Diagnostic Engineering & Diagnostic System Development - Business Needs

By Michael Walsh

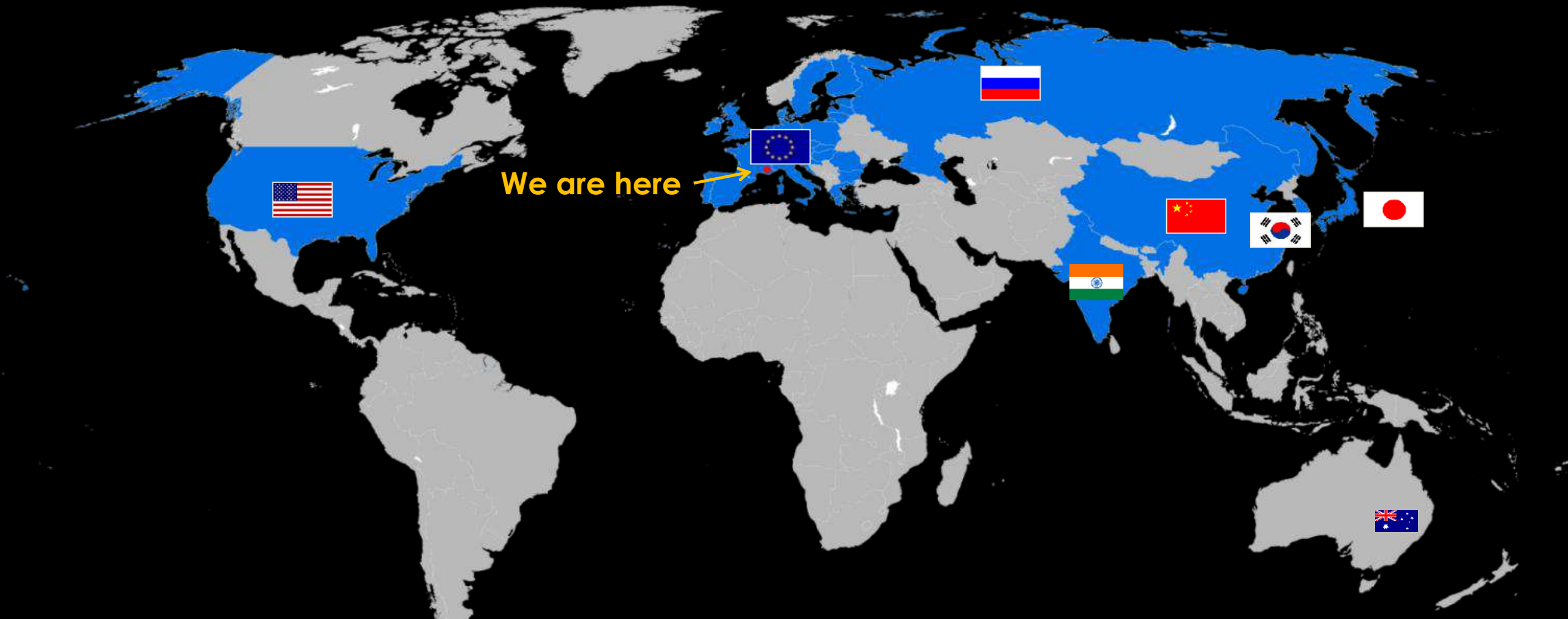
8th April 2021

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

Outline

- Introduction and Background
- Procurement of Port Plug Assemblies
- Port Integration Facility Creation (PIF)
- Port Handling Tools
- Mechanical Assemblies & Electrical Vacuum Feedthroughs
- Collaboration Opportunities

Who is working on Diagnostics?



As well as having many projects going on around the world, IOCT has also many internal projects to complete as well. It also had to integrate many systems coming from the different partners

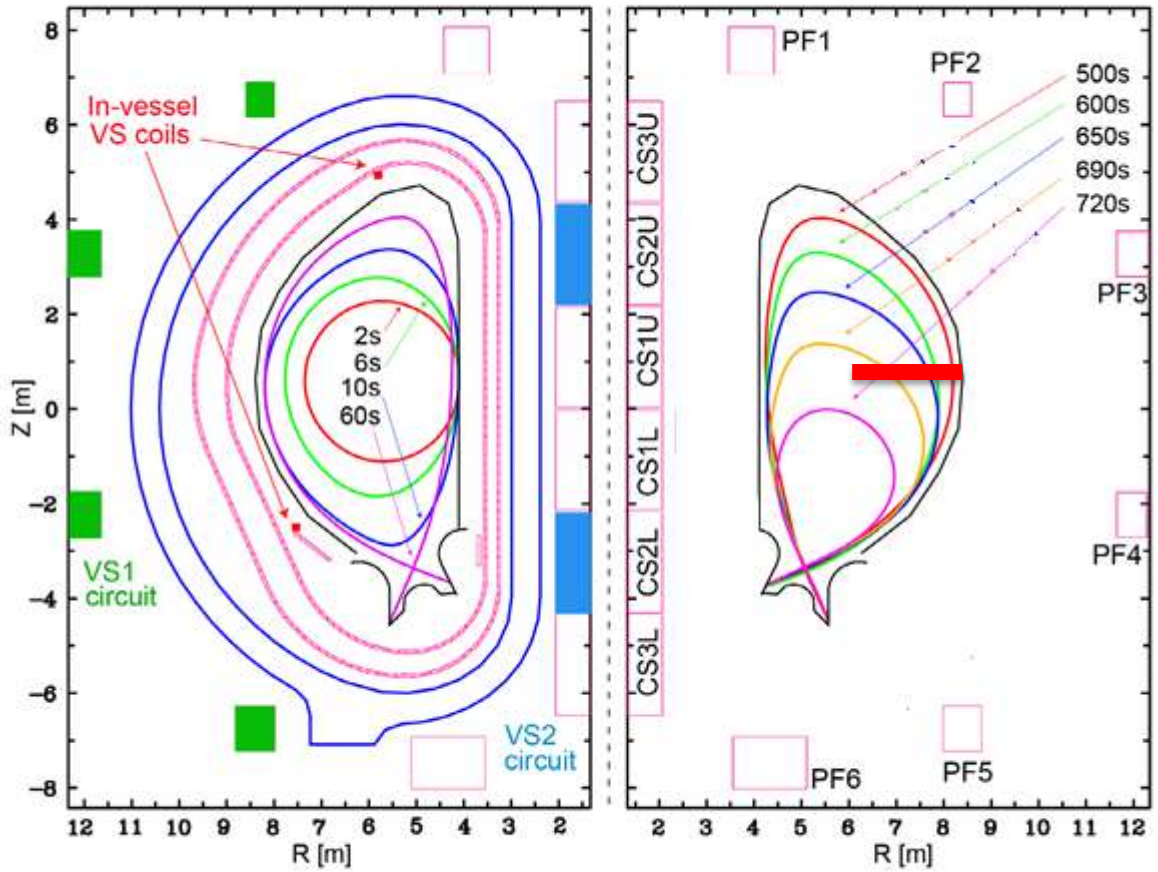
ITER some of the essentials to contextualize

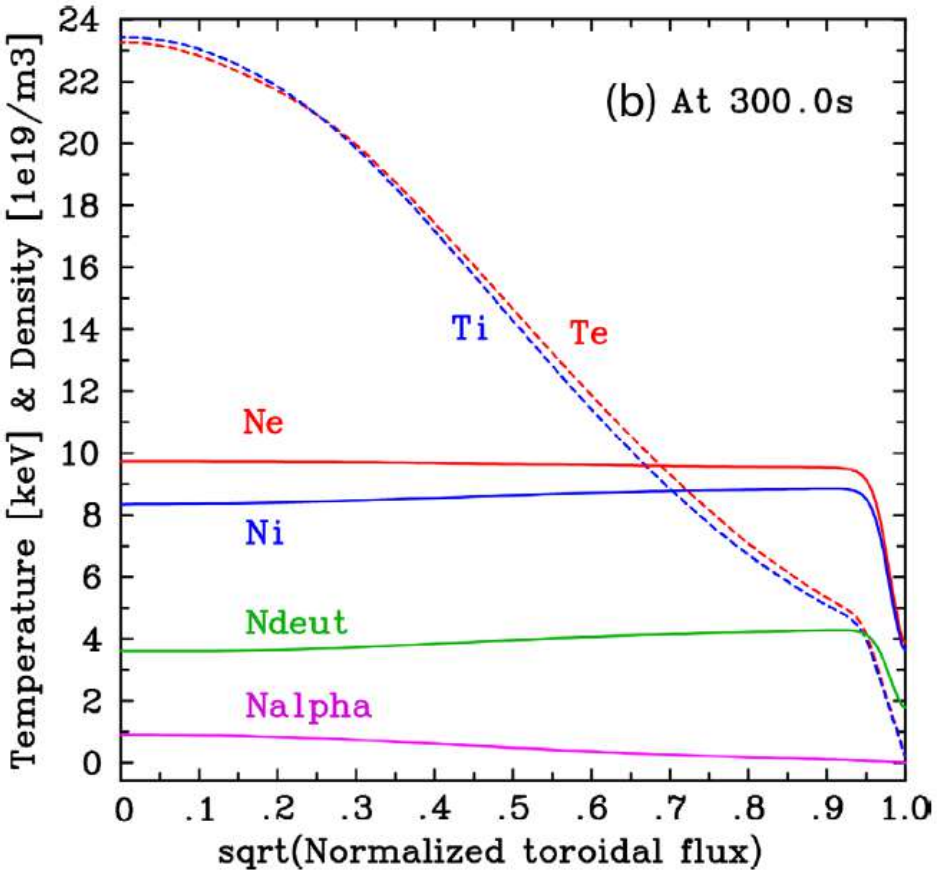
- Temperature ~250 Million K
- 5.3T magnetic field @6.2m
- Carries a large current (15MA)
- Large (>800m^3) Vacuum Chamber (use D_2 and T_2)
- Sitting inside a large cryostat
- Neutrons produced in the process (D and T→ 14.1MeV)
- Very large plant infrastructure (as seen)
- Long pulse operation (>400s)
- For diagnostics- Industrial scale approach needed

Why do we need Diagnostics?

Q=10 scenario with (ELMy H-mode):

I_p= 15MA, P_{aux}= 50MW, $H_{98(y,2)}$ = 1





No other way to know what is happening?

Let’s take a look at what is needed?

- 50 different diagnostics identified for different measurement roles;
- Just over 100 projects in all;
- In all phases now including delivered and installed;

PBS55 - Diagnostics
A- Magnetics systems
B- Neutrons systems
C- Optical systems
D- Bolometry systems
E- Spectroscopy systems
F- Microwave systems
G- Operational systems

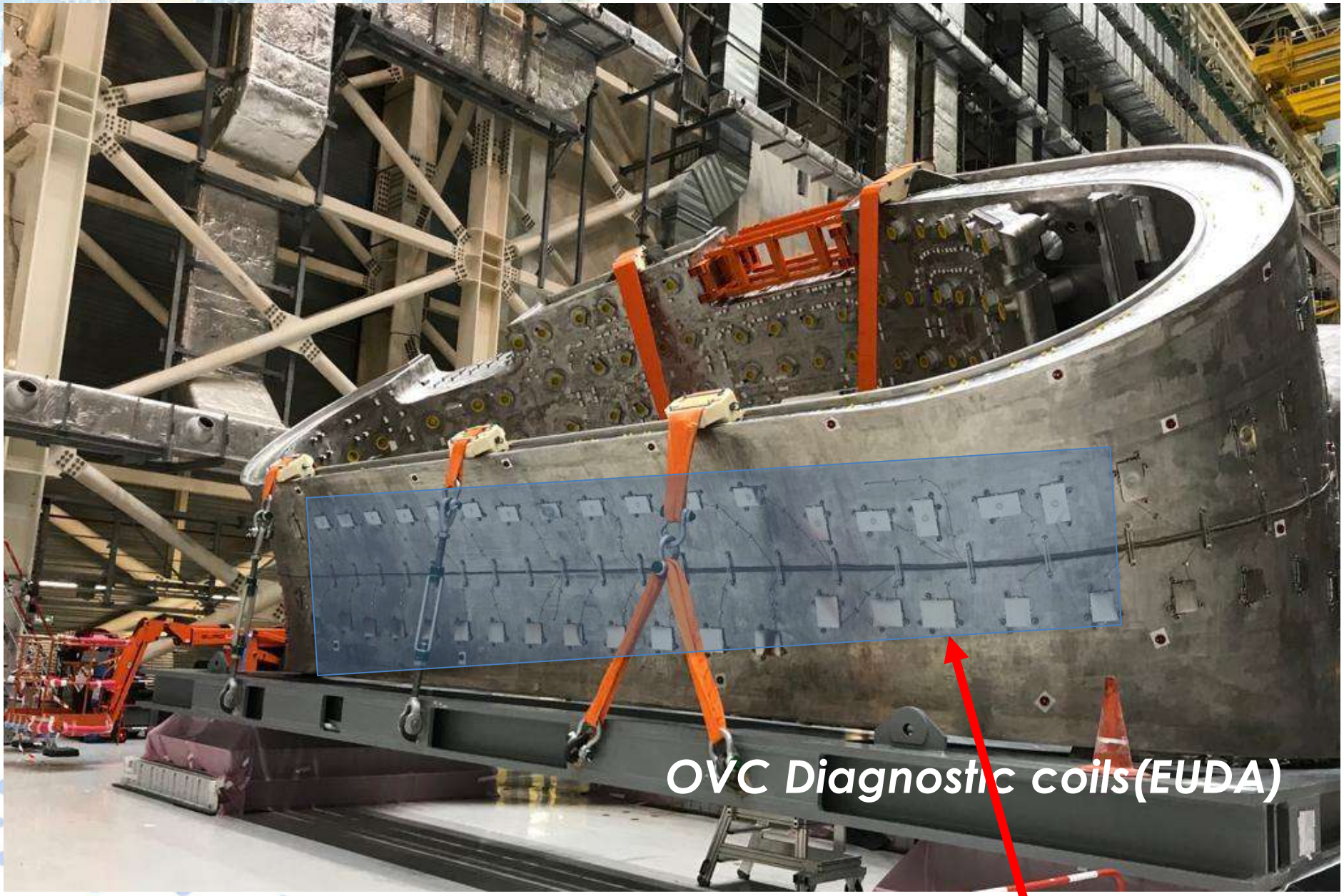
PBS55-Engineering of:
Q- Equatorial Ports
U- Upper Ports
L- Lower ports
NW- Windows
NE- Electrical Services

