Convergence of Design and Fabrication Methods for ITER Vacuum Vessel and In-vessel Components

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for the ITER International Team and Participant Teams

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Topics to be covered

ITER Vacuum Vessel and FW/Blanket

- Selection of Design Solutions
- Required Tolerances and Design/Fabrication Methods

Selection of Design Solutions

Vacuum Vessel

(a) Nine VV sectors each spanning 40° (see *FIG 1)*

(b) Nine lower ports

(as shown in *FIG 1 - 3*)

(c) Independent cooling configuration in the VV field joint regions (see *FIG 1*)

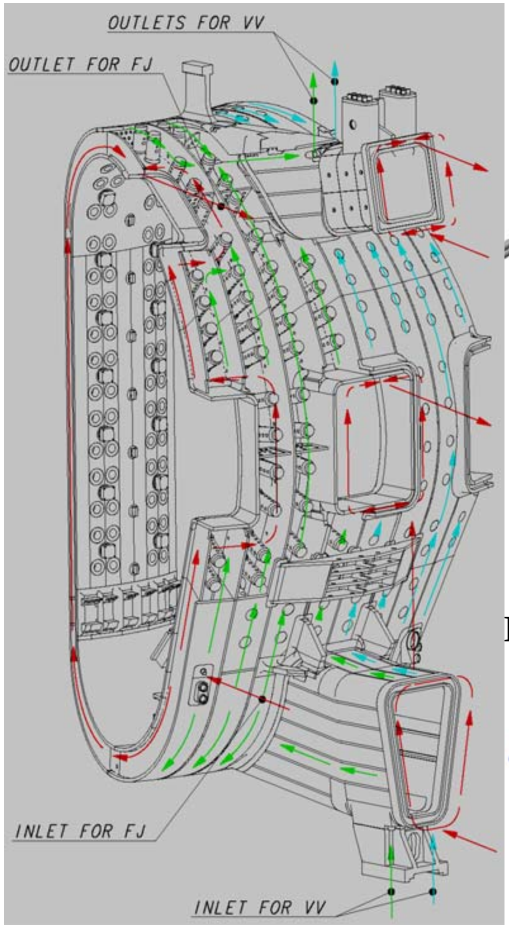


FIG. 1 ITER 2004 Vacuum Vessel

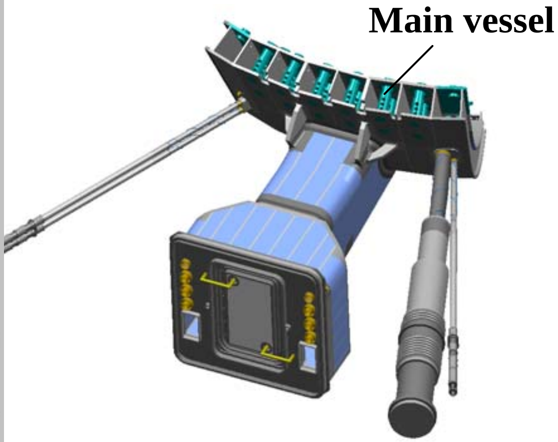


FIG. 2 Lower port and penetrations

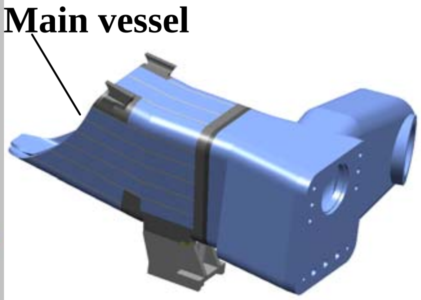


FIG. 3 Cryopump port (Two cryopumps)

Selection of Design Solutions

Vacuum Vessel

(d) **Single-wall port structure at the upper and equatorial levels (see *FIG 4*)**

