The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2267-2

Joint ITER-IAEA-ICTP Advanced Workshop on Fusion and Plasma Physics

3 - 14 October 2011

The ITER Project

SNIPES Joseph Allan

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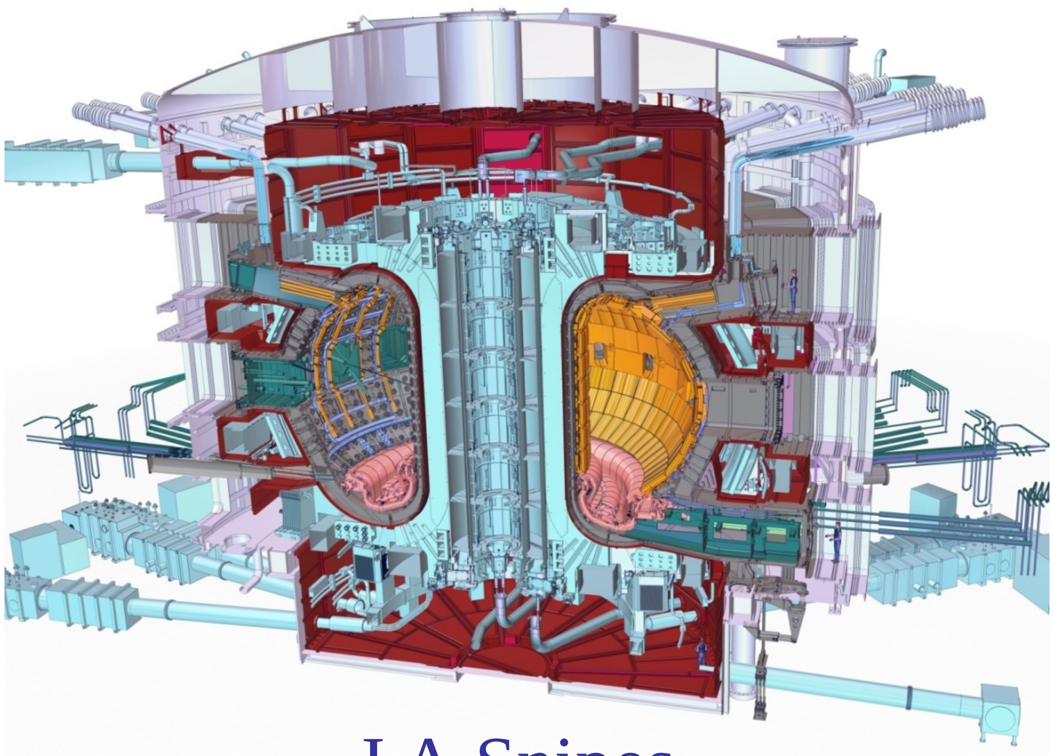
FRANCE

The ITER Project



J A Snipes

ITER Organization

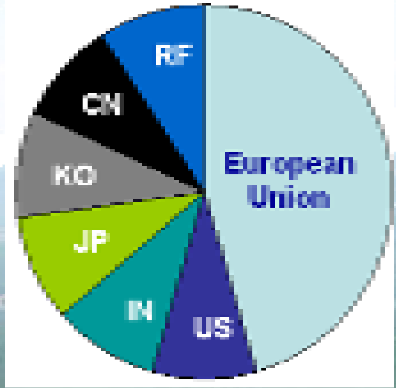
13115 St. Paul-lez-Durance, France

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

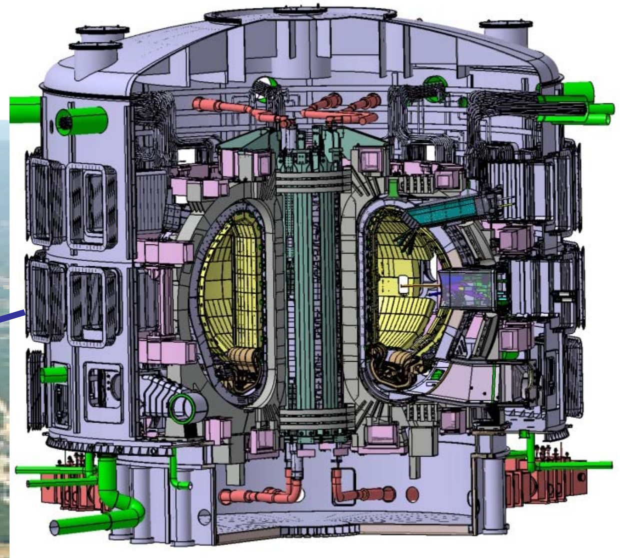
Outline

- ITER Project Overview
  - What is ITER?
  - ITER Management Structure
- Progress in Design and Construction
  - ITER schedule
  - Design nearing completion
  - Major components under construction
  - Building status
- Conclusions

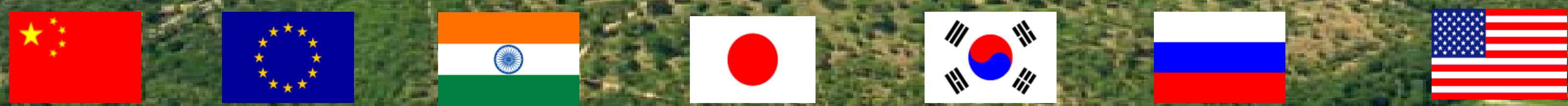
ITER - A Unique Scientific, Technological and Industrial Project



Seven Party Sharing



- **Objective -** Demonstrate the scientific and technological feasibility of controlled fusion energy
- **Goal -** produce significant fusion power amplification (10x the power input):**output 500 MW**



ITER Scope - Mission Goals

Physics:

- ITER is designed to produce a plasma dominated by α-particle heating
- produce a significant fusion power amplification factor (Q ≥ 10) in long-pulse operation
- aim to achieve steady-state operation of a tokamak (Q = 5)
- retain the possibility of exploring 'controlled ignition' (Q ≥ 30)

Technology:

- demonstrate integrated operation of technologies for a fusion power plant
- test components required for a fusion power plant
- test concepts for a tritium breeding module

ITER Overall Project Cost (OPC)

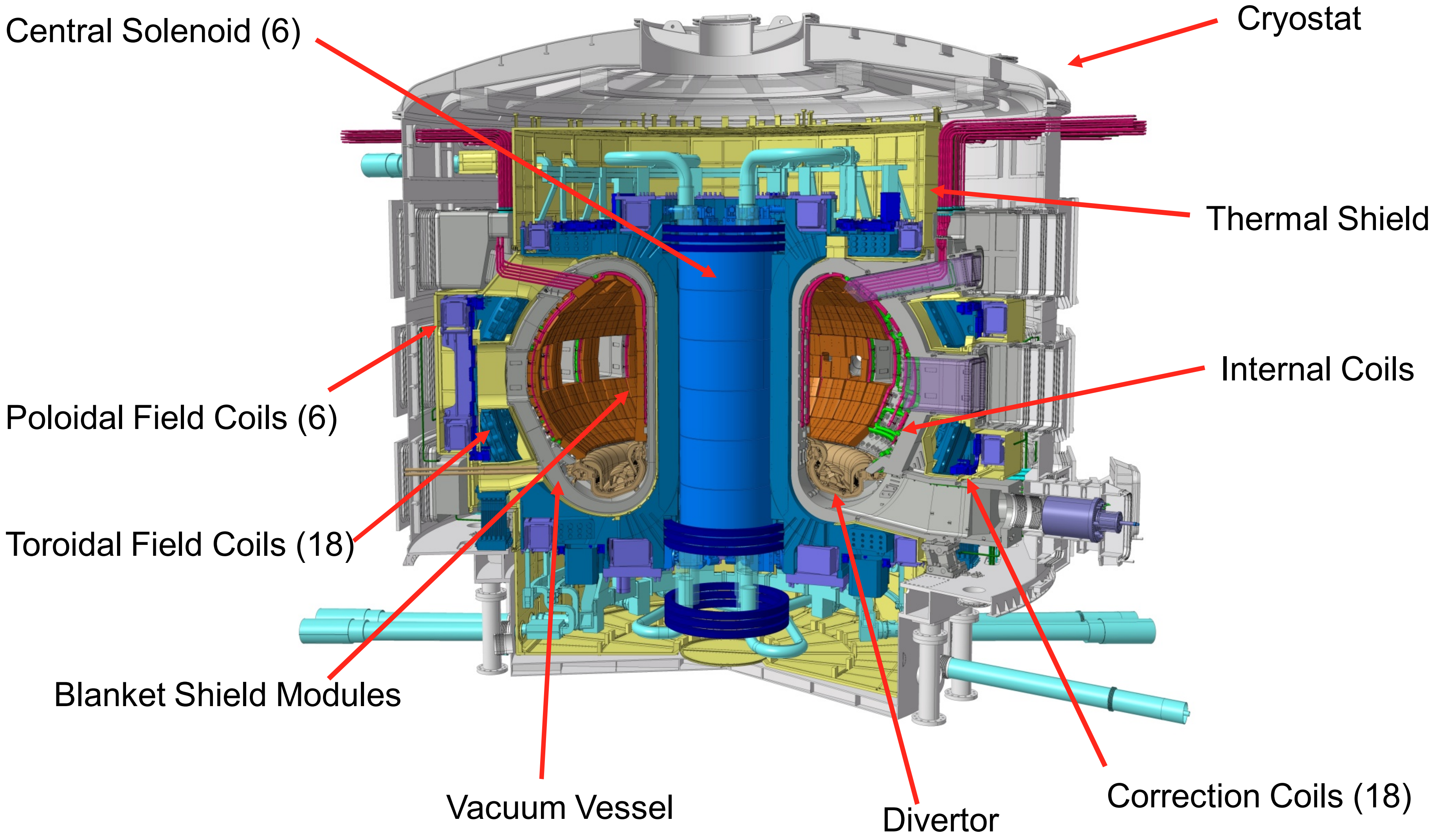
- **The cap on the total cost for the Construction Phase approved in July 2010 is 4700 kIUA**

- **Table shows the total cost over the lifetime of the project:**

Construction Phase	4584.7 kIUA
Additional Resources	115.3 kIUA
Operation Phase	188 kIUA per year
Deactivation Phase	EUR 281 Million
Decommissioning Phase	EUR 530 Million

NB: 1 kIUA = 1M $US (1989) = 1.58M Euro (2011)

ITER Tokamak - Major Components



ITER Organization Structure

Financial Audit Board

Management Advisory Committee

ITER Council

Science and Technology Advisory Committee

Test Blanket Module Program Committee

Office of the Director-General
Director: Takayuki Shirao

- IO Strategic Planning
- External Relations
- Communication
- Others

ITER Council Secretariat

Internal Audit Service

Legal Affairs

Osamu Motojima

Director-General

Project Board

Bureau of International Cooperation
Head:

DDG Carlos Alejaldre

DDG Wang Shaoqi

DDG Valery Chuyanov

DDG Richard Hawryluk

DDG Yong -Hwan Kim

DDG Dhiraj Bora

IO-DA Coordination

Domestic Agencies
- China
- EU
- India
- Japan
- Korea
- Russia
- USA

Department for Administration
DDG & Director: Richard Hawryluk

Department for ITER Project
DDG & Director: Remmelt Haange

Chief Scientist: Valery Chuyanov

Department for Safety Quality & Security
- Health & Safety Control
- Nuclear Safety & Analysis
- Quality Assurance

DDG & Director Carlos Alejaldre

Directorate for General Administration
Director Jin Ju

- Human Resources
- Procurement & Contract
- Document Control
- General Services

Directorate for Finance, Budget & Control
Director (acting) Richard Hawryluk

- Finance & Budget
- Project Management
- Project Information System

Directorate for Plasma Operation
Director David Campbell

- Science
- Technology

Directorate for Tokamak
Director (acting) Remmelt Haange

- Magnet
- Vessel
- Internal Components

Directorate for Central Engineering & Plant
Director Yong-Hwan Kim

- Electrical Engineering
- Fuel Cycle Engineering
- Plant Engineering

Directorate for CODAC, Heating & Diagnostics
Director Dhiraj Bora

- Control System
- Diagnostics
- Heating and Current Drive

Directorate for Buildings & Site Infrastructure
Director Timothy Watson

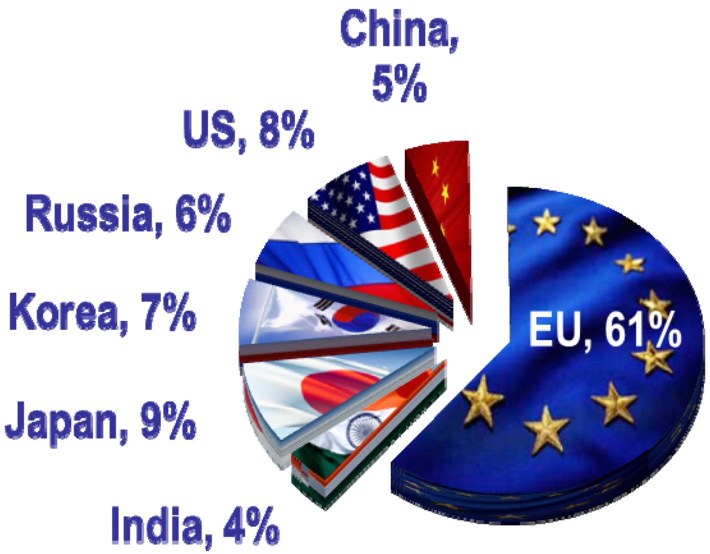
- Building System
- Site Management & Logistics
- Nuclear Buildings
- Non-Nuclear Buildings

Directorate for Central Integration & Engineering
Director Mitsunori Kondoh

- Assembly and Operations
- CAD & Design Coordination
- Technical Integration

Human Resources

- As of end May 2011, the IO has a total of 475 staff members with 305 professional and 170 technical support staff members;
- Since January, the IO has posted 20 positions, and 220 applications have been received. 11 staff members' employment contracts started (9 Professional staff, 2 technical support staff) while 10 persons left the IO. With the foreseen recruitments and departures, the total staff number will be 494 by the end of 2011.



P Staff Distribution by Members

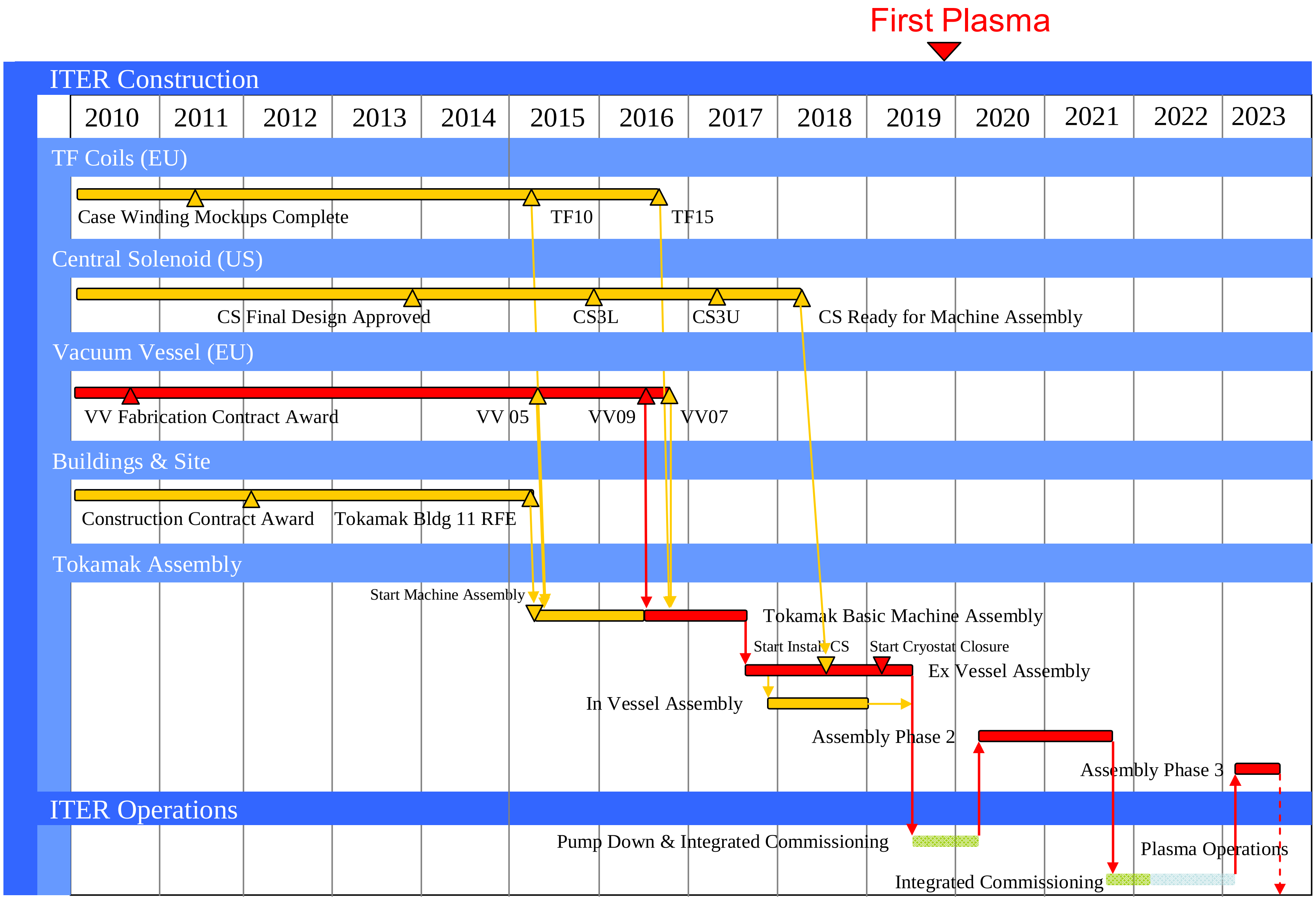
	Professional staff	Support staff	Total
CN	16	4	20
EU	185	125	310
IN	12	16	28
JA	26	7	33
KO	21	5	26
RU	19	3	22
US	26	10	36
Total	305	170	475

