FUSION FOR ENERGY | Big Science Business Forum 2022

The Geometrical Compliance of Large & High Precision Mechanical Components in Fusion: Challenges & Opportunities

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BSBF 2022 - Parallel session C1:

High Precision and Large Mechanical Components

6 October 2022, Granada Conference Center

FUSION FOR ENERGY | Big Science Business Forum 2022

Table of Content

- Introduction and Overview
- Geometrical Compliance: definition and main challenges
- Business Opportunities For Industries
- Conclusion

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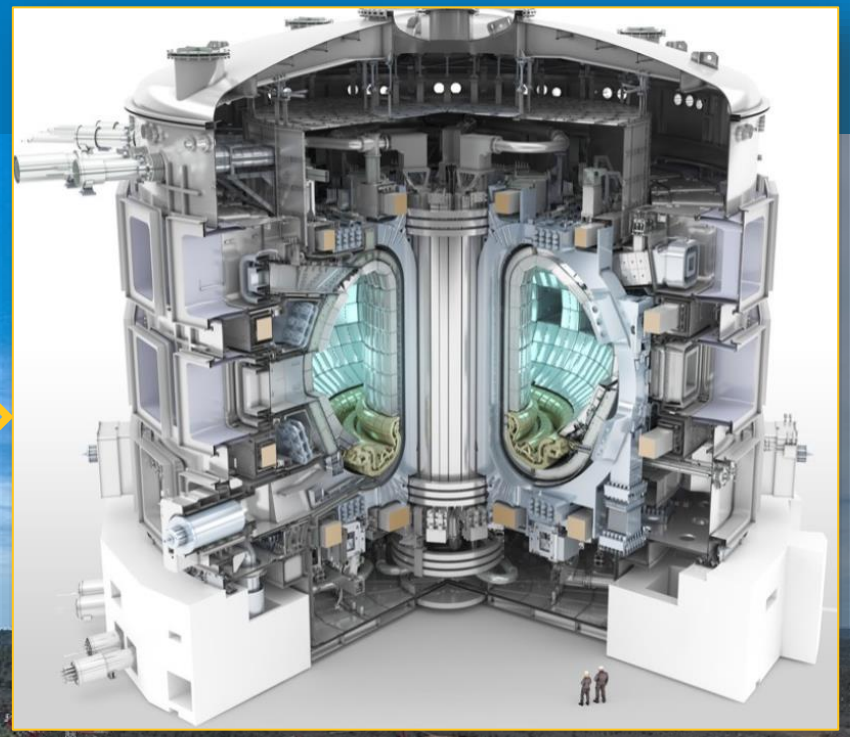
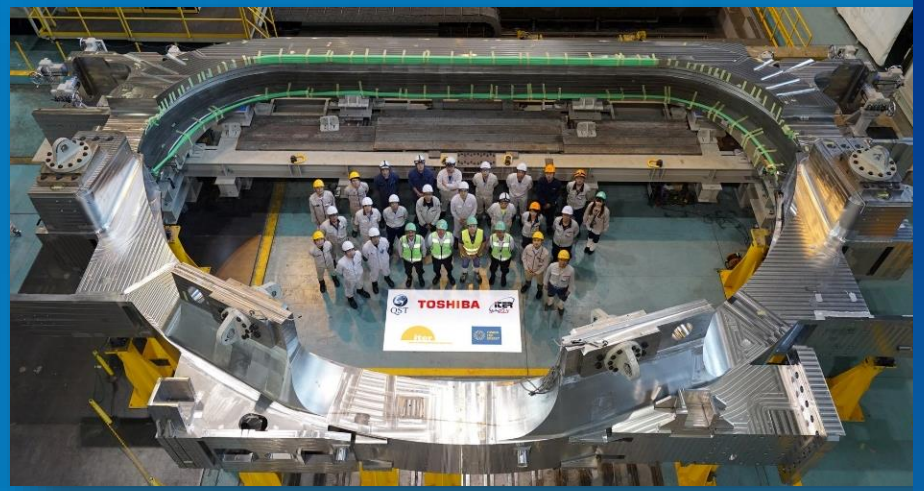
ITER Project & F4E

- Under construction in France (35 nations involved)
- Demonstrate that Fusion is a valuable source of energy
- Fusion for Energy provides the European in-kind contributions to ITER



Vacuum Vessel Sector
Size : 8 m x 14 m
Tolerance: ±1 mm Global ±0.15 mm Local



Toroidal Field Coil
Size: 10 m x 17 m
Tolerance: ±1.5 mm Global ±0.2 mm Local

In the World of Fusion

- Large Components ~ [10^{3} to 10^{4} mm]
- High Precision Components ~ [10^{0} to 10^{-1} mm]

"You can only make as well as you can Measure"

Joseph Whitworth (1803-1887)

Ensuring *(manufacturing) & **Assessing** (measuring) the Product Geometrical Compliance is challenging*

Introduction & Overview

- The flexibility of mechanical components affects both the manufacturing process and the acceptance/rejection process;

- Excessive component deformation due to internal variables (to manufacturing process) or external variables (like deadweight or temperature) shall be avoided - minimized - compensated according to the product needs;

Effect of Internal Variables to Manufacturing Process	Effect of External Variables on Component Shape	Effect of Internal/External Variables on Measurement Process
Distortion induced by welding.. $\Delta L_{WD\_VV} \approx 0.5 - 50$ mm* (VV Welding coupons)	Deformation by gravity, temperature $\Delta l_{SS} \approx 0.15$ mm (1°C@10m)	Measurement Uncertainty If Unc > 20% tolerance (e.g. 0.1 mm →20 μm) Acceptance Zone must be REDUCED

