Manufacturing of the ITER tungsten divertor – prototyping/ qualification and status of series production

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china eu india japan korea russia usa

Contents

Divertor Design: Divertor Cassette Assembly

54 Cassette Assemblies, i.e. Cassette Boby (CB) and 3 Plasma Facing Components (PFCs) in bottom of Vacuum Vessel

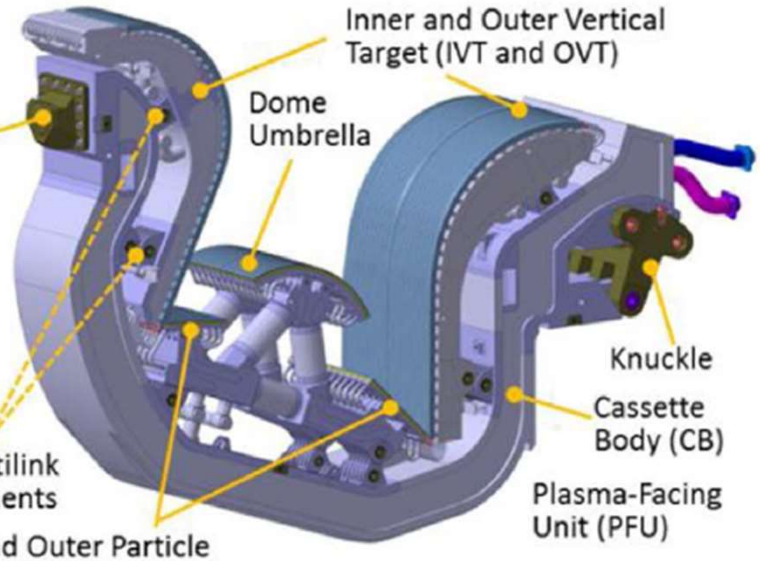
- Plasma-Facing Unit (PFU) attached on Steel Support Structure (SSS)
- CB hosting PFCs and diagnostics/ instrumentation
- CBs are engaged divertor rail attached in VV
- Water cooled

Final Design Review in 2008

Procurement Arrangements signed in 2009-2010

Change from CFC to Full Tungsten Divertor in 2013

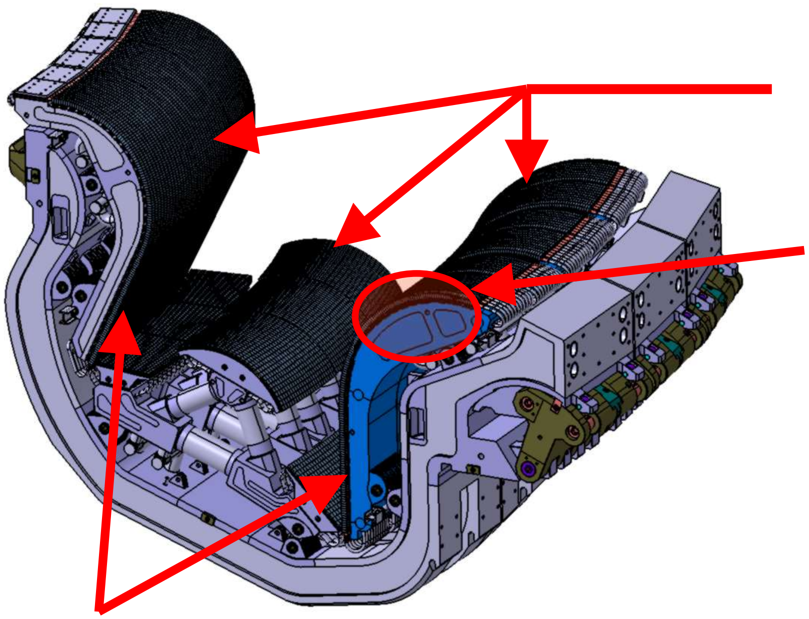
Series production is in progress for last years



Divertor Cassette Assembly (CA)