The ITER Project Team - Domestic Agencies

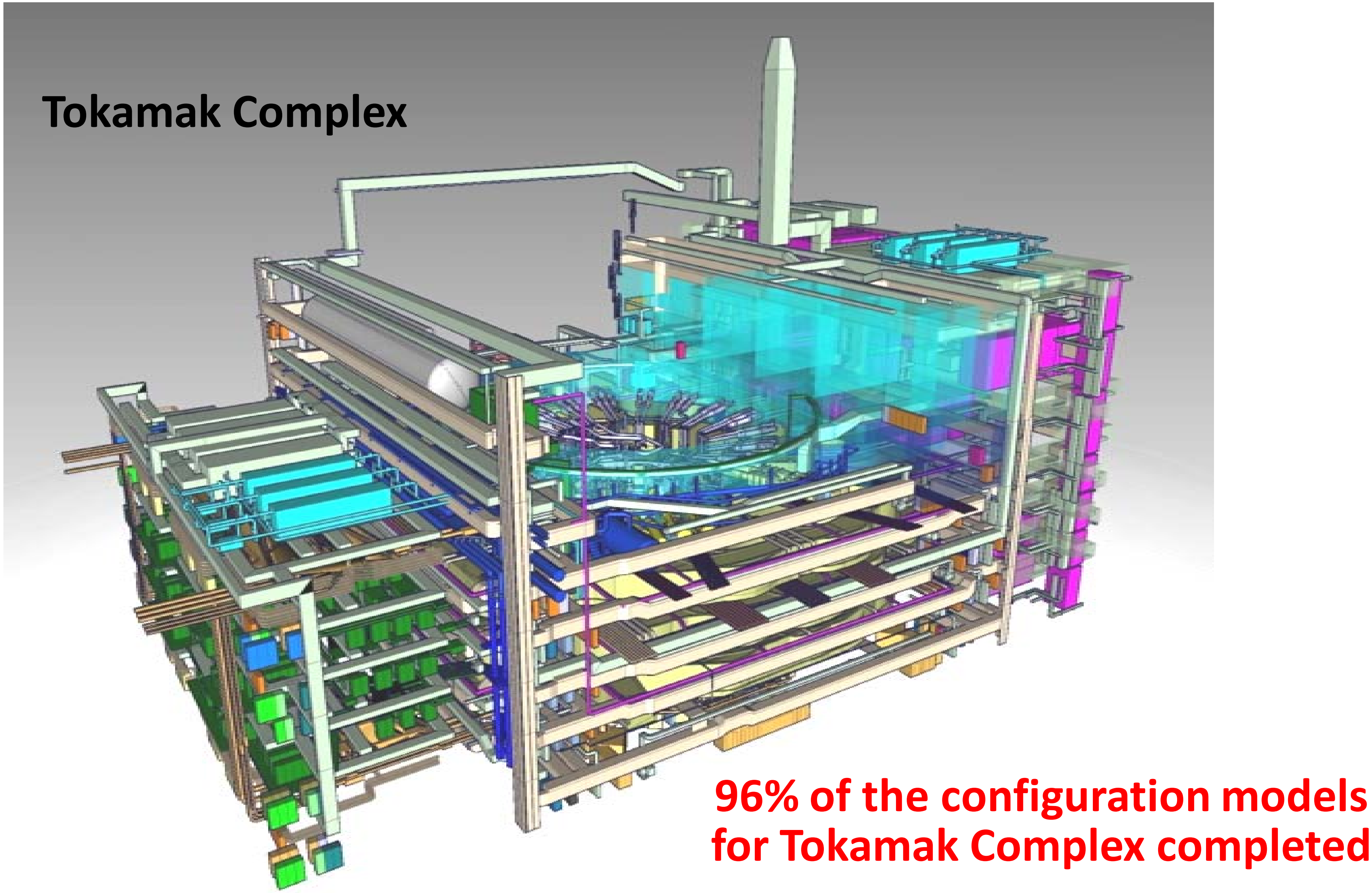
- **90% of ITER components will be supplied “in-kind” by the Members through their Domestic Agencies**

Progress on ITER Design and Construction

Present ITER Construction Schedule



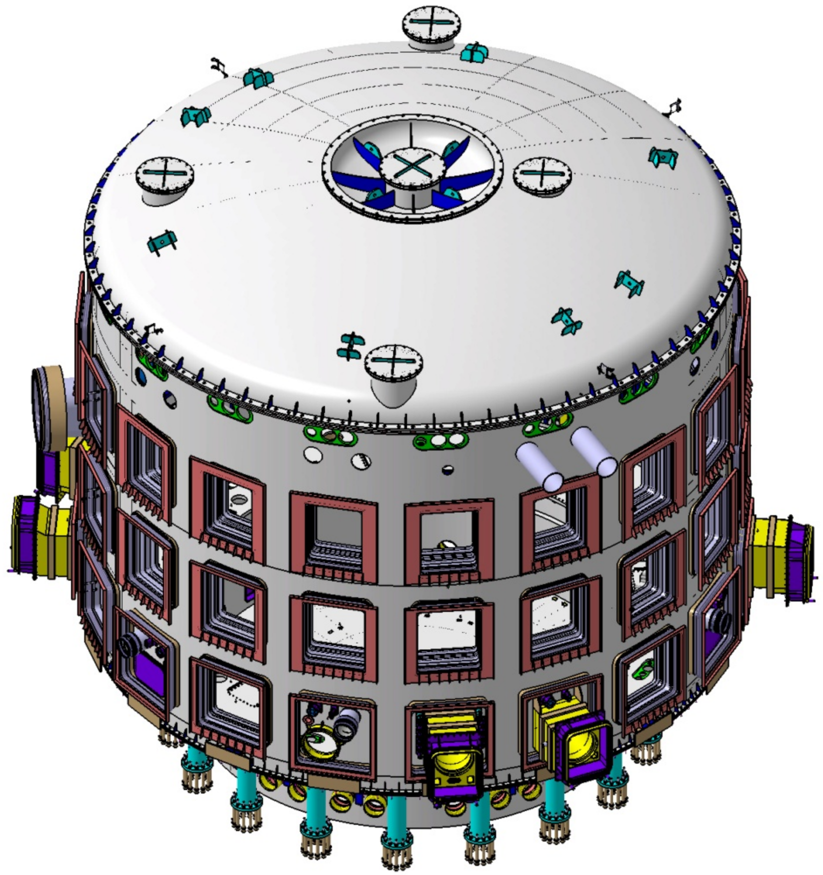
Plant Systems Configuration Models

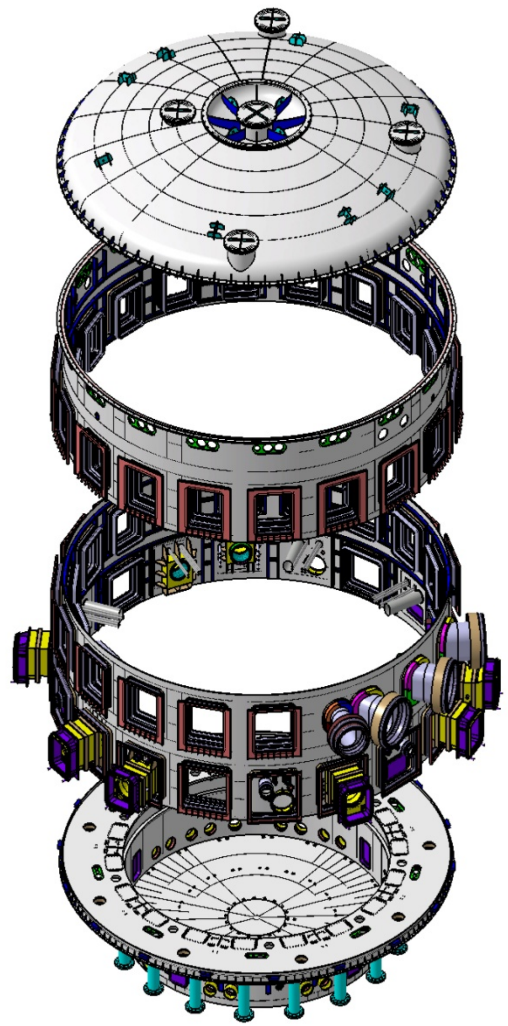


Status of Procurement Arrangements (PAs)

- The IO and relevant Domestic Agencies have signed 55 PAs, amounting to a total of over €3000M, representing 70% of the total procurement value for the construction of ITER;
- PAs are prioritized according to the Integrated Project Schedule (IPS); approximately 20 more PAs are scheduled to be signed by the end of 2011;
- Additional Direct Investment (ADI) for project changes that have been accepted into the Baseline total €16M
- These were added to the Overall Project Cost (OPC) as approved at the Extraordinary Meeting of the ITER Council (IC-Ex) in July 2010

Cryostat Status





Top Lid

Upper Cylinder

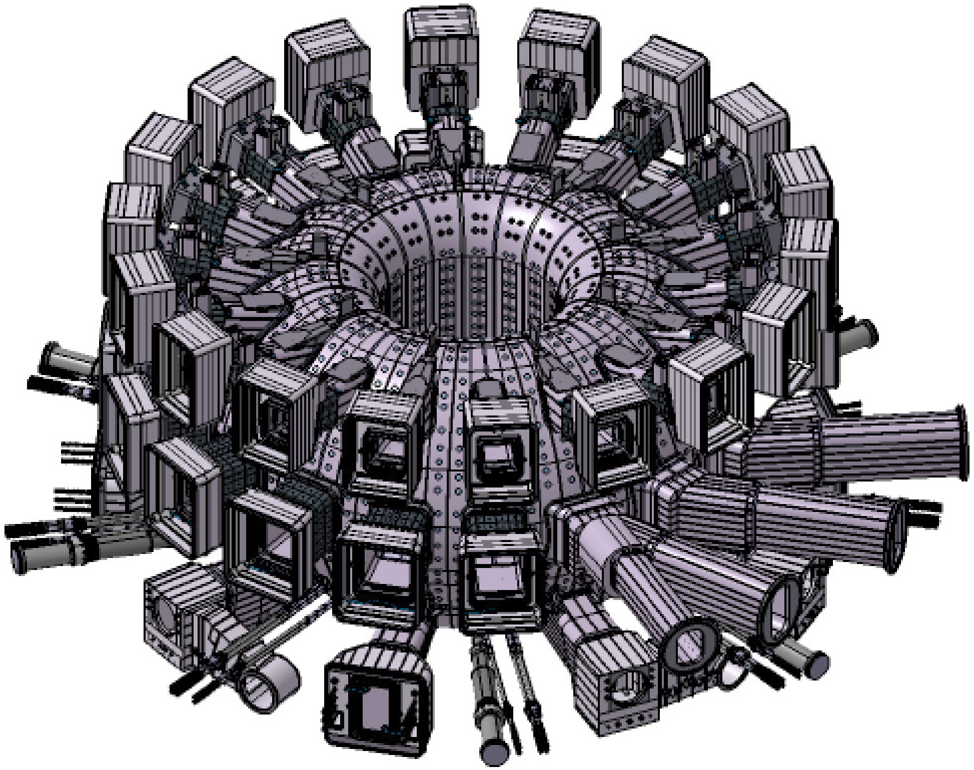
Lower Cylinder

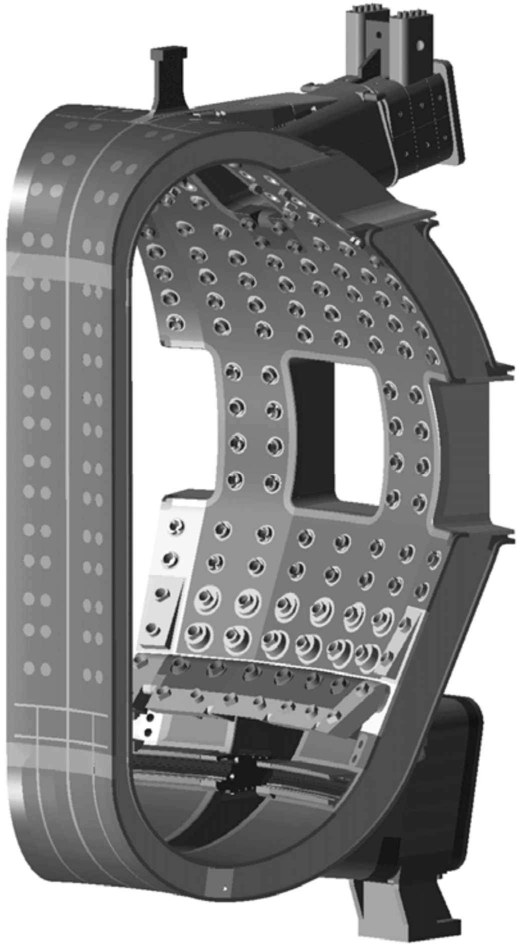
Base Section

- **Provides the vacuum insulation for operating the superconducting magnets and thermal shield system**
- **304L Stainless steel 40 – 180 mm thick**
- **Weight ~3500 tonnes**

- IN-DA signed PA September 2011

Vacuum Vessel Status



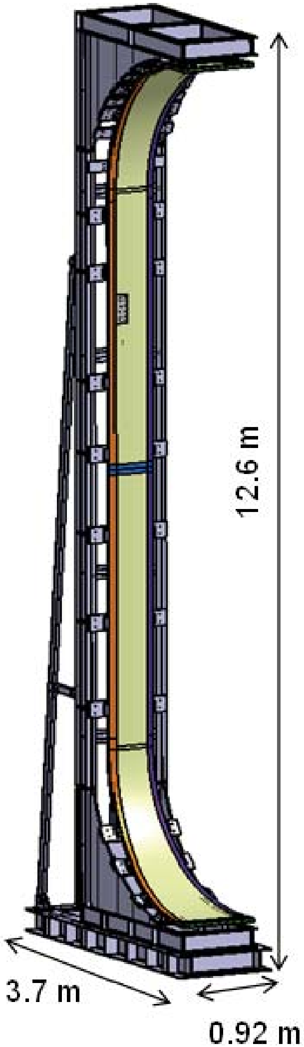


- Vacuum Vessel is double-walled stainless steel
  - 19.4m outer diameter, 11.3m height, 5300 tonnes
  - provides primary tritium confinement barrier

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

Large Scale Mock-Ups of Vacuum Vessel and Thermal Shield

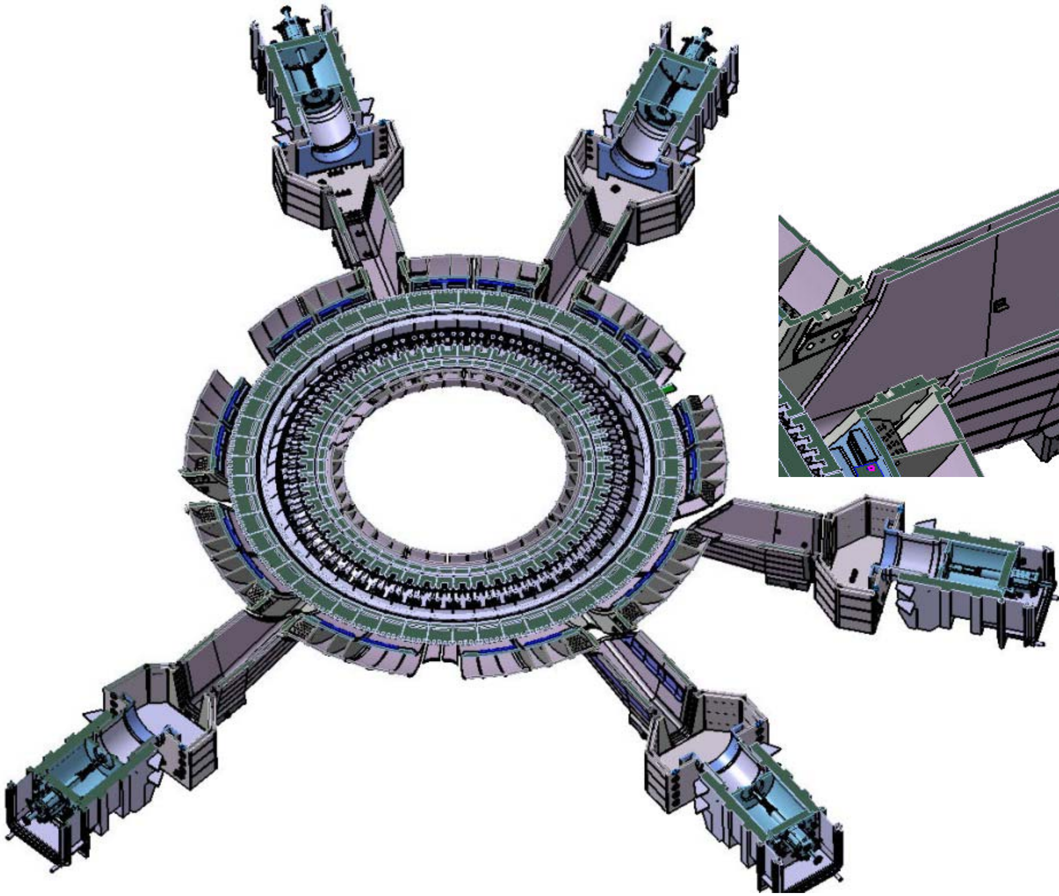
Inboard segment of a VV sector

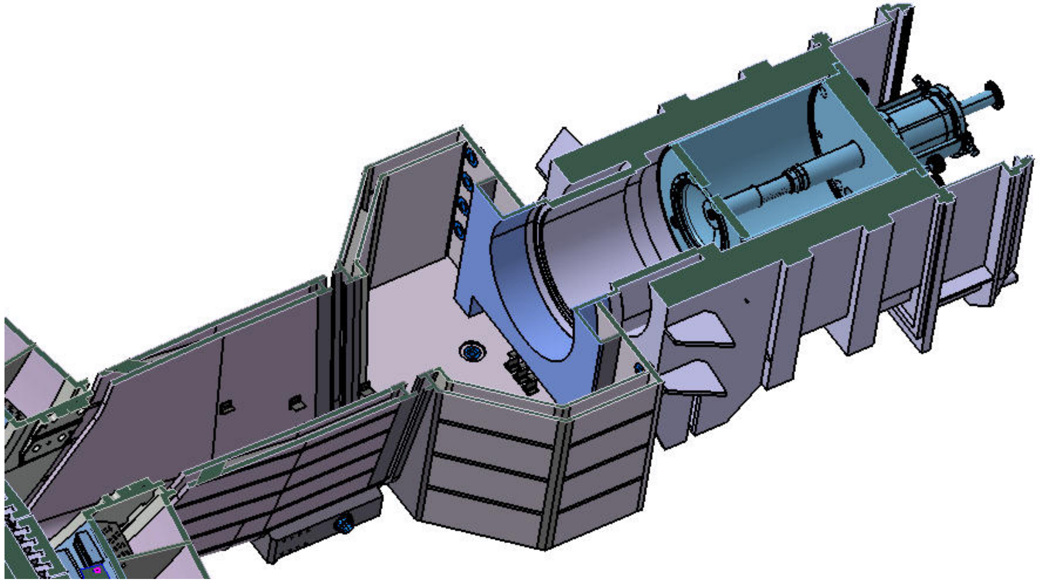


- **Korean Domestic Agency is verifying the manufacturing design and fabrication methods**

