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KOREA DOMESTIC AGENCY

ID: PD/1-2

Manufacturing Completion of the First ITER Vacuum Vessel Sector

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on behalf of VV Project Team

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Virtual Event

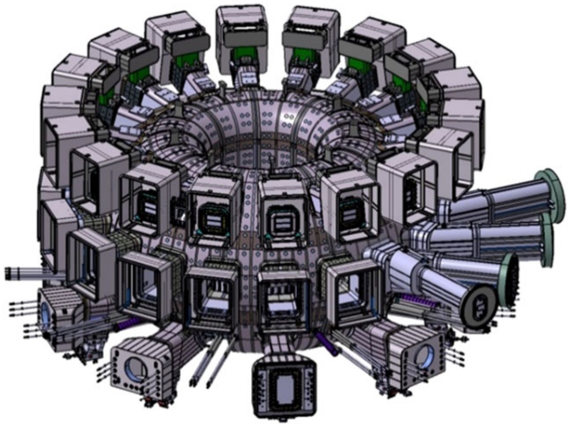
Outline

- **Introduction**
- **Technical Challenges**
  - Nuclear Safety Process
  - Tight Tolerance Requirement
  - Full Inspection Requirement
  - Other Challenges
- **Lessons learned**

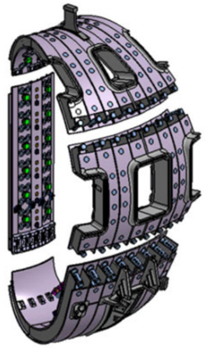
Introduction

ITER Vacuum Vessel - Overall Description

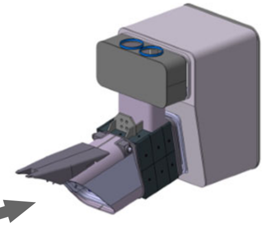
- **A torus shaped double wall structure**
  - **To provide the high vacuum for plasma** and **the primary radioactivity confinement boundary**
  - **To support in-vessel components** (Blanket, Divertor, etc)



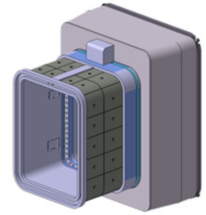
Main Vessel (40º Sector)



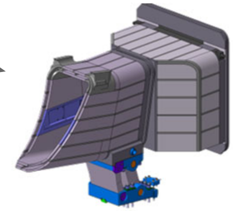
In-wall Shielding



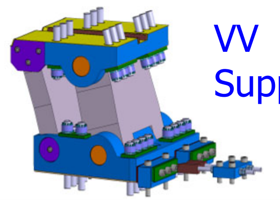
Upper Port (18)



Equatorial Port (17)



Lower Port (9)

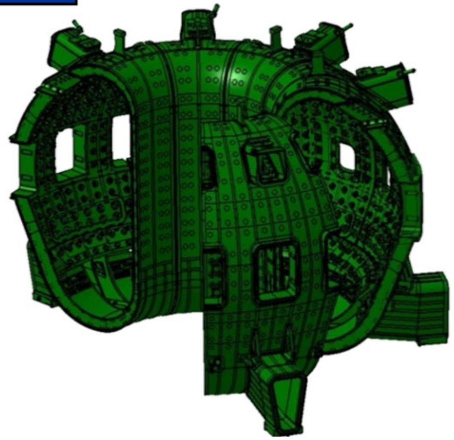


VV Support (9)

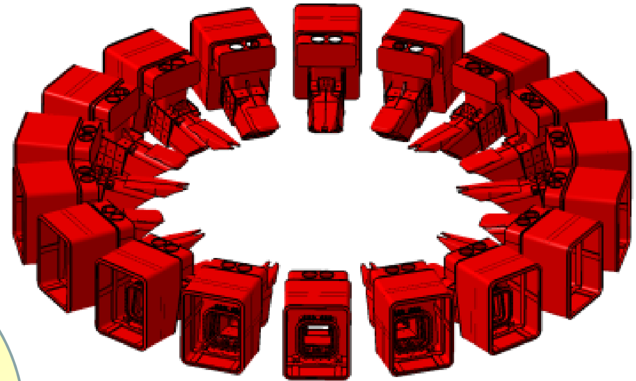
Major dimensions		Weight (ton)	
Outer diameter	19.4 m	Main vessel	1611
Height	11.4 m	Shielding	1733
Double wall thickness	0.34-0.75 m	Ports	1781
Interior surface	850 m^2	Supports	111
Interior volume	1600 m^3	Total	5236

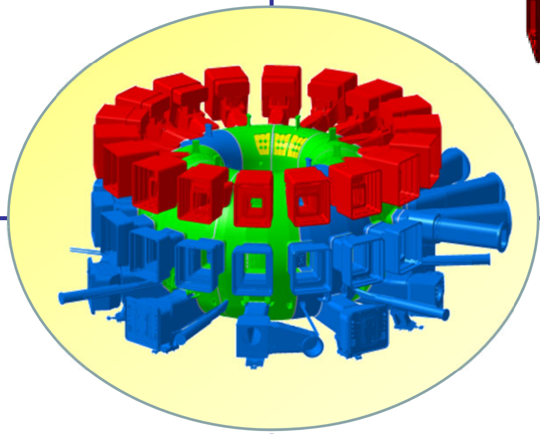
ITER VV - Procurement Sharing

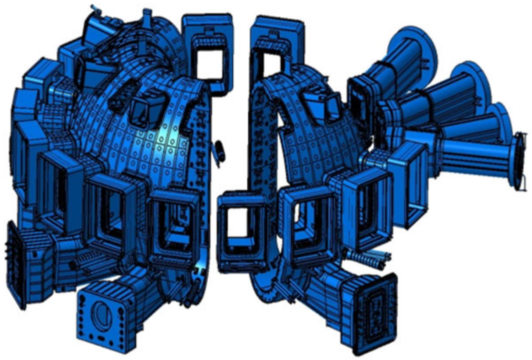
EU	Description
Items	5 Sectors of Main Vessel



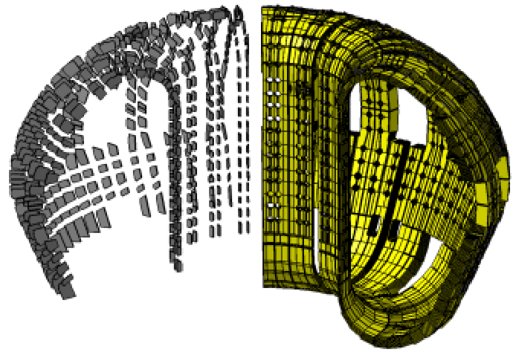
RF	Description
Items	18 Upper Ports







KO	Description
Items	(2 + 2) Sectors of Main Vessel 17 Equatorial Ports 9 Lower Ports



IN	Description
Items	In-Wall Shields/ribs

Requirement

• Regulatory Requirements

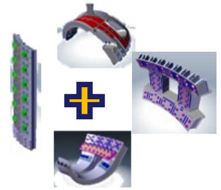
Requirements	Description
Safety	• **PIC (Protection Important Class) components** according to French order dated 7 Feb 2012 (**INB Order**)
Nuclear pressure vessel	• **Level N2 and Category IV NPE** according to the guidelines of the ASN for application of French Order dated 30 Dec 2015 (**ESPN Order**) • **Agreed Notified Body (ANB) involvement** for conformity assessment

