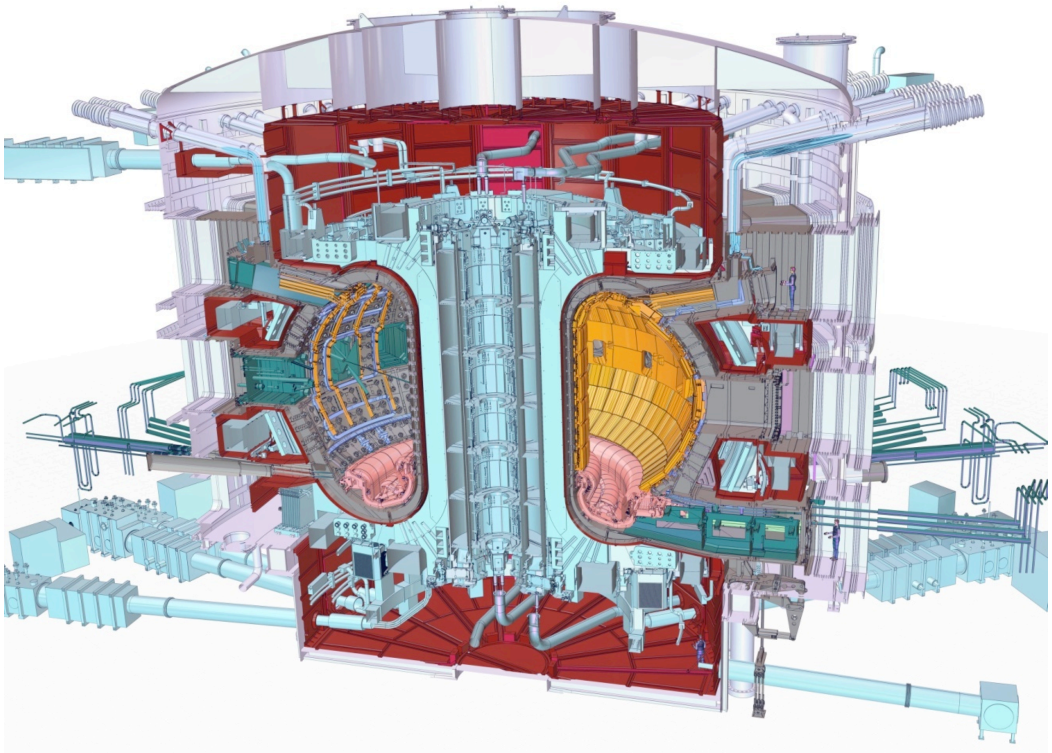
IEEE 24th Symposium on Fusion Engineering (SOFE)

Status and Challenges of the ITER Tokamak Core



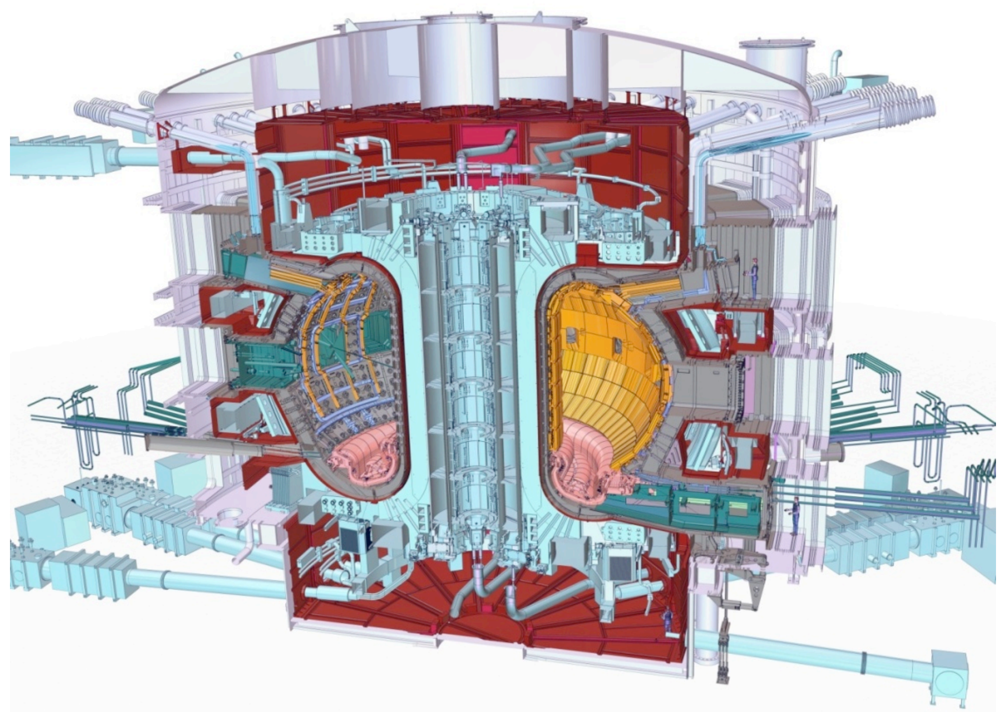
Gary Johnson – Former Deputy Director General – ITER Tokamak

Presented by A. Rene Raffray

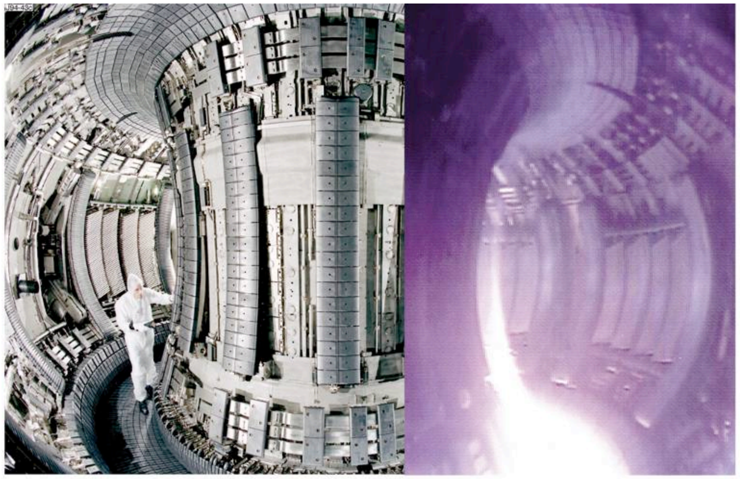
June 27, 2011

Technical Challenges of the Tokamak

- *Tokamak*
  - Large scale up of many systems
  - High quality high tech components
  - Tight tolerances
  - Manufacturing around the world
  - Highly integrated design
- *Superconducting magnets*
  - Unprecedented magnet size
  - High field performance ~12T
  - Conductor and magnet manufacturing
- *Vessel Systems*
  - Large size
  - High quality components
  - Safety boundary
- *Plasma facing components*
  - High steady heat flux
  - EM loads under off-normal events
  - Special materials
  - Plasma-Wall Interaction
  - RH requirements

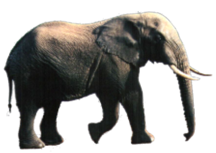


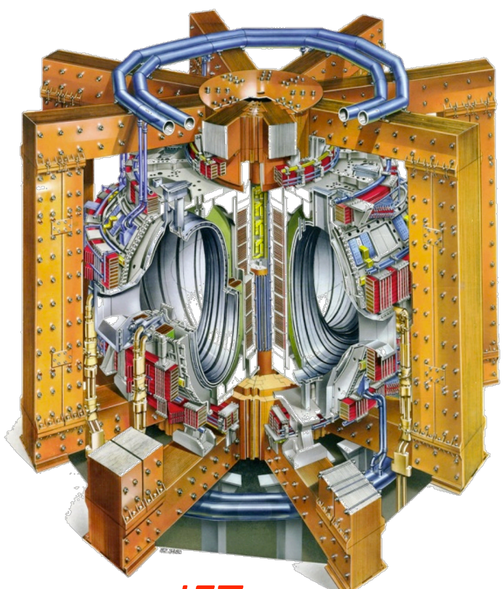
Tokamaks



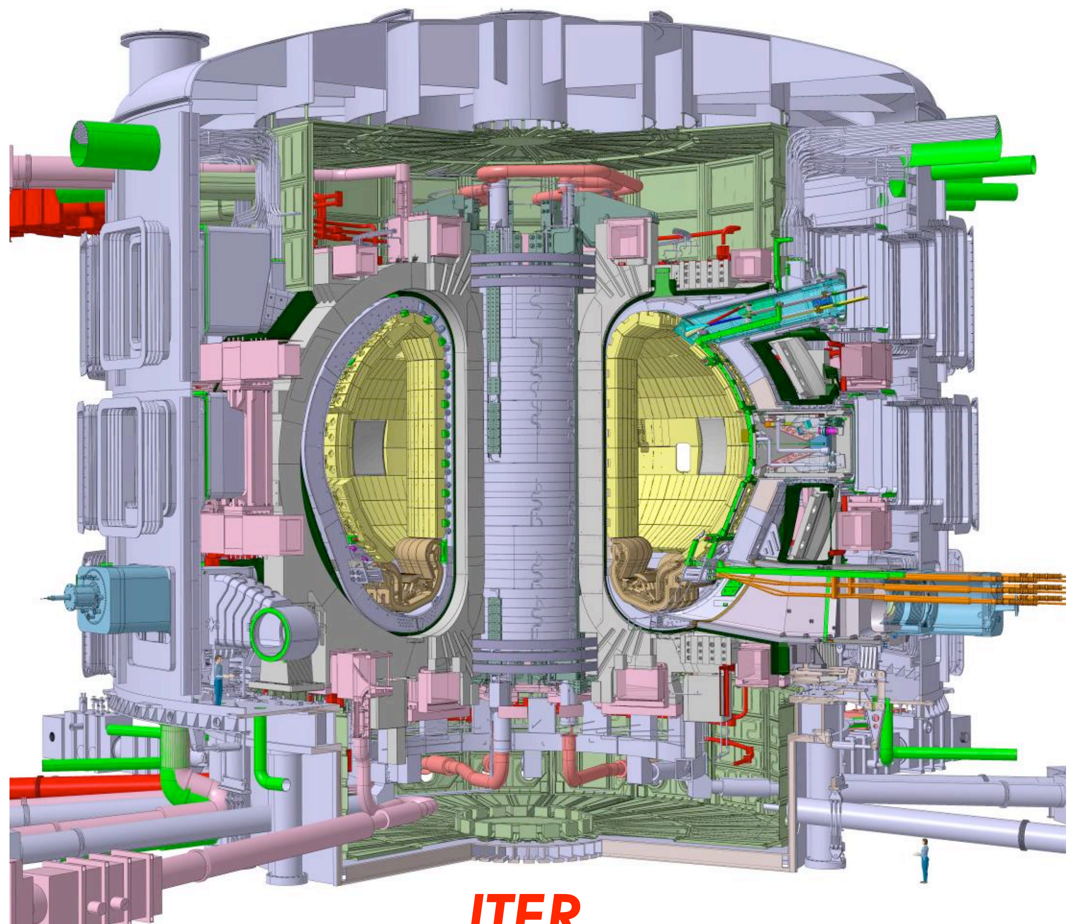
JET – Internals & Plasma

ITER will allow us to produce plasmas with
temperatures of 100 - 200 million °C
(10 times the temperature of the sun's core)
⇒ 500 MW of fusion power