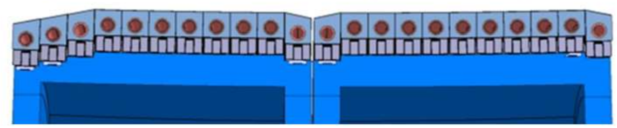
3.6 m length, 2.5 m height, 8.2 ton

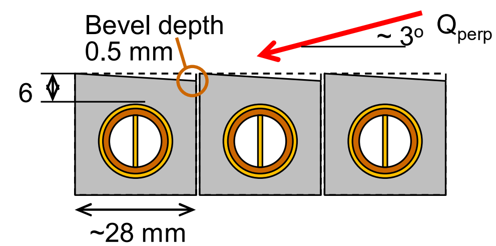
Divertor Design: shaping to mitigate leading edge impacts



Optimize tilting of Vertical Targets and Dome to protect inter-cassette leading edges

Outer baffle shaping to mitigate W melting during downward VDE (current quench)





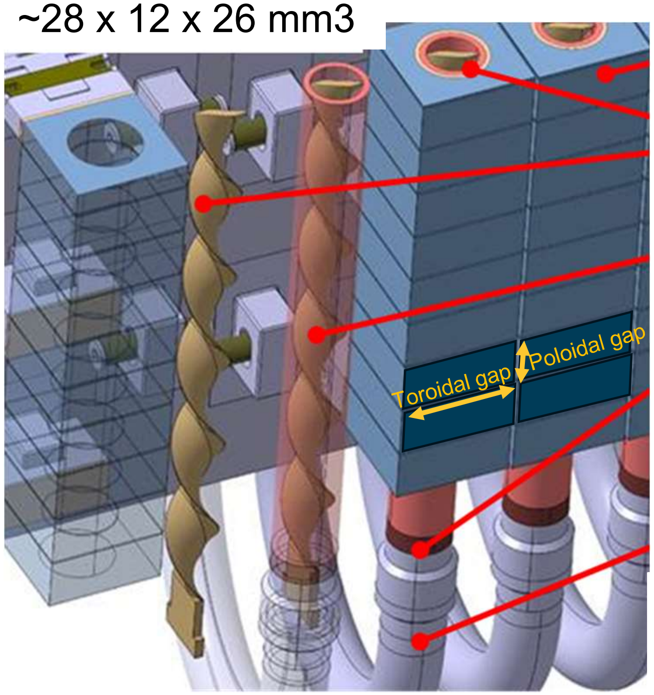
Individual monoblock shaping in high heat flux areas to protect leading edges

Tilting by 3D machining at steel surfaces
Minimum PFU variants, minimum monoblock variants
Bevel depth accommodates assembly tolerance. Note: deeper bevel, higher peak heat flux

Divertor Design: Plasma-Facing Units

Tungsten Monoblock for Vertical Targets

~28 x 12 x 26 mm3



W monoblock

Cu Interlayer

Swirl tape (Cu)

CuCrZr tube

Alloy625

316L

Target part

Toroidal gap width 0.4 +/- 0.1 mm

Poloidal gap width 0.5 +/- 0.2 mm

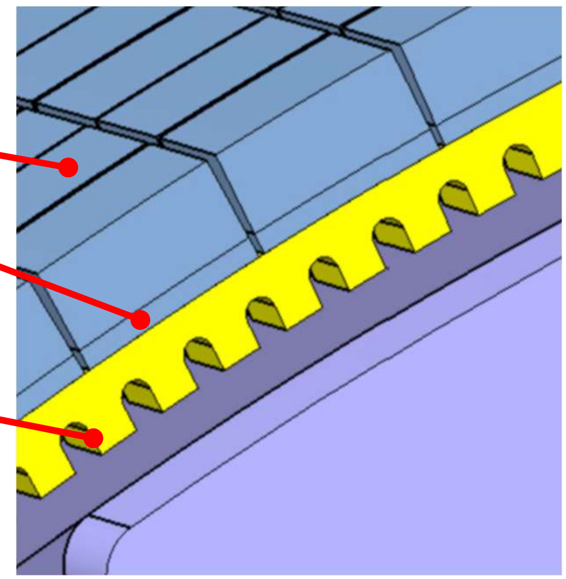
Tungsten flat tiles for Dome

~25 x 25 x 8 mm3 (castellation to be ¼ area)