PBS57- IVVS
+PBS58- PPTF
+TSM

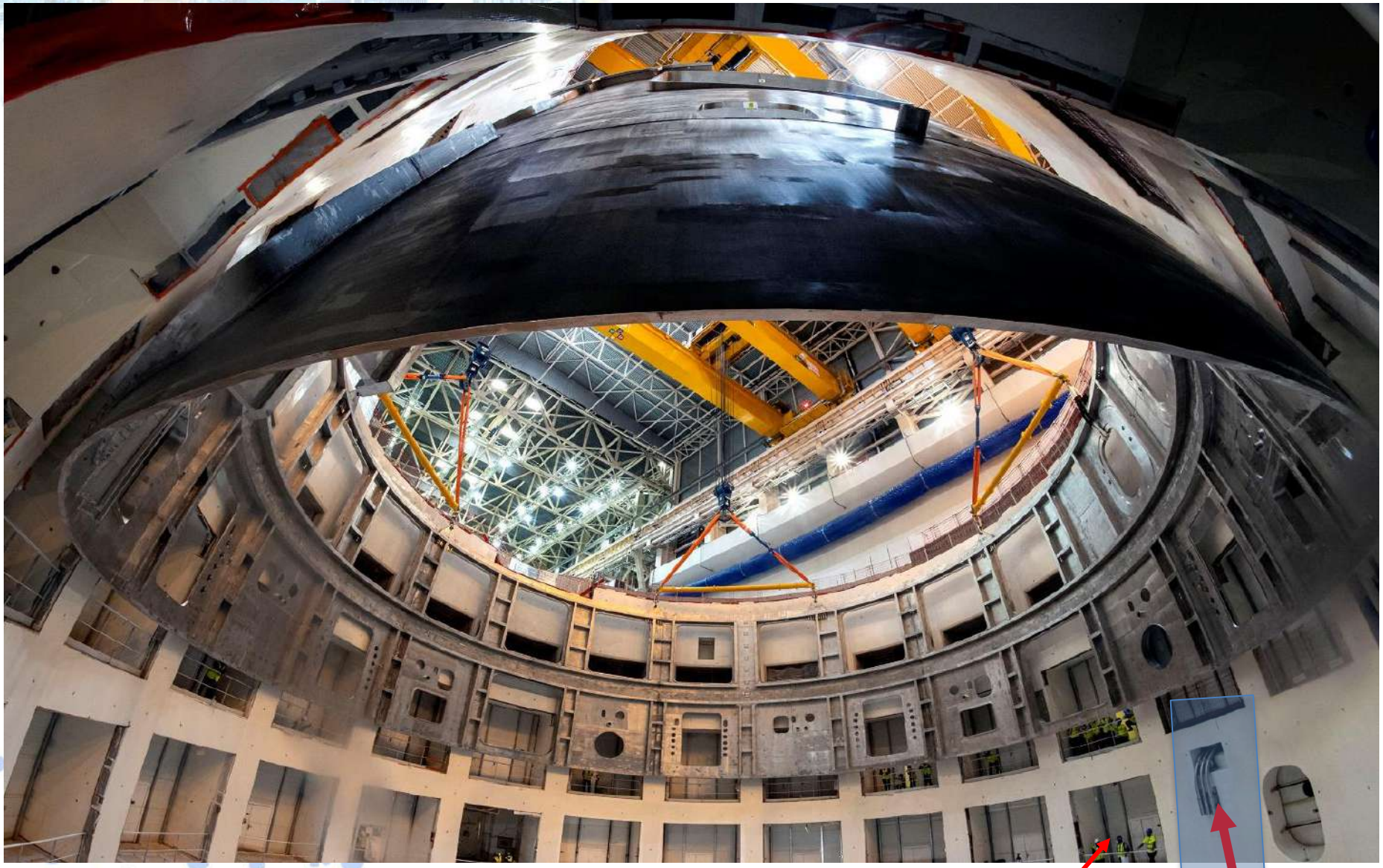
But much work still to do in all areas

A few examples of work done and Delivered

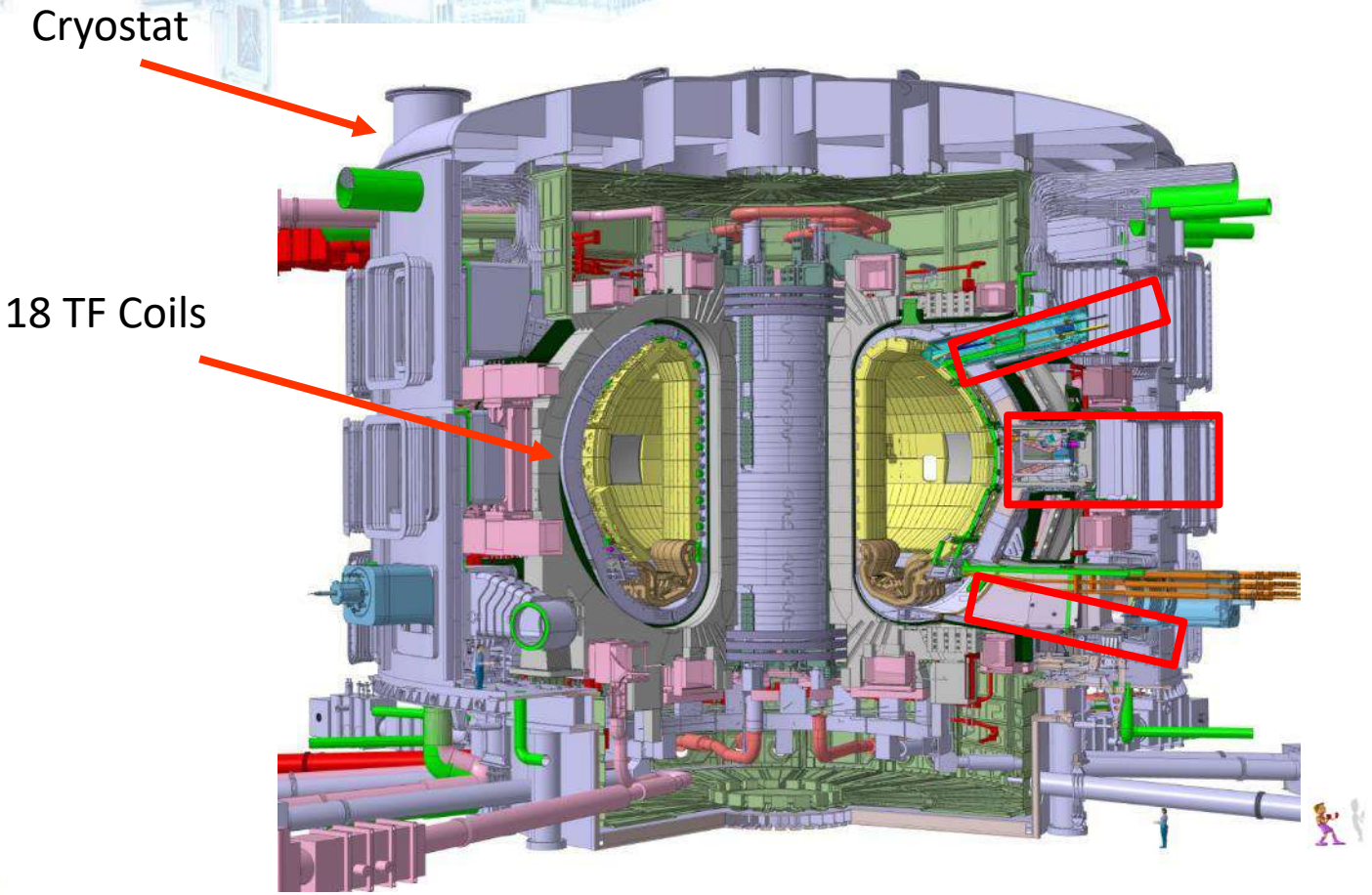
Outer Vessel Diagnostic Coils fully installed on the Vacuum vessel Sector 6(KODA)



Neutron Flux Monitor Installation before Cryostat



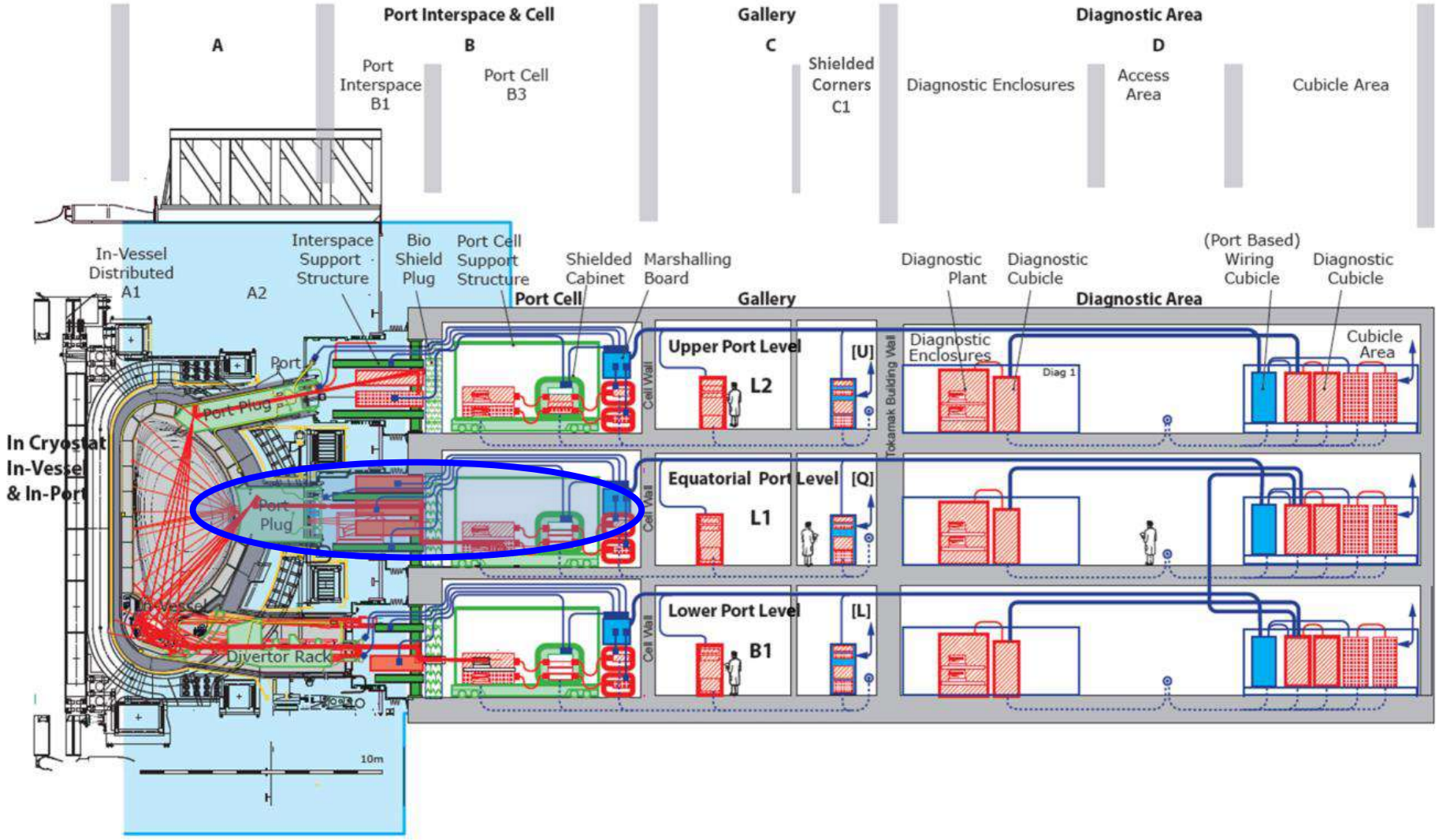
Engineering and ports on ITER



INB174

Many components in ITER have confinement functions and hence they are nuclear components

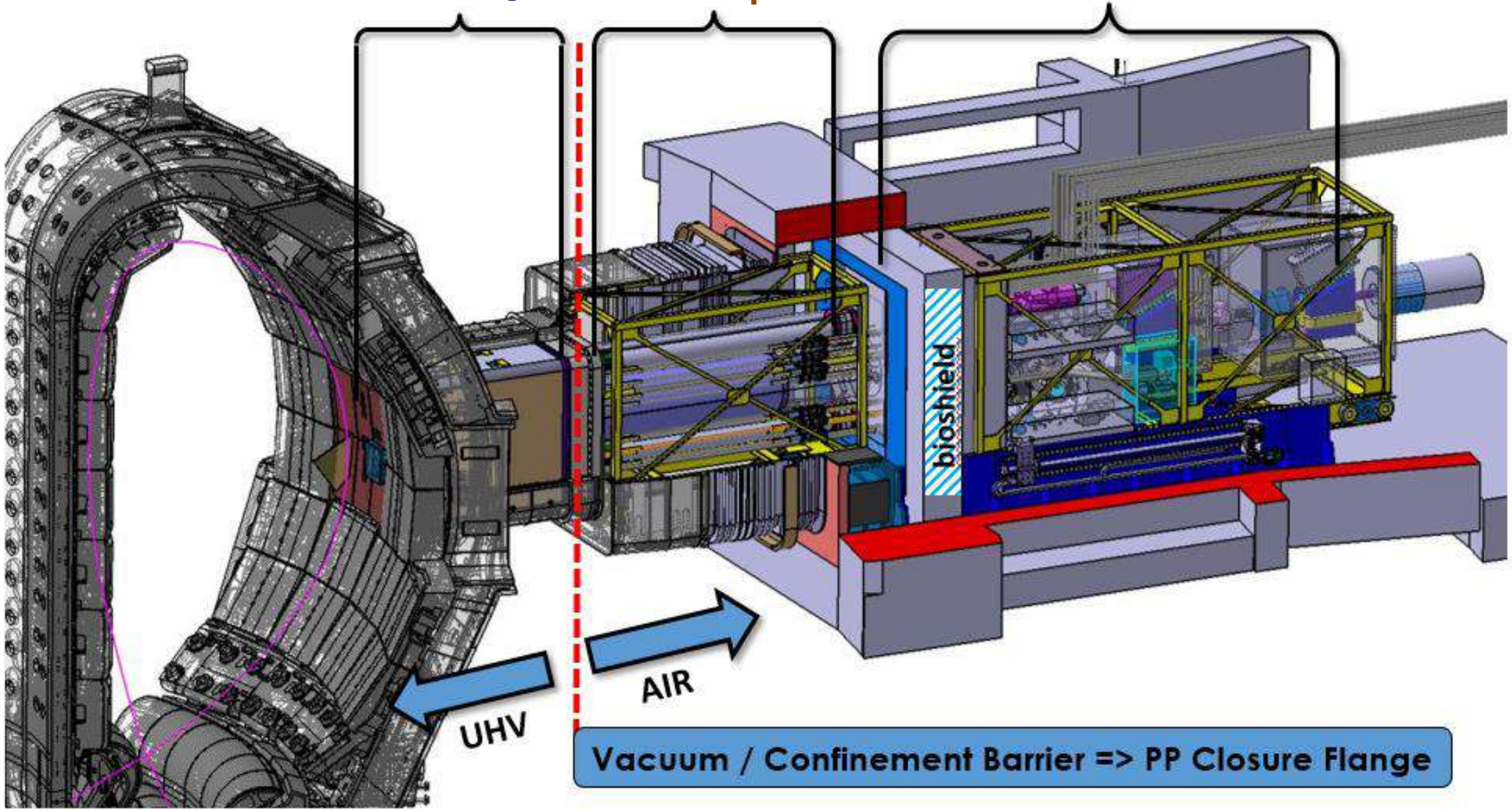
This is how it fits in Overall



Context for the scope of integration contracts

Contract => In-Vessel Part:
Port-Plugs

Contract => Ex-Vessel Part:
Inter Space
Port Cell



Now the work that needs to be done

Procurement and Integration of IO Port Plug Assemblies (ex-vessel)

Contract: Procurement and Integration of IO Ports (ex-vessel)

The purpose of this Contract is for the procurement and integration of *Ports Port Cell equipment* (Inter Space and Port Cell Support Structures) for the Equatorial Ports Assemblies #8 & 17 [X2]