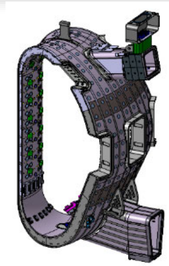
• Technical Requirements

Requirements	Description
Material	316L(N)-ITER-Grade with special requirements
Design load	Dead weight, coolant pressure, various electromagnetic loads
Tolerance	Accurate field joint fit-up and precise assembly of in-vessel components
Welding **Inspection**	Full penetration welding 100% volumetric NDE even at single side accessing region
Testing	Baking condition: 200 ^{o}C Testing pressure: 0.5 MPa, Vacuum leak rate: < 10^{-8} Pa-m^3/s
Code	RCC-MR 2007 edition

Brief history of the 1st sector manufacturing

2008	2010	2012	2017	2019	2020
PA signature	Contract Award for Manufacturing	Start of manufacturing	Completion of the first segment	Completion of 4 segments	Delivery of S#6 to ITER





Needs 101 months for 1st sector manufacturing

ITER VV sector #6 (1st sector)

Technical Challenges

Technical Challenges of ITER VV

- **Main technical difficulties are caused by strict nuclear regulation**
  1. **Nuclear Safety Process**
  2. **Tight manufacturing tolerances** even a heavy welded structure having total 1.4 km lengths weld seams
  3. **100% volumetric inspection requirement** by ESPN order
  4. **Complicated interfaces** among related parties, for example,
     - ✓ Involved several DAs, IO and ANB
     - ✓ Manufacturing of IWS by INDA (ATL), Upper Port Stub Extension by RFDA (MAN)
     - ✓ Assembly into Sector : by KODA (HHI)

Technical Challenges

1. Nuclear Safety Process

Challenge-1: Nuclear Safety Process (1/2)

- **Whole manufacturing procedure of the ITER VV should observe nuclear regulatory requirements.**
  1. To maintain traceability for all activities as nuclear pressure vessel
  2. All applicable documents shall be approved by KODA, IO and ANB prior to actual manufacturing
  3. All manufacturing activities have been inspected and recorded with approved Manufacturing Inspection Plan (MIP)

  ➔ A great deal of time and effort are required to proceed the manufacturing by a long documents review & approval process, and the complicated work interface

A necessity arose for process simplification !!

Challenge-1: Nuclear Safety Process (2/2)

- **In 2015, IO EPB (Executive Project Board) decided to create the Vacuum Vessel Project Team (VVPT)**

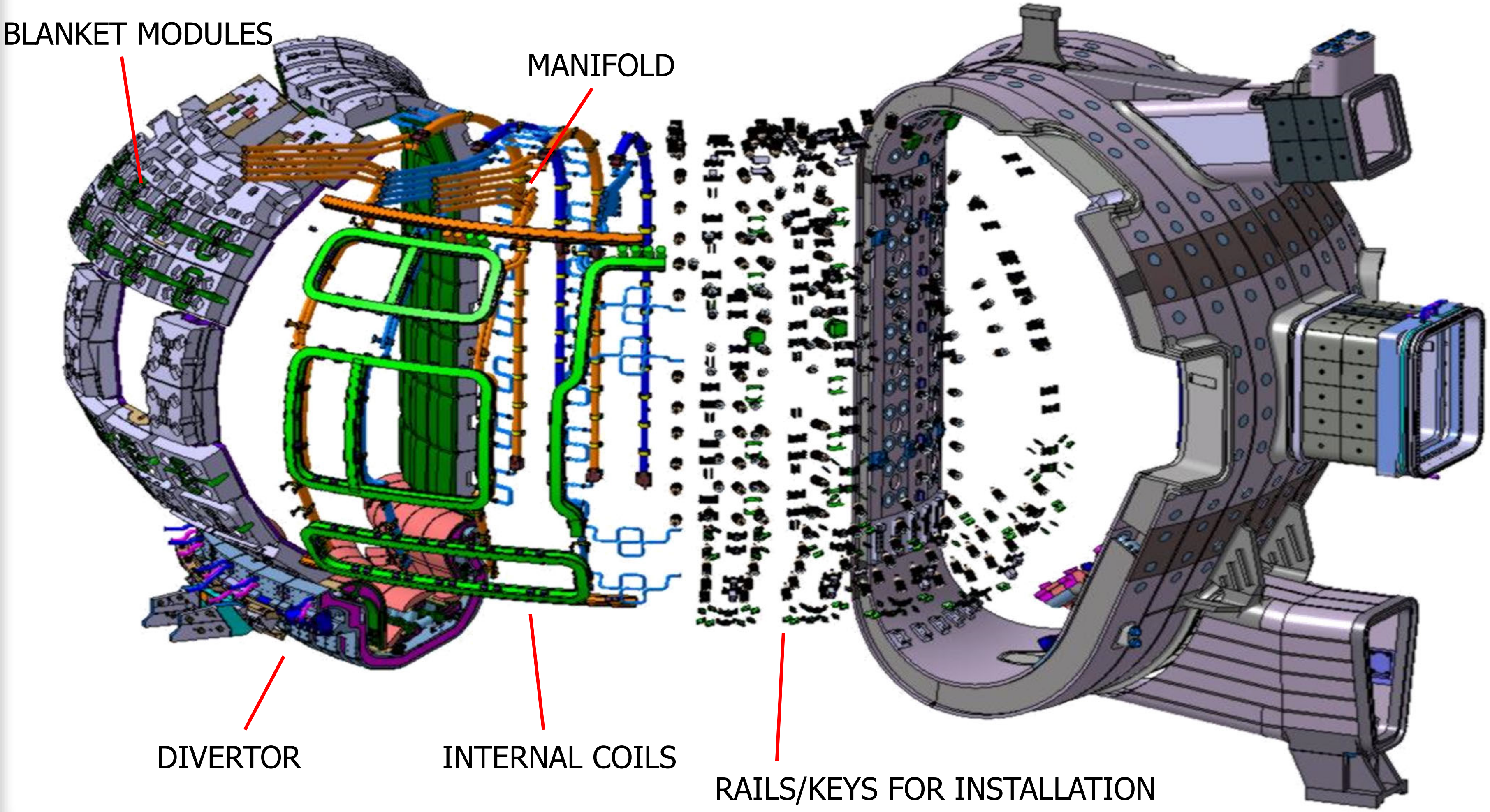
1. **Purpose**
   - ✓ One team sprit : IO-CT + IO-DAs
   - ✓ Simplification of project management of the VV
2. **The whole process has been greatly simplified after implementation of the VVPT,**
   - ✓ The simplification of the document control procedure by a time review and approval as one team
   - ✓ All inspections were performed at once
   - ✓ A total of 45,000 inspection points were performed and about 500 manufacturing documents have been developed for manufacturing of the ITER VV sector#6

