Status of ITER and Progress on Critical Systems

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Magnet Division Head

CERN, 18 Dec 2013

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

CONTENT

iter china eu india japan korea russia usa

- ITER Project, History, Organisation and Why
- ITER Tokamak and Site
- Buildings
- Supporting Systems
- Tokamak Core Systems, focus on Magnets
- Schedule and Challenges
- Conclusions and the Future

ITER: Objectives

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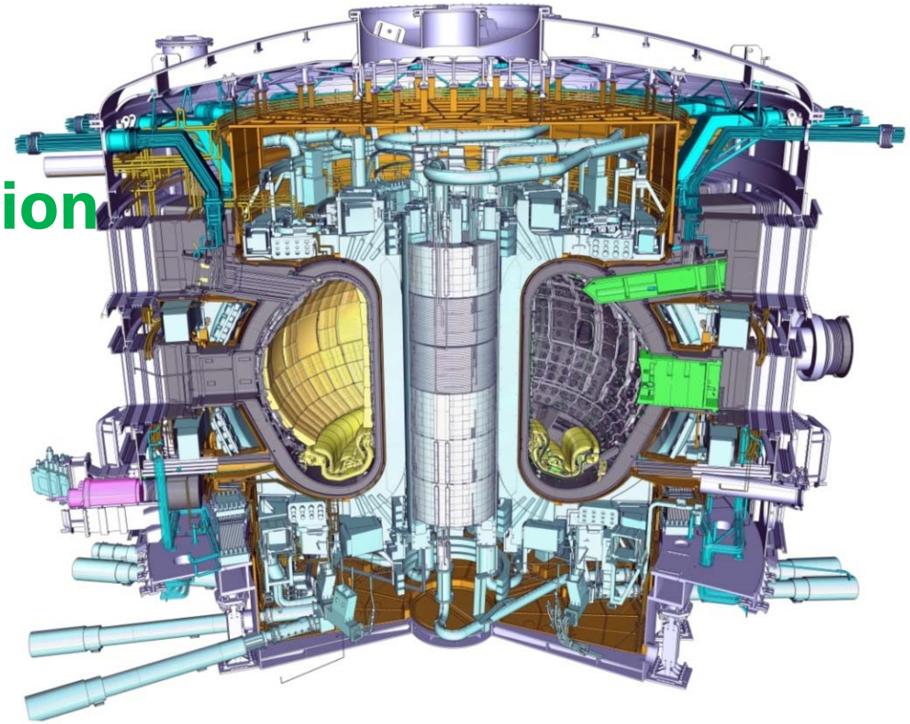
- The main goal of ITER is to demonstrate the **scientific** and **technological feasibility** of **fusion power.**
- In particular
  - o to achieve extended burn of D-T plasmas, with steady state as the ultimate goal,
  - o to integrate/test all critical fusion power reactor technologies/ components,
  - o to demonstrate safety and environmental acceptability of fusion.



Beyond ITER -1

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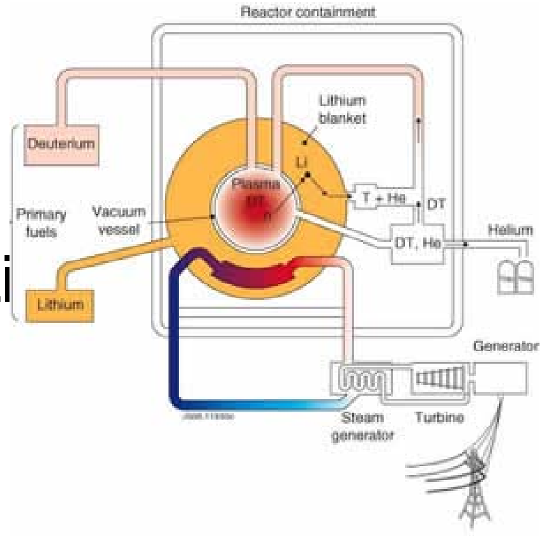
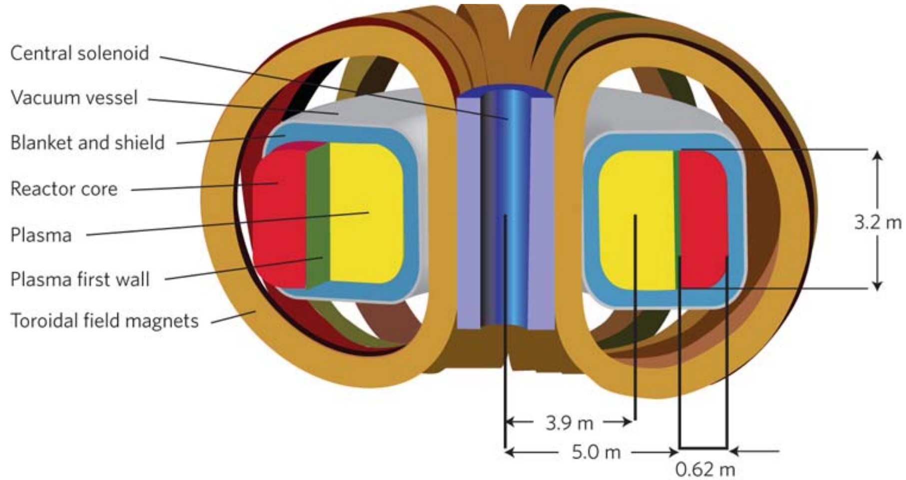
The ultimate objective of the magnet fusion programme is a ‘commercial’ power plant. Opinions differ on what this could be



- EU, US, JA: ‘Pure’ fusion where a blanket of Li is used to breed tritium which is then fused with D to give He, α particles which heat the plasma & 14MeV neutrons to convert to heat

- CN, KO: ‘Hybrid’ fusion. Fusing plasma forms a neutron source which catalyse a fission chain reaction in a blanket of fissile materials, often PWR depleted fuel rods.



Beyond ITER -2

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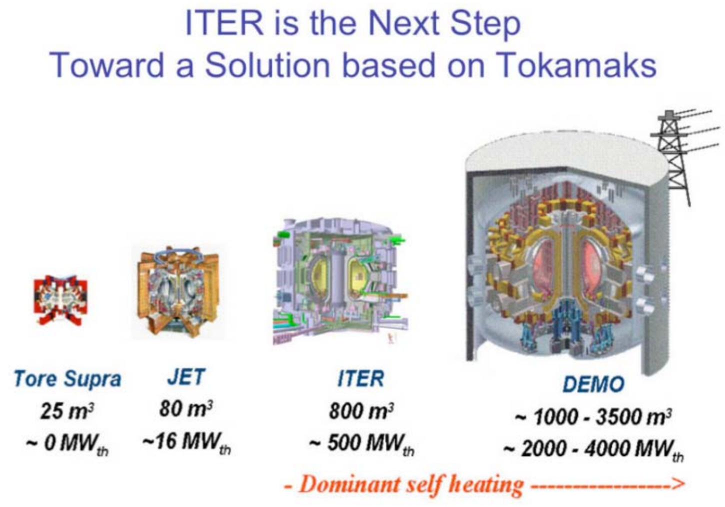
The core problem with fusion IS POOR PLASMA ENERGY CONFINEMENT. Plasmas have to be large (losses scale with the surface area, heating with the volume) and present day pure fusion power plants are, like ITER, large and expensive….high financial risk



Option 1: build big (EU DEMO programme….picture above)
Option 2: energy multiplication with fission reactions. Hybrid reactors are smaller than ITER. Also can consume fission waste
Option 3 (could be considered): Treat ITER as a test stand for improving plasma confinement to provide physics basis for smaller reactors. ITER is the largest, in the future aim small.

ITER Pre-history

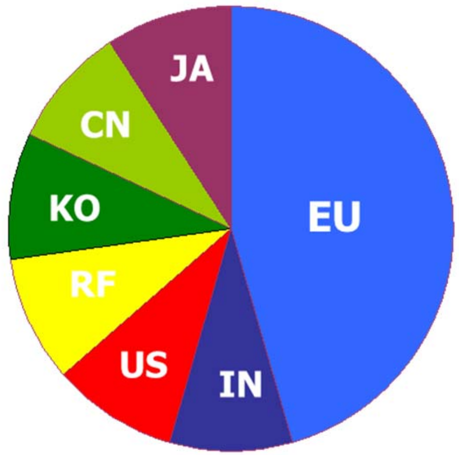
- Born in **1985** at a **superpower summit meeting** in Geneva between Reagan & Gorbachev.
- It consolidate the loose INTOR collaboration between EU, RF, US and JA. As EU had a leading role through NET, the first site was at Garching. The CDA phase lasted 1988-1991
- The EDA phase lasted 1993-2001, on 3 sites (San Diego, Garching, Naka) as no one could agree on one. US left in 1998, San Diego closed
- Agreement for construction and site came in 2005. It is now supported by 7 parties (CN, EU, IN, KO, JA, RF, US)

1985 Superpower Summit Meeting

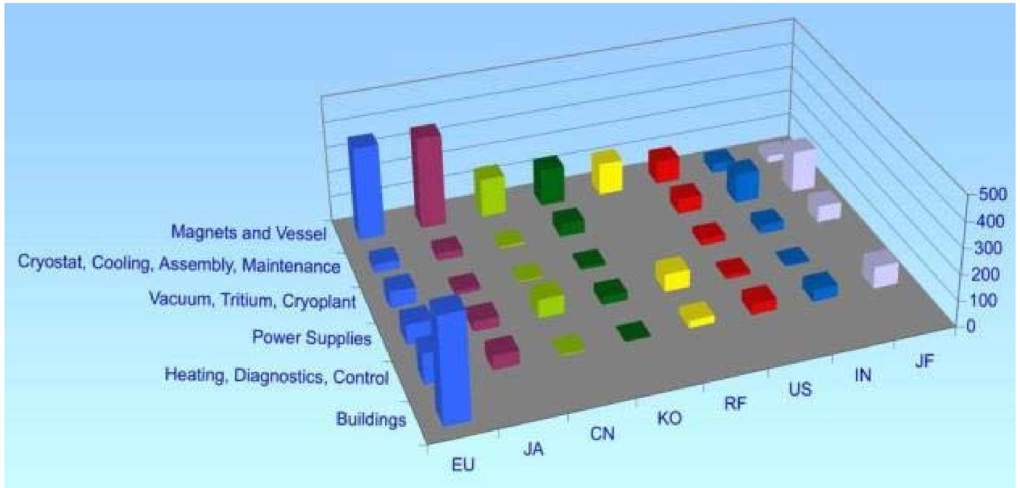
1988 Opening Ceremony of ITER CDA at IPP Garching Germany

Political Organisation

- The Parties have agreed on a cost sharing arrangement
  - **5/11th for EU (host),**
  - **1/11th for the 6 other parties.**
- They have also agree on a sharing of technologies and of industrial productions
  - **90% in-kind contributions,**
  - **10% cash contributions.**
- The breakdown of who contributes what is at **the component level** and is cast in the *so-called* **ITER Agreement.**



ITER Cost Sharing



ITER Task Sharing (per main subsystem)

And Management Challenges

ITER is largely (90%) build by in-kind contributions. These were agreed in 2005 to suit the priorities of the 7 parties to be involved in all critical technologies

The result is an un-logical division of contributions, excessive duplication of tooling, far too many suppliers, lack of commercial competition and a vast number of unnecessary interfaces

The parties bring an institutional approach to procurement that enhances the complications of the interfaces

And the parties are in effect managers of the IO (forming the governing boards) and contractors (executing PAs). Conflicts of interest are evident in resolving quality problems

Not surprisingly it is challenging to keep schedule and budget

ITER Site Construction – 1

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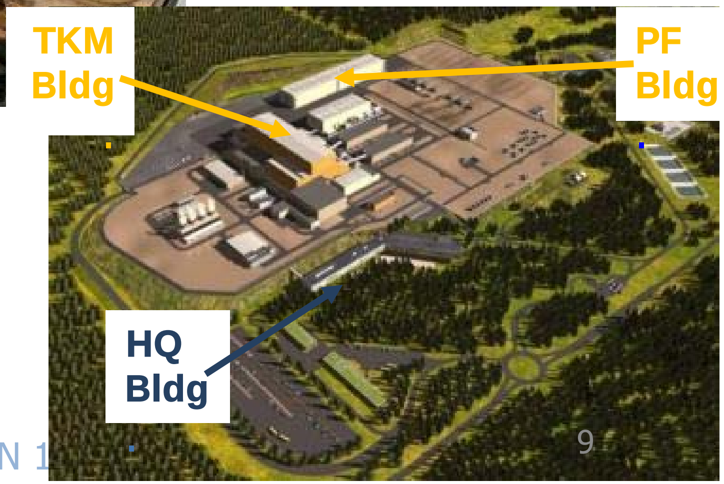
- ITER site was selected in **2005** to be near **Saint-Paul-Lez-Durance** in the South of France.
- France has completed **extensive roadwork upgrades** for transportation of large components from Marseille harbor (104 km).
- Civil engineering is underway since 2010 and the **French Government** has authorized **the creation of the nuclear installation** in November 2012.

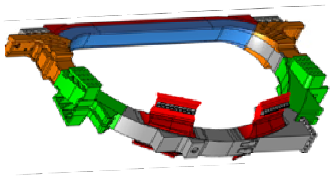
1 km x 400 m
ITER Platform
(2.5 million m³ excavation)



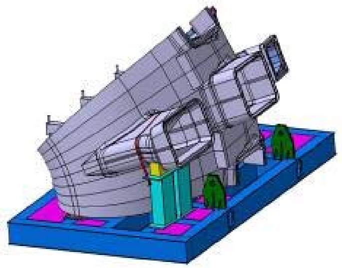
Model of ITER site

ITER Site Construction – 2

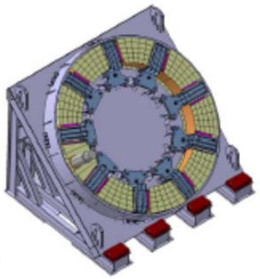
Local Communities Provided Road Upgrades



TF Coil ~360 t
16 m Tall x 9 m
Wide



VV Sector ~400 t
12 m Tall x 9 m Wide



PF1 Coil ~200 t
9.4 m Diameter

Test Load on Road in Sept 2013

First components will arrive at ITER in 2014

ITER Site Construction – 3

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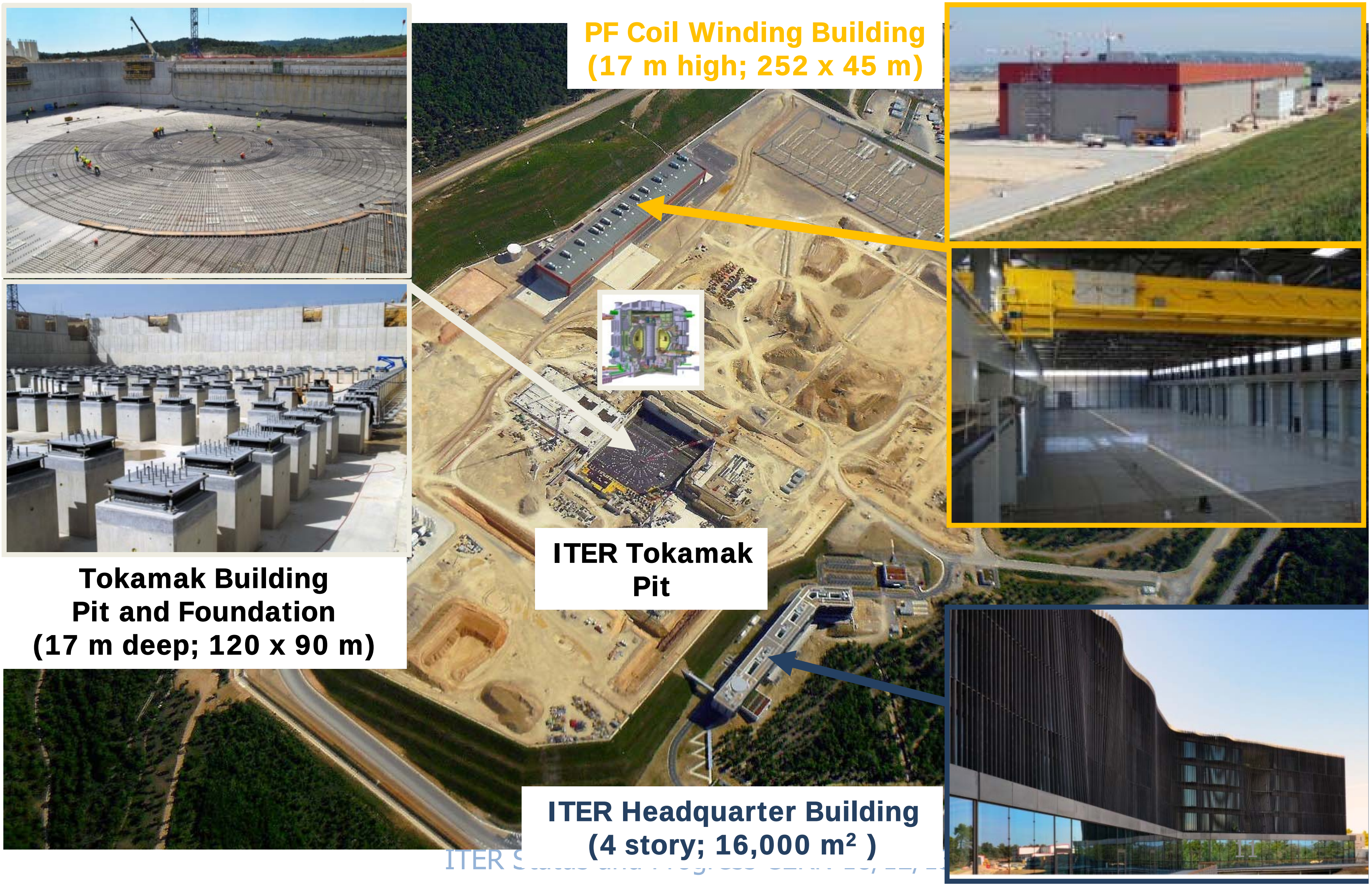

ITER Services

Primarily

- Power Supplies
- Cryoplant
- Cooling Water

ITER Power Supply System

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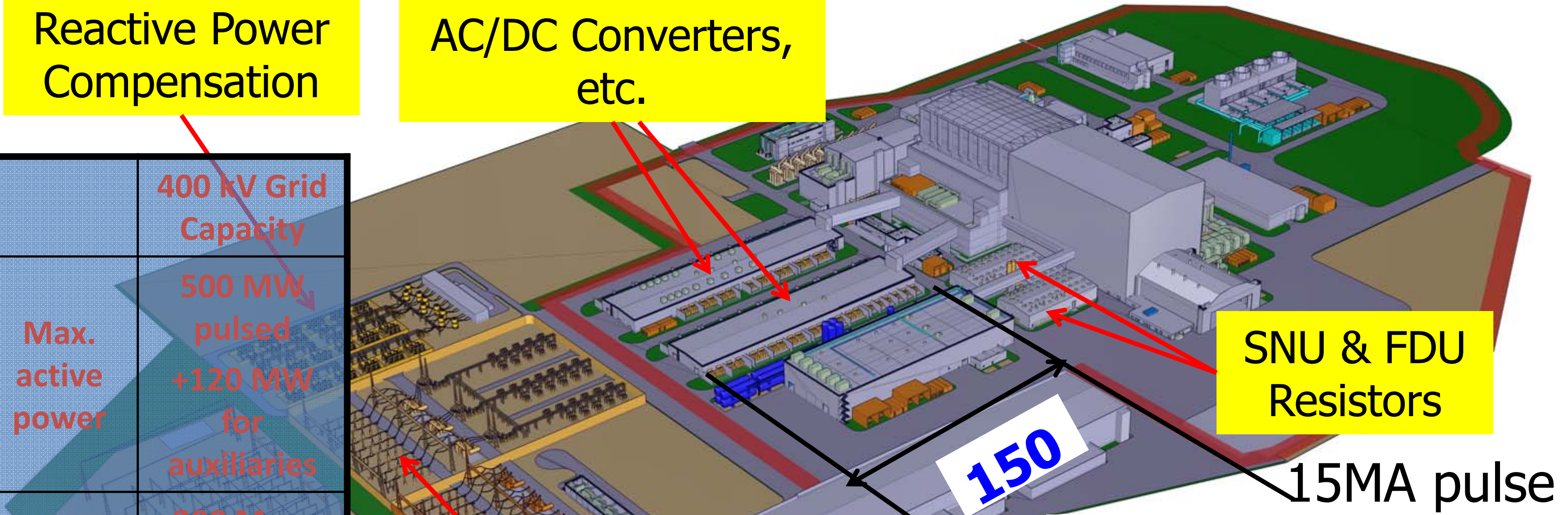
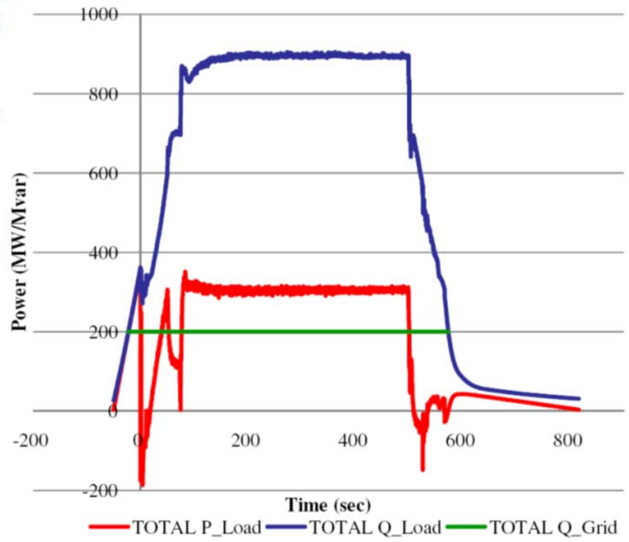
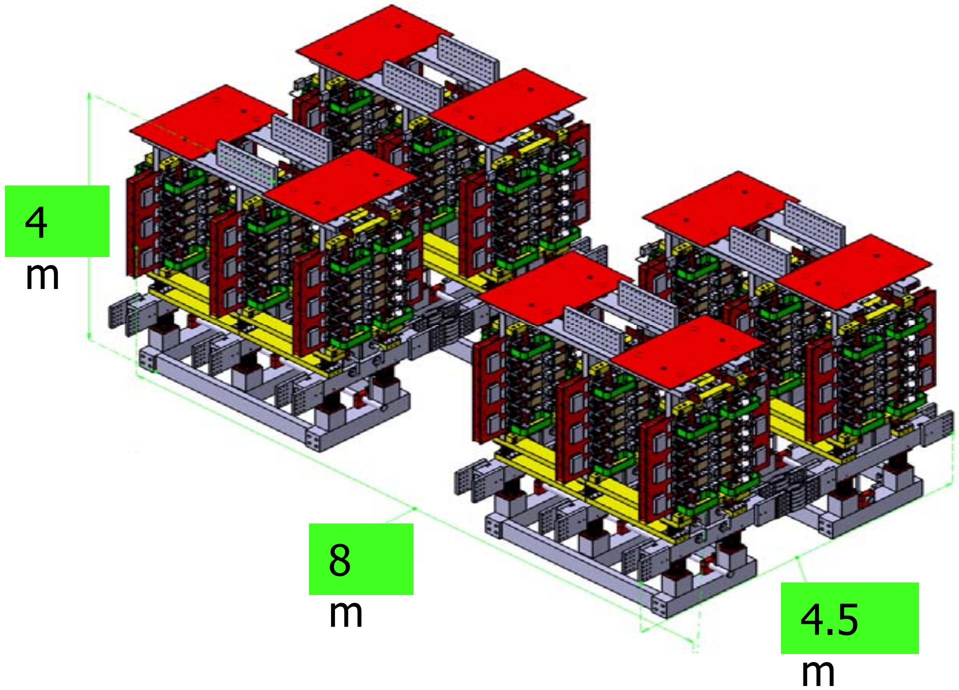