W Tile

Cu Interlayer

CuCrZr heat sink



Divertor Design: Materials in Standards

Materials	Forms	Standards	Application
Tungsten	Plate	ASTM B760	For 12 mm thick W armor
316L(N)-IG	Plate, forging	RCC-MR Sec 2	Structure, pressure retaining
316L (EN grade 1.4404)	Pipes	EN 10216-5	Structure, pressure retaining
XM-19	Plate, forging	ASTM A240; ASTM A182	Structure, pressure retaining
Steel 660	Bolts, plate, bar	ASTM A453	Structure, bolting
CuCrZr-IG	Plate, pipe, forging	UNS C18150; EN 12163/12167	Heat sink, pressure retaining
NiAl bronze	Plate, rod, forging	EN 12167, ASTM B150, EN 12163	Fixing elements (anti-seizing)
Oxygen Free Cu	Sheet, bar	ASTM B152, ASTM B150, EN 1652	Compliant layer at W joint
Alloy 718	Bolt, Bar	ASTM B637, RCC-MR Sec 2	High strength at high T
Alloy 625	Bar	ASTM B446	Inspersion for CuCrZr - steel joint
Weld filler materials	Electrode, wire	EN, AWS, ASTM	For welding Joint
Brazing alloys	Foil	DA specification	For brazing Joint

Divertor Design: specific requirements for Materials

- **Standards for steel products, Ni alloys and Cu alloys define general requirements such as chemical composition, mechanical properties at T_{room}.**

- **In addition, specific requirements were added:**

- **Production Process** (non-metallic inclusion requirements - ITER Vacuum Handbook)

Final thickness less than 5 mm, shall be made from cross-forged material which is **electro-slag re-melted (ESR)** or **vacuum arc re-melted (VAR)**.

- **Mechanical test at elevated temperature**

Tensile properties at 250°C

- **Magnetic permeability requirements**

Limits for ferrite content, magnetic permeability

- **Grain size requirements**

- **Impurity contents for radioprotection requirements**

Limits for Cobalt, Niobium, Tantalum contents

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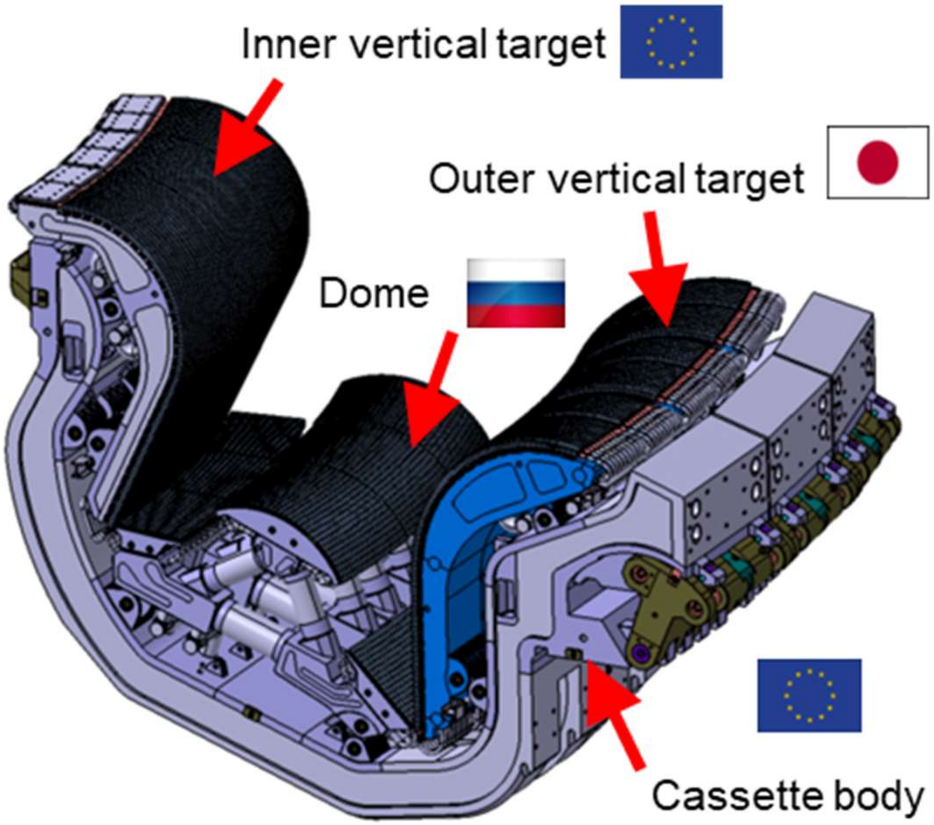
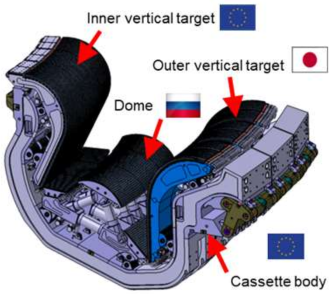
EU Procurement status: series production in progress