SHALL BE NEGLIGIBLE WITH RESPECT TO THE TOLERANCE BAND OTHERWISE THE WHOLE MANUFACTURING PROCESS CAN BE JEOPARDIZE

*J.Caixas et all, "Weld distortion prediction of the ITER Vacuum Vessel using Finite Element simulations", October 2013 Fusion Engineering and Design 88(9-10):2011-2014

FUSION FOR ENERGY | Big Science Business Forum 2022

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Geometrical Compliance

Geometrical Requirement = Dimension ± Tolerance

> *Tolerance is the **acceptable limit** within which a **dimension** is defined & manufactured. Tolerance is any **deviation** in dimension of the manufactured part which can be **safely** <u>tolerated</u> and <u>accepted</u>.*

Geometrical Requirements

- Assemblability Requirements
- Manufacturability Requirements
- Functional and Safety Requirements

GD&T: Geometric Dimensioning &Tolerancing (ISO-GPS)

Geometrical Compliance

- Ensuring → Manufacturing Route
- Assessing → Measurement Process
- Inter-Linking → Measurement to feed Manufacturing

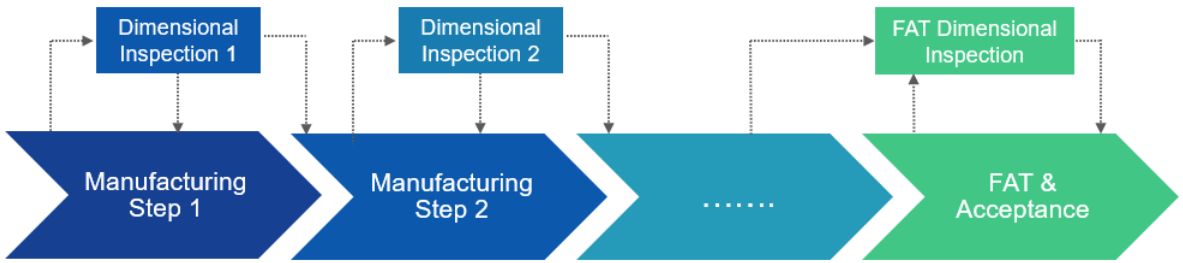
In-Process Control, Virtual Assembly/Fitting, Metrology-Guided Assembly,…

Geometrical Compliance

Synergies between Manufacturing Route and Measurement Strategy

Geometrical Status of the component (& max. acceptable effect of manufacturing and external variables) shall be:

- Quantified a-priori in defining the manufacturing route
- Tracked throughout the whole manufacturing process



Manufacturing Route and **Measurement** Strategy as one **integrated** process

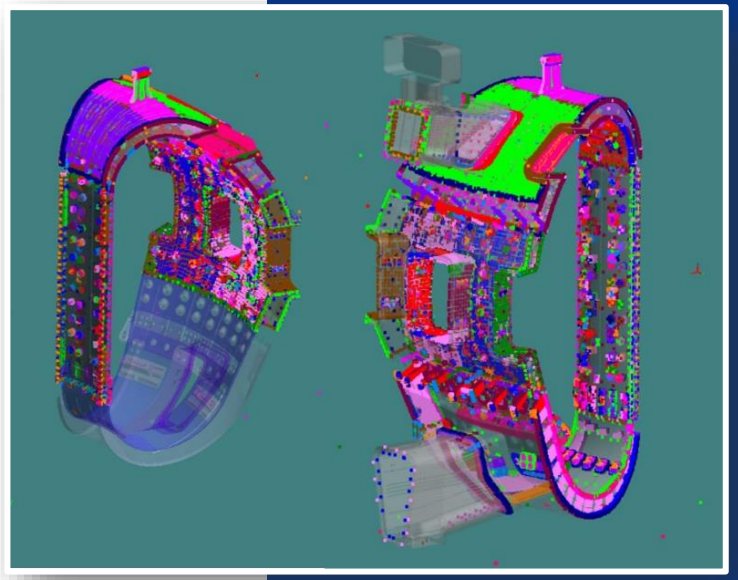
Measurement processes shall not be thought as a snapshot of a certain status of the product but as a control fully embedded in the manufacturing process to:

- Keep under control effect of internal/external variables (Verify assumption behind the manufacturing process)
- Reduce the risk of the final geometrical non-conformance of the product

