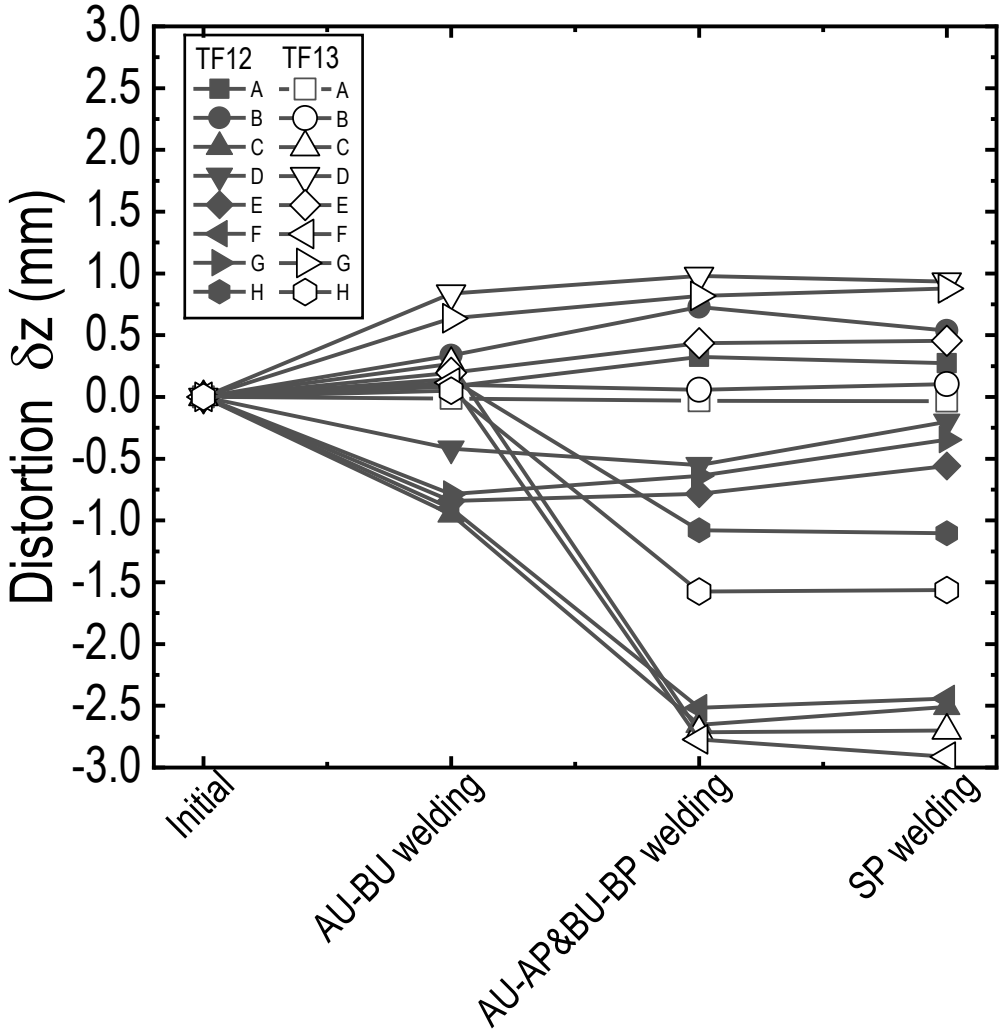
❑ Closure weld of first and second TF coils completed.