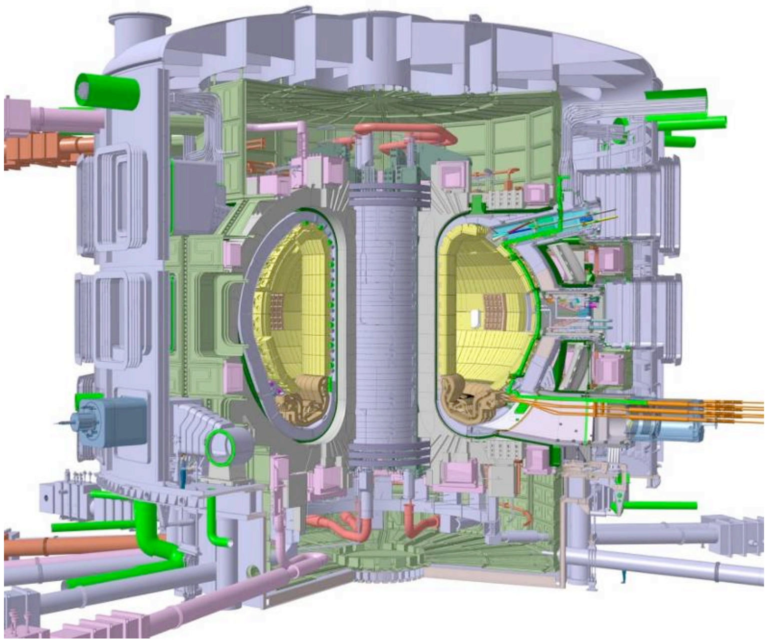


JET



ITER

ITER Tokamak – Mass Comparison

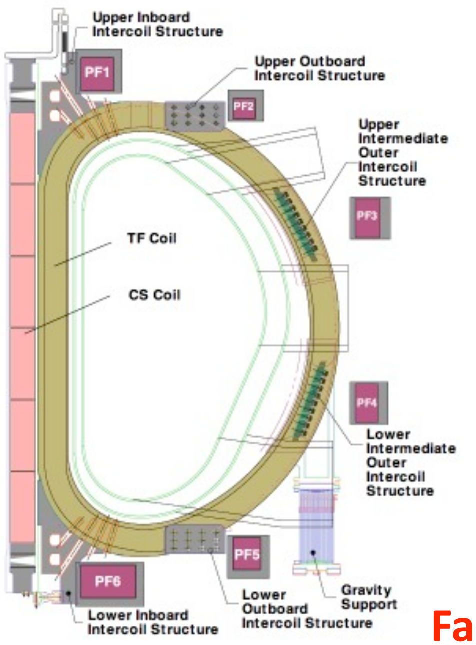


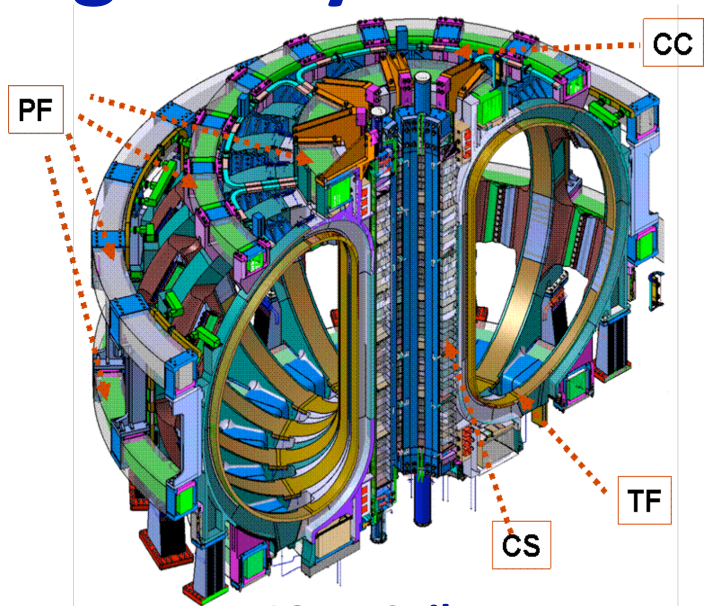
ITER Machine mass:
~23000 t
28 m diameter x 29 m tall

Charles de Gaulle mass:
~38000 t (empty)
856 ft (261 m) long
(Commissioned 2001)

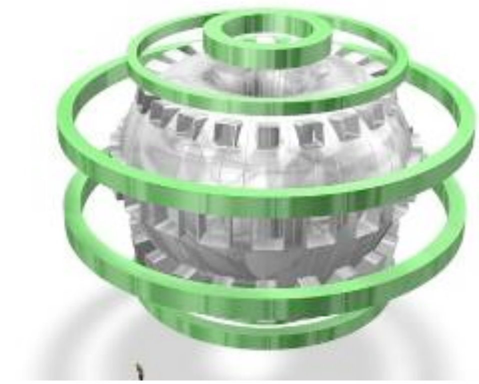
Superconducting Magnets

Magnet System





18 TF Coils
(EU & JP)



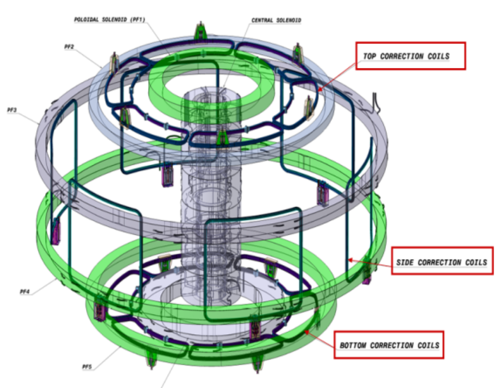
6 PF Coils (EU & RF)

Facts

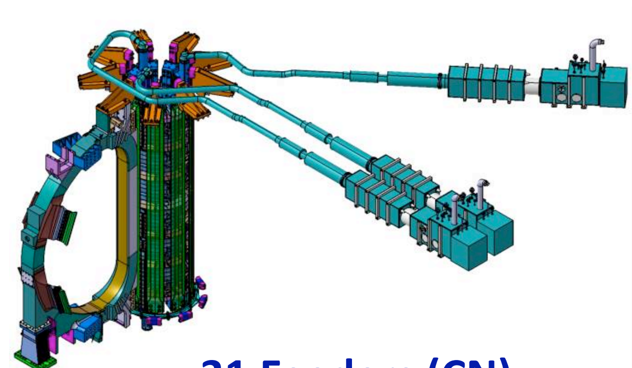
- 48 superconducting coils (~9800 tons)
- 11.8 T (peak TF field)
- 68 kA (peak current)
- Stored energy – 51 GJ

Technical Challenges

- Large size
- Tight tolerances
- High field performance
- Conductor and magnet manufacturing



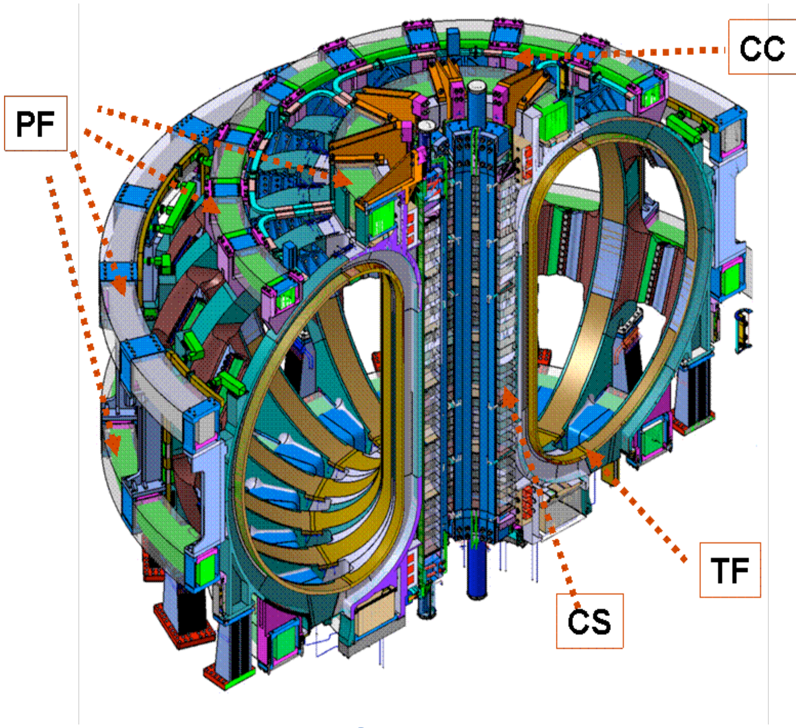
9 Pairs of Correction Coils (CN)



31 Feeders (CN)

Central Solenoid (CS) Coils – Stack of 6 (US)

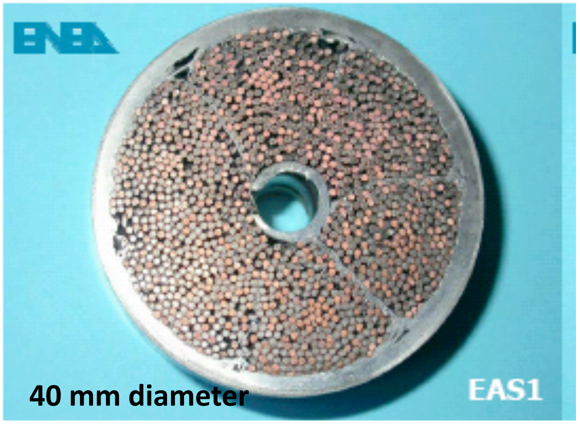
Magnet Energy Comparison



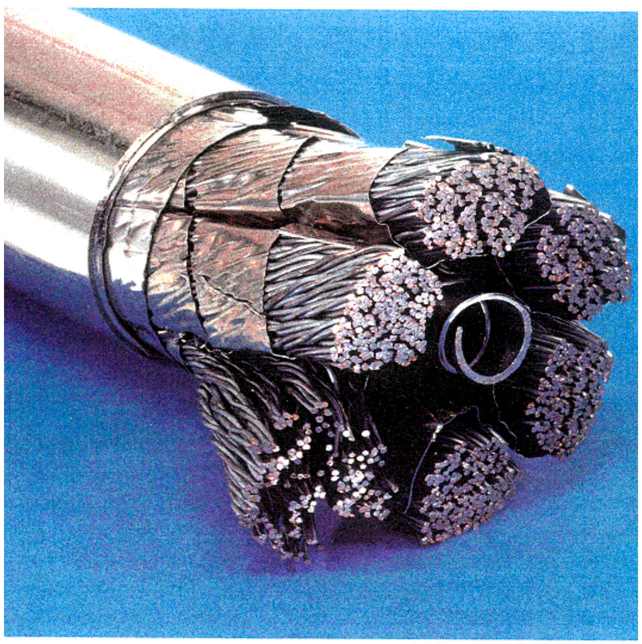
Superconducting Magnet Energy:
~51 GJ

Charles de Gaulle Energy:
~38000 t at ~14 km/hr

TF Conductor Procurement



ITER TF Conductor



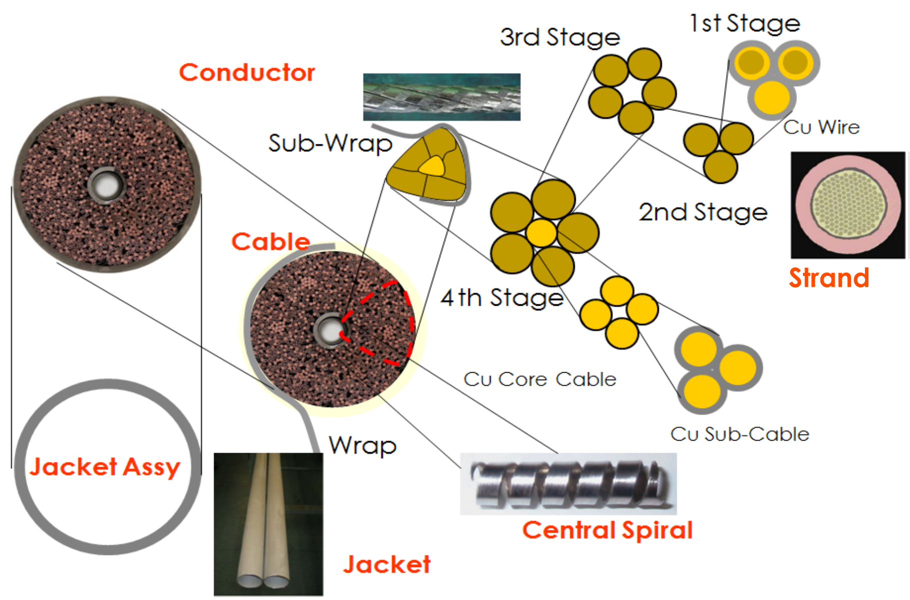
Facts

- ~90 km / 400 t of Nb_3Sn conductor

  (The biggest Nb_3Sn conductor procurement in history)