Examples

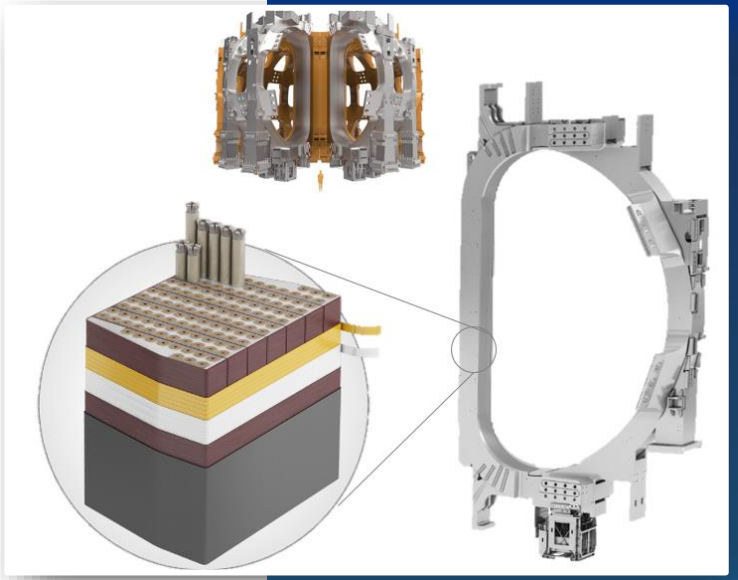
Vacuum Vessel Sector

Fit-Up of Segments before welding guided by metrology using as-Built data



Toroidal Field Coil

Positioning of the WP inside the casing guided by metrology using as-Built Data



FUSION FOR ENERGY | Big Science Business Forum 2022

Table of Content

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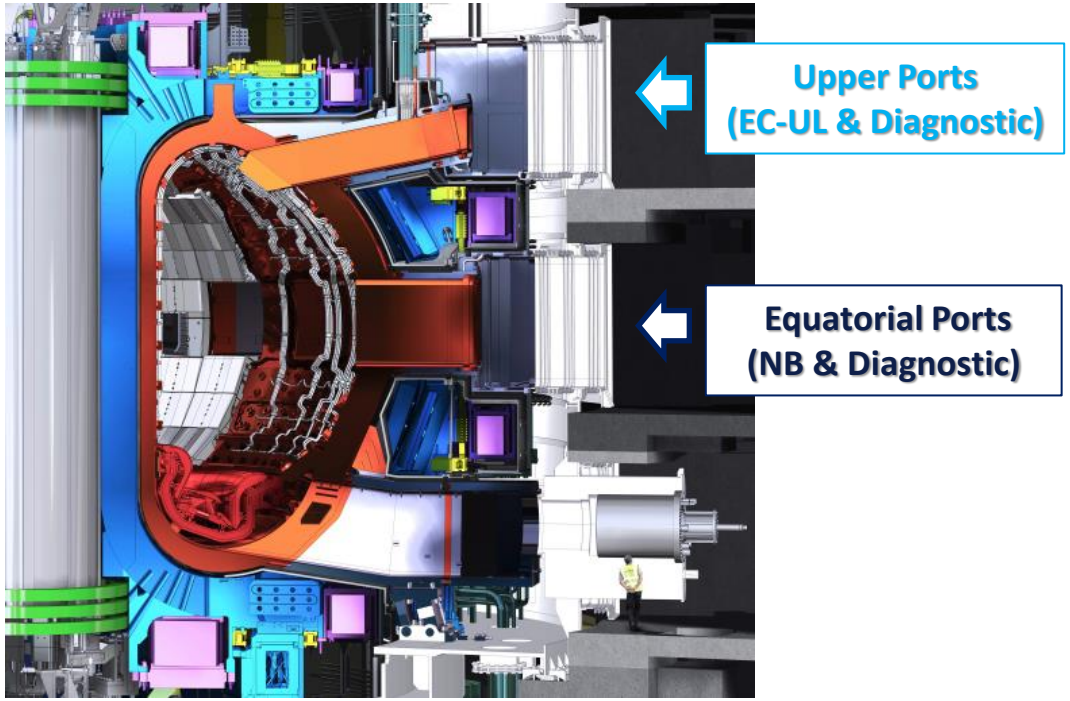
Overview of Main Manufacturing Contract and R&D activities

Manufacturing contract

- Neutral Beams (NB) Passive Magnetic Shielding
- Neutral Beams (NB) Remote Handling System (RHS)
- Neutral Beams (NB) Cryopumps
- Electron Cyclotron (EC) Upper Launcher (EC-UL)
- Diagnostic Port Engineering



R&D Activities → Possibility of GRANTS

- Measurement Compensation
- CAD morphing using AS-Built data

additional Info upon request

Business Opportunities

NB Passive Magnetic Shielding

Dedicated talk: Parallel session A1 - Electrical, Power electronics, electro-mechanical…

General Scope

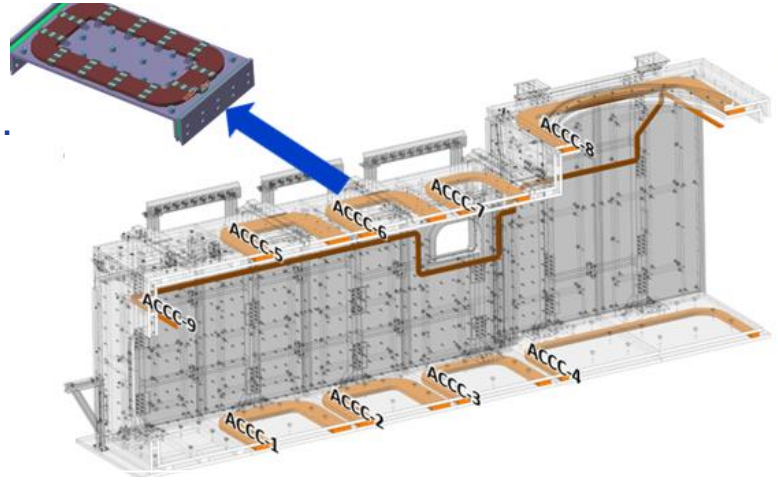
- Manufacturing design and full assembly of 2 PMS and ACCC

Main Technical Challenges

- Construction and precise assembly (1mm gaps/0.1 mm tolerances) of heavy components (500 t) nuclear classified (RCC-MR) + coil design and manufacturing