Measurement of closure welding deformation



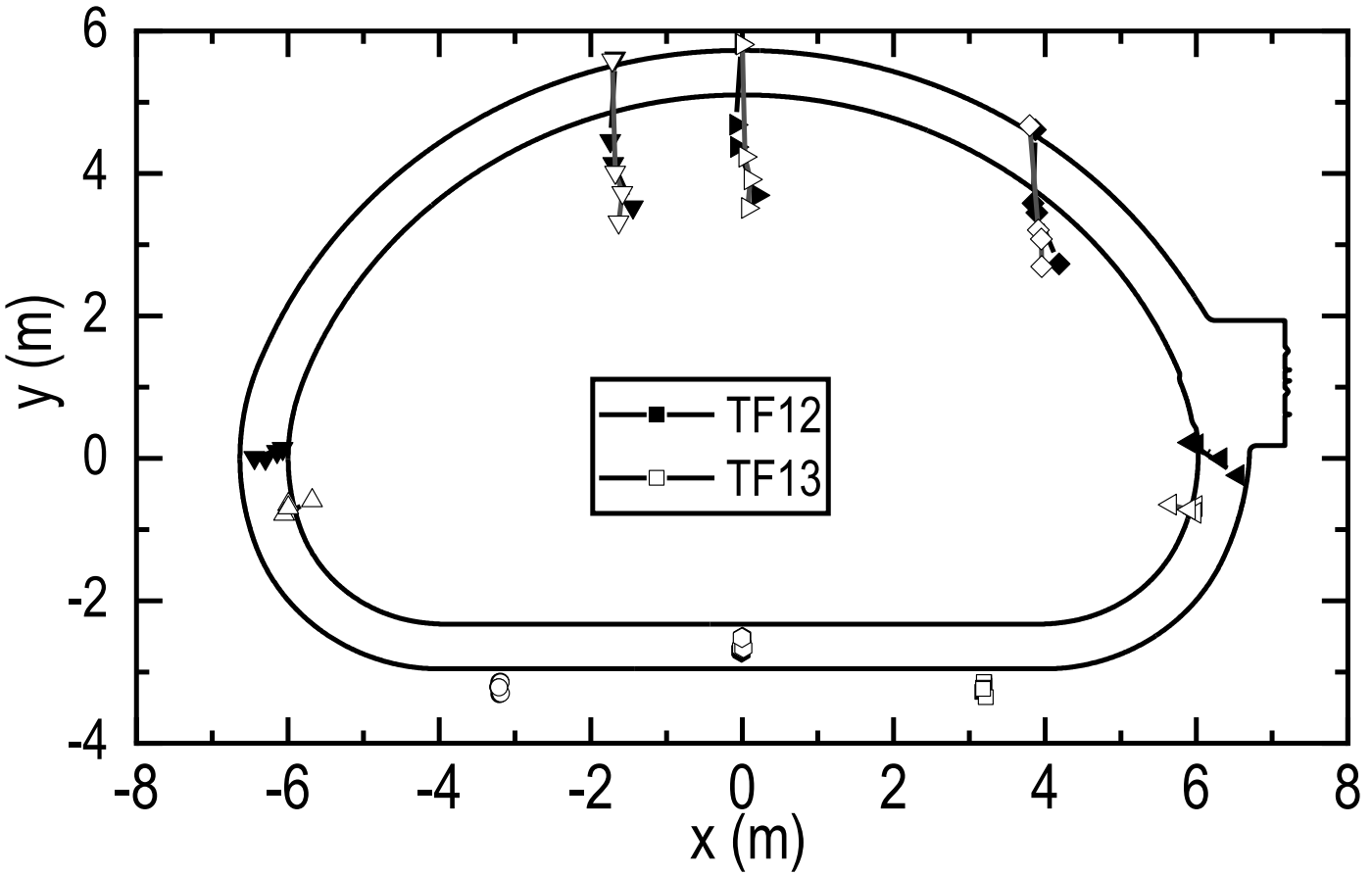
❑ Welding deformation was measured using fiducial points on coil case (Open circles)

Closure welding deformation



Distortion

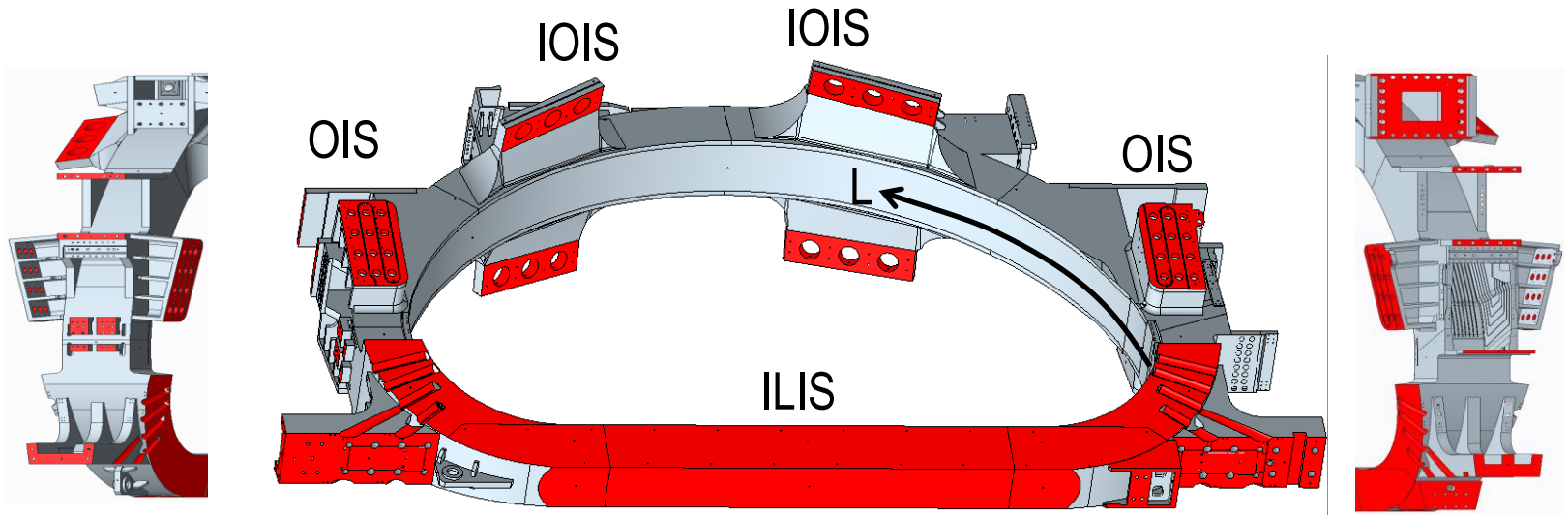
- Distortion by AU-BU welding is within +/1.5 mm



