Progress in the Design and Manufacture of High Vacuum Components for ITER

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FIP/1-6Ra

Manufacturing Design and Progress of the First Sector for ITER Vacuum Vessel

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FIP/1-6Rb

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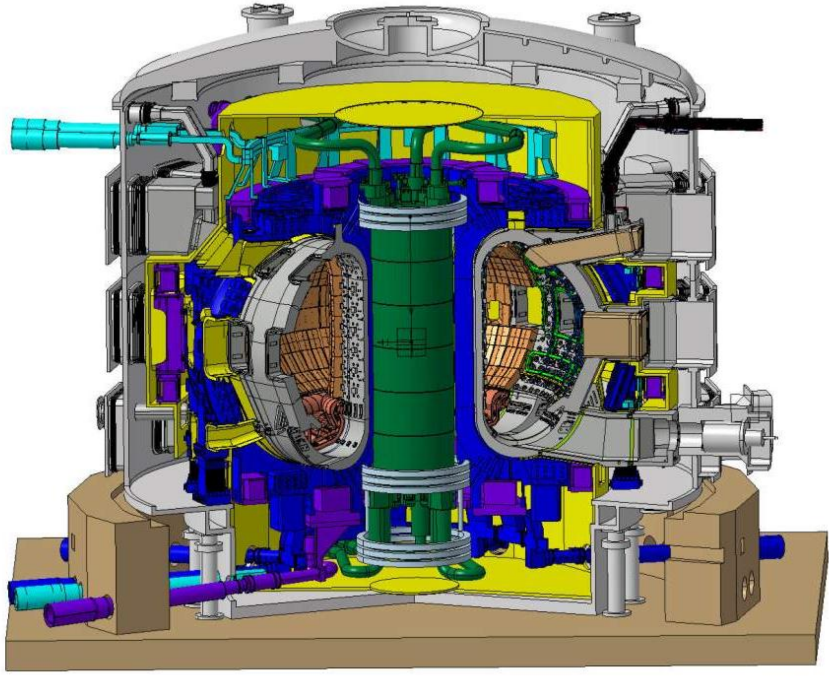
Outline

- **Introduction**

- **Vacuum Vessel**
  - Status of Design and Manufacture
  - Five Procurement Arrangements
  - EU DA Seven Sectors
  - KO DA Two Sectors and Eq./Low. Ports
  - RF DA Upper Ports
  - IN DA IWS
  - First Vacuum Vessel Sector

- **Cryostat**
  - Status of Design and Challenges
  - Status of Procurement
  - Cryostat Manufacturing
  - Prototype Activities
  - Cryostat Workshop

- **Summary**



Introduction

- The ITER Vacuum Vessel (VV) and Cryostat will provide the necessary high-vacuum for plasma operation (VV) and allow for cooldown of the superconducting magnets to cryogenic temperature (Cryostat).

- The design of the two systems has been developed by the ITER Organization (IO). The detailed design of some specific components still needs to be completed.

- Procurement Arrangements (PAs) with four Domestic Agencies (DAs) have been signed to develop the manufacturing design and manufacture the components of these systems.

- Manufacturing contracts have been placed in 2010-2012 followed by many preparation and qualification activities. Production of the full-scale VV sectors and cryostat sections has started with the procurement of base materials and manufacture of mock-ups or full-scale components.

Vacuum Vessel

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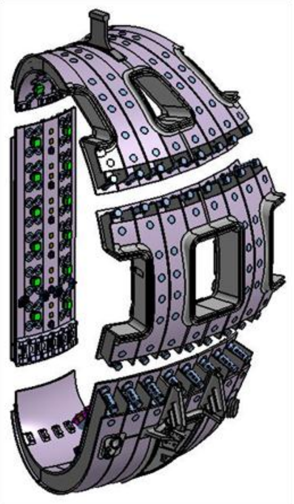
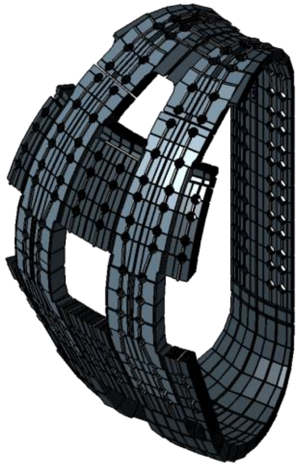
ITER Vacuum Vessel

A torus shaped, water cooled, double wall structure

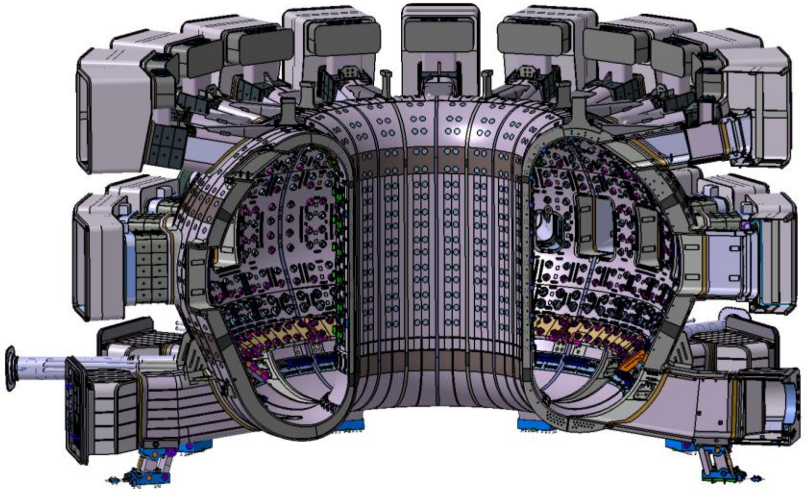
- To provide high vacuum for plasma (~10^{-5}-10^{-6} Pa)
- To improve radiation shielding and plasma stability
- ***To provide primary confinement of radioactivity through the water cooled structure under pressure (ESPN/RCC-MR)***
- To support in-vessel components (blanket, divertor, etc)



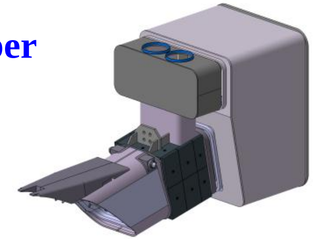
Main VV 9 x 40 deg. Sector composed of 4 segments



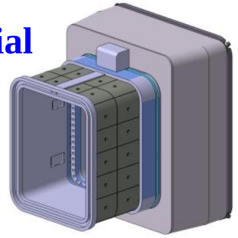
In-Wall Shielding



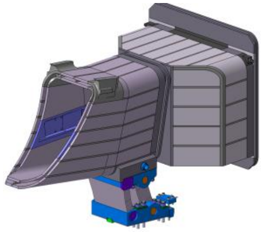
Upper



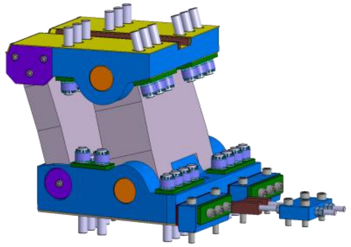
Equatorial



Lower



Ports



VV supports (Dual hinge type)