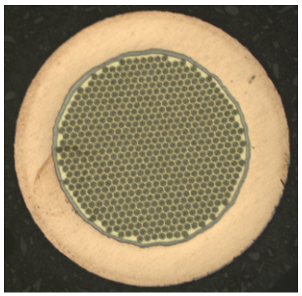
  - ~150,000 km of strand (15 x around Earth)
  - Operates at ~5 K
  - 11.8 T (peak TF field)
  - 68 kA (peak TF current)

- Manufactured by EU, JA, RF, CN, KO, & US

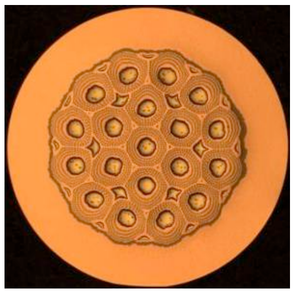


TF Strand Production Status

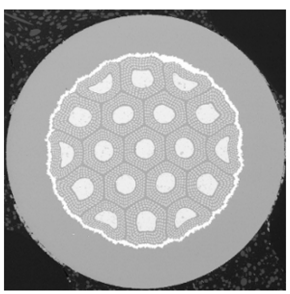
- **JA, KO, RF, EU, US, & CN are qualified for strand production. Most have launched strand industrial production and started data input into ITER Conductor Database.**



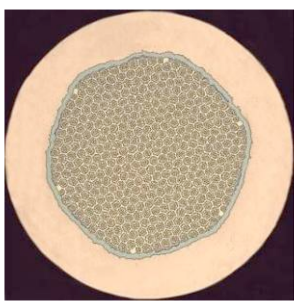
Hitachi, JA
(Br)



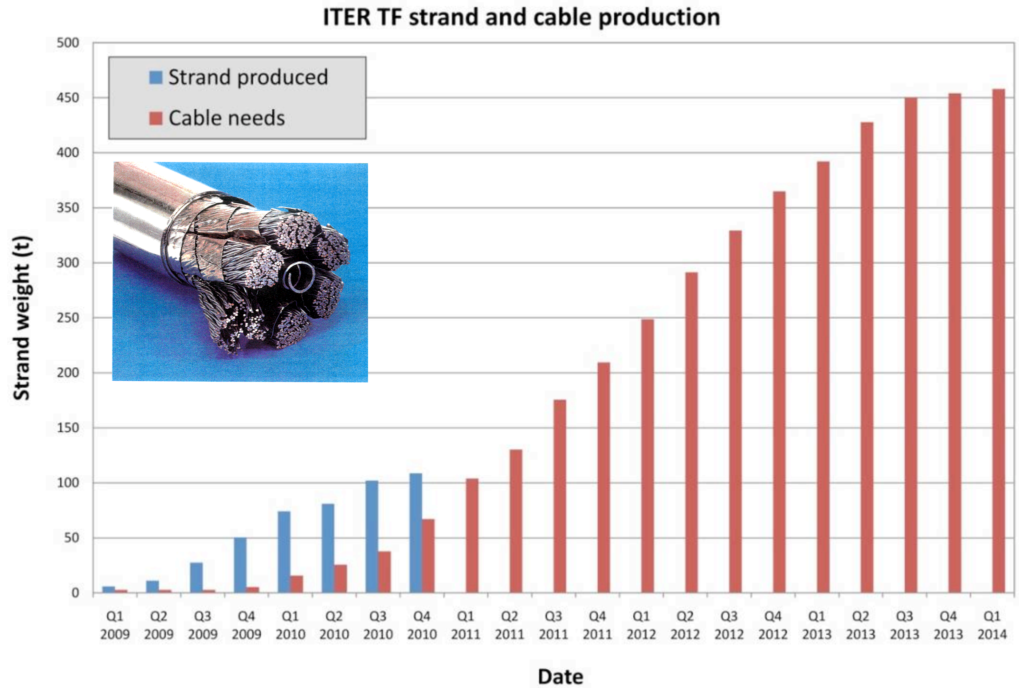
KAT, KO
(IT)



OST, EU/US
(IT)

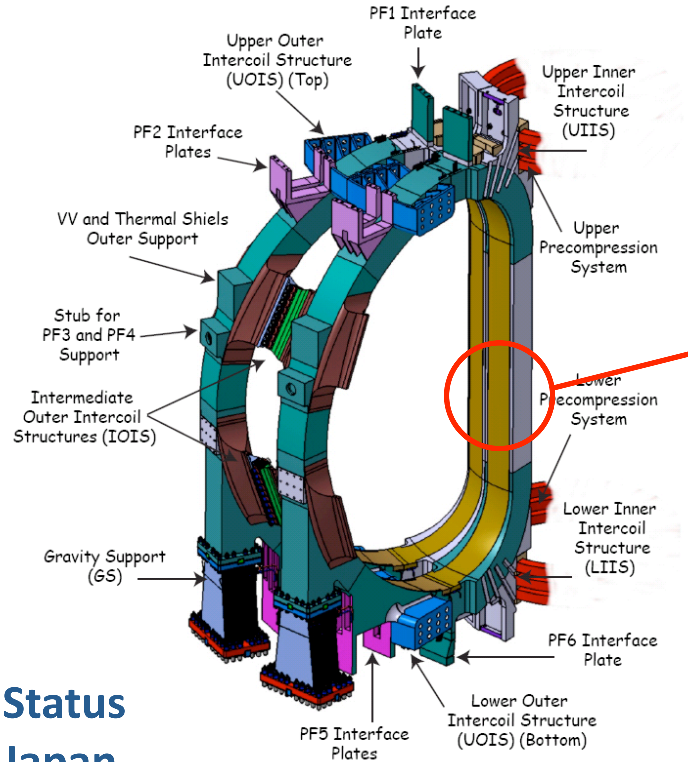


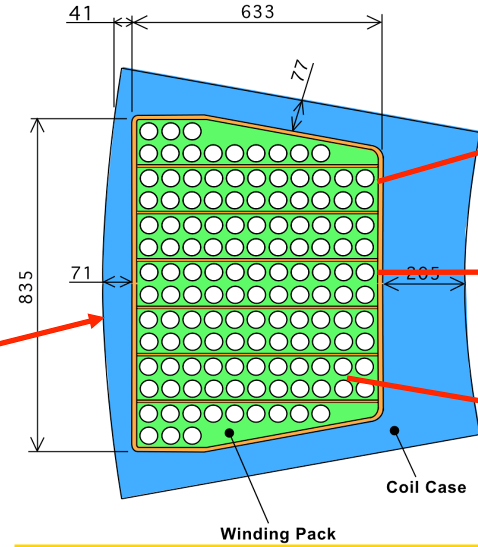
ChMP, RF
(Br)



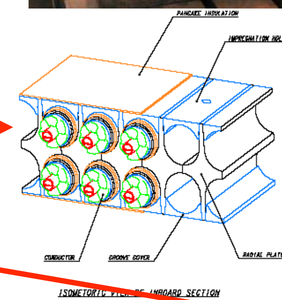
- **As of today, >170 tons (>37 000 km) of Nb_3Sn strands have been registered into the Database; this corresponds to the material needed to manufacture ~7 TF coils, and at present provides an ample margin relative to the cabling schedule.**