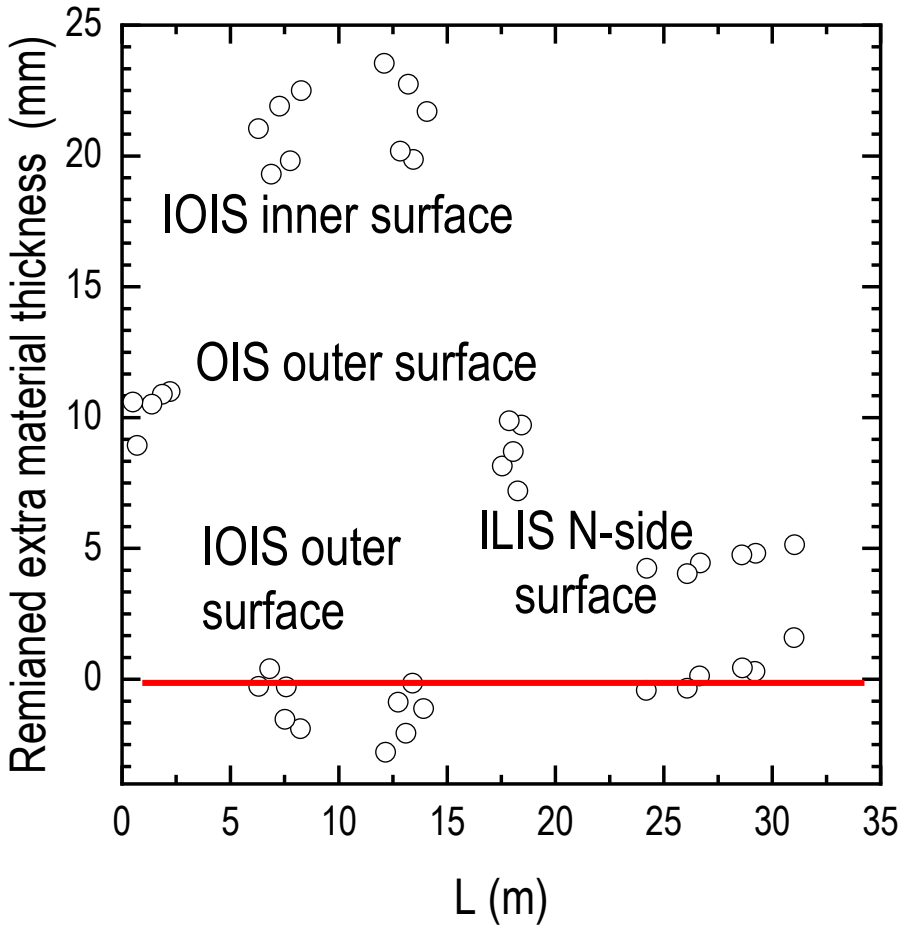
In-plane deformation
(Displacement is multipled by 200)

- If expected welding shrinkage by AU-BU welding, in-plane deformation is about 5 mm.

Interface position



Surfaces to be machined (Interfaces)



