ITER MAGNETS

Presented by

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On behalf of

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Outline

ITER Magnets System

Magnets R&D for ITER

Conclusions

ITER Main Features

Central Solenoid

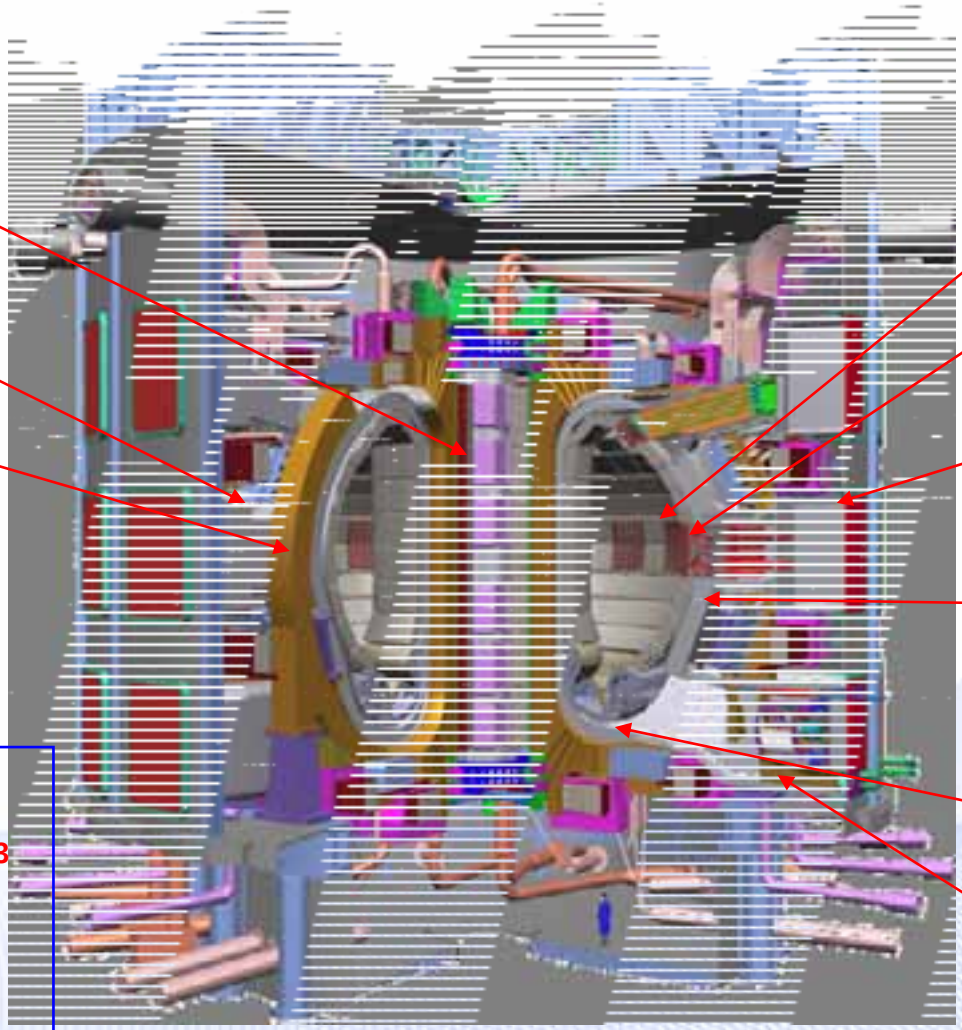
Nb_3Sn, 6 modules

Poloidal Field Coil

Nb-Ti, 6

Toroidal Field Coil

Nb_3Sn, 18, wedged



Blanket Module

440 modules

Vacuum Vessel

9 sectors

Cryostat

24 m high x 28 m dia.