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

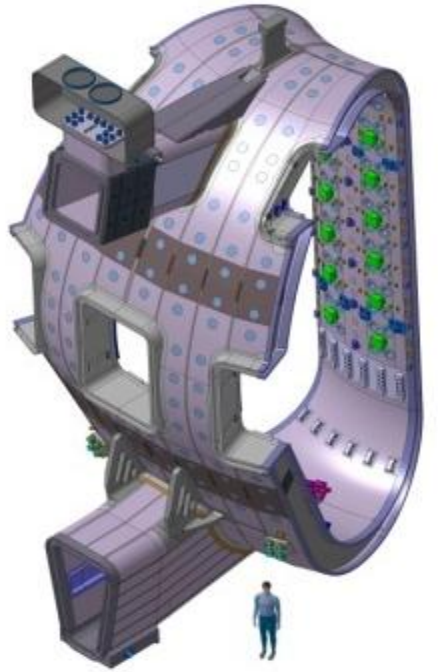
Status of Vacuum Vessel Design and Manufacture

Status: VV baseline design has been completed by IO for all sectors except for a few details, like NBI ports, port flange seals, etc. Manufacturing designs complete for first EU and KO sectors.

Manufacturing Started:

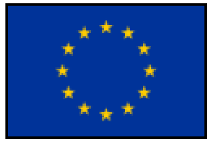
- Manufacturing (plate cutting, forming and welding) started for first KO Sector in February 2012.
- First EU Sector started in March 2014.
- Full-scale production of IWS shielding plates and ribs started.

VV Sector Delivery: The first Sector should be delivered to the ITER Site in 2017; VV assembly is under a direct contract by ITER Organization with ENSA.

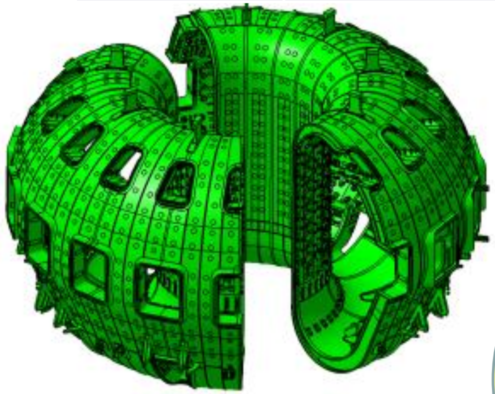


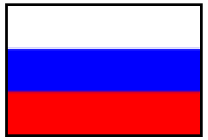
Component	Procurement Party	Supplier
Main Vessel	EU (7 Sectors) Korea (2 Sectors)	AMW (Ansaldo Nucleare, Mangiarotti, Walter Tosto) HHI (Hyundai Heavy Industries)
Ports	Russia (Upper Ports) Korea (Lower and Equatorial Ports)	Efremov Institute / MAN T&D AG Hyundai Heavy Industries
In-Wall Shielding	India	Avasarala Technologies Ltd.

Five Procurement Arrangements (PAs)

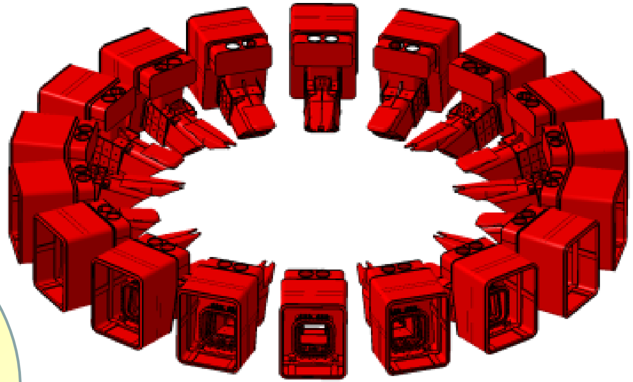


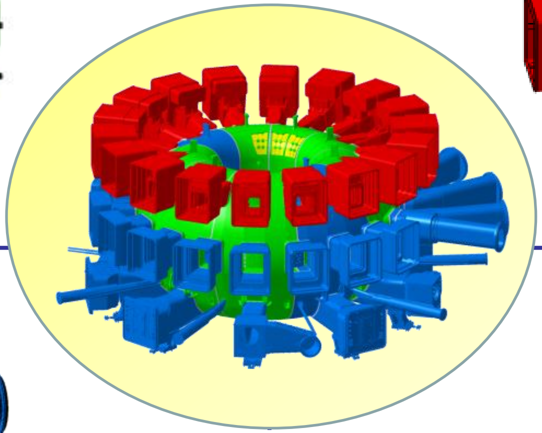
EU	Description
Items	7 Sectors of Main Vessel
Contractor	Ansaldo Mangiarotti Walter Tosto



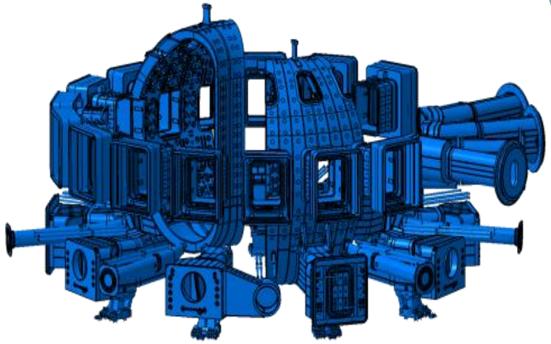


RF	Description
Items	18 Upper Ports
Contractor	MAN Diesel & Turbo





Total 234.28 kIUA
8% of total In-kind
(kIUA= ITER Unit of Account,
1 kIUA ~ 1.6 M€)



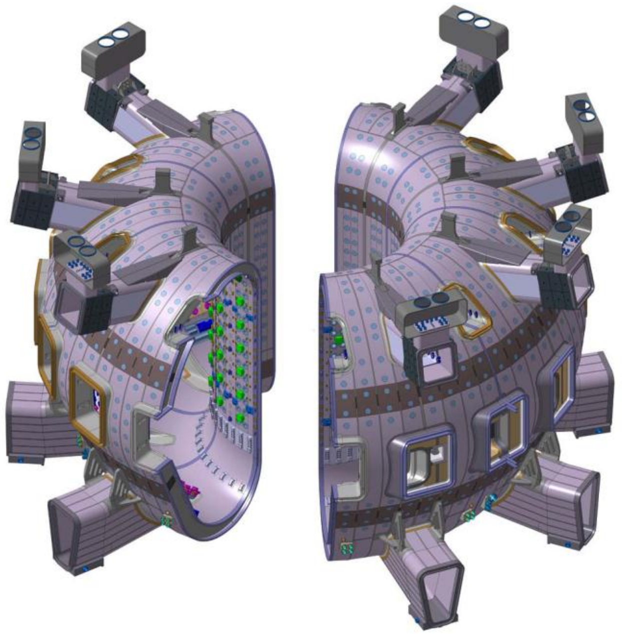
KO	Description
Items	2 Sectors of Main Vessel 17 Eq. & 9 Lower Ports
Contractor	Hyundai Heavy Industry

IN	Description
Items	In-Wall Shielding
Contractor	Avasarala Technologies Ltd.

