

# ITER Magnet Systems – from Qualification to Full Scale Construction

**H. Nakajima<sup>1</sup>**, T. Hemmi<sup>1</sup>, M. Iguchi<sup>1</sup>, T. Nabara<sup>1</sup>, K. Matsui<sup>1</sup>, Y. Chida<sup>1</sup>, H. Kajitani<sup>1</sup>, K. Takano<sup>1</sup>, T. Isono<sup>1</sup>, N. Koizumi<sup>1</sup>, Y. Nunoya<sup>1</sup>, K. Hamada<sup>1</sup>, K. Okuno<sup>1</sup>, A. Foussat<sup>2</sup>, R. Gallix<sup>2</sup>, A. Devred<sup>2</sup>, P. Libeyre<sup>2</sup>, N. Mitchell<sup>2</sup>, A. Bonito Oliva<sup>3</sup>, B. Bellesia<sup>3</sup>, E. Boter<sup>3</sup>, M. Cornelis<sup>3</sup>, J. Cornella<sup>3</sup>, R. Harrison<sup>3</sup>, L. Poncet<sup>3</sup>, T. Boutboul<sup>3</sup>, H. Rajainmaki<sup>3</sup>, P. Valente<sup>3</sup>, C. Sborchia<sup>3</sup>, M. Losasso<sup>3</sup>, I Rodin<sup>4</sup>, V. S. Vysotsky<sup>5</sup>, K. Chan<sup>6</sup>, N. Martovetsky<sup>6</sup>, S. H. Park<sup>7</sup>, H. Li<sup>8</sup>, Y. Wu<sup>9</sup>, J. Wei<sup>9</sup>

<sup>1</sup> **Japan Atomic Energy Agency (JAEA), Japan Domestic Agency (JA), Naka, Japan**

<sup>2</sup> ITER Organization (IO), Route de Vinon sur Verdon, 13115 Saint Paul Lez Durance, France

<sup>3</sup> Fusion for Energy (F4E), European Domestic Agency (EU), Barcelona, Spain

<sup>4</sup> Efremov Scientific Research Institute, Russian Federation Domestic Agency (RF), St.-Petersburg, Russia

<sup>5</sup> Russian Scientific R&D Cable Institute (VNIKP), Moscow, Russia

<sup>6</sup> US ITER Project Office (USIPO), United States Domestic Agency (US), Oak Ridge, USA

<sup>7</sup> National Fusion Research Institute, Korean Domestic Agency (KO), Daejeon, Korea

<sup>8</sup> China Domestic Agency (CN), Beijing, China

<sup>9</sup> Institute for Plasma Physics, Chinese Academy Science (ASIPP), Hefei, China

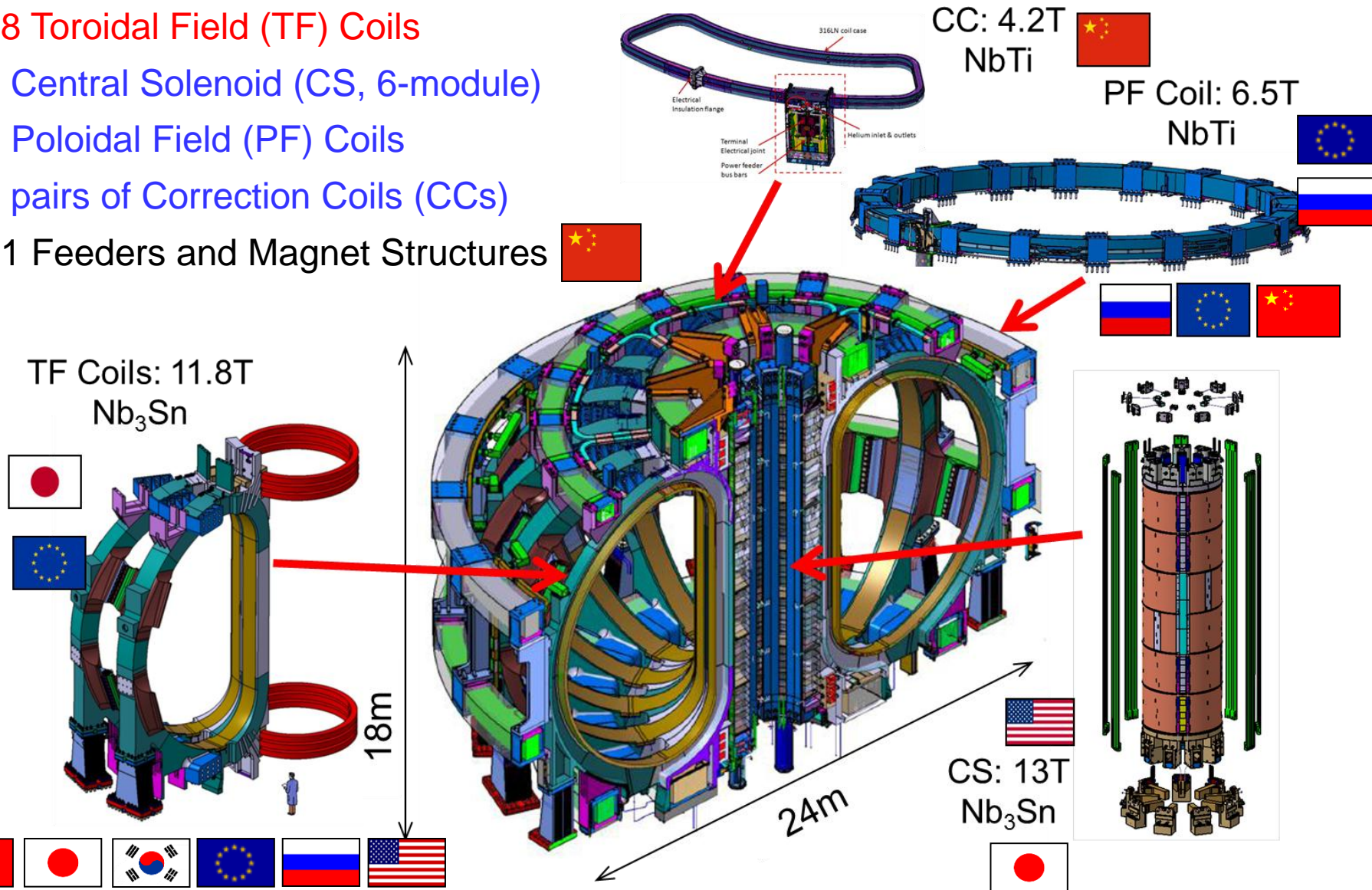
**24<sup>th</sup> IAEA FUSION ENERGY CONFERENCE**