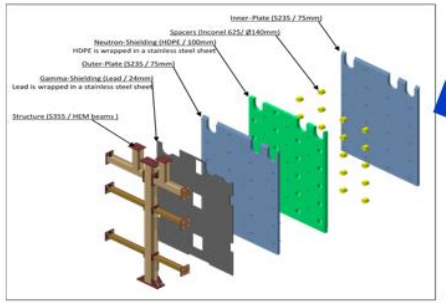
Status/Deadlines

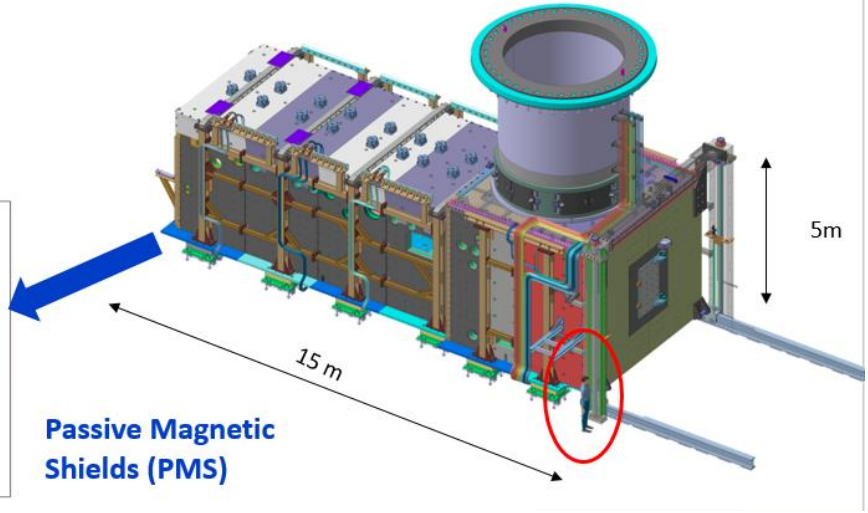
- Market Survey for ACCC closed (link)
- Market Survey for steel material on-going (link)
- Market survey for complete scope: Q4 2022
- Call for tender: Q2 2023



Active Compensation Correction Coils (ACCC)

Active Compensation Corrections Coils





Passive Magnetic Shields (PMS)

Passive Magnetic Shield SYstem

Business Opportunities

NB Remote Handling System (NBRHS)

Dedicated talk: Parallel session D4 - Remote Handling Systems

General Scope

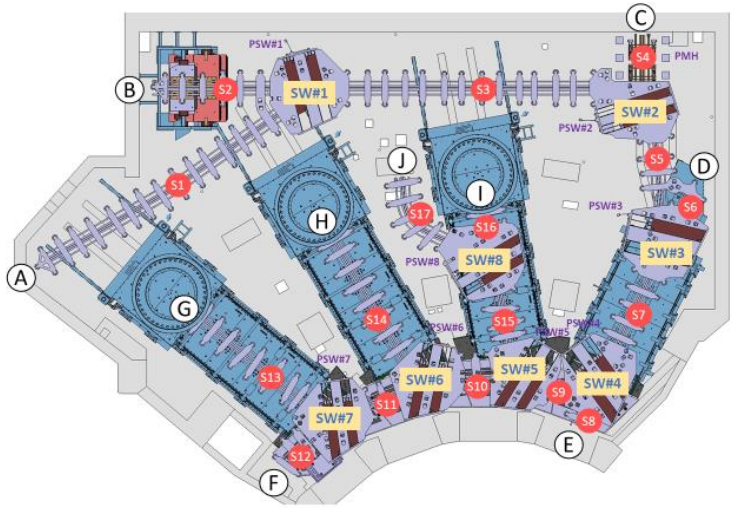
- Manufacturing of the 40 t nuclear grade crane (manufacturing design, fabrication, installation and commissioning)

Main Technical Challenges

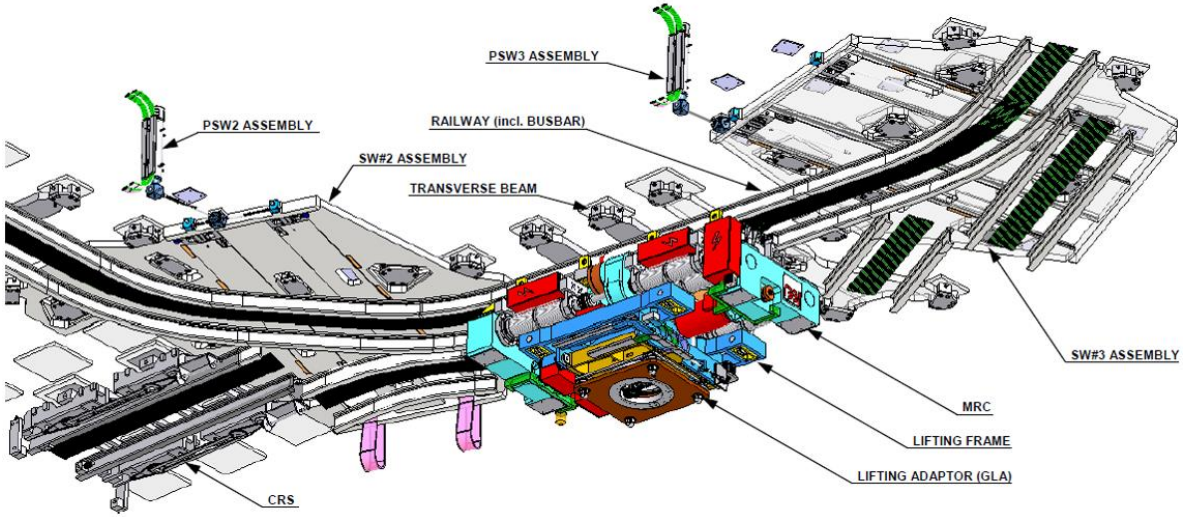
- ~140 m crane railway with high precision manufacturing, installation and alignment