Vacuum Vessel - 7 Sectors (EUDA)

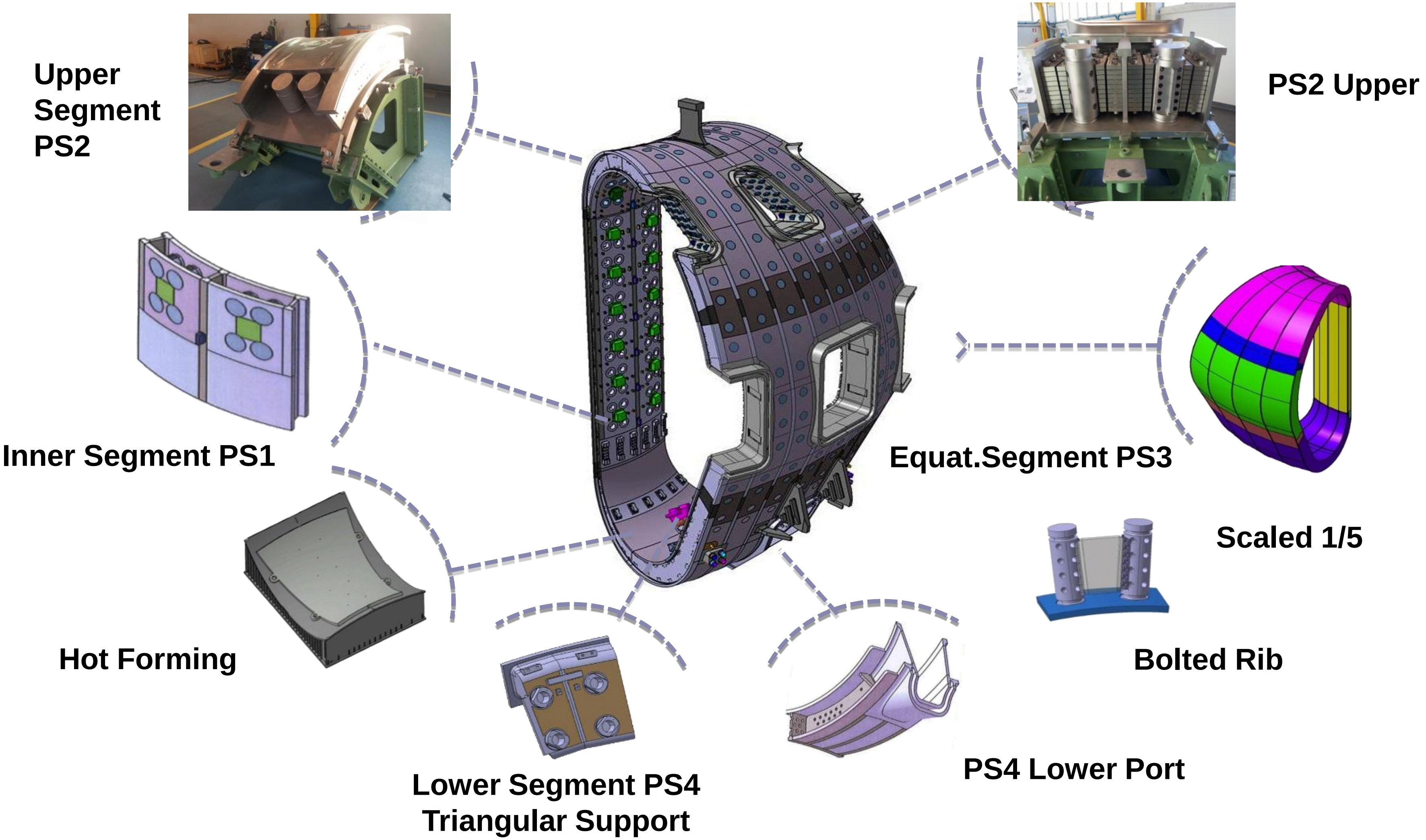
Overall Status of EU VV Sectors

- Manufacturing design completed for Sector#5 in 2013
- Manufacturing started for Sector#5 Inboard Segment
- Mock-up activities almost completed
- Procurement of base materials (plates+forgings) on-going
- Welding qualification (TIG + EB) on-going
- Justification of manufacturing strategy and detailed tolerance allocation on-going



Vacuum Vessel - 7 Sectors (EUDA)

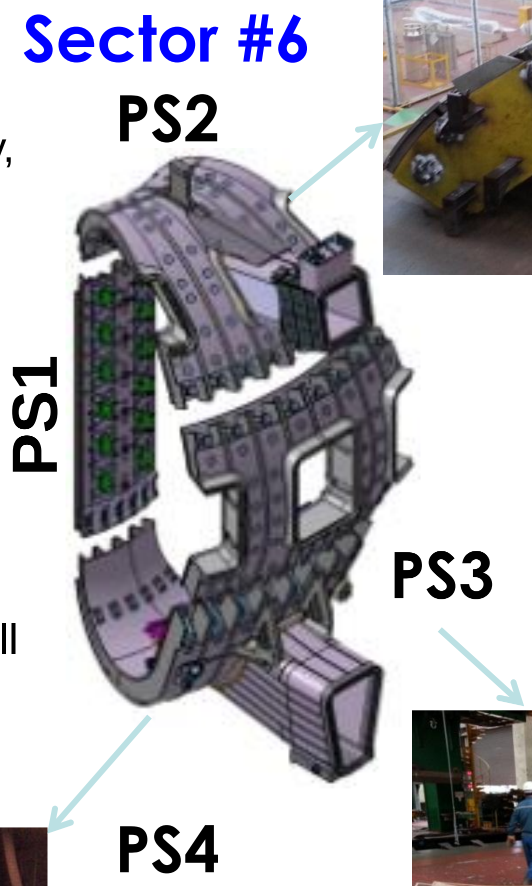
Main mock-ups almost completed, to validate manufacturing route



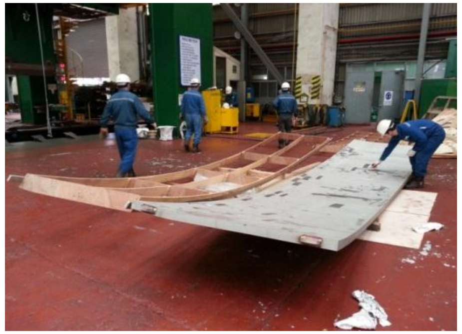
Vacuum Vessel – 2 Sectors (KODA)