**8-13 October 2012**

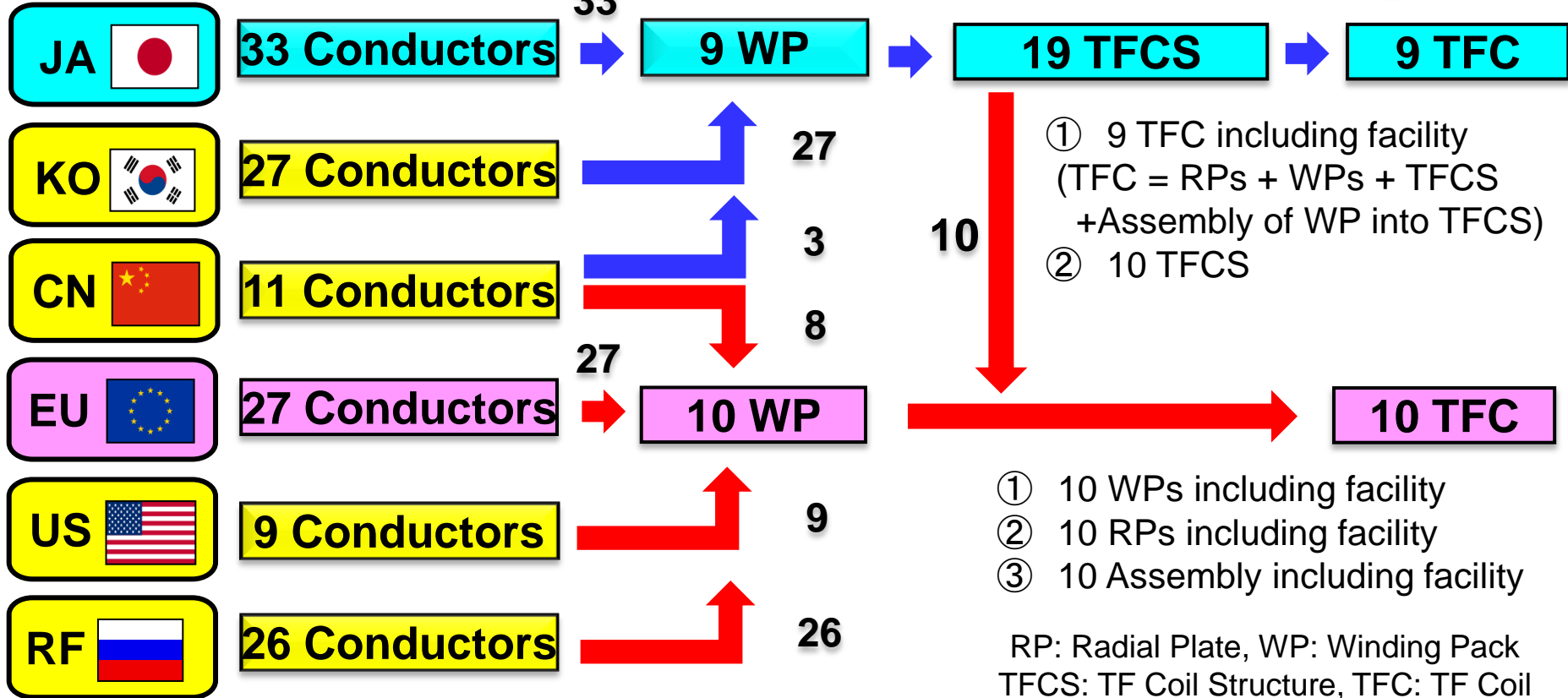
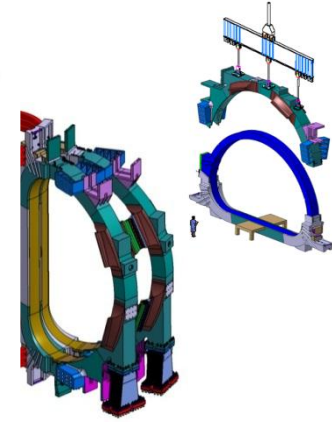
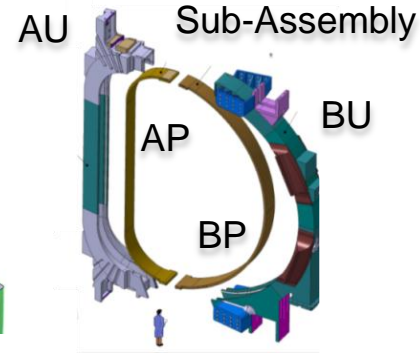
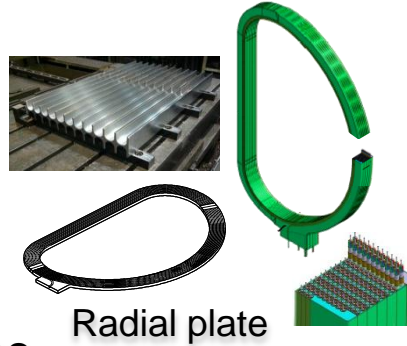
**San Diego, USA**