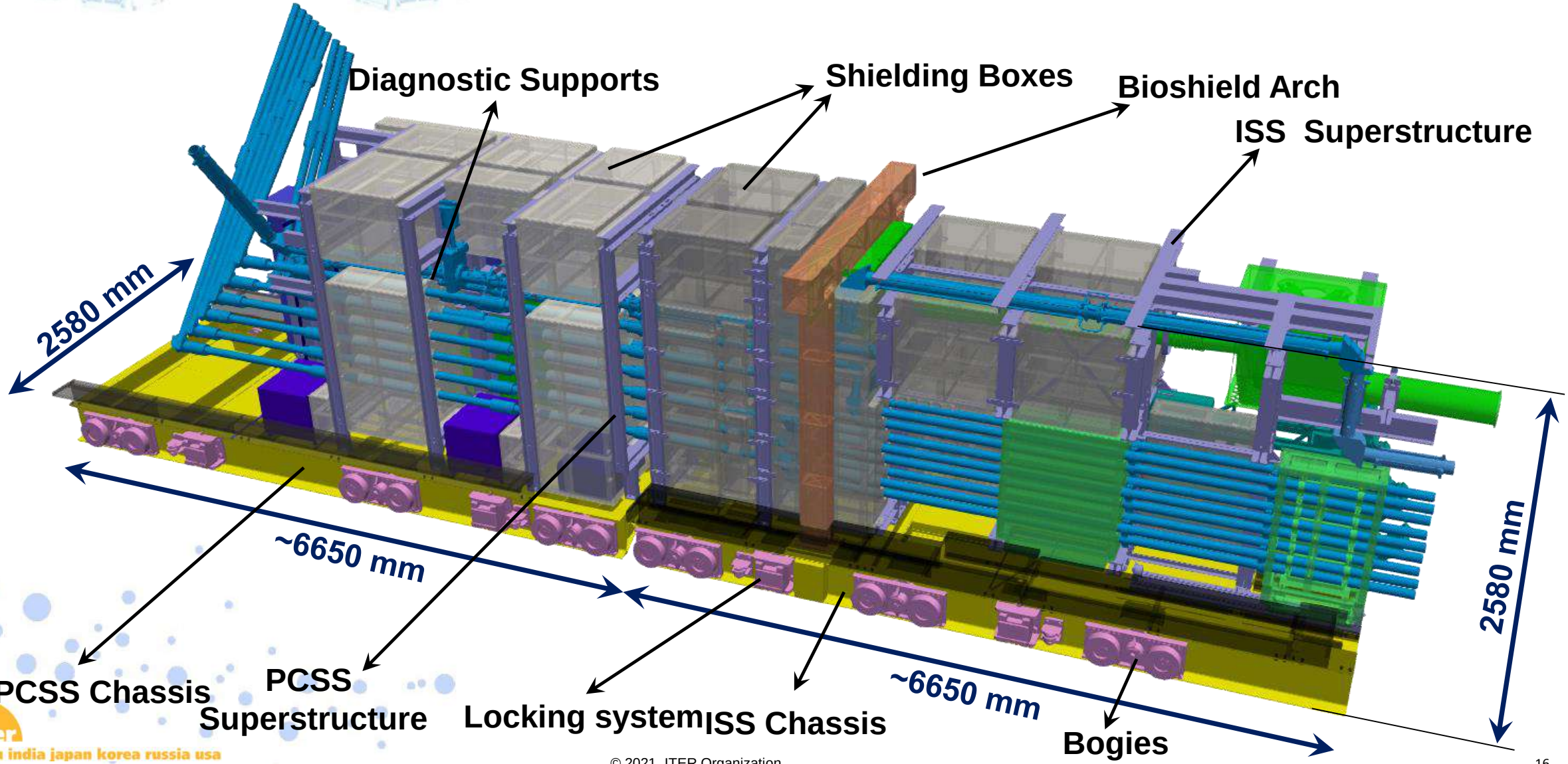
The Scope includes:

- Manufacturing of chassis, superstructures and shielding boxes (metallic structure type SS 316L low Co filled with borated concrete)
- Manufacturing and assembly of mechanical components (supports, bogies, locking system… SS 316L low Co)
- Pre-assembly and pre-integration of components and diagnostic related services at supplier premises (piping, diagnostics, electrical services…)
- Steelwork: 15 tonnes in ISS + 11 tonnes in PCSS typical – SS type 316L low Co

Launch date: : Q2 2021.

Contract: Procurement and Integration of IO Ports (ex-vessel)

PCSS assembly [typical weight 52 tonnes]ISS assembly [typical weight 61 tonnes]



Procurement and Integration of IO Port Plug Assemblies (in-vessel)

Procurement and Integration of IO Port Plug Assemblies(I)

The purpose of this Contract is for the procurement and integration of ITER-In Port Plugs and sub-assemblies for three Equatorial Port Plugs Assemblies and three Upper Port Plug Assemblies

An option to add one lower port will also be included

Contract: Procurement and Integration of IO Port Plugs (in-vessel)

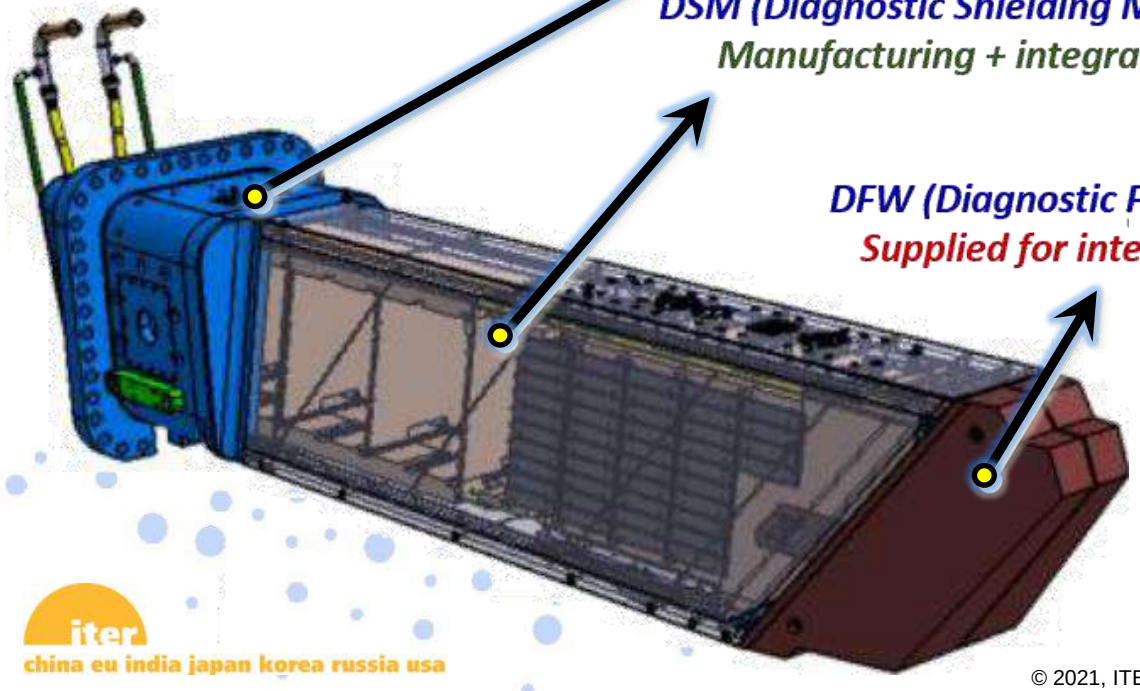
The Scope includes:

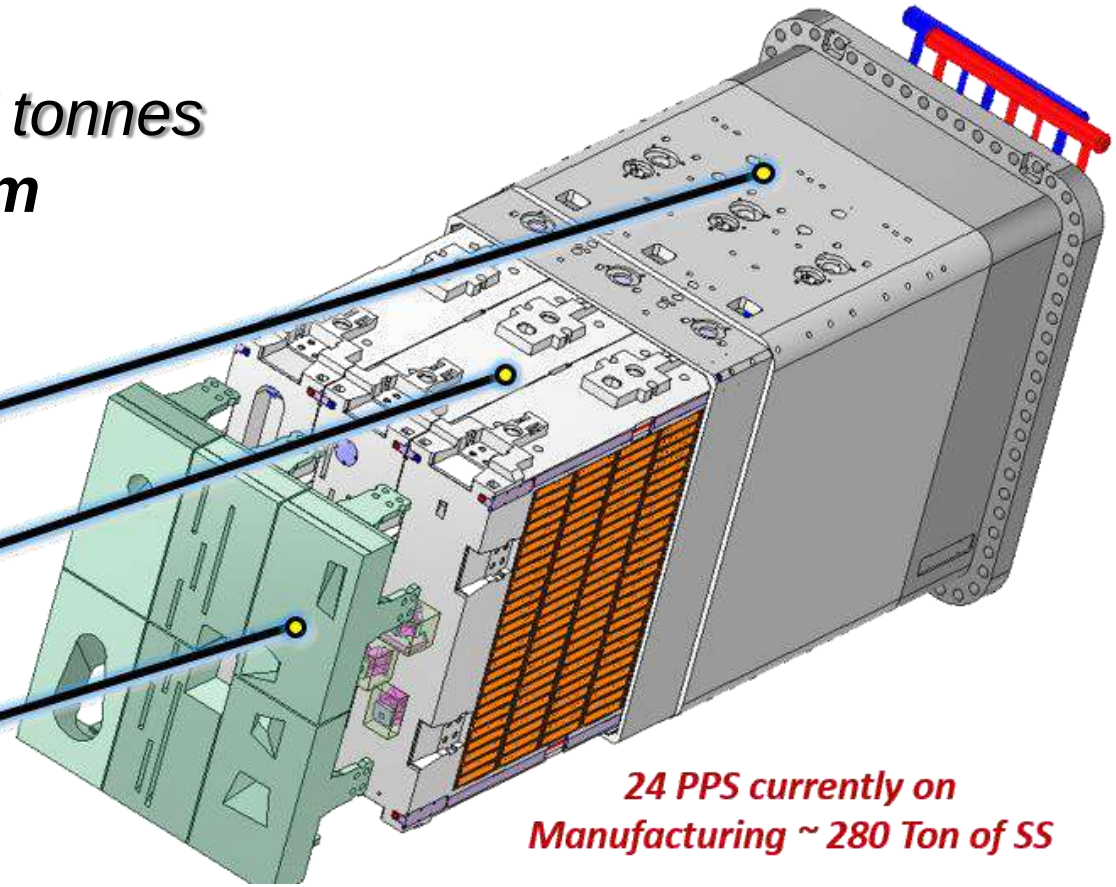
- Manufacturing of DSMs [UPPs and EPPs] (SS 316L low Co)
- Manufacturing of and assembly shielding trays [B4C procurement excluded], SS backfilling elements and internal piping (SS 316L low Co)
- Assembly and integration of diagnostic and related services (piping, diagnostics, electrical services…)
- Steelwork/port: 6 tonnes in UPP per DSM [~18 tonnes] + 8 tonnes in EPP per DSM [~50 tonnes] – SS type 316L low Co

Launch date: : Q2 2021.

Contract: Procurement and Integration of IO Port Plugs (in-vessel)

3x Upper Port Plug Assembly: typical weight 17 tonnes
Typical dimensions: 6m x 1.35m x 1.36m





PPS (Port Plug Structure)
Supplied for integration

DSM (Diagnostic Shielding Module)
Manufacturing + integration

DFW (Diagnostic First Wall)
Supplied for integration

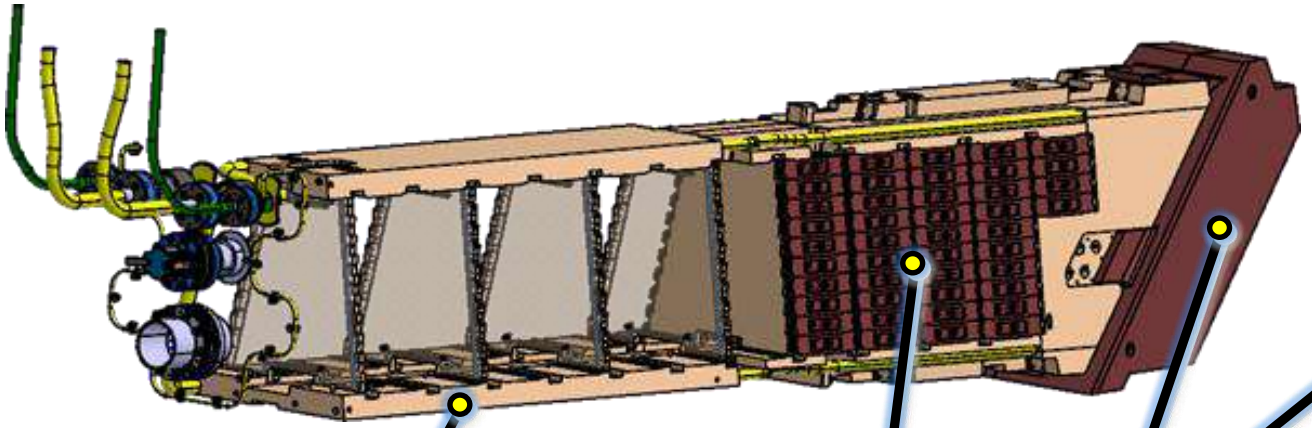
24 PPS currently on Manufacturing ~ 280 Ton of SS

2x Equatorial Port Plug Assembly: typical weight 48tonnes
Typical dimensions: 3.3m x 2.4 m x 1.95m

iter
china eu india japan korea russia usa

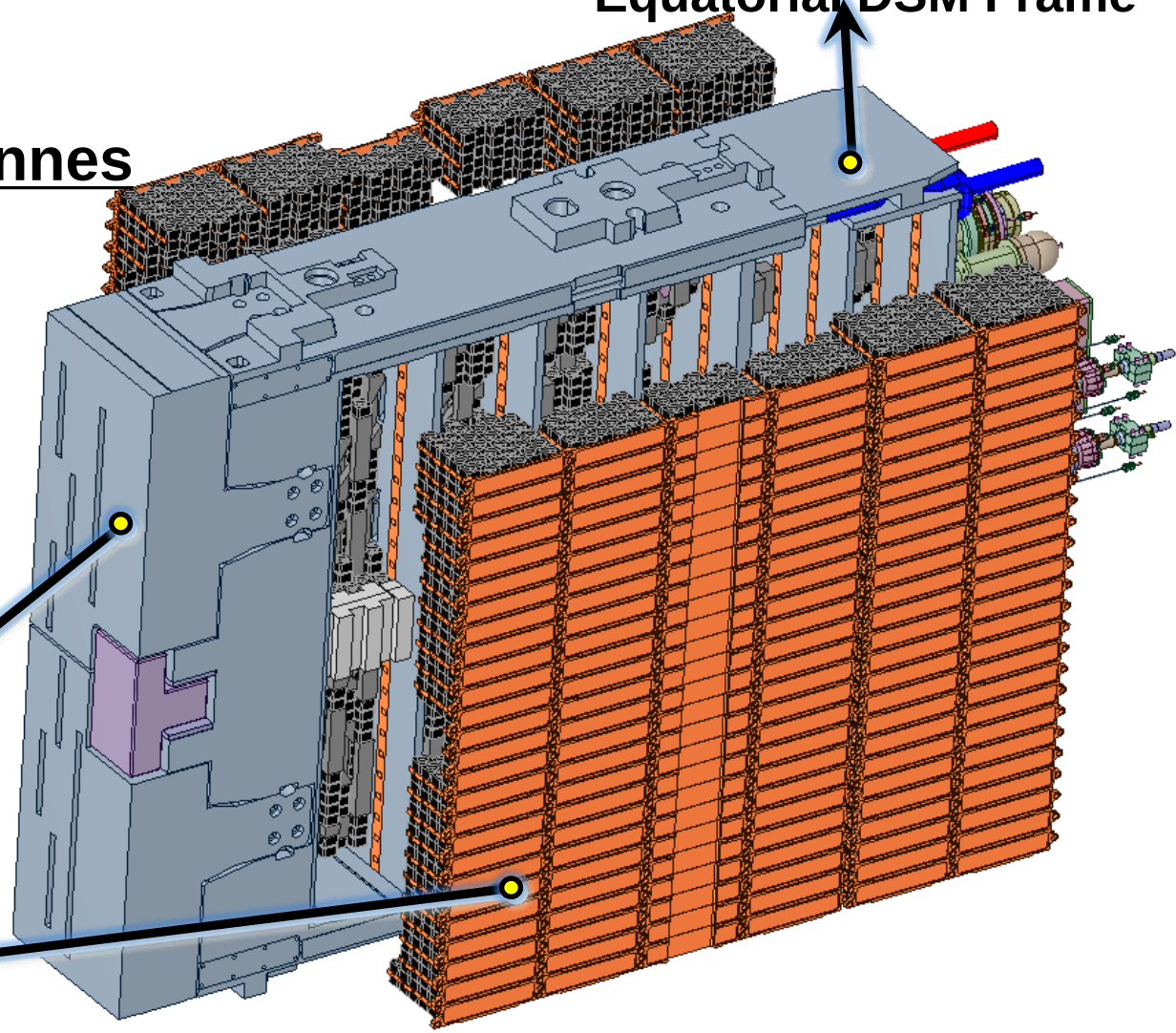
Contract: Procurement and Integration of IO Port Plugs (in-vessel)