Photos: KO DA

Torus Vacuum Controlled by 5 Lower Port Cryopumps



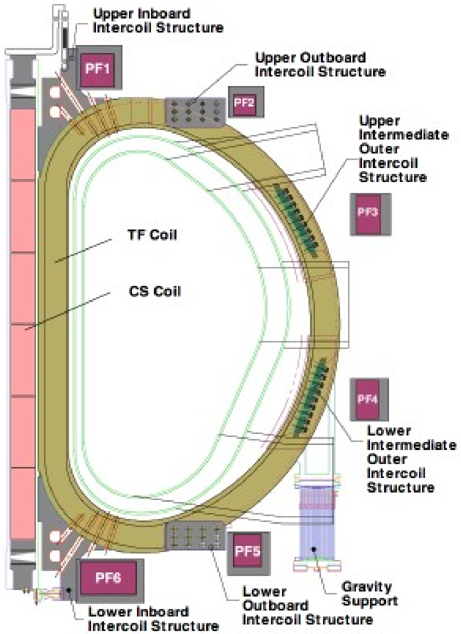


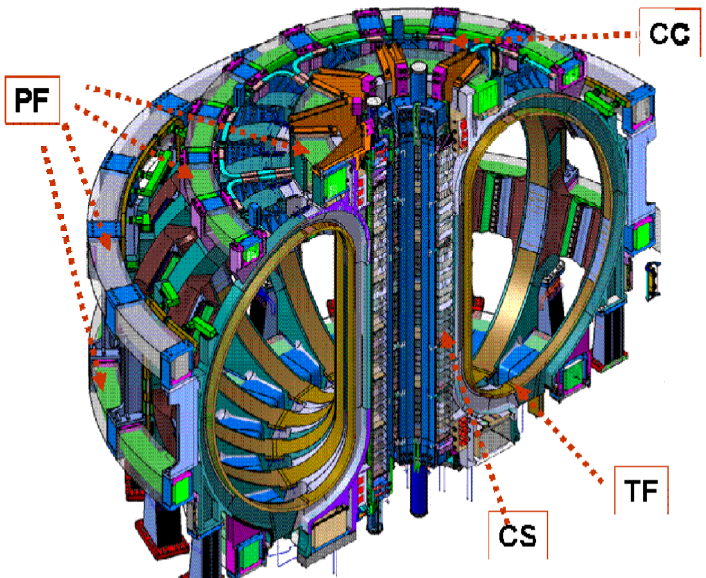
NB cryopumps require ~3 hour regeneration/day w/o plasma ➔

MAX # Pulses	Pulse Length (s)
40	400
18	1000
7	3000

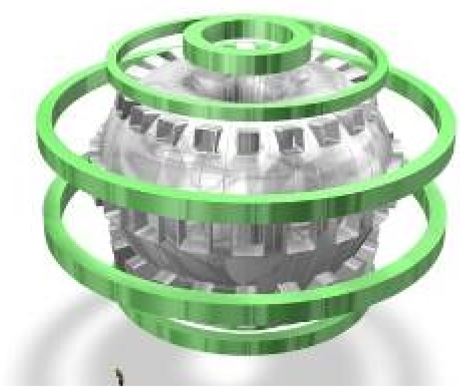
~10 s required to change pumping speed from 0 – 100%

Magnet System

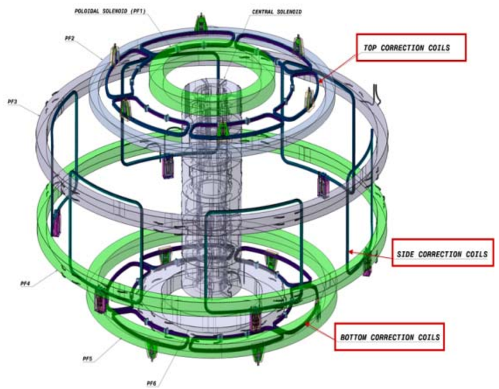




18 TF Coils (EU & JP)



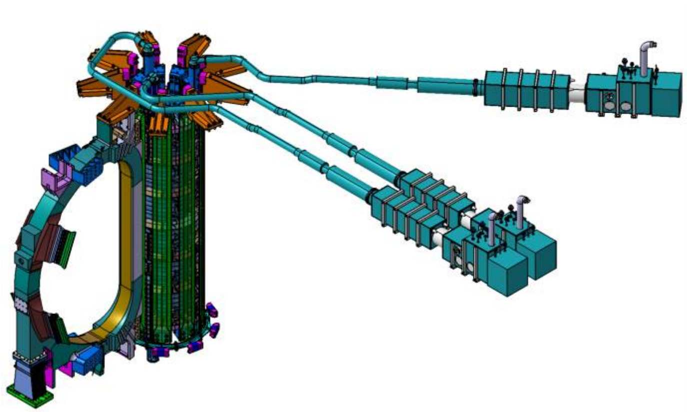
6 PF Coils (EU & RF)



9 Correction Coil Pairs (CN)

48 superconducting coils
- ~9800 tons
- ~187 km of conductor

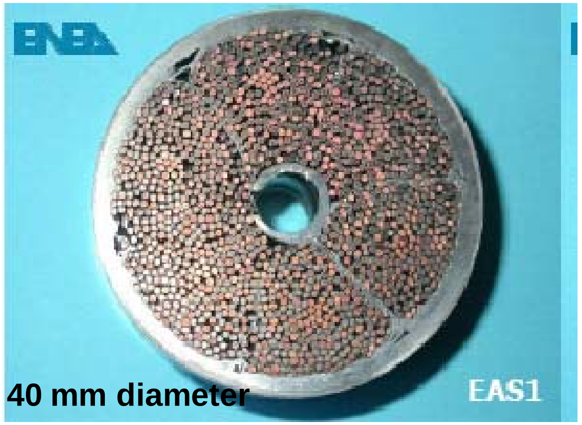
11.8 T (peak TF field)
68 kA (peak current)
Stored energy: 51 GJ



31 Feeders (CN)

CS Coils – Stack of 6 (US)

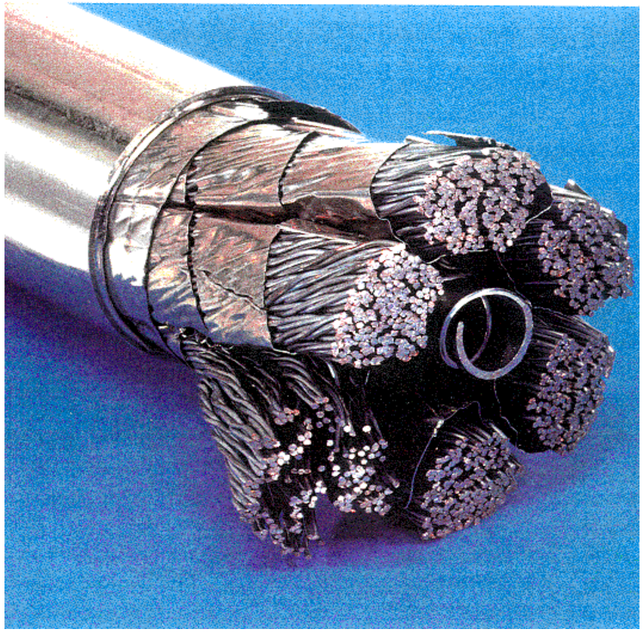
TF Conductor Procurement

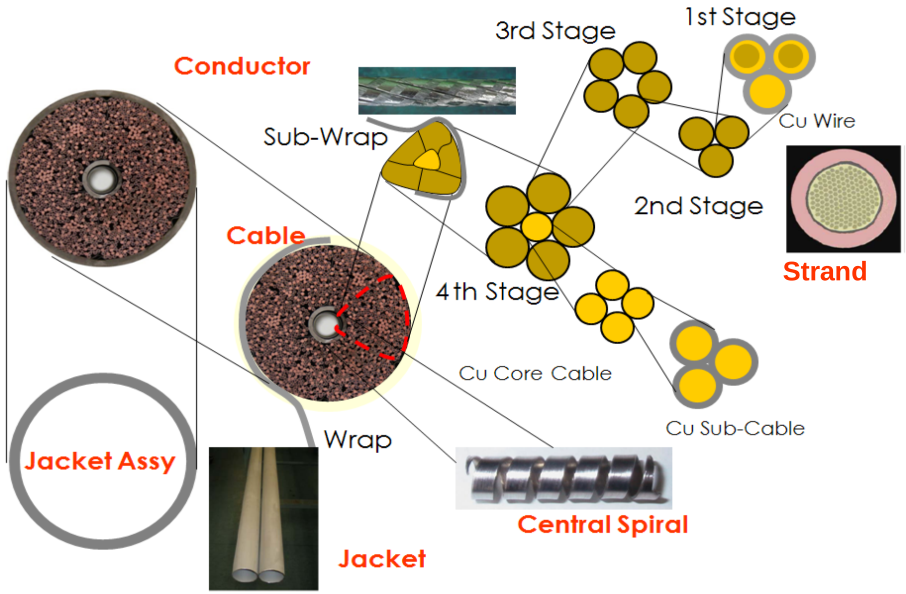


ITER TF Conductor

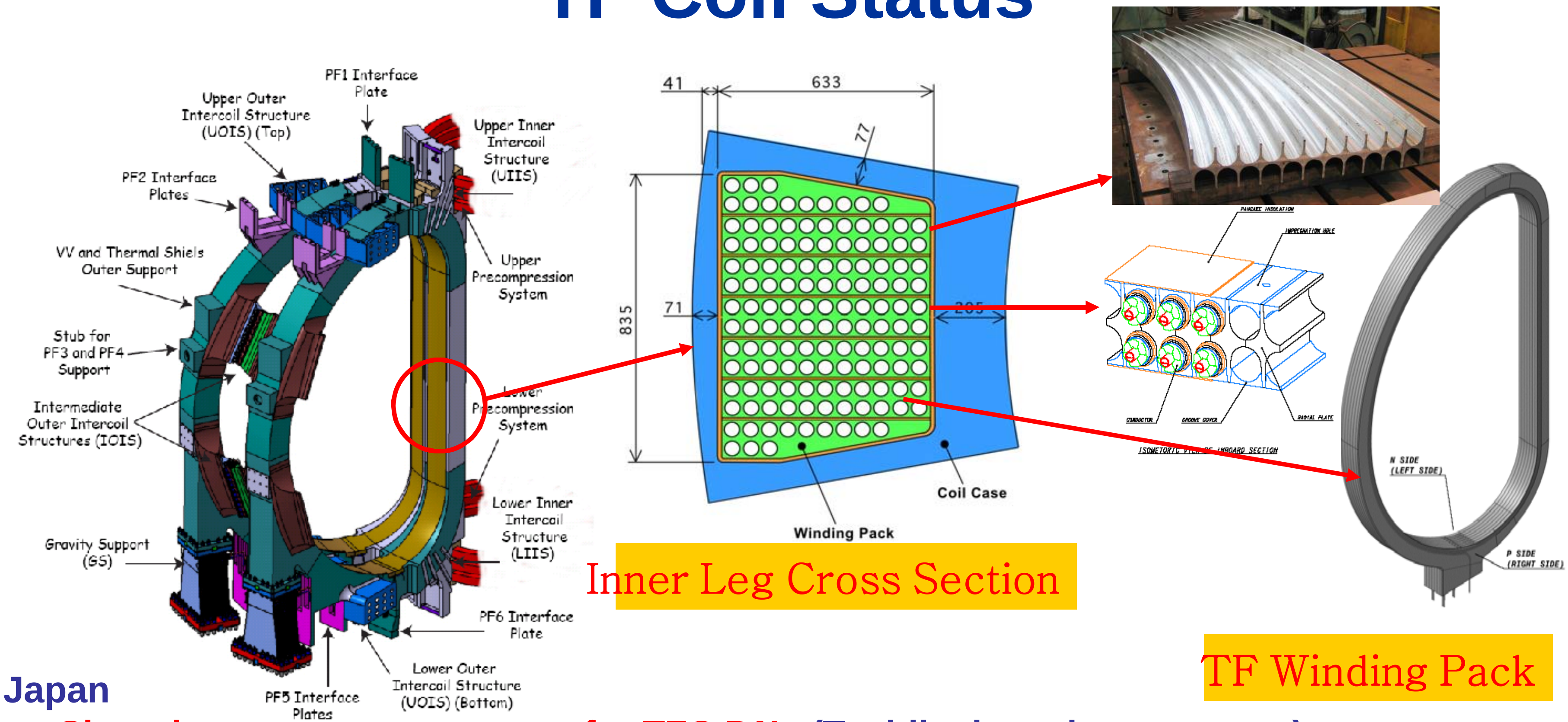
- ~90 km / 400 t of Nb_3Sn conductor
  (The biggest Nb_3Sn conductor procurement in history!)
  ~150000 km of strand (15 x around Earth)
  Operates at ~5 K
  11.8 T (peak TF field)
  68 kA (peak TF current)

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





TF Coil Status



Japan

- **Signed procurement contract for TFC PA's (Toshiba is main contractor)**
- **Commissioning of winding machine @ Toshiba in progress**
- **Welding trials in progress for TFCs and TFC Case**

Europe

- **Signed a procurement contract for prototype radial plates**
- **Winding Package call-for-tender underway**
- **Contract signed to qualify the TFC Case welds**

Progress on TF Coils - Japan

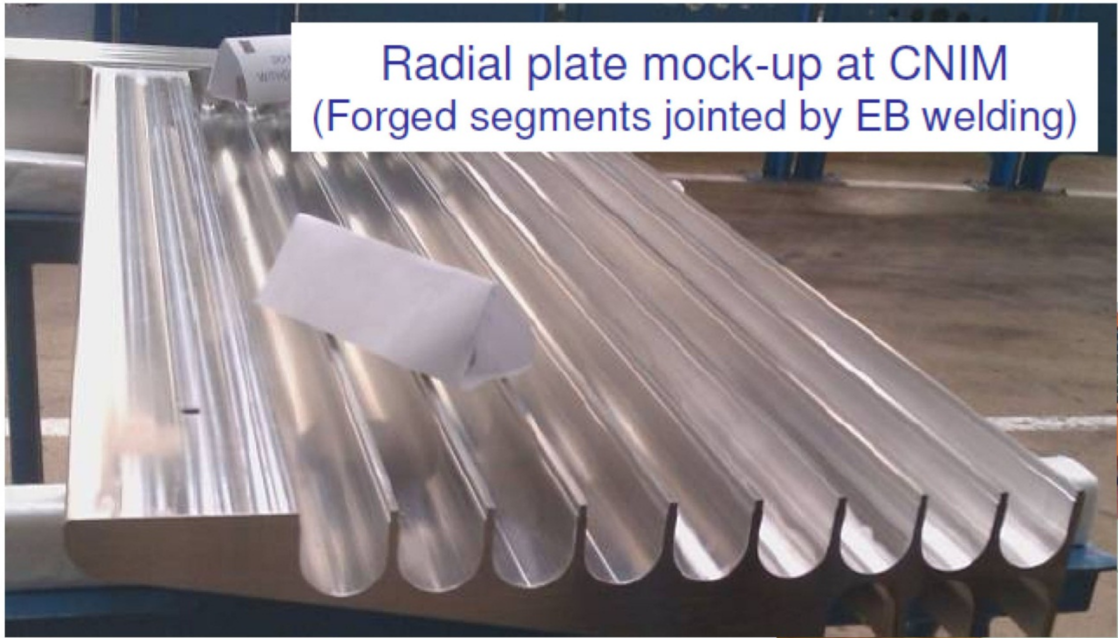
Completed one third scale 3-turn winding trials at Toshiba