Technical Challenges

2. Tight Tolerance Requirement

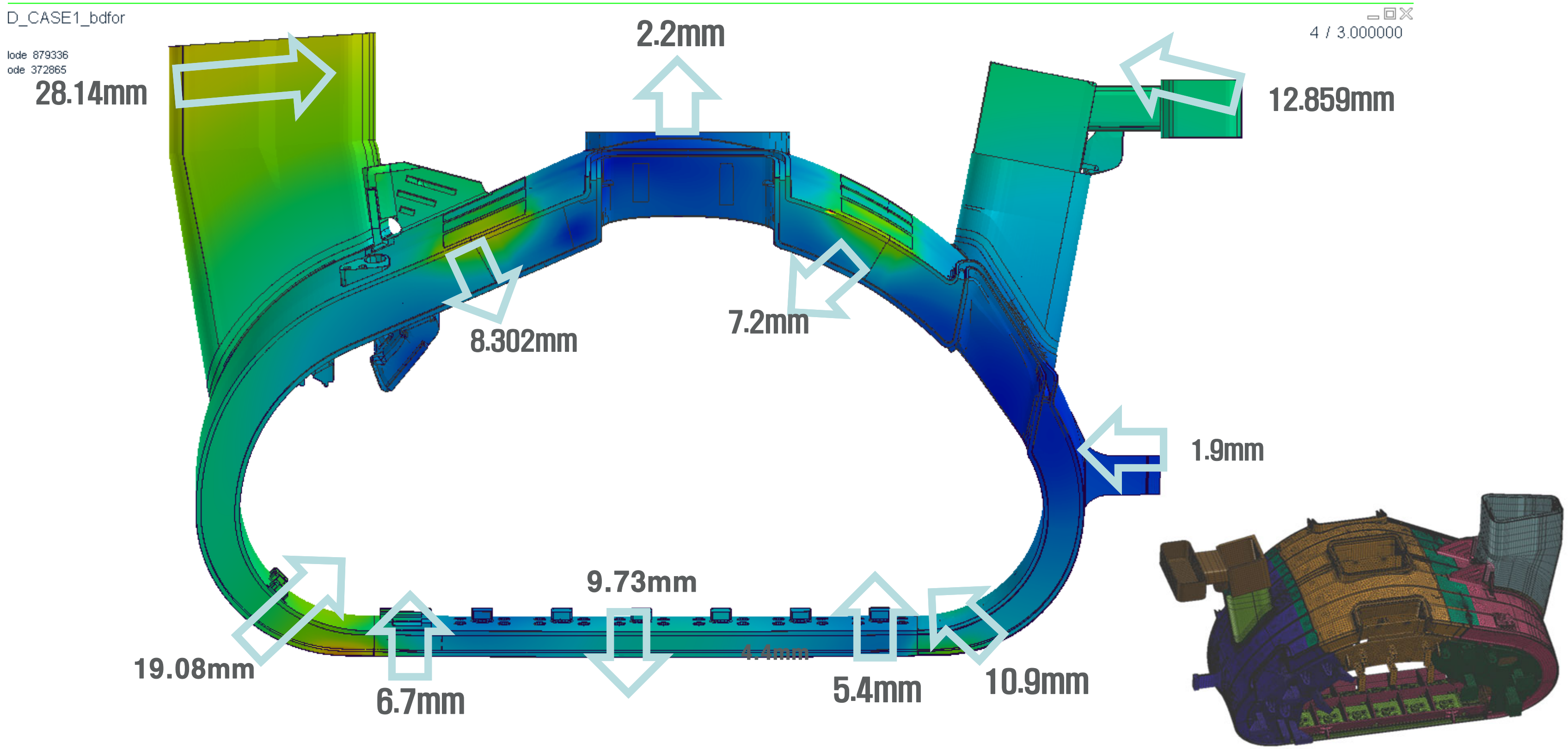
Challenge-2: Tight Tolerance Requirement (1/8)

- **Interface with in-vessel components**



Challenge-2: Tight Tolerance Requirement (2/8)

- **Welding distortion analysis to determine counter deformation during final assembly**



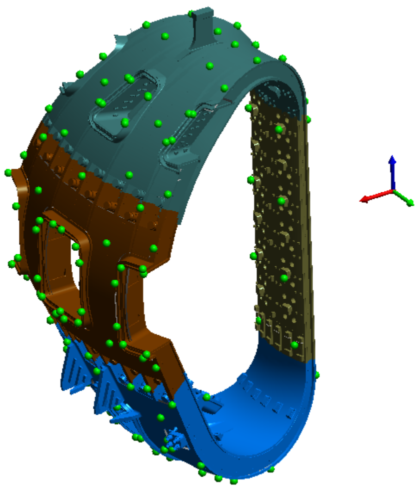
Calculated welding distortion based on HHI final assembly sequence

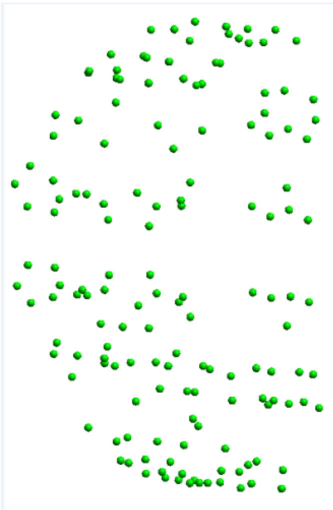
Challenge-2: Tight Tolerance Requirement (3/8)

- **Final Assembly based on Virtual Fitting**

Virtual Fitting in advance based on final 3D result of each PS and UPSE/LPSE for fit-up baseline
(Reference position set-up for each Fiducial Posts based on 1) required tolerance, 2) as built dimension for each segment, 3) required weld root fit-up tolerance, 4) welding distortion analysis results)

PS1+PS3 fit-up based on the Virtual Fitting result



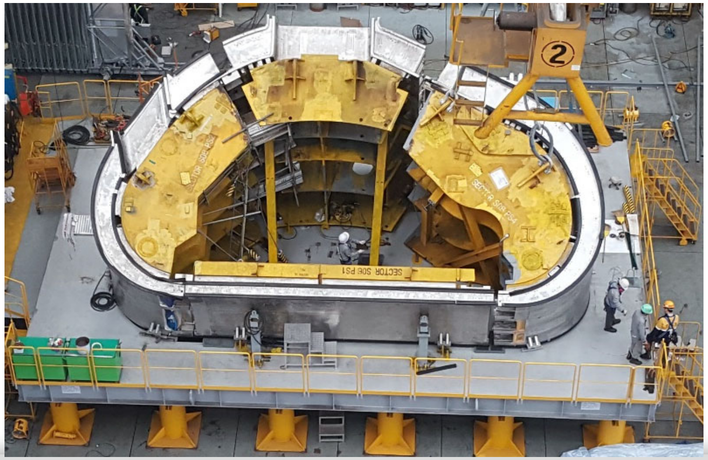


Challenge-2: Tight Tolerance Requirement (4/8)

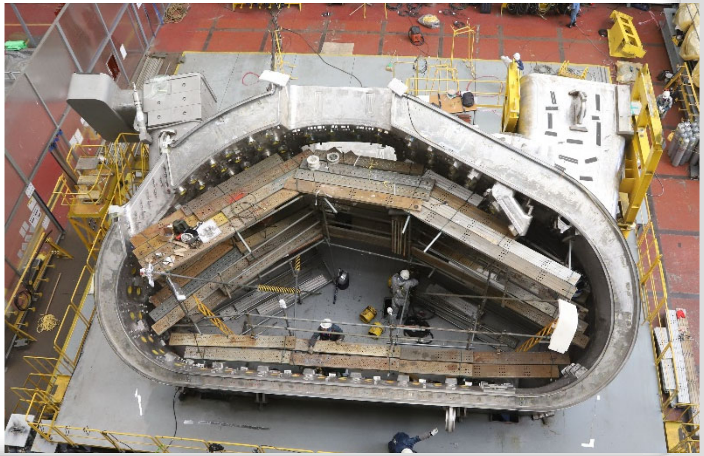
- **Final Assembly based on Virtual Fitting**