(e) **Vacuum vessel gravity support located below lower ports (see *FIG 5*)**

(f) **3D formed shells in the upper and lower inboard regions (*FIG 6*)**

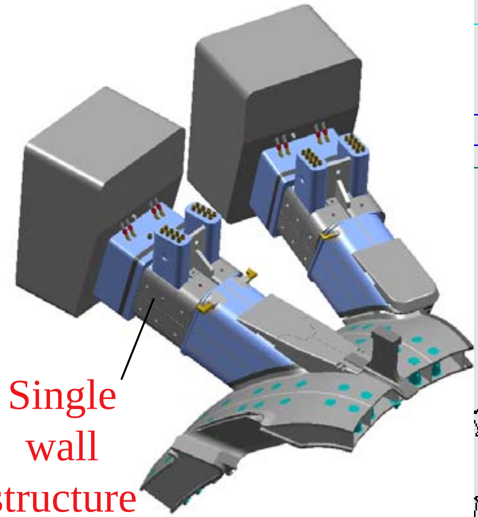


FIG. 4 Upper port structure

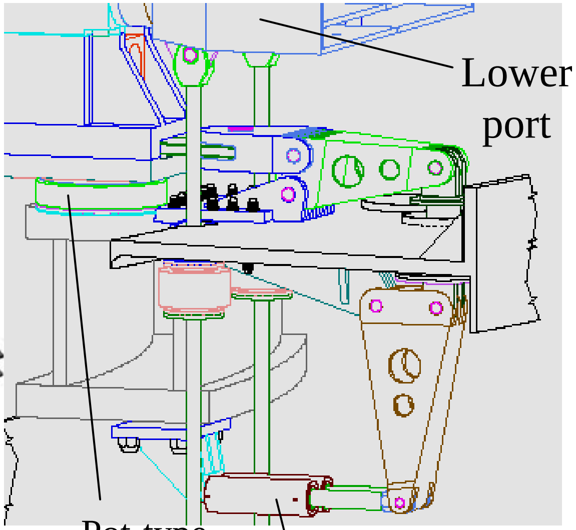


FIG. 5 Radial/vertical support

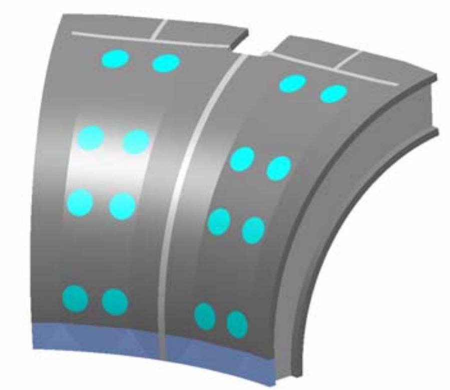
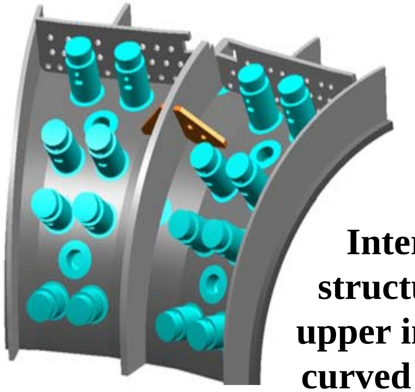


FIG. 6 Upper inboard region of the VV sector



Internal structure of upper inboard curved region

Selection of Design Solutions

FW/Blanket

(a) Central support leg (CSL) for first wall panel: race-track shape cross section (see *FIG. 6* and *7*)

(b) Plasma-facing surface to avoid the leading edge problem (see *FIG. 8*)

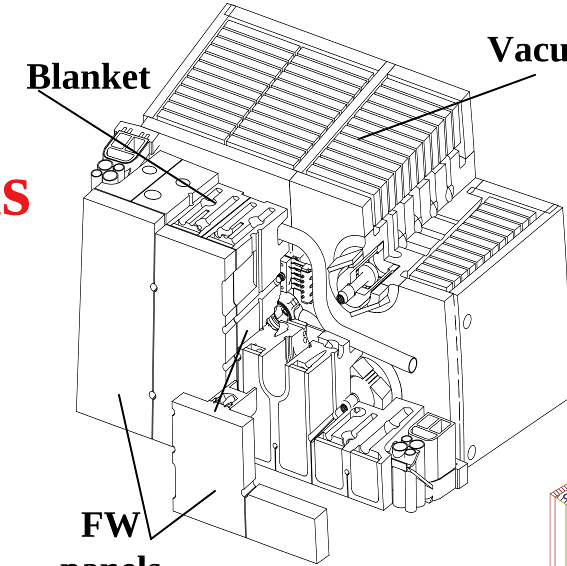


FIG. 6 Outboard module

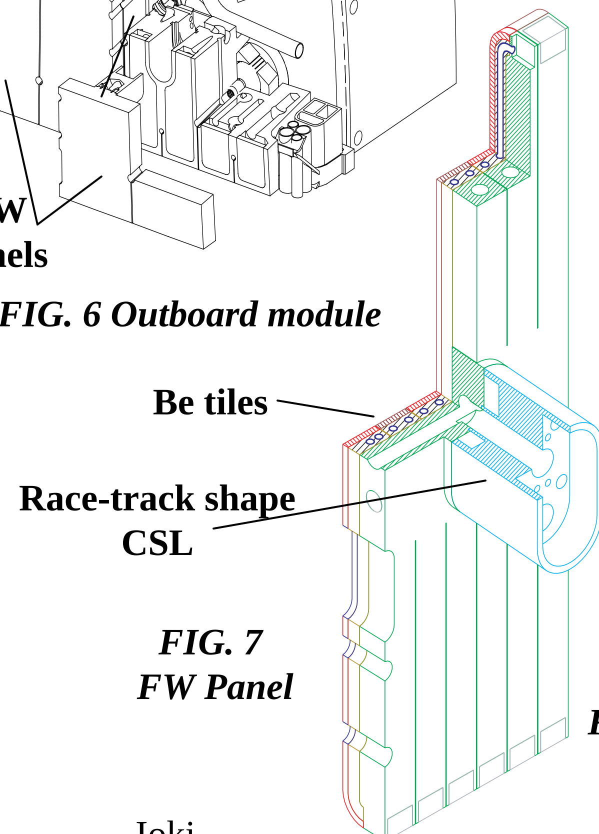


FIG. 7 FW Panel

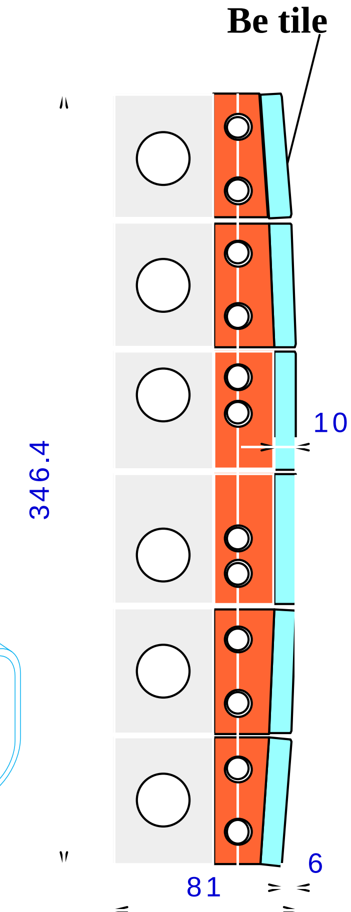


FIG 8 Inboard FW panel (Toroidal cross section)