# ITER magnet system

- 18 Toroidal Field (TF) Coils
- 1 Central Solenoid (CS, 6-module)
- 6 Poloidal Field (PF) Coils
- 9 pairs of Correction Coils (CCs)
- 31 Feeders and Magnet Structures

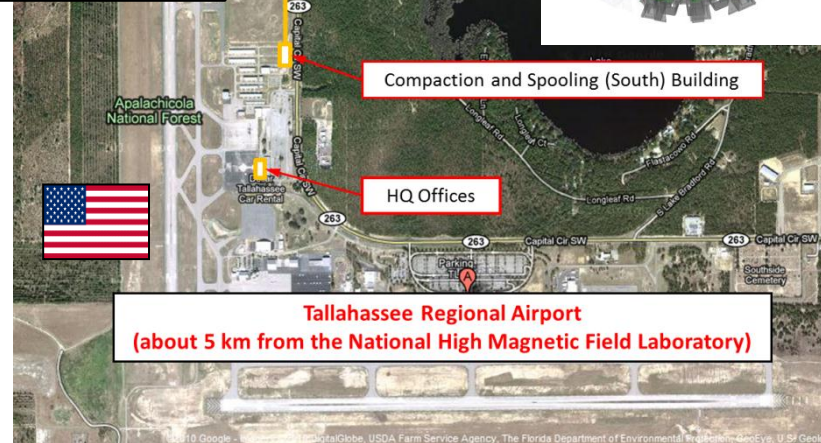
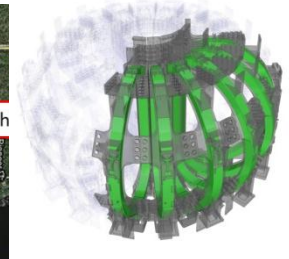
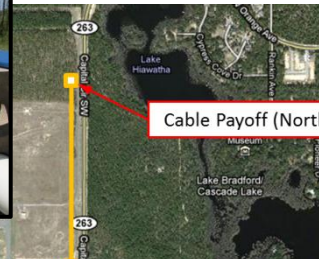
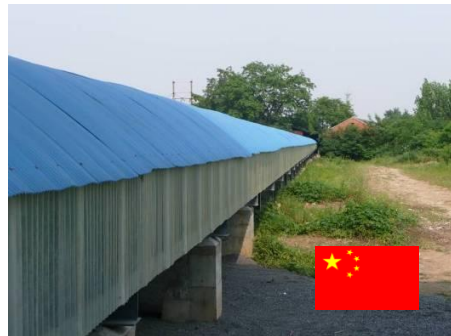


# Procurement sharing in TF coil



# Manufacturing status of TF conductors

Supplying DA	CN	EU	JA	KO	RF	US	Total
Amount of TF strands (tons)	28.0	95.3	108.0	93.0	97.0	44.7	437.5
Completion as of 2012.9	0.6	71.8	100.5	69.4	64.8	40.5	347.6
Number of TF Cables	11	27	33	27	26	9	133
Completion as of 2012.9	0	2	27	13	7	0	49
Number of TF Conductors	11	27	33	27	26	9	133
Completion as of 2012.9	0	2	26	9	6	0	43



(Courtesy of IO, CNDA, F4E, RFDA, USDA)

# Transportation of 760-m Dummy Conductor



CNDA ⇒ JADA in March, 2012

(Courtesy of CNDA)

EUDA ⇒ EUDA in July, 2012



(Courtesy of F4E)



KODA ⇒ JADA in July, 2012

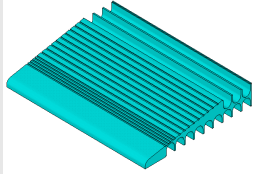
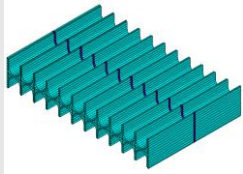
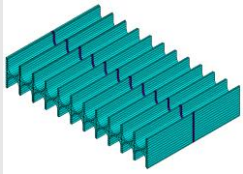