Port Plug (IC Heating), 6 heating
3 test blankets
2 limiters/RH
rem. diagnostics

Divertor 54 cassettes

Torus Cryopump

8 units

Fusion Power: 500 MW

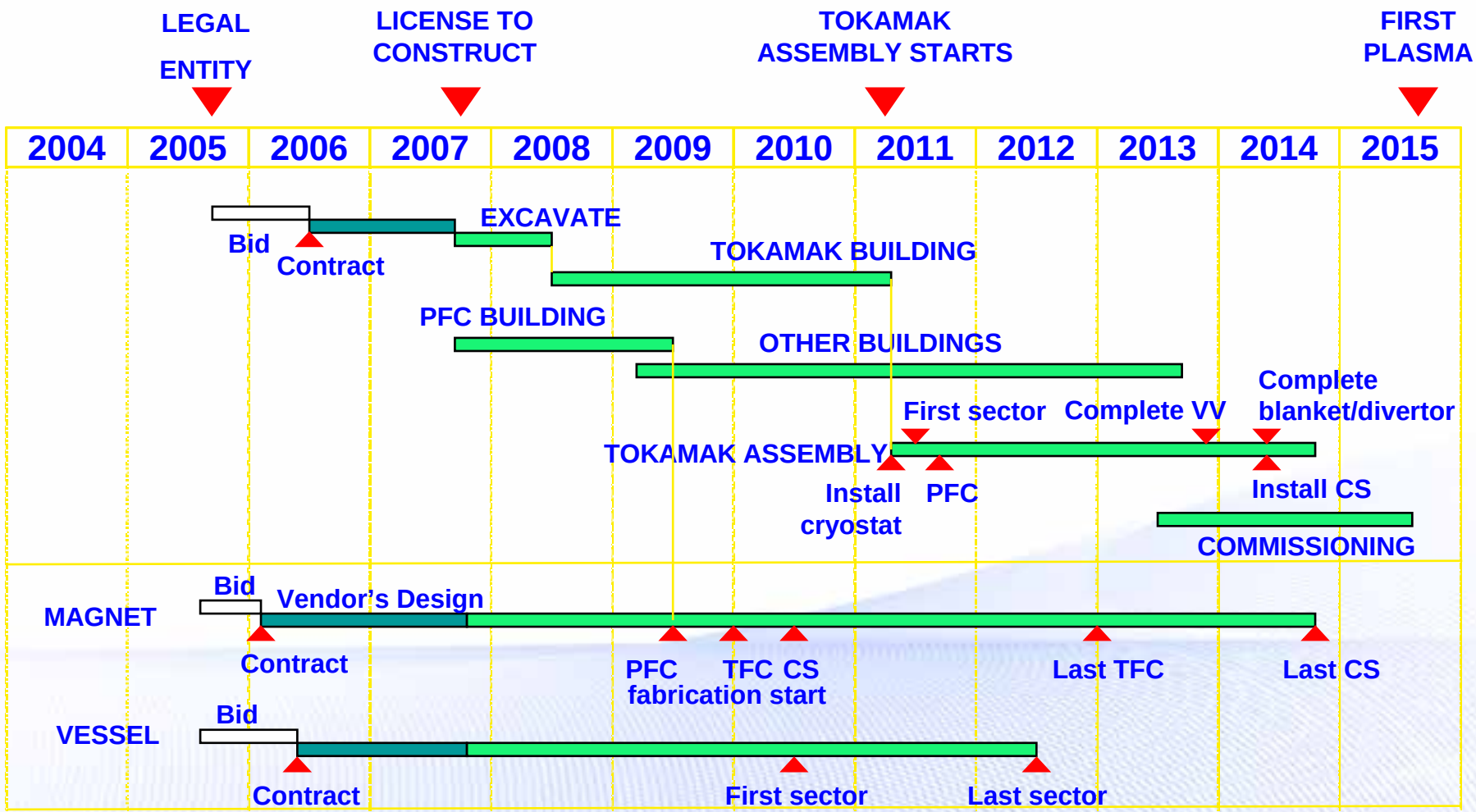
Plasma Volume: 840 m^3

Plasma Current: 15 MA

Temperature: ~20 keV

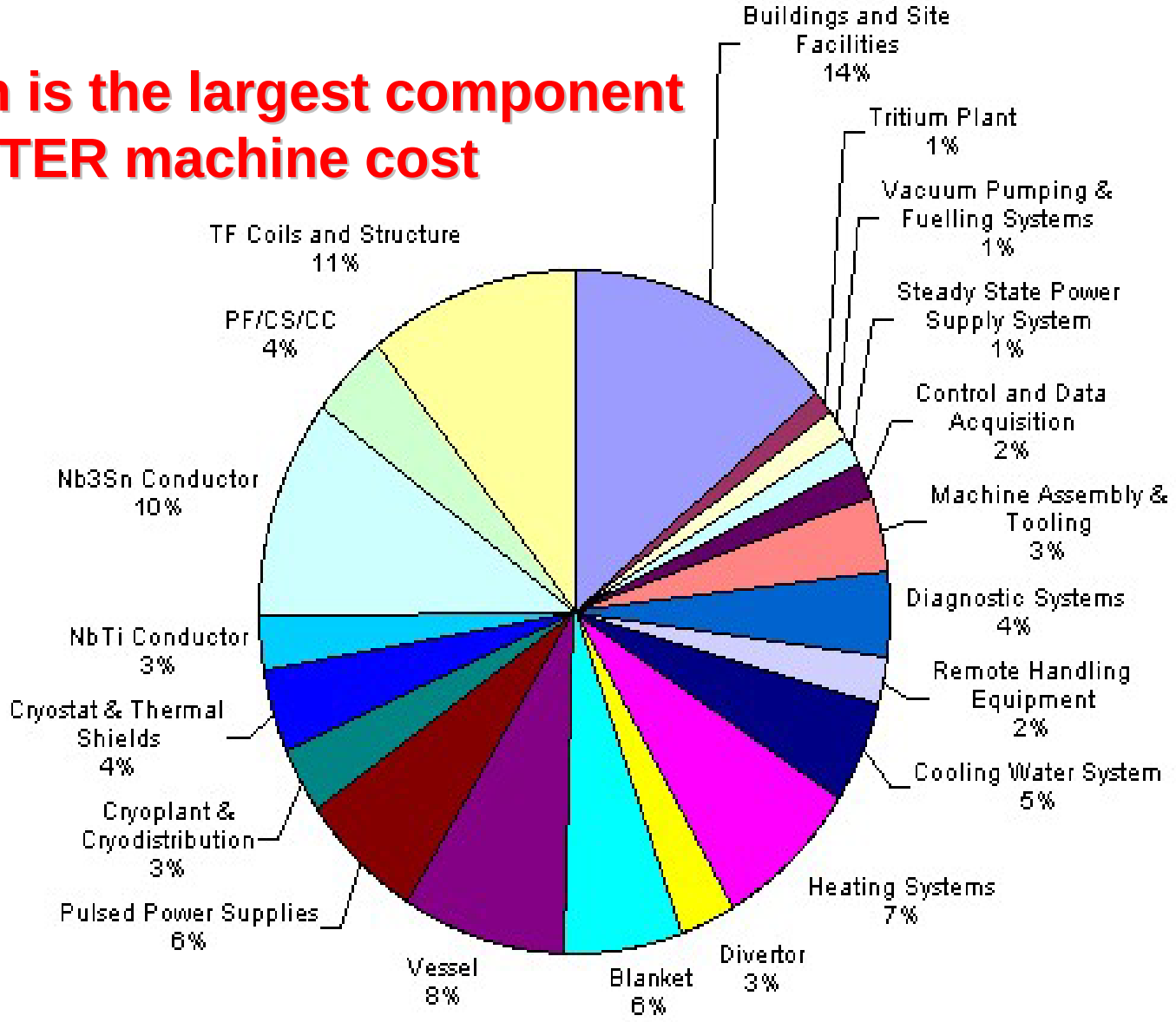
Density: ~10^{20} m^{-3}