Winding Support Jig

Winding & Bending Rollers

Photos: JAEA and Contractor Toshiba

Progress on TF Coils - EU



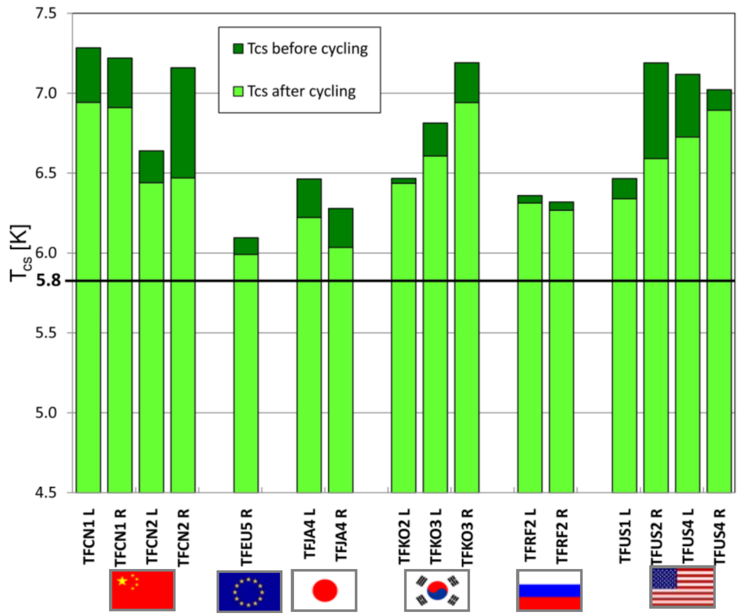
Radial plate mock-up at CNIM
(Forged segments jointed by EB welding)

Radial plate welding mock-up at SIMIC
(Powder hipped segments joined by narrow gap TIG welding)

Photos: F4E & Contractors SIMIC, CNIM and Le Creneau

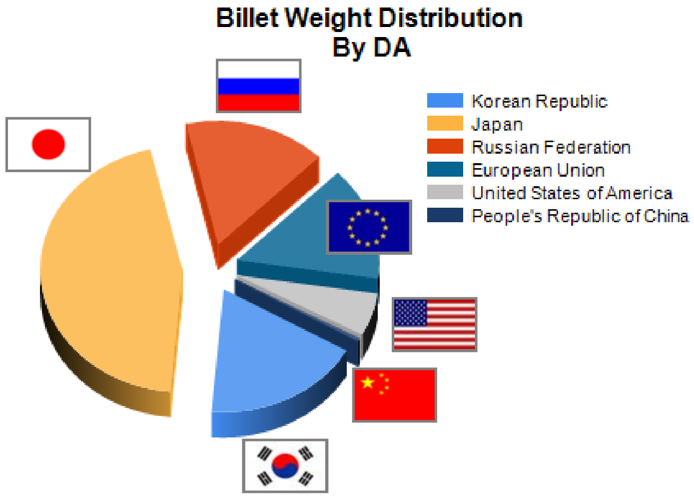
TF & PF conductor activity underway in Heifei, China

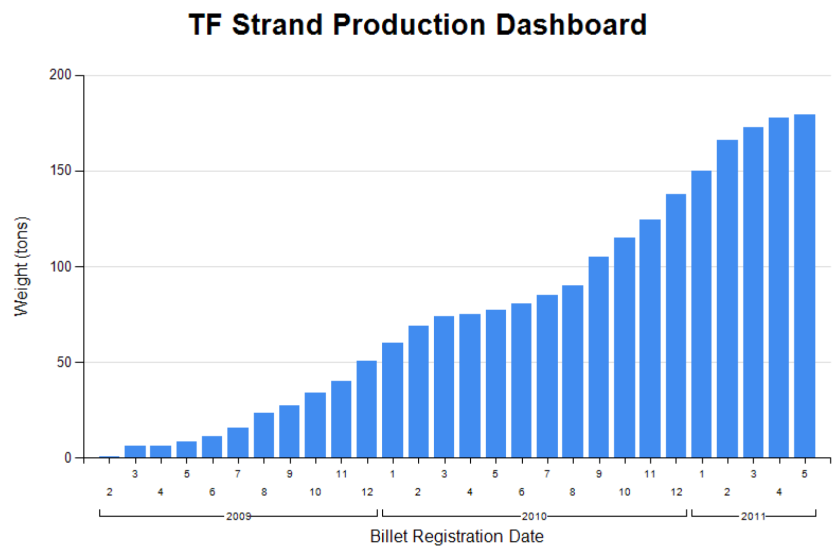
TF Conductor Production



TF Qualification Sample Summary

- **All TF conductor qualification samples were manufactured at CRPP and enabled supplier qualification in all 6 DAs involved in TF conductor production**
- **As of today, over 40% of required 450t of Nb_3Sn strand has been produced around the world**

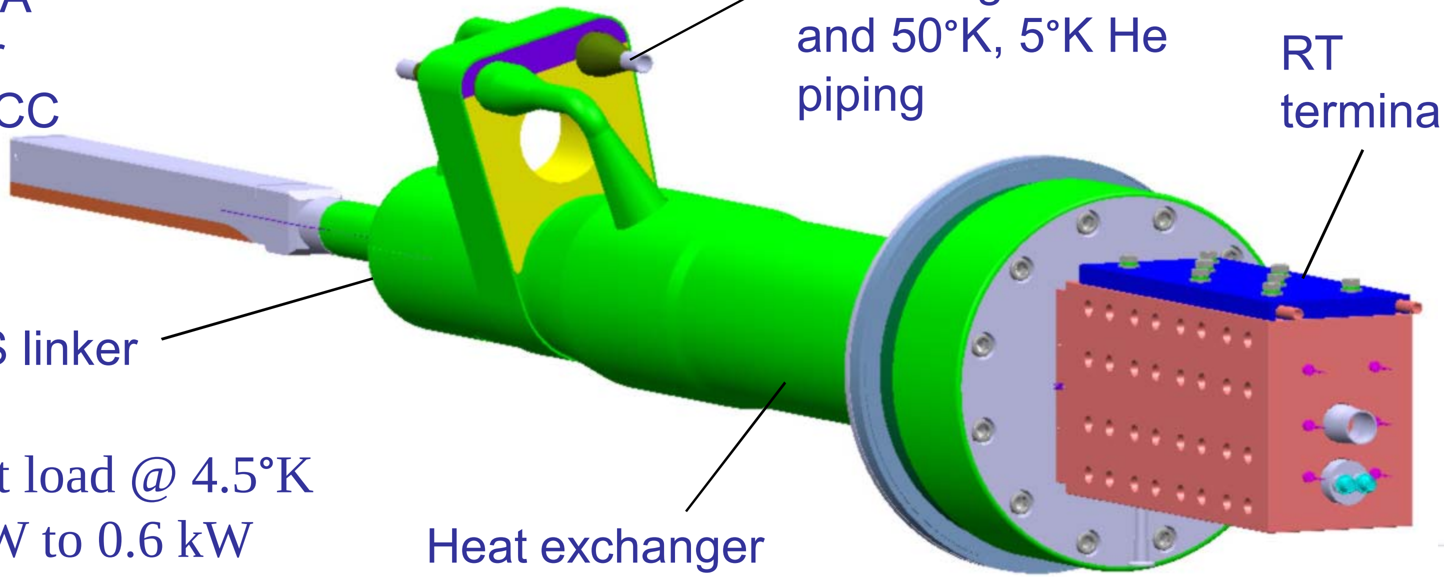




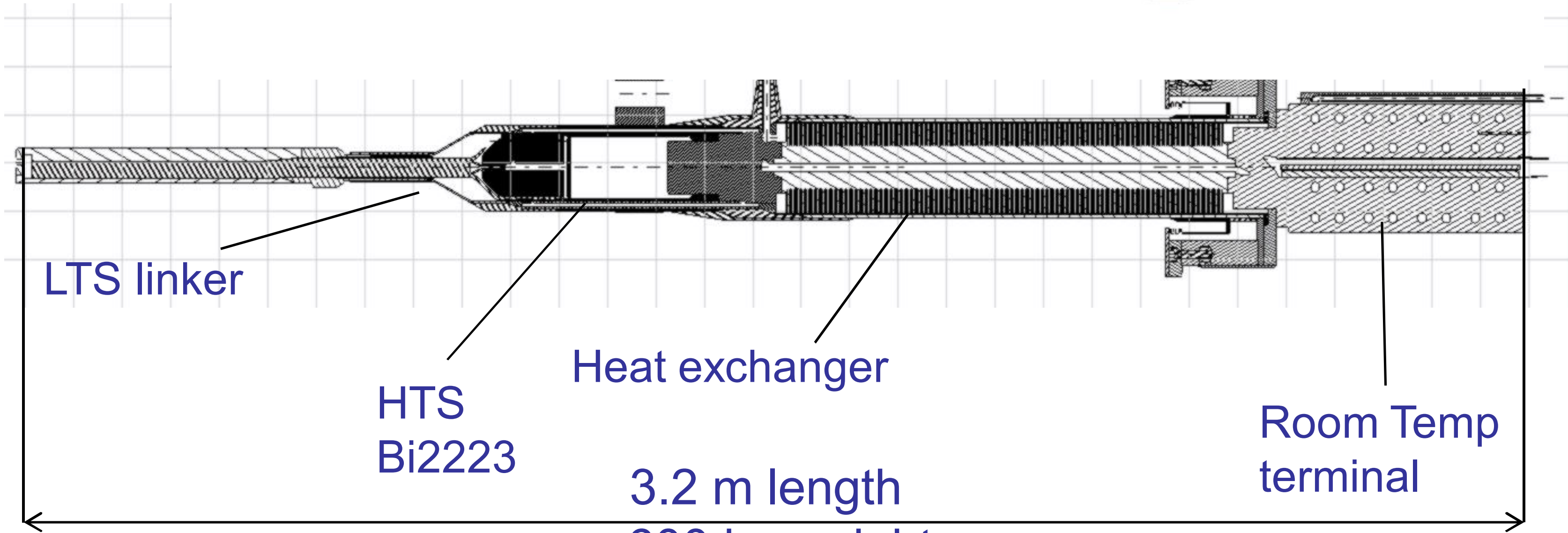
TF Strand Production Summary

High Temperature Superconductor Lead Design

10 kA – 68 kA capability for TF, PF, and CC coil leads

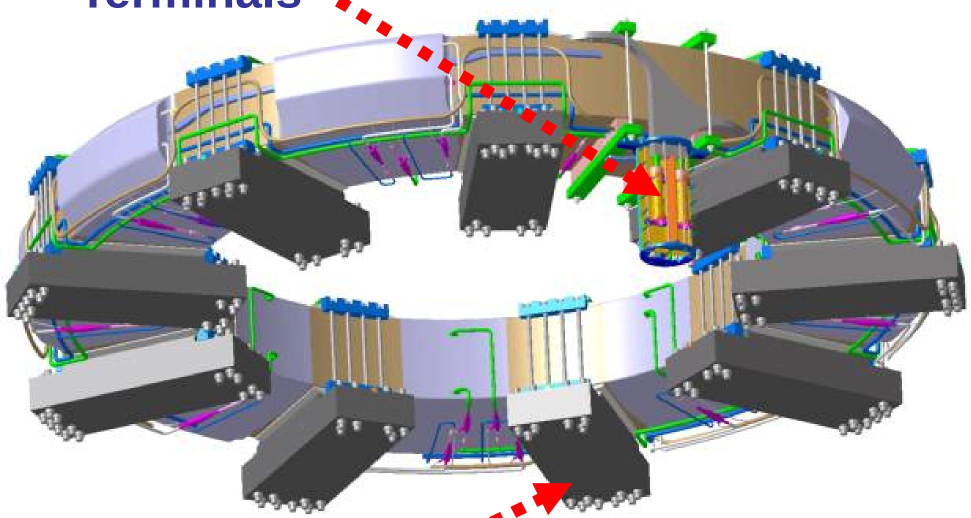


Reduces heat load @ 4.5°K from ~2.5 kW to 0.6 kW

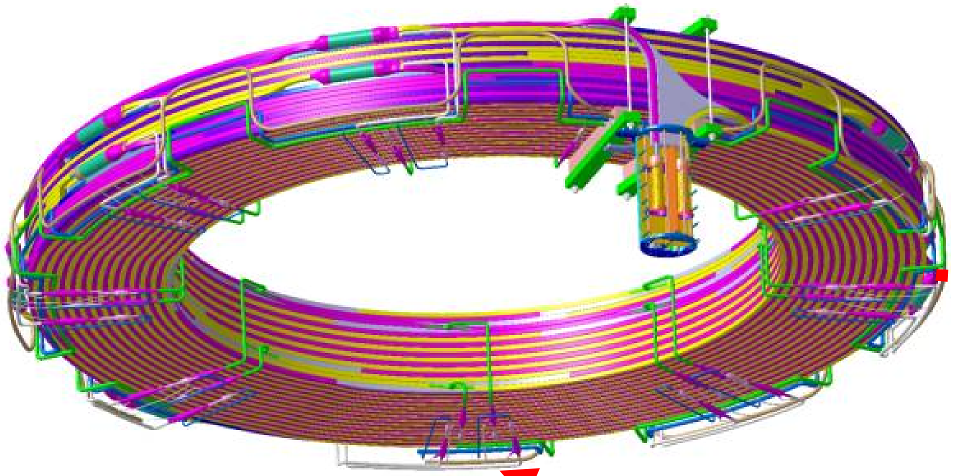


Poloidal Field Coil Status

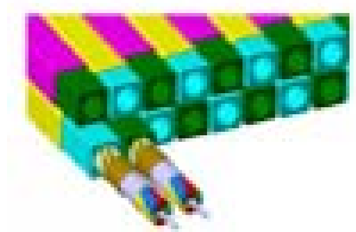
Terminals



Support clamps



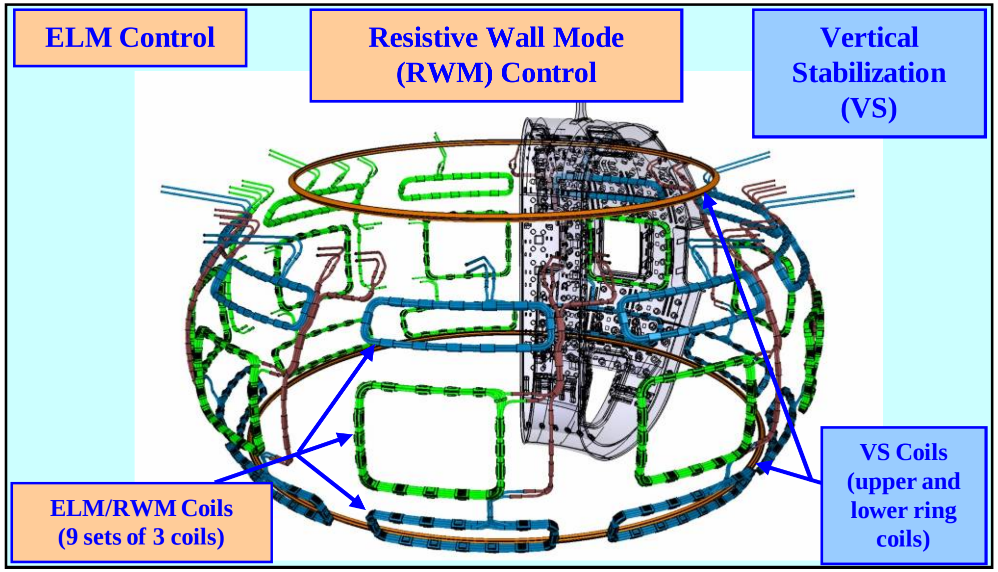
He inlets



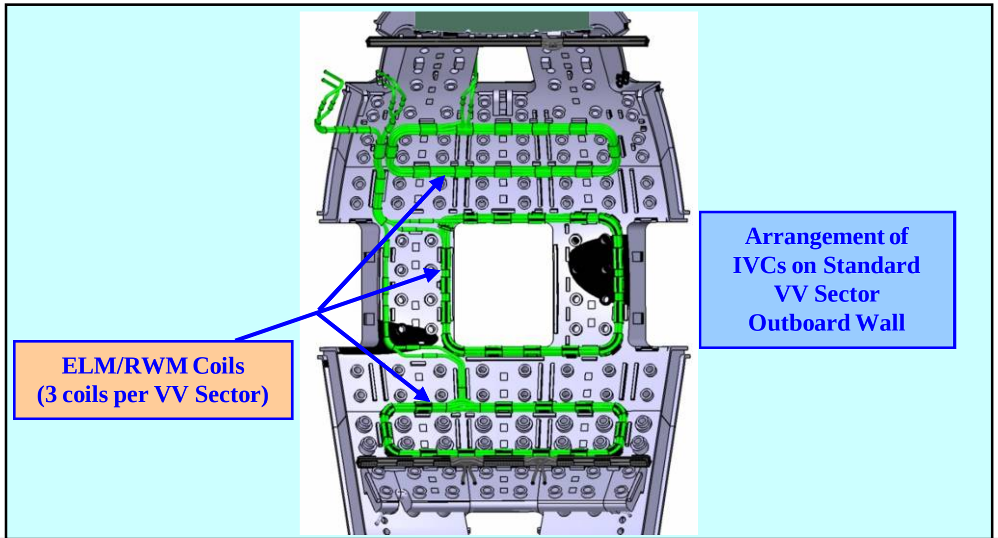
Conductor Winding

- PF Coil 2,3,4,5,&6 PA signed with EU
- PF Coil 1 PA signed with RF
- So big must be manufactured on site! PF3: 24.5 m dia. & 386 ton
- PF coil winding building is 250 m long x 45 m wide and is nearing completion at ITER!