Status/Deadlines

- Launch of call for tender: Q2 2024
- Delivery: Q3 2027



Monorail layout overlapped with the NB Injectors



Monorail Crane System

Business Opportunities

NB Cryopumps

Dedicated talk: Parallel session C3 - Cryogenic, Vacuum & Leak detection system

General Scope

- Manufacturing and Assembly of the Neutral Beams (NB) Cryopumps

Main Technical Challenges

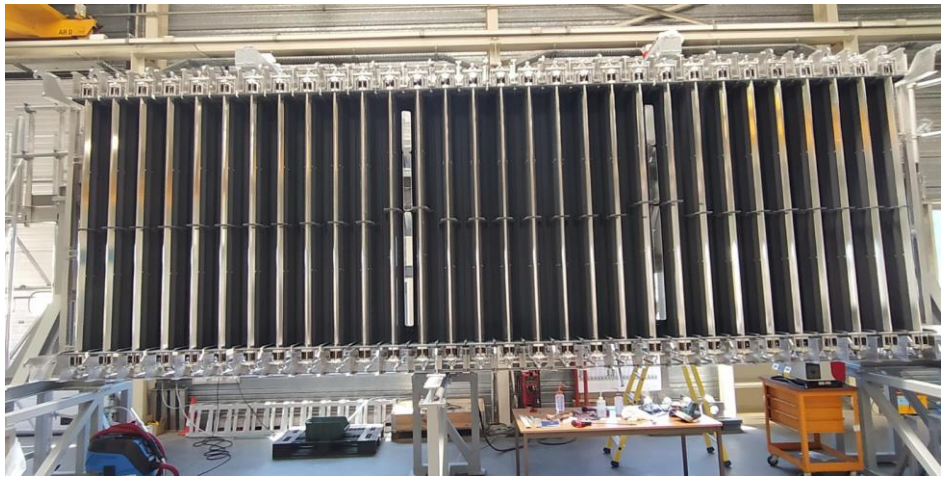
- Manufacturing of vacuum and cryogenic assemblies to tight tolerances

Contract Value

- Range C: 4MEUR-12 MEUR

Status/Deadlines

- Current phase: final design
- Launch of call for tender: 2024 / Delivery: 2029



Prototype Neutral Beam cryopump assembly for the Mitica facility

Business Opportunities

Electron Cyclotron Upper Launcher (EC-UL) and ex-vessel waveguide

F4E-OMF-1120 – subcontracting opportunities

General Scope

- Procurement of raw materials
- Manufacturing of prototypes and testing activities.

Main Technical Challenges

- Materials including CuCrZr, 316L/N/-IG forgings/plates/pipes

Contract Value

- Ad-hoc

Status/Deadlines

- 2022-2023

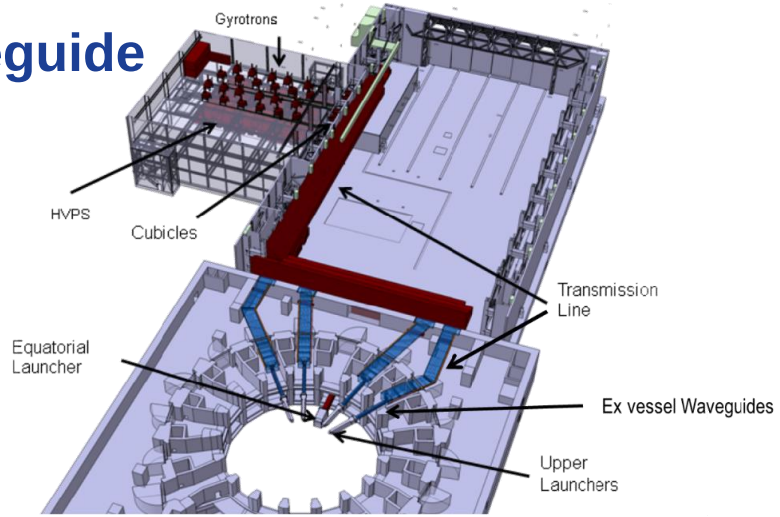
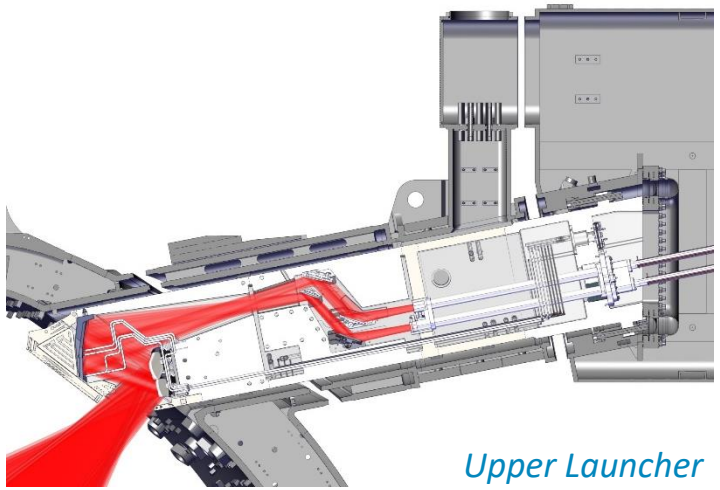
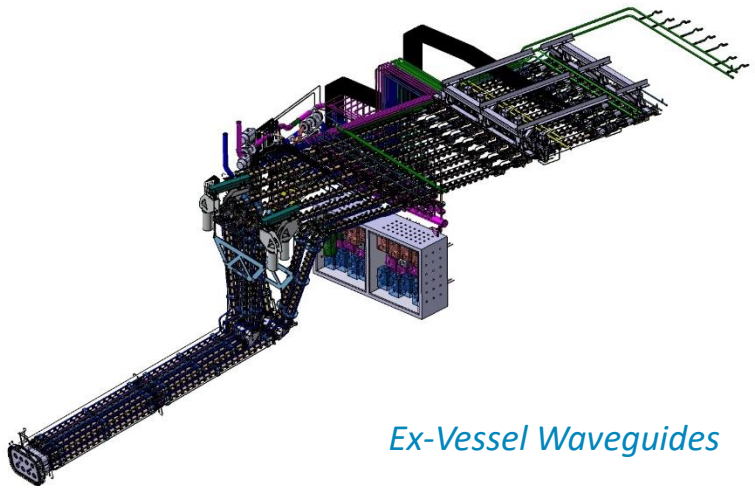