PS1+PS3+PS2 Fit-up based on the Virtual Fitting Result

PS1+PS3+PS2+PS4 Fit-up based on the Virtual Fitting Result and Welding/NDE

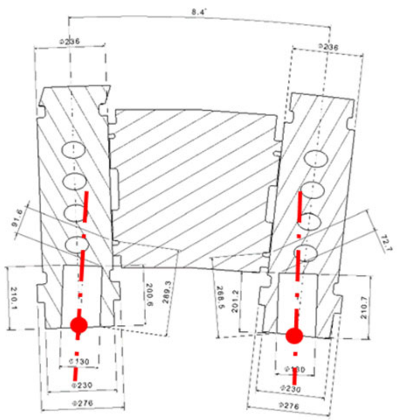


UPSE/LPSE Assembly & Jig removal



Challenge-2: Tight Tolerance Requirement (5/8)

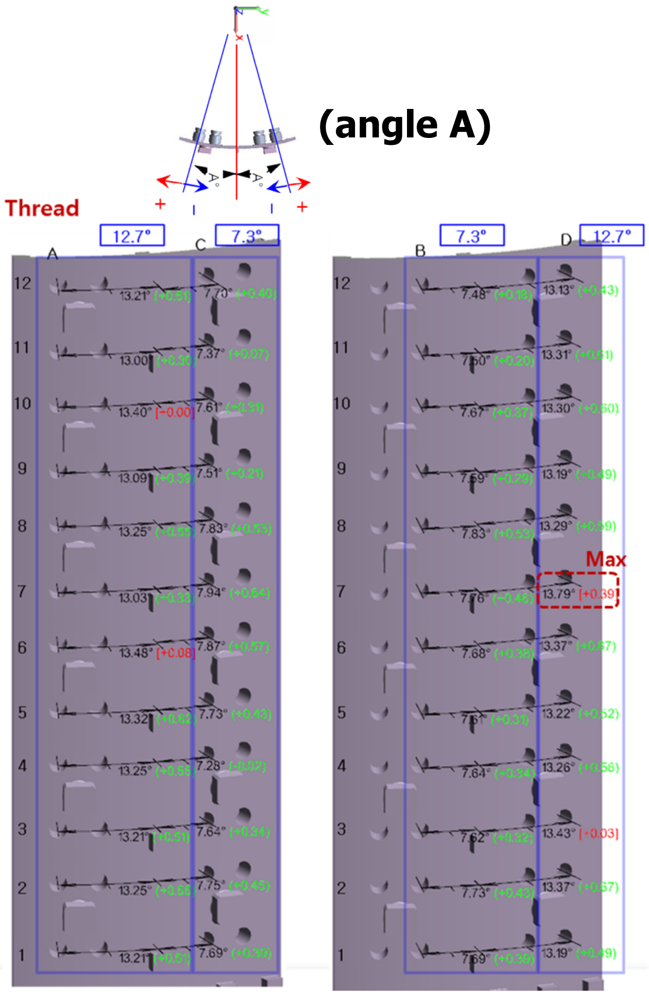
• Technical requirements - Tolerance



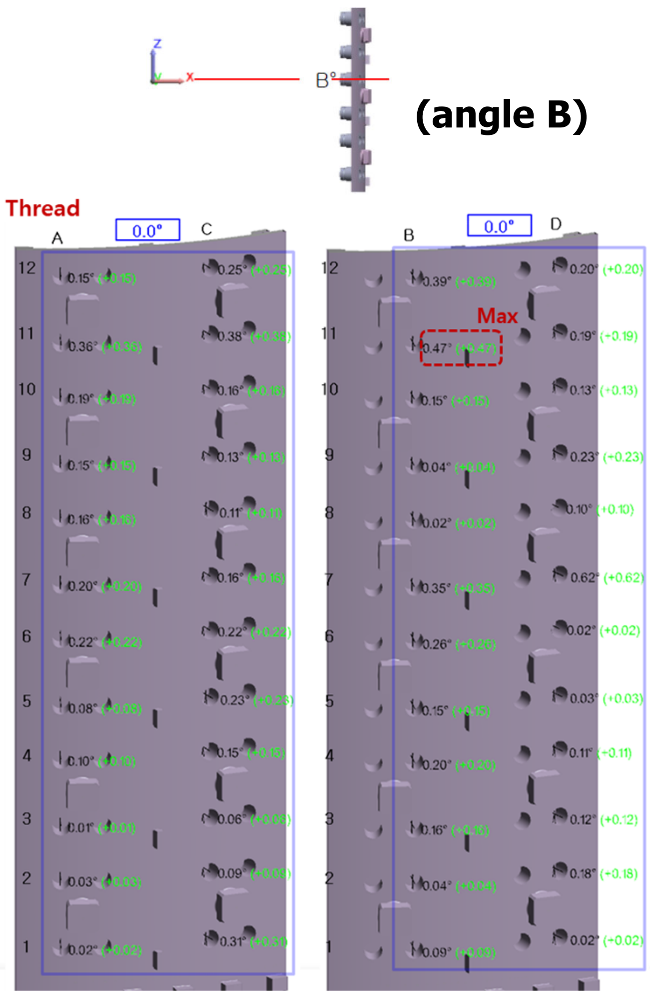
Required tolerance for FSH

- Angle of Thread Hole :
  - ✓ Max 0.7° (common)

Final results of S6 PS1 FSH Thread Hole Angle



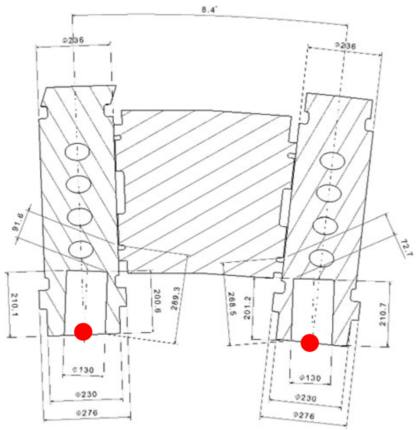
<A angle Max = Max: 1.09°(0.7°+0.39°)>



<B angle Max = Max: 0.47°>

Challenge-2: Tight Tolerance Requirement (6/8)