In-Vessel Coils



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



Background

- Vertical Stability (VS) coils provide fast response for plasma vertical position control
- Uncontrolled Edge Localized Modes (ELMs) can lead to unacceptably rapid erosion of the divertor target
- ELM coils provide resonant magnetic pertubations (RMP) at plasma edge to stabilize ELMs

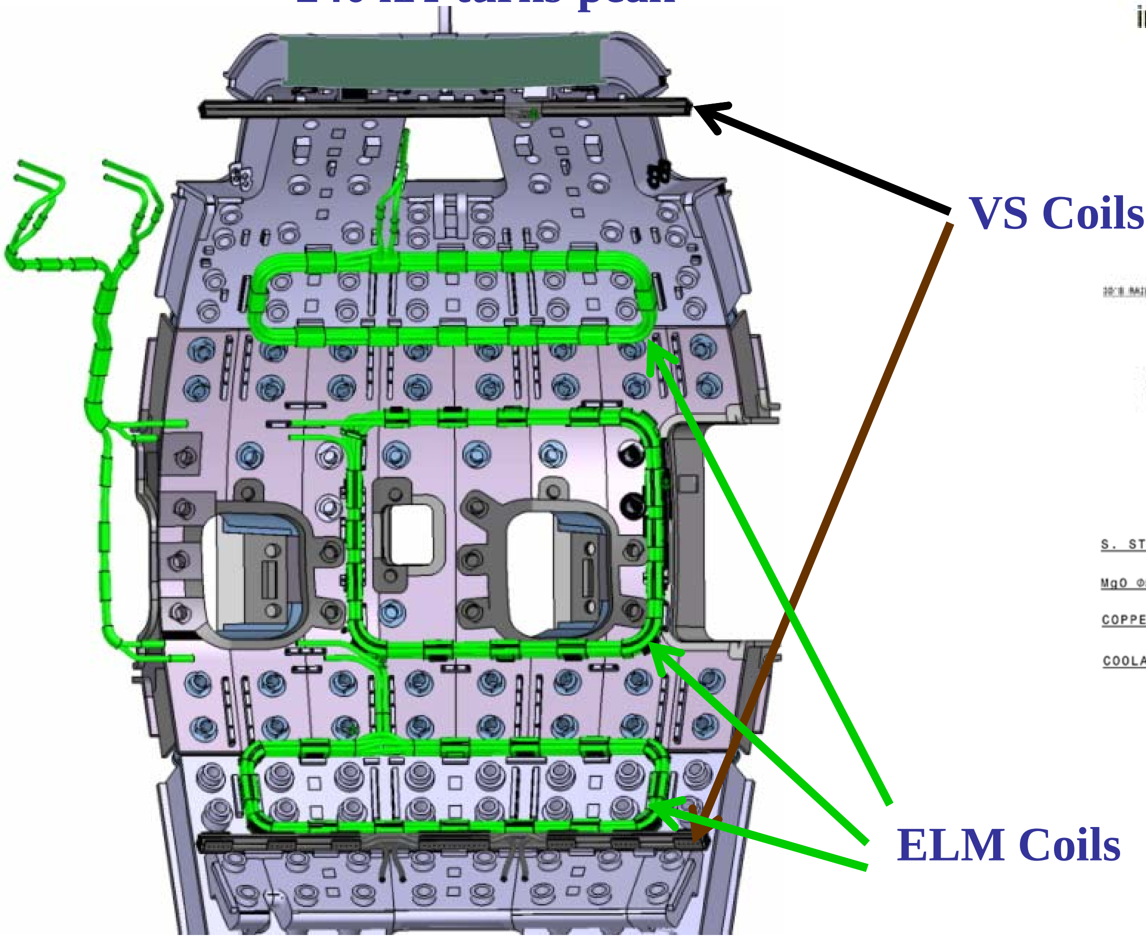
Status

- Preliminary Design Review completed
- R&D activities on conductor and joints are in progress
- Interfaces have been fully implemented into VV design
- Decision whether to implement ELM coils must be made in 2012 in time for blanket PA

Latest In-Vessel Coil Design

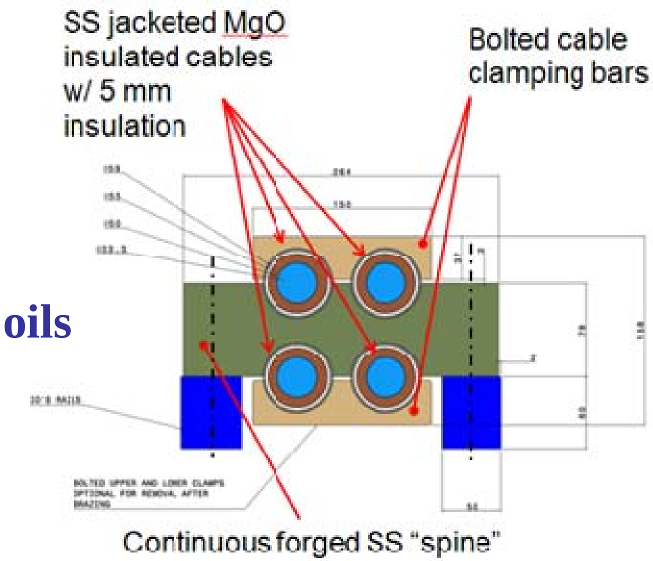
2 Fast Vertical Stability (VS) Coils

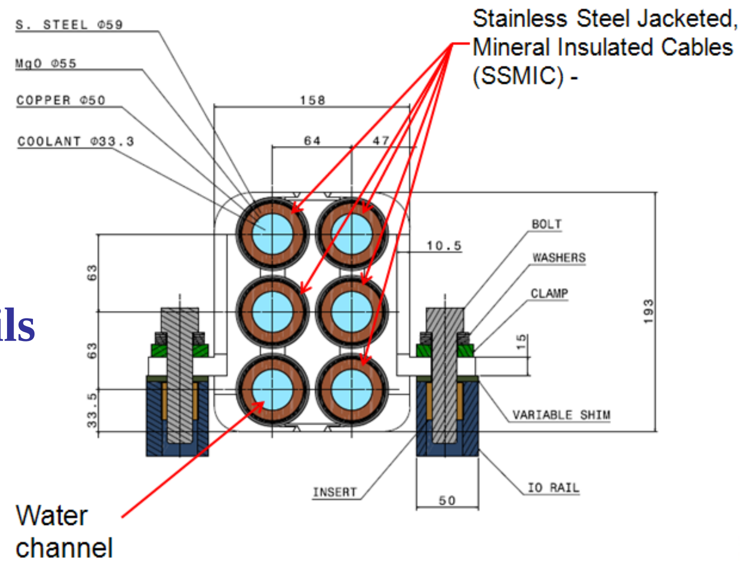
240 kA-turns peak



3 ELM Suppression Coils in each of 9 sectors

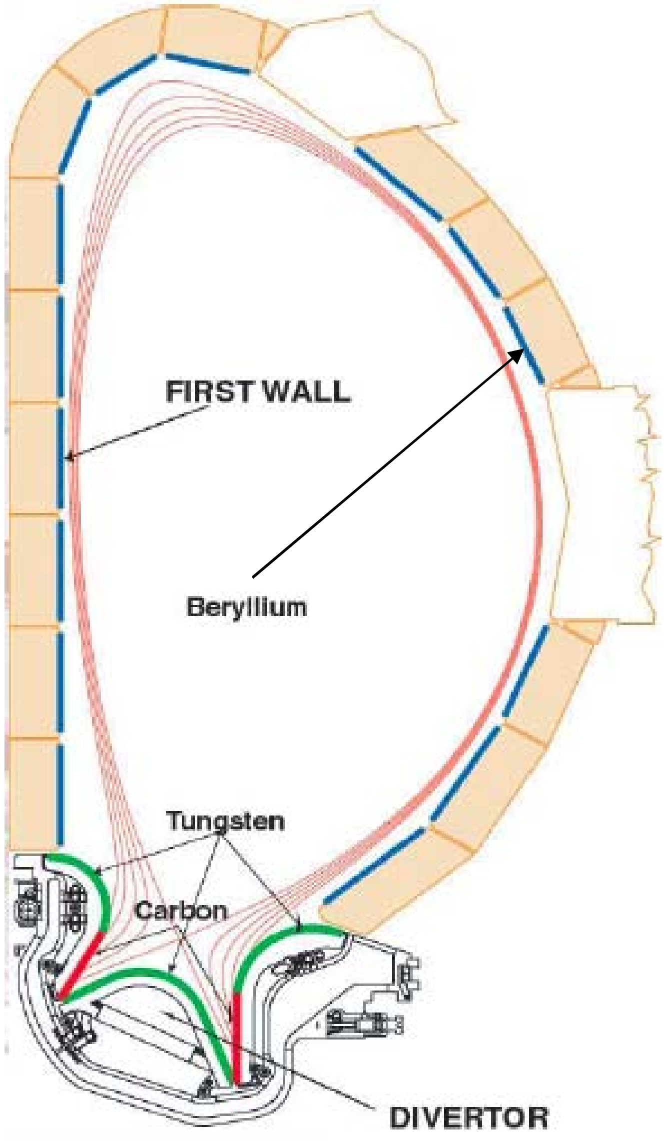
90 kA-turns peak





In-Vessel Components - Materials

- **CFC divertor targets (~50m²):**
  - erosion lifetime (ELMs!) and tritium codeposition
  - dust production
- **Be first wall (~700m²):**
  - dust production and hydrogen production in off-normal events
  - melting during VDEs
- **W-clad divertor elements (~100m²):**
  - melt layer loss at ELMs and disruptions
  - W dust production - radiological hazard in by-pass event



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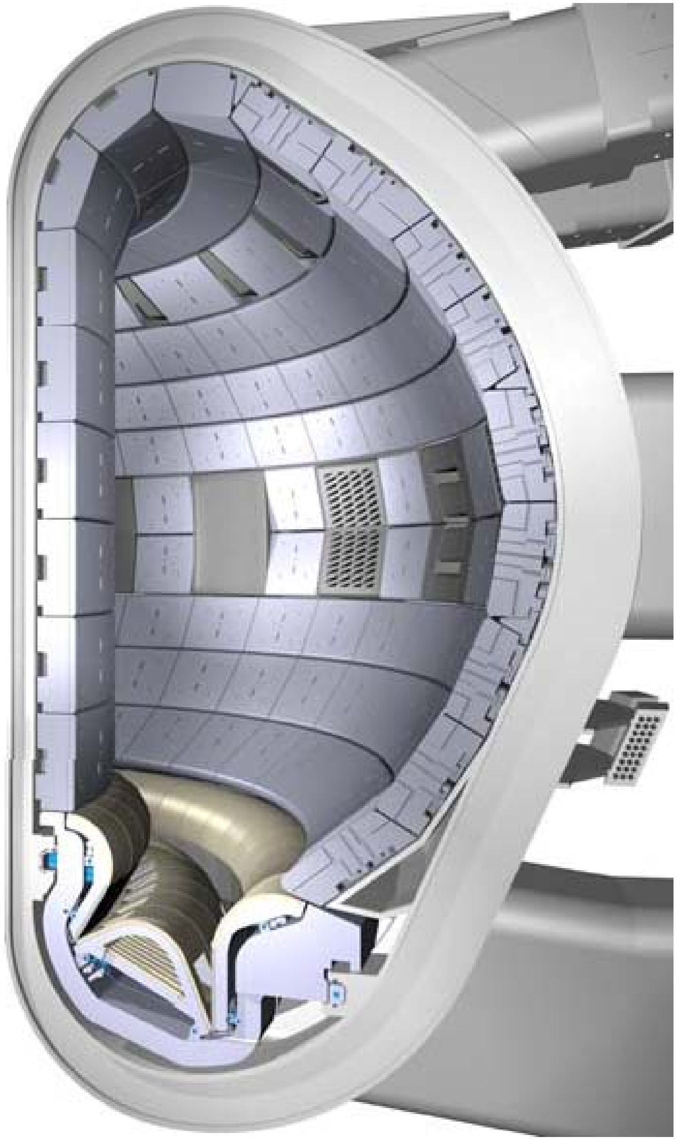
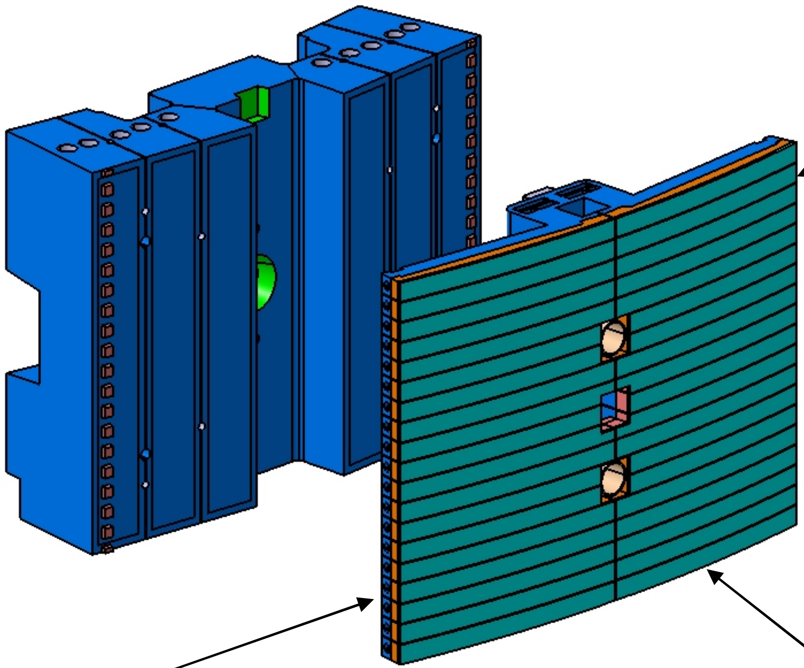


In-Vessel Components - Blanket/ First Wall

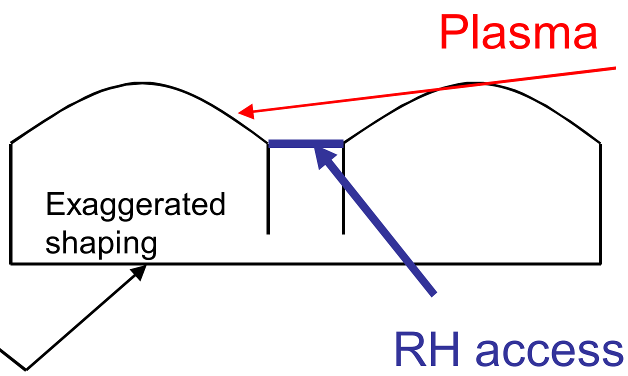


Horizontal Fingers

Reduce halo loads

Reduce eddy currents

Easier manufacture



In-Vessel Removable Single FW Panel

Reduce RH operations

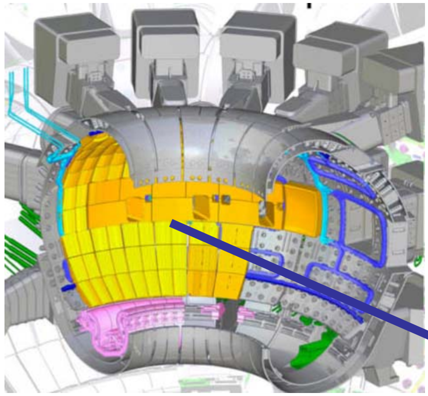
Improve Power Handling

Toroidal Shaping

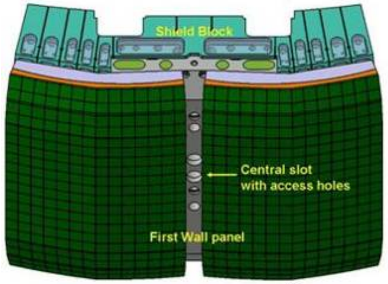
Allow good access for RH

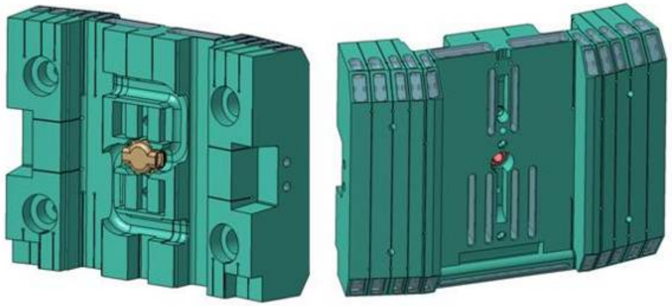
Shadow leading edges

Blanket Shield Module Status

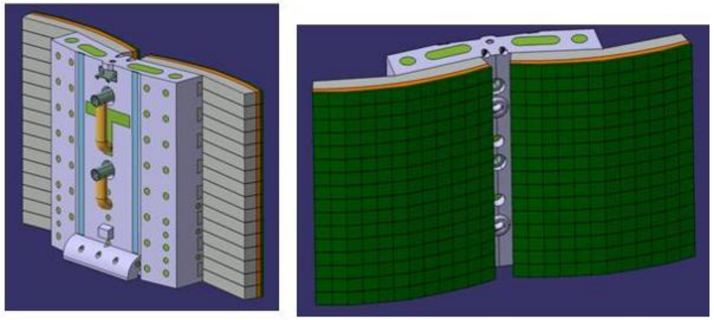


- 440 blanket modules
- 18 poloidally
- 18 or 36 toroidally
- Mass: 1530 tons

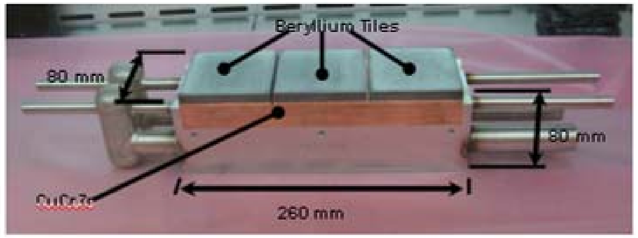




Shield Module



First Wall Panel

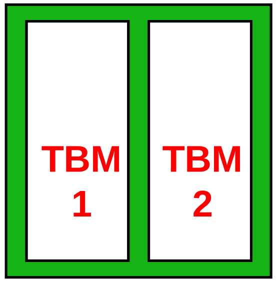


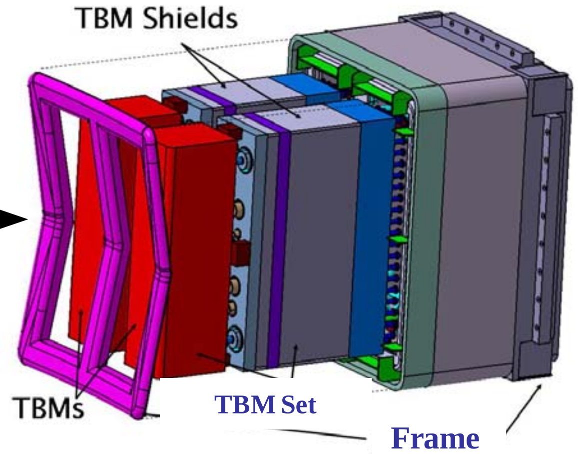
Mock-ups

- Conceptual design complete for several standard modules
- Mock ups provided by US, EU, RF, KO, CN and JP
- Nearing completion of the formal test program - 12,000 normal cycles at 0.875MW/m2 and 1000 MARFE cycles at 1.4MW/m2