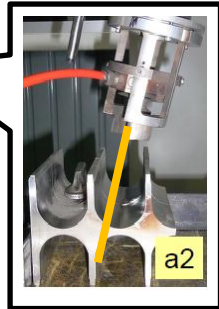
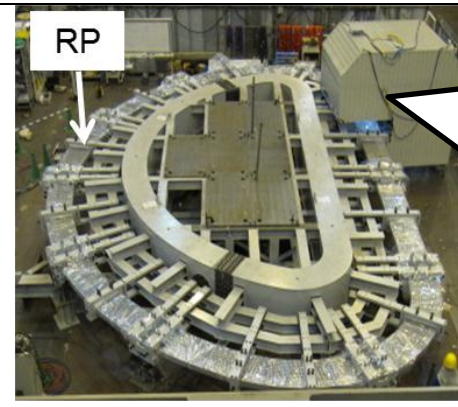
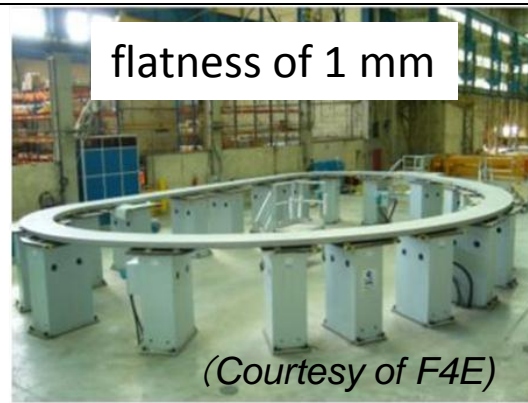


# Qualification of radial plate in EU and JA

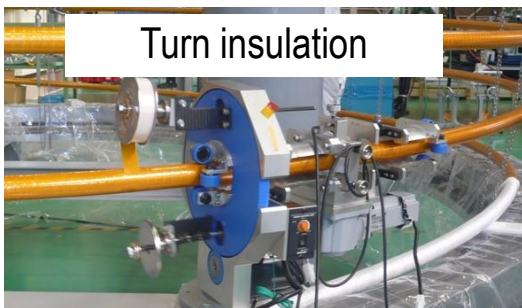
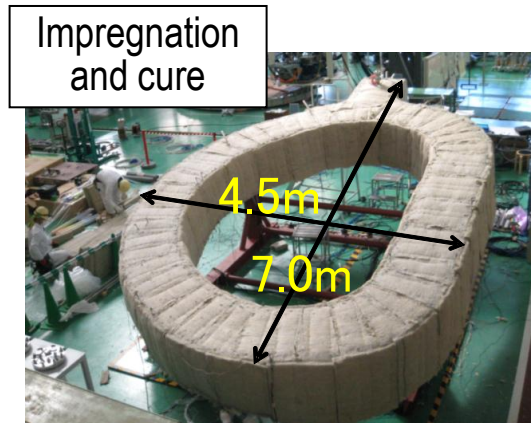
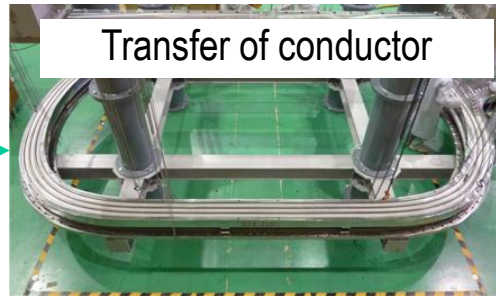


ITR/2-4

	F4E		JAEA
Type of radial plates	Side 	Regular 	Regular 
Material	Forged plates	HIP Plates	Hot rolled plate
No. of sections	7	16	10
Welding	Electron beam	Narrow gap TIG	Laser (Cross shaped section)
Final Machining	Local machining of welded region	Full region	No (Local grinding of welded region)



# Pre-qualification of TFC WP with 1/3 DP prototype (JA)



- Trial winding, heat treatment, and impregnation of 1/3 Double pancake (DP) have been carried out.
- Feasibility of automatic winding technique with high accuracy, deformation control after heat treatment, and impregnation using CE resin have been demonstrated.