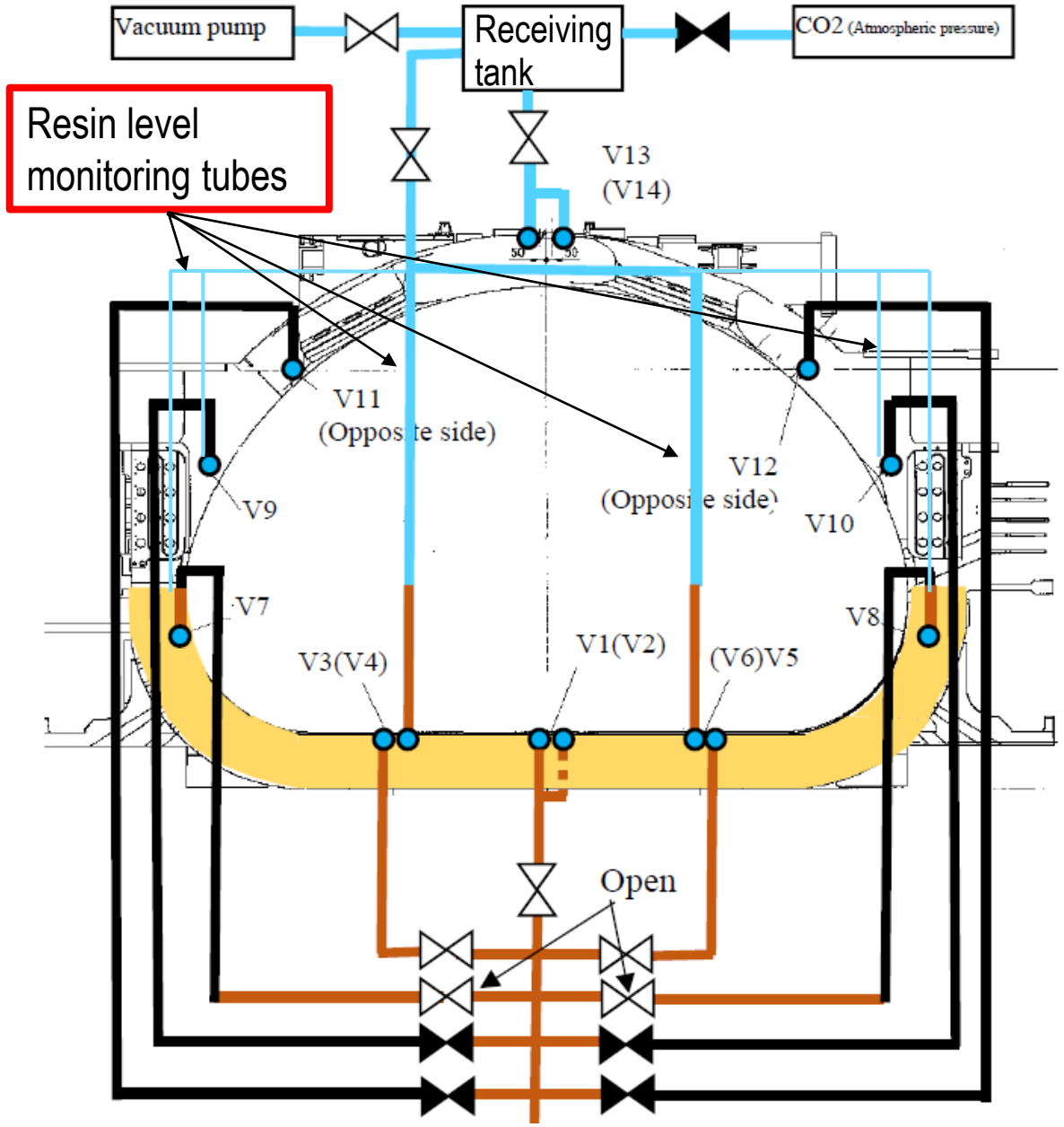
Remained extra material

- ❑ Thickness of the extra material is marginal at ILIS and IOIS surfaces.
- ❑ It is being re-measured after setting TF coil on final machine.
- ❑ If deviated,

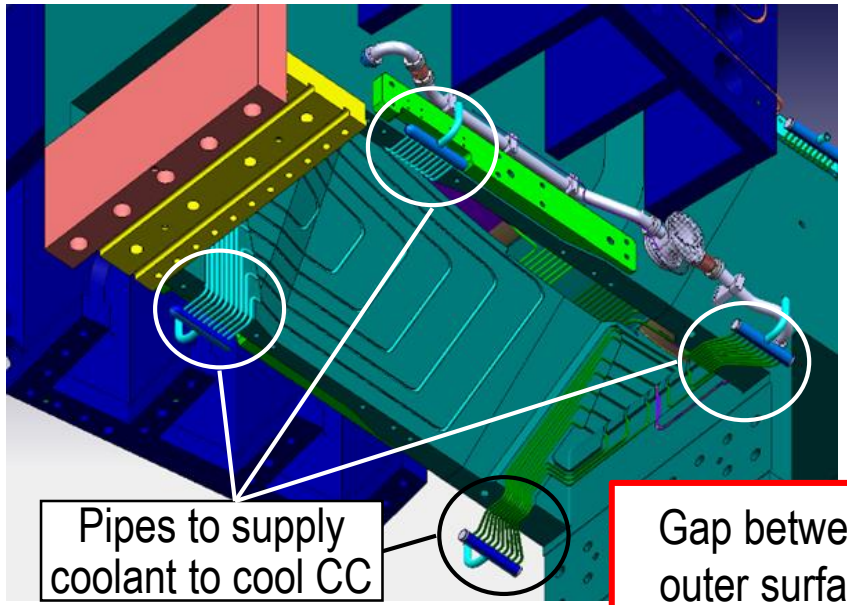
1) Shim will be used on ILIS.
2) Position of IOIS is shifted by 5 mm.