Selection of Design Solutions

FW/Blanket

(c) Shield block design to reduce the EM loads

(d) New coolant flow configuration in the shield block (lower pressure drop)

(e) New segmentation of blanket modules in the NB region

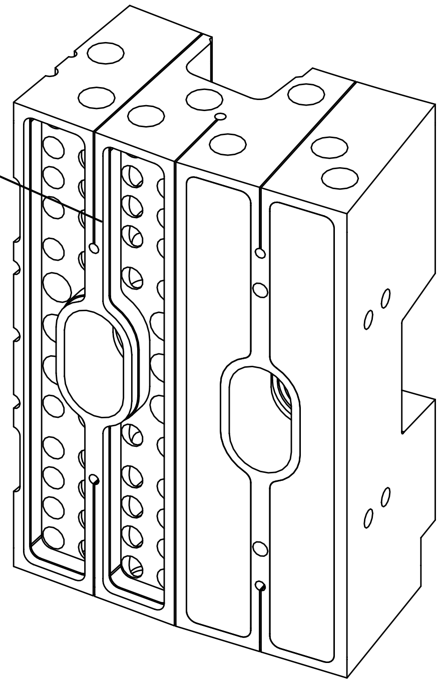
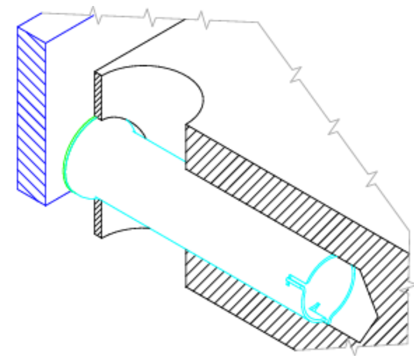
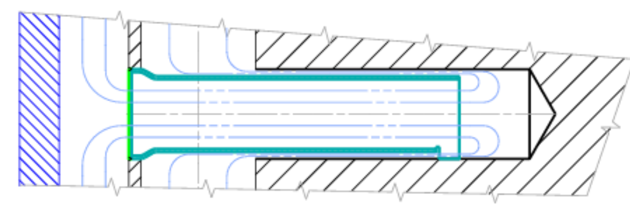


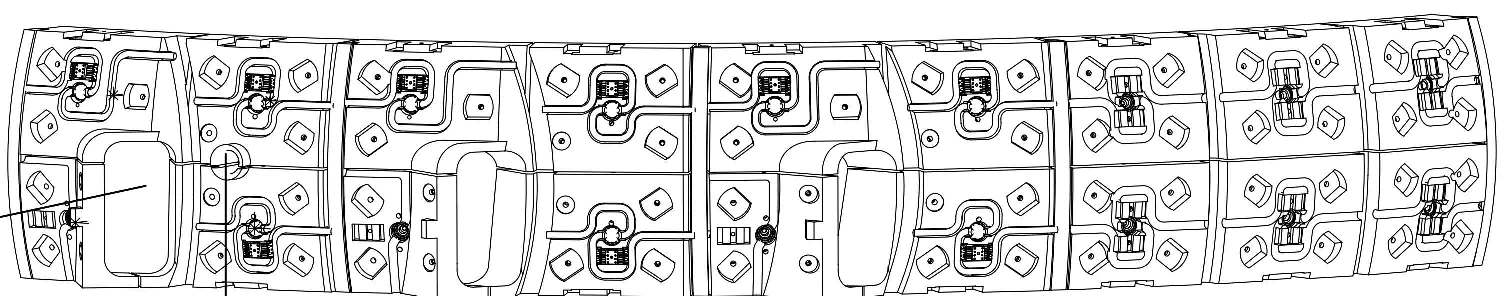
Fig 9 Shield Block



Vertical manifold (60mm)



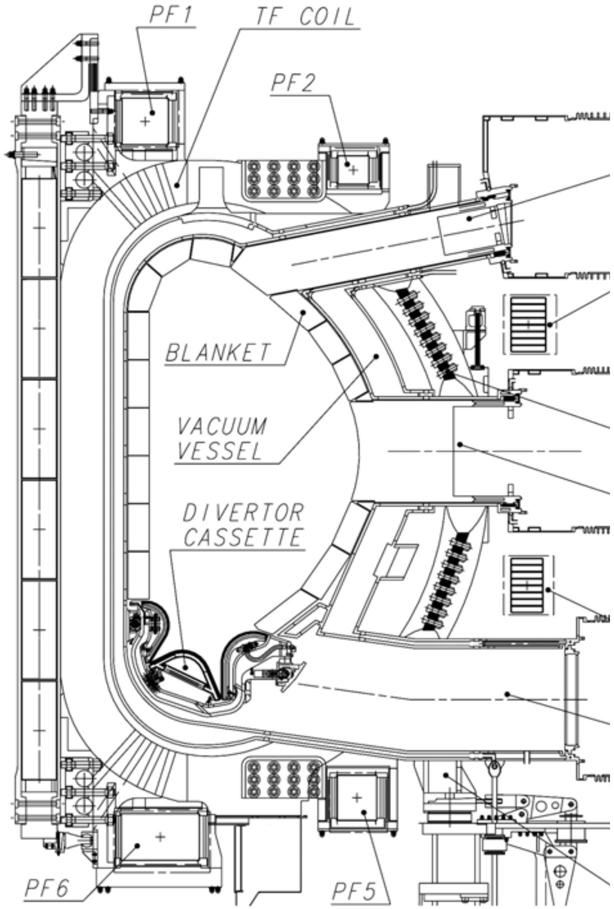
Crosssection of radial cooling channel (45mm) and insertion tube(parameter)



Why the VV tolerances are to be minimized?