Upper DSM Assembly: typical weight 6 tonnes



Upper DSM Frame

Shielding Trays



Equatorial DSM Assembly: typical weight 8 tonnes

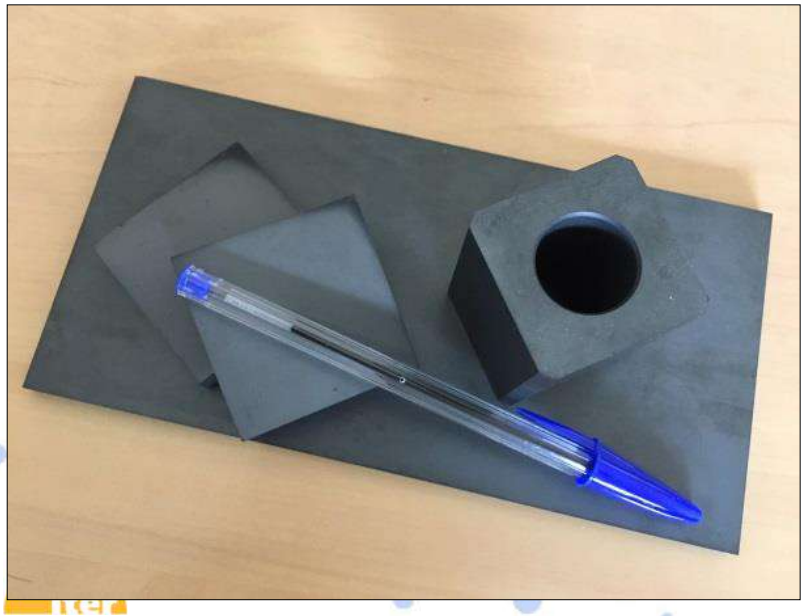
Boron Carbide Shielding blocks Contract

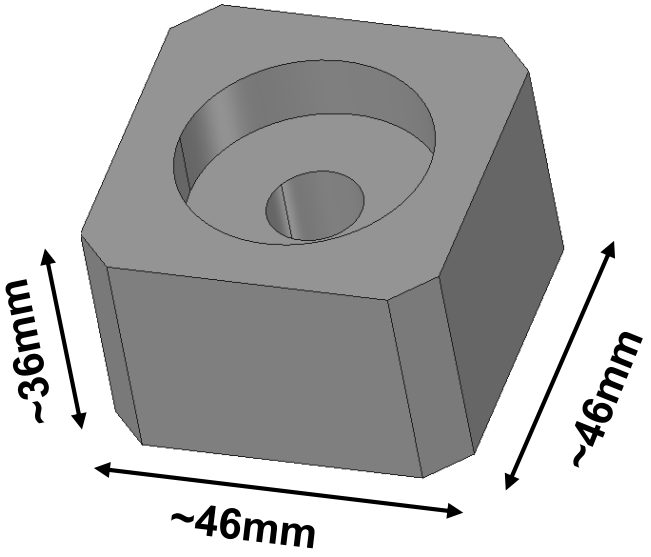
Procurement of B4C for shielding of Equatorial and IO Port Plugs

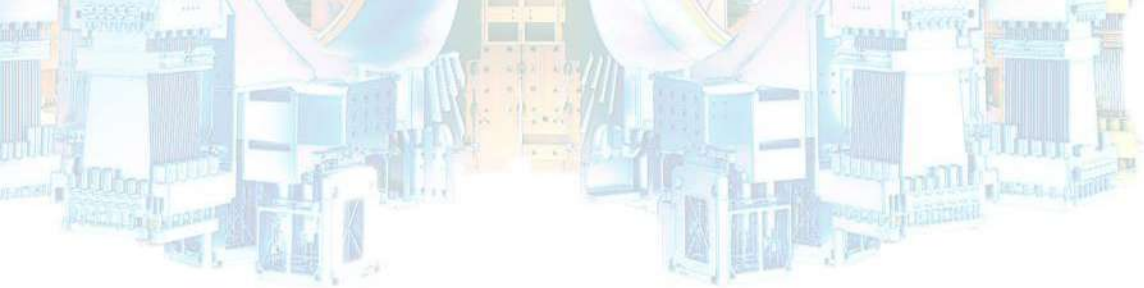
The purpose of this Contract is for the procurement of the B4C blocks for shielding trays in Equatorial and Upper IO Port Plugs

The Scope includes:

- B4C blocks as per given dimensions for Shielding trays in EQ#8/17 and UP#4/5/6 (100,000 blocks approx)
- Option for B4C of EQ#2 (40,000 blocks aprox)
- Maximum outgassing rate in blocks: ***1x10^{-8} Pa m^3/s m^2***
- Preferred manufacturing method: Sintered + Hot pressed





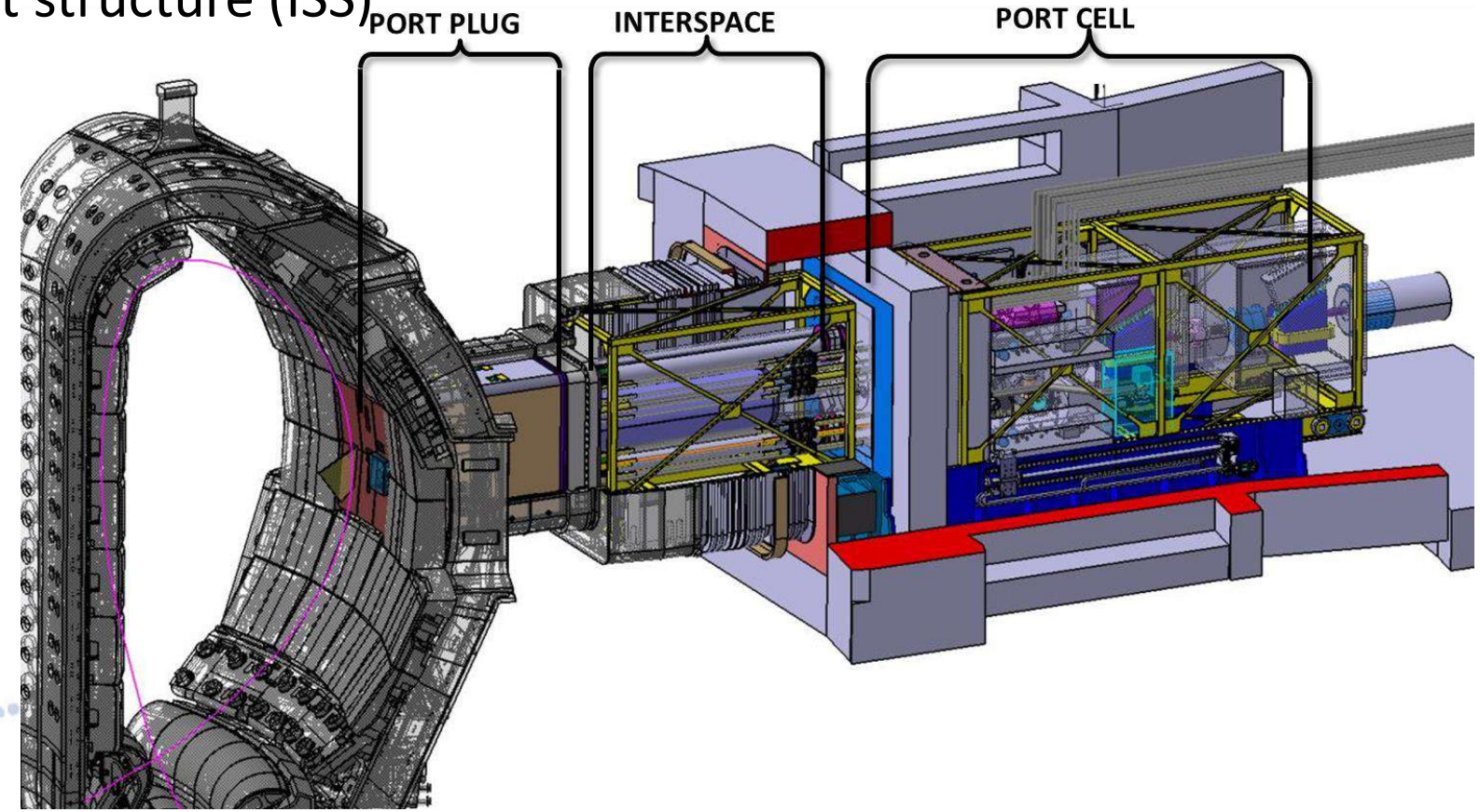


Now assembly and testing the Port Plugs is coming to the top of the work queue

Introduction to the Port Integration Facility (PIF)

The purpose of the Port Integration Facility (PIF) is the final assembly, testing and refurbishment of port equipment on ITER site in the pre-nuclear phase:

- port cell support structure (PCSS)
- interspace support structure (ISS)
- port plugs (PP)



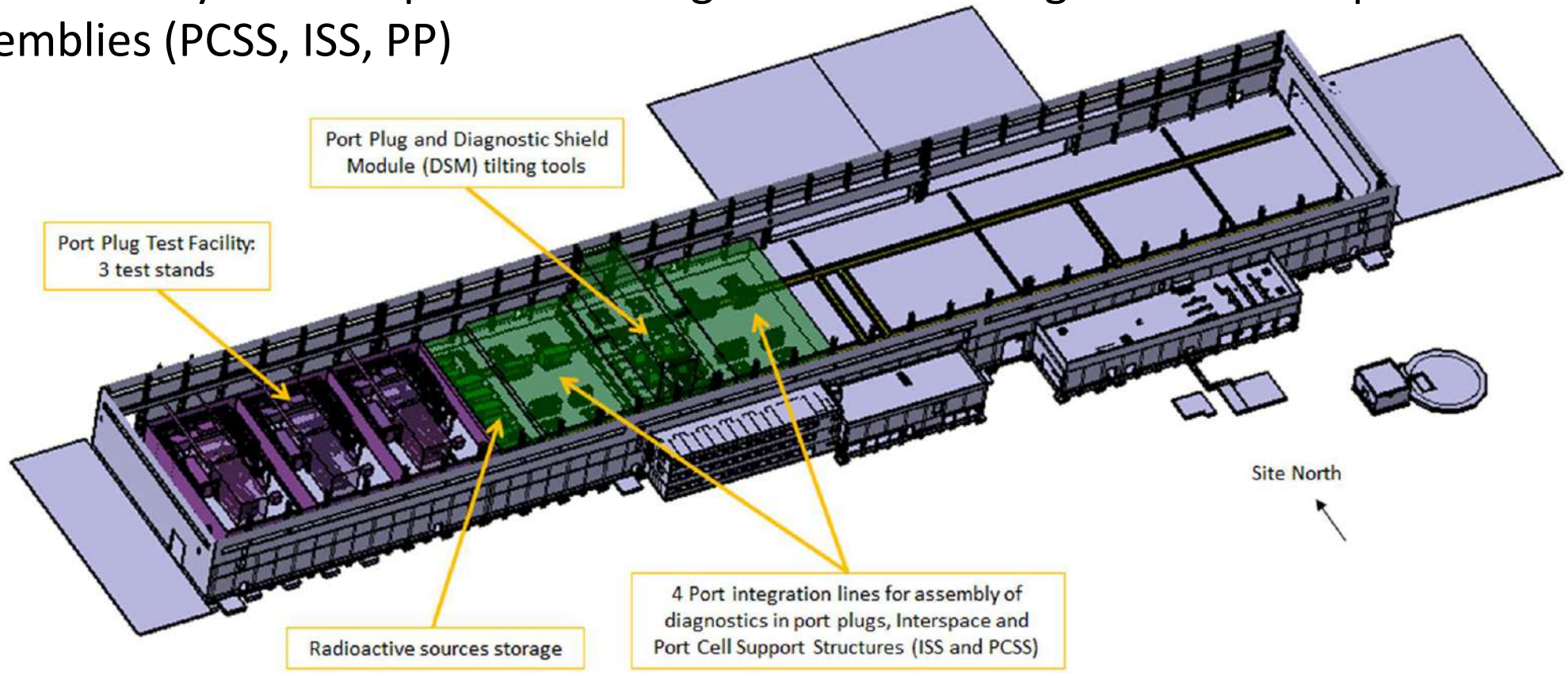
This will reside in the PF Coil Building(Building 55)

This will begin in 2022 and expand in due course

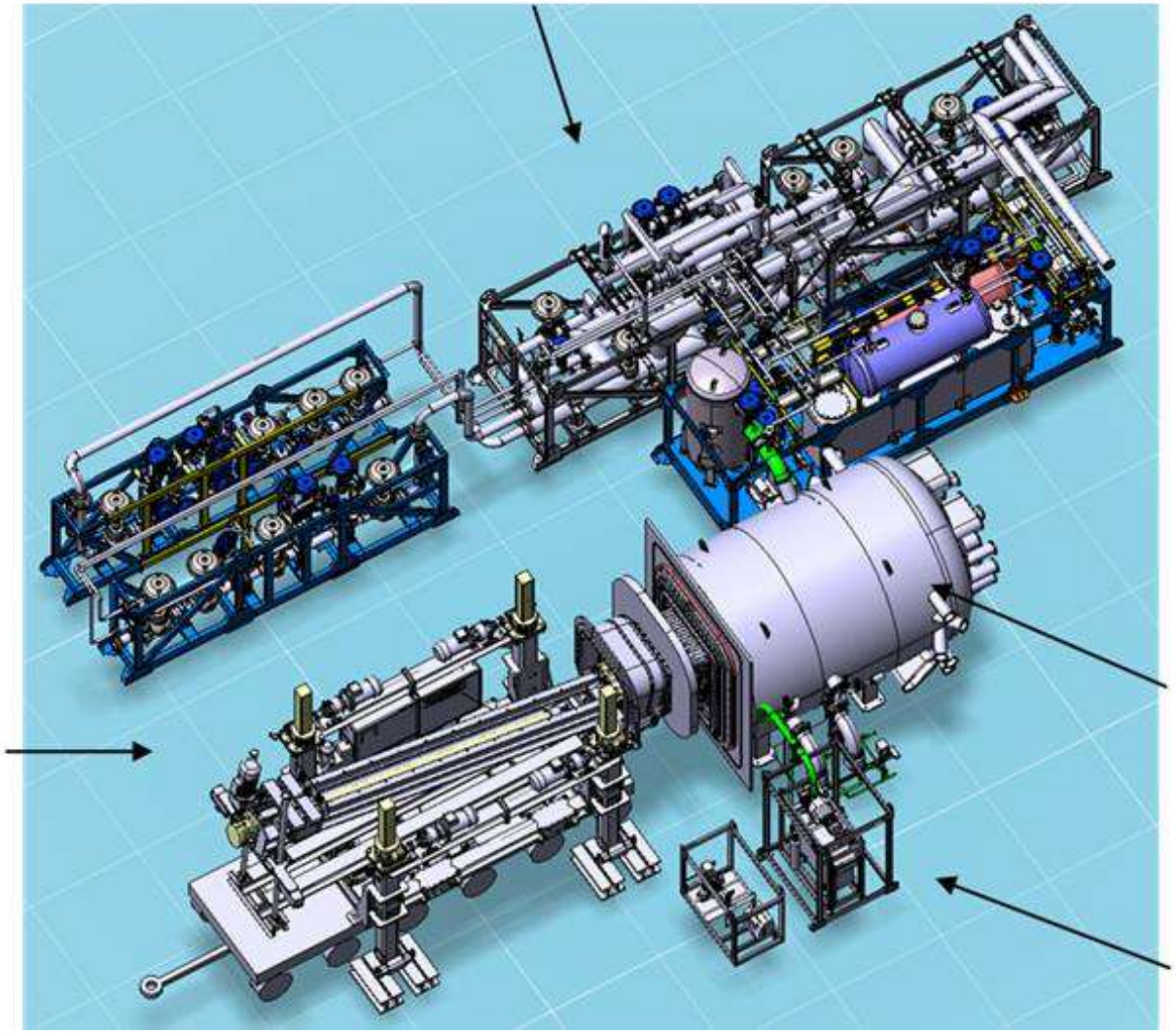
Introduction to the Port Integration Facility (PIF)