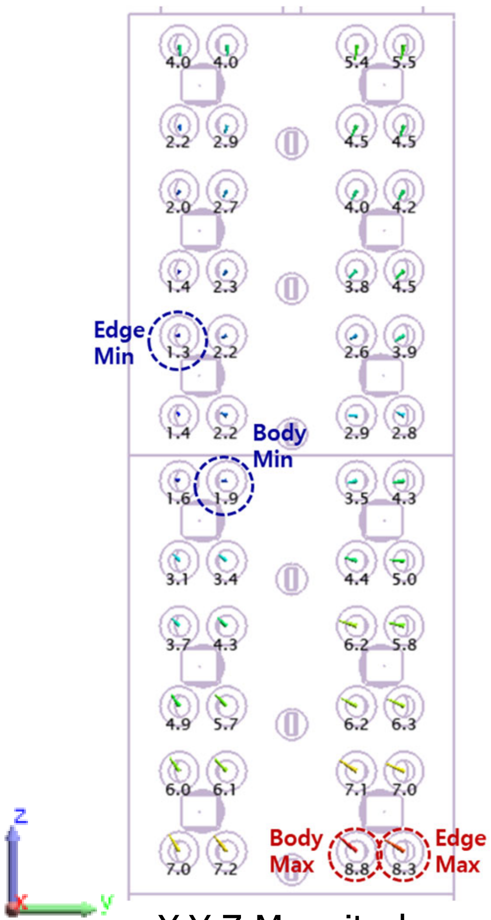
• Technical requirements - Tolerance



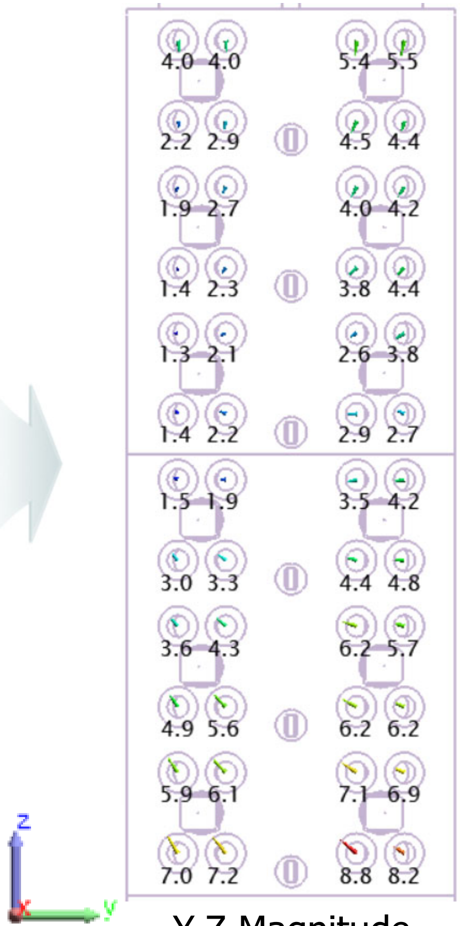
Required tolerance for FSH

- Location :
  - ✓ +/- 2mm (for edge)
  - ✓ +/- 4mm (for body)

Final results of S6 PS1 FSH Thread Hole Position



X-Y-Z Magnitude



Y-Z Magnitude
(Except radial effect)

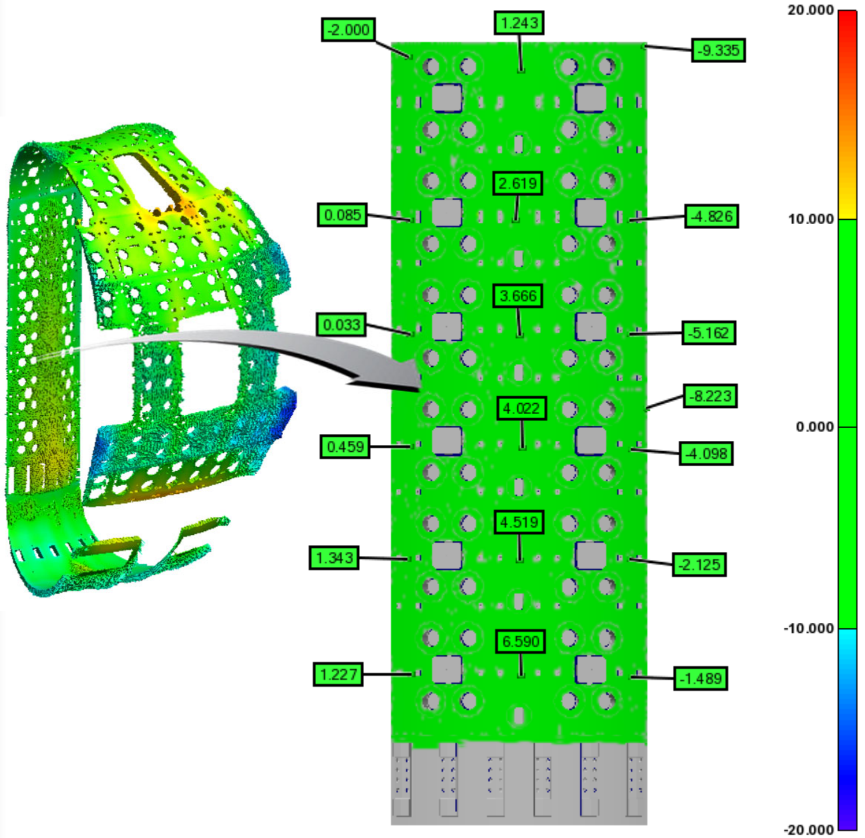
Challenge-2: Tight Tolerance Requirement (7/8)