Manufacturing status

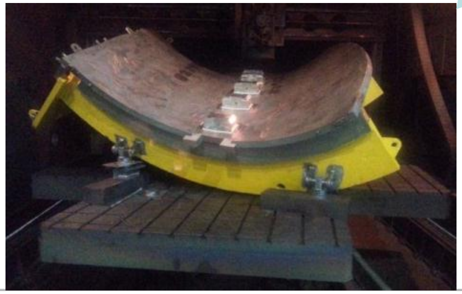
- **Sector #6 all segments fabrication** is in progress:
  - PS4: for inner shell to divertor rail stop body, weld (EBW) & NDE were completed.
  - PS2: NDE has been performed for the weld joints of 14 keys - no defects were found in the joints.
  - PS3: inner shell welding is in preparation after cutting, forming and machining of welding groove.
  - PS1: plate cutting and forming for inner shell were completed.
- **Sector #1: fabrication** is in preparation



8 keys welding



Triangular support back plate



Vacuum Vessel – 2 Sectors & Ports (KODA)

Fabrication of Upper Segment (PS2)

Welding of Centering Keys and Inter-Modular Keys

Port Stub

R&D for IVC & Blanket Manifold Rail Support

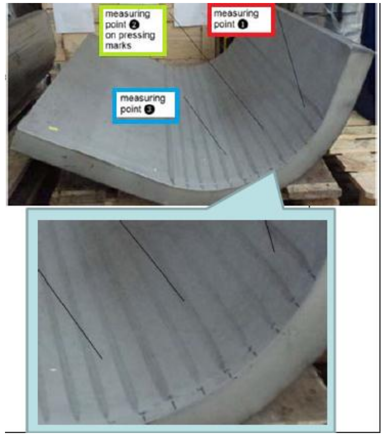
Vacuum Vessel – 18 Upper Ports (RF DA)

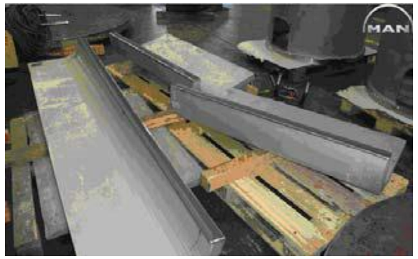
Manufacturing Design

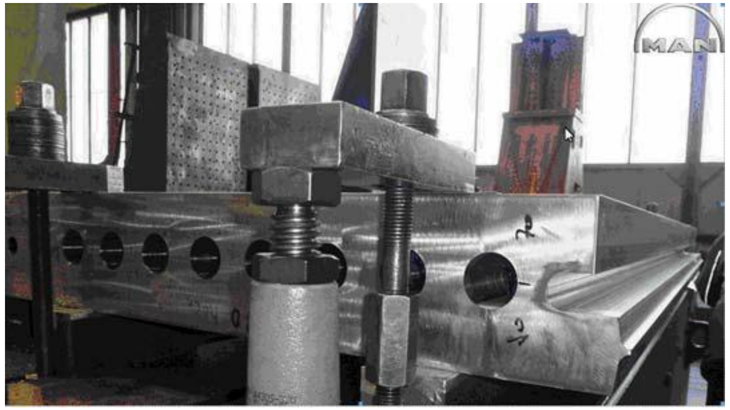
- Manufacture has started in May 2014 after approval of the manufacturing design

Manufacturing Trials

- Forming/machining trials are in progress







Preparation for Manufacture

- Contract on forming for the whole scope of the PSE double–wall part was concluded
- NG-TIG welding machines have been purchased and delivered
- Specific welding equipment for the PSE bulkhead welding was purchased

Vacuum Vessel – In-Wall Shielding (IN DA)

Manufacturing of block and supporting rib

Final machining of plate

Final machined plates

Dimensional Inspection

Welding qualification

Status

- Manufacturing design well advanced
- Full scale production of first sectors started
- About 1,700 ton of base material already procured

First Sector of Vacuum Vessel

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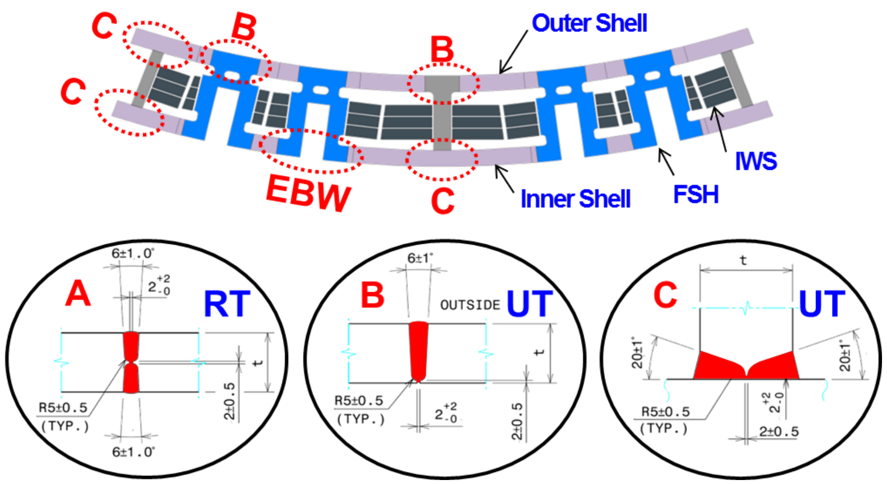
Peculiar Manufacturing Design of KO Sectors

- **Welding Design**

✓ Narrow gap gas tungsten arc welding (GTAW) and electron beam welding (EBW) are main welding process.

✓ T-shape adapter between outer shell and rib satisfies the code requirements such as the full penetration weld and the minimum distance between the welds due to lots weld components and complexity of assembly.

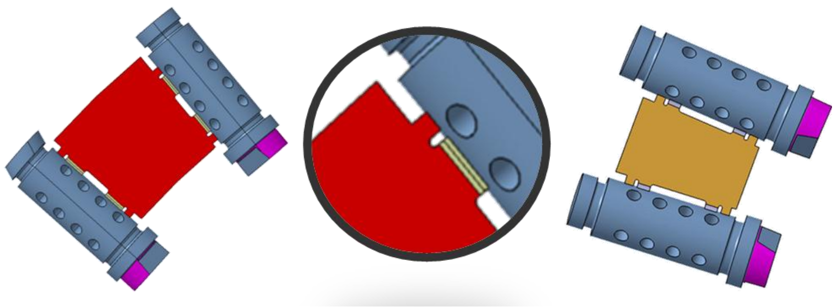


Welding Joint Details for Inboard Segment

- **Self-sustaining Welded IWS Support Rib**

✓ To minimize welding deformation of FSHs which have very tight tolerance, a self-sustaining weld concept is applied to IWS support ribs.

✓ The self-sustaining welded rib has discrete welded parts and just contact parts on FSHs. The contact zone takes a role as a stopper to restrain the welding contraction.