# Qualification of tooling for TFC WP in EU



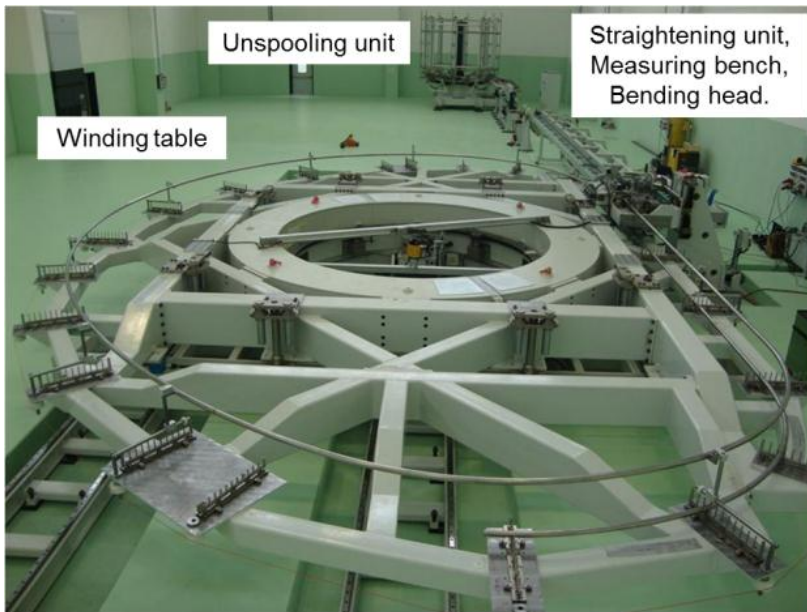
New building for WPs



Vacuum Chamber



Heat treatments furnace



TF coil DP winding line

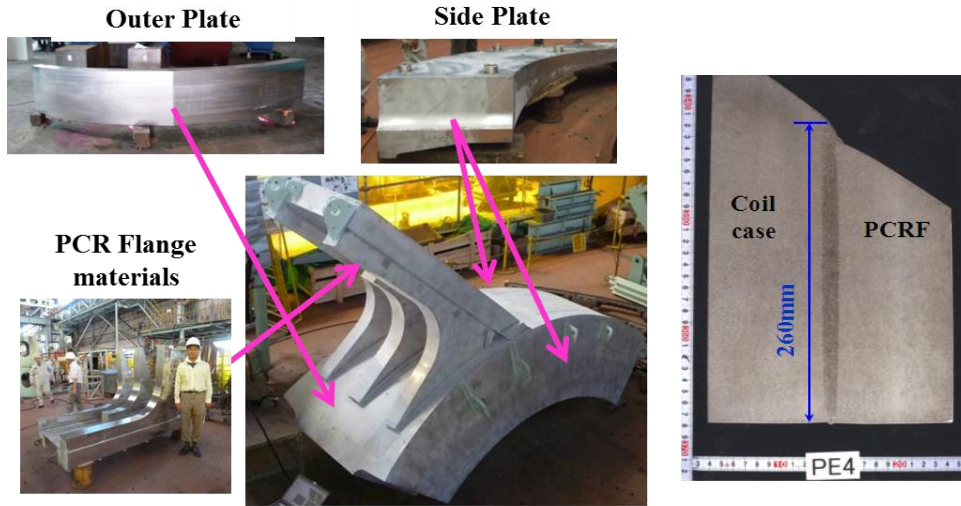
- The commissioning tests of the winding line have been successfully completed in July 2012.
- The full size manufacture of one turn winding with EU 100-m Nb<sub>3</sub>Sn conductors have been started.
- The qualification with full size DP winding will be completed by the beginning of 2013.

*(Courtesy of F4E)*

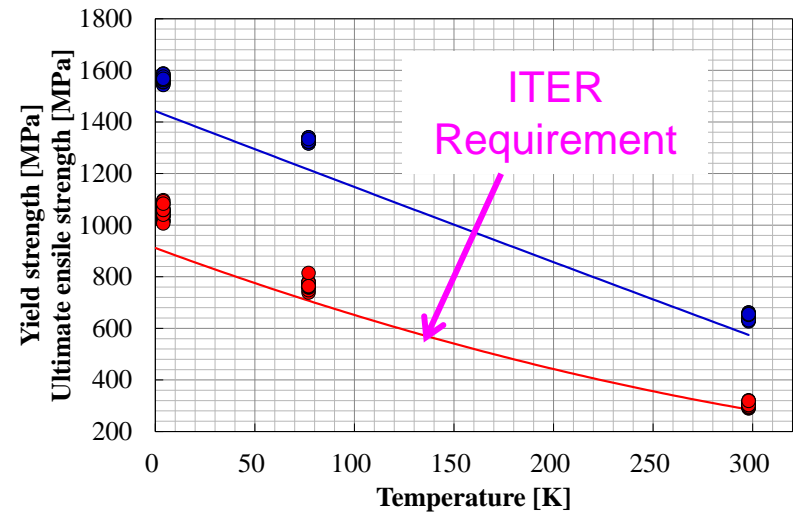
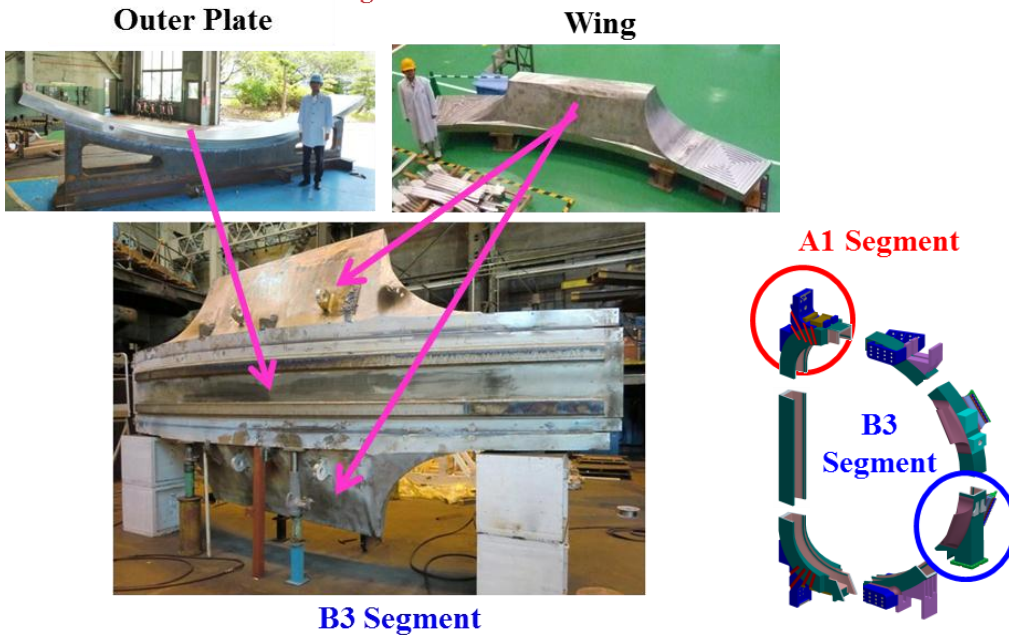