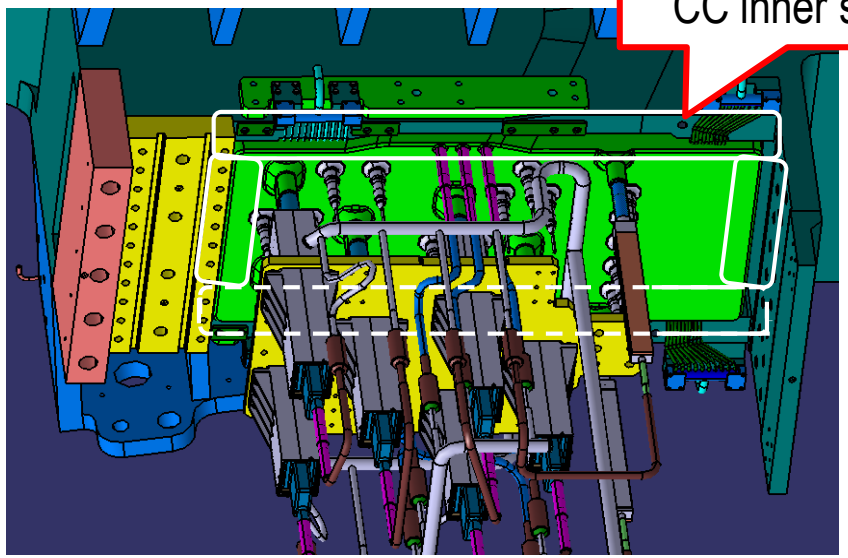
Resin Injection

- Resin was injected from bottom holes to upper injection holes as resin level increase.
  - ✓ Resin injection started with V1 & V2 holes.
  - ✓ Valves to V3 (V4) & V5(V6) were opened as resin level reached V3(V4) & V5(V6).
  - ✓ Valves to V7 & V8 were opened as resin level reached V7 & V8.
  - ✓ Valves to V9 & V10 were opened as resin level reached V9 & V10.
  - ✓ Valves to V11 & V12 were opened as resin level reached V11 & V12.