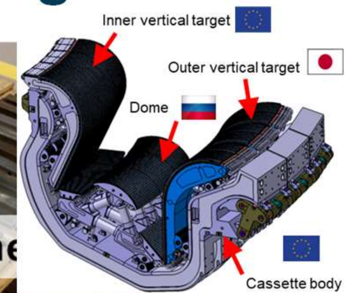


EU Procurement status: series production in progress



Factory acceptance test on going

JA and RF Procurement status: series production in progress



Factory acceptance test on going

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Qualification of technologies

A. Pressure retaining vacuum boundary joint

- Steel - steel welding joint in accordance with ISO 15614-nn

- CuCrZr-Steel welding joint for tube in accordance with ISO 15614-nn

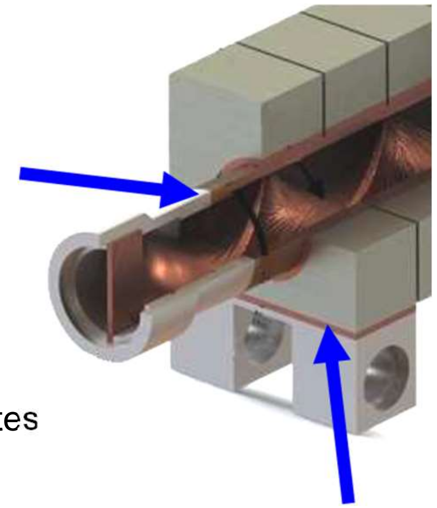
Additionally, rotary bending test followed by leak test

Tensile test at elevated T

- CuCrZr-Steel joint for hypervapotron cooling channel

Cyclic pressure test at 8 MPa, high pressure test at 20 MPa followed by Leak tes

Tensile test at elevated T



B. Armour heat sink joint – mockups and full scale prototype

Monoblock geometry at target: Thermal fatigue test at defined heat flux at 10 MW/m^2 5000 cycles, at 20 MW/m^2 300 cycles (90% of W surface); at baffle: 5 MW/m^2 5000 cycles

Flat tile geometry: Thermal fatigue test at defined heat flux at 5 MW/m^2, 5000 cycles

C. PFU support leg joint – PFU leg sample

Cyclic zero-pull fatigue test 0-8 kN 15 k cycles

Tensile test

Qualification by manufacturing full scale prototypes

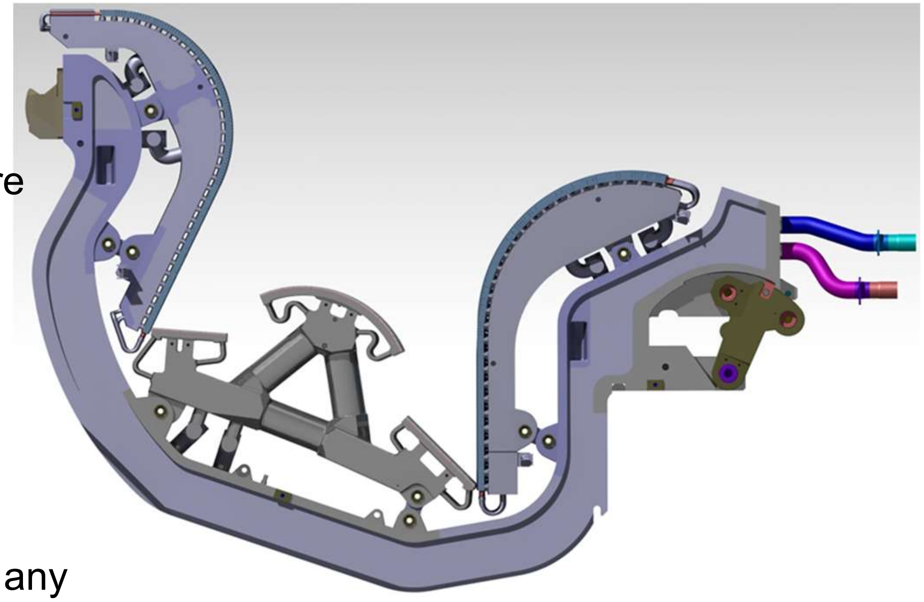
Manufacturing of prototype PFUs, Steel Structure, Assembly, Factory Acceptance Test