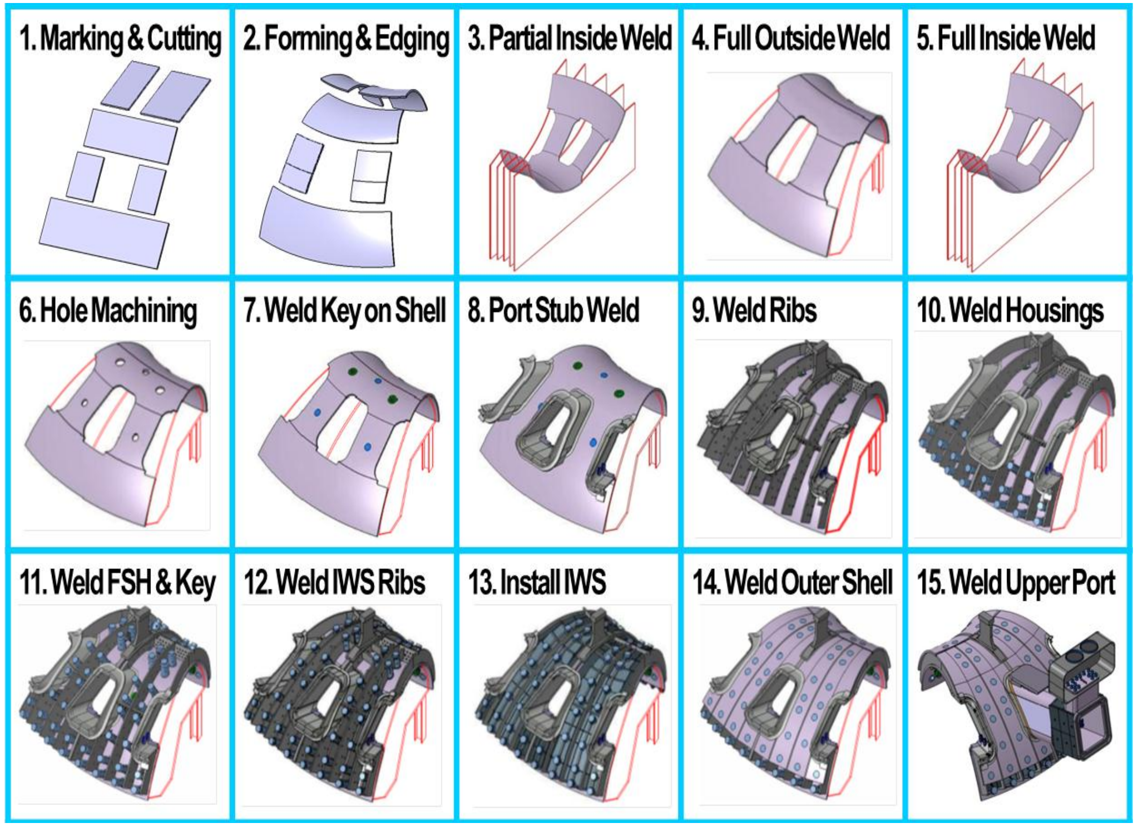


Self-sustaining Welded IWS Support Rib

Fabrication Sequence of a Segment

- Each segment is to be made according to the following Sequence

1. *Cutting and forming of inner and outer shell*
2. *Welding of inner shells*
3. *Welding of ribs to the inner shell*
4. *Machining FSH holes and welding FSH to the inner shell*
5. *Machining port hole and welding port stub*
6. *Welding support ribs for IWS*
7. *Assembly of IWS*
8. *Welding the outer shells*
9. *Final machining of a segment*



Fabrication Sequence of Upper Segment (PS2) for the First VV Sector

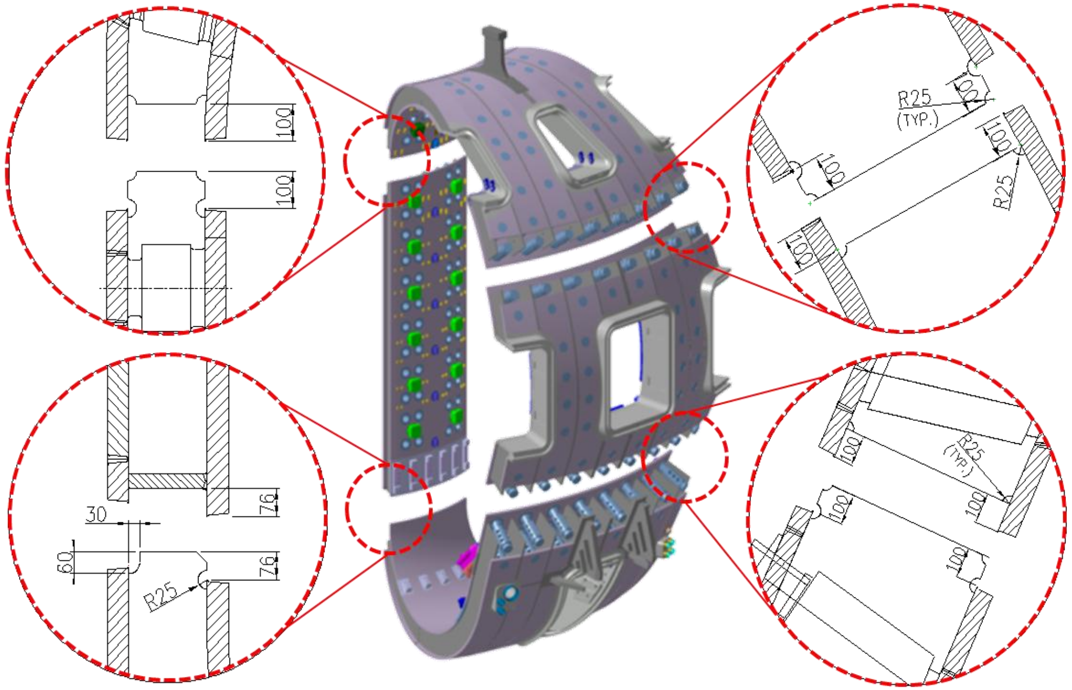
Segment Joint Design for Segment Assembly

- **Cup-and-Cone Type Segment Joints**

✓ For minimizing the welding deformation during final joint of segments, HHI has been developed the design of segment joints without poloidal rib splices to reduce the butt welding work.

✓ Prior to machining on final welding of segment, 3-D measurement of each segment should be conducted to collect their locations and adjust machining quantities.

✓ The margin will be machined to provide proper welding condition. Scallops are needed in the cross welding lines and can provide the space to take RT.