	400 kV Grid Capacity
Max. active power	500 MW pulsed +120 MW for auxiliaries
Max. reactive power	200 Mvar pulsed + 48 Mvar for auxiliaries



DC System – AC/DC Converters

- 55kA PF Converter being developed in China



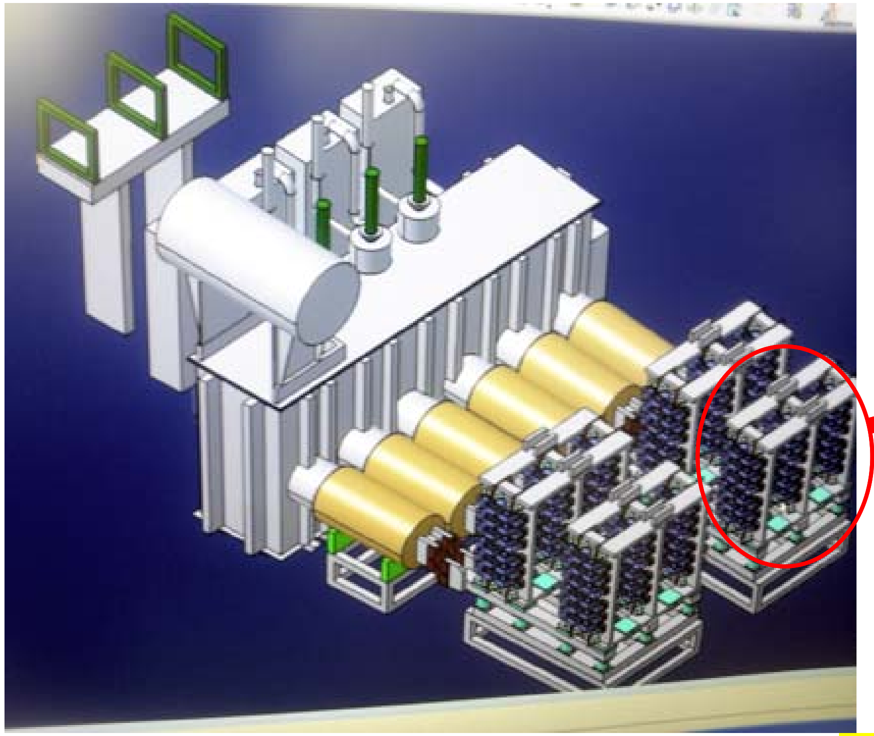
Prototype bridge arm:
- ABB 5STP52U5200
- 5.2kV, 4.1kA
- 125 mm (5”)
- 12 in parallel

Test facilities at ASIPP

- Installation of prototype is underway at ASIPP

DC System – AC/DC Converters

- TF, CS, VS, and CC Converters being developed in Korea (1)



Prototype antiparallel 6-pulse pair

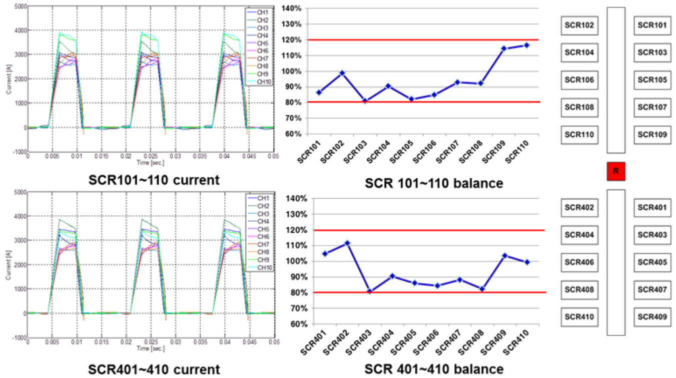
iter KOREA 한국사업단 → DAWONSYS HYOSUNG

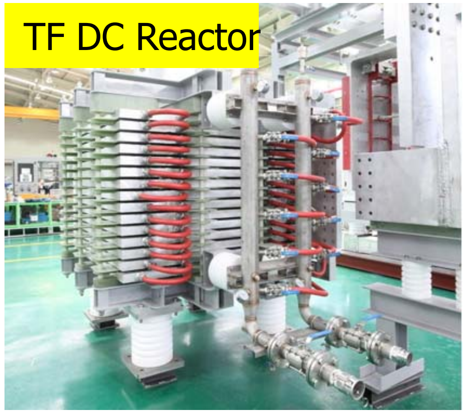
DC System – AC/DC Converters

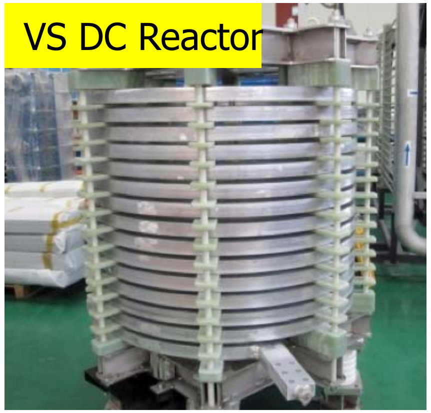
iter china eu india japan korea russia usa

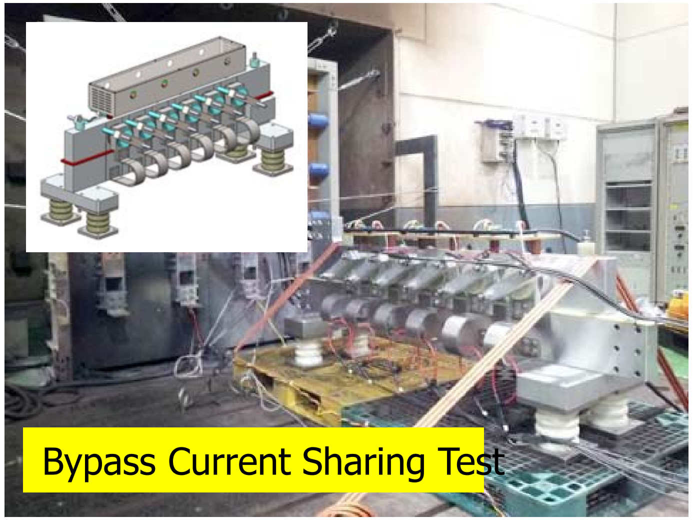
- TF, CS, VS, and CC Converters being developed in Korea (2)

Thyristor Selection	4.2kV/4.2 75kA 100mm (4")	2.8kV/3. 74kA 78mm (3")
TF (68kA)	16	
CS (45KA)	10	
VS (22.5KA)	6	
CC (10KA)		4









DC System – Switching Network Units

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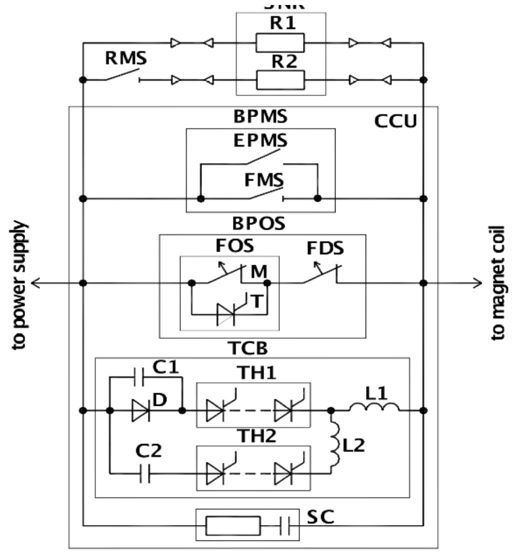
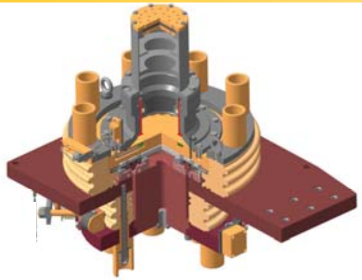
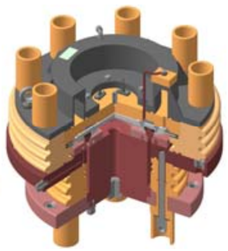
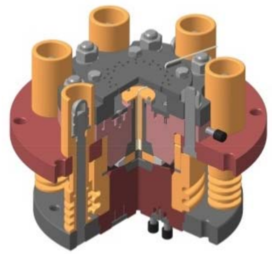




Fast Open Switch (FOS)



Fast Make Switch (FMS)

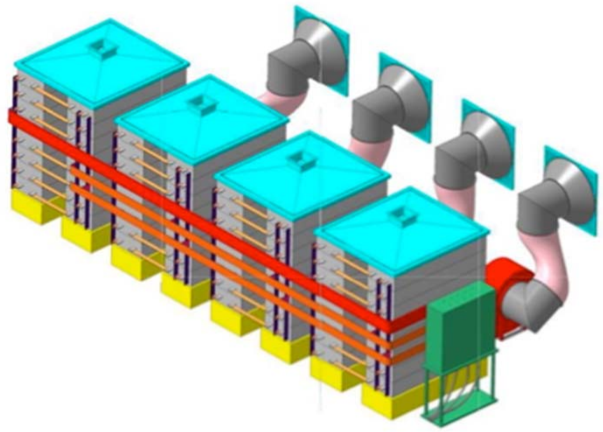


Extra Protective Make Switch (EPMS)

Unique high V & I, fast (< 5mS) pneumatic-EM switches developed by Efremov Institute

Multi-action (3 stage) DC Circuit Breaker for *repetitive operation* (30,000 pulses)

	CS1U,CS1L	PF1,CS2U,CS2L,CS3L	PF6
Current	45kA	45kA	45kA
Voltage	6kV	8.5kV	8.5kV
Energy	1.2GJ	0.8 – 1.0 GJ	1.5GJ



Typ. Switching Network Resistor (SNR) ~ 1 GJ Forced-air cooled

D.V. Efremov Institute

DC System – Fast Discharge Units

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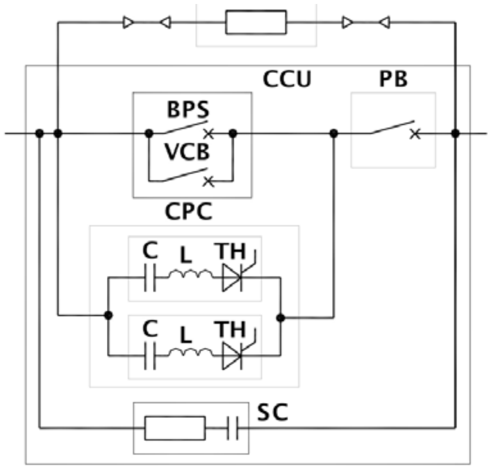
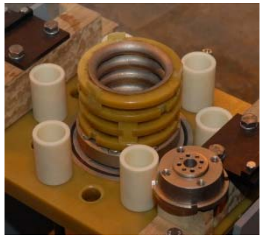
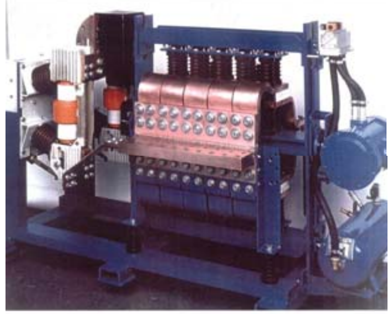


Ultra-reliable multi-action (3 stage) DC Circuit Breaker for *limited number* of operations

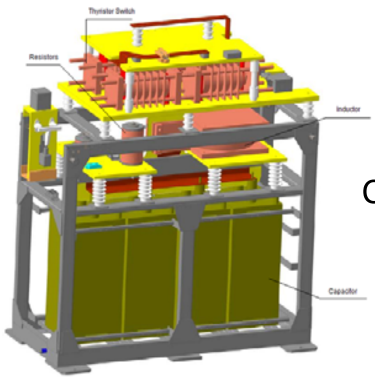
	TF (9 units)	CS,PF (12 units)
Current	68kA unipolar	45,55kA bipolar
Voltage	10kV	10kV
Energy	4.6GJ	1.0 –2.9GJ



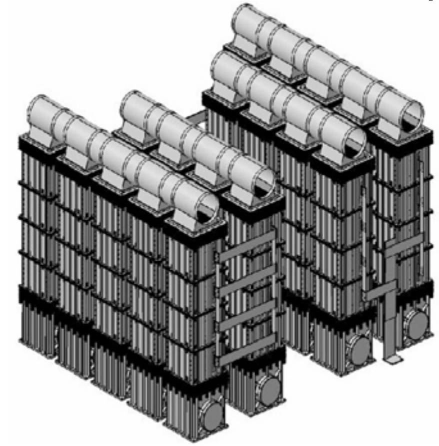
70kA Explosively Actuated Piro-Breaker



70kA Vacuum Circuit Breaker (VCB) & Bypass Switch (BPS)



CS/PF Bipolar Counter-pulse Unit



4.6 GJ TF Discharg e Resistor

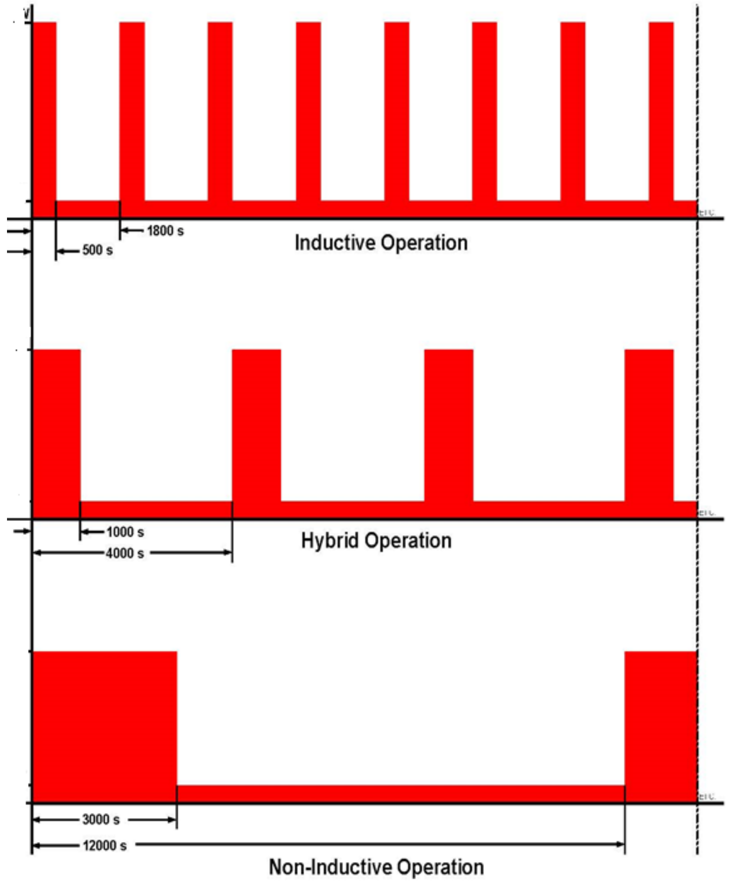
Unique switching devices developed for ITER

ИТЭР РФ ITER RF → D.V. Efremov Institute ← FUSION FOR ENERGY

Component Cooling Water Systems

Design challenges of Heat Removal System

- The pulsed nature of ITER operations presents distinct challenge to the design of the HRS
- Challenges for HRS design is to provide an optimum design solution to meet a very high peak heat load of about 1150 MW with an average heat removal capacity



Component Cooling Water Systems

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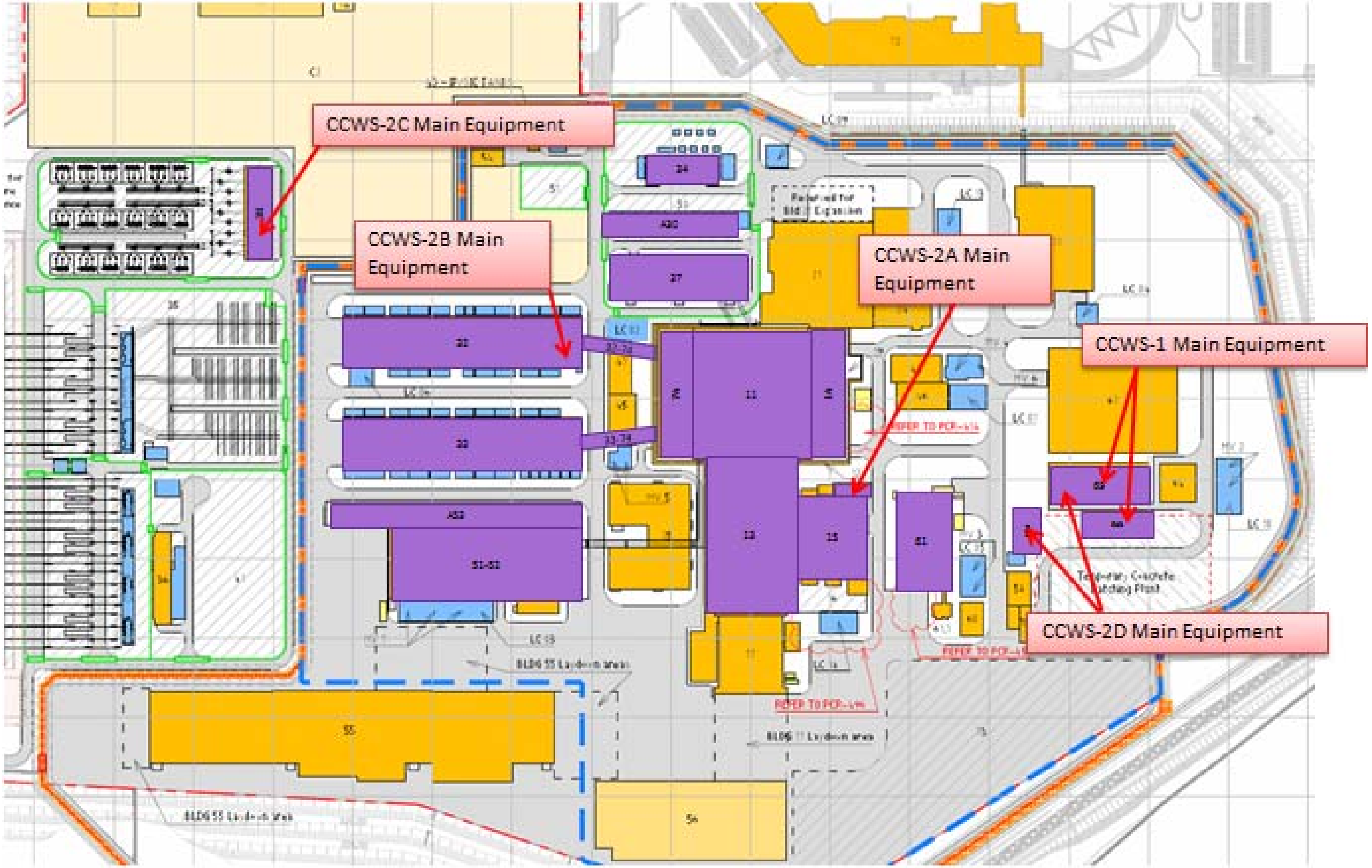


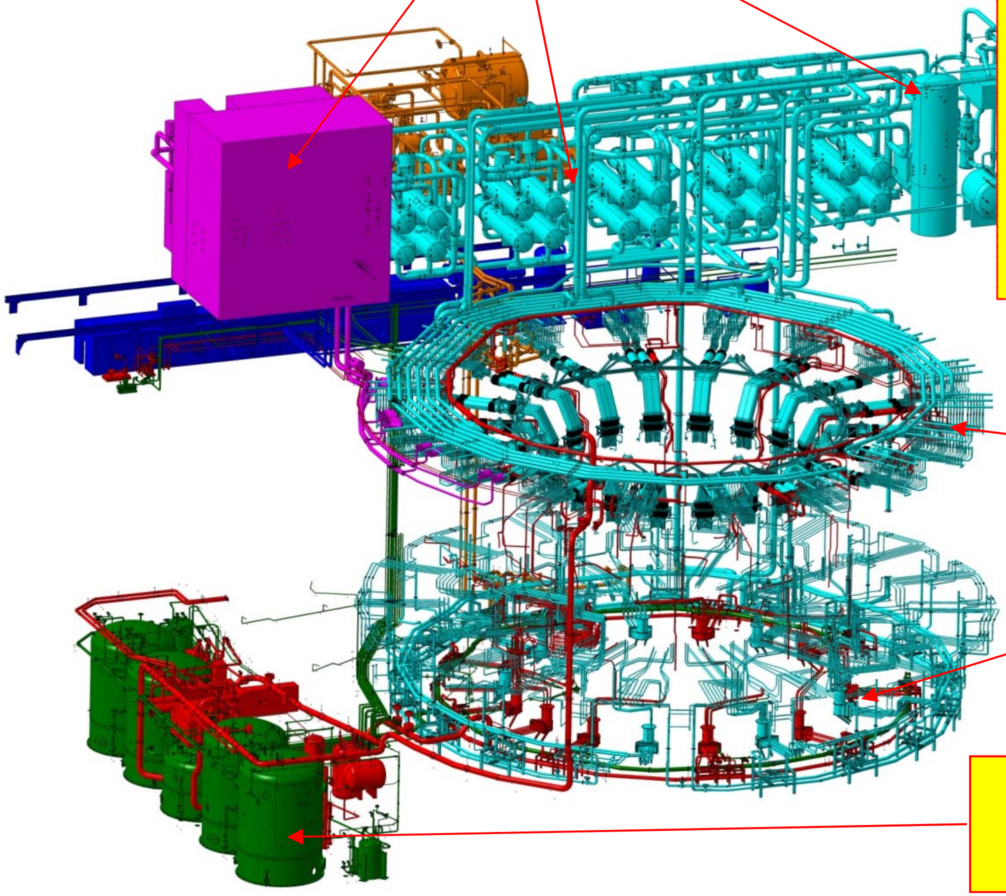
Location of CCWS equipment

Tokamak Cooling Water System

Components and Systems that will be manufactured by US- ITER

- In Cryostat length 10.4 km
- Out Cryostat length 23.4 km
- Total length 33.8 km