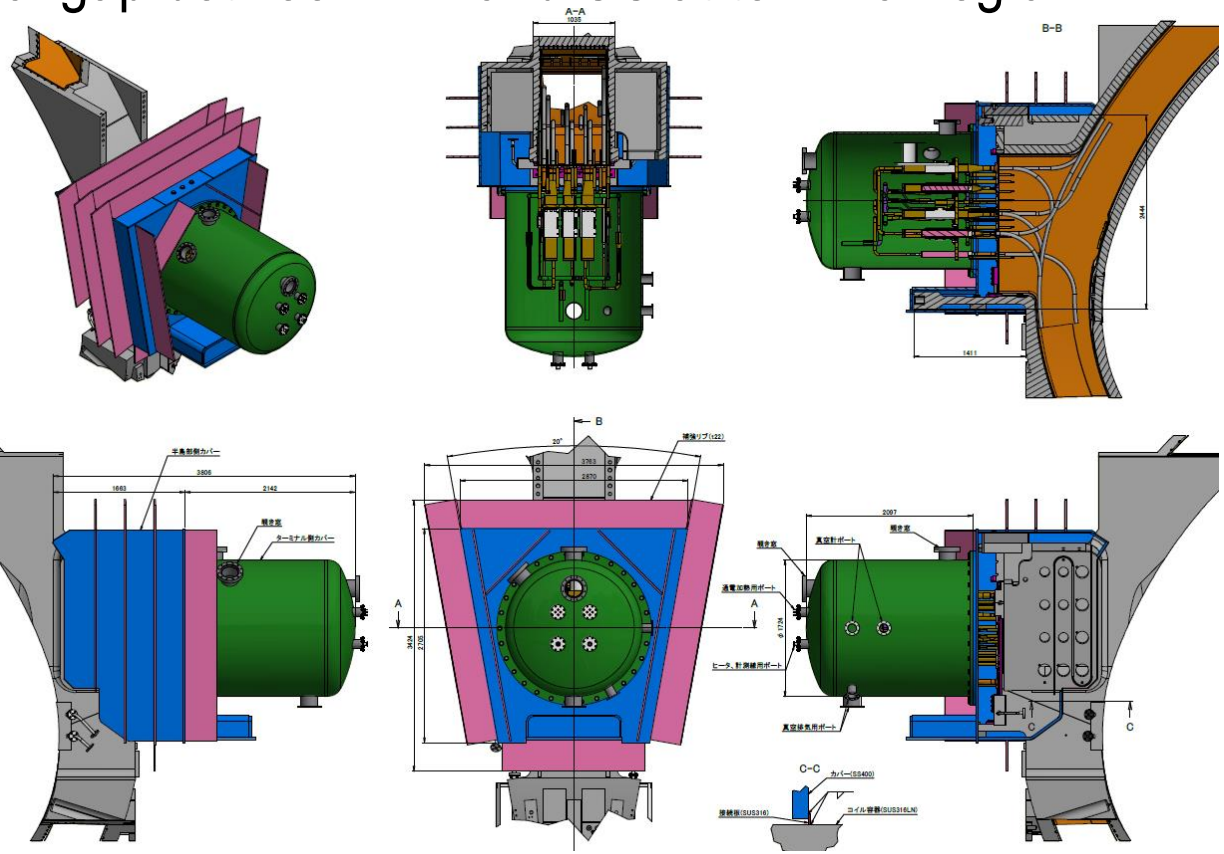


Sealing during gap-filling impregnation





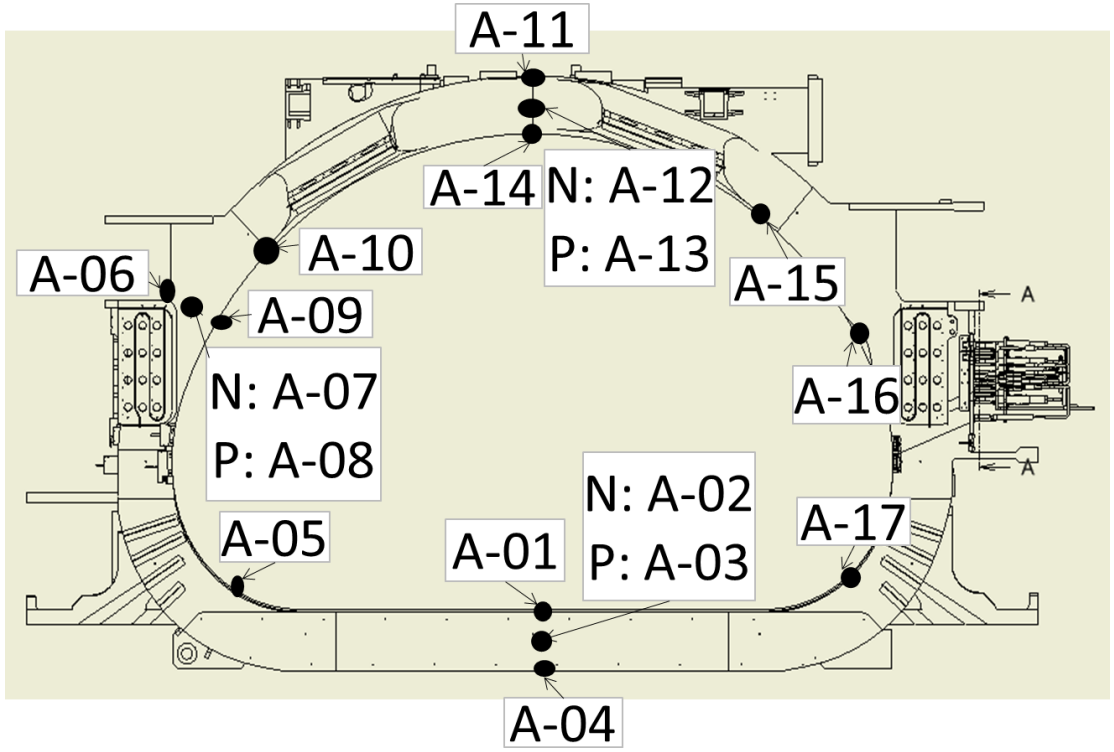
- Large force by vacuum and pressurizing (15 ton)
- Relative displacement between WP and CC makes it difficult to seal gap between WP and CC at terminal region