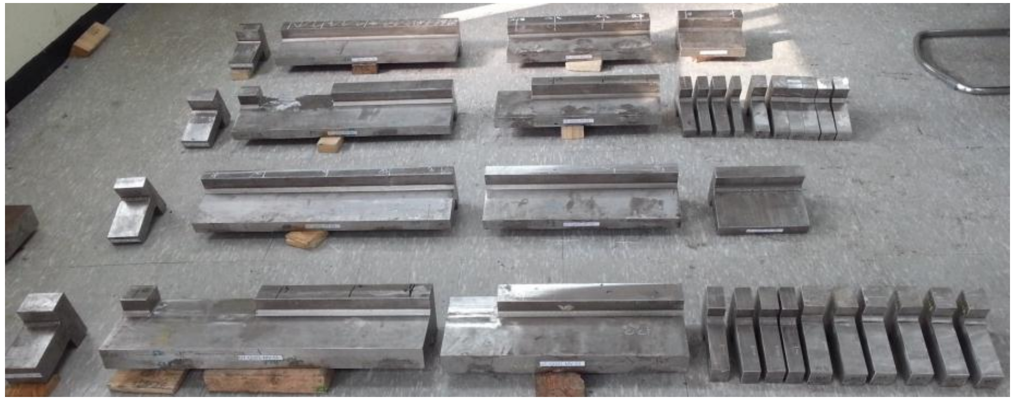


Cup-and-Cone Type Joints for Final Segment Assembly

Qualification for Ultrasonic Test

- **UT Qualification for T-rib Welding**

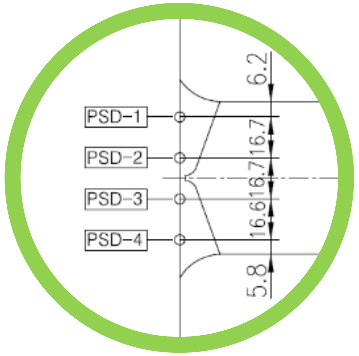
✓ UT for T-rib Welding is qualified by 48 test blocks included artificial defects.



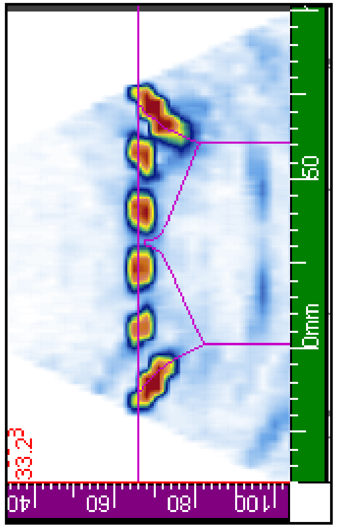
Omni Scan MX (Olympus)

Phased Array Probe

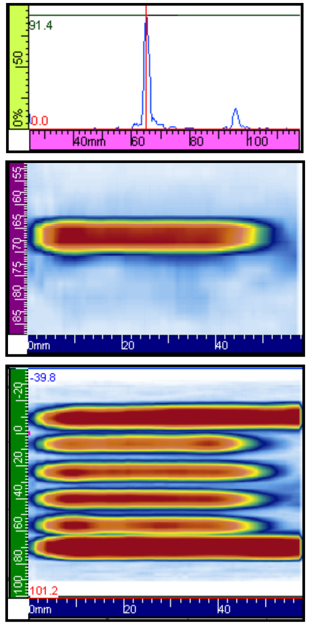
Macrostructure



Parallel Side Drilled Holes



Sectional Scan



A, B & C-Scan

Manufacturing Progress on the First VV Sector

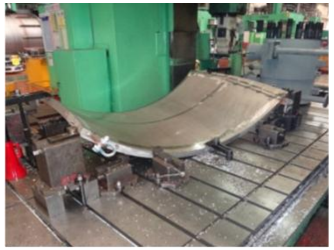
- **Fabrication Process of Upper Segment (PS2) for the First Sector**

✓ The fabrication of the first sector (VV sector #6) was started in early 2012 from cutting stainless steel plates for PS2 inner shell at first. The PS2 inner shell consists of 3-D shaped plates which were produced by 10,000 ton press using cold forming method without post heat treatment.

✓ The jigs were mounted on the inner shell and to minimize the weld distortions. After assembly welding of the inner shell, machining for key holes has been performed based on the measurement results. Inter-modular and central keys were welded on the inner shell by GTAW. NDE works are conducted for inner shell welds and no defect was detected.

✓ Currently, upper central port stub and poloidal T-ribs shall be assembled to this inner shell, so that the port stub and T-ribs are fabricating also in parallel.

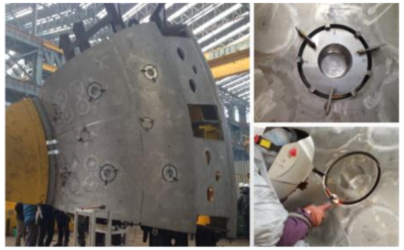
3D forming



Machining for Welding

Fit-up on Heavy Jigs

Completed Inner Shell



Fit-up & Welding for Keys

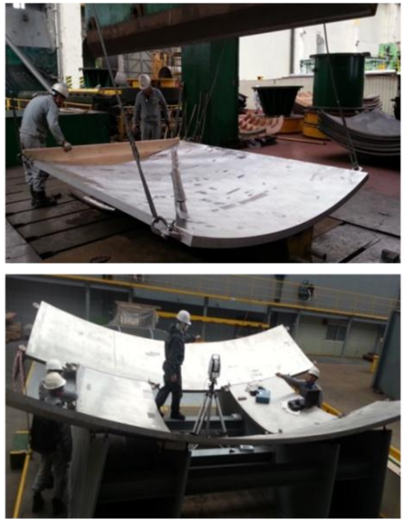
Manufacturing Progress on the First VV Sector

• Manufacturing Progress of All Segments for the First Sector

✓ All segments for Sector #6 are being fabricated behind the ITER project schedule as a nuclear component under strict regulations.

Upper Segment (PS2) & Poloidal ribs

Lower Segment (PS4) & Triangular Support



Inboard Segment (PS1) & Equatorial Segment (PS3)

Machined Components (Port Stub & FSHs)

- **After a long preparation time since a contract with HHI, fabrication was started with limited scope-wised approval. The first sector has been progressing slowly in front of the ITER project schedule as a nuclear component under strict regulations. Nevertheless, the fabrication was started for all segments of the sector and fabrication speed can improve after solving current issues.**