• Technical requirements - Tolerance

Final results of S6 Inner & Outer Shell

<u>Required tolerance for Shells</u>

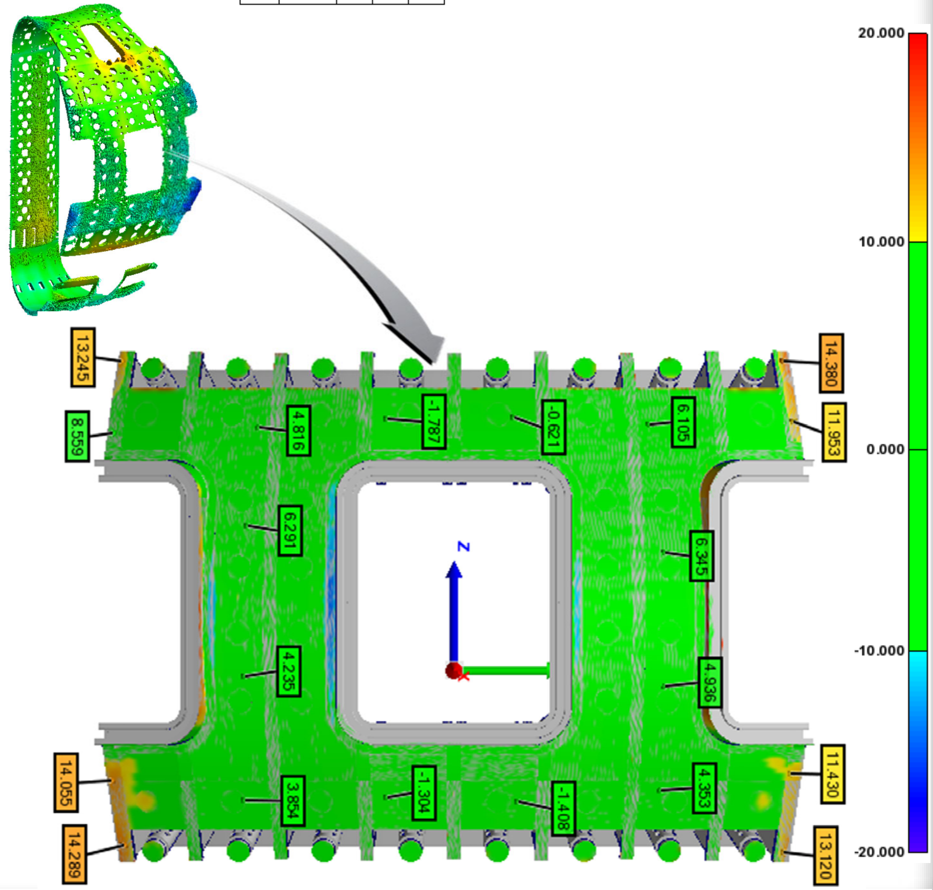
- Inner Shell: | ⌓ | 20.0 | A | B | C |



<Inner Shell of PS1 = Max: 6.59 mm, Min: -9.335 mm>

<u>Required tolerance for Shells</u>

- Outer Shell: | ⌓ | 3 0 | A | B | C |

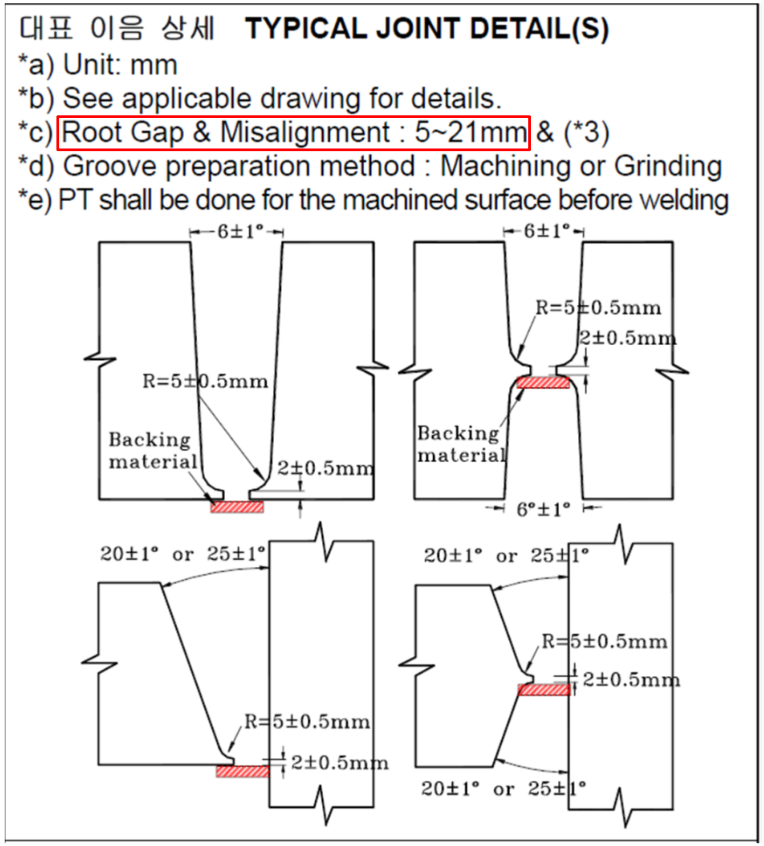


<Outer Shell of PS3 = Max: 14.38 mm, Min: -1.787 mm>

Challenge-2: Tight Tolerance Requirement (8/8)

• **Welding technology for wide root gap & misalignment**

PS4 setting for final assembly



Welding Procedure Specification for wide root gap & misalignment (Max. 21 mm)

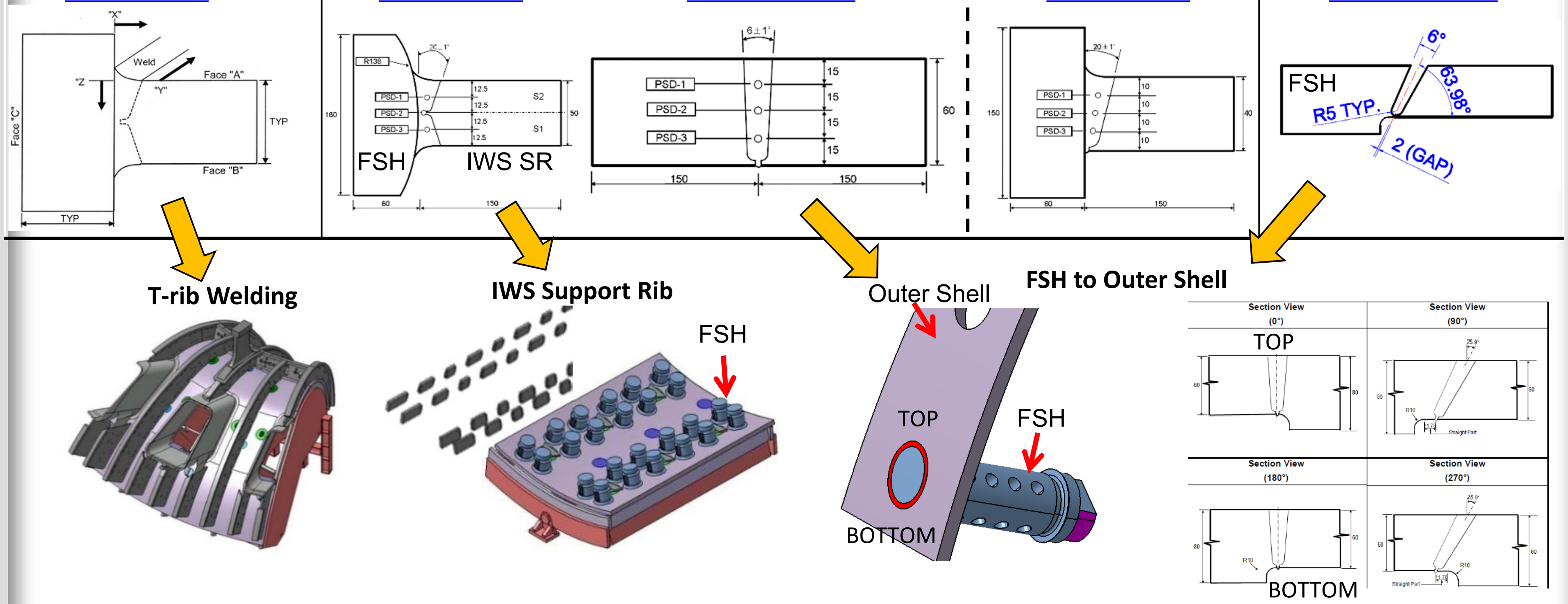
Technical Challenges

3. Full Inspection Requirement

Challenge-3: Full Inspection Requirement (1/5)

- **PAUT: Qualification for various VV weld configurations**

UT-Q Group 1	UT-Q Group 2			UT-Q Group 3
III.1 T Weld	III.1 T Weld	II.1 Butt Weld	III.2 T Weld	II.1 Butt Weld



- **15 times of UT qualifications were successfully completed (with 157 qualification blocks and 141 documents) under VVPT & ANB witness.**

Challenge-3: Full Inspection Requirement (2/5)

- **PAUT: modifications on the general configurations, mainly to difficult access, bring difficulties during the production.**
  1. Special cases (mainly poor accessibility for UT): Jigs/Fixtures for welding distortion, Surface curvature, Geometrical shape, Thread holes, Water cooling holes, Existing weld lines, etc
  2. Special cases leads to higher UT sensitivities and modified acceptance criteria
     → Applied compensation gain

➔ **To achieve 100% volumetric examination requirement, all special cases were technically verified and successfully qualified.**

Challenge-3: Full Inspection Requirement (3/5)