It consists in:

- 3 Port Plug Test Facilities (PPTF, being manufactured now by RF-DA), to test upper and equatorial PP, and diagnostic racks
- Port assembly workshops for the integration of the diagnostics in the ports' sub-assemblies (PCSS, ISS, PP)



One PPTF Assembly Shown



32m X 19m

To do the assembly in the PIF, firstly we need tools

Engineering design of Port Integration Facility and tooling FWC

The contract consists of:

- Procurement of the standard tools
- Design, manufacturing and delivery of the non-standard handling tools and testing equipment
- Design and equipment of the workshops

The tools will look something like above

Or this one

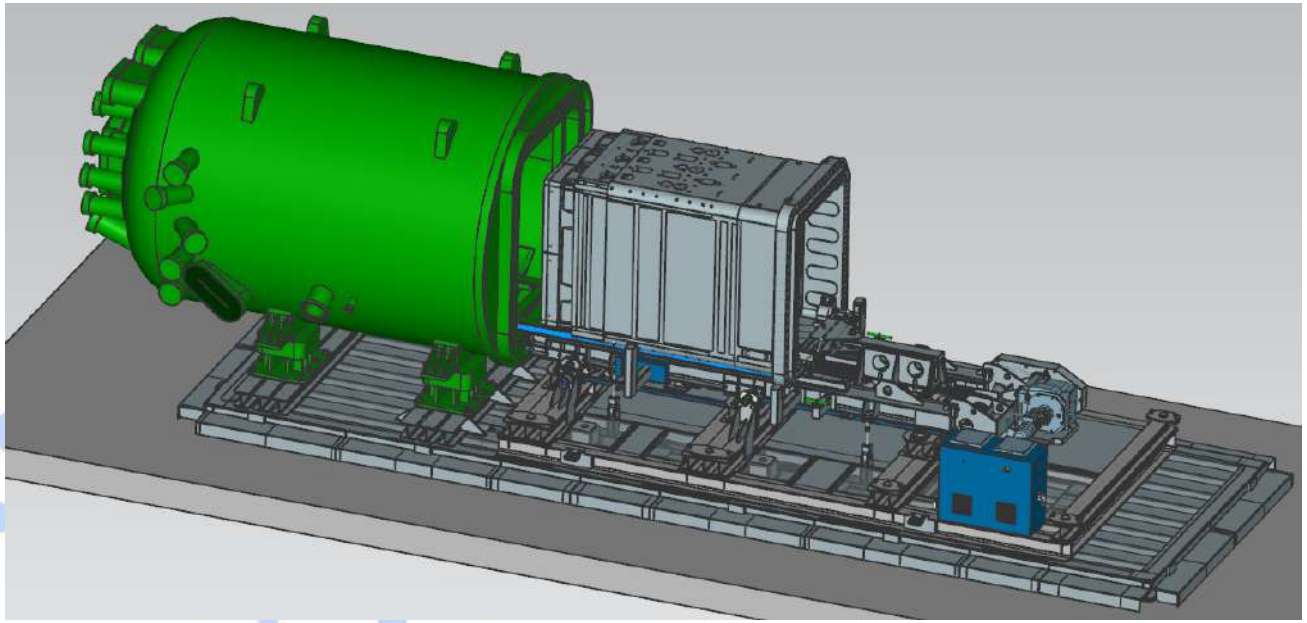
Launch date: : Q2 2021.

To do the assembly in the PIF, we need a team to do the assembly and testing of all the ports

Port Integration Facility Service and Management FWC

The purpose of this contract is to perform the assembly and tests of the port structures in the PIF during the ITER Assembly Phases 1 to 4 defined for the staged approach:

- Final assembly and refurbishment of the PP,
- PP testing before installation in the tokamak,
- PP refurbishment (first plasma PP and PP that failed the PPTF tests),
- Assembly of the ISS and PCSS of all the diagnostic ports.



Estimated Work:

- Commissioning of 3 PPTF test stands
- 25 Port Plugs to test in the PPTF
- 26 ISS + 26 PCSS to assemble or refurbish
- This will be an important team to bring these ports to full readiness before insertion in the machine
- This will take place over the next 4 to 8 years

Launch date: Q2 2021.

Then we also need many tools to be able to manipulate the port plugs and manage the assembly in the HotCell and in the port area around the machine

Framework Contract for Design of Tools for Port Handling in Port Cells and Hot-Cell

This tender is for supporting of design and development of maintenance tooling for port handling of diagnostic ports and components in Port Cells and Hot Cell Facility*.

**This is for the tool Design only, the manufacturing will come later in time.*

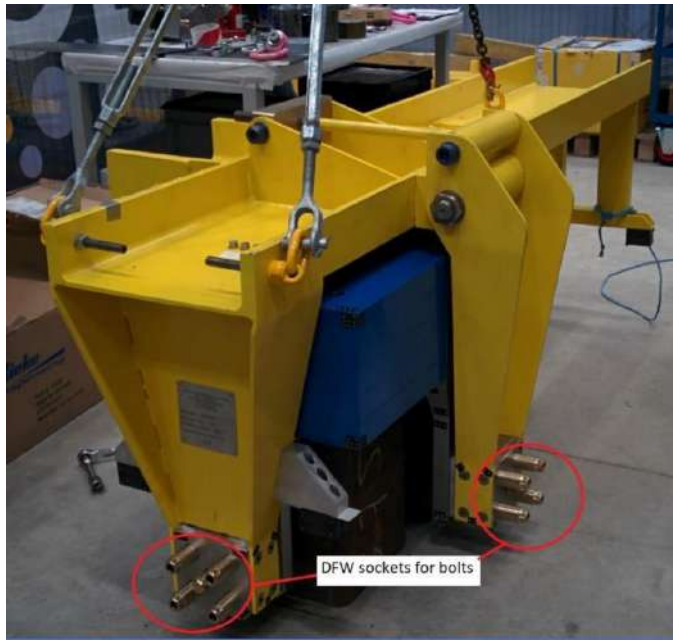
The Scope includes:

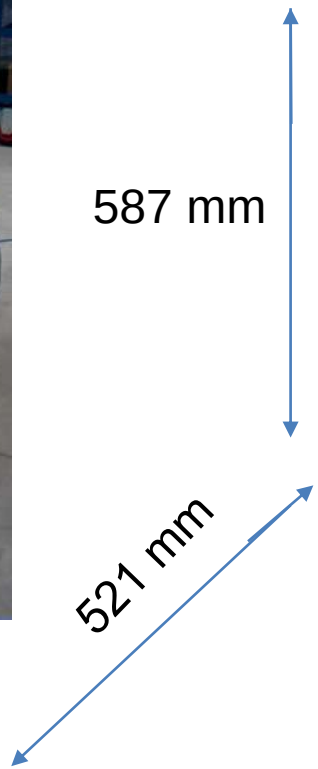
- Mechanical design and mock-ups of remote tools for port infrastructure
  - Lifting frames (for nuclear environment), end-effectors for cutting/ welding, end-effectors for articulated arms to remove/ install components, inspection tools etc to be used in the Hot Cell Facility
- Design of tools dedicated for the Port Cell maintenance of port structures and diagnostics
  - Assisted-manual end-effectors for inspection of safety-related components, tools to remove/ install shielding blocks, tools for diagnostic/ services installation and removal, cutting/ welding tools
- Structural integrity analysis of RH and Port Cell maintenance tools
- Manufacturing assessment for eventual procurement

Launch date: Q2-2021

Framework Contract for Tools for Port Handling

This tender is for supporting of design and development of maintenance tooling for port handling of diagnostic ports and components in Port Cells and Hot Cell Facility.



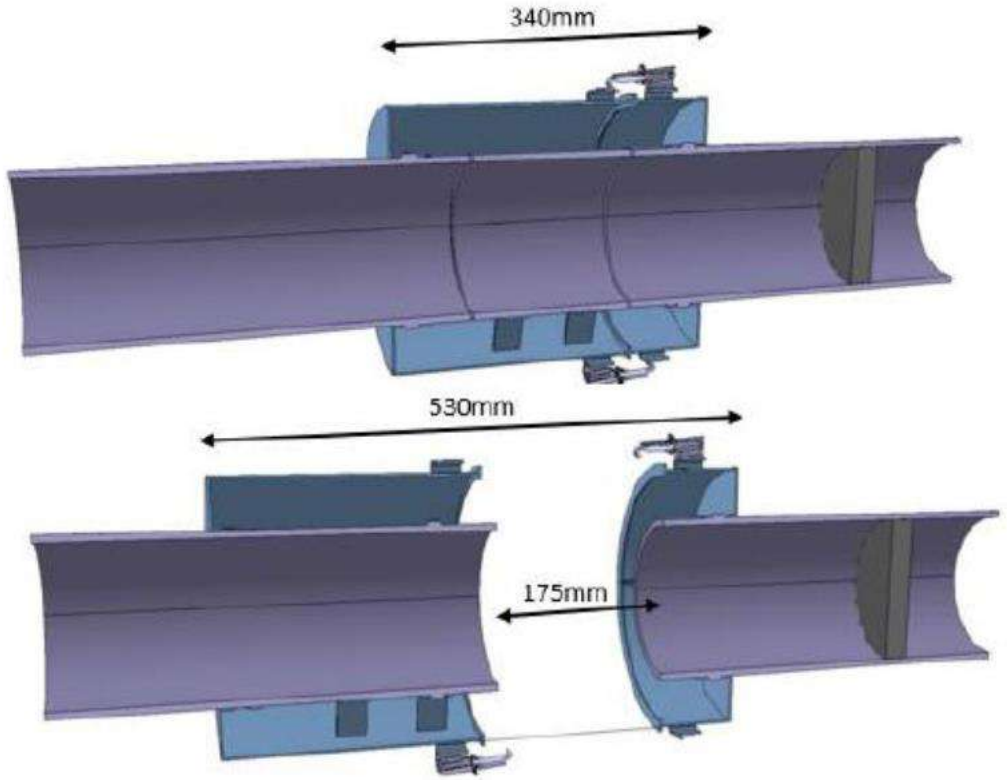


Diagnostic First Wall lifting/ handling frame (in yellow)

Inserting the DSM into the GEPP frame by means of an RH-compatible spreader (courtesy of RACE)

Framework Contract for Tools for Port Handling

This tender is for supporting of design and development of maintenance tooling for port handling of diagnostic ports and components in Port Cells and Hot Cell Facility.



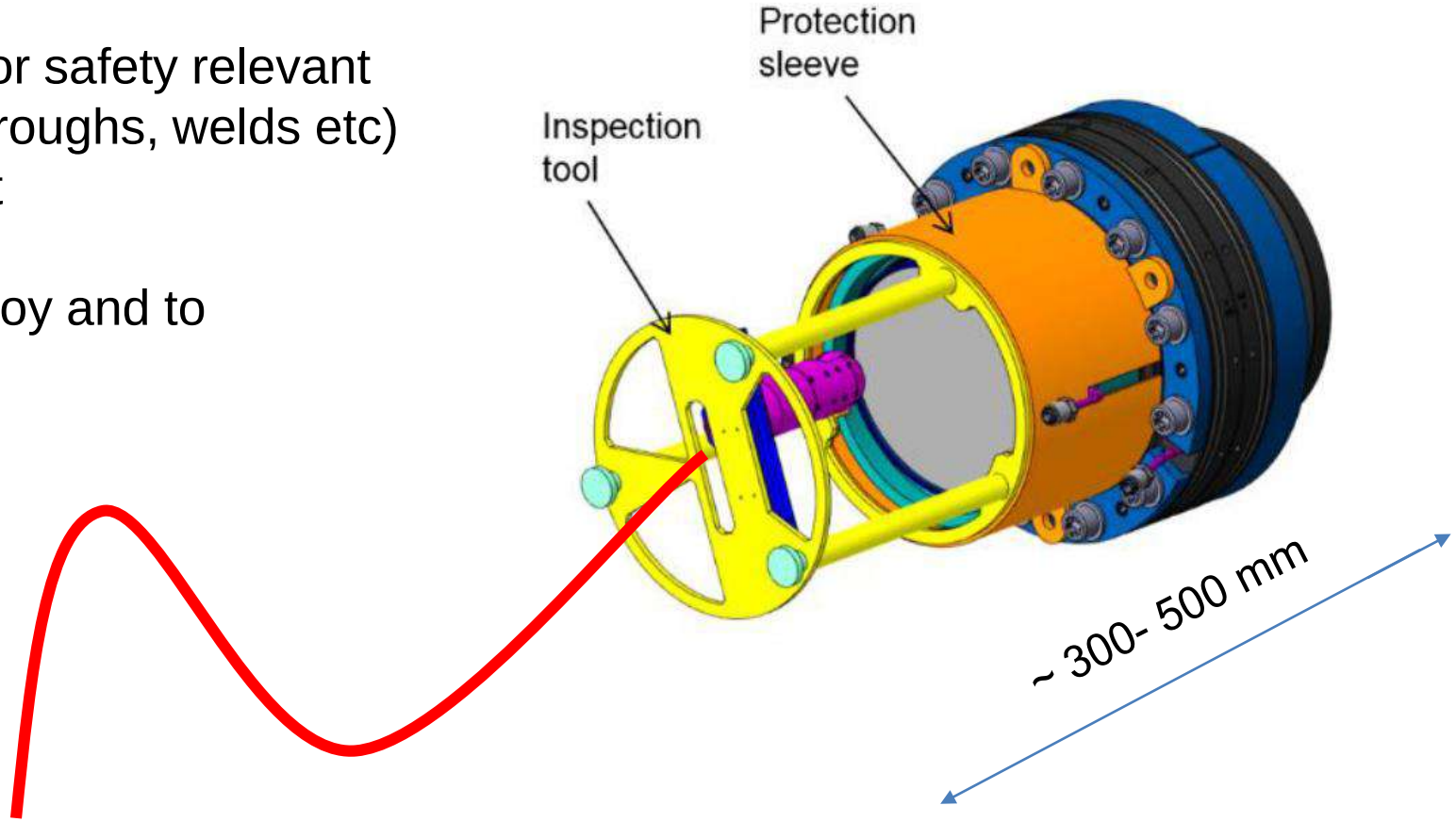
Vacuum pipe before and after cutting which has to be maintained remotely or assisted-manually (left) and a possible distantly-operated cutting robotic tool (right).

Framework Contract for Tools for Port Handling

This tender is for supporting of design and development of maintenance tooling for port handling of diagnostic ports at Port Integration Facility and Hot Cell Facility.

- To design of inspection tools for safety relevant components (windows, feedthroughs, welds etc) in harsh radiation environment
- To develop procedures to deploy and to maintain these tools

Target signature date: Q3 2022.