1. PFU manufacturing in larger furnace

Long (>2 m) and large component to meet tight tolerances
Assembly of the long PFU (mounting and welding) on structure

2. Steel Structure - "No weld is the best weld"

Management of welding distortion
Welding in limited access, e.g. pipes
100% volumetric Non-Destructive Test (NDT) for pressure retaining vacuum boundary welds in limited access
Final machining to achieve Dimensional/ geometrical compliance



3. Factory Acceptance Tests

Visual Test with clear Acceptance Criteria for purpose
Water flow test
Hydraulic Pressure test
Hot He Leak Test (250 C, 5 MPa) and leak localization if any
Dimension Inspection

Manufacturing in series production: 3 main points

3 main points: **HHF technology, dimensional/ geometrical compliance, leak tightness**

❑ High Heat Flux technology

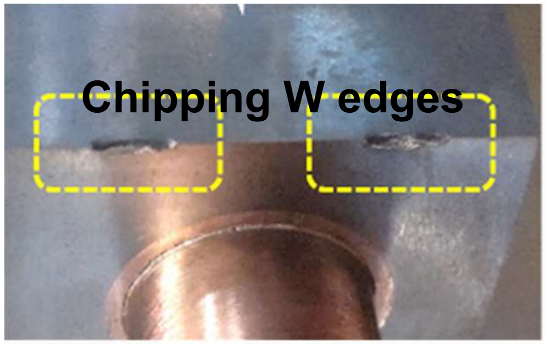
- Reliable manufacturing process and non-destructive test
- Sampling High Heat Flux test

❑ Dimensional/ geometrical compliance

- Strategy to meet stringent tolerances in a large scale
- Management of welding distortion
- Establishing PFU gap and profile control
- Attention to W edges

❑ Leak tightness

- Qualified welding procedures and Non-Destructive Test for pressure retaining vacuum boundary welds
- Correct implementation of Hot He Leak Test



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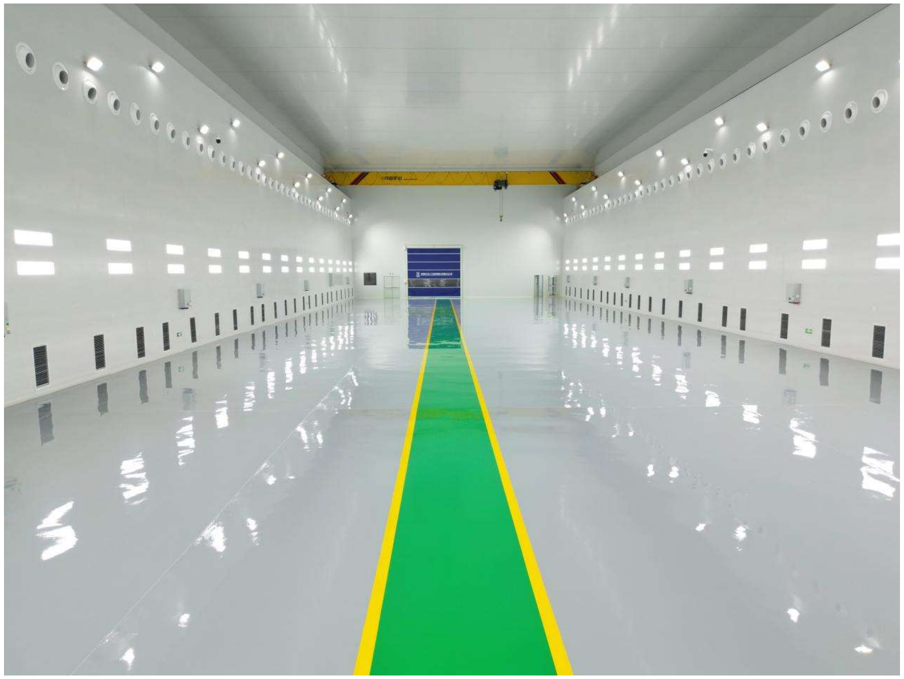
4. Cassette Assembly Integration