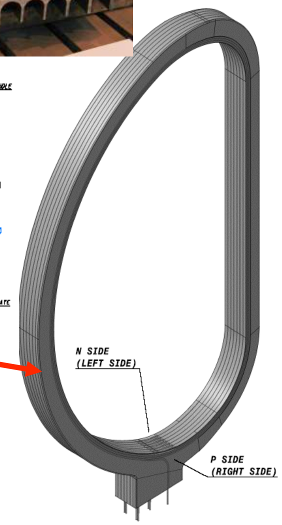
TF Coil Status





Inner Leg Cross Section





TF Winding Pack

Status

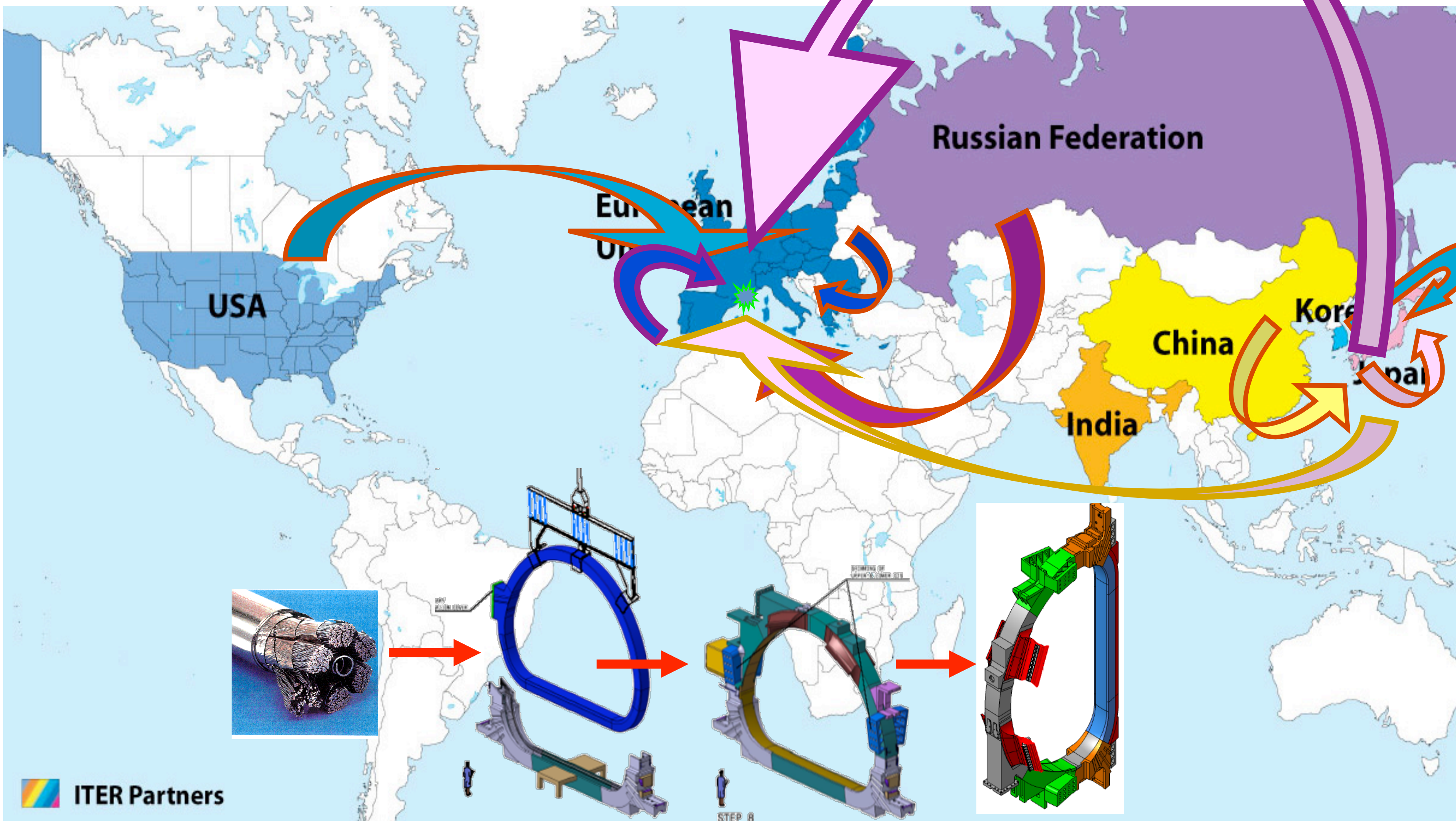
Japan

- JADA signed a development contract with Toshiba for winding trials and fabrication of structural section prototypes.
- This is now finished. One prototype radial plate has been made.

Europe

- EUDA has signed a procurement contract for their 9 TF coils as well as for prototype radial plates with SIMIC (IT) and CNIM (FR).
- Two prototype radial plates are nearly complete .
- A winding facility is starting construction by ASG at La Spezia.

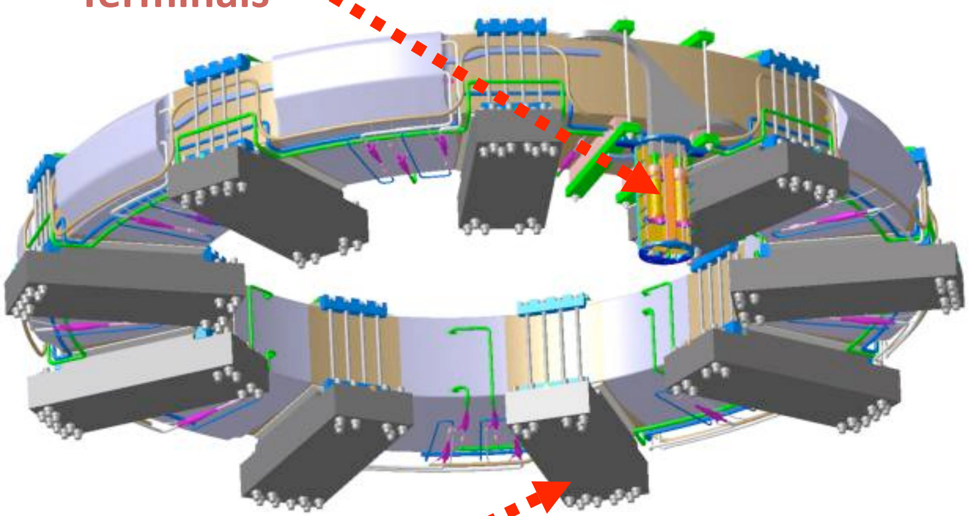
TF Coils - A Worldwide Collaboration



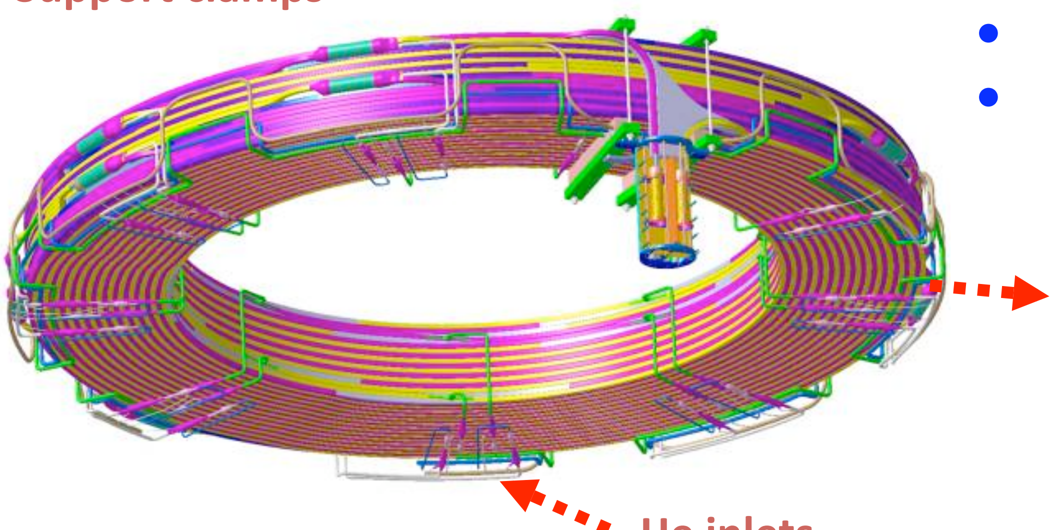
The biggest Nb3Sn conductor procurement in history!

Poloidal Field Coils

Terminals



Support clamps



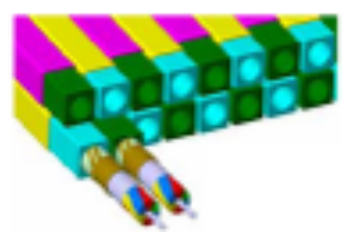
He inlets

Facts

- So big that it must be manufactured on site!
- PF3: 24.5 m dia. & 386 ton
- Building is 250 m long x 45 m wide and will be the first on site!

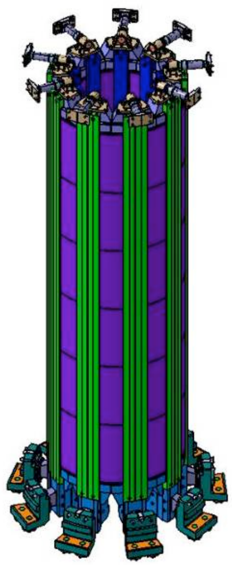
Status

- PF Coil 2,3,4,5,&6 PA signed with EU
- PF Coil 1 - PA signed in March 2011



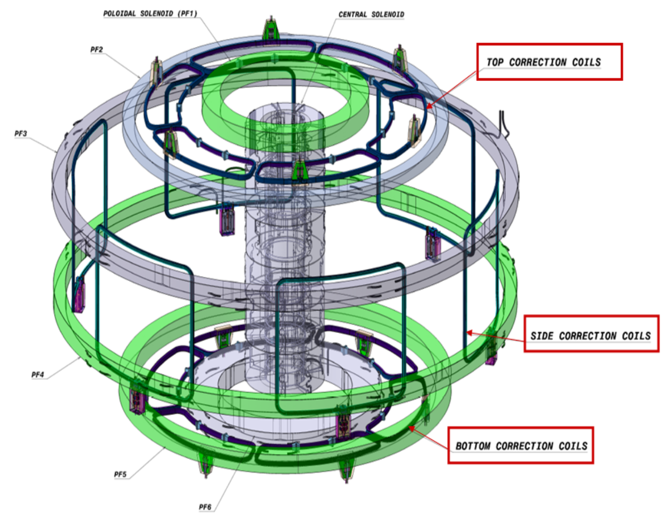
Conductor Winding

CS & CC Status



Central Solenoid
(13.6 m tall x 4.2 m dia
~1000 ton)

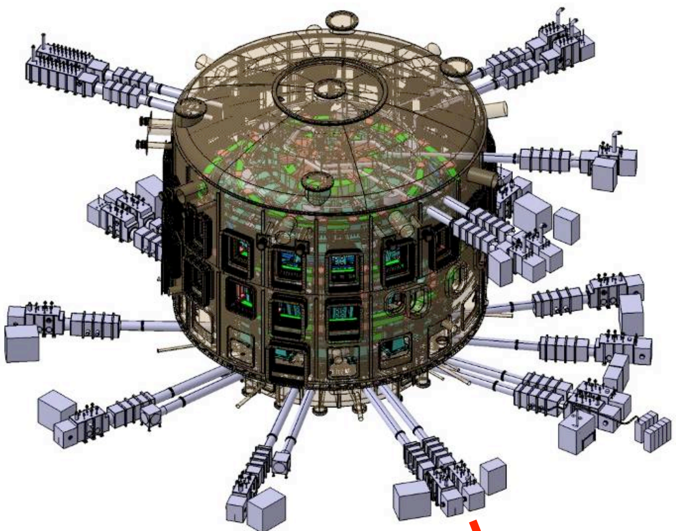
Status
- PA signed in March 2010 with USA
- CS PDR scheduled for September 2011
- Coil tendering in progress



Correction Coils (9 pairs) (CN)

Status
- Procurement contract for CC coils signed with ASIPP in December 2010
- Manufacturing line under procurement at Hefei

Feeders Status

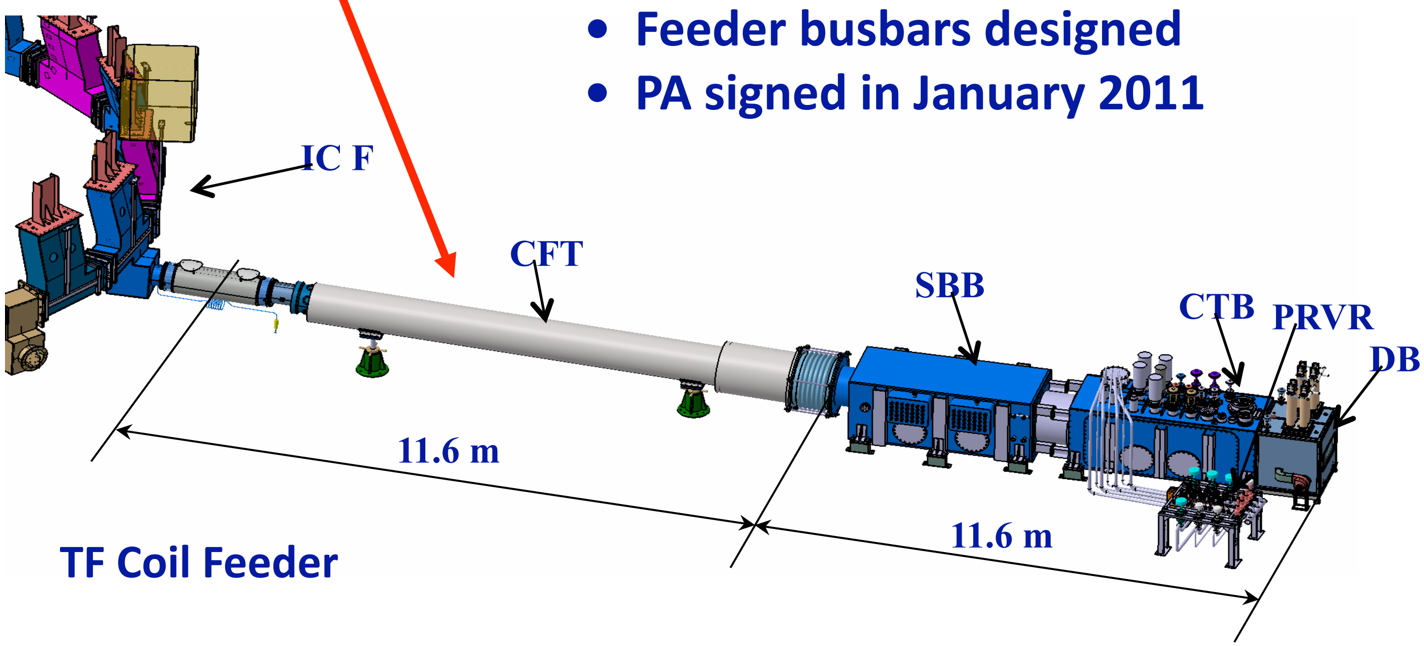


Main Functions

- Provide main services to coils:
- Cryogenic He coolant
- Power SC busbars
- Instrumentation cables