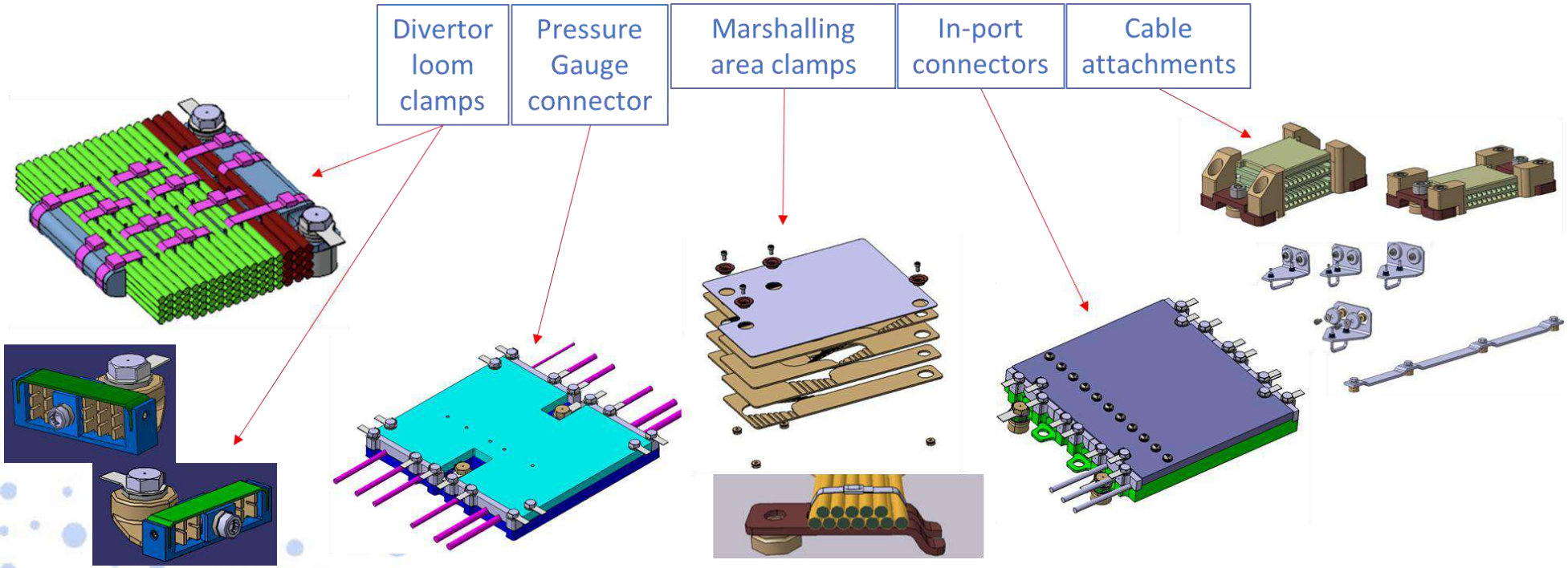
Assisted-manually operated inspection tool

Diagnostic Systems- In-vessel Wiring Components

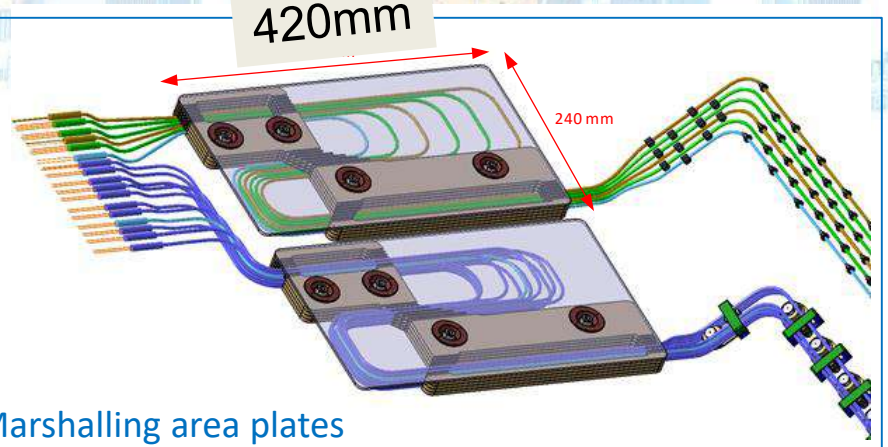
Manufacturing of Lower Port & Marshalling Area Attachments

Manufacturing Mechanical Components – Intro

- Cable clamping and connection hardware components.
- UHV components (strong emphasis on clean working, use of approved cutting fluids, etc.).
- High quality components and follow up (QC 1).
- Non-PIC/SIC.
- Materials supply (CuCrZr, Al, low impurity SS, insulation e.g. Vespel, Macor).
- Key activities: high precision component fabrication (machining, spark erosion).

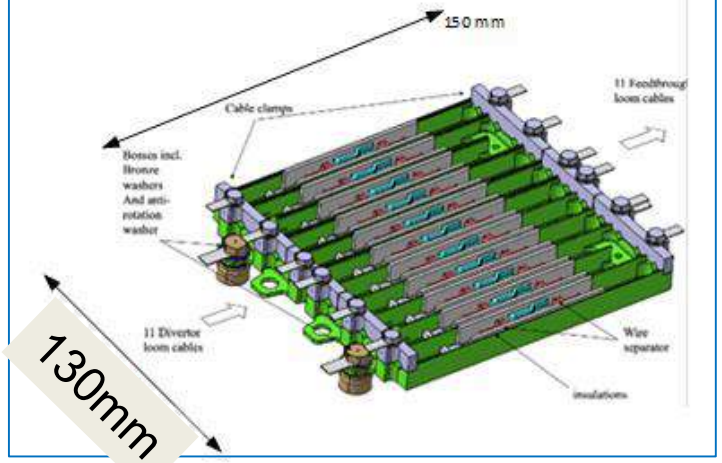


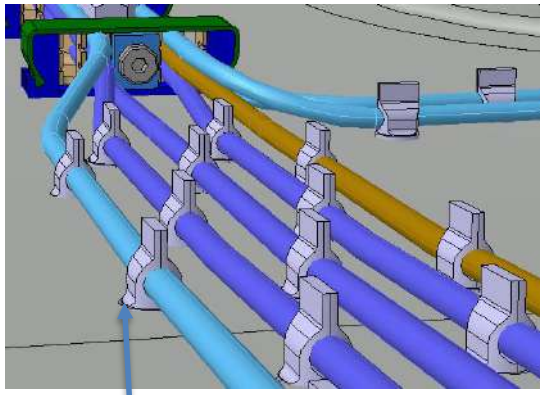
Manufacturing – Main Mechanical components



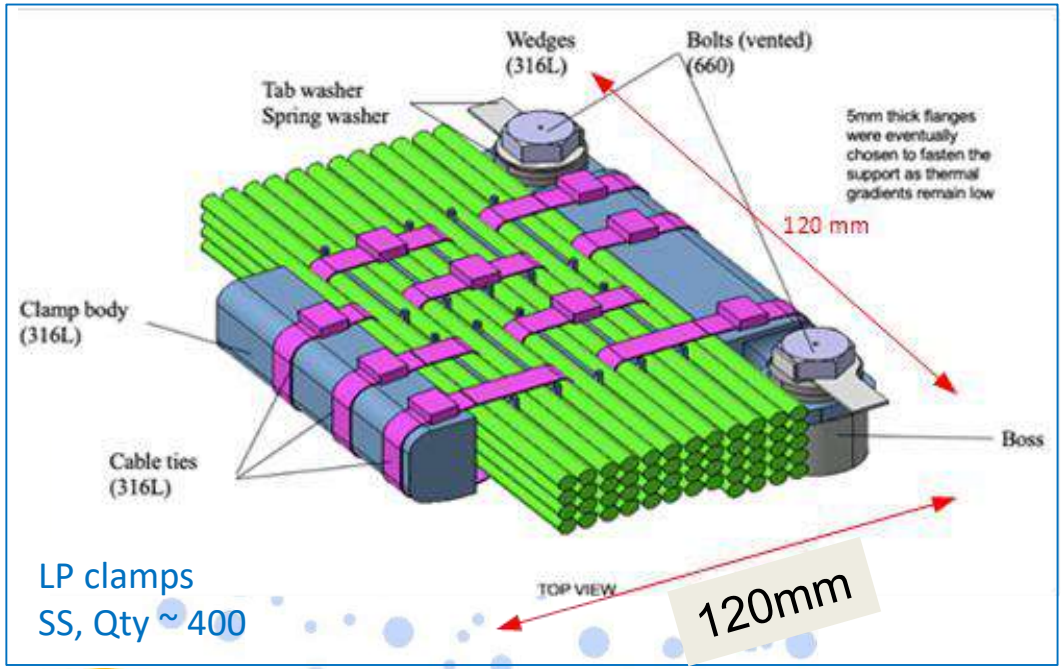
Marshalling area plates
Aluminium, Qty ~ 100

In-Port connectors
Al, Vespel/Macor, Qty ~ 420

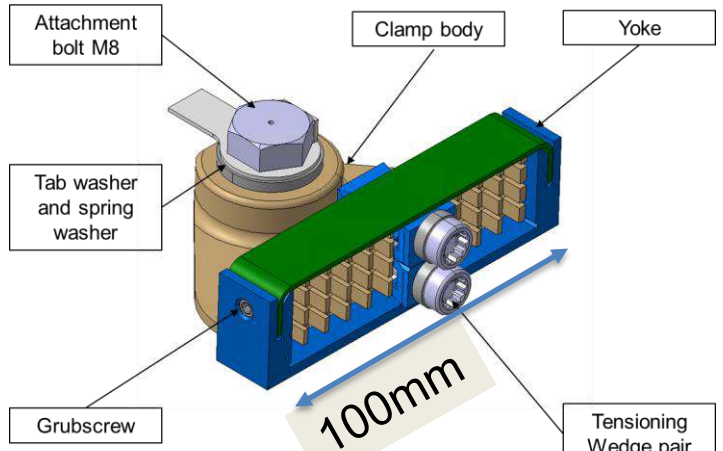




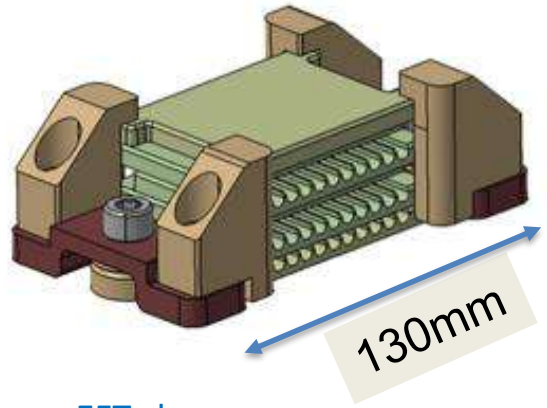
Clips
SS, Qty ~ 9200



LP clamps
SS, Qty ~ 400



CC clamps
CuCrZr, SS, Qty ~ 1120



EFT clamps
Al, SS, Qty ~ 900

Manufacturing – Summary

- Approximately 3600 multi-piece assemblies (e.g. clamps, connector boxes) and 9200 single-piece clips.

- Launch date: Q2-2021

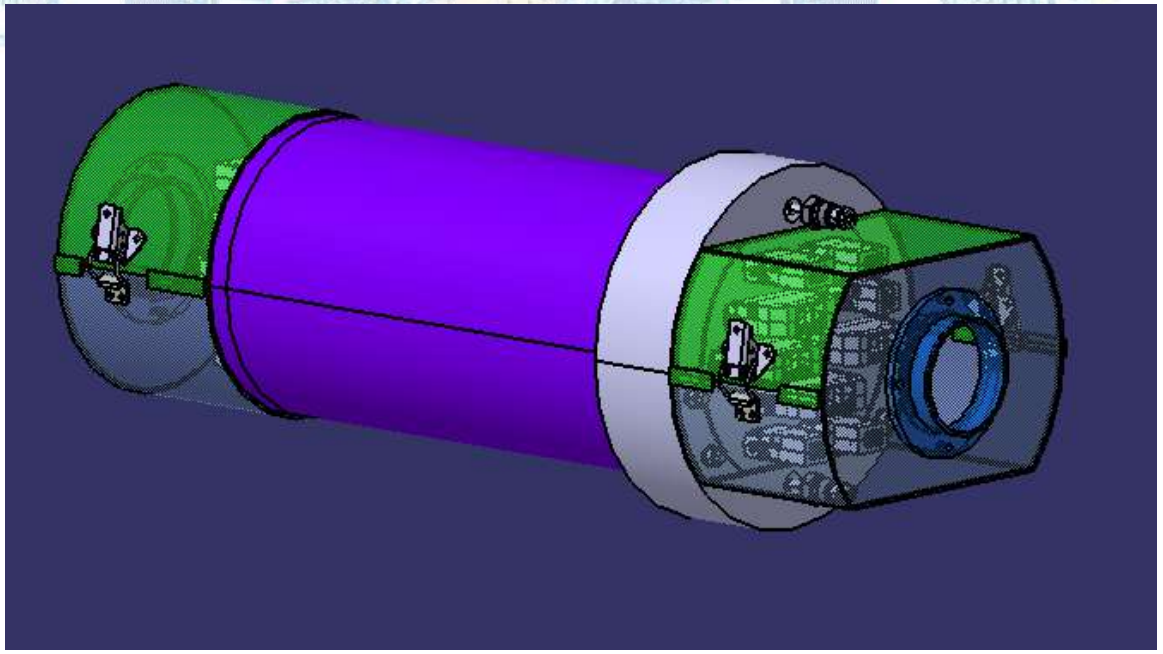
- Anticipated contract strategy: CFT

Diagnostic Systems- Cryostat Electrical Feedthroughs

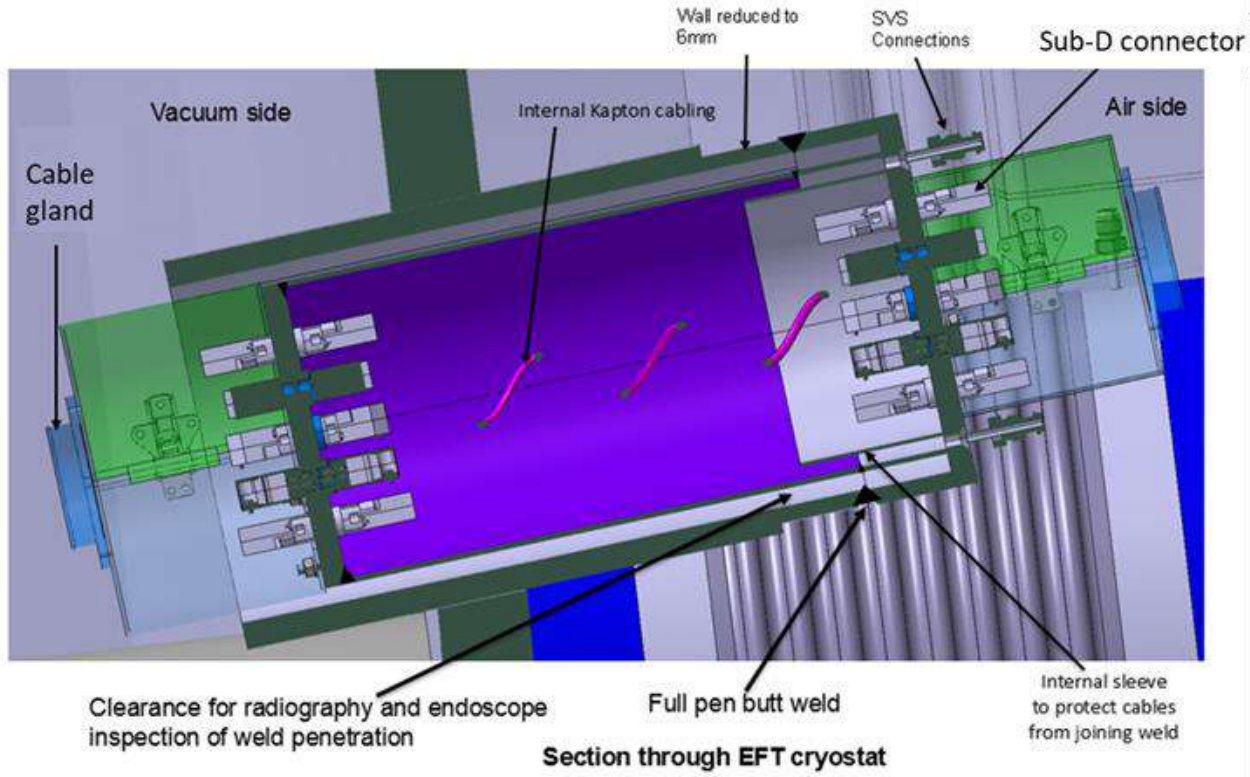
Manufacturing – Intro

- Electrical vacuum feedthroughs.
- HV components (strong emphasis on clean working, use of approved cutting fluids, etc.)
- High quality components and follow up (QC 2).
- Non-PIC/SIC.
- Materials supply (low impurity SS) + electrical feedthroughs and connectors (~ COTS).
- Key activities: machining, welding + inspection, helium leak testing, electrical connections + testing.