Contract signed and site preparation started in China



Contract scope

- Qualification of all sites, equipment, personnel and procedures
- Reception and acceptance of large quantities of Free Issued Items (Divertor components and diagnostics, etc)
- Integration of 2 Cassette Assembly prototypes, 33 Standard series, 21 Non-Standard series, 4 spares
- Factory Acceptance of the Cassette Assemblies

1st CA integration in 2027 Q1

Start of Divertor Installation in 2032 Q2

4. Installation: Divertor Assembly Tools manipulated on Rails

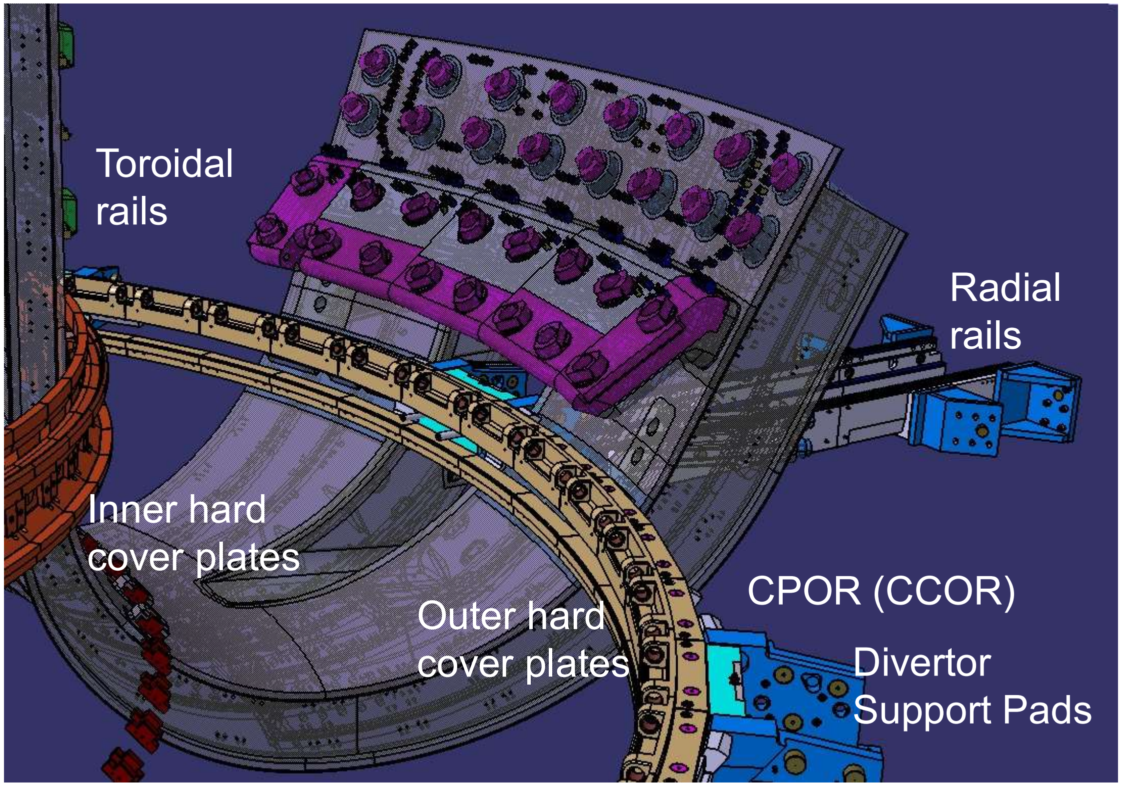
Radial Rails: to support the CA radial movers and diagnostics rack

Toroidal Rails: alignment of CAs; attach CAs to VV; support CA toroidal movers

Central Cassette Outer Rails (CCORs): to bridge outer toroidal rail at remote handling port

Hard Cover Plates custom-machining to accommodate as-built Vacuum Vessel

Assembly tools carries Divertor CAs to position. Pipe welding after engaging CA at rails (Hard Cover Plate)



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5. Summary

- **Divertor Design - Actively cooled components, 3.6 m long 2.5 m height**
- **Procurement status – 3 DAs are involved. In series production after prototype phase**
- **Qualification and Manufacturing – successful full-scale prototype, in addition to technology qualification. Reflecting lesson learned toward series production**
- **Integration and Installation – Integration activity is about to start**

Thank you very much