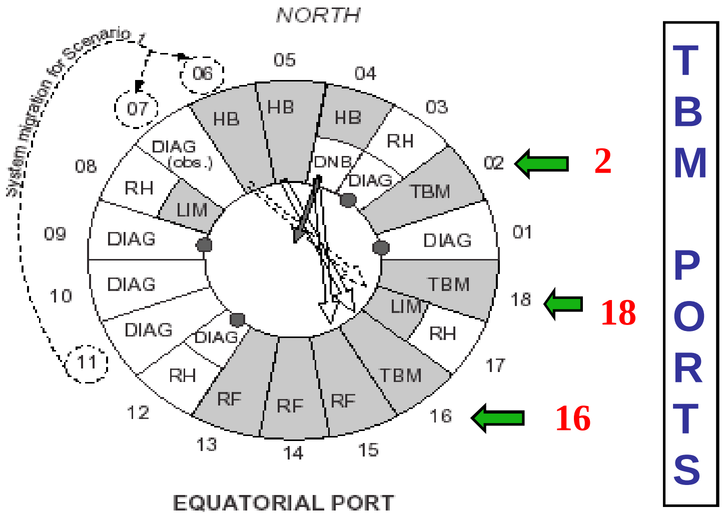
Test Blanket Systems in ITER

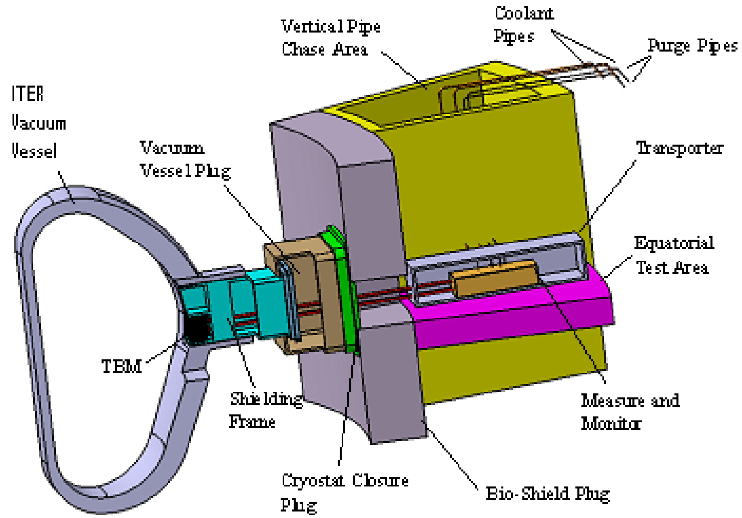
- ♦ **3 ITER equatorial ports** devoted to tritium breeding test blanket modules (TBMs)
- ♦ Each TBM is half-port size ➔ **6 TBMs** to test different tritium breeding technologies





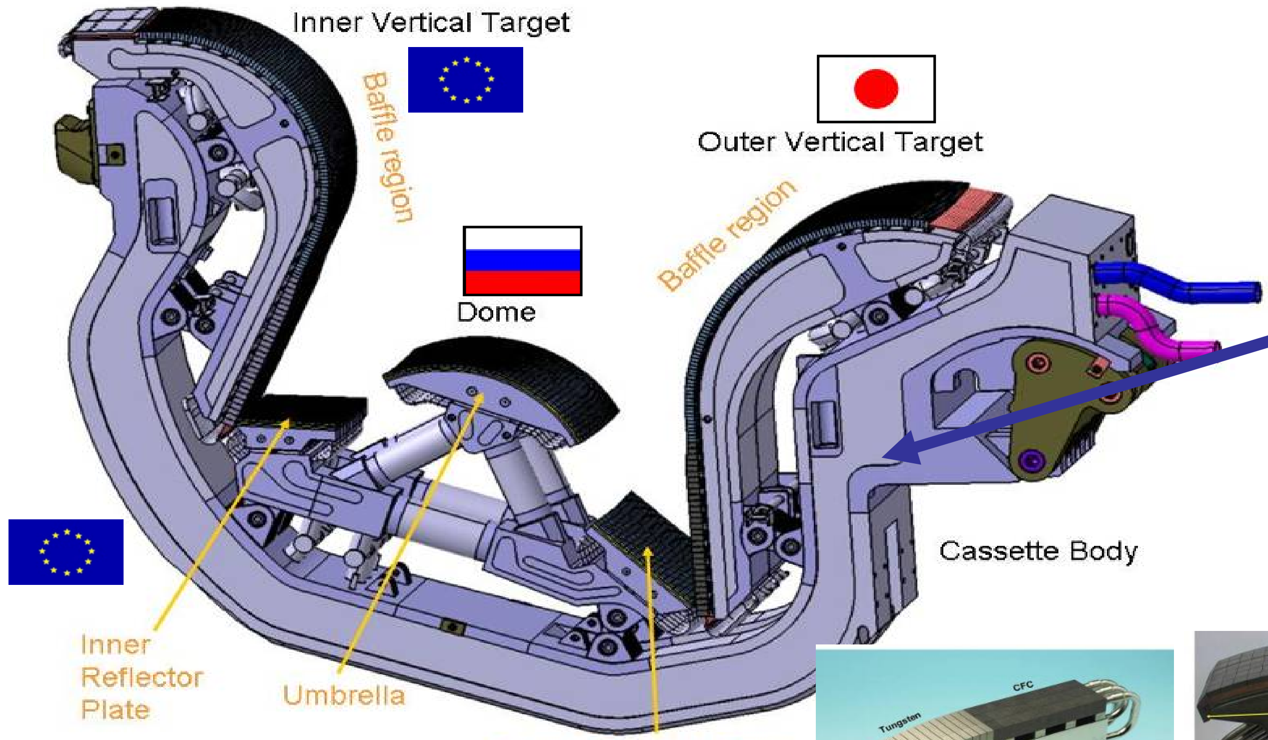
Exploded view of a TBM Port Plug

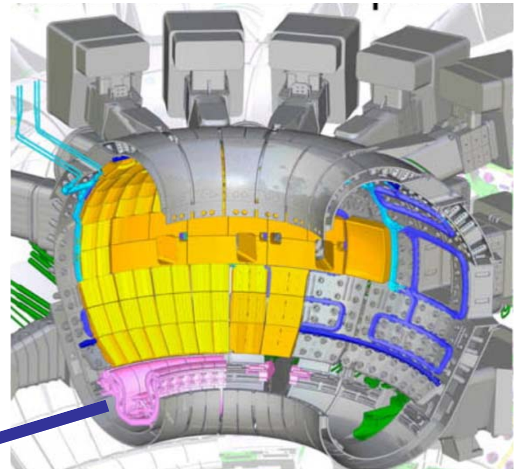




Example of Test Blanket Systems Locations

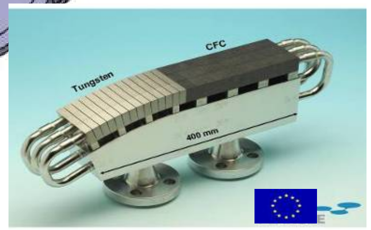
Divertor Status

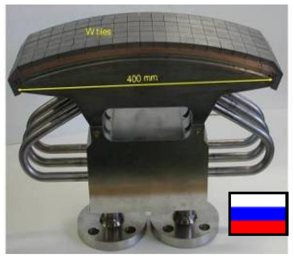


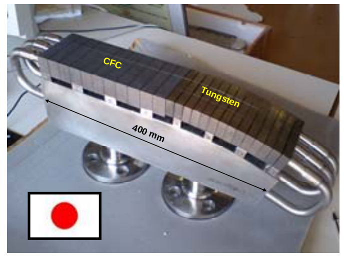


54 Divertor assemblies

4320 Heat flux elements







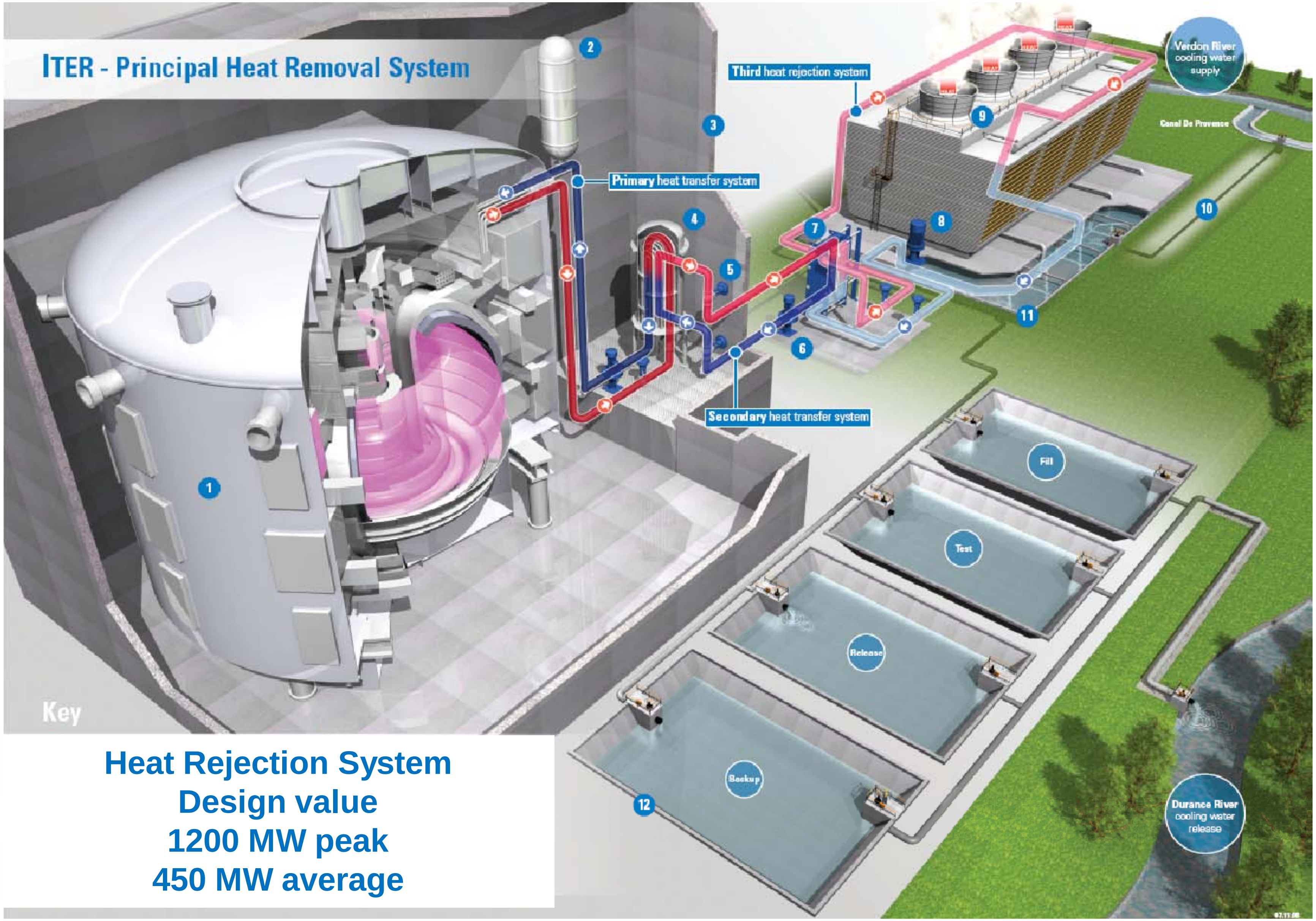
- CFC/W design complete
- Four of five PA's Signed
- Initiating all-tungsten design

Qualification Prototypes

- All the 3 Domestic Agencies have qualified

- Pre-PA Qualification process successfully completed in all the concerned DAs.

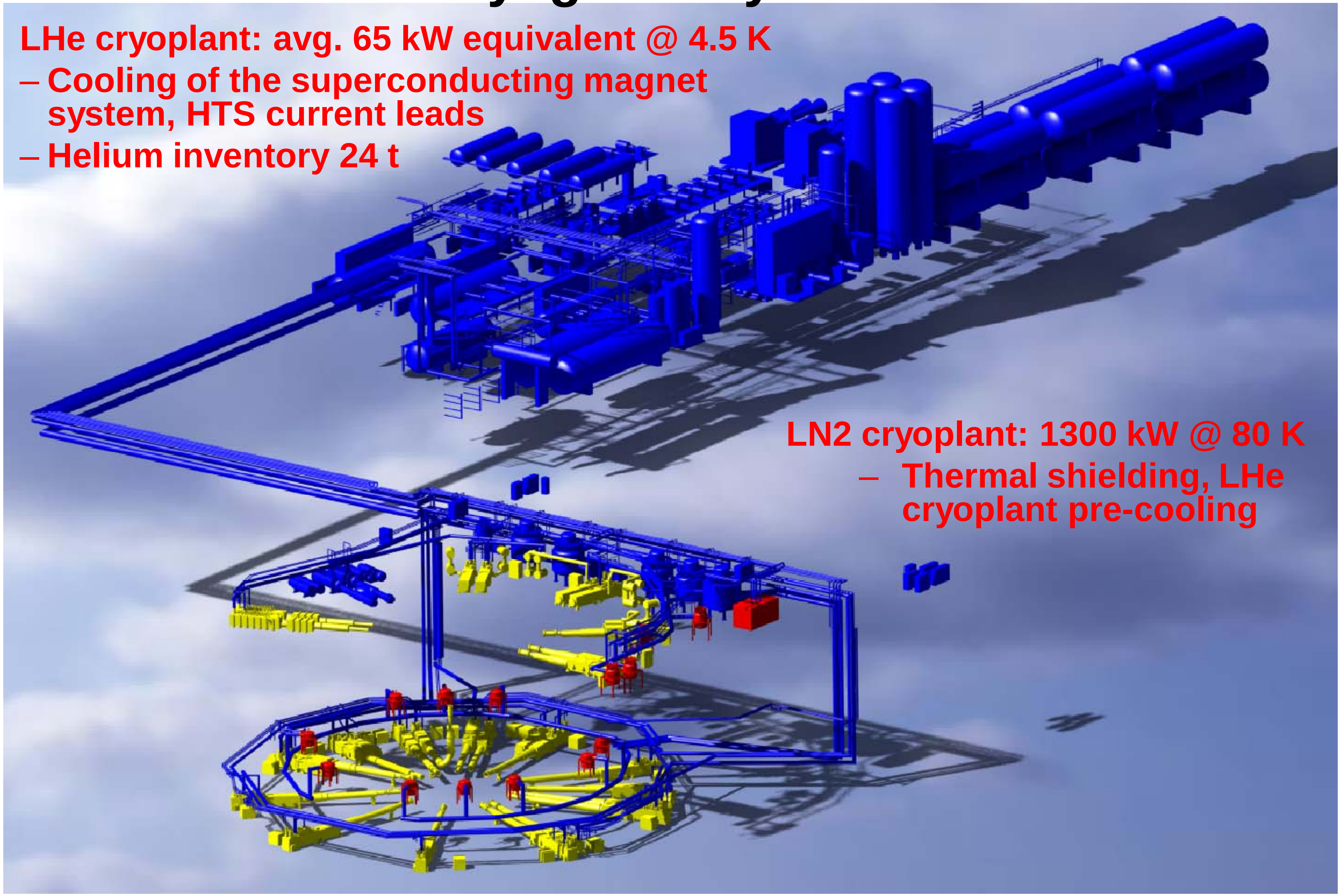
ITER Cooling Water Systems (CWS)