Figure 1: EC system layout

EC system layout



Upper Launcher



Ex-Vessel Waveguides

Business Opportunities

Diagnostic Port Engineering

F4E-OMF-1883 Dedicated talk: Parallel session A3 - Diagnostics, Detectors, Sensors, ….

General Scope

- manufacturing of 6 port structures + feedthroughs + integration of 14 diagnostic sub-systems + Assembly of port plugs, interspace and port cell structures

Main Technical Challenges

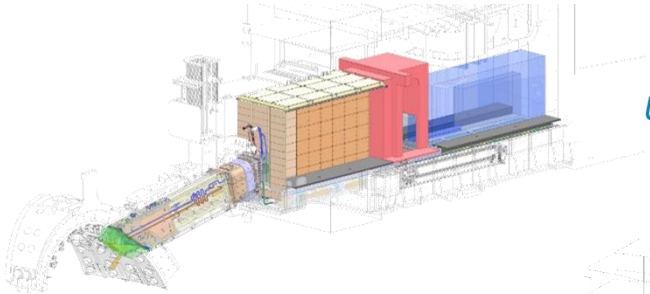
- Manufacturing and precise of heavy components

Contract Value

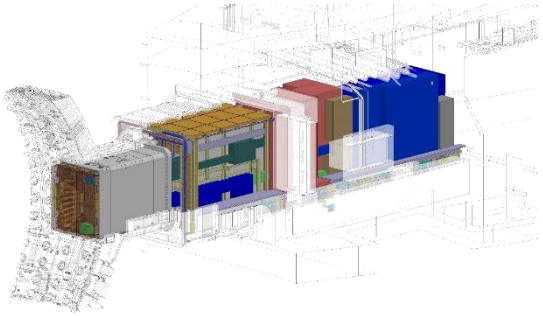
- Range D: >12 MEUR

Status/Deadlines

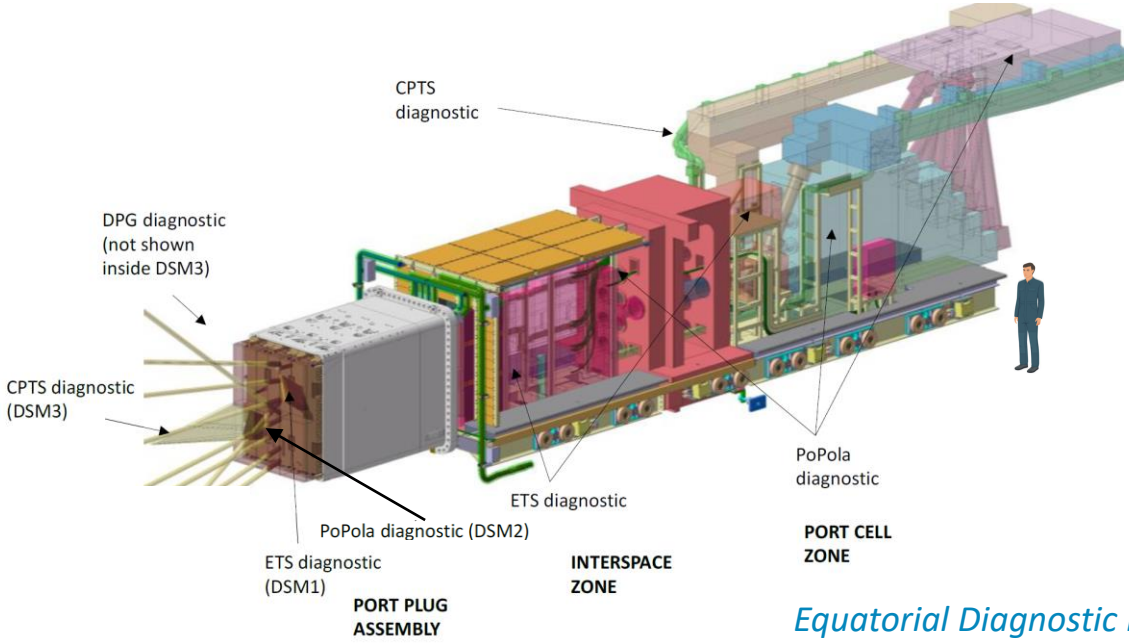
- Call for expression of interest: Q3 2022