- Number of valves 3000
- Weight of piping 5800 kN
- Weight of valves & sup. 1740 kN Total Weight 7540 kN



Piping distribution procured by ITER

Drain Tanks under manufacturing by US- ITER

Cryoplant

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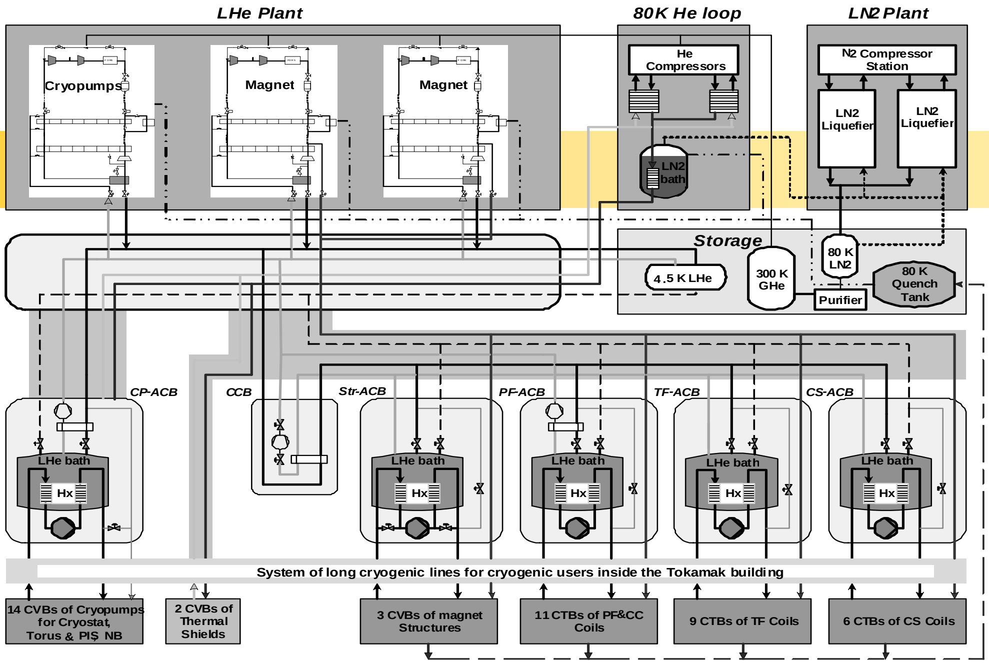
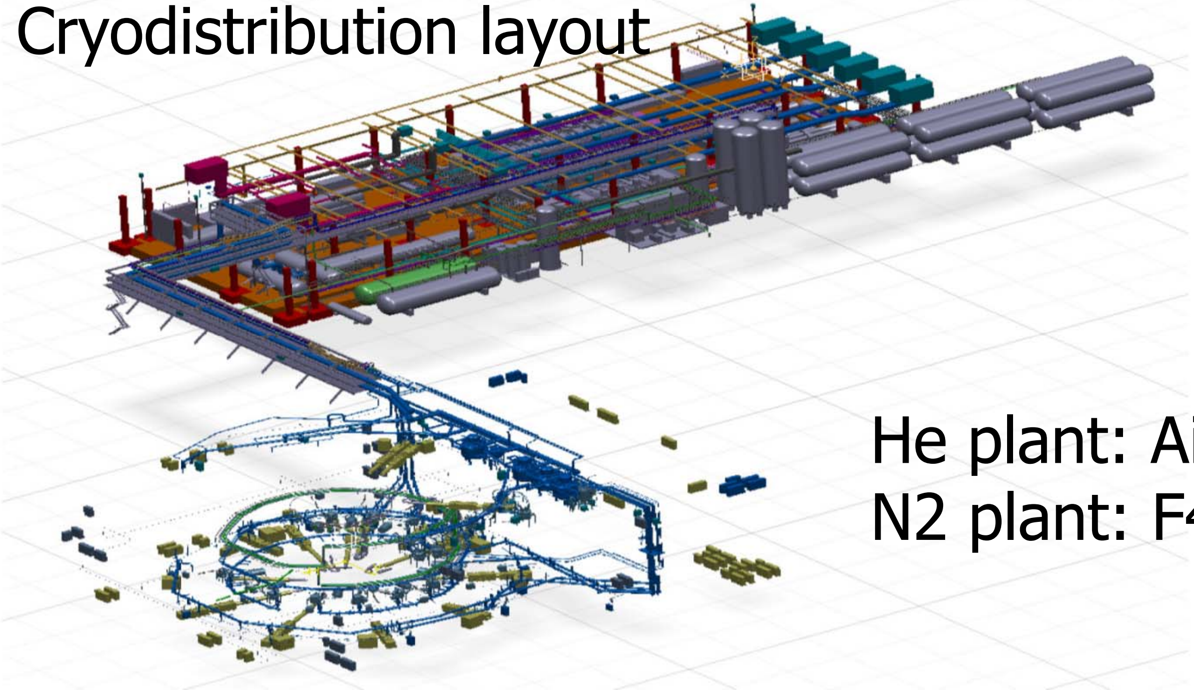


System Architecture
3 He refrigerators
2 N2 refrigerators

Overall Cryoplant and Cryodistribution layout

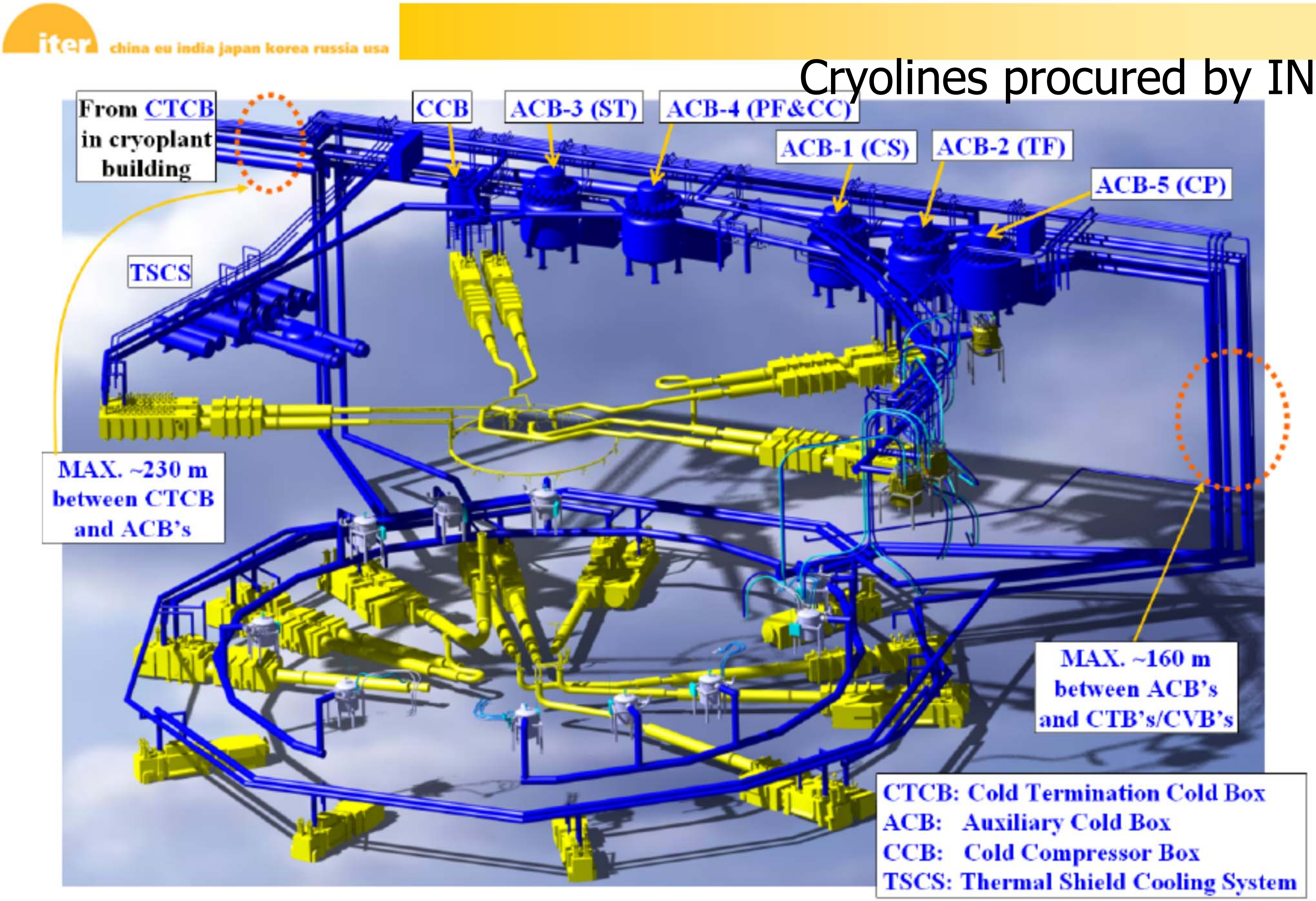


65kW at 4.5K
1300kW at 80K

He plant: Air liquide (IO contract)
N2 plant: F4E

Cryo Components in Tokamak Building

Cryolines procured by INDA



ITER Tokamak

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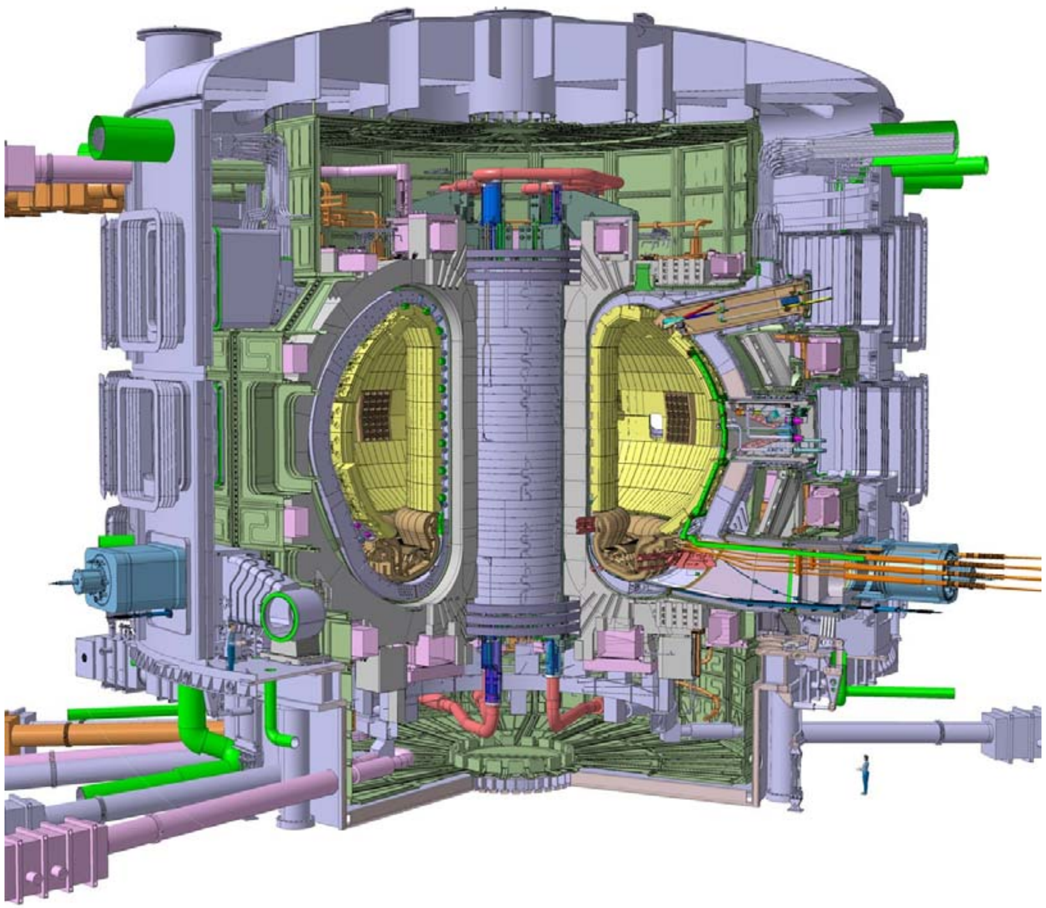
- The main components of the ITER Tokamak are
  - **vacuum vessel** (which delimits plasma chamber),
  - magnet system (which controls plasma confinement, shaping and stability),
  - **cryostat** (which shields vacuum vessel and magnet system),
  - **blankets and divertor** (which absorb neutron flux and eliminate plasma ashes).



ITER Tokamak

Cryostat

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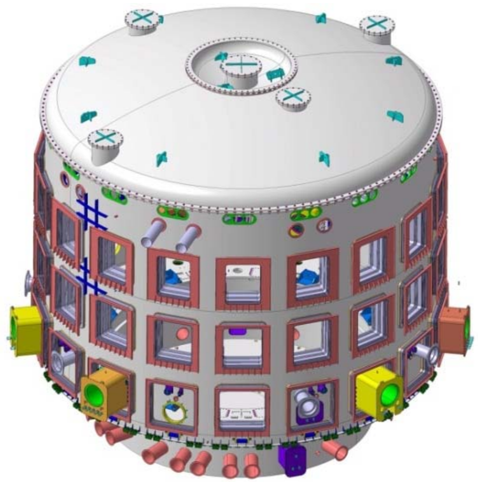
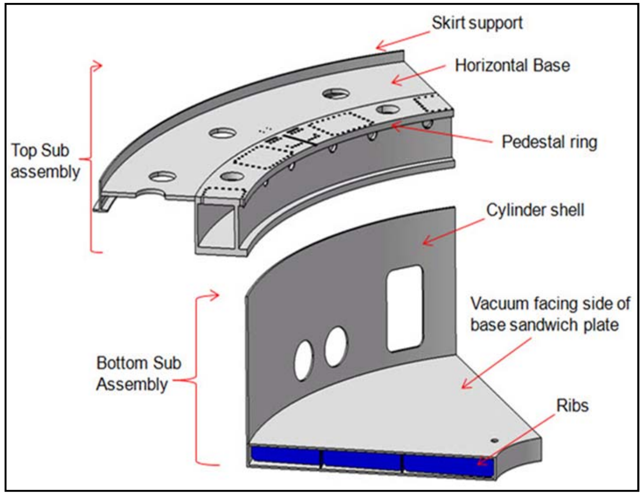




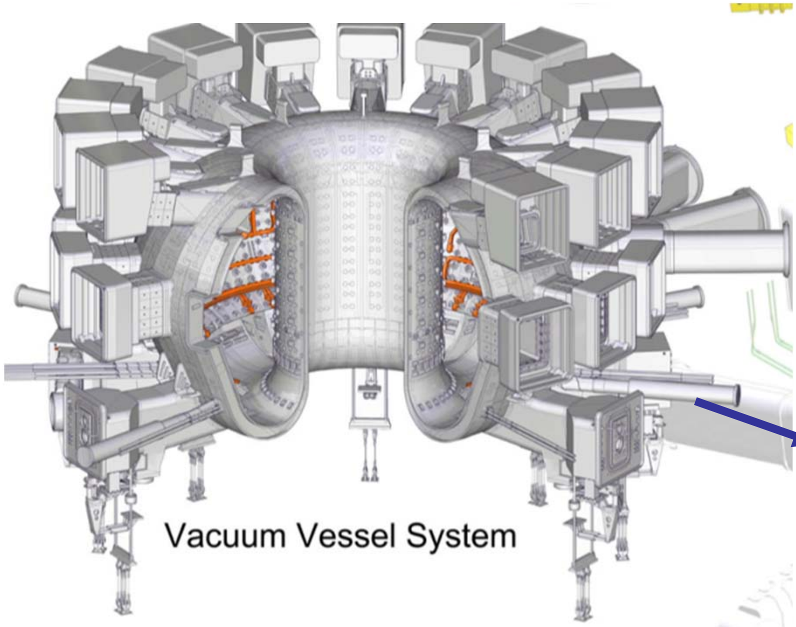

40^0 Mock-up manufacturing of pedestal ring

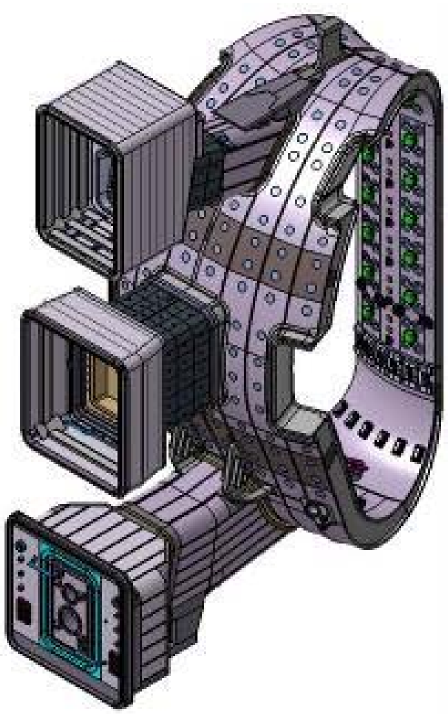
40^0 Mock-up manufacturing of cryostat skirt(105mm thick) & pedestal ring top plate (200mm thick)

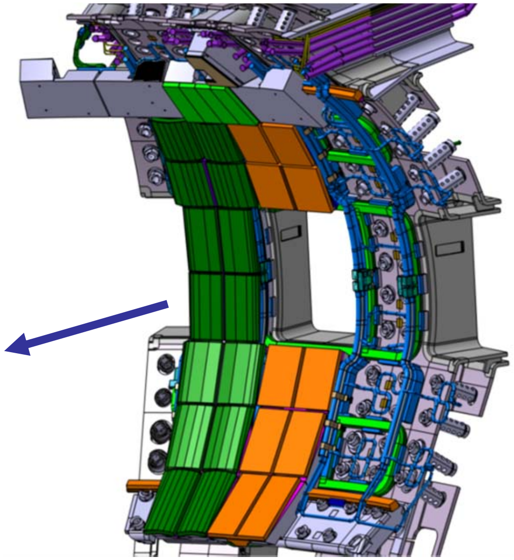
INDIA


Cryostat workshop construction at IO site

Vacuum Vessel







ELM & VS Coils
VV interfaces implemented

Facts
- First safety barrier for ITER
- Nuclear Component
- ~5300 tons (VV, ports, shielding only)
- 19.4 m torus outer diameter
- 11.3 m torus height

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

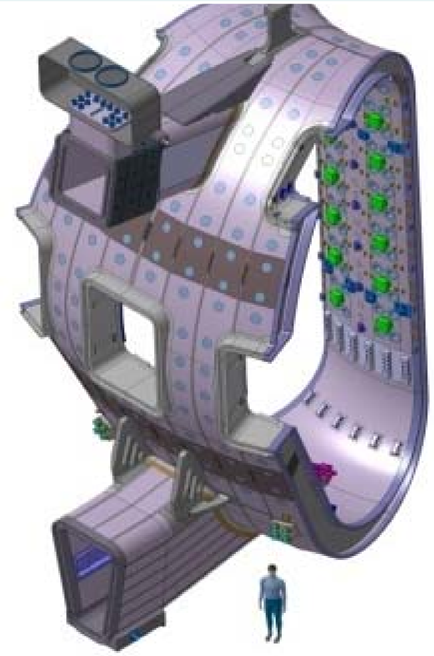
Vacuum Vessel Current Status

Component	Procurement Party	Supplier
Main Vessel	EU (7 Sectors) Korea (2 Sectors)	AMW (Ansaldo Nucleare Mangiarotti Walter Tosto) HHI (Hyundai Heavy Industries)
Ports	Russia (Upper Ports) Korea (Lower and Eq. Ports)	Efremov Institute/MAN T&D AG Hyundai Heavy Industries
In-wall Shielding	India	Avasarala Technologies Ltd.

VV Sector Delivery: First Sector delivered to the ITER Site in Aug 2016. The VV assembly is under a direct contract by IO with ENSA.

Manufacturing Started:

- **Manufacturing (plate cutting and forming) and welding started for first KO Sector.**
- **First EU Sector started in Sept. 2013**
- **Water jet cutting of shielding plates started**



VV fabrication in European Industry

china eu india japan korea russia usa

EU

Bolted Rib Mock-up

Mock-up of the inboard part of a vacuum vessel segment, produced by AMW, in Italy.

Triangular Support Mock-up

VV fabrication in Korean Industry

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Inboard Segment Mock-up

Upper Inner Shell

Upper Segment Mock-up

Triangular Support Mock-up

T-ribs Welding

Equatorial Port Mock-up

At Hyundai Heavy Industries in Ulsan, South Korea, fabrication is in full swing.