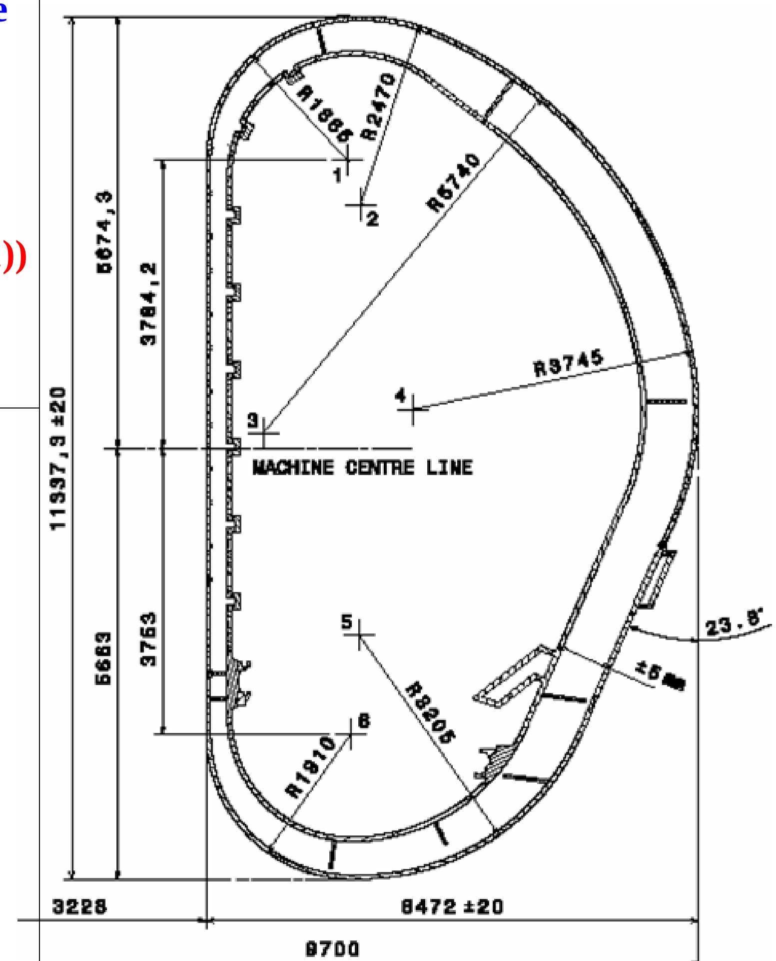
- To achieve the tolerances required for the FW position (the FW/blanket modules are fixed onto the VV)
- To minimize the required gap between the VV and the VVTS (thermal shield) /TF coil
- To minimize the error field due to the ferromagnetic inserts and eddy currents induced in the VV

(The circularity/cyclic symmetry is important)



Required fabrication tolerances for the VV sector

Fabrication tolerance of VV sector at factory	**Unit**	**Value**
- Sector overall height	mm	± 20
- Sector overall width	mm	± 20
- Surface deviations of a 40-degree sector from the reference geometry (both for the plasma- and cryostat-facing surfaces)	mm	± 10 (= *(1))
- Sector wall thickness (distance from inner to outer surface)	mm	± 5
Details		
*(1)Surface tolerances of a 40-degree sector from the reference geometry after fabrication at factory	mm	± 10
*(2)Vessel weld distortion due to field/shop welds at the site	mm	± 5
*(3)Torus positioning versus ideal location with all support fixtures removed	mm	± 3
*(4)Sector wall thickness (distance inner-outer - shell)	mm	± 5
*(5)Mismatch of the sector surfaces at field joints	mm	± 5



How to achieve the required dimensional accuracy?

- To utilize accurate and rigid fixtures

- Accurate 3-D forming (by pressing etc.)

- Application of advanced welding technology (e.g. EB welding at some locations)

- More accurate prediction of welding distortion and shrinkage :Full scale mock-up fabrication and analytical methods

- Step-by-step dimension control in the fabrication procedure

- Final machining at the final stage

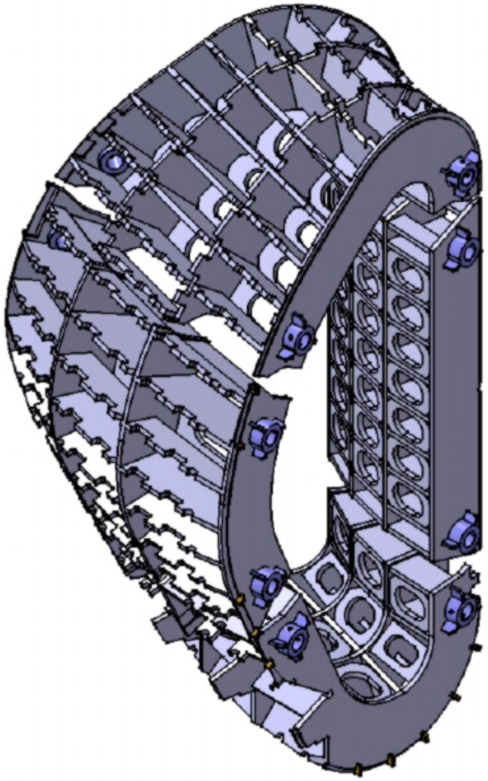
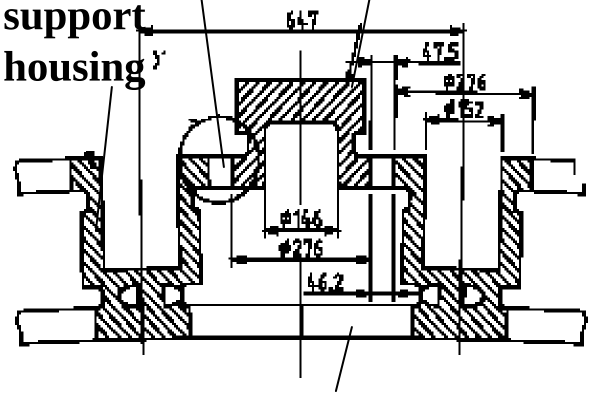