- **PAUT: Special case for various VV weld configurations**

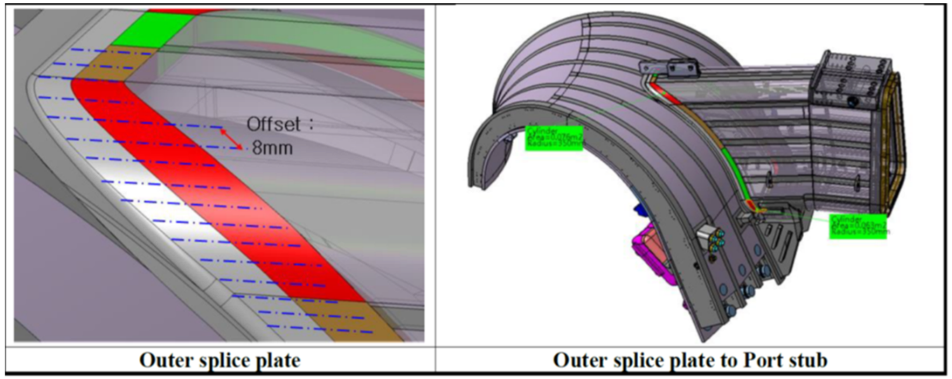


Figure 29. Isometric view of corner joint

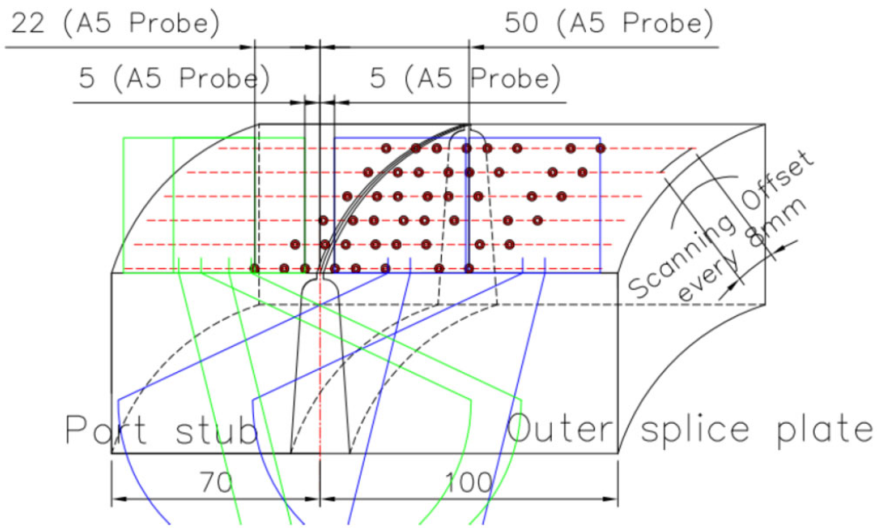
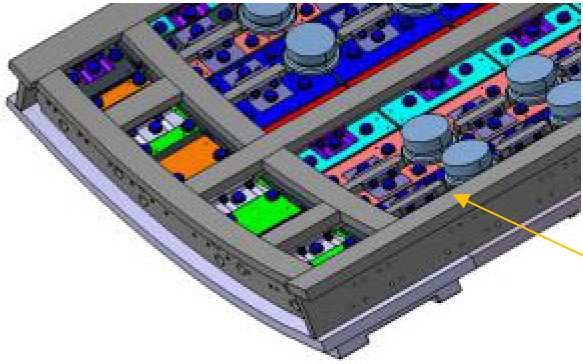


Figure 30. Example of line scanning.

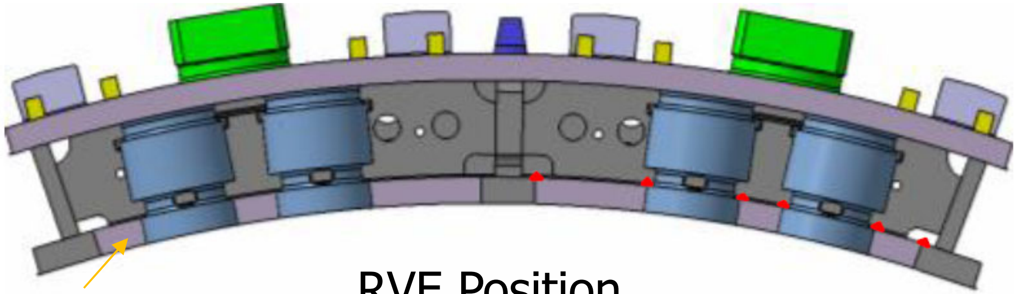
Challenge-3: Full Inspection Requirement (4/5)

- **Remote Visual Examination for weldments (100% Visual examination)**

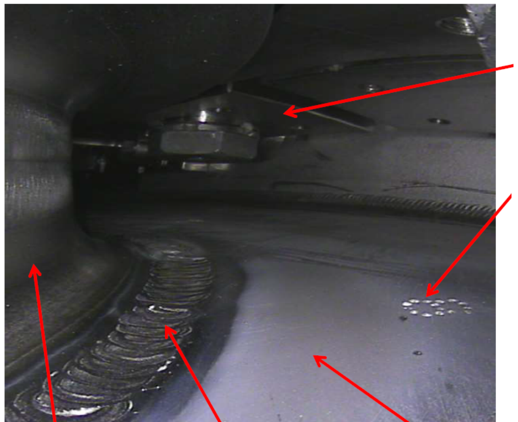


Welding Position

Outer Shell



RVE Position



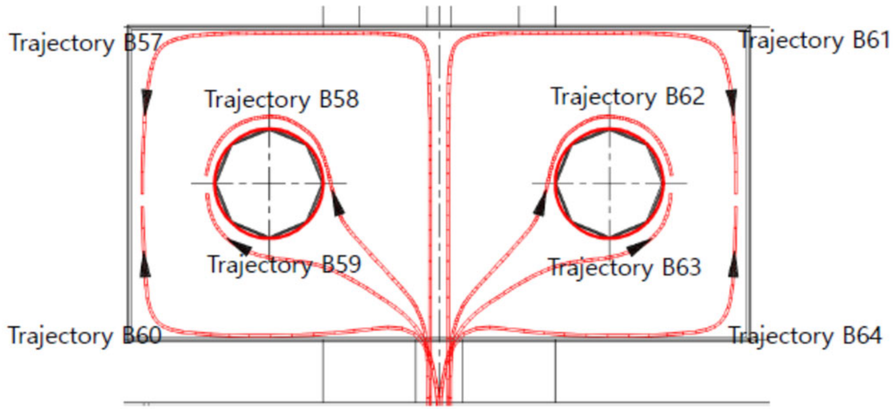
IWS

Marking No

FSH

Backside Bead

Outer Shell



Challenge-3: Full Inspection Requirement (5/5)

- **Remote Visual Examination for weldments (100% Visual examination)**
  1. RVE technology has been successfully qualified (resolution capability at least equal to that of direct visual examination).
  2. Nuclear requirement (100% VT on backside welds) was satisfied using RVE technology.