KO

VV Upper Port Extension in Russia

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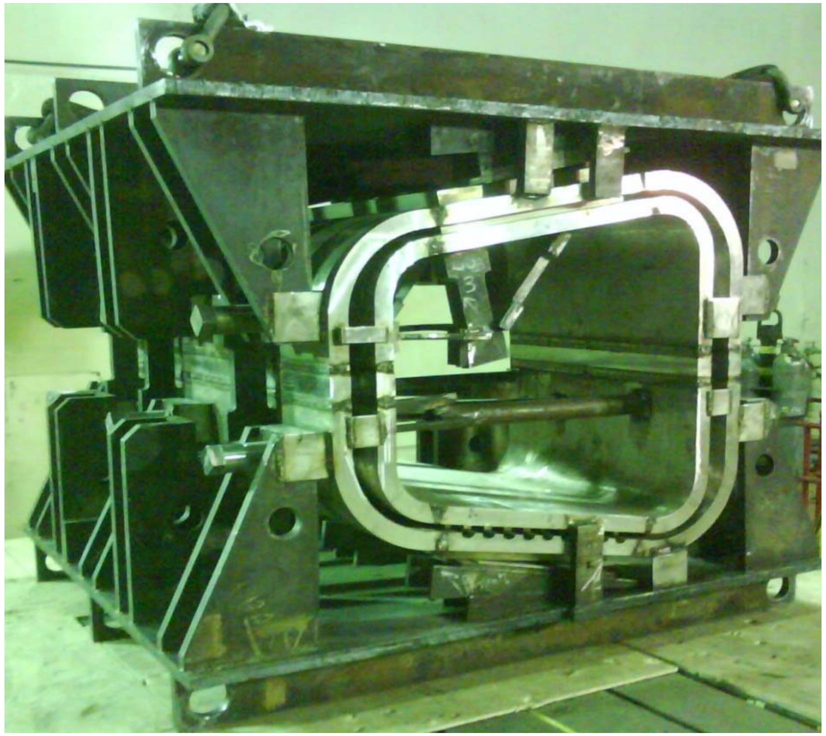
RUSSIA

- Prototype manufactured by Izhorskye Zavod under contract from Efremov.
- Final manufacturing tolerances acceptable.
- Contract for upper port manufacture awarded in December 2012 to MAN Turbo & Diesel AG.



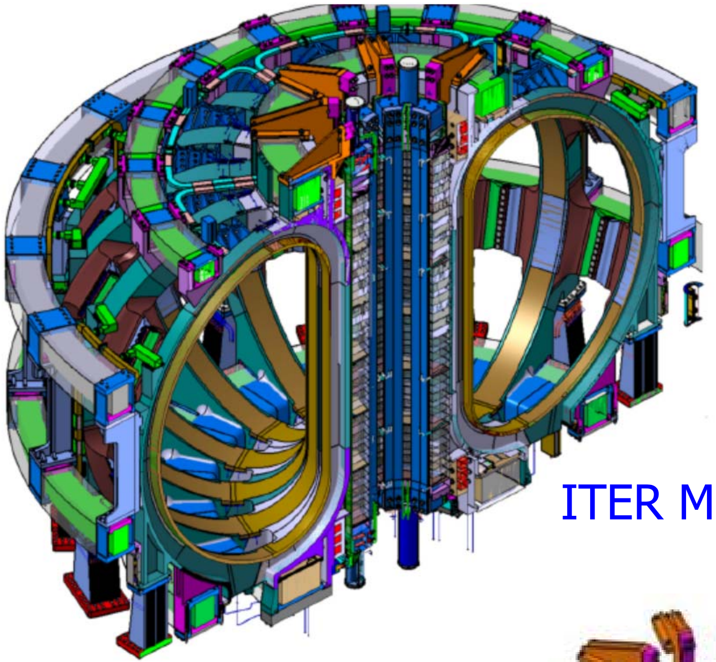
Magnets -1

Overview

Sharing between Domestic Agencies, and the Main Industrial Suppliers

All magnet production is now either in the prototyping or production phase

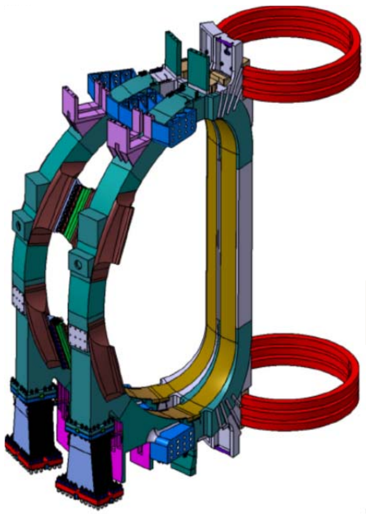
ITER Magnet System – Overview



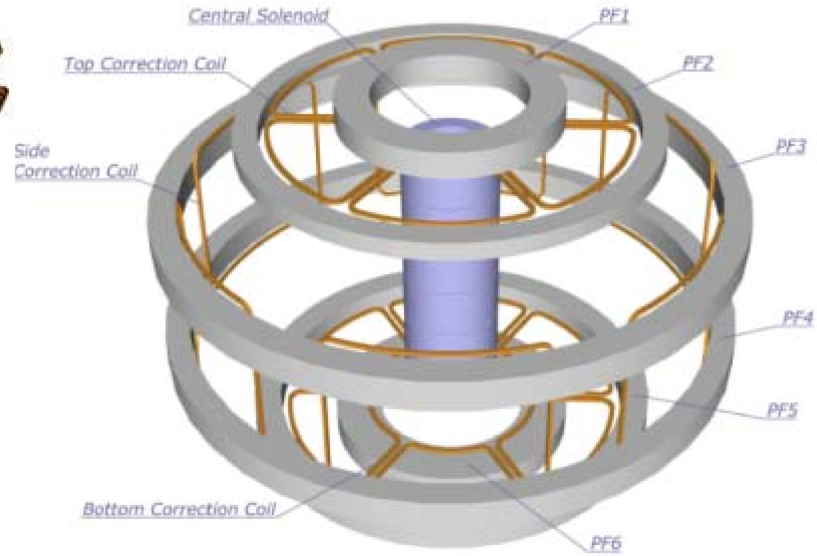
- The ITER magnet system is made up of
  - 18 Toroidal Field (TF) Coils,
  - a 6-module Central Solenoid (CS),
  - 6 Poloidal Field (PF) Coils,
  - 9 pairs of Correction Coils (CCs).

ITER Magnet System

Pair of TF Coils



CS Coil



(PF1)

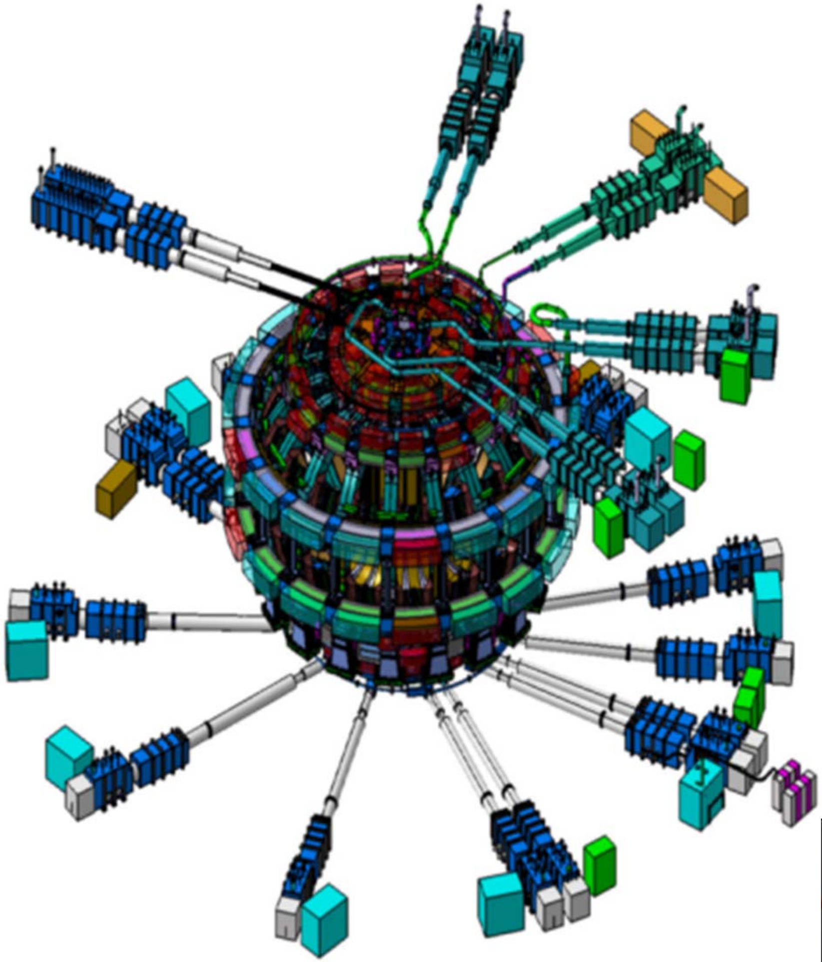
PF Coils

(PF2-6)

CCs

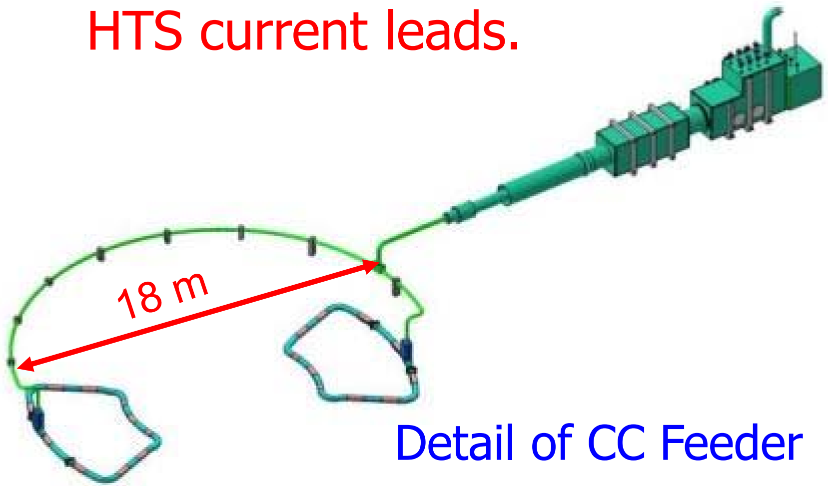
ITER Feeder System – Overview

- The magnets are supplied in current and cryogenic fluids by 31 Feeders.



ITER Feeder System

- The magnet Feeders include
  - NbTi CICC busbars,
  - Ag-Au(5.4%) BiSCCO 2223 HTS current leads.

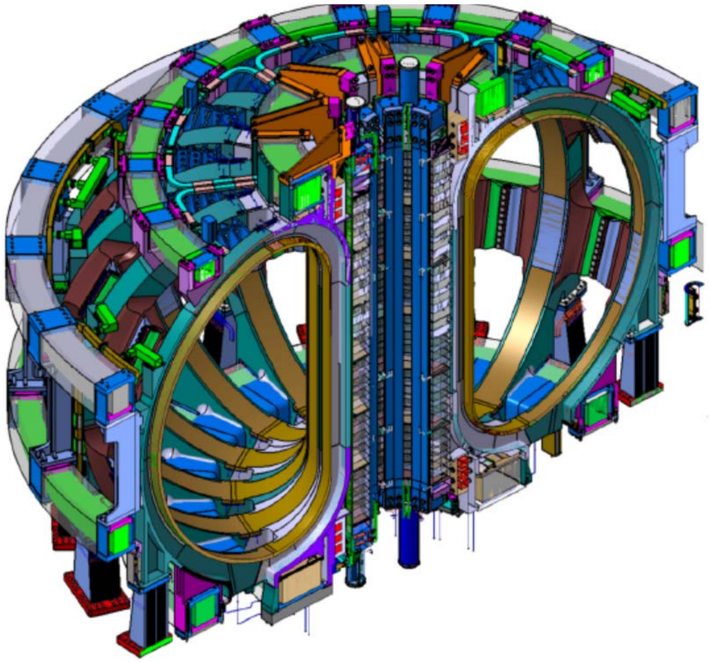


Detail of CC Feeder

68 kA Trial Lead Developed by ASIPP

Some Major Parameters

china eu india japan korea russia usa



ITER Superconducting Magnet System Energy ~51 GJ

TF coil height x width	15x9m
TF coil weight	334t
PF3 diameter	24m
PF3 coil weight	304t
CS weight	954t
CS height	13m
Total weight Nb3Sn	550t
Total weight NbTi	250t
Total length s/c strand	180000km
Total length LV/HV cryostat cable	140km
Total number HTS current leads	60

ITER Magnet Supply: 10 PAs

CS with US
(General Atomics)

Pre-compression rings: EU
(EADS CAS)

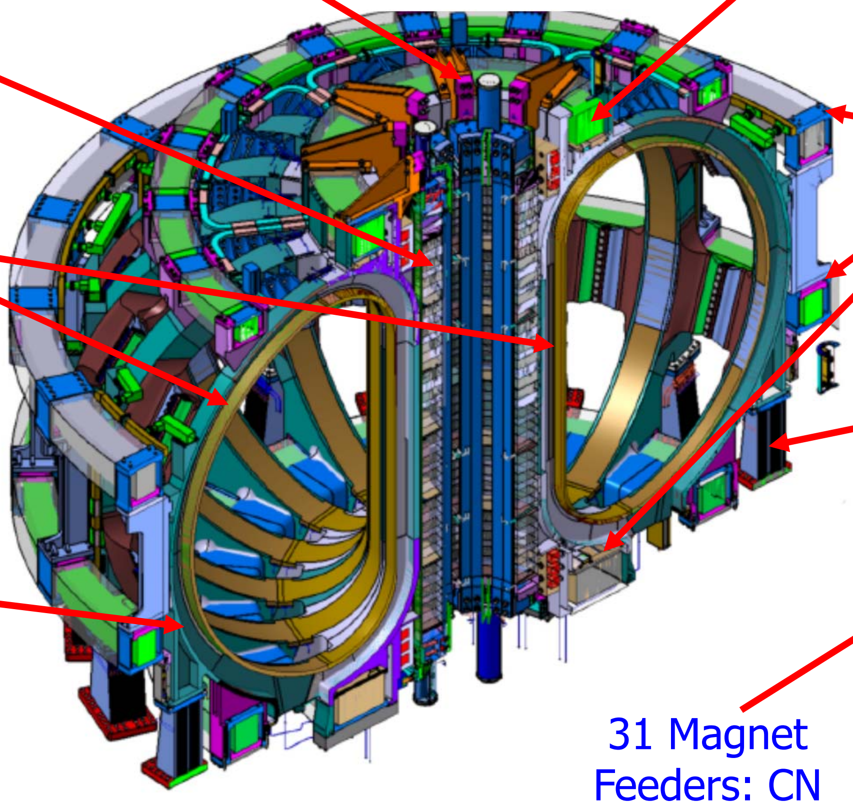
PF1: RF
(Efremov)

Instrumentation
ITER

9+1 TF coils with EU
(Iberdrola/ASG/Elytt
Consort.)

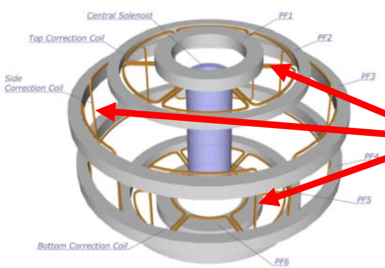
9 TF coils with JA
(MHI & Toshiba)

19 TF coil cases: JA
(MHI/Hyundai Consort.,
MHI, Toshiba)



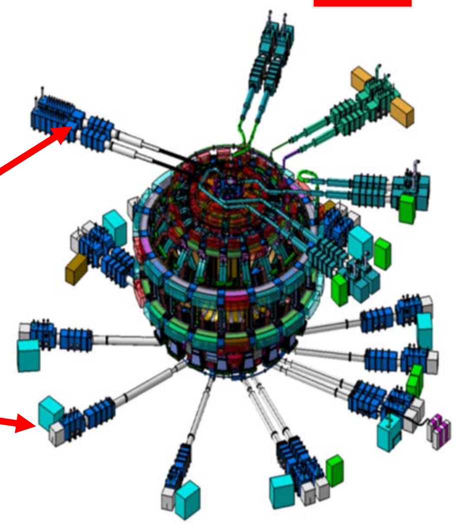
PF2-6: EU
(ASG & ASIPP)

Magnet Supports: CN
(SWIP)



9 pairs of CCs: CN
(ASIPP)

31 Magnet
Feeders: CN
(ASIPP)



ITER Conductor Supply: 11 PAs

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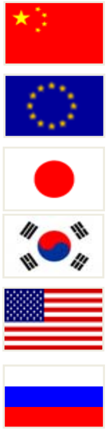
Nb_3Sn

TF Conductor





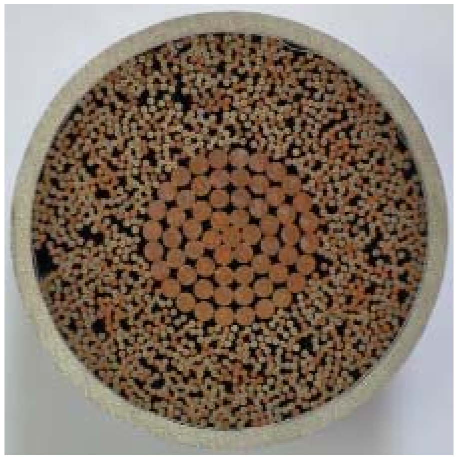
(dummy)
CS Conductor

PF Conductor

Nb–Ti



CC Conductor

MB Conductor


(dummy)
CB Conductor

Magnets -2

- **TF Conductor & Coils**

Main Features of TF Coils -1

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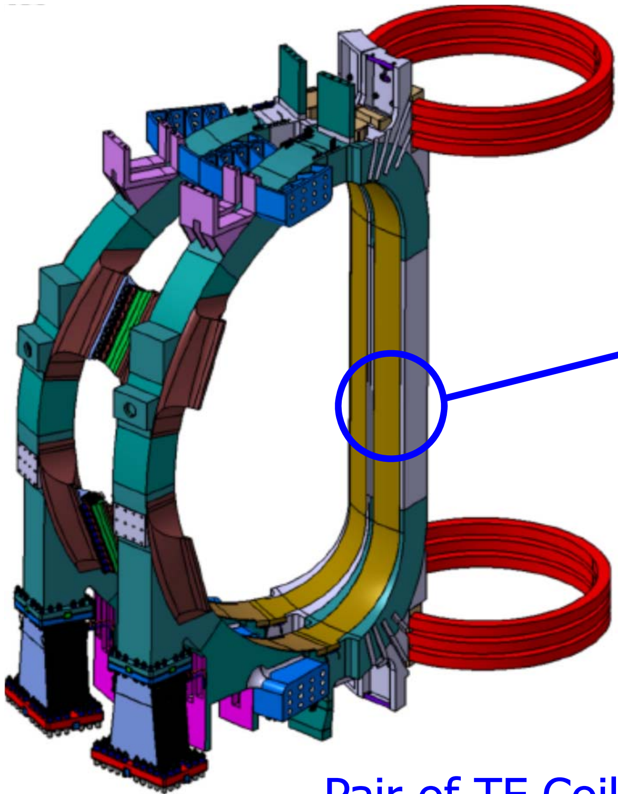
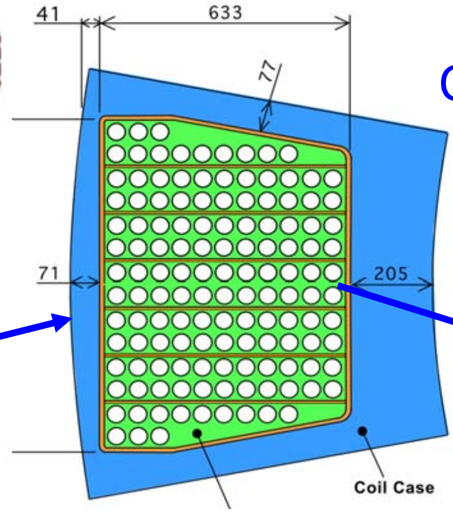


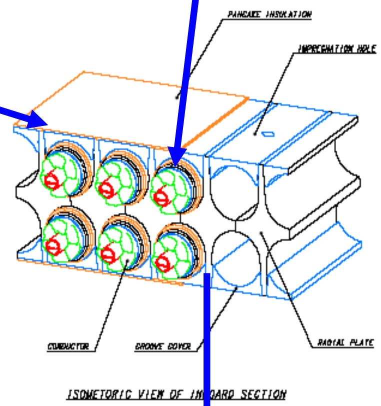
Pair of TF Coils



Winding Pack

CIC Conductor

Nb_3Sn Rope-Type Cable



Double Pancake

- Main assembly steps: wind, react, transfer and impregnate.

Stainless Steel Radial Plate

Main Features of TF Coils -2

Manufacturing Challenges

Nb3Sn strand and conductor
- Nb3Sn required, brittle and has to be formed after winding by heat treatment of about 600C for 200hrs
- Has to achieve a high critical current and controlled AC loss

Fitting conductor into radial plates
- High tolerances on RPs (tenths of mm over 15m)
- High tolerances on winding and control of conductor distortion during Nb3Sn heat treatment

Massive structures with small tolerances (few mm)

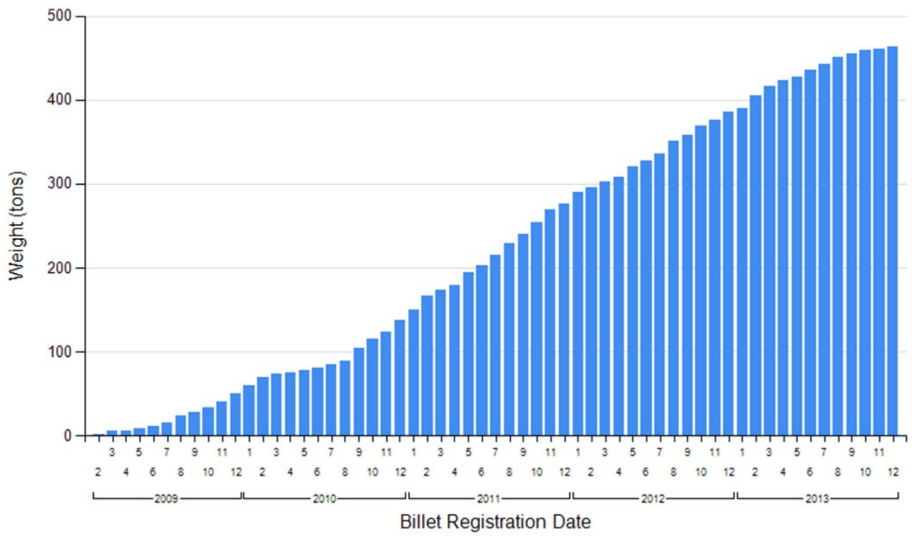
Assembly of RP to winding and fitting winding pack into case

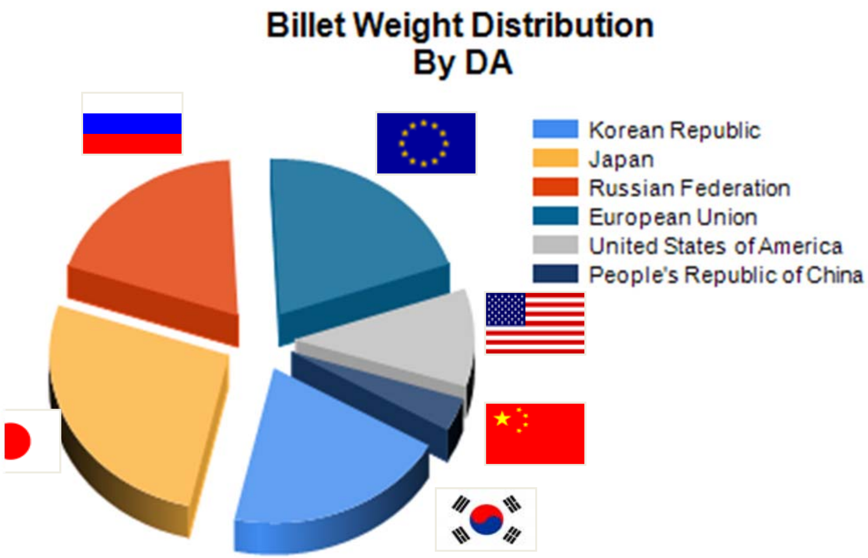
ITER TF Strand Production

china eu india japan korea russia usa

- As of today, ~463 tons (95,000 km) of Nb_3Sn strands have been produced; this corresponds to ~96% of total amount needed.
- It is the largest Nb_3Sn strand production ever – pre-ITER world production was ~15 t/year.