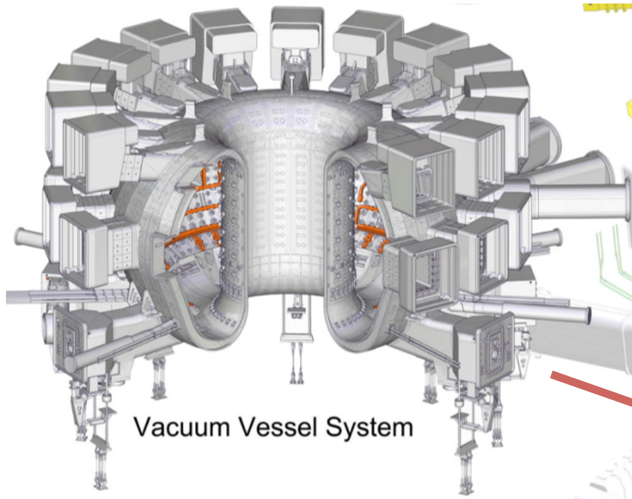
Status

- FDR completed in October 2010 (31 feeders)
- Extensive design collaboration with ASIPP-CN
- Feeder busbars designed
- PA signed in January 2011

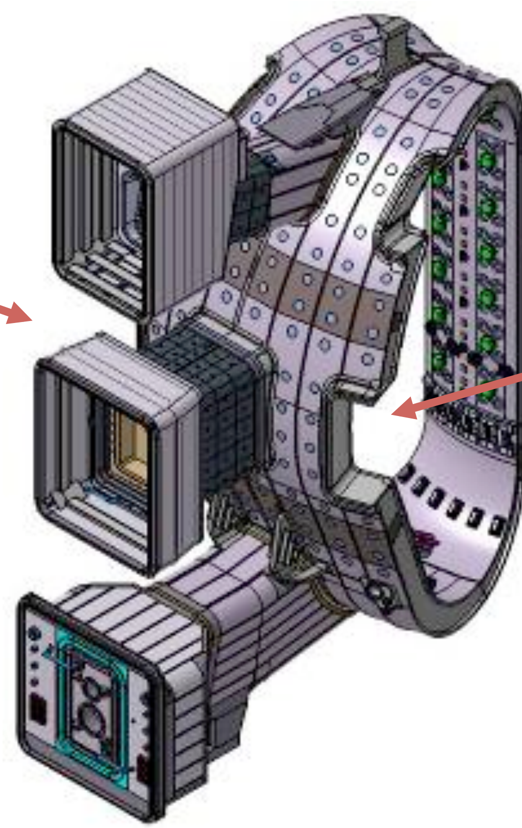


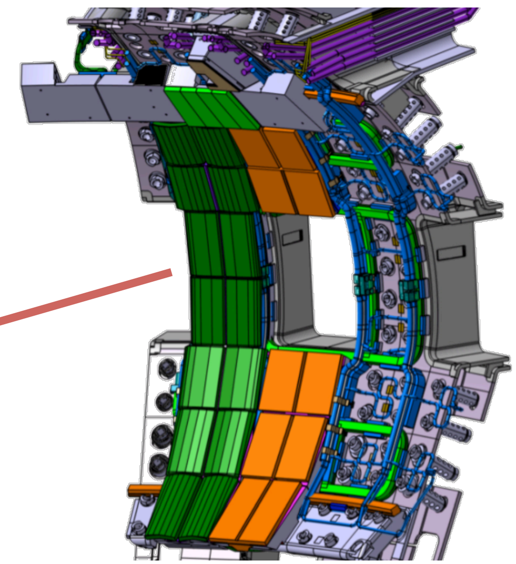
TF Coil Feeder

Vessel Systems



VV Status





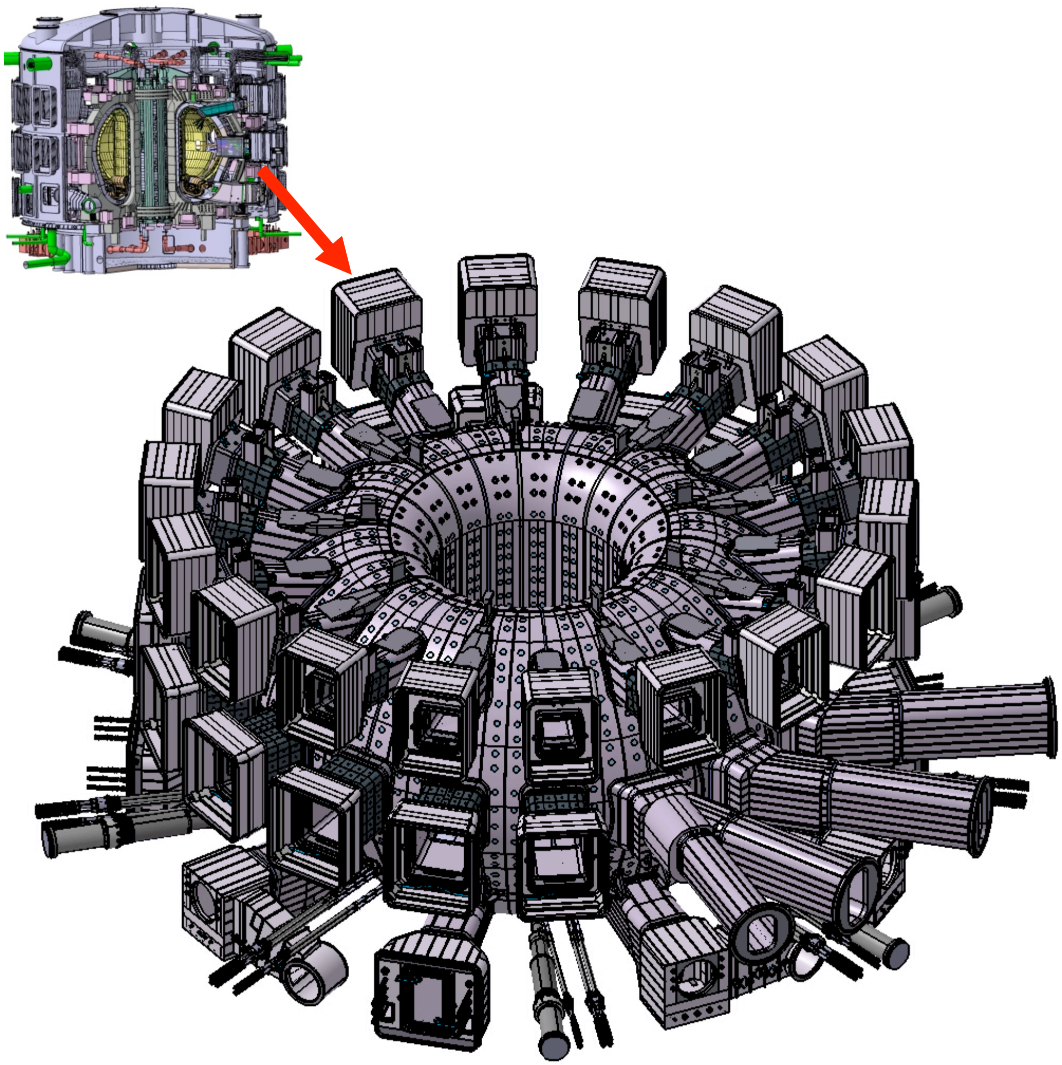
Facts
- First safety barrier for ITER
- SS 316 LN-IG
- ~5300 tons (VV, ports, shielding only)
- 19.4 m (63 ft) torus outer diameter
- 11.3 m (37 ft) torus height

ELM & VS Coils
(VV interfaces implemented)

Status
- VV sector and port PA's signed (EU, KO, IN, & RF)
- KO - VV & port contract awarded to Hyundai Heavy Industries
- EU - VV contract awarded to the AMW collaborations
- Manufacturing schedule is on critical path!!!

Technical Challenges
- Large Size
- Tight tolerances
- High quality components
- Part of safety boundary

Vacuum Vessel - Mass Comparison

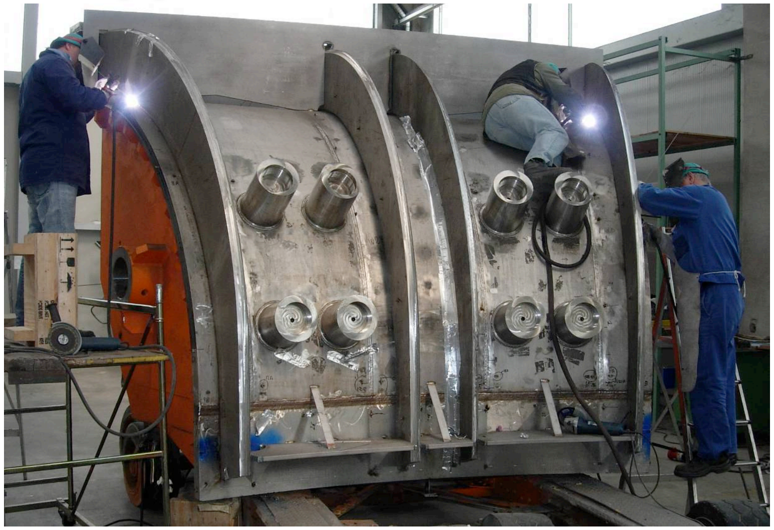


VV & In-vessel components mass: ~8000 t
~19.5 m outside diameter x 11.2 m tall

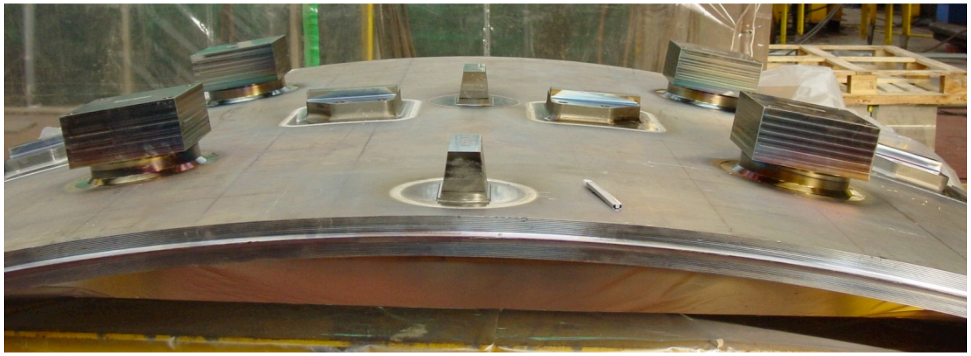
Eiffel Tower mass: ~7300 t
324 m tall
(Completed 1889)