Heat Rejection System
Design value
1200 MW peak
450 MW average

Cooling Water System: *Removes heat from components and rejects heat to the environment*

Cryogenic System



Cools down the superconducting magnets, cryopumps, and thermal shield

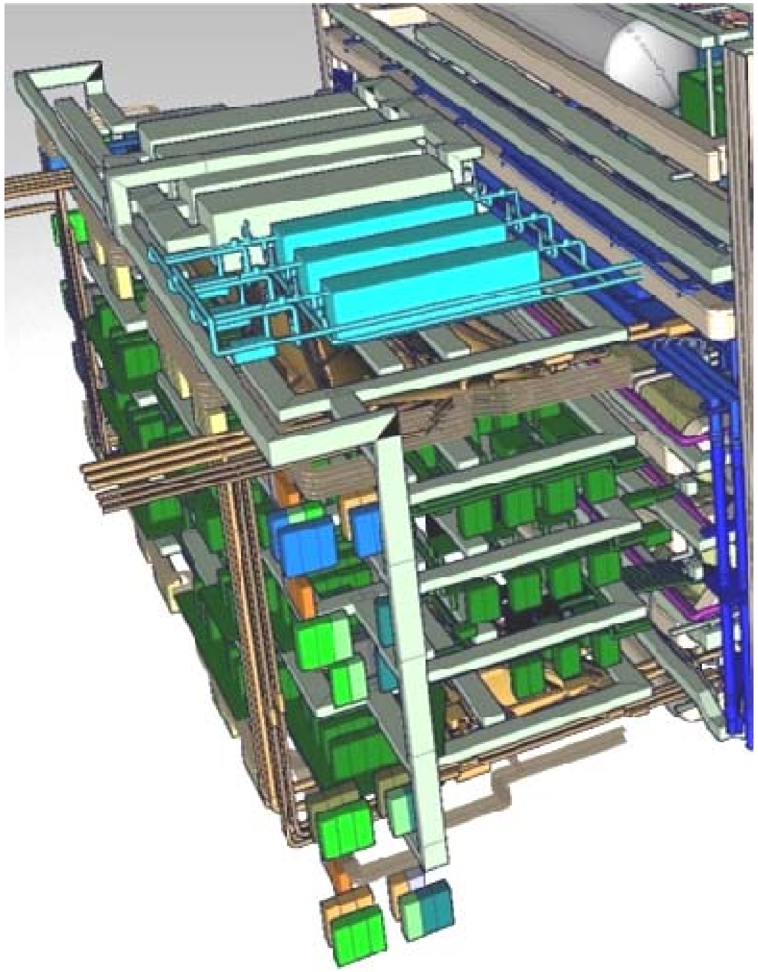
Tritium Handling

- **Handling of D and T involves techniques typical in gas processing**
  - Hydrogen isotopes are gaseous under normal conditions
    - H_2, D_2 and T_2 are colourless, odourless and tasteless
  - ITER Pellet Injection works with solid deuterium and tritium ice
    - Melting points of D_2, T_2 are 18.7K (-254.4°C) and 20.6K (-252.5°C), respectively
  - Tritium Plant Isotope Separation Systems distills liquid hydrogen
- **Pumps, pipe work, valves, instruments must be "tritium compatible"**
  - Leak tight to highest standards (individual leak rates < 10^{-10} Pam^3s^{-1})
    - Deuterium and Tritium should neither be trapped nor should they leak out
      - Economical and ecological incentives
  - Only metals or ceramics in direct contact with tritium
    - Organic materials (polymers, etc.) degrade due to beta radiation
- **4kg of tritium will be held on ITER site**

Tritium Plant

Tritium plant processes tritium for the tokamak and plant systems

- **7 Stories**
  - 2 below grade
- **L = 80 m**
- **W = 25 m**
- **H = 35 m**



T site inventory: < 4 kg

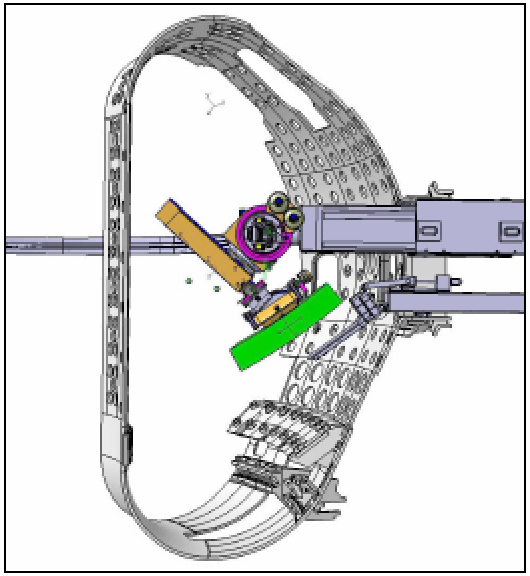
Plasma T throughput: ~ 1 kg/h

Plasma T inventory: ~ 0.2 g

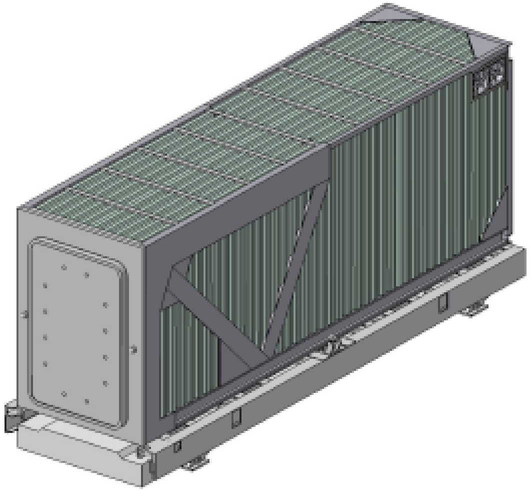
T release limit < 0.6 g/year

Remote Handling

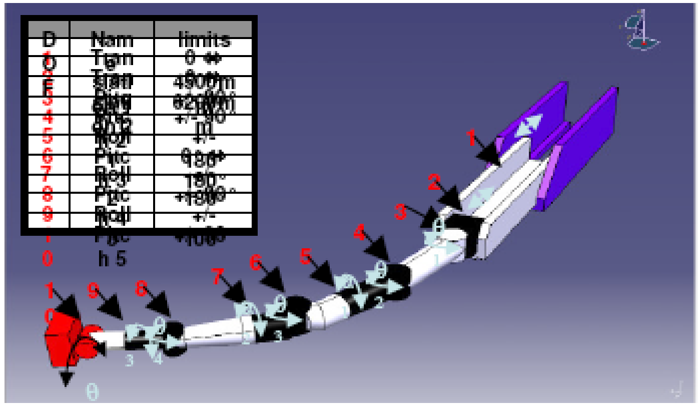
Must handle 4.5 ton blanket modules and 9 ton divertor cassettes



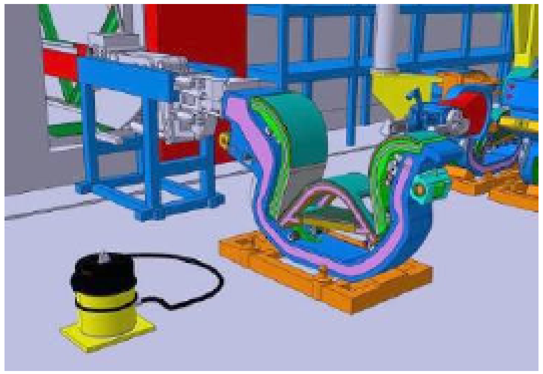
Blanket RH System (JA)



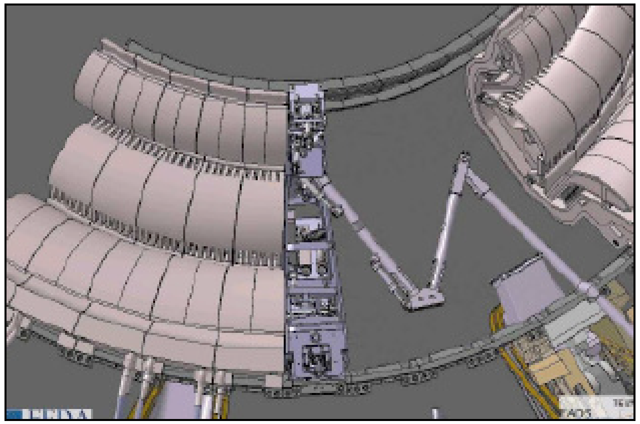
Transfer Cask Systems (EU+CN)



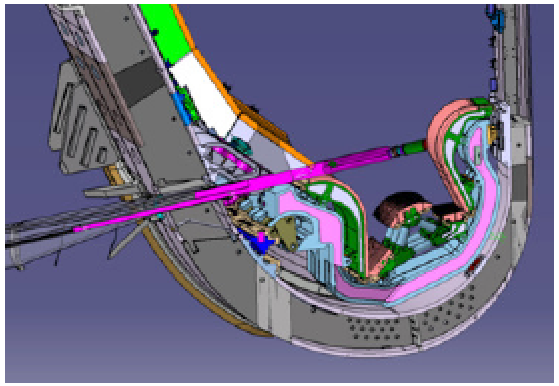
Multi Purpose Deployer



Hot Cell RH Equipment



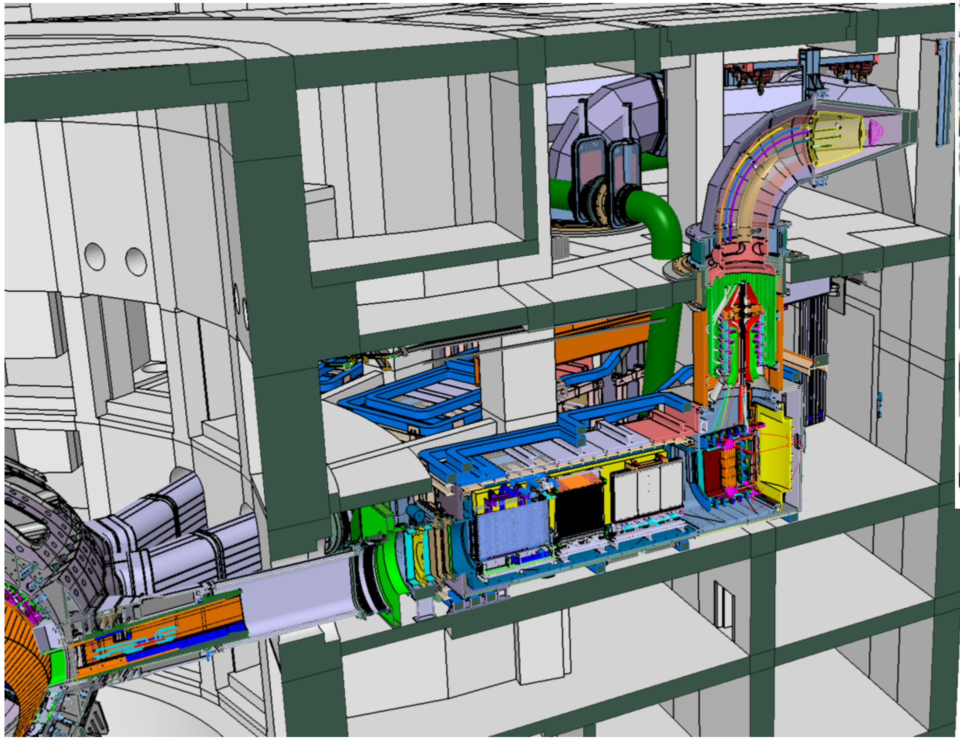
Cassette Toroidal Mover

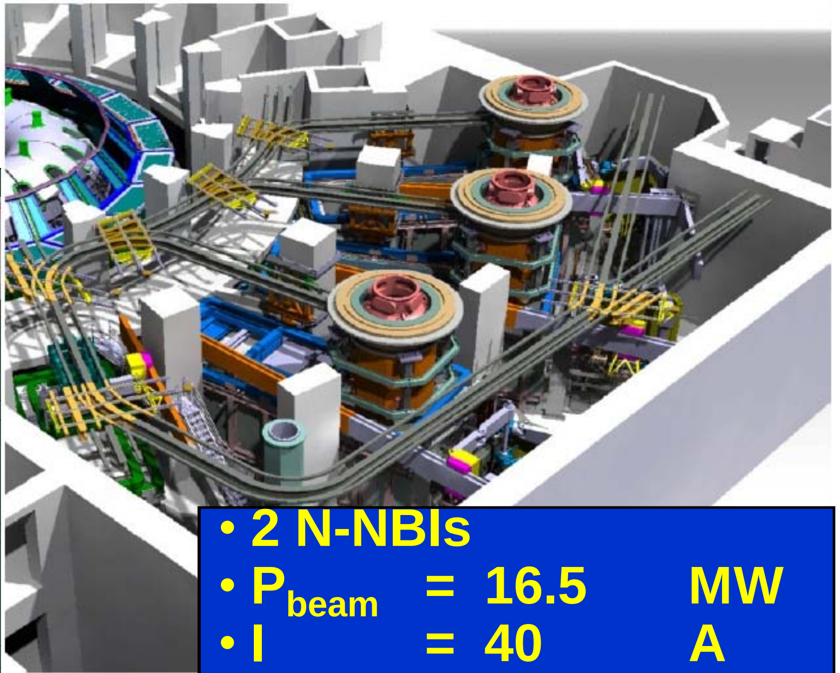


In-Vessel Viewing System

Development of Negative-Neutral Beam Injection Systems Is Ongoing

- **100kV ion source test bed (begin 2014)**
- **full size HNB injector test bed (end 2016)**





- **2 N-NBIs**
- **P_{beam} = 16.5 MW**
- **I = 40 A**
- **V = 1 MV**
- **T_{pulse} = 3600 s**

60 GJ to be delivered to the plasma by each beam

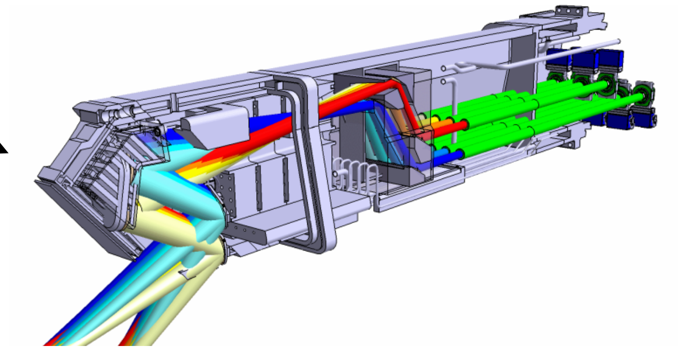
Neutral beam test facility being built in Padova, Italy to perform full-scale tests of 1 MeV negative ion neutral beam technology