# Optimization and industrialization of TFCS manufacture



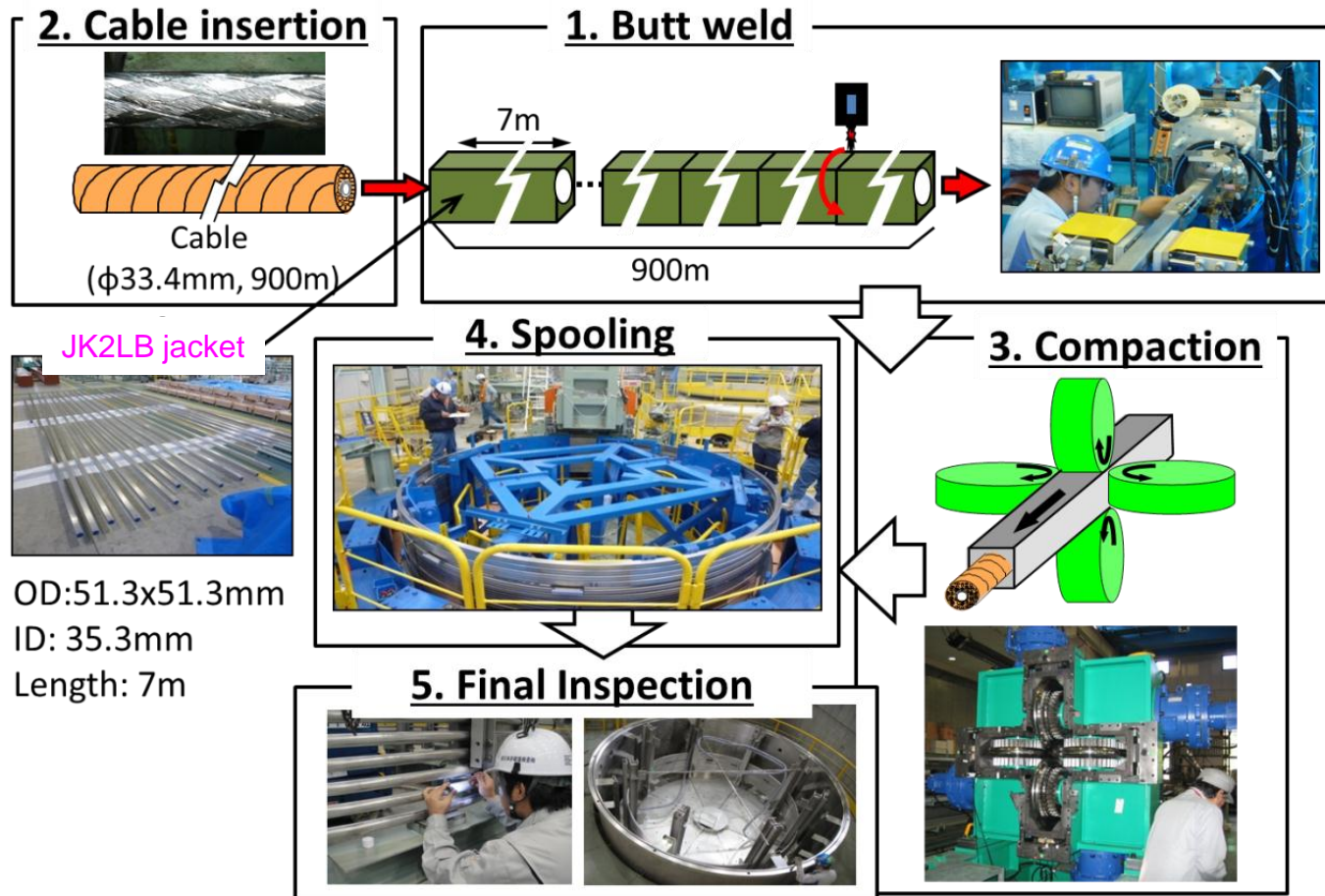
- Trial manufactures of two different types of structures have been completed in Phase II.
- Technical data and manufacturing knowledge to finalize the manufacturing plan has been established.
- Material qualification has been completed to use QC at room temperature.