Vacuum Vessel Prototypes

Full Size Prototype of the
ITER Vacuum Vessel (2001)
(JA Domestic Agency)

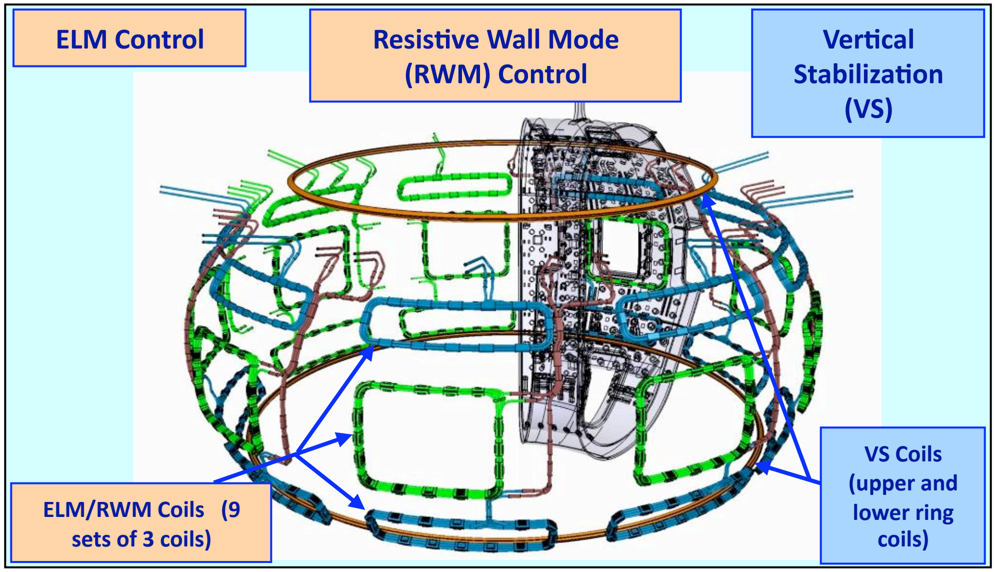


VV Mock-up of Electron Beam welding on the inner shell (EU Domestic Agency)

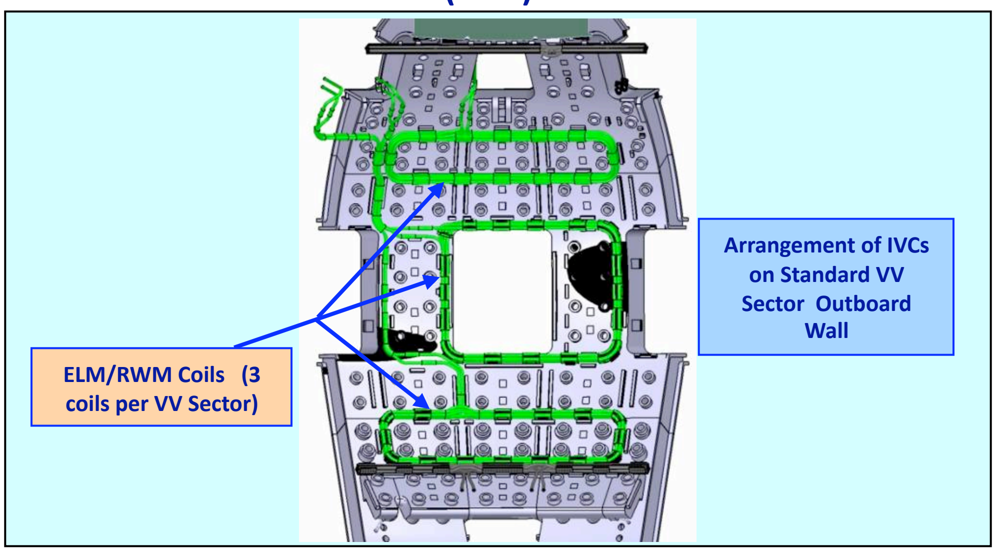


Mock-up of E-beam Welding for Key and Blanket Manifold Support
(KO Domestic Agency & HHI)

Plasma Instability Control / Mitigation



ITER In-Vessel Coils (IVCs) : 27 ELM & 2 VS Coils



Background

- Edge Localized Mode (ELM) control is a requirement for ITER
- Uncontrolled ELMs can lead to unacceptably rapid erosion of the divertor target
- ELM coils provide resonant magnetic pertubations (RMP) at plasma edge

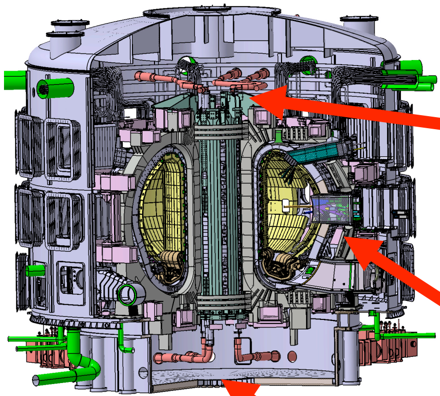
Technical Challenges

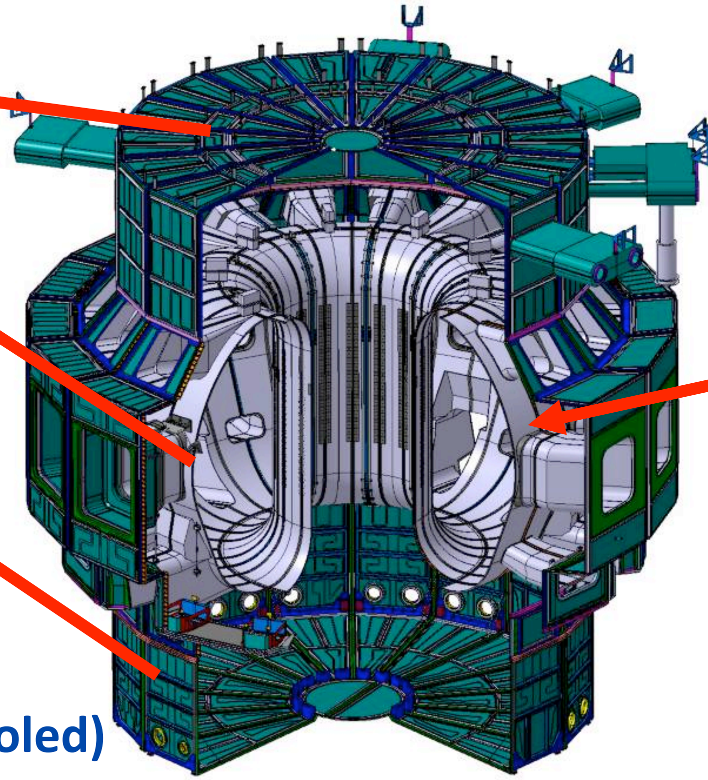
- High currents in neutron environment (~60 kA @ 2.3 kV)
- Scale up of conductor (26 to 59 mm diameter)
- Remote handling
- Interfaces

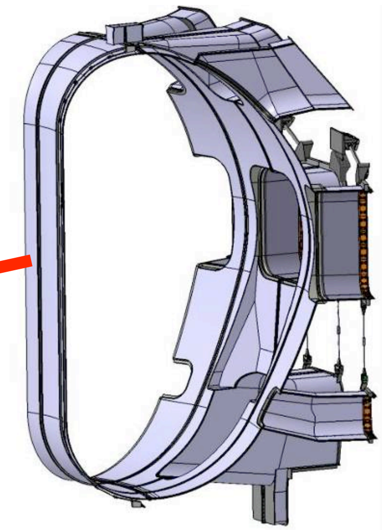
Status

- IVC PDR has been completed
- R&D activities on conductor and joints are in progress
- IVC interfaces have been fully implemented into VV design
- Alternative concepts are being investigated

Thermal Shield Status



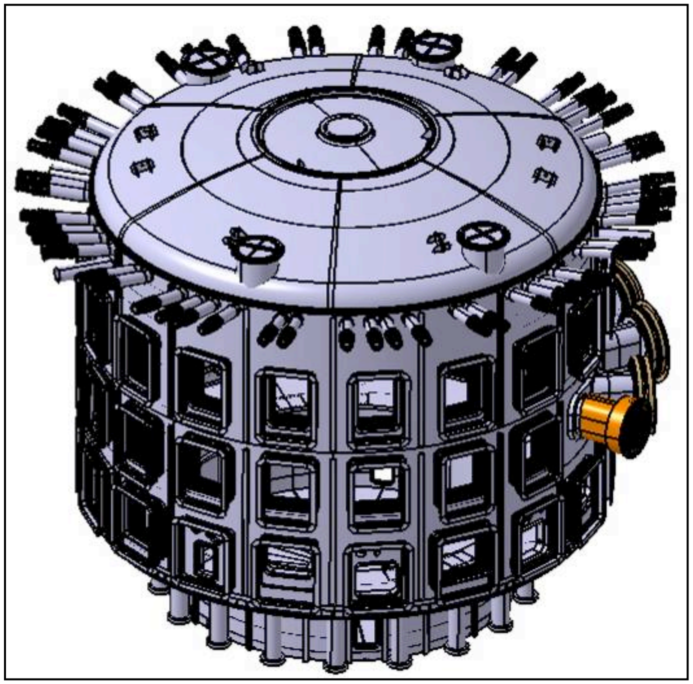


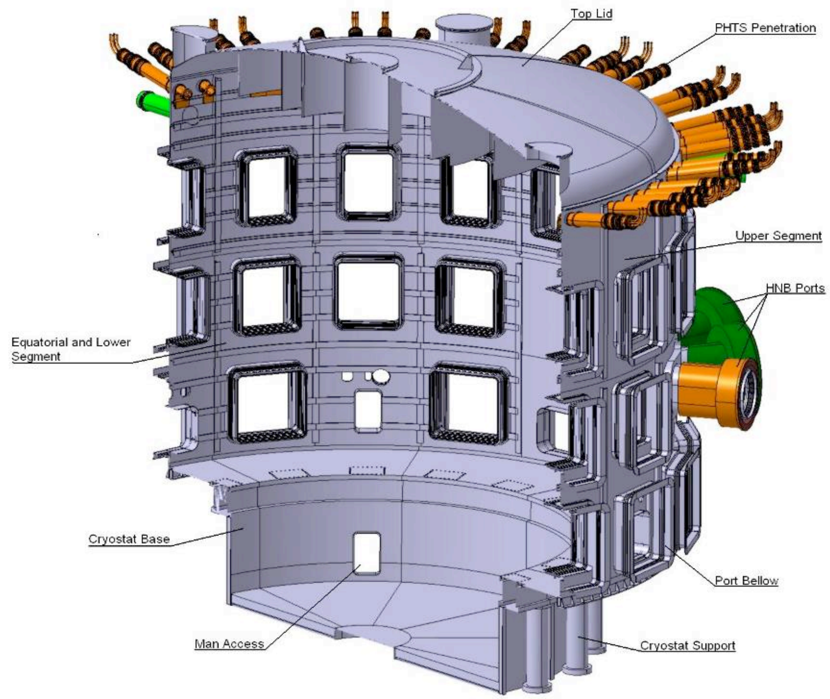


Facts
- Operation at 80 K (He cooled)
- SS 316 LN-IG
- ~880 tons
- 28 m outer diameter
- 23 m tall