TF Strand Production Dashboard





Dashboard of Billet Registration in Conductor Database

(Courtesy of G. Bevillard, A. Vostner, ITER-IO)

ITER Conductor Manufacture

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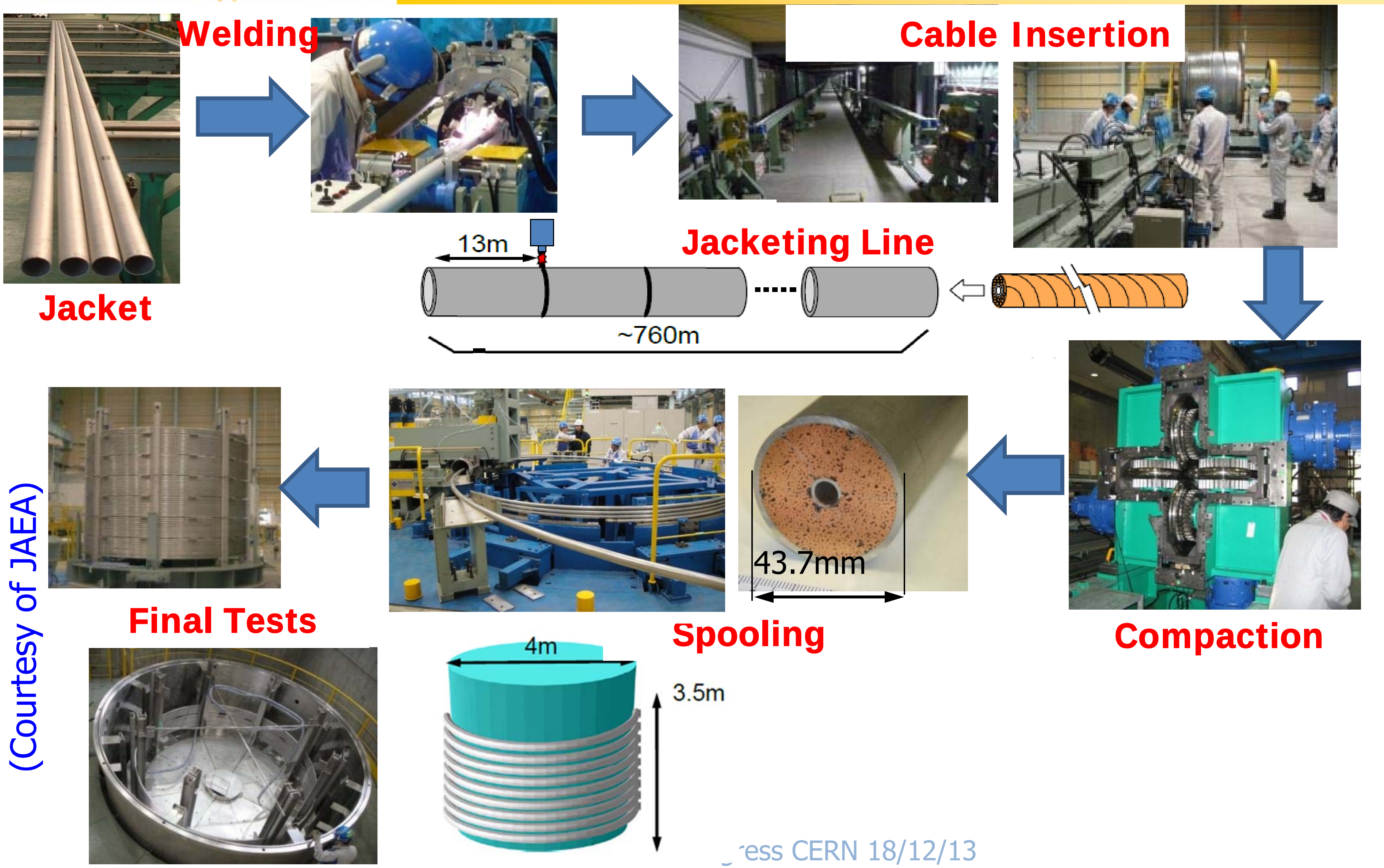
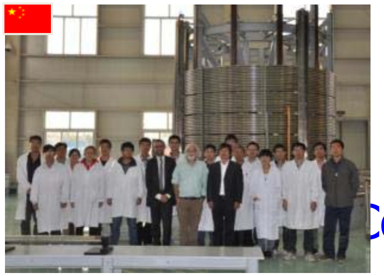
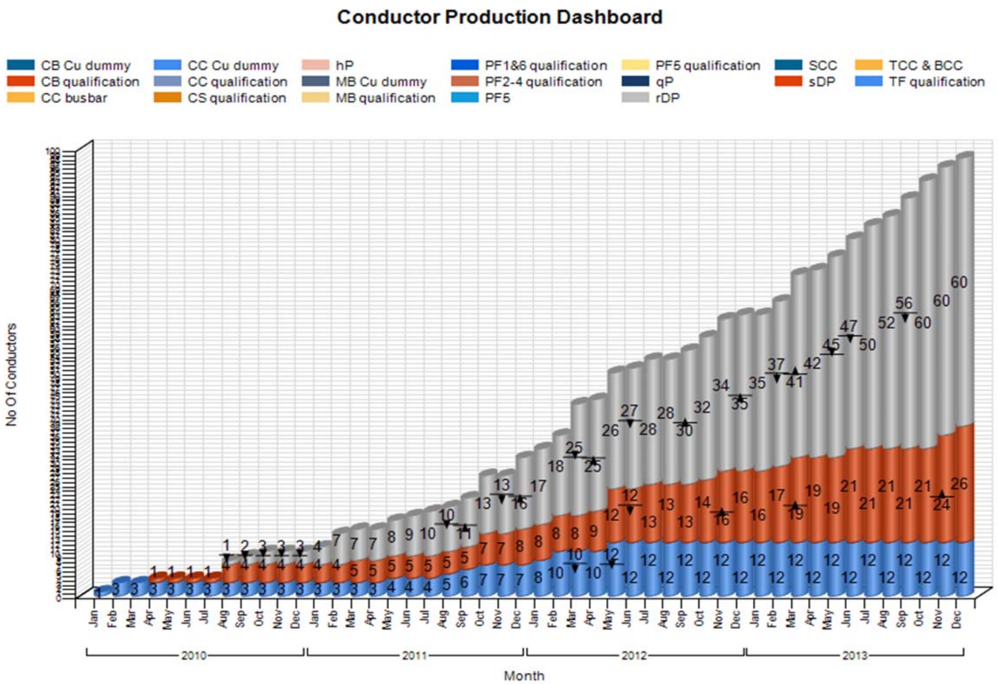


ITER TF Conductor Production

iter china eu india japan korea russia usa

- In addition to 12 x Cu and sc qualification ULs, a total of 60 x 760 m rDP ULs and 26 x 415 m sDP ULs have been manufactured by JA, KO, RF, F4E and CN; this corresponds to ~12 TF Coils.





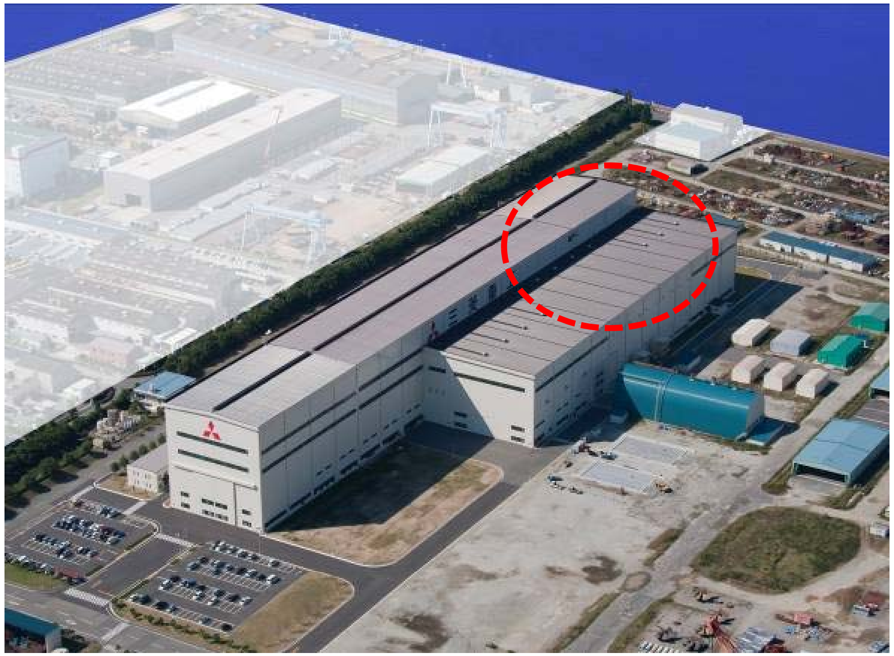
Dashboard of TF Conductor Registration

Conductor Database (Courtesy of G. Bevillard, ITER-IO)

Progress on TF Coils: Facilities in EU and JA

Construction of Facilities (ASG and MHI)

La Spezia new 80x220m (in 4 bays) completed 2011: picture shows 1 bay

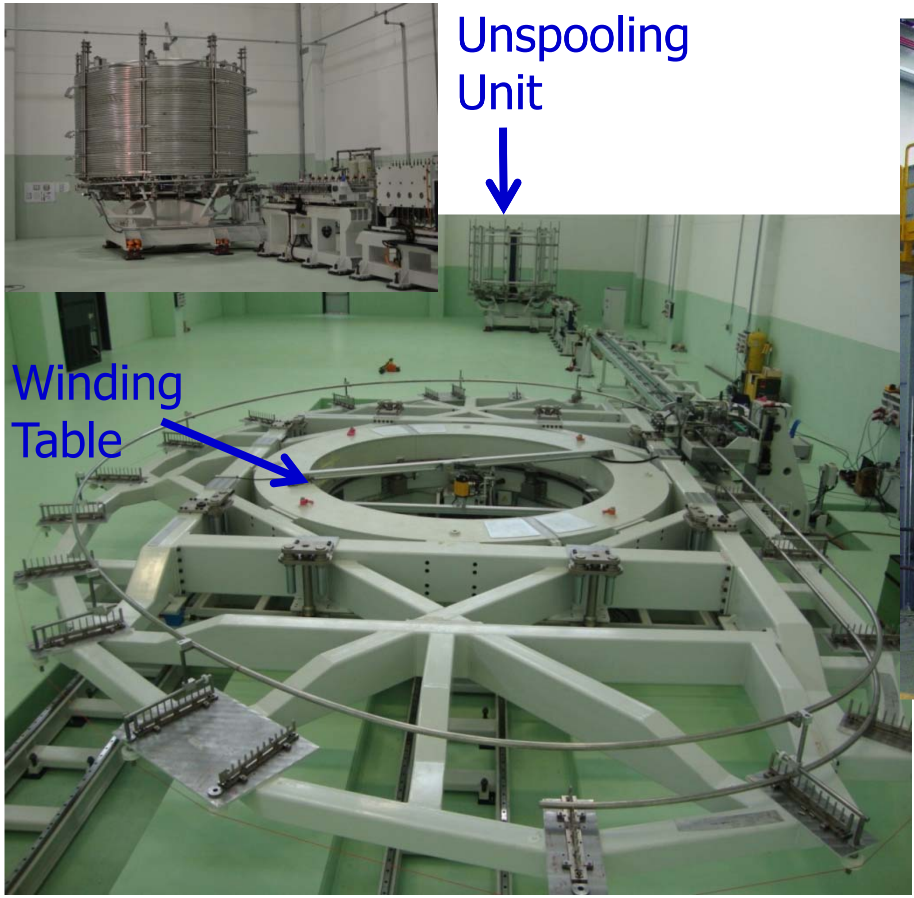


Kobe conversion of end of existing buildings started 2013 (red circle)

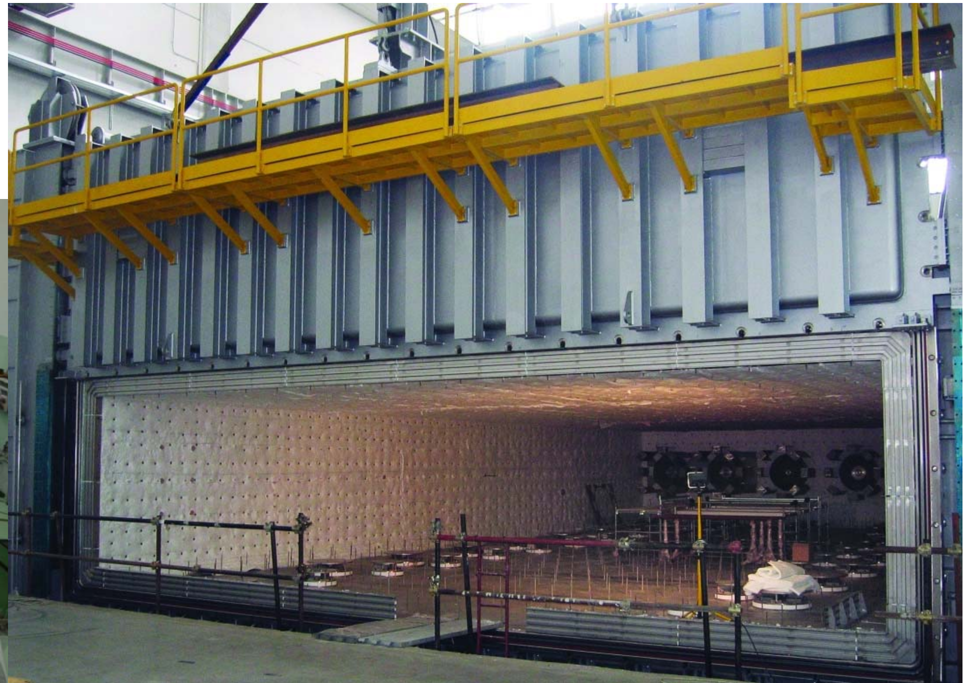
Progress on TF Coils: EU – Tooling 1

china eu india japan korea russia usa

- EU has commissioned the winding line and heat treatment oven



Winding line at ASG



Heat Treatment Oven at ASG

(Courtesy of
A. Bonito-Oliva, F4E)

Progress on TF Coils: EU – Tooling 2

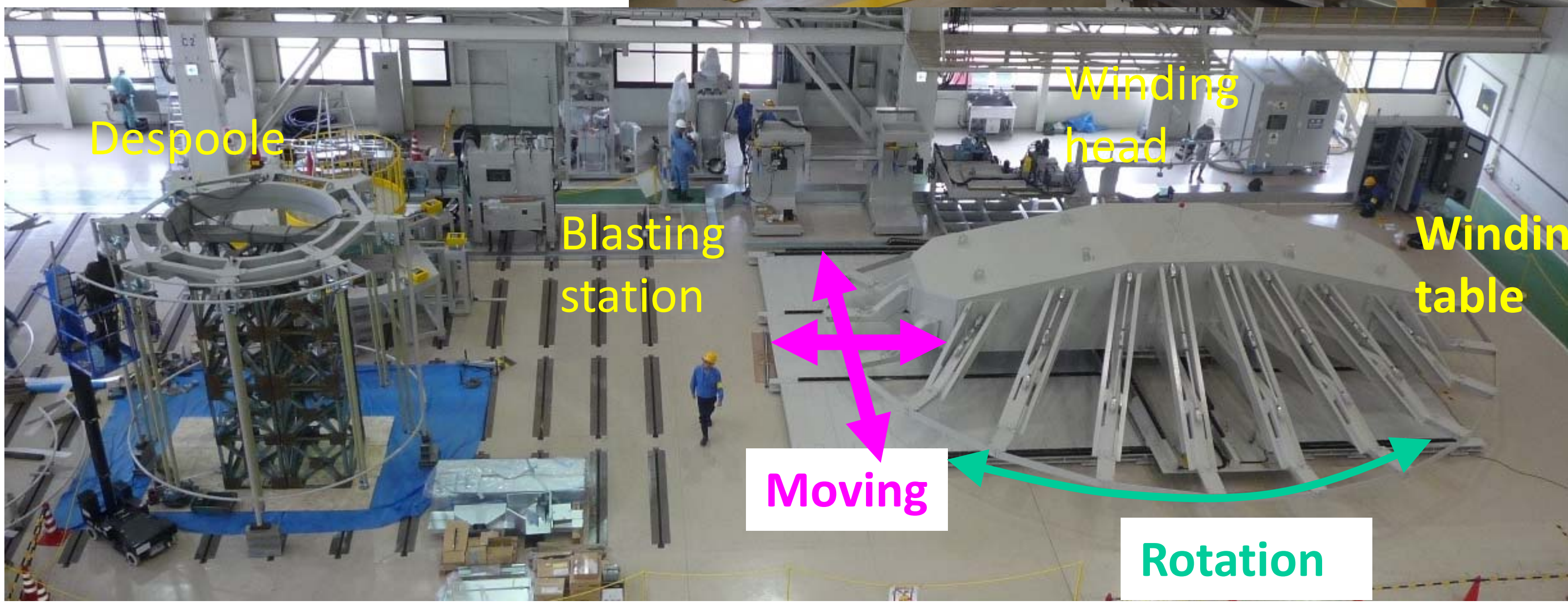
(Courtesy of
A. Bonito-Oliva, F4E)

Wrapping tooling for turn insulation of double pancake during assembly at Elytt (Bilbao, Spain) and during commissioning at ASG

Progress on TF Coils: JA-Dummy DP

Dummy DP winding at
MHI (Futami)

(Courtesy of N. Koizumi, JAEA)



Progress on Radial Plates

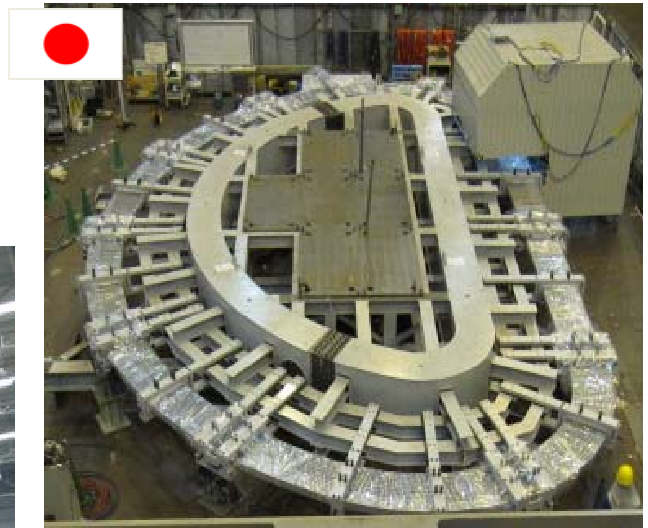
iter china eu india japan korea russia usa

- EU has manufactured 2 full size Radial Plate (RP) prototypes: one sDP and one rDP, while JA manufactured 1 full size rDP RP prototype.

Full-Size sDP RP Prototype in EU

Courtesy F4E

Full-Size rDP RP Prototype in EU



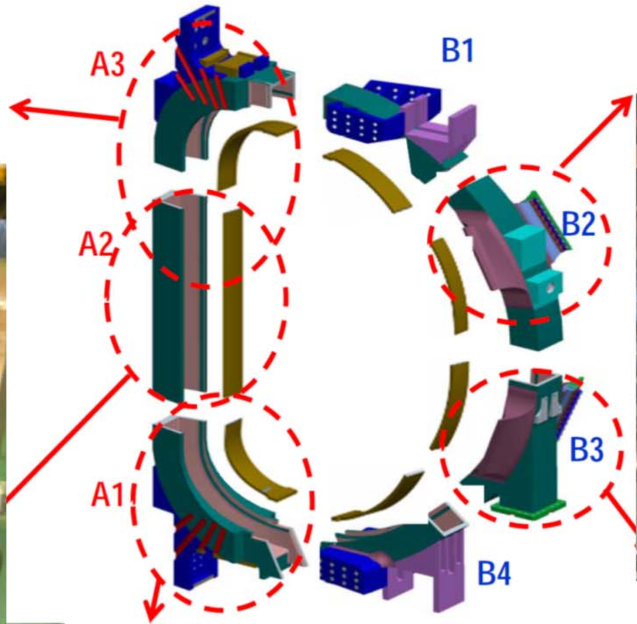
Full-Size rDP RP Prototype in JA

EU has awarded contract for full supply of 10x7 RPs, JAEA so far 3x7 RPs

Progress on TF Structures: JA

JADA has placed contracts with MHI/HHI for 1 complete set of structures and 6 sets of materials

Production ongoing



Pictures courtesy JAEA & Contractors MHI

Magnets -3

- PF Conductors & Coils , Correction Coils

PF and Correction Coils

china eu india japan korea russia usa

Manufacturing Challenges

- NbTi conductor with thick jacket, high quality welding for fatigue tolerance
- High voltage
- Large dimensions

- For CC, high tolerance on large dimensions and weak winding, welding and winding accuracy critical

PF Conductor Status – 1

- EU & RF are responsible for the PF1&6 conductors, which rely on Nb–Ti strand 1, while CN is responsible for the PF 2-5 conductors, which rely on Nb–Ti strand 2.