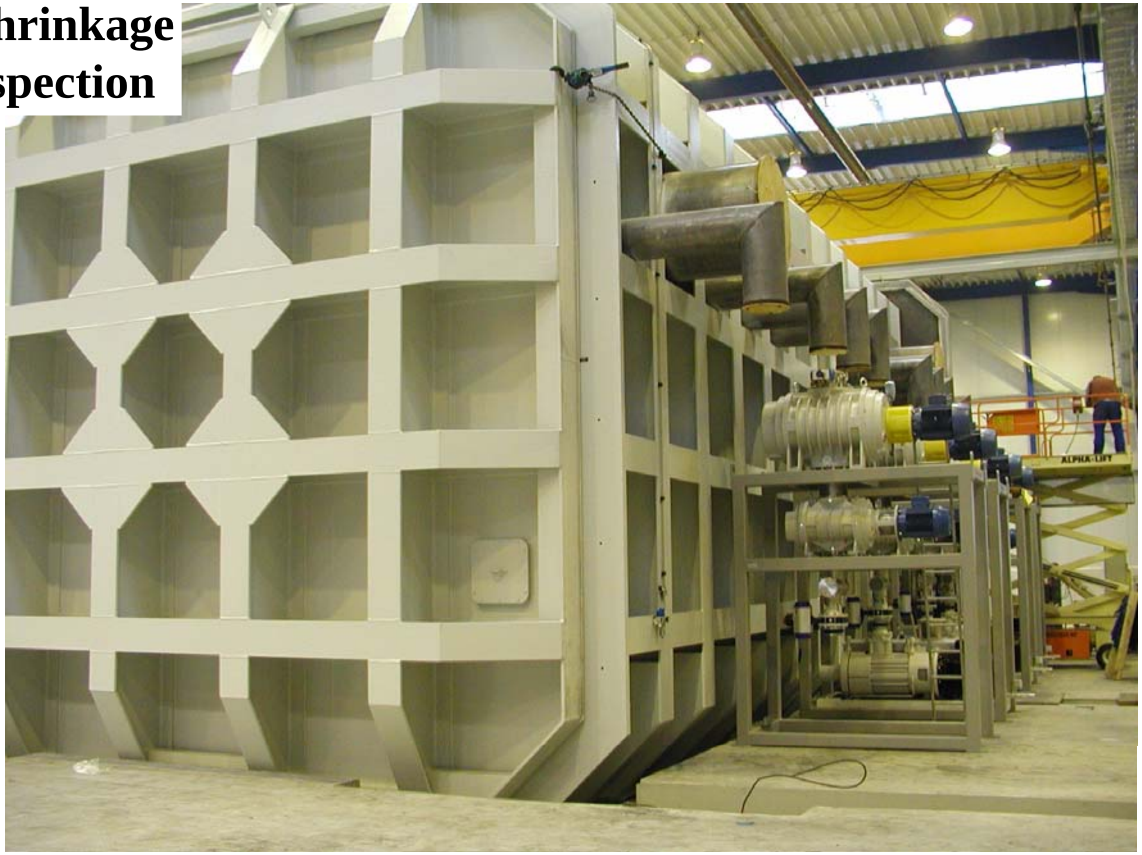
Fig. An example of the fixture design for the VV sector fabrication (EUPT)

Advanced welding technology -EB welding-

- **Smaller deformation and shrinkage**
- **Advantage in ultrasonic inspection**



ITER vacuum vessel



Electron Beam welding facility with a chamber 7m x 7m x 14m (under construction in Pro-beam Germany)

R&D Achievement in ITER EDA -L3 Project-

[Full Scale Sector Model (JAPT)]

Achieved Tolerances in L3 project
Individual Poloidal Segments ± 3 mm
Overall Sector Height ± 5 mm
Overall Sector Width ± 5 mm
Machined Edge of Field Joint ± 3 mm
Measured Leak Rate $<3.6 \times 10^{-10}$ Pa m^3/s