Weld Reinforcement Width

Weld Reinforcement Height

Technical Challenges

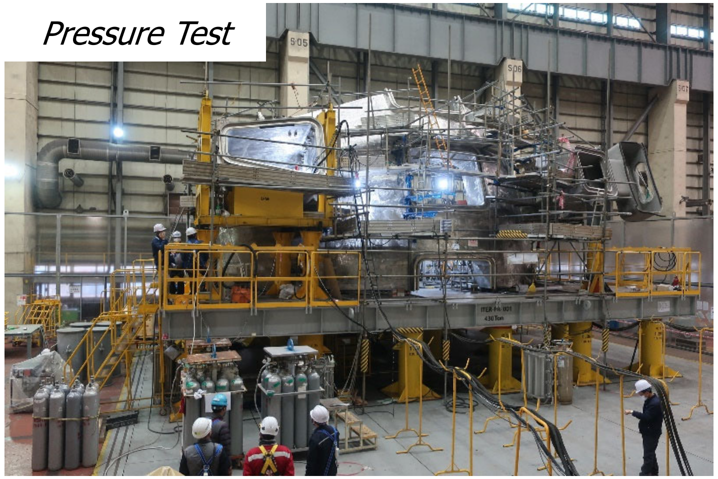
Others

Other Challenges (1/3)

• Factory Acceptance Test

Pre-pumping

Pressure Test



Pre-pumping → **Pressure Test** → **He Leak Test** → **Final DI**

Pre-pumping

Pre-pumping done before Pressure Test

Pressure Test

- **Reduced(0.5MPa) pneumatic pressure test done**
- Exemption of deformation check during pressure test of the sector by DR-IO-007-2019

Replaced

Flow test on sectors replaced by visual test to detect blockages by DR-IO-001-2019

Removal

<u>**Removal of baking on sector before the leak test at factory** by DR-IO-018-2019</u>

He Leak Test

- **Background of the leak test relaxed (10^{-9} → 10^{-7} Pam³/s)** according to DR-IO-011-2019
- The leak rate acceptance criteria remains as 1×10^{-8} Pa·m³/s

Final DI

- All location of the FPs measured
- Point measurement & Surface scanning carried out

Other Challenges (2/3)

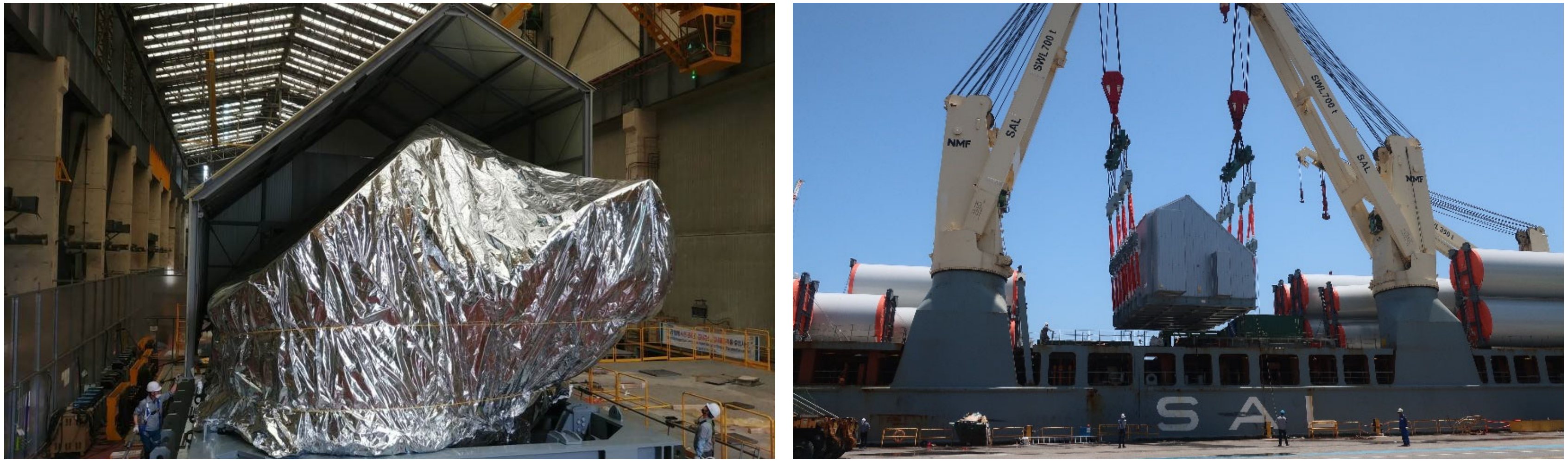
- **Factory Acceptance Test**
  - ✓ He Leak Test was passed successfully
    - The calculated leak rate : 6.08×10^{-9} $Pa \cdot m^3 \cdot s^{-1}$

      (The acceptance criteria : 1×10^{-8} $Pa \cdot m^3 \cdot s^{-1}$)

He Leak Test of the ITER VV sector #6

Other Challenges (3/3)

- **Transportation**
  - ✓ **ITER VV transportation is considered as PIA** according to French Regulation
    - Transportation Plan, Quality Plan and MIP have to be approved by ANB in advance
    - Following documents also have to be approved before shipping
      - 1) Packing Procedure, 2) Packing List, 3) Technical Information, 4) Invoice
      - 5) Packing Control Record, 6) Certificate of Compliance, 7) Deliverable Documentation,
      - 8) Delivery Report, 9) Shipping Requirement, 10) Release Note, 11) EMR
      - 12) Equipment storage & preservation requirement by IO TRO
      - 13) Hazard analysis & specification for transportation/storage by IO TRO

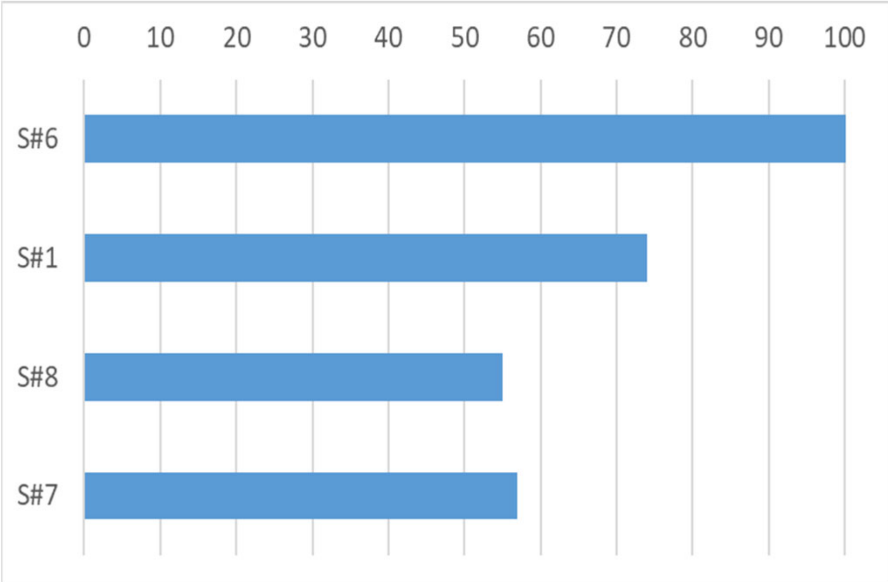


ITER VV sector #6 Hermitical Covering and Transportation

LESSONS LEARNED

LESSONS LEARNED (1/2)

- **Expected significant manufacturing schedule reduction for the remaining KO sectors by,**
  1. Use developed manufacturing documents and techniques for 1st sector
  2. Improved document management system and the updated quality control to prevent similar non-conformities
  3. Several technical improvements such as additional splice T-rib between PS1 & PS4 for the final assembly, the improved weld joint design for PAUT feasibility, the improved jig system and welding sequence



Expected manufacturing duration for KO 4 sectors [months]

LESSONS LEARNED (2/2)

- **Significance of the regulation and code for vacuum vessel manufacturing,**
  1. It is clearly recognized that the importance of the regulation and code for manufacturing of the ITER VV sector.
  2. The appropriate regulation and code need to be developed for VV of a future fusion power plant which well balanced between economic and safety point of view.
  3. In order to achieve this goal, the simplified vacuum vessel design also has to be developed in parallel.

Thank you for attention!