Nb–Ti Strand 1 developed by VNIINM (1.6:1)

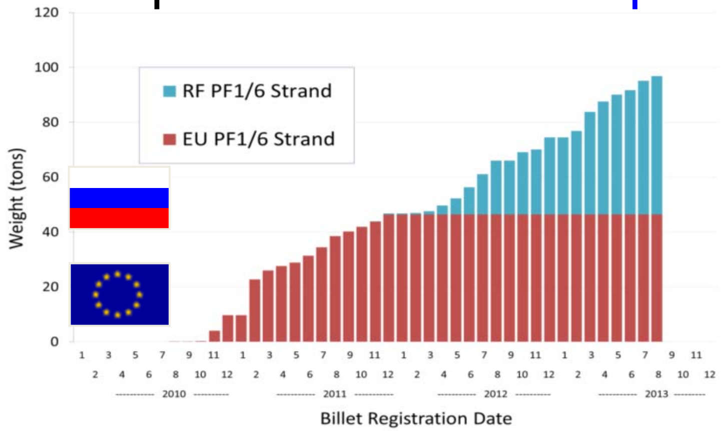
Nb–Ti Strand 2 developed by WST (2.3:1)

PF Conductor Status – 2

china eu india japan korea russia usa

- RF have registered ~95 t of Nb–Ti strand (production complete) and have completed cable production. F4E are performing PF6 jacketing qualification

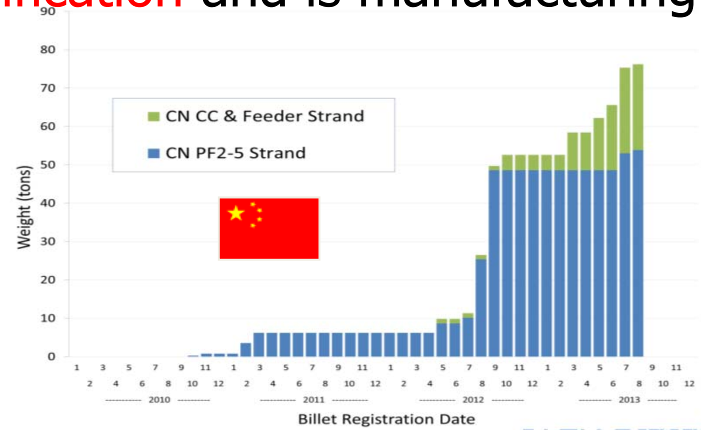
PF1-6 Registration



PF1&6 Cable Delivery at Criotec

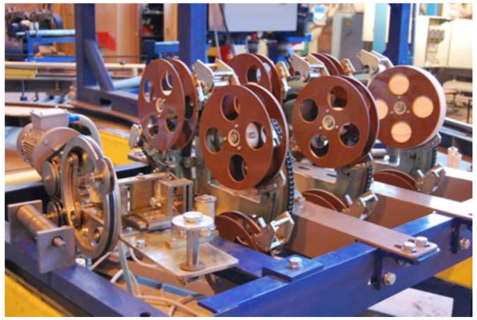
- CN has registered ~80 t of Nb–Ti strand 2, completed PF jacketing qualification and is manufacturing PF5 conductors.

PF2-5 Registration



Compaction & Spooling of PF5 Cu Dummy at ASIPP

PF1 Coil Development at Efremov



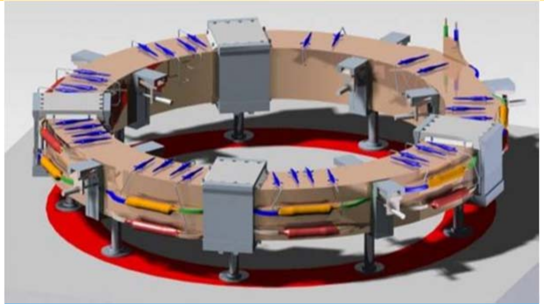
Insulating machine

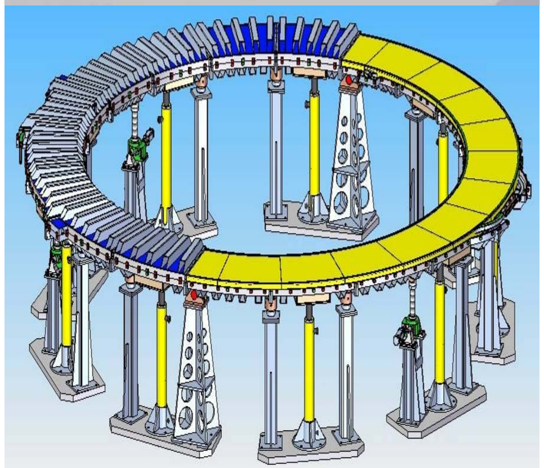
- Efremov has procured main tooling for PF1 coil manufacture.

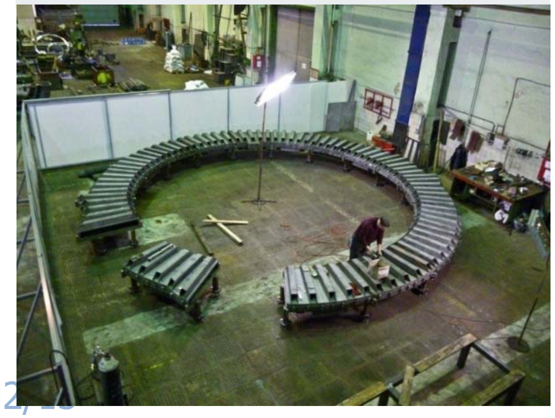
Bending equipment

Winding table

Vacuum chamber for impregnation and baking







Equipment for resin mixing

(Courtesy of I. Rodin, Efremov)

PF2-6 Coil Development by F4E

Building on Cadarache site completed in 2011
240mx45m

Engineering integrator for PF2-5 is selected: ASG
PF6 will be made off-site by ASIPP (China)

Correction Coil Winding Development in CN

iter china eu india japan korea russia usa

Winding facility constructed by ASIPP in Hefei. Tooling commissioning underway

Coil handling jig

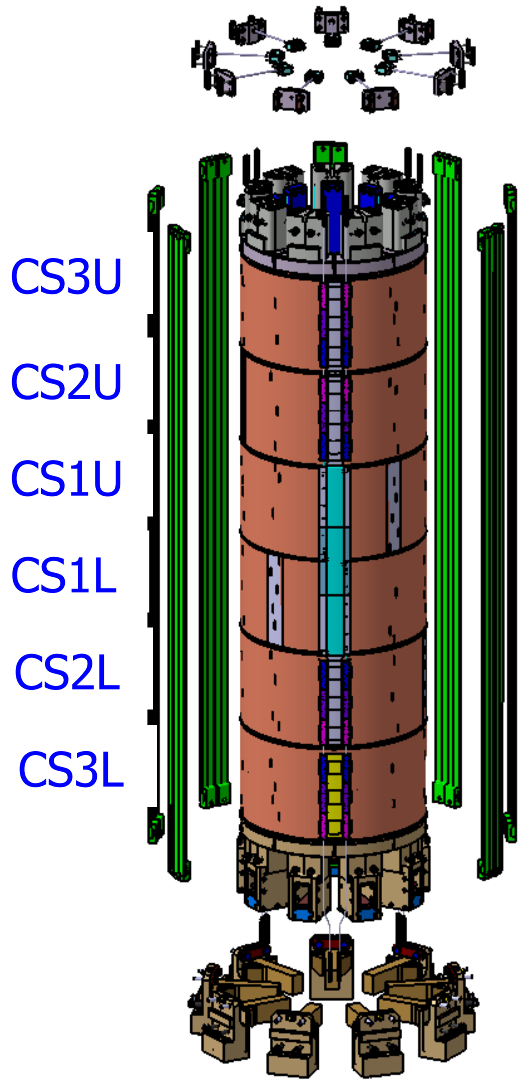
2x 4kW Yb robot lasers for case welding being commissioned

Courtesy ASIPP

Magnets -4

•**CS Conductor and Coils**

CS Coils



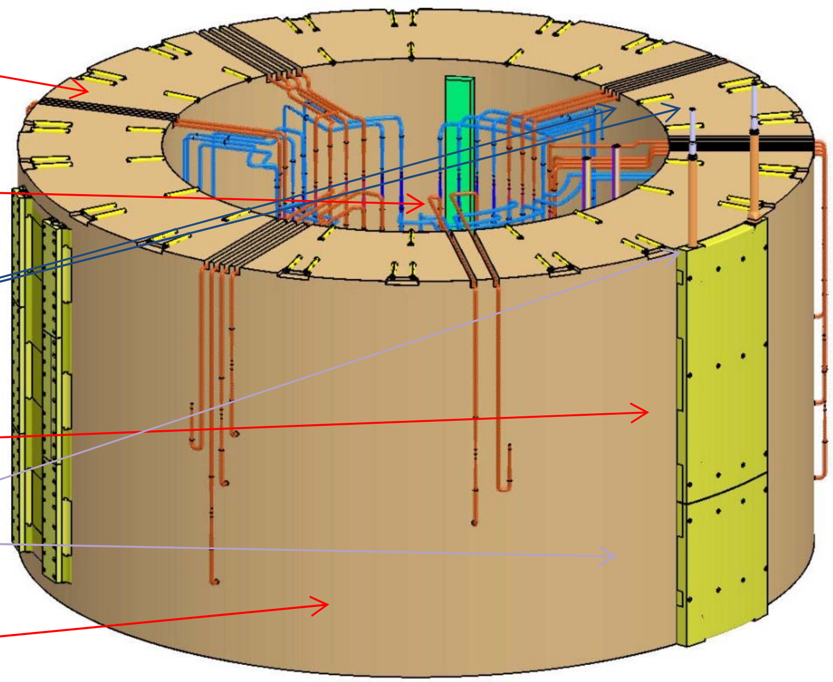
- In comparison to the TF coils, which are operated in a steady state, the CS and PF coils must drive inductively 30,000 x 15 MA plasma pulses with a burn duration of 400 s.
- During their life time, the CS coil modules will have to sustain severe and repeated electromagnetic (EM) cycles to high current and field conditions.

CS conductors are to be procured in kind by Japan; they are 100% funded by EU (Broader Approach) and will be delivered to the USA for coil manufacture.

CS Coils

Manufacturing Challenges

- Coils wound as Hexa-pancakes. Critical issues are tolerances, joints and high voltage insulation.
- Busbars have to be led down the outside of the coil…support and flexibility are critical, tolerance sensitive, issues
- Support structure has high fatigue stresses and requires high mechanical performance at RT due to pre-load



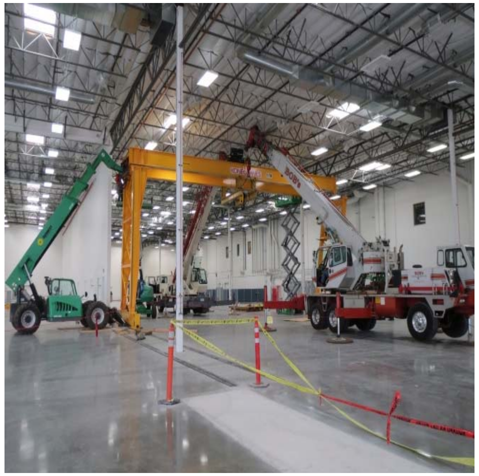
CS Coil Winding Facility

Renovation of part of 20000m2 facility completed by GA in Poway, San Diego mid 2013.

Tooling deliveries end 2013/14

Winding: Taurin

Insulation: Ridgeway

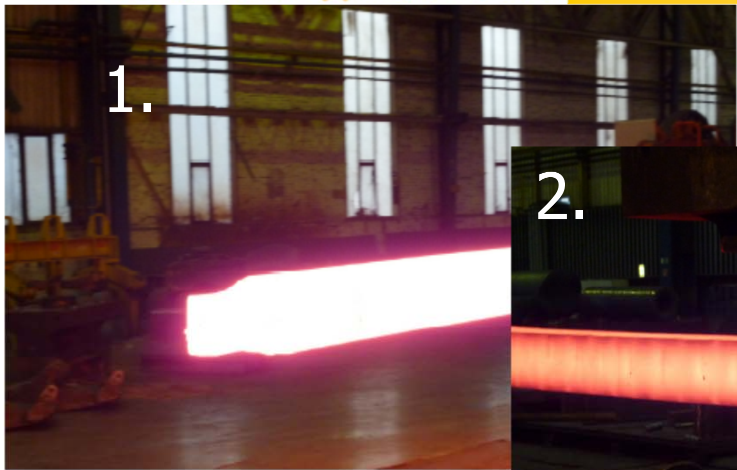


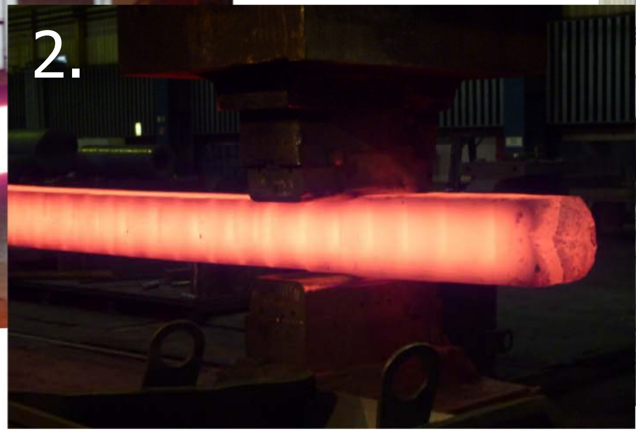
Extension to house HT, VPI, and 4k Test stations.

Gantry Crane Installation

Courtesy of US-IPO and GA

CS Structure- Trial Tie-Plate Forging





Courtesy of US-IPO

Right: after final machining May 2013

US CfT in 2014

CS Conductor Performance Issue

iter china eu india japan korea russia usa

Nb_3Sn is a brittle compound formed during manufacture by a 200hr heat treatment at 650C. ITER conductors require an ‘open’ structure to allow cooling. Allows strands to bend under loads

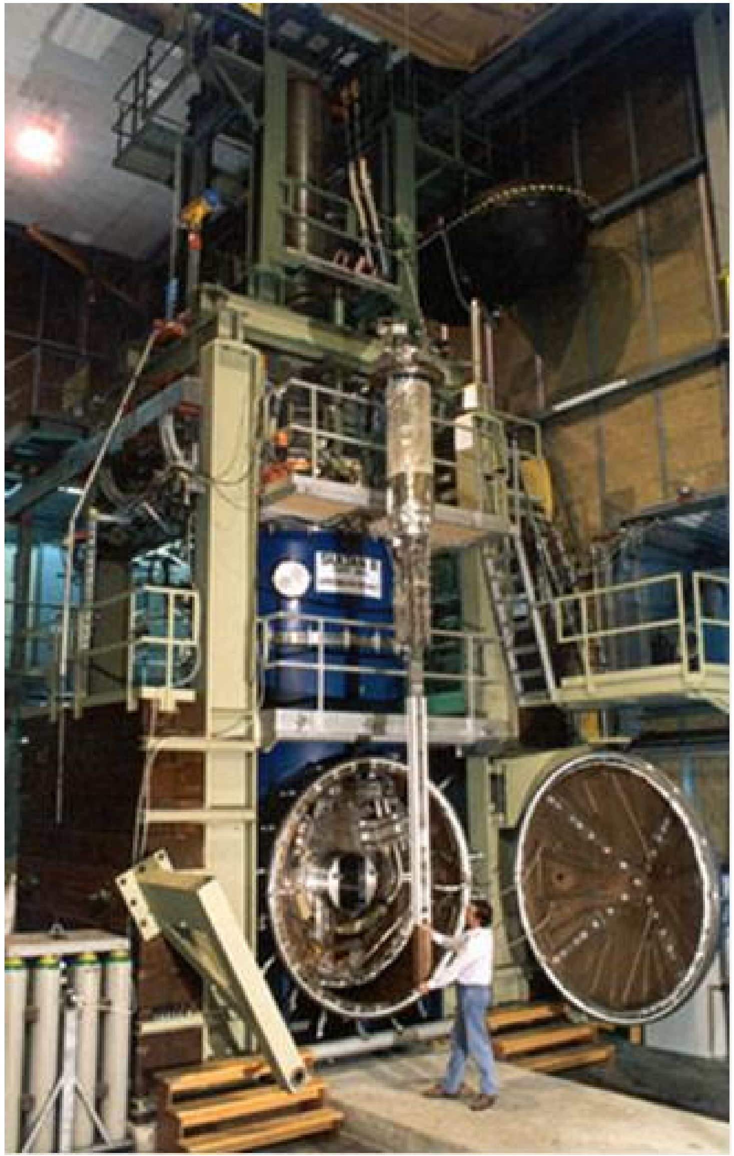
Performance problems were found in the CS conductor. Degradation of current sharing temperature with cycling to unacceptably low values in full size SULTAN conductor tests

Major challenge for project: *Solved by extensive collaboration programme of analysis, sample fabrication, and diagnostic investigations between IO, US and JA lasting ~2 years*

Solution: adjustment of cable pattern and void fraction to provide support: CSJA1->CSJA2->CSIO1->CSIO2/CSJA3

Bad............better...............good

SULTAN and sample

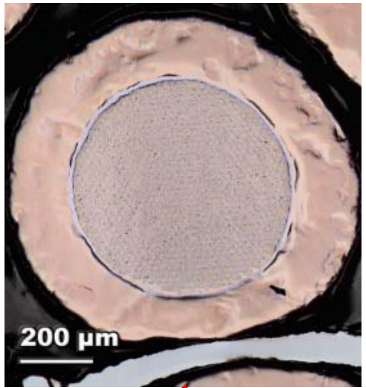


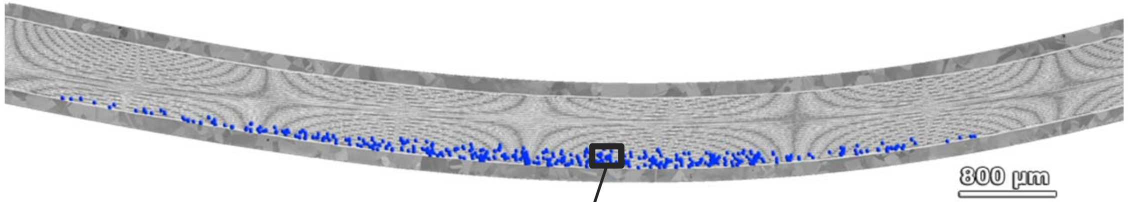
SULTAN facility at CRPP/PSI in Villigen CH provides high field (11.5T) high current (up to 100kA) testing of 3.5m lengths of paired conductors, 0.35m in high field

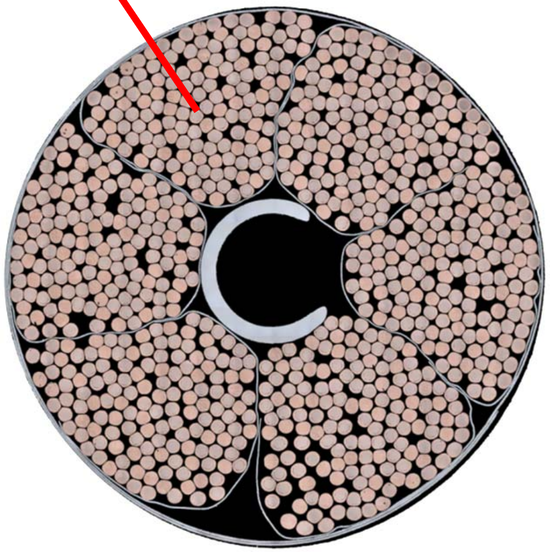
CS SULTAN Sample Summary

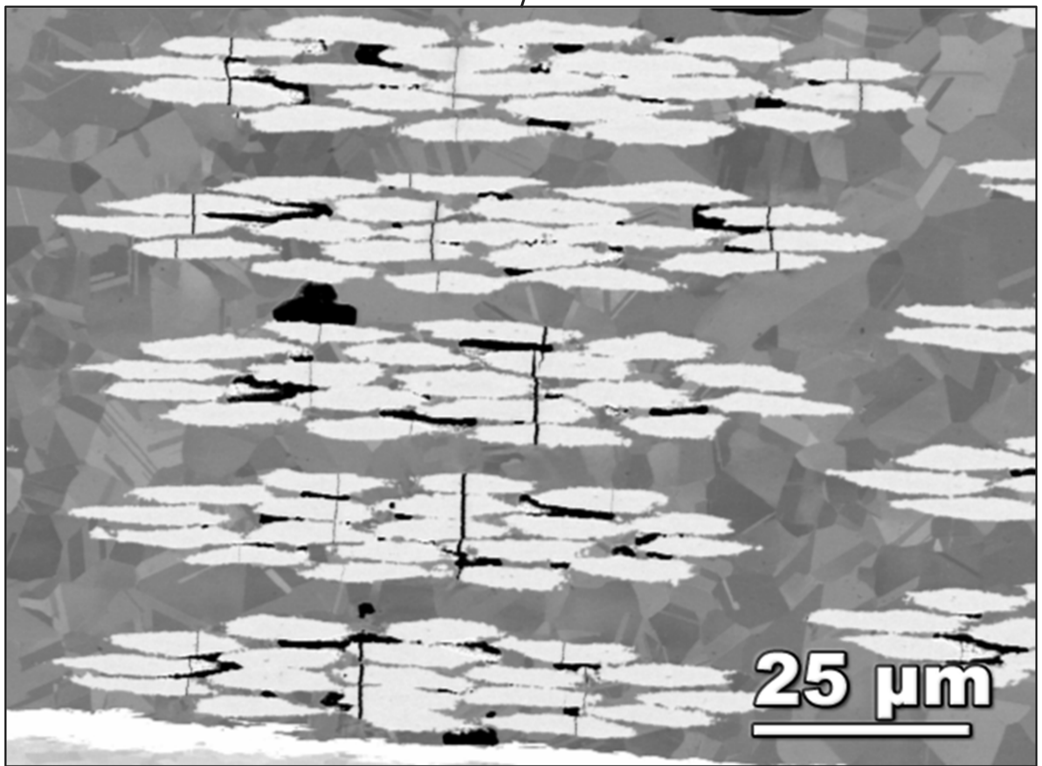
Sample Name	Strand	Inner Triplet	Twist Pitches	Performance Rating based on full requirements
CSJA1	Hit.BR 2G	2 SC + 1 Cu	Baseline	Failed
	Fur. BR 2G	2 SC + 1 Cu	Baseline	Failed
CSJA2	Jastec BR 3G	2 SC + 1 Cu	Baseline	Failed but could work with degraded performance
	Jastec BR 3G	2 SC + 1 Cu	Baseline	Failed
CSIO1	OST IT	2 SC + 1 Cu	Baseline	Promising, needs more tests to be sure
	OST IT	3 SC	Baseline	**Qualified within limits of test**
CSIO2	OST IT	2 SC + 1 Cu	Short	**Qualified within limits of test**
	OST IT	2 SC + 1 Cu	Pseudo-long	Promising, needs more tests to be sure
CSJA3	Jastec. BR 3G	2 SC + 1 Cu	Short	**Qualified within limits of test**
	Fur. BR 3G	2 SC + 1 Cu	Short	**Qualified within limits of test**
CSJA5	Hit BR 3G	2 SC + 1 Cu	Short	**Qualified within limits of test**
	Fur. BR 3G	2 SC + 1 Cu	Short	**Qualified within limits of test**