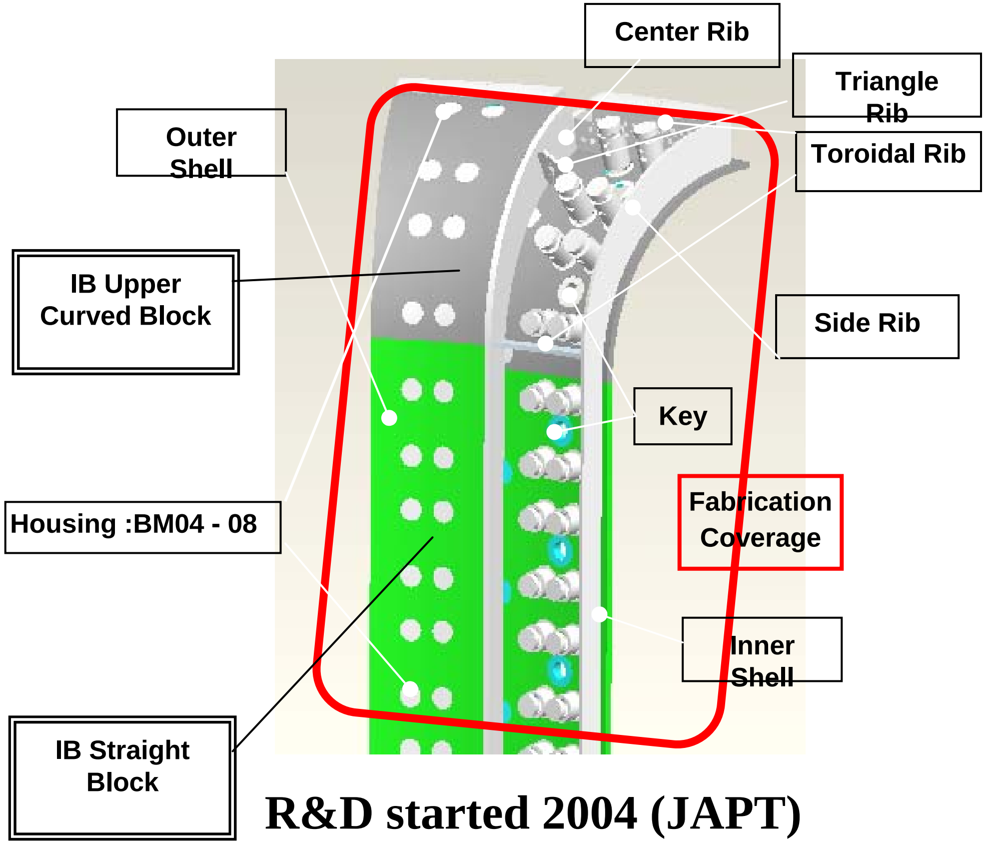
These R&D results are still applicable to the present design VV, but new R&D is needed to evaluate the welding deformation and achievable tolerances.

QuickTime™ and a
GIF decompressor
are needed to see this picture.

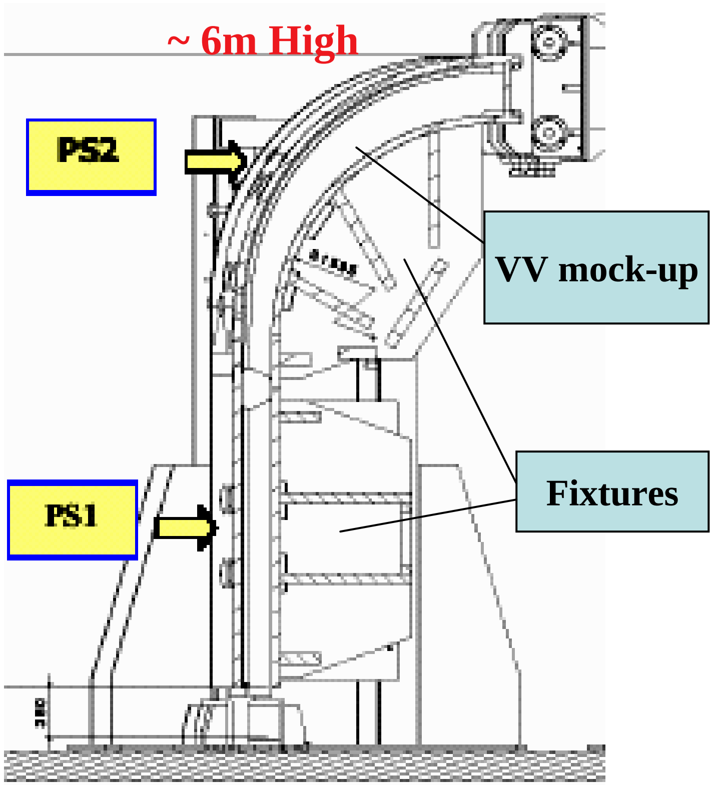
ITER VV Design updated after the EDA Phase

New R&D to Fabricate Full-scale Partial VV Mock-ups

To get data of the deformations and achievable tolerances
To establish the fabrication methods and non-destructive inspection methods



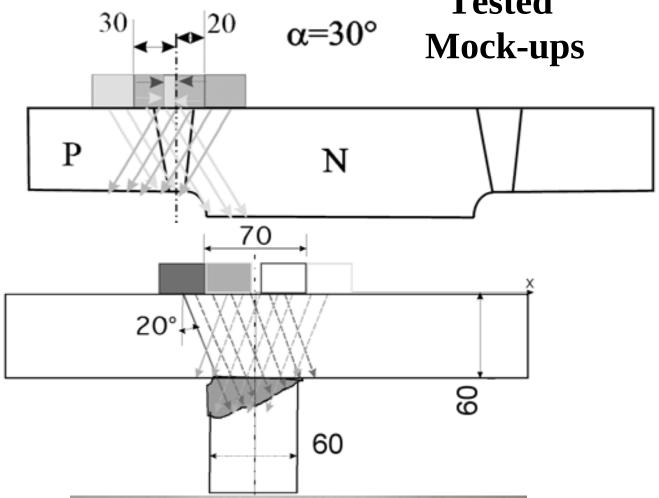
R&D started 2004 (JAPT)



R&D started 2003 (EUPT)

Non Destructive Inspection on Welds

Development of UT Methods



Most weld joints in the inner shell are RT inspected to assure 100% weld efficiency.

One-sided weld joints between the outer shell and the ribs/housings and the field joints will be inspected by UT.