Cryostat

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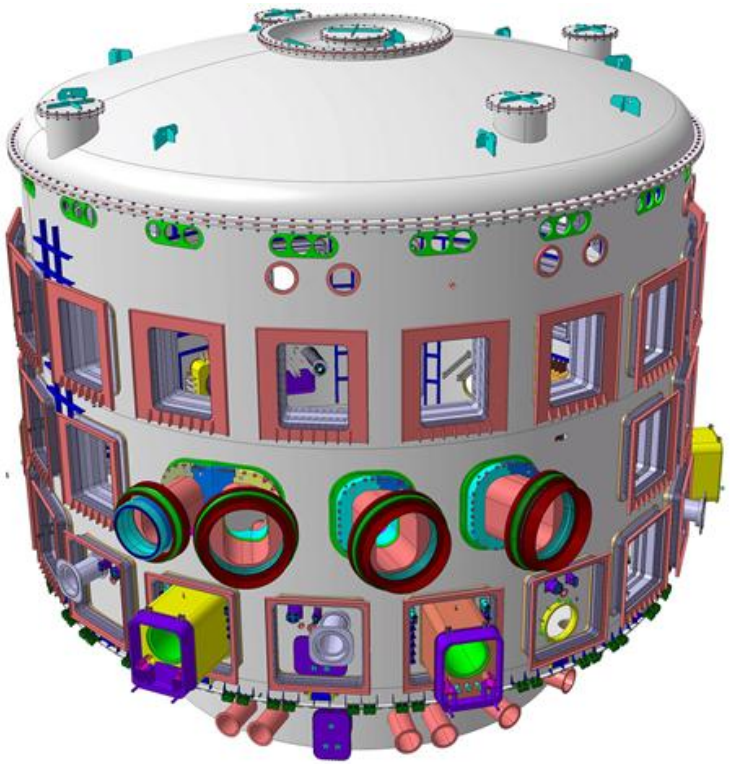
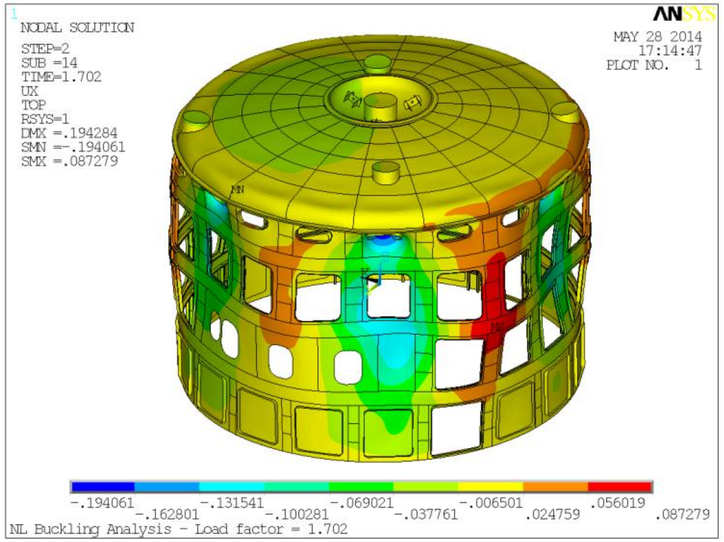
Cryostat Overall Design Parameters



- Cryostat is a large volume vacuum vessel with an internal base pressure of 1×10^{-4} Pa.
- It supports the magnet systems and Vacuum Vessel and withstands all the loading conditions transferred to the pit floor.
- Lower crown support with sliding bearings.
- Designed according to ASME VIII Div.2.

Cryostat Outside Diameter (max)	28.54 m
Cryostat Height	29.25 m
Wall Thickness	40 mm-180 mm
Number of Sections	4
Main cylinder Shell Thickness	50 & 60 mm
Structure & Material of Construction	Single wall with reinforced rib (Dual mark 304L/304)
Toroidal Resistance	>10 μΩ
Design base Pressure	1×10^{-4} Pa
Required Leak Rate of completed Cryostat (including inside components)	$\leq 1 \times 10^{-4}$ Pam^{-3}/s
- Cryostat Surface Area	~3400 m^2
- Interior Free Volume	~8500 m^3
- Interior Total Volume	~16000 m^3
Mass *(Approximate)*	
- Top lid Main	656 ton
- Upper cylinder	600 ton
- Lower Cylinder (+ TCPH-214 t)	809 ton (1023 ton)
- Base Section	1250 ton
- Total mass	~3500 ton

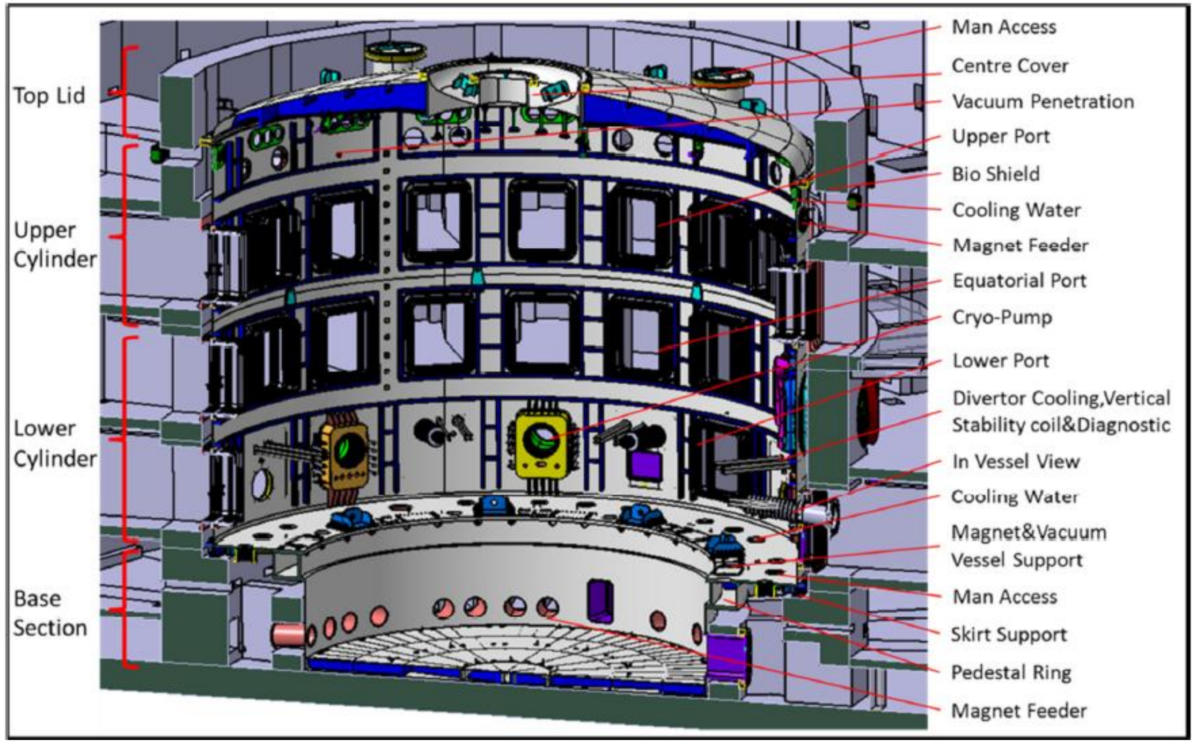
Cryostat Design Challenges



Cryostat buckling analysis under vacuum loading

- Complex loading conditions: vacuum, gravity seismic, electro-magnetic, thermal events in case of water or He leaks
- Extensive structural analyses: plastic collapse, local failure, collapse from buckling, and collapse from cyclic loading (fatigue).