Strand Filament Breakage





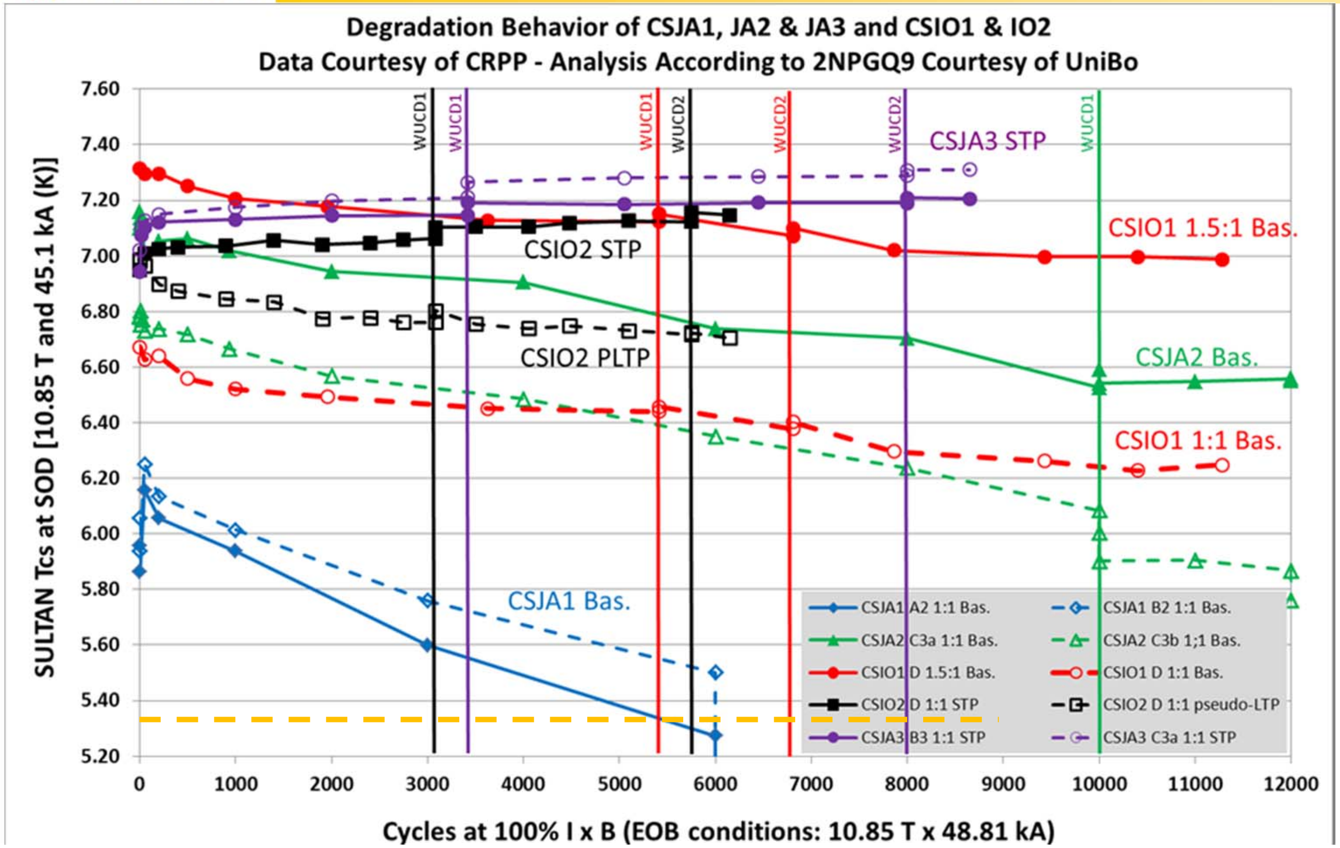


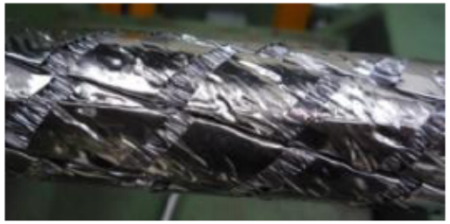


Courtesy of FSU

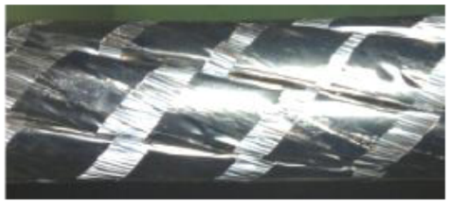
CS conductor Sultan Test Results

china eu india japan korea russia usa





Short Twist Pitches (CSIO2)



Standard Twist Pitches (CSIO1)

Long Twist Pitches (CSIO2)

(Courtesy of L. Muzzi, ICAS)

Magnets -5

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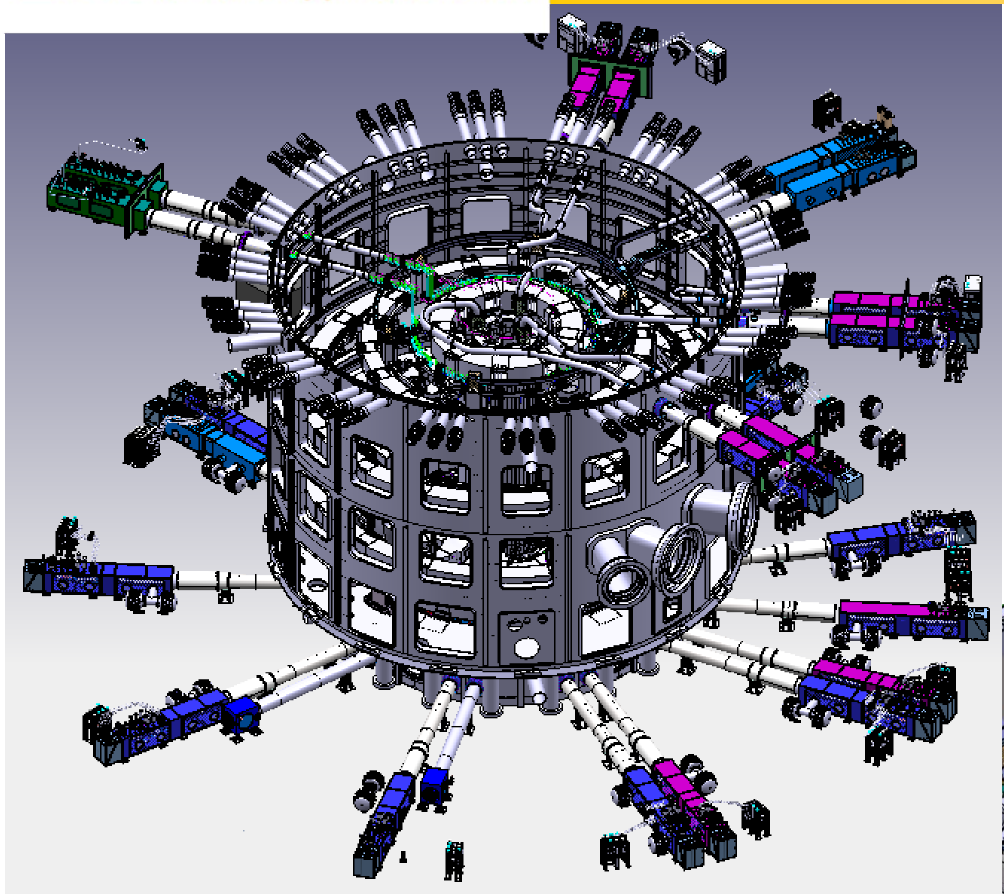
- Feeders

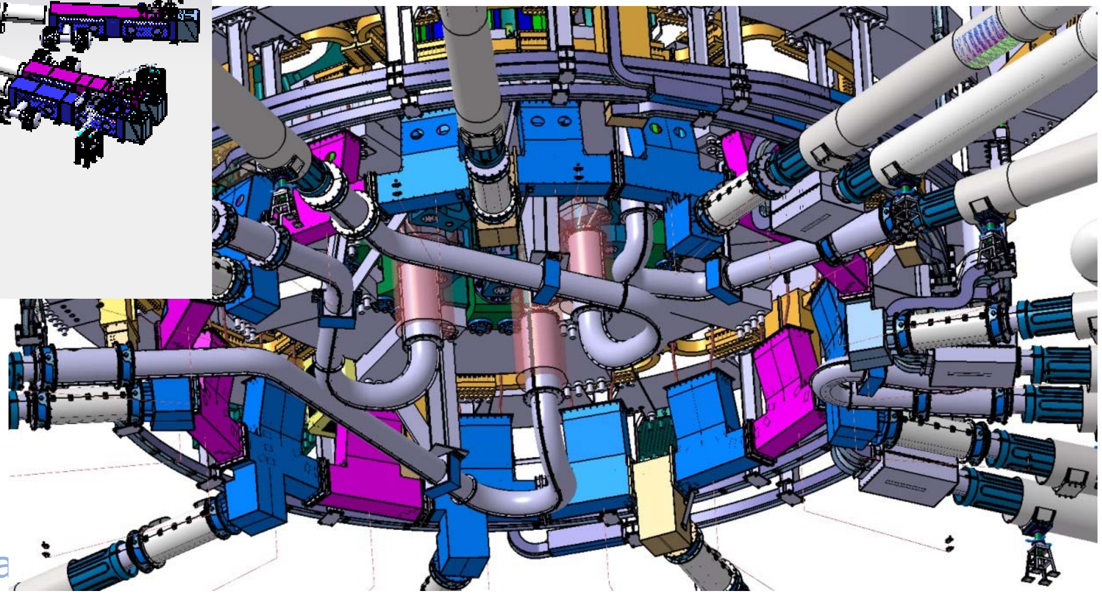
Feeders



Provide current, He and instrumentation supplies to coils and structures

S/C busbars that interface to RT busbars

Highly complex integration



Feeders Overview

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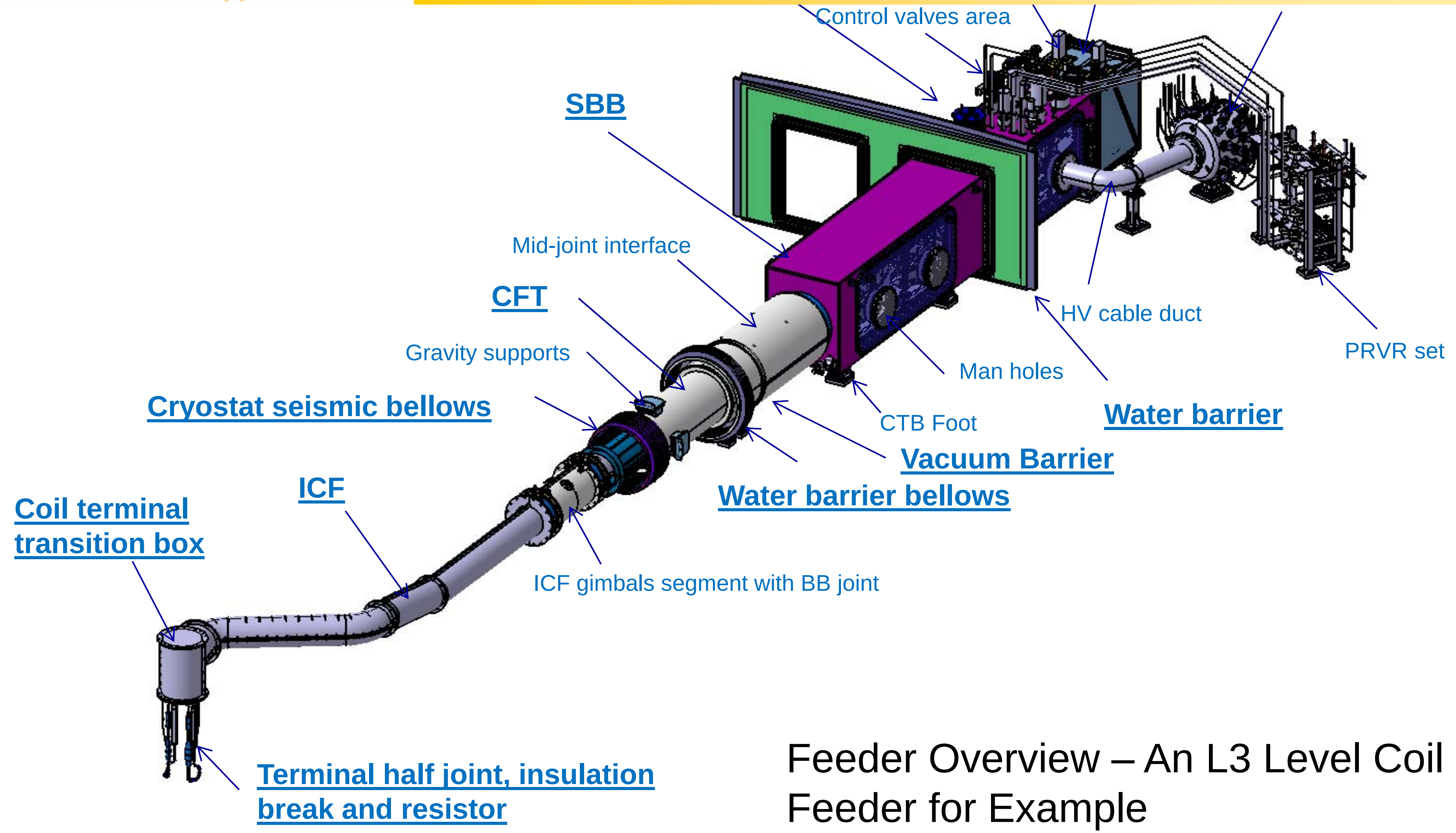
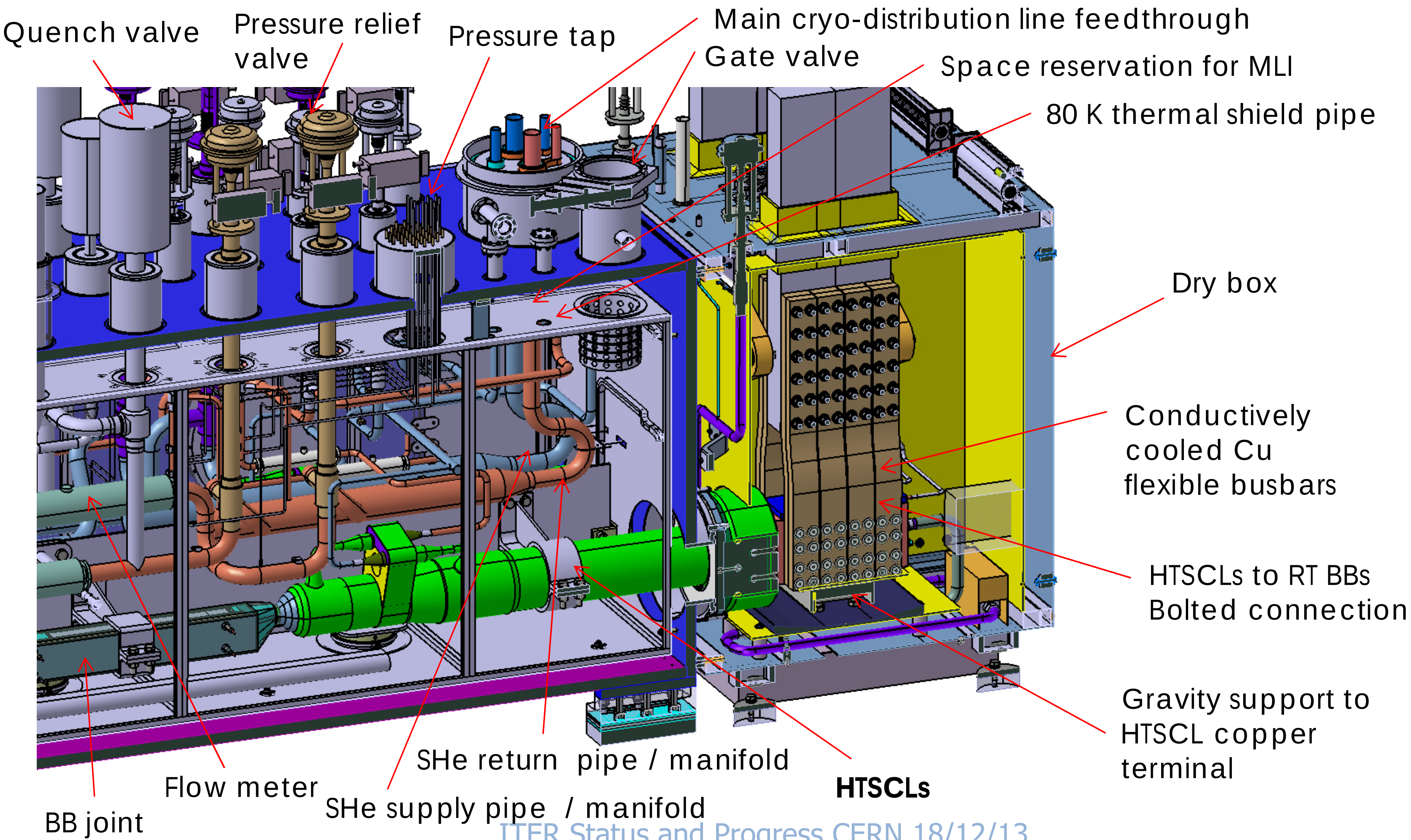


Feeder Overview – An L3 Level Coil Feeder for Example

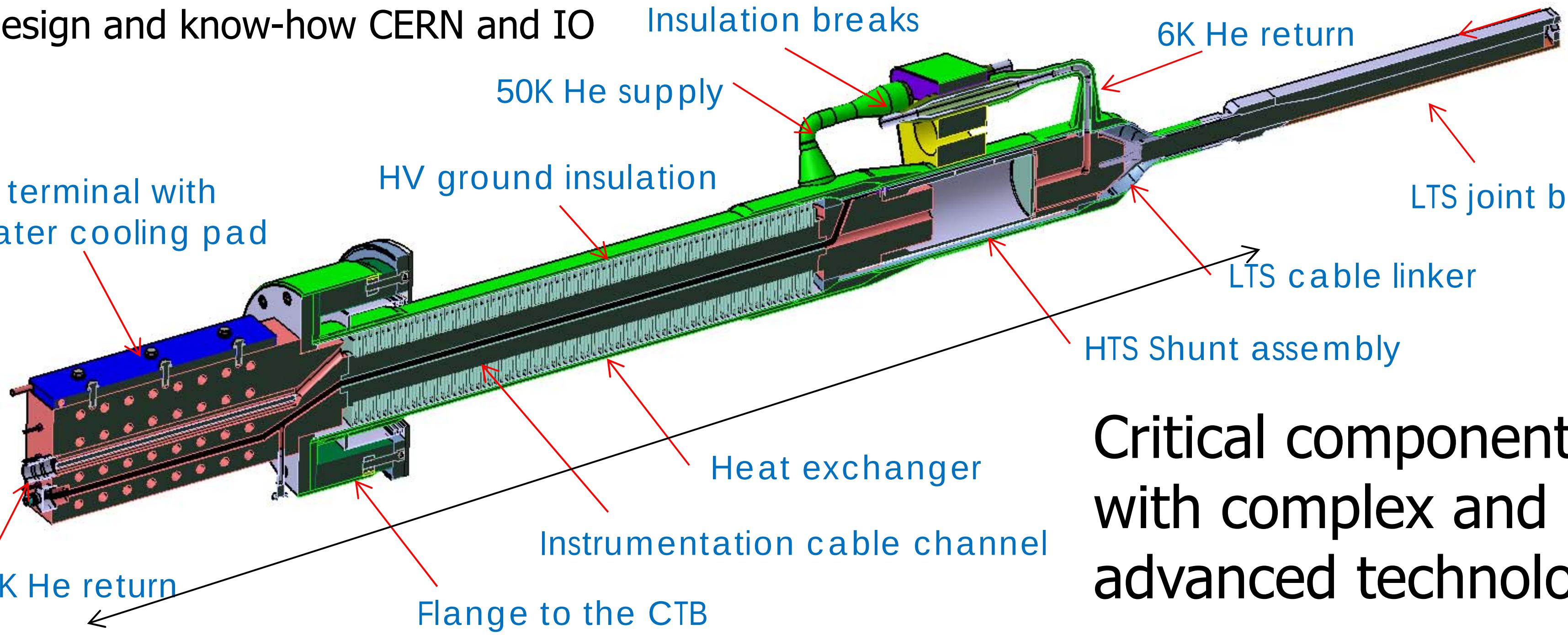
Feeder CTB Close-up

china eu india japan korea russia usa



Feeder HTS Leads - 1

Manufacture at ASIPP
Design and know-how CERN and IO



Critical component with complex and advanced technology

Brazing joint

Machining of the grooves

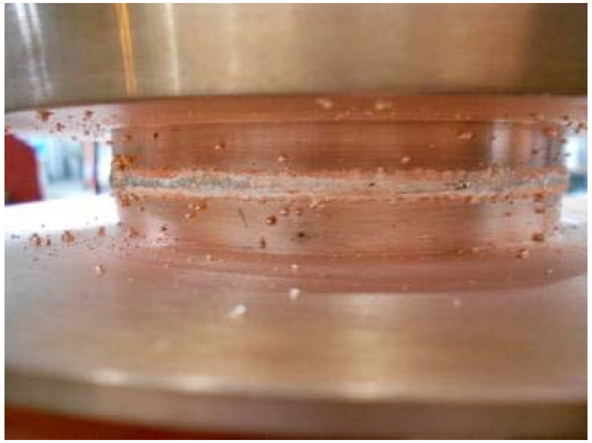
HTS Elements

Feeder HTS Leads - 2

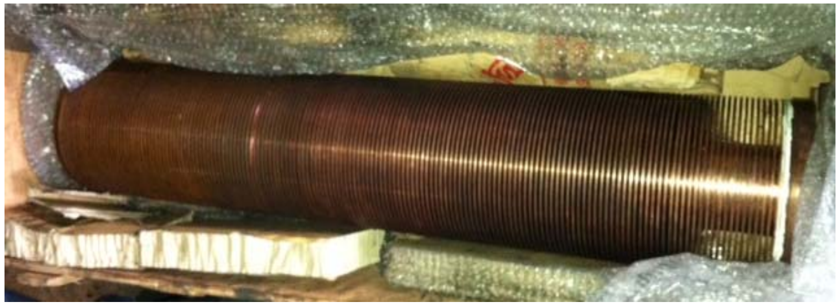
Early (2008) Pre-prototype HTS leads under test at ASIPP