Upper Diagnostic Port



Equatorial Diagnostic Port



Equatorial Diagnostic Port

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Large (10m) and High Precision (1 - 0.1mm)

Geometrical Compliance

Effect of Internal/external variables

Manufacturing Route to Ensure Compliance

Metrology Strategy to assess Compliance

Manufacturing ↔ Metrology

Business Opportunities

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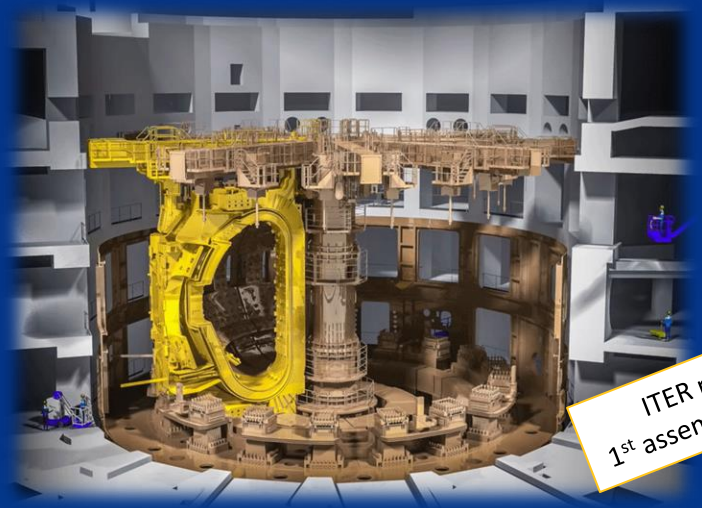
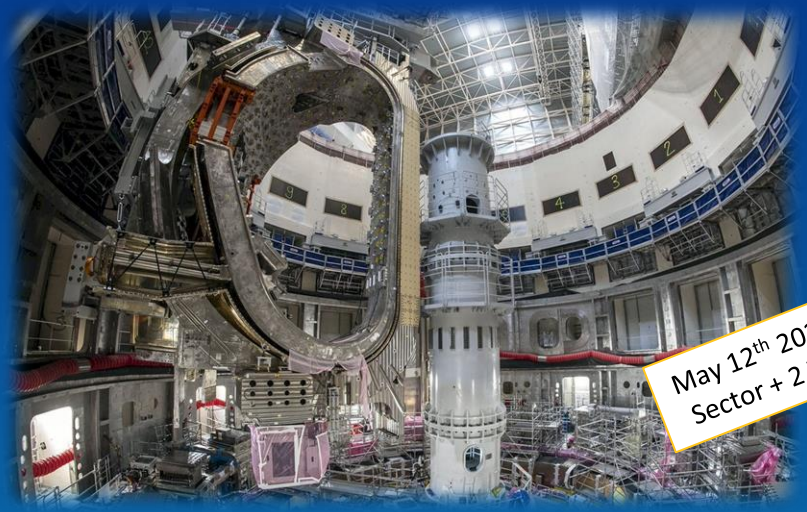
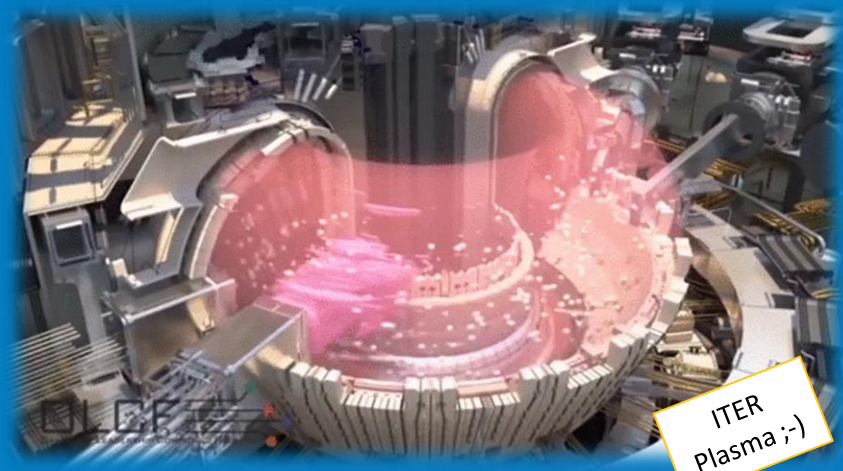


ITER machine
1st assembly sequence

May 5th 2022
The Big Lift



May 12th 2022 - 1 VV Sector + 2 TFCs in Pit



ITER Plasma ;-)

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Thank you for your attention

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ADDITIONAL SLIDE: Geometrical Compliance

Effect of internal and external Variables (some simple examples)

Manufacturing

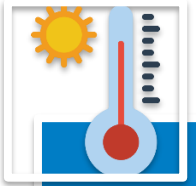
- Distortion induced by manufacturing process shall be well quantified
- Manufacturing Processes shall be qualified

$\Delta L_{WD\_VV} \approx 0.5 - 50$ mm*
(Welding coupons)

External Variables

- Deformation cannot be avoided
- Magnitude shall be well quantified
- Design of supporting structure and/or active compensation system

$\Delta l_{SS} \approx 0.15$ mm (1ºC@10m)