Manufacturing – Intro



Cryostat Electrical Feedthrough (EFT)
Qty – 9 + 1 spare
Approx dimensions: Ø 230 x 630mm



Section through EFT cryostat

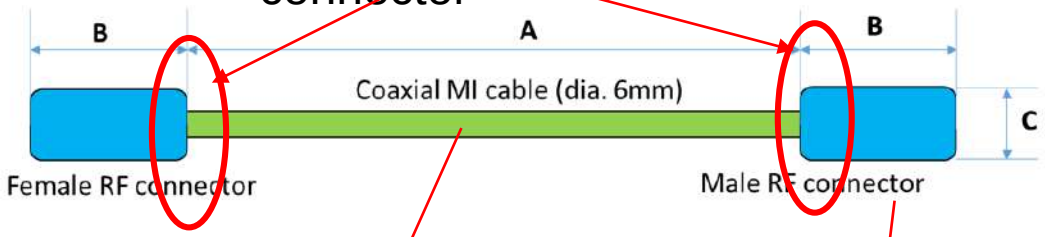
Manufacturing – Summary

- 10 EFT assemblies in total.
- Launch date: : Q2 2022.
- Anticipated contract strategy: CFT

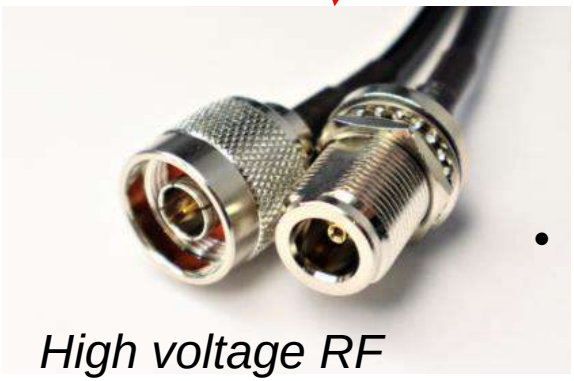
Diagnostic Systems- High Power RF Feedthroughs

Development and Supply of Coaxial Mineral Insulated Cables for High RF Power

Welded joint between MI cable and RF connector



Coaxial MI cable



High voltage RF connector

(for illustration only)

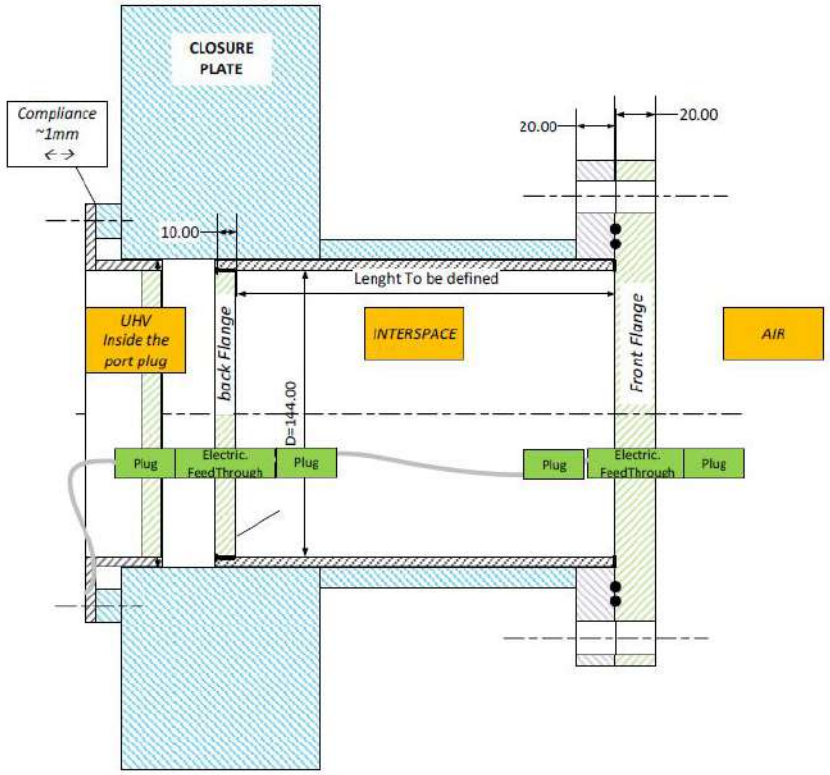
- Coaxil MIC
  - Outer diameter: 6 mm
  - Conductor size: 11 AWG
  - Coaxial MIC material:
    - Outer sheath material (2 layers): outer part in SS 316L / inner part in copper
    - Insulant: Alumina (SiO2) or Magnesia (MgO)
    - Conductor: Copper
- Hermaic RF connector
  - Connection type: push-on, pull-off
  - Termination type: NH or SHV type
  - RF connector material
    - Conductor: Copper
    - Insulant: Alumina (SiO2) or Magnesia (MgO)
- Electrical charateristics
  - Rated Voltage: 1kV (3kV in case of impedance mismatch)
  - Power handling: > 1kW
  - Insulation resistance: > 1GΩ @ 2000 VDC room ambient environmental conditions
  - Dielectric strength: 3000V RMS @ 60Hz
  - Frequency range: 0 – 200 MHz
  - Charateristic impedance: 50 Ω +/- 10 Ω @100MHz
  - Voltage Standing Wave Ratio: <1.15 in 10MHz – 200MHz
- Other requirements
  - Maximum temperature: < 350 ^{o}C during opertion, 500 thermal cycling (room temperatue - 240^{o}C) for baking
  - Radiation hardness: ~ 1x10^{9}Gy gamma dose and ~1x10^{19} n/cm2 neutron fluence
  - Vacuum class: UHV (Ultra-High Vacuum)
  - Leak tightness: 1x10^{-10} Pa m3/s air equivalent

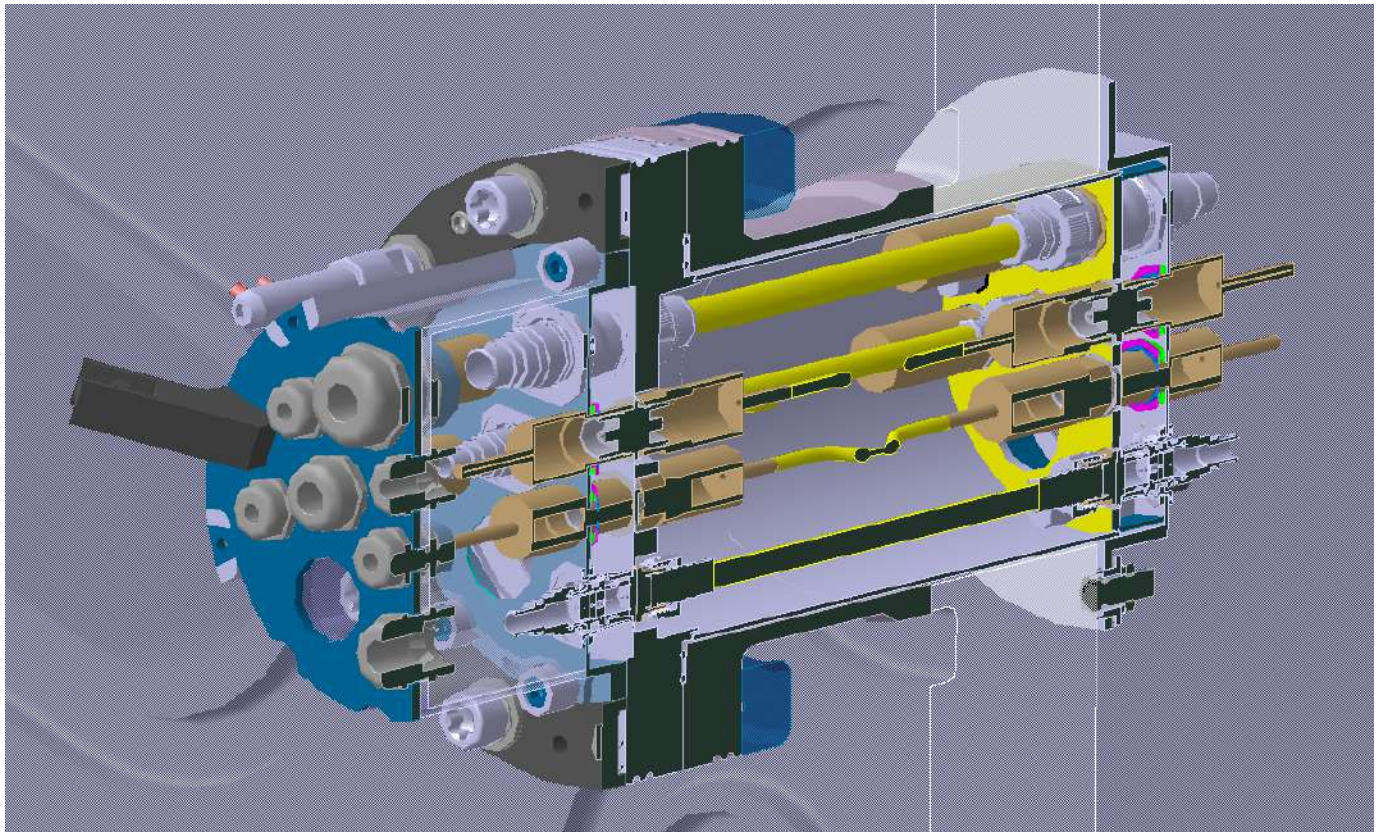
Launch date: Q2-2021

Diagnostic Systems- Multi Connection Vacuum Feedthrough

Manufacturing of electrical feedthrough

- Transmit multiple electric lines across vacuum boundary and nuclear safety barrier
- Accommodate different types of electrical signals (instrumentation, DC power, RF power, etc)
- Double confinement barriers
- RH compatible design





Launch date:Q2 2021

Specialized Diagnostics Systems Prototyping and Manufacturing Services Contract

Specialized Diagnostics Systems Prototyping and Manufacturing Services

- ITER diagnostics will be subject to extreme conditions (e.g. UHV, high temperatures, neutron and gamma radiation), limited installation space, and infrequent maintenance access

- This requires reliable design and adaptation of existing concepts to ITER conditions and space constraints

- This is achieved through extensive prototyping and testing activities, including complex manufacturing and assembly techniques

The contract will cover services of experienced specialized manufacturers with ability to tackle the **development, prototyping, manufacture and assembly of complex UHV and plasma diagnostics**

Required experiences and facilities(I)

- Development, manufacture, and assembly of

  - opto-mechanical diagnostics
  - X-Ray instruments and spectrometers
  - diagnostics and instruments for neutron sources
  - high power microwave devices
  - radiation shielding
  - detectors for gammas and neutrons,
  - instruments complying with the RCC-MRx standard for Nucl. Envirom.,
  - high loads actuation mechanisms operating in high vacuum;

[see next slide too)

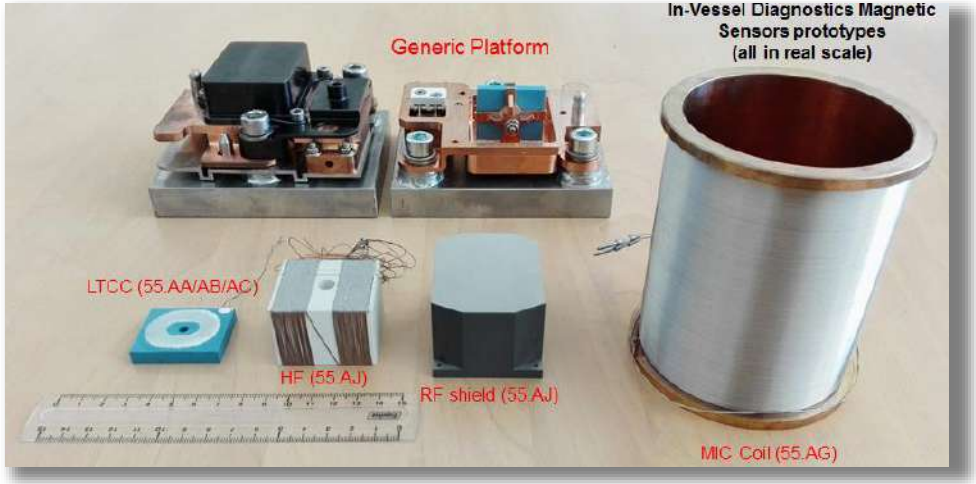
Required experiences and facilities (II)

- Development and testing of UHV feedthroughs (optical, mechanical, electrical)
- Development of custom procedures for bending, wiring, and joining techniques for Mineral Insulated cables;
- Testing facilities;
- Machining and assemblies using welding, e-beam welding and brazing;
- Computer Aided Design;

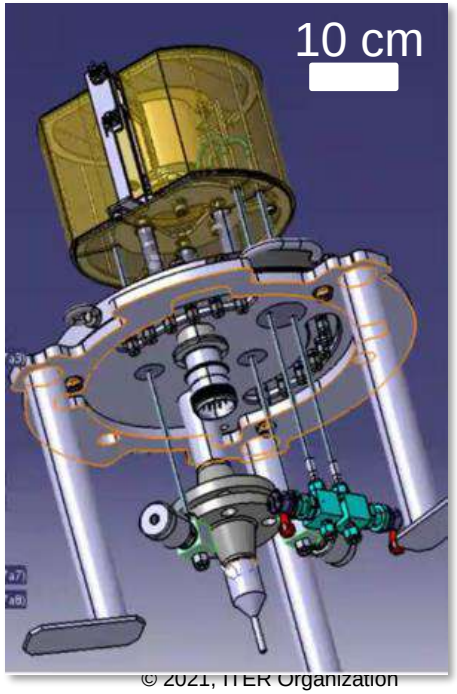
In-vessel looms

RF cleaning test for mirror assembly

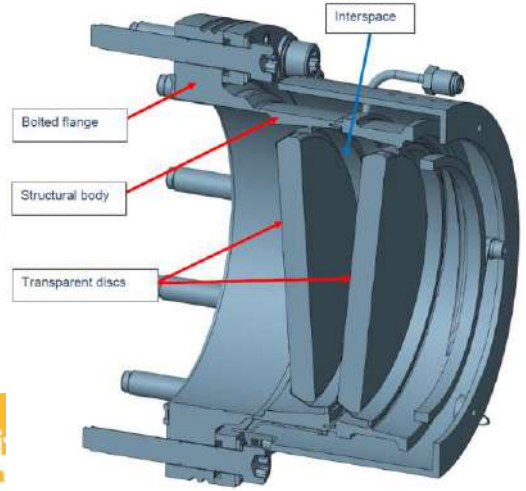
Prototypes of magnetic sensors

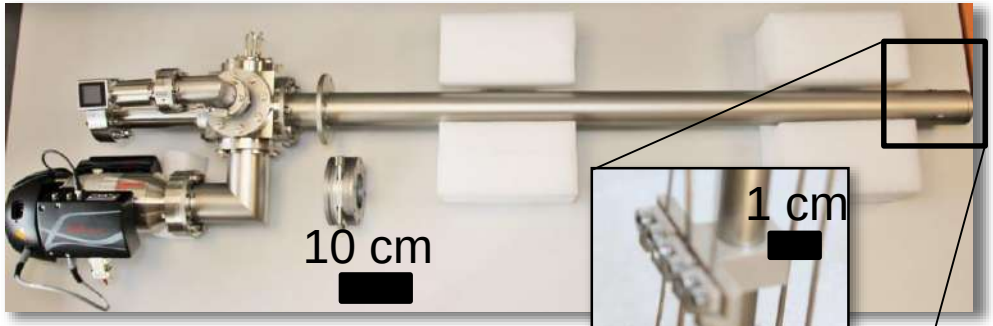


Model of shutter test assembly



Vacuum window





Assembly for ITER Hall sensor test in a tokamak

Launch date: Q2:2021

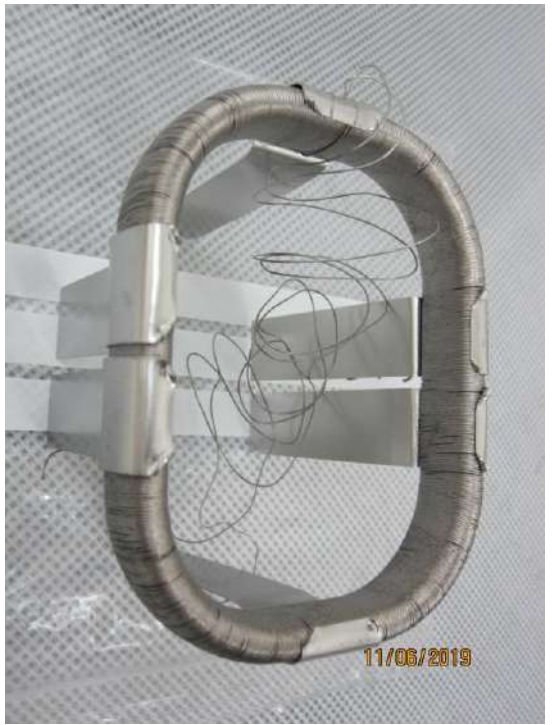
Diagnostic Systems – Divertor Rogowskii Coils (aka Halo Sensors)