Full prototype test scheduled 2014

Feeder HTS Leads -2



EB welding of heat exchanger to shunt



Machining of copper fin Heat Exchanger and steel container to tolerances within few micro m, fitting HE into tube

Manufacturing mock-up underway Dec 2013

Feeder Manufacturing Facilities Complete

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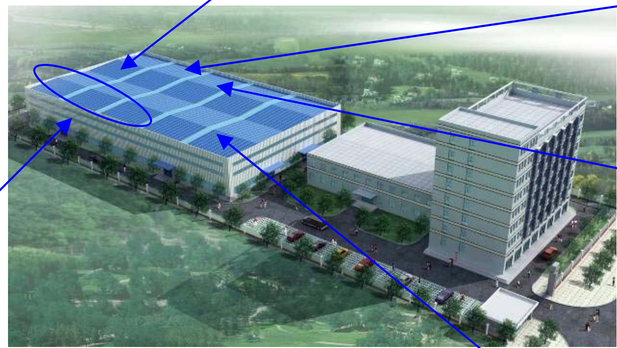
Off-site ASIPP workshop for:

- Feeder insulation
- HV test
- Pipe bending
- Integration assembly

In Hefei

Workshop for insulation

HV Test area



Tubing bending area

Assembly area

First 1000m² clean room of 8 class of ISO14644 for Feeder assembly

Feeder Prototypes and Mock-ups Complete

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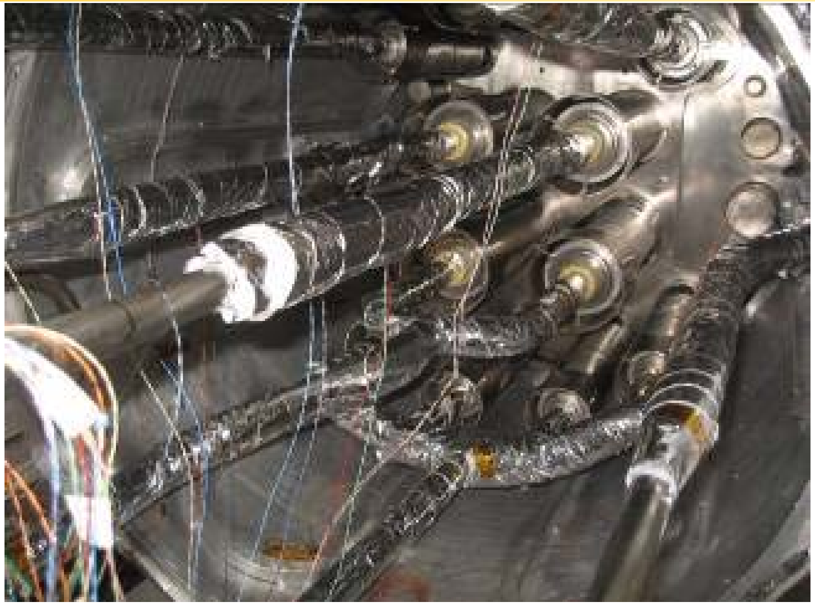
Vacuum barrier



Thermal shield

Feeder Tooling is under fabrication

Conductor bending for S bends

Large number of components
Many geometric variations
Difficult assembly

Jig for PF feeder assembly

Magnets -6

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- Instrumentation

Instrumentation

Procured directly by IO. Covers HV cables, sensors, wires, insulating breaks. IO runs laboratory in CERN for testing

Complex due to high voltage (28kV design), vacuum, 4K temperature, ultra high reliability and assembly considerations

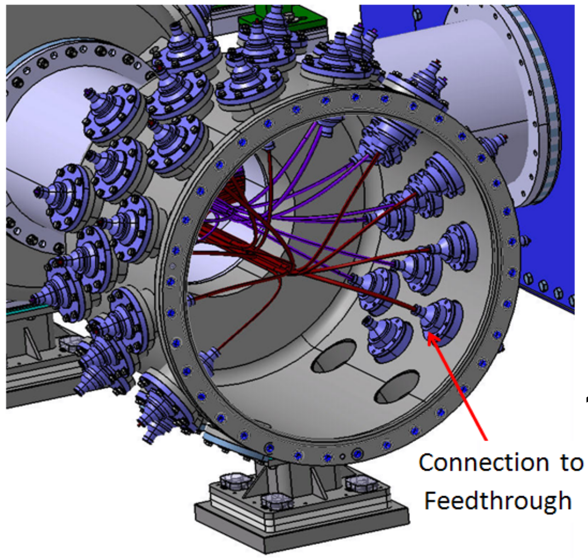
Required for

- Quench Detection (all at high voltage)
- Temperature Sensors
- Strain and Displacement Sensors
- Feedthroughs, Insulating Breaks
- Vacuum Plugs on Cables

Instrumentation: HV Feedthrough

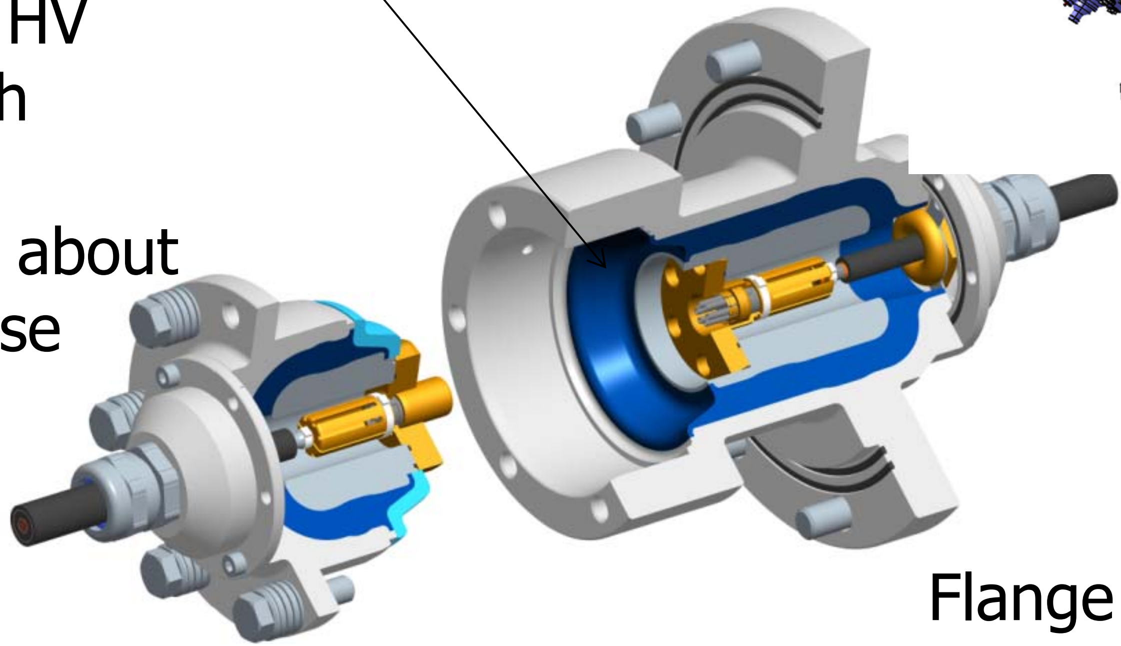
Glass fibre reinforced polyester, moulding compou

- Halogen free
- High mechanical strength
- Low coefficient of thermal expansion.

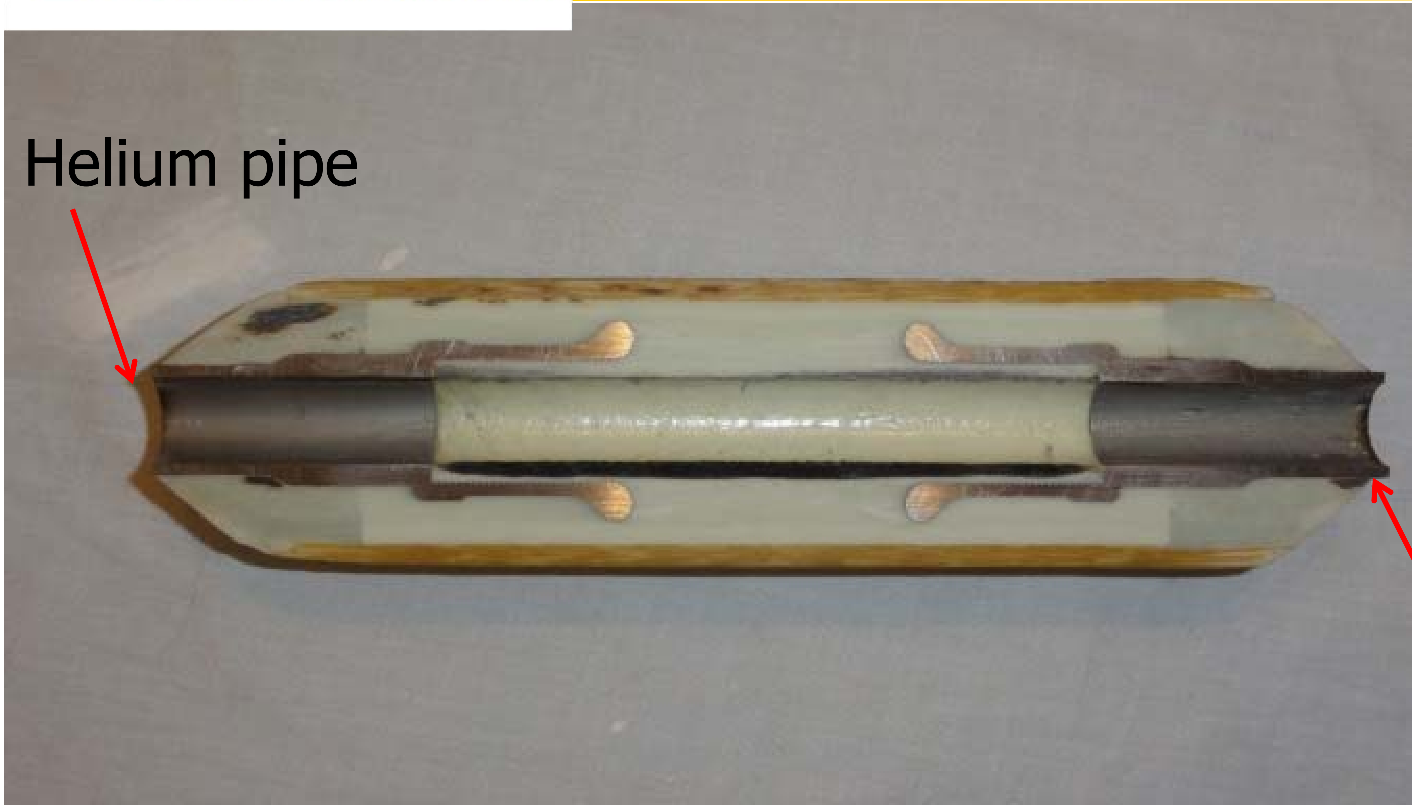


Example of HV Feedthrough

ITER needs about 1000 of these



Instrumentation: He line insulating break



Section through 30kV insulating break for He pipe

Helium pipe

ITER requires about 1500 of these. Replacement in event of leaks would require several months → very high reliability

Production starting at ASIPP (CN) under IO contract

Instrumentation: HV wires and cables

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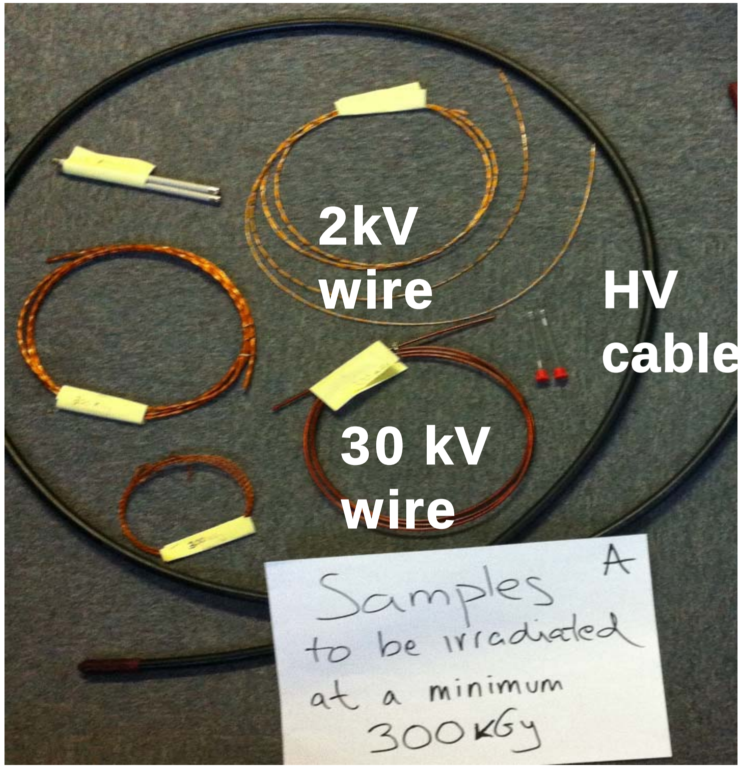
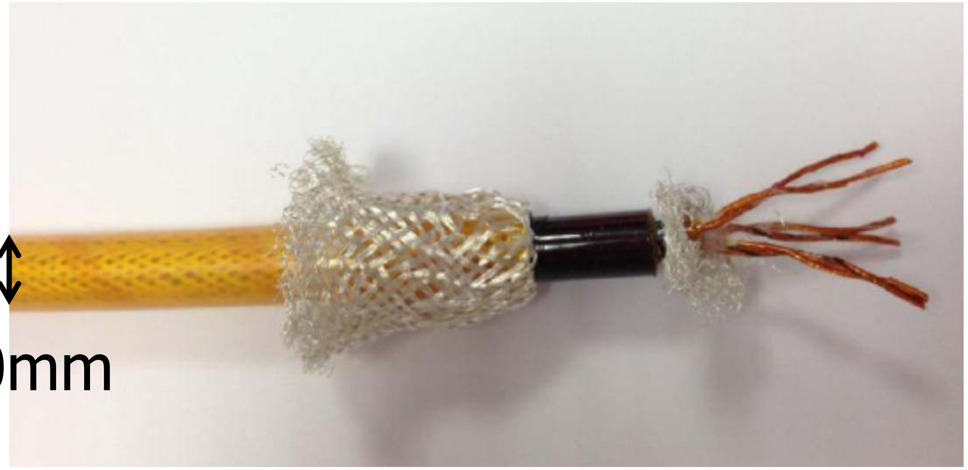


High voltage cables (samples for irradiation testing)



High voltage cable showing ground screen and 3 inner twisted pairs

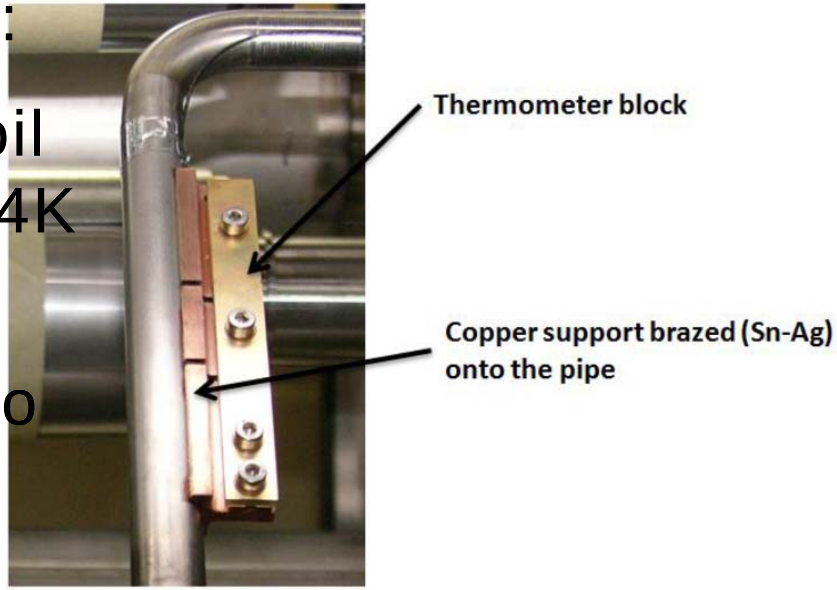
ITER needs about 14km of 6 & 9 core HV cables and 7km of optical fibres

Temperature sensors

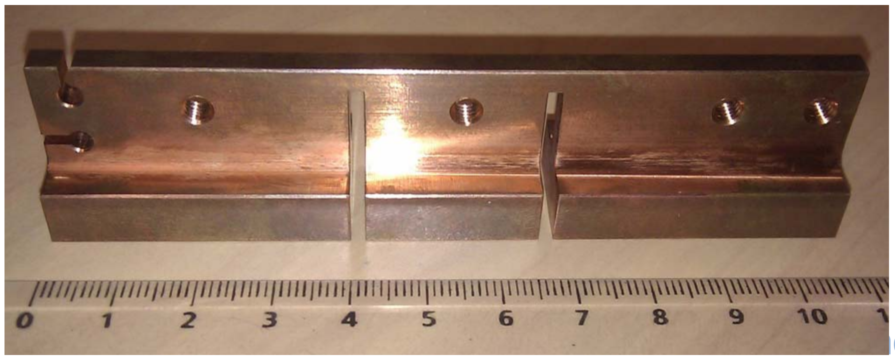
- Two types, about 1000 of each:

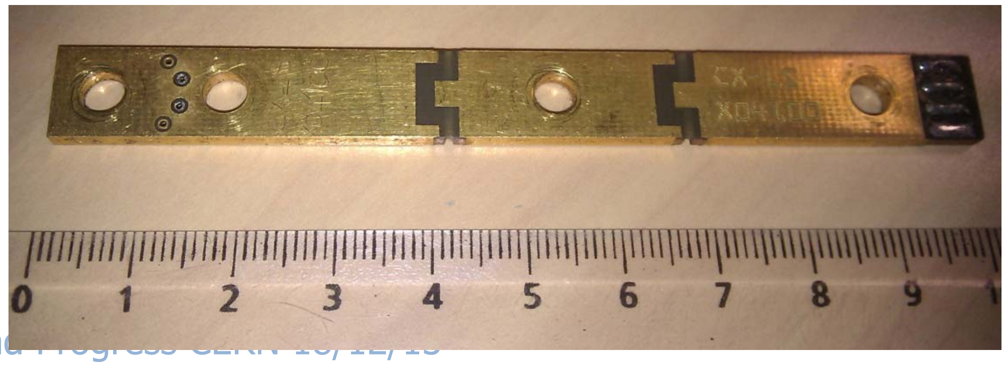
Cernox – range 4 K to 300 K, coil inlet, magnet structures, feeder 4K process pipes.

Platinum PT100 – range 50 K to 300 K, used on e.g. radiation shield.



No penetration of pipes (avoids welding/leak issues)
Simple installation (full chain of sensors, wires, feedthroughs and conditioners. Contract placed with CEA (Grenoble)





Schedule

ITER has difficulties to maintain the latest first plasma date of late 2020. Largest delays are in buildings but many other component delays hidden by shadow; recovery strategies under discussion to match buildings to high technology components

Complexity of project structure, vast number of interfaces created by procurement in-kind subdivision and bureaucratic nature of management organisation are responsible for most of them

ENCOURAGINGLY almost no delay due to technical issues even with the technologically highly advanced nature of the project

Technical Challenges

Most challenging high visibility issues so far

Vacuum vessel plate cracks

Surface cracks not reported to Authorised Nuclear Body, machined off. Work just restarting

Vacuum Vessel manufacturing design and NDT procedure agreement with ANB

Full redesign of Cryostat supports (required by French Regulator after Fukushima incident)

Layout of reinforcing bars for B2 slab

Inadequate structural analysis. Work (concrete pouring) stopped for 6 months, just restarted

CS conductor performance

Degradation due to filament cracking. Resolved after 18month technical programme, no schedule impact

Completion of building design

Embedded plates increase from 100 in 2001 to 50000 in 2012 to 100000 now, mostly required by regulator)

Conclusions and The Future

• ITER relies on an unprecedented collaboration of 7 Parties around the world; 24 years after its inception, ITER has entered the construction phase. *Technical challenges are being overcome: no 'showstoppers'.*

• Site is cleared, nuclear license obtained, buildings under construction

• TF conductors are well into production, 95% of the required Nb_3Sn strands already completed. PF strand production is over 50% complete

• TF, CS coil winding facility commissioning is nearing completion in Europe, US and Japan, qualification well underway. Facilities for feeder production in CN are complete and manufacturing trials are underway.

• Vacuum vessel manufacturing has started, prototyping of ports underway

• Cryostat manufacturing facility under construction on site

• Many major industrial contracts launched (power supplies, cryoplant)