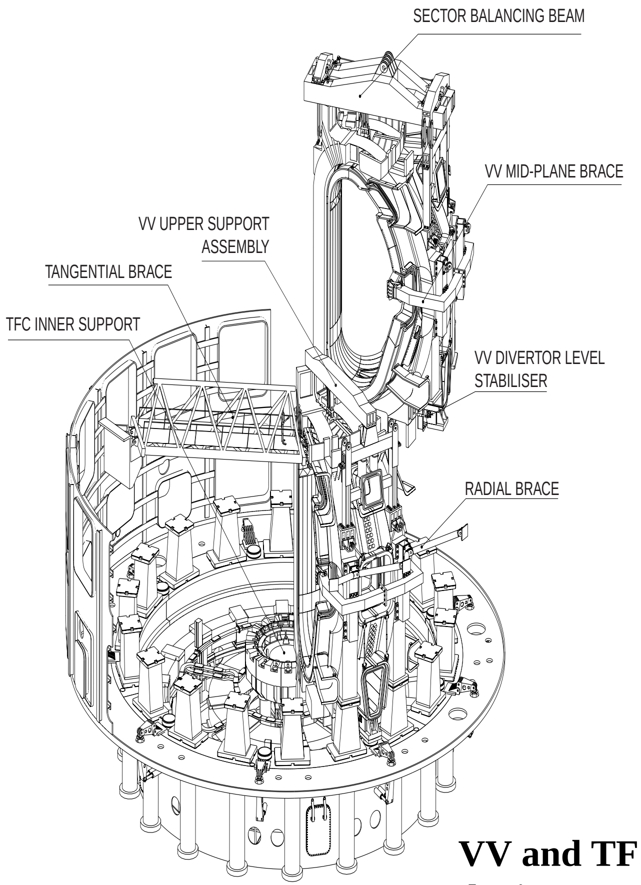
UT inspection on austenitic stainless steel welds 60 mm thick is challenging.

Considering the limited access, waves launched at an angle of 20 or 30 degree has been tested.

Combination of two waves (shear and longitudinal) has been tested.

Test equipment for UT inspection (RFPT)

VV tolerances After Assembly/Positioning in the Pit



VV and TF coils during assembly in the pit

Assembly/positioning tolerances at site		
- Surface deviations of the torus from the reference geometry after assembly at the pit	**mm**	**± 15 =*(1)+*(2)**
- Surface deviations of the torus from the reference tokamak geometry after positioning at the pit (Final deviations)	**mm**	**± 18 =*(1)+*(2) +*(3)**
Details		
***(1)Surface tolerances of a 40-degree sector from the reference geometry after fabrication at factory**	**mm**	**± 10**
***(2)Vessel weld distortion due to field/shop welds at t he site**	**mm**	**± 5**
***(3)Torus positioning versus ideal location with all support fixtures removed**	**mm**	**± 3**
***(5)Mismatch of the sector surfaces at field joints**	**mm**	**± 5**

VV Torus Assembly Sequence

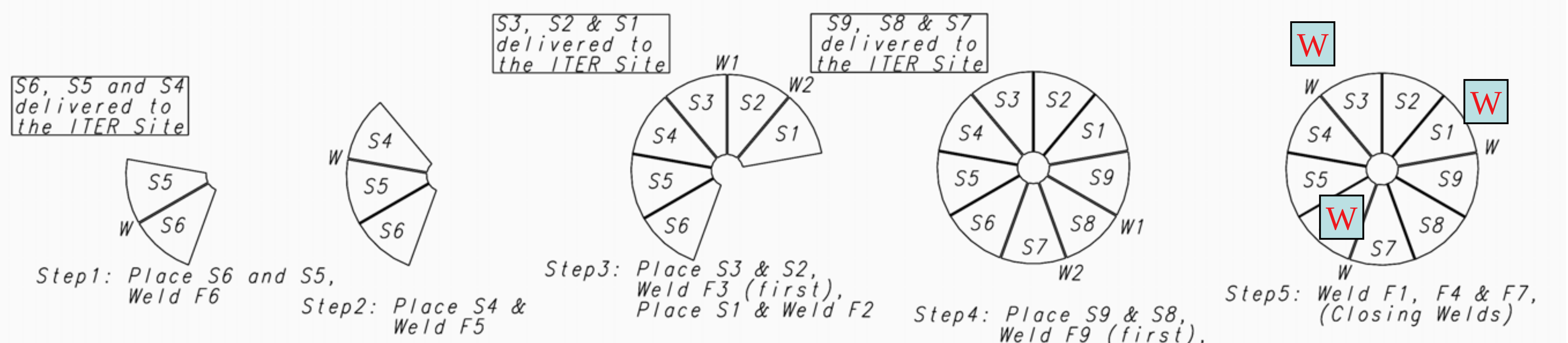
- It was proposed that the final welding be performed in parallel at 2 locations.

- The estimated residual stress due to the non-symmetric layout of the last welds is ~80MPa (the final welding at 2 locations between 160 and 200 deg sectors.

- A new sequence has been proposed to achieve a symmetric layout of the last welds.

- The final welding is performed in parallel at 3 locations between 120 degree sectors.

- This sequence has the advantage of reducing residual stresses and the global deformation will be smaller.



VV Torus Assembly Sequence

Adjustment of FW/Blanket Position

After the VV fabrication and assembly, the position of the VV inner surface is measured. Based on the measurement data, the FW/blanket position is adjusted precisely.

- The blanket module flexible supports are to be custom machined (shown in the next slide).

- Pads used on the contact surafce of the keys are also custom machined.