Status
- PA signed with Korea in May 2010
- Drawings for VV TS issued August 2010
- Design and Fabrication contract placed in 2010
- Final Design for Cryostat TS to be completed in 2011

Cryostat Status



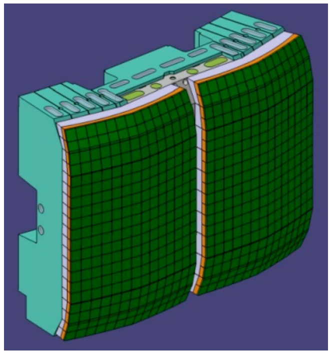


Status

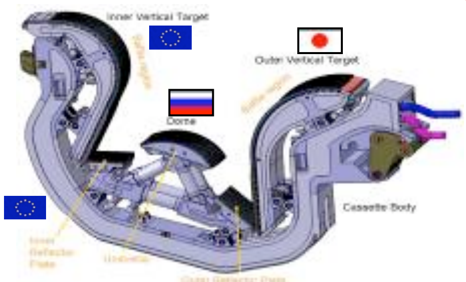
- **CDR completed in November 2009**
- **PDR completed in June 2010**
- **FDR completed in Nov 2010**
- **PA signing planned for July 2011**

Plasma Facing Systems

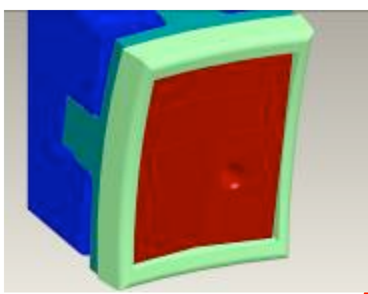
In-Vessel Components – Blanket & Divertor



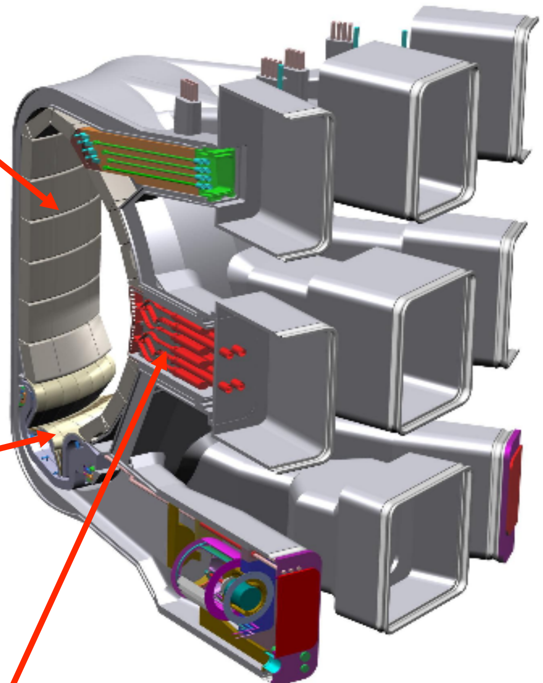
Blanket



Divertor



Port Plug



Blanket main functions :

- Exhaust the majority of the plasma power
- Contribute in providing neutron shielding to superconducting coils
- Provide limiting surfaces that define the plasma boundary during startup and shutdown.

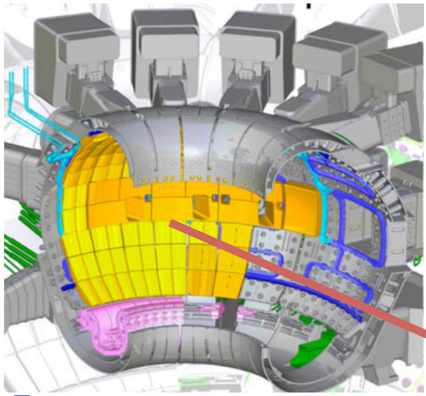
Divertor main functions :

- Minimize the helium and impurities content in the plasma
- Exhaust part of the plasma thermal power

See presentation in SO2A (Tue PM):
S. W. Lisgo, R. A. Pitts: "Challenges for the ITER Plasma Interface"

Baseline Blanket Status

(more details in next presentation: "Design of the ITER First Wall & Blanket")



Facts

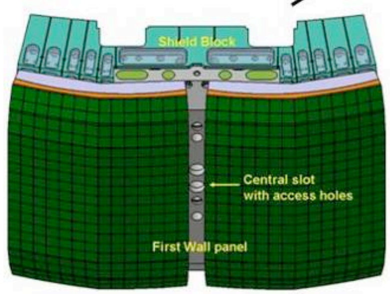
- 440 blanket modules
- ~4 tons each
- 18 poloidal rows
- 18 or 36 toroidal rows
- ~100 different variants
- Mass: 1530 tons

Technical Challenges

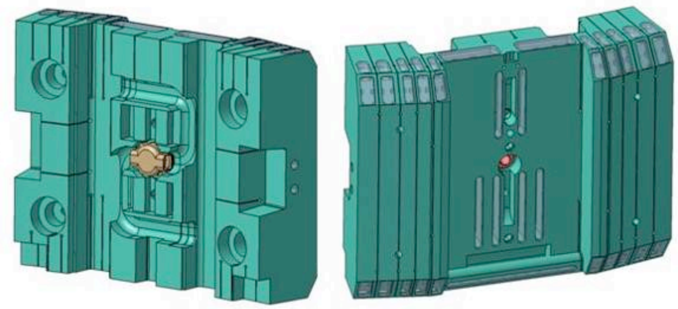
- High steady state heat flux ~ 5 MW/m²
- High EM loads from off-normal events
- Material bonding techniques
- Remote handling requirements
- Demanding interface accommodation

Example FW Mock-Up R&D Results

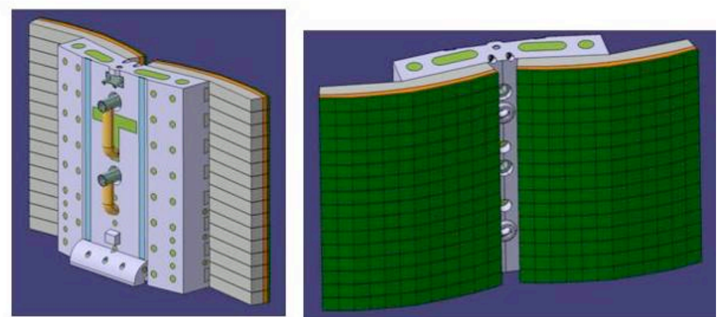
- Successful tests at 0.875 MW/m² (12,000 normal cycles) and 1.4 MW/m² (1000 cycles)