Very large number of (complex) interfaces



Cryostat Manufacturing

- The major challenges involved in Cryostat manufacturing design are stringent tolerances, few hundreds of penetrations, high vacuum compatible few kilometers welding of large wall thicknesses, access limitation for welding and non-destructive examination, in-situ leak detection of each factory and field weld joint and interfaces with large number of tokamak systems.
- Cryostat manufacturing contract (factory fabrication, ITER site fabrication and Tokamak pit assembly, welding and testing) has been awarded to Larsen & Toubro Limited, on **17 August 2012**.
- Cryostat material is being procured from **Industeel (plates), Jindal & L&TSHF (forgings)**
- 1st Stage MRR for base pedestal and lower cylinder carried out in April 2013.
- Site workshop completed by Spie Batignolles in **September 2014**.

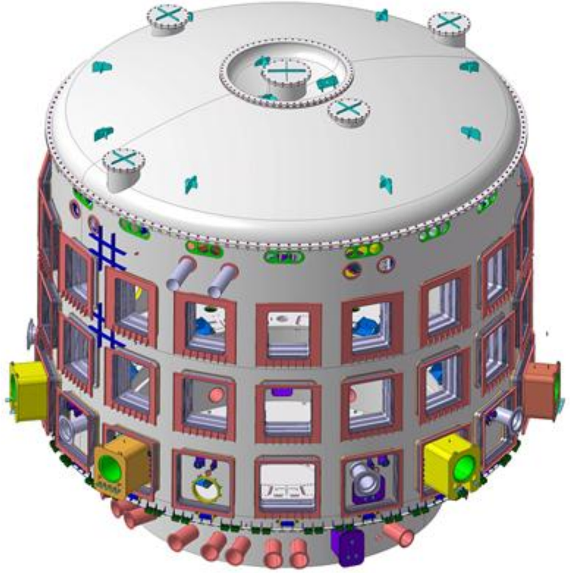
Stages of Cryostat Manufacturing & Final Acceptance

Cryostat Engineering / Manufacturing

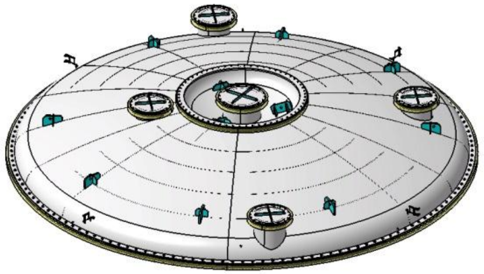
Cryostat Base Section | Cryostat Lower Cylinder | Cryostat Upper Cylinder | Cryostat Top Lid

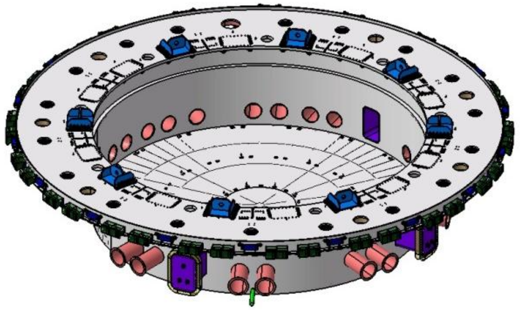
Manufacturing Study → Material Procurement → Industry Site Manufacturing → IO Site Manufacturing → Assembly in the Tokamak Pit → Final Acceptance

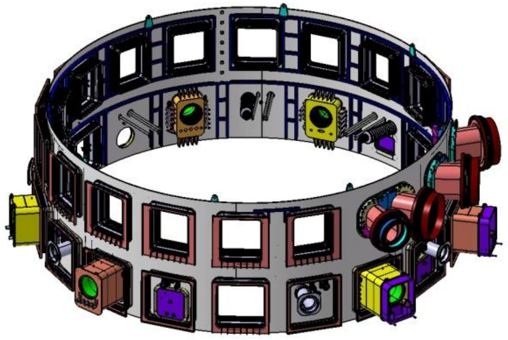
Global Acceptance Test

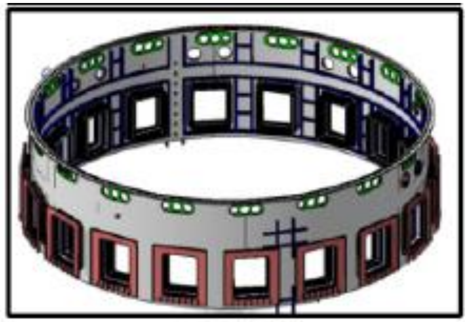


- Segment fabrication in the factory
- Segmentation to follow the transportation site restriction
- Site fabrication in ITER Site WORKSHOP
- Assembly in Tokamak pit









Prototype (40^0) of the Cryostat Base Section



Cryostat pedestal ring - top plate 200 mm and skirt plate 105 mm thick welded together


Cryostat pedestal ring bottom plate & base pedestal sandwich structure

Cryostat Site Workshop

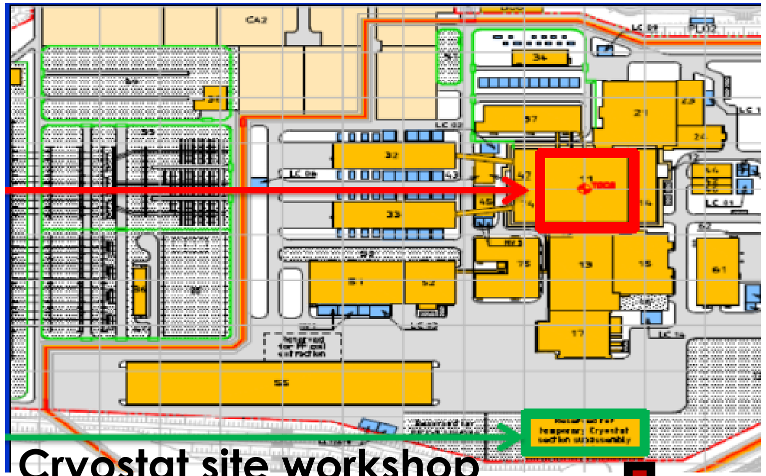
June 6, 2013

Coconut Breaking Ceremony

marking the beginning of the Cryostat Site Workshop Construction

Tokamak hall

300 m



Cryostat site workshop

110m x 50m x 27m Height - 200 Ton crane

Cryostat Workshop completed in Sept. 2014

Summary

Disclaimer: The views and opinions expressed herein do not necessarily reflect those of the ITER Organization

Summary

- The first two sectors of the ITER Vacuum Vessel and the Cryostat lower parts are now in the manufacturing phase after completion and approval of the manufacturing design.

- EU DA and the AMW consortium have completed the manufacturing documents of sector#5 and started manufacture.

- KO DA and HHI have started manufacturing of sector#6 and all LPSEs.

- IN DA and ATL have started the full-scale fabrication of the IWS rib and blocks for the first two VV sectors.
- RF DA and MDT are also almost ready to start manufacturing of the upper ports.

- The manufacture of the Cryostat base pedestal and lower cylinder has started and it is foreseen that assembly of these first two sections will be started in the on-site manufacturing facility in 2016.

Thank you for your attention

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