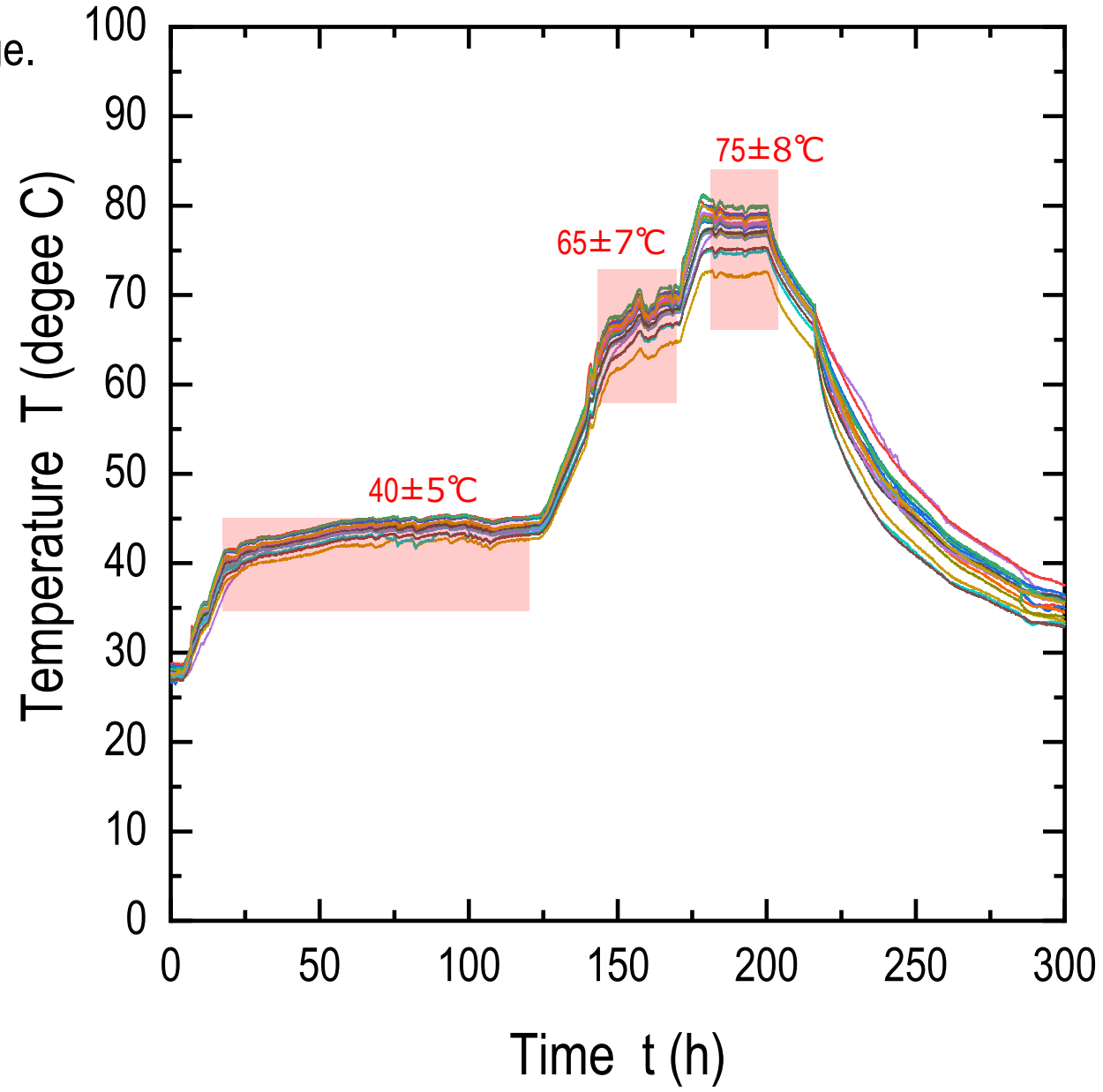


- Pressure outside CC is a little (≈25kPa) higher than that inside CC by controlling pressure in terminal cover.