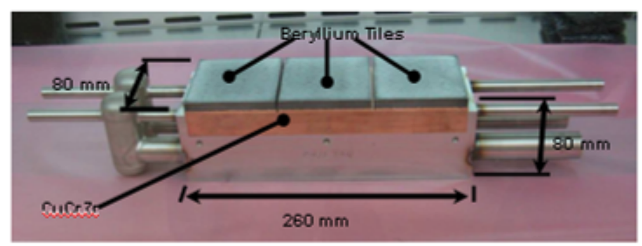


Shield Module



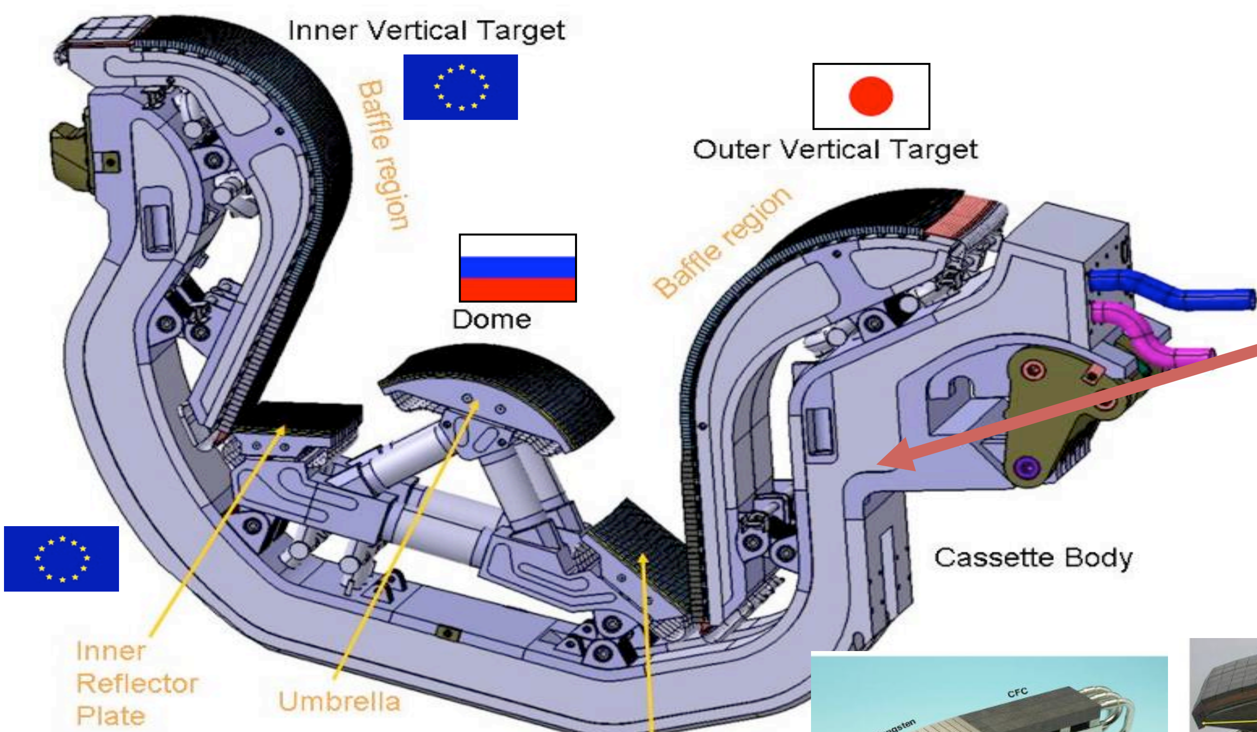
First Wall Panel

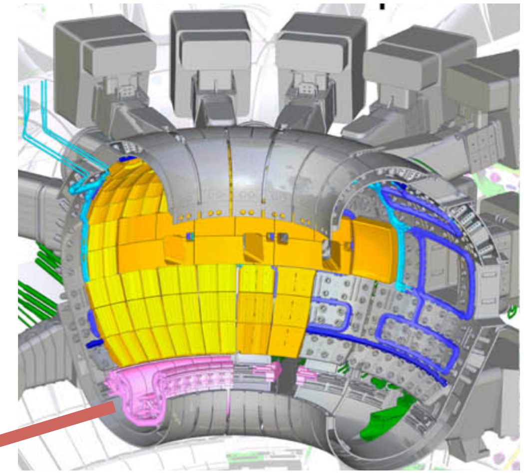




Mock-ups

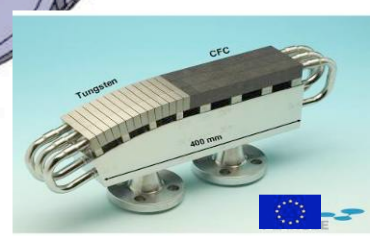
Divertor Status

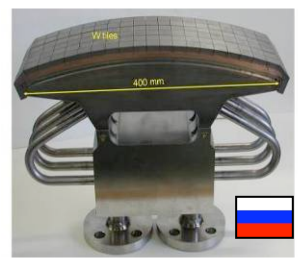


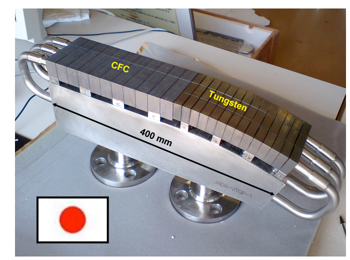


Facts

- 54 Divertor assemblies
- 4320 Heat flux elements







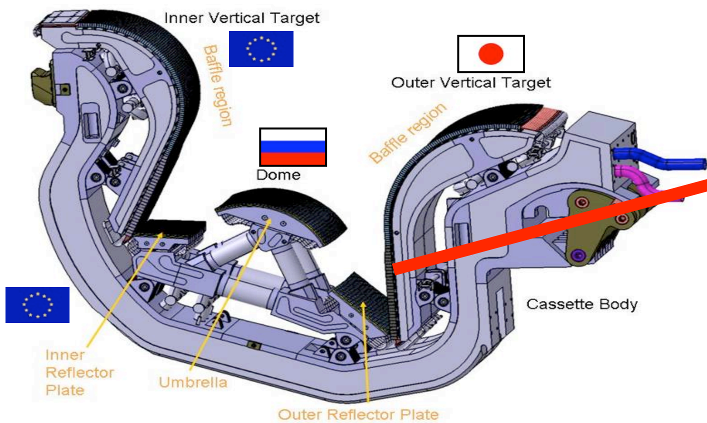
Technical Challenges

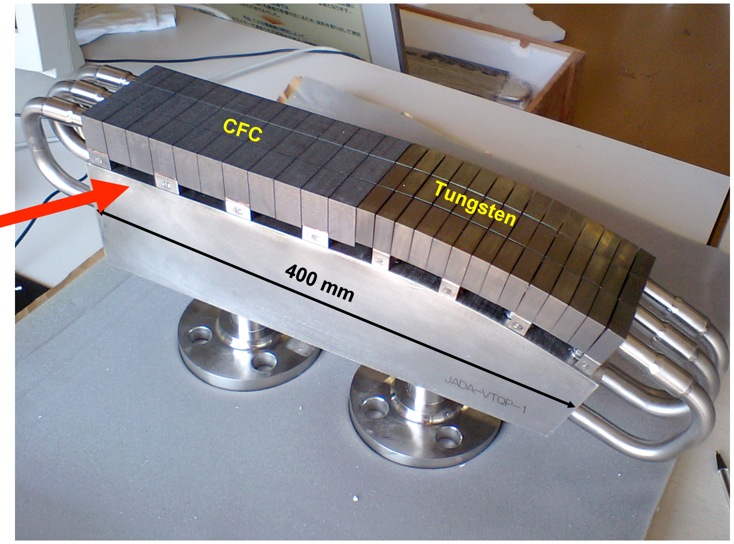
- High steady state heat flux up to 10 MW/m^2 (3000 cycles) & 20 MW/m^2 (300 cycles)
- Material bonding techniques
- Remote handling requirements

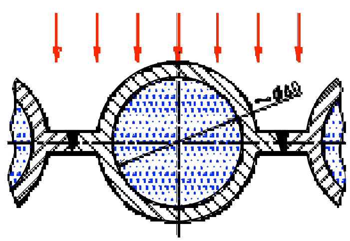
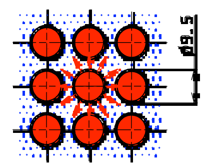
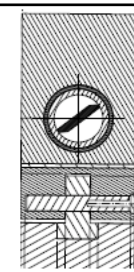
Qualification Prototypes - Status

- All the 3 Domestic Agencies have qualified
- Pre-PA Qualification process successfully completed in all the concerned DAs.

Power Handling Comparisons

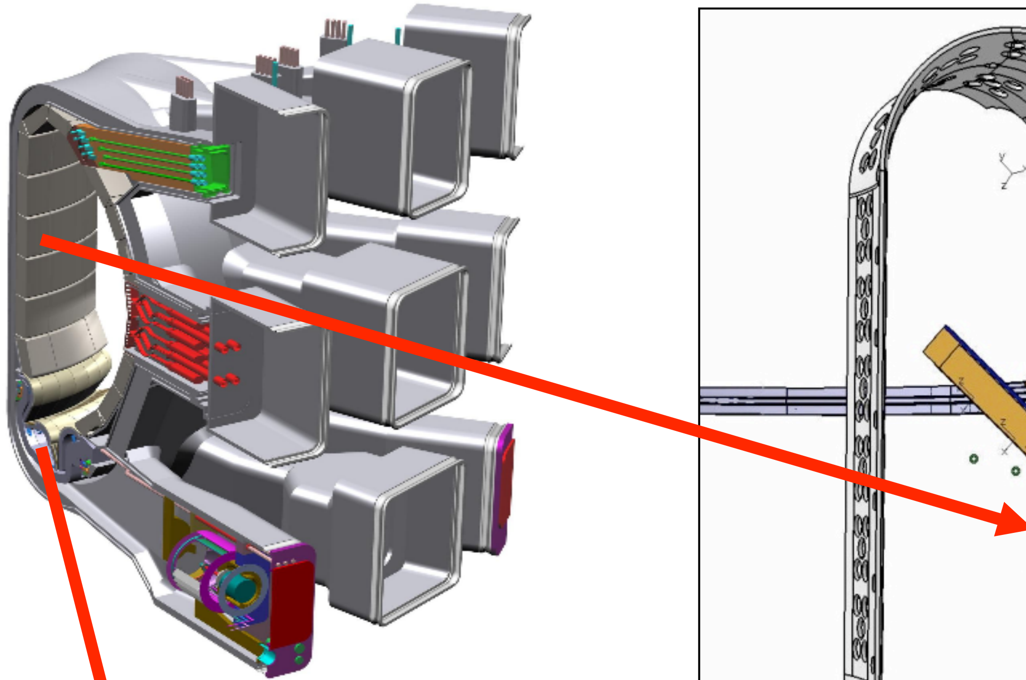


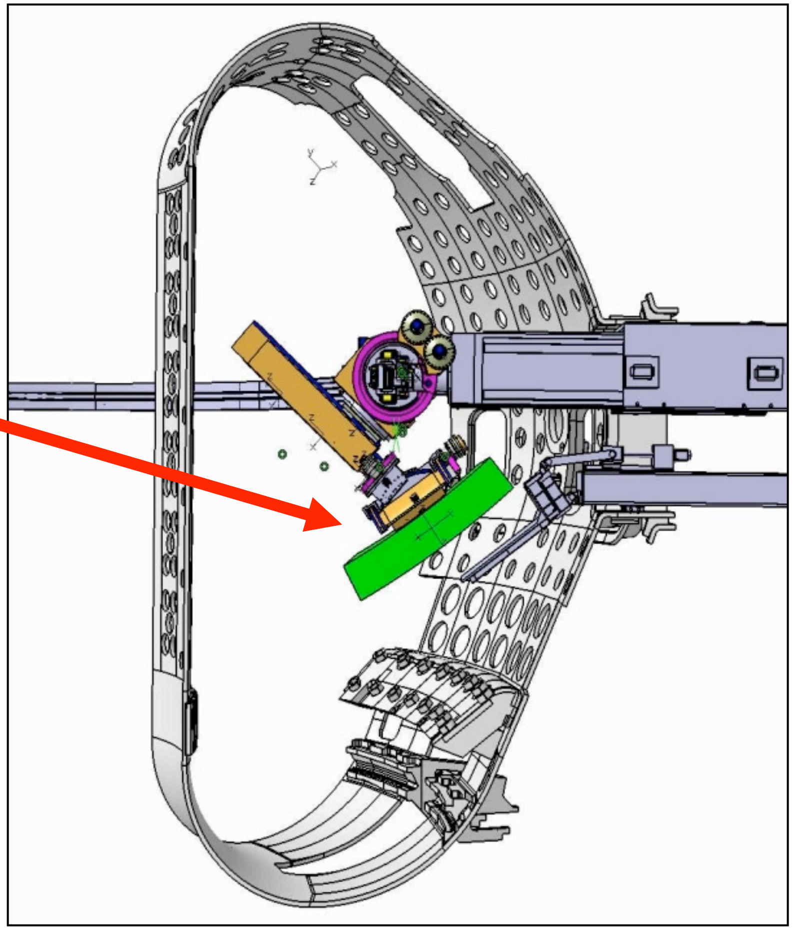


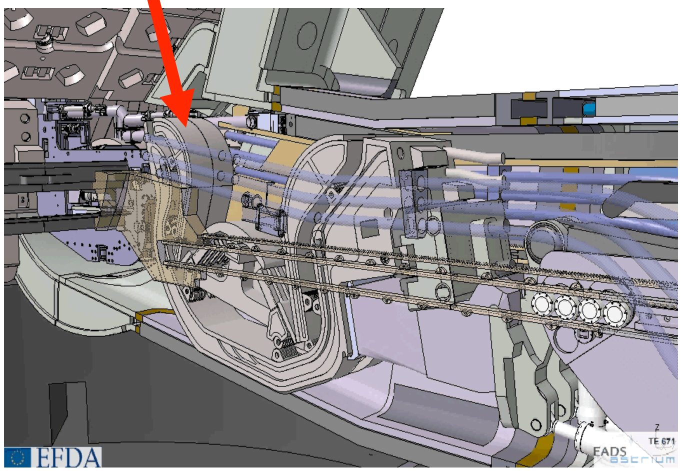
HIGH HEAT FLUX COMPONENTS	FOSSILE FIRED BOILER WALL (ABB)	FISSION REACTOR (PWR) CORE	ITER DIVERTOR
DESIGN			 12/15 mm ID/OD
HEAT FLUX - Average MW/m^2 - Maximum MW/m^2	0.2 0.3	0.7 1.5	3 – 5 (W areas) 10 – 20 (CFC areas)

In-Vessel Remote Handling

ITER_D_3ZRGRA v1.1







Blanket Module Handling ~4.5 ton

Divertor Cassette Handling ~9 ton

Summary

- The large size and unique requirements of ITER have presented many technical challenges for the design and manufacturing
- ITER designs, R&D, and manufacturing plans are addressing these challenges
- Key design activities required for first plasma are nearly complete
- Procurement contracts for many major systems are in place and ITER components are in fabrication around the world

Disclaimer

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