# Status of manufacture of CS conductor and winding



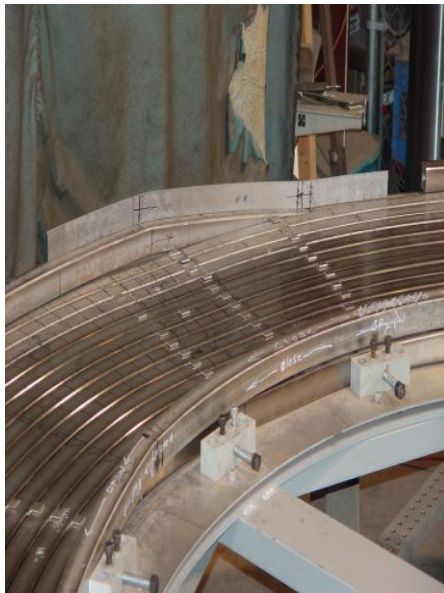
- JA manufactured a 200-m dummy CS conductor to confirm a design and performance of jacketing line for the CS conductors. JA has been manufacturing several types of conductors for manufacturing trials to be performed in US.
- JA has awarded a contract on CS conductors for the first module in August 2012.



# Status of qualification of CS manufacture

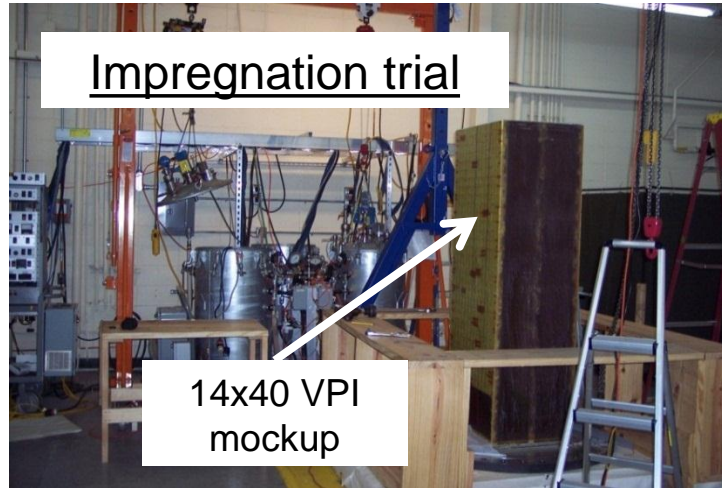


- Bending trials to demonstrate manufacturability of radial and axial transitions have been completed.
- The VPI process has been established and valuable inputs to actual fabrication have been obtained.
- Two types joints, interpancake and bus joints, which satisfy ITER requirement have been developed.



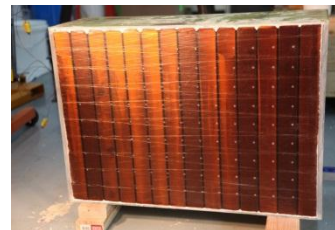
Axial transitions  
(vertical joggles)

*(Courtesy of USDA)*

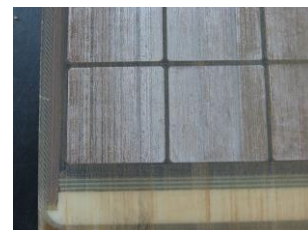


Impregnation trial

14x40 VPI  
mockup



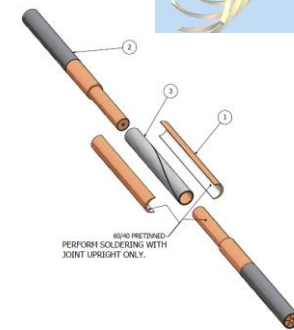
Cross-section after dissection



## Interpancake joints



6-finger



Sintered joint 6x6

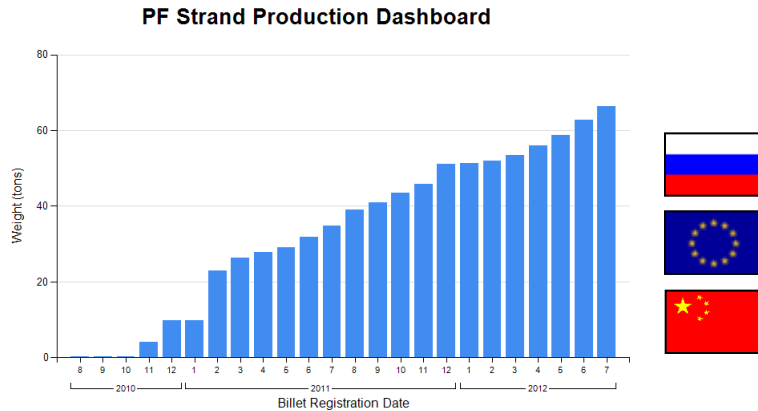


Butt joint

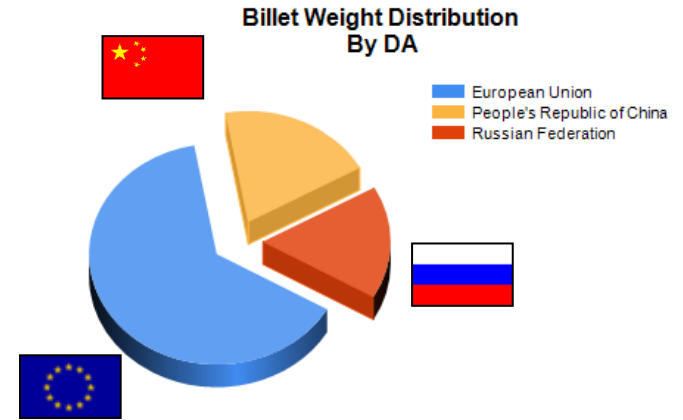
# ITER PF Conductor Status

- RF/F4E and CN have completed ~65 t of strands 1 & 2 (25% of supply).