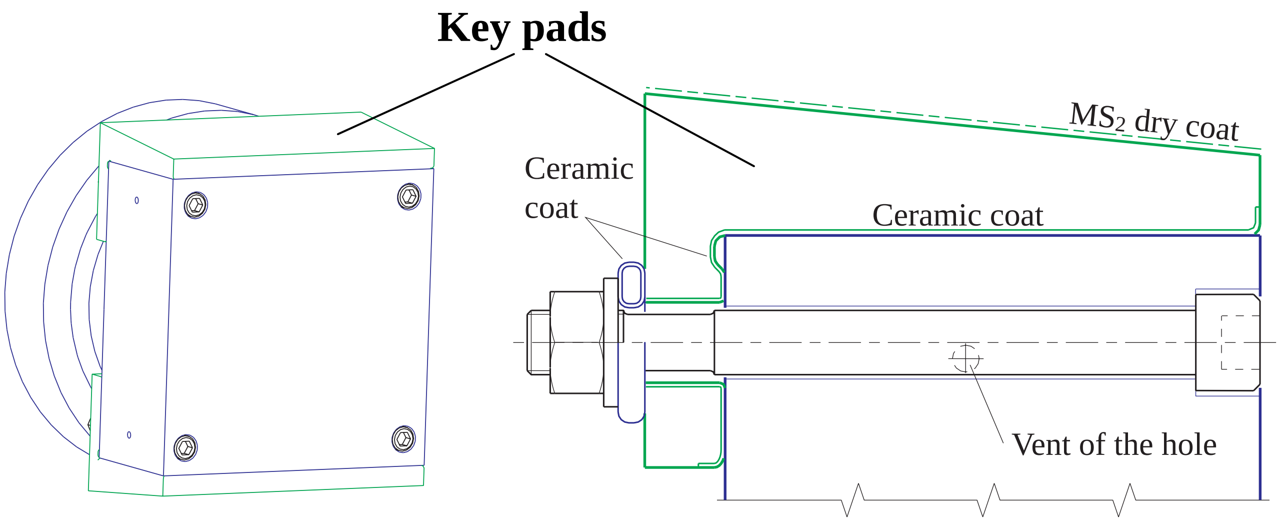


Fig. Keypads of the Inboard ITM Key (left) and Detail of the Fixing Screw with Ceramic Electrical Insulation (right)

Compensation of VV errors in blanket support

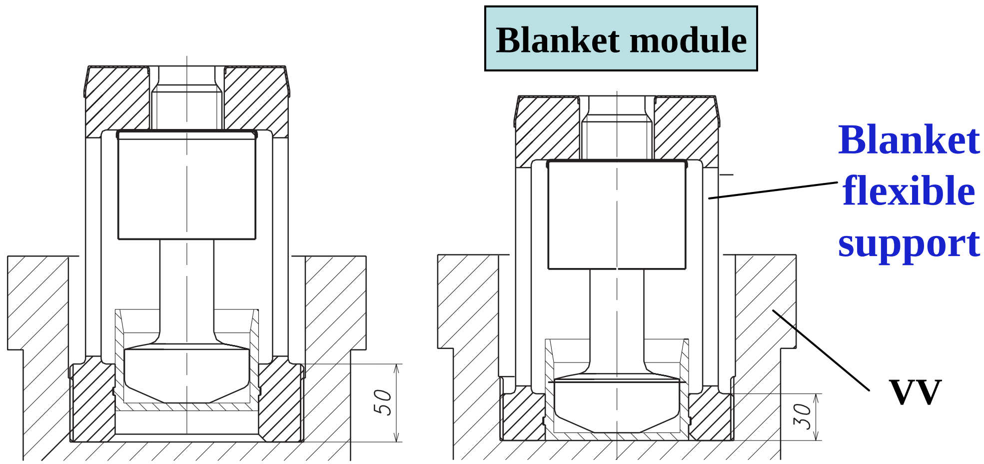


Fig. Compensation of the VV Errors by Adapted Cartridges:
+10 mm Level Up (left),
-10 mm Level Down (right)

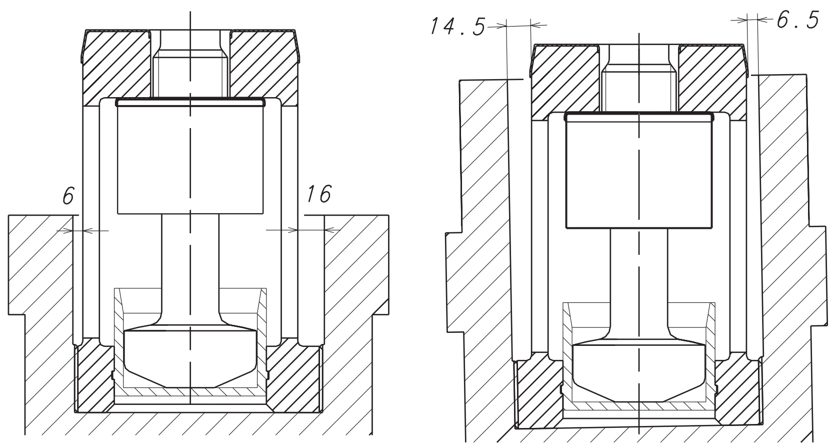


Fig. Compensation of the VV Errors by Adapted Cartridges:
5 mm Offset (left),
25 mrad Rotation (right)

Summary

Based on interactive work between design activities and R&D programs, most of the ITER VV and in-vessel component designs are converging by joint efforts of the International Team and Participant Teams.

The VV design and fabrication methods/procedure have been developed to minimize the VV fabrication tolerances and to achieve the required FW tolerances.

Additional R&D on full-scale VV partial models are now on-going and to be completed before the start of ITER construction.