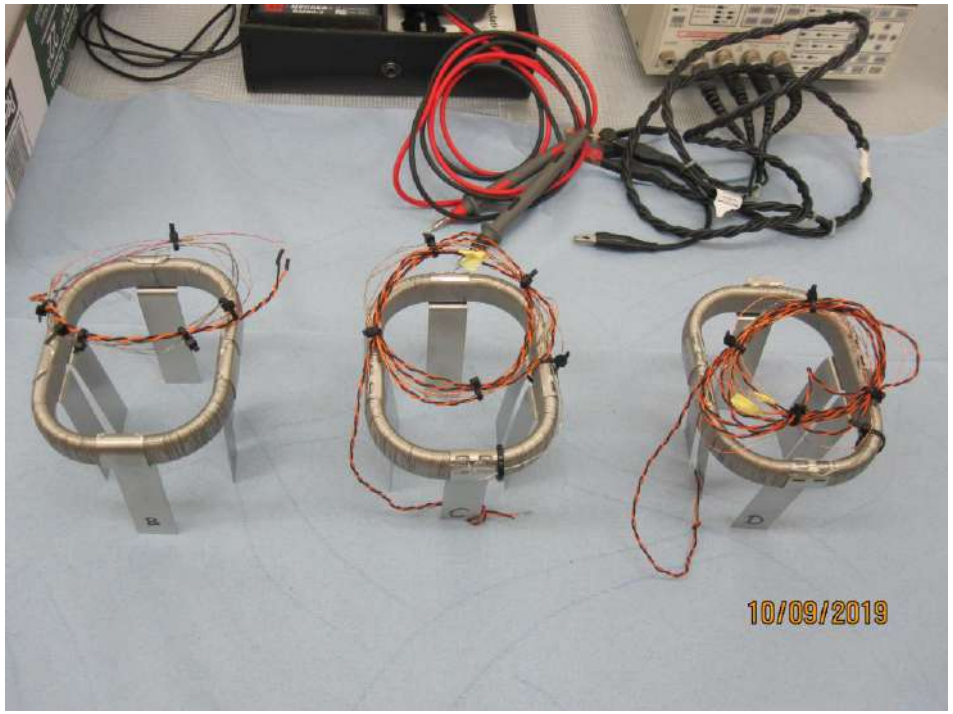
Possible Collaboration Project
[IO will share the cost of these developments]

Rogowski Prototypes

- MI cable (0.5mm) wound on 3D printed Inconel former
- Three brazed Mineral Insulated cable prototypes completed
- Sensitivity as predicted; errors 0.3 – 2% depending on orientation
- Thermal testing indicates adequate cooling

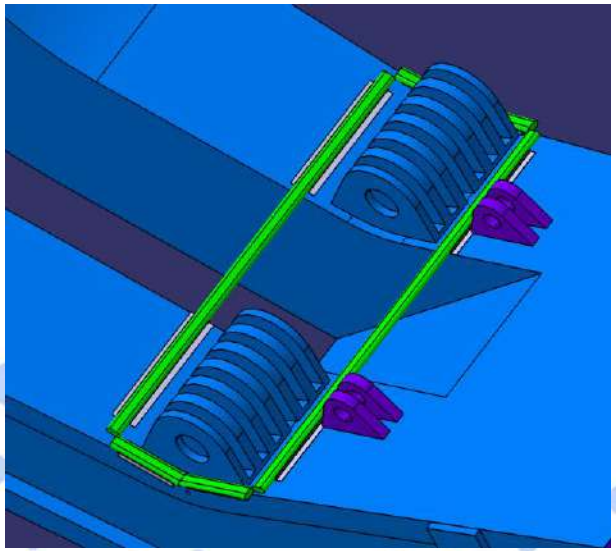
200mmX150mm

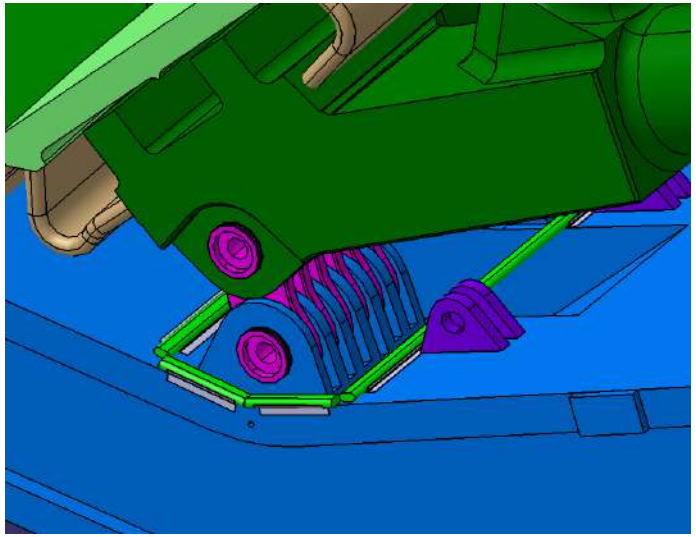


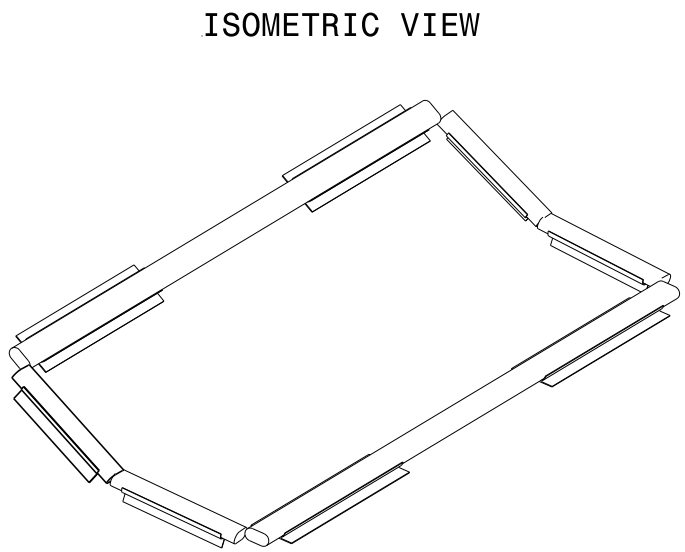


Divertor Rogowski Prototyping

- Divertor protoypes needed next step design review
  - Fabrication of 3D coil geometry
  - Demonstration of segmented coil concept
  - Demonstration of Cu based brazing







What are we looking for here?

- Ideally a collaborator who is prepared to support these projects
- Development of the Prototypes for Divertor Rogowskiis
- Completion of Design and manufacture of both Divertor and Blanket Rogowskii coils
  - Fabrication of 400 blanket Rogowskiis
  - Fabrication of 60 Divertor coils

Launch date: 2021

Diagnostic Systems – Radial Gamma Camera and High Resolution Neutron Camera

Collaboration Projects
[IO will share the cost of these developments]

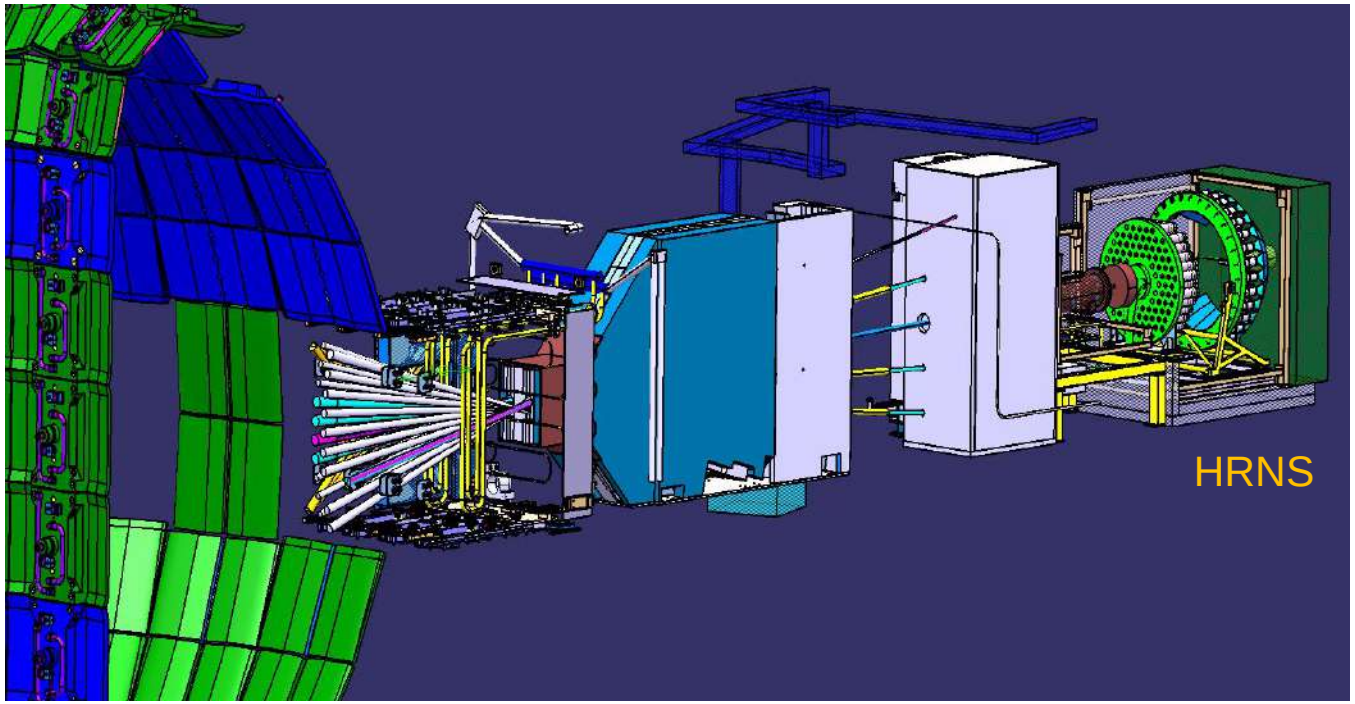
High Resolution Neutron Spectrometer

PRIMARY ROLE:

Dedicated to measure time-resolved neutron energy spectra for DD and DT plasmas, providing mainly the determination of the DD and DT fuel. Four spectroscopic systems have been considered.

This system has an important operational role for the ITER machine as it is the only system for the measurement of the DD and DT fuel in plasma core.

Needs COLLABORATORS



iter
china eu india japan korea russia usa

Launch date: 2021

Radial Gamma Ray Spectrometer

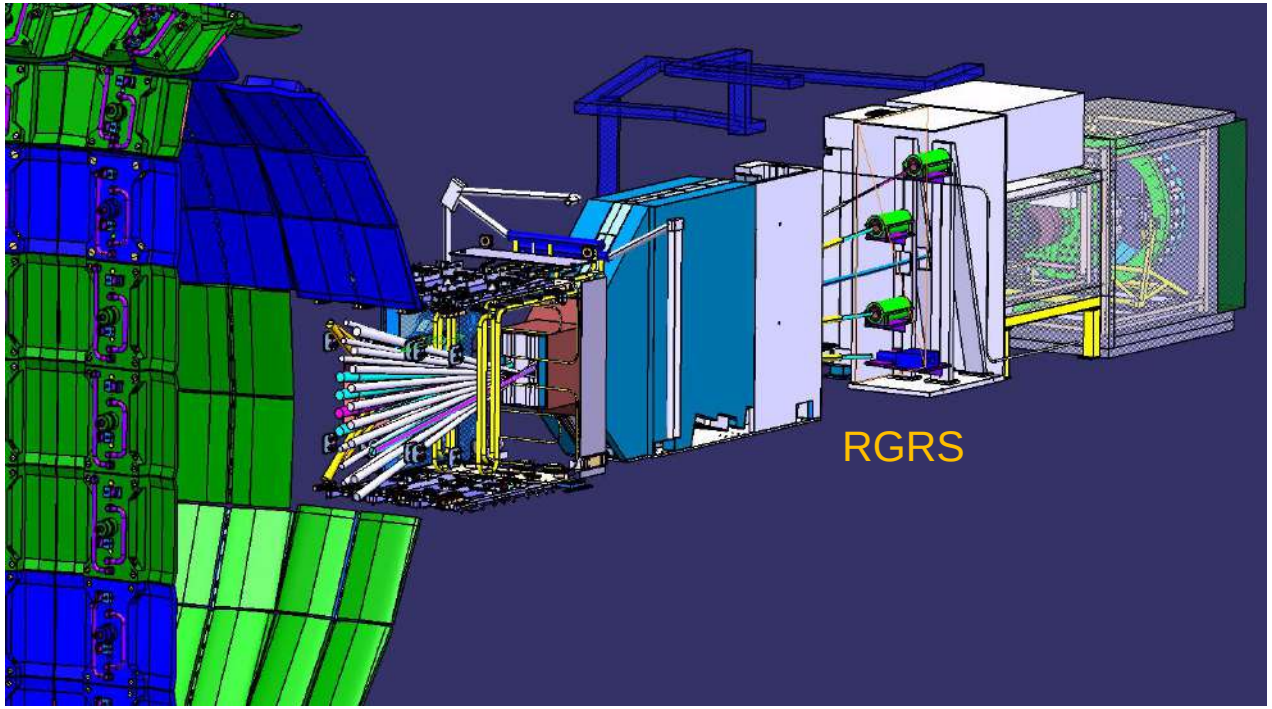
PRIMARY ROLE:

The Radial Gamma-Ray Spectrometer (RGRS) is a multiple detector, multiple lines-of-sight spectrometer optimized in the energy range up to 17 MeV.

Thus the primary aim of the RGRS diagnostic is to diagnose the runaway electrons and the fusion alpha particles.

RGRS technique is one of the few techniques which can provide information on the fusion alpha particles.

Needs COLLABORATORS:



Launch date: 2031

Overview of Upcoming Business Opportunities

Package	Forecasted Time to Launch	Budget Category
Procurement and Integration of IO Ports (ex-vessel)	Q2-2021	C
Procurement and Integration of IO Port Plug Assemblies (in-vessel)	Q2-2021	D
Boron Carbide Shielding Blocks	Q1-2022	C
Engineering design of Port Integration Facility and tooling	Q2-2021	B
Port Integration Facility Service and Management	Q1-2022	C
Design of Tools for Port Handling in Port Cells and Hot-Cell	Q2-2021	A
Design and Supply of Port Handling Tools	Q2-2021	A
Manufacturing of Lower Port & Marshalling Area Attachments	Q2-2021	B
Manufacturing of Cryostat Electrical Feedthroughs	Q2-2022	A
Coaxial Mineral Insulated Cables for High RF Power	Q2-2021	B
Manufacturing of electrical feedthrough	Q2-2021	B
Specialized Diagnostics Systems Prototyping and Manufacturing	Q2-2021	B

Summary

- Advancing on many fronts with first systems delivered
- Many technical challenges being addressed systematically
- With many challenges there are many opportunities for external companies to make substantial contributions
- All the contracts outlined here are imminent

Thank you for Listening