Good Progress in Gyrotron Development for Electron Cyclotron Heating & CD System

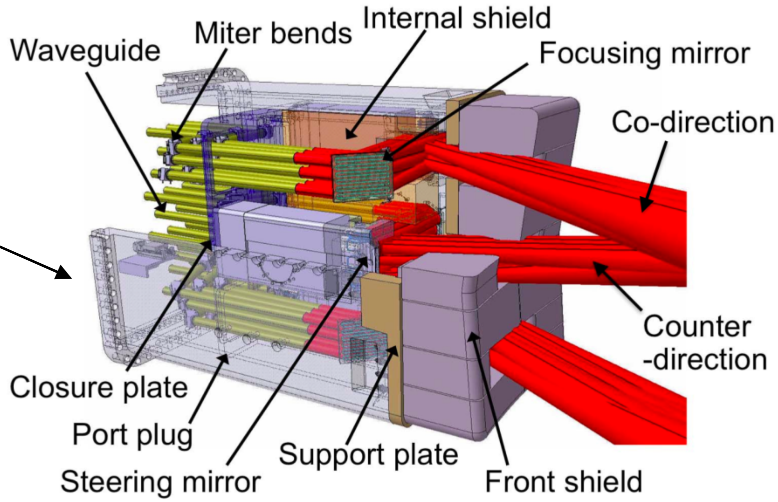
RF Gyrotron

IAP RAS GYCOM INF

Upper Launcher



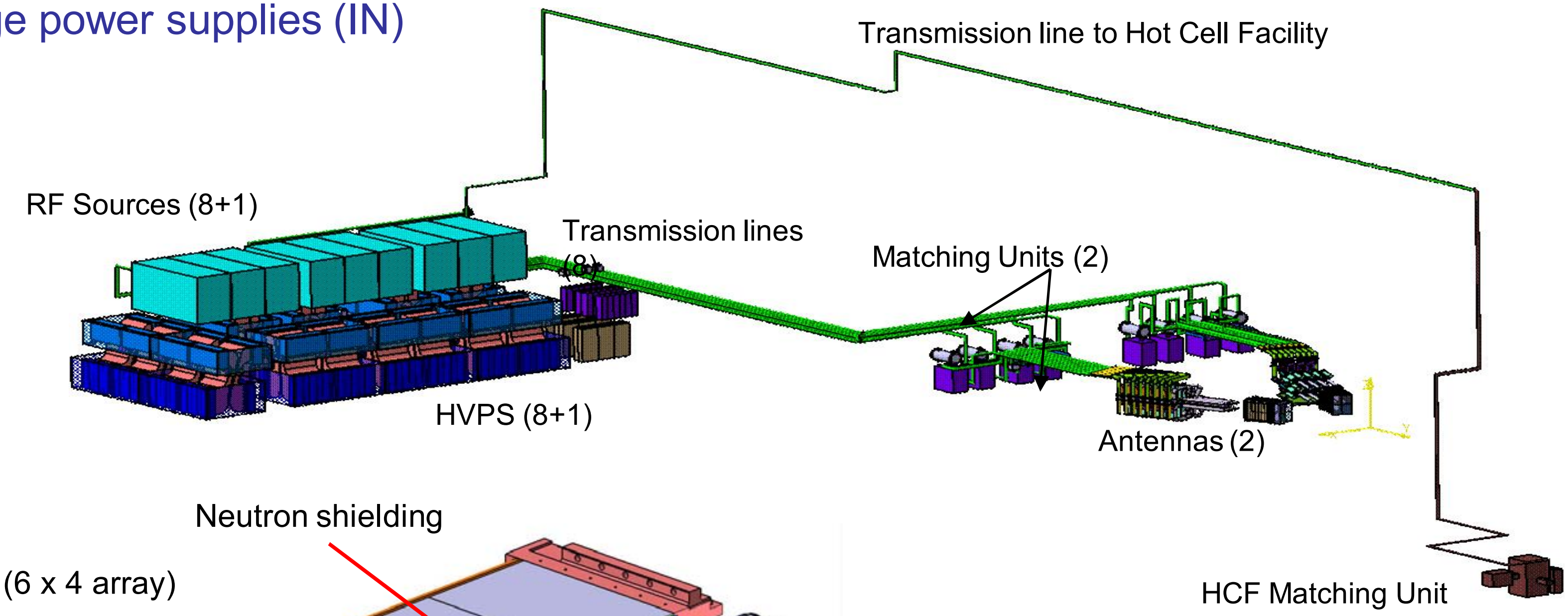
Equatorial Launcher

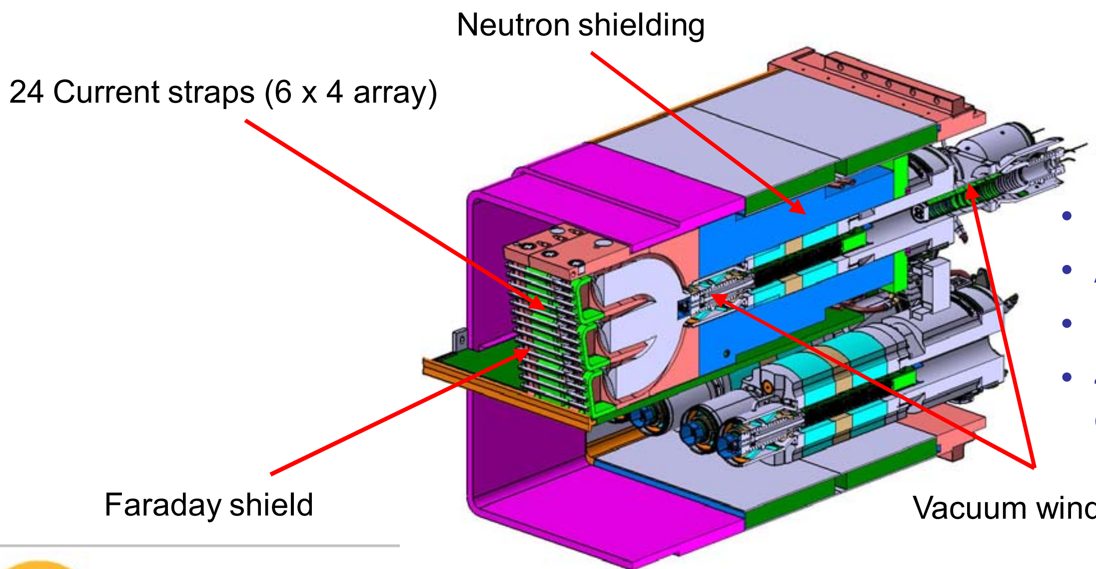


- 170 GHz EC system
- Transmit up to 20 MW from 1 equatorial and 4 upper launchers
- Total of 24 gyrotrons rated to 1 MW can be steered to any of the 5 launchers

Ion Cyclotron Heating & CD System

- Two antennae (equatorial port plugs) (EU)
- Transmission and matching systems (US)
- RF sources (8x3MW + 1 spare, 40-55MHz, for 20MW in plasma) (IN)
- High Voltage power supplies (IN)





- Dimensions: 2.1 m H x 1.7 m W x 3.6 m L
- All components actively cooled
- Max. dry mass: 45 metric tons
- 4 x 6 radiating straps grouped in 8 poloidal triplets

Itinerary of ITER Components

ITER Site

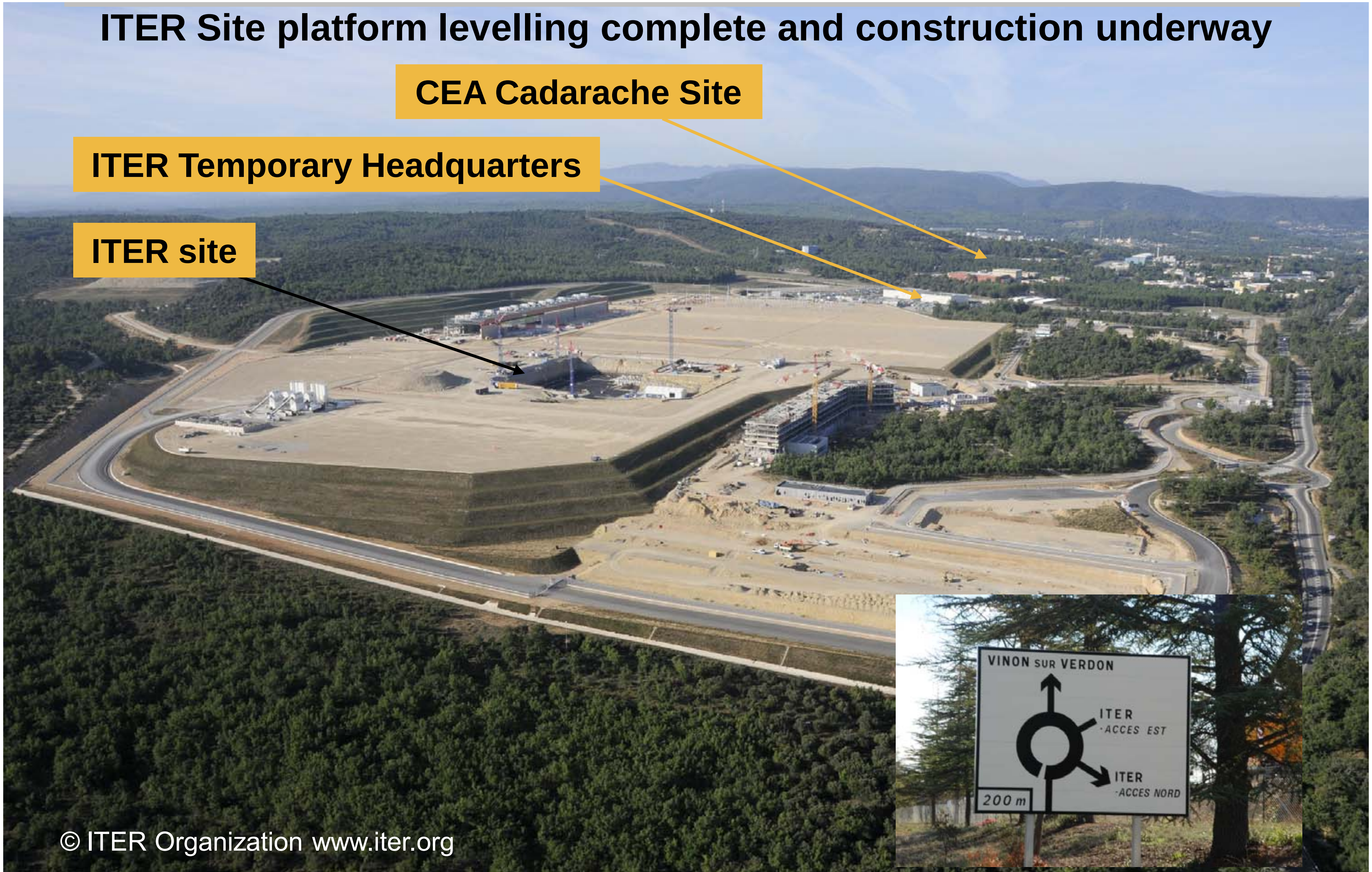
= Itinerary of ITER Components

Site Construction Progress

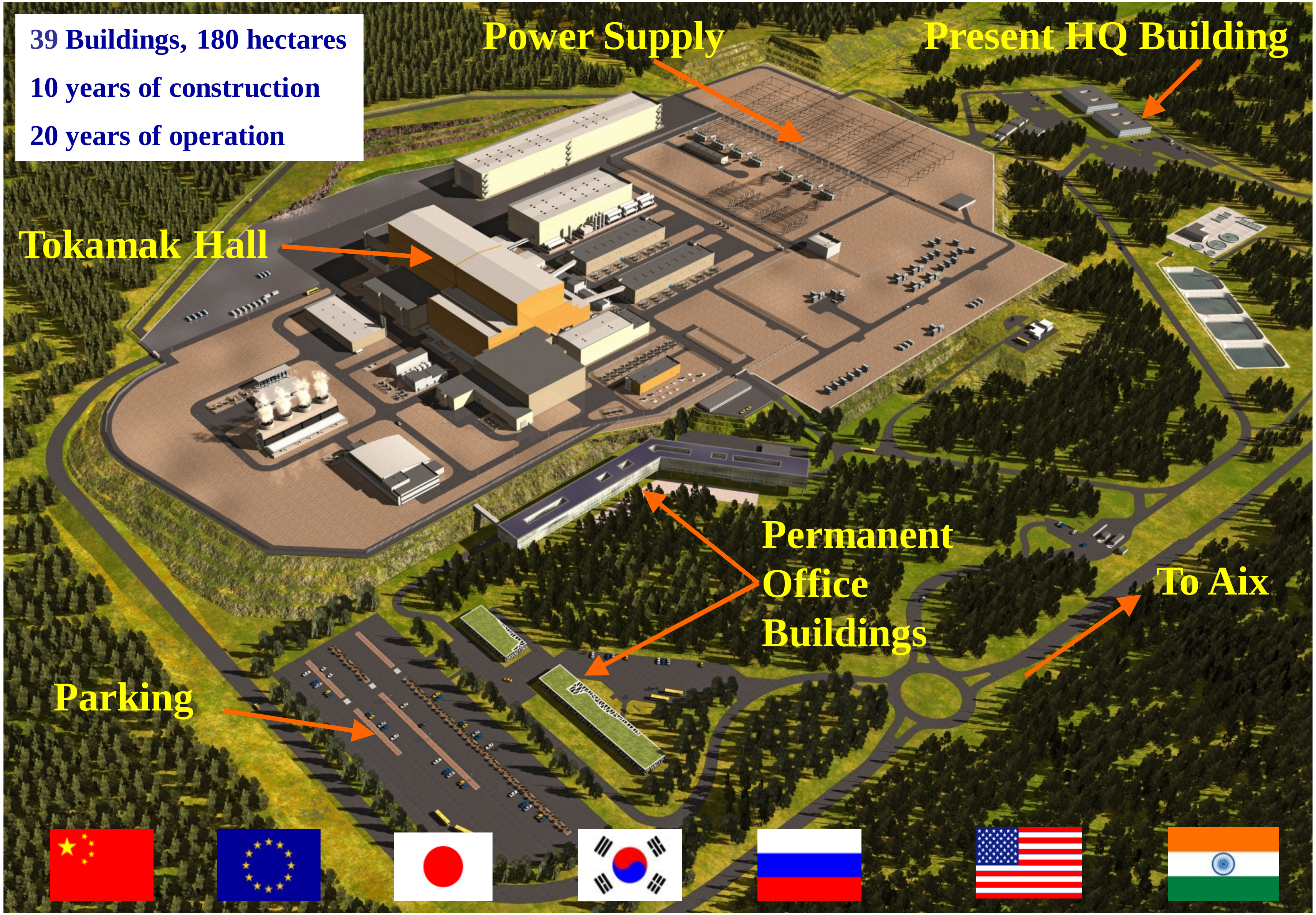
- Construction of the Tokamak Complex is underway
- The Hot Cell building and Assembly Hall excavation and the concrete seismic basemat are complete
- The construction of the ITER Headquarters main office building is progressing well with completion scheduled for late summer 2012
- The PF coil building is nearly complete. The building is expected to be finished by the end of 2011
- Réseau de Transport d'Electricité installation of the 400 kV substation to power ITER is underway

The ITER site in 2005

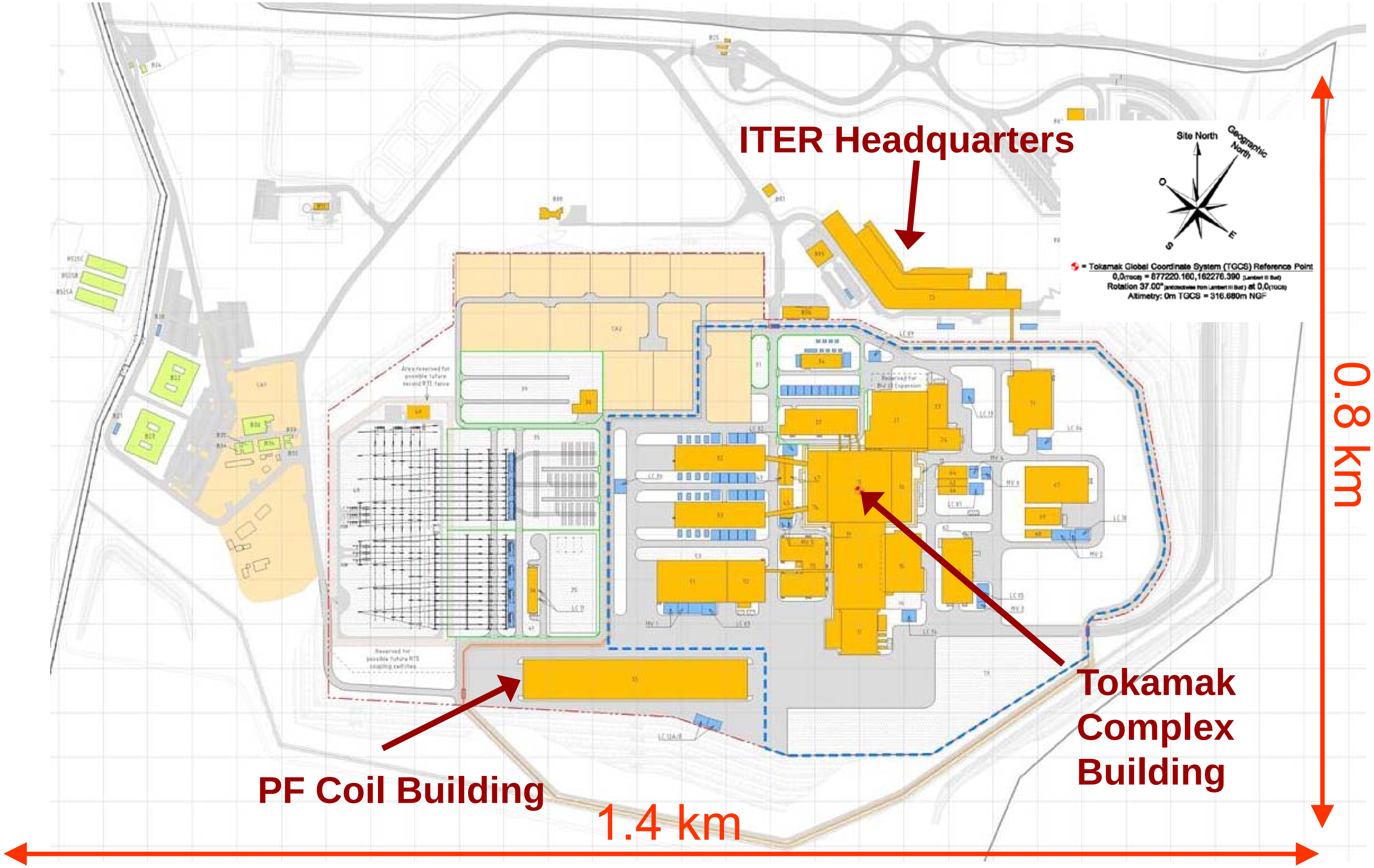
ITER Site in September 2011



ITER Site after Construction



Plan View of ITER Site



Construction of the Tokamak Complex

Construction of the ITER Head Quarters

Construction of the Poloidal Field Winding Building

Construction of the 400 kV Substation

Conclusions

- **The ITER Project is rapidly evolving**
  - 7 International Parties → 475 staff working together as a Team
  - Building a 500 MW long pulse burning plasma experiment
  - Contracts already signed for 70% of construction procurement value
  - Vacuum vessel construction is underway in Korea
  - TF superconductor production underway in EU, JA, RF, CN, KO, US
- **Designs progressing on**
  - In-vessel coils
  - Blanket shield modules
  - Tungsten divertor
- **Building construction on site progressing for**
  - PF coil building – to be complete at the end of this year
  - Main office building – to be complete fall 2012
  - Tokamak complex finishing seismic basemat