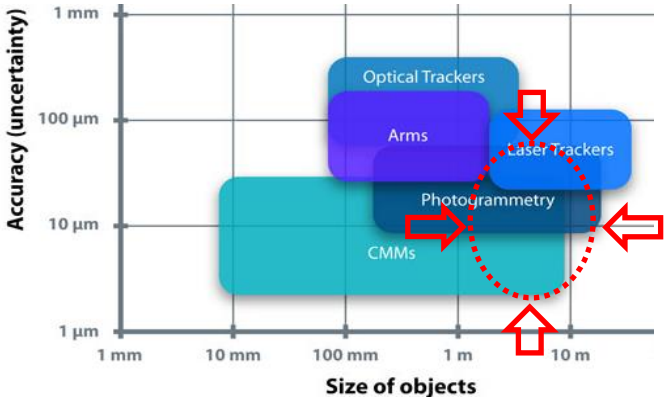


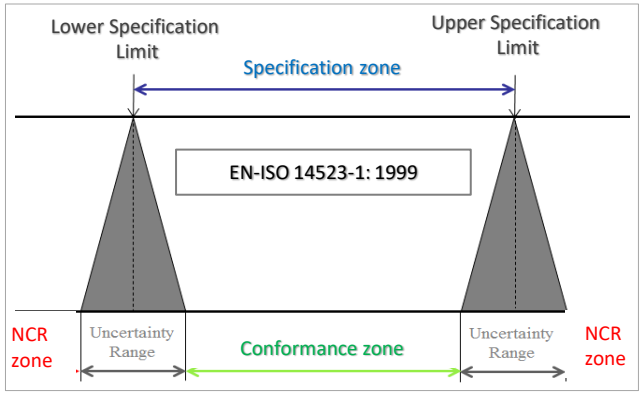
Measurement

- Measurement Process Uncertainty (Instrument + external variables + ..)
- Uncertainty < 20% of tolerance
- if not specification zone must be **reduced** to conformance zone

ID	Def [mm]	
6	58.19	COUPON 6 AUTOMATIC TIG NARROW GAP WELDING WITH MANUAL TIG ROOT PASS
7	0.37	COUPON 7 E.B. WELDING
8	0.45	COUPON 8 E.B. WELDING WITH MANUAL TIG ROOT PASS
9	19.43	COUPON 9 AUTOMATIC TIG WELDING AND MANUAL TIG WELDING
10	27.52	COUPON 10 AUTOMATIC TIG WELDING AND SMAW
11	54.28	COUPON 11 TIG MANUAL + SMAW WELDING

*J.Caixas et all, Weld distortion prediction of the ITER VV





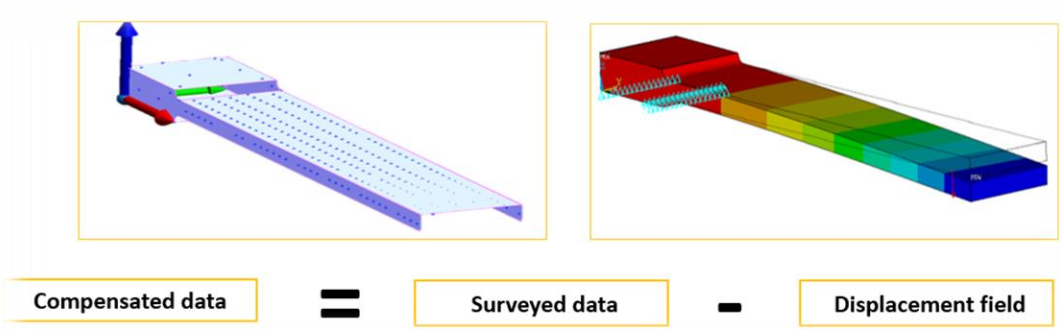
ADDITIONAL SLIDE: Business Opportunities

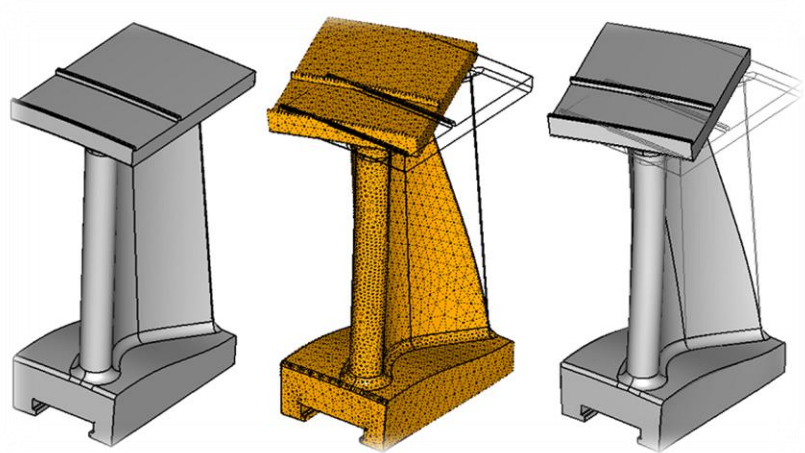
R&D: Measurement Compensation Based on FEA

Possibility of GRANT – if interest from industry is shown

Measurement compensation is the process of changing measured point coordinates to take into account a specific effect.

- High fidelity FEA models can be used to simulate how the part shape is affected by the experimental set-up and measured data can be compensated (Needed FEA uncertainty can be well below standard FEA uncertainty, model validation is crucial)





R&D: CAD morphing based on As-Built Data

Possibility of GRANT – if interest from industry is shown

Obtain the AS-Built virtual representation of manufactured component

- by directly morphing the CAD using acquired measured data, maintaining CAD structure and topology