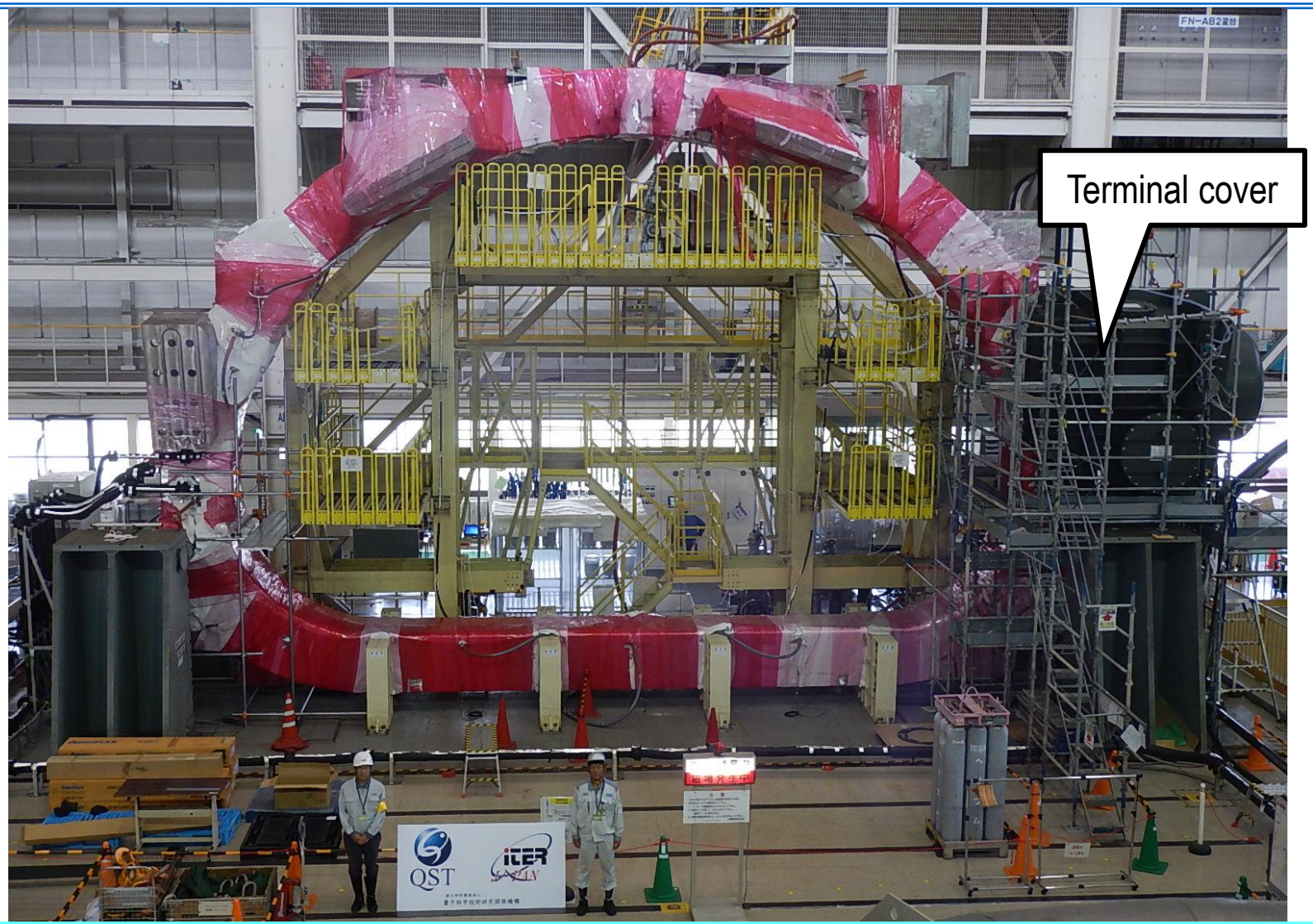
Temperature Chart

- Temperature variation within WP was kept under target range.
  - 40±5℃
  - 65±7℃
  - 75±8℃





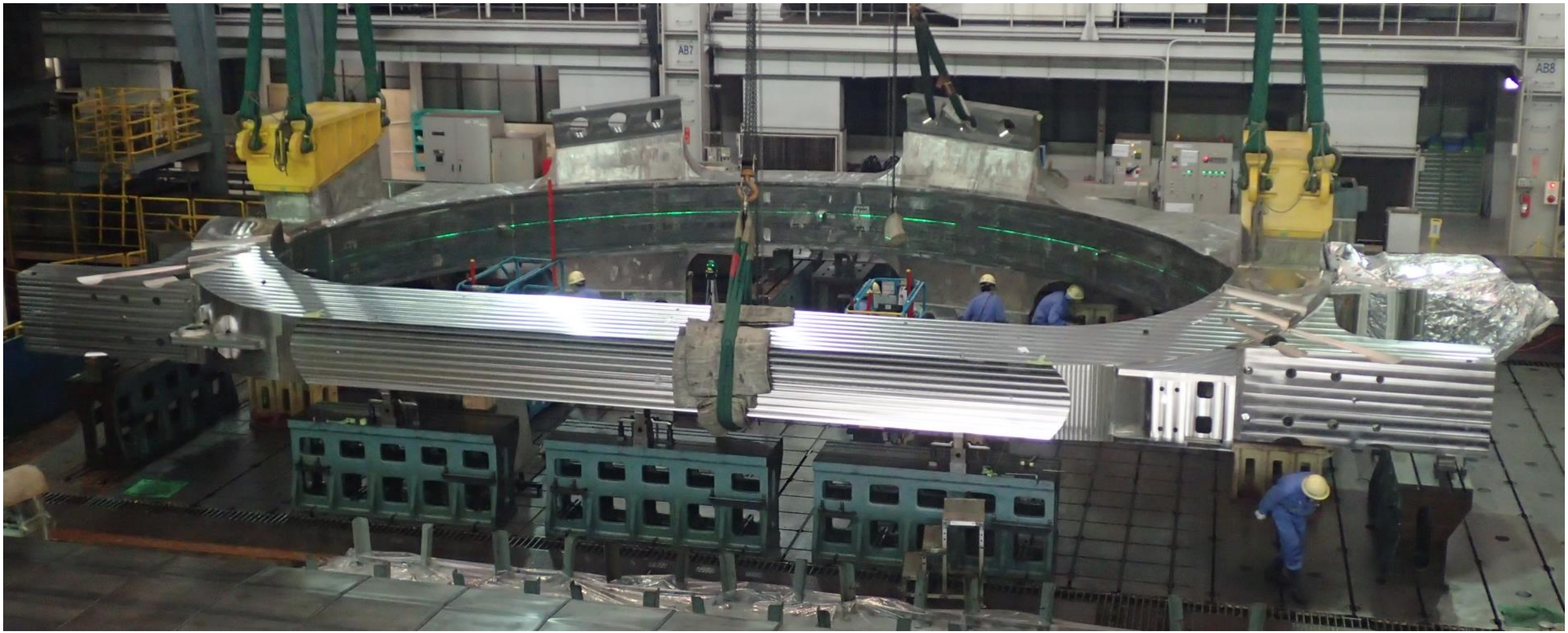
Gap-filling impregnation



❑ Gap-filling impregnation of the first TF coil is successfully completed

Final machining

- The fist TF coil is on large gantry machine, Super-miller.



- CCL at inboard straight section is preliminary evaluated to be within ϕ0.5 mm.

5. Summary

- Series production of TF coil WP and CC are progressing in Japan.
- As of September of 2019, from a total of 63 DPs, JADA completed winding of 55 DPs and DP impregnation of 40 DPs.
- In addition, 3 WPs and 8 CCs have been completed.
- The assembly of the WP and CC is proceeding.
  1. Gap-filling impregnation completed in the first TF coil, and
  2. closure welding completed in the second TF coil.
- Since the remaining process in the first TF coil is only final machining, we can say that the procedure of ITER TF coil fabrication have been well developed and established.