NbTi Strand Registration



NbTi Strand Distribution



- CN has completed PF tube and PF welding qualification and has manufactured 800 m PF5 Cu dummy.



PF5 Cu Dummy Cable at Changton

(Courtesy of A. Devred, IO)



Compaction & Spooling of PF5 Cu Dummy at ASIPP



## Status of manufacture of PF1 coil

- The winding/insulation facility of the PF1 double pancakes is practically assembled and put into operation.
- Pre-qualification of the winding/insulation facility is completed and ready for the qualification with PF1 dummy conductor lengths, which will be delivered from EU.
- The VPI equipment of the PF1 double pancakes has already been manufactured.

*(Courtesy of RFDA)*



*Winding equipment*



*Conductor turn insulation trial*

## Building for PF2 - PF6 coil winding

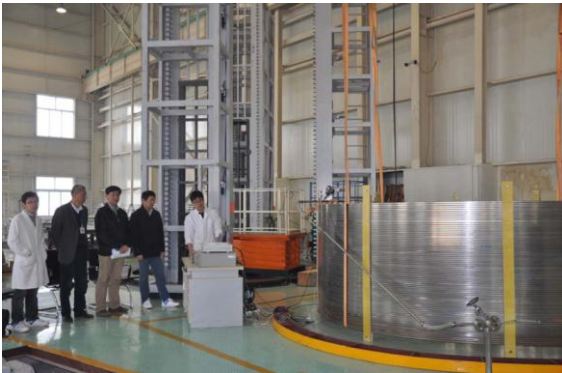
A building for the manufacture of the EU PF coils (PF2 – PF6) has been constructed at the ITER site in February 2012.



# ITER CC Conductor Status



- CN has completed **~920 m CC Cu dummy**, which was delivered to CC coil manufacturing facility in **May 2012**.



Pressure Drop Test  
At ASIPP



Truck Leaving ASIPP



Storage at CC coil  
Manufacturing Facility

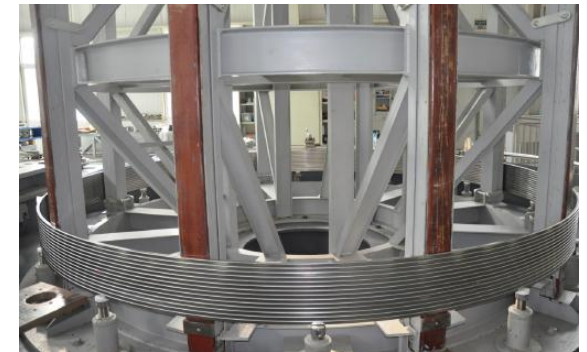
- CN has also completed **~200 m CC Phase II sc UL**.

- Phase II SULTAN sample (**CCCN3**) to be tested in **October 2012**.

(Courtesy of A. Devred, IO)



CC sc Cable  
at ASIPP



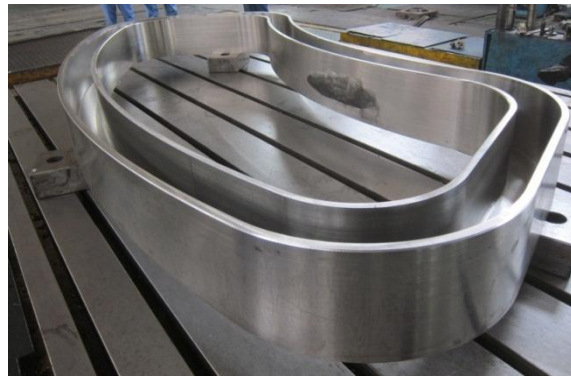
Spooled CC Phase II  
Conductor at ASIPP



- Procurement of the manufacturing equipment is near completion and qualification of manufacturing processes has already started.
- The winding equipment has been installed and is now under commissioning with a 920-m CC dummy conductor.
- Prototype segments of the coil case have been produced and assembled by using qualified TIG welding process.
- Procurement of two 4 kW fiber laser machines for the final closure welding has been performed and qualification trials are underway.



CC winding table with Side Correction Coils mold



Prototype segment of coil case for the bottom Correction Coils



Welding robot with a 4kW fiber laser welding equipment

*(Courtesy of CNDA and IO)*



# Conclusions

- The qualifications and constructions of ITER superconducting magnets including components are going well in collaboration between the ITER organization and 6 Domestic Agencies (DA).
- Conductors:
  - ✓ For the TF conductors, the qualification phase is over and full scale construction of 30% conductors has been completed in 6 DAs. For PF and CC conductors, the qualification phase is almost over and full scale construction will start soon. For CS conductors, the qualification phase is under way.
- TF Coil:
  - ✓ The manufacture of the TF coil and structure is also ready for full scale construction in both EU and JA. Final qualification using actual size prototypes are under way at the EU and JA manufacturers, and full scale constructions will start in 2013.
- Correction Coil:
  - ✓ The procurement of the manufacturing equipment is near completion and the qualification of the manufacturing processes is going well..
- The qualification processes for other magnets and components are also progressing towards the main goal of first plasma in 2020.

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