Construction Schedule



ITER cost breakdown

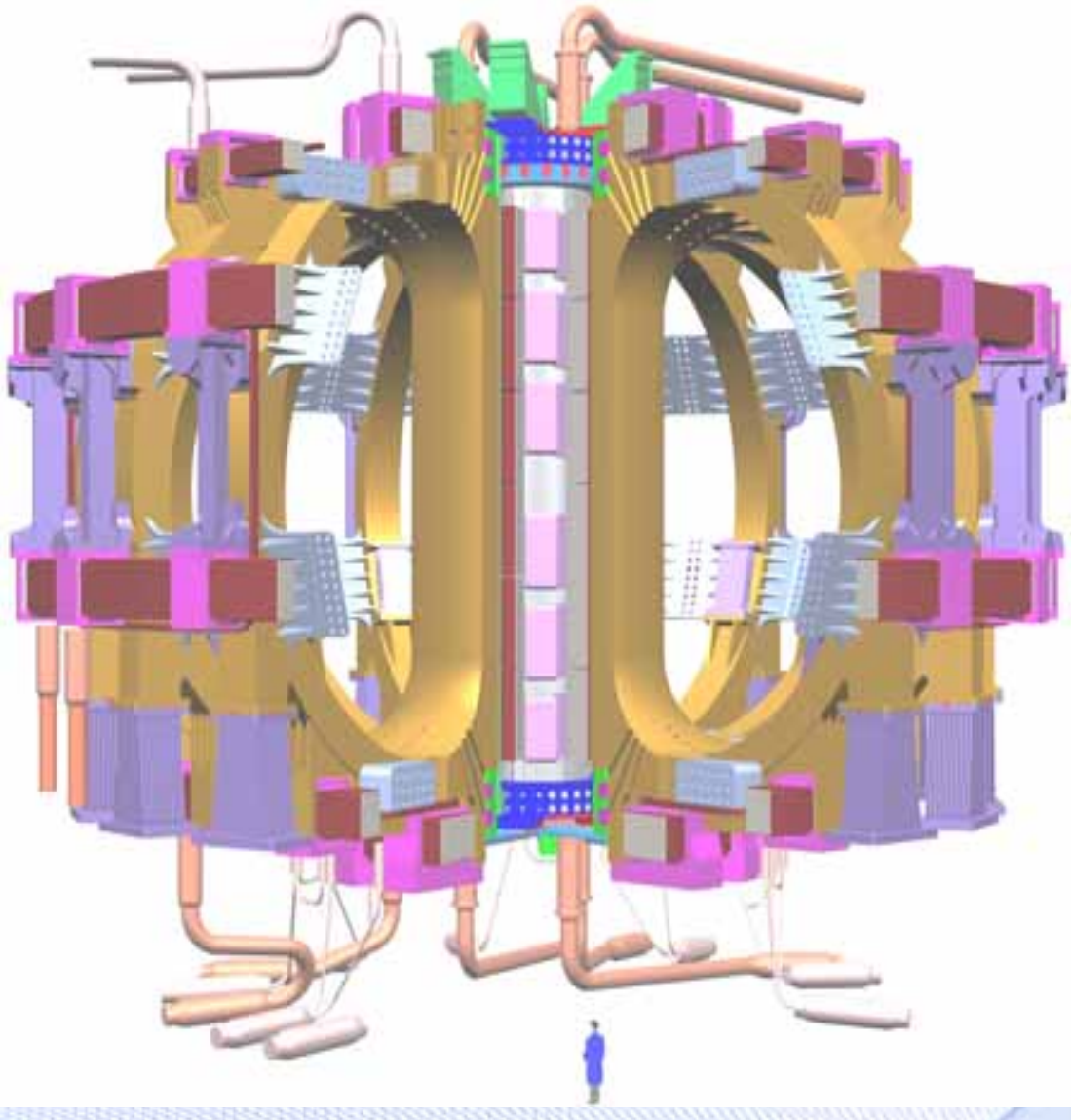
Magnet system is the largest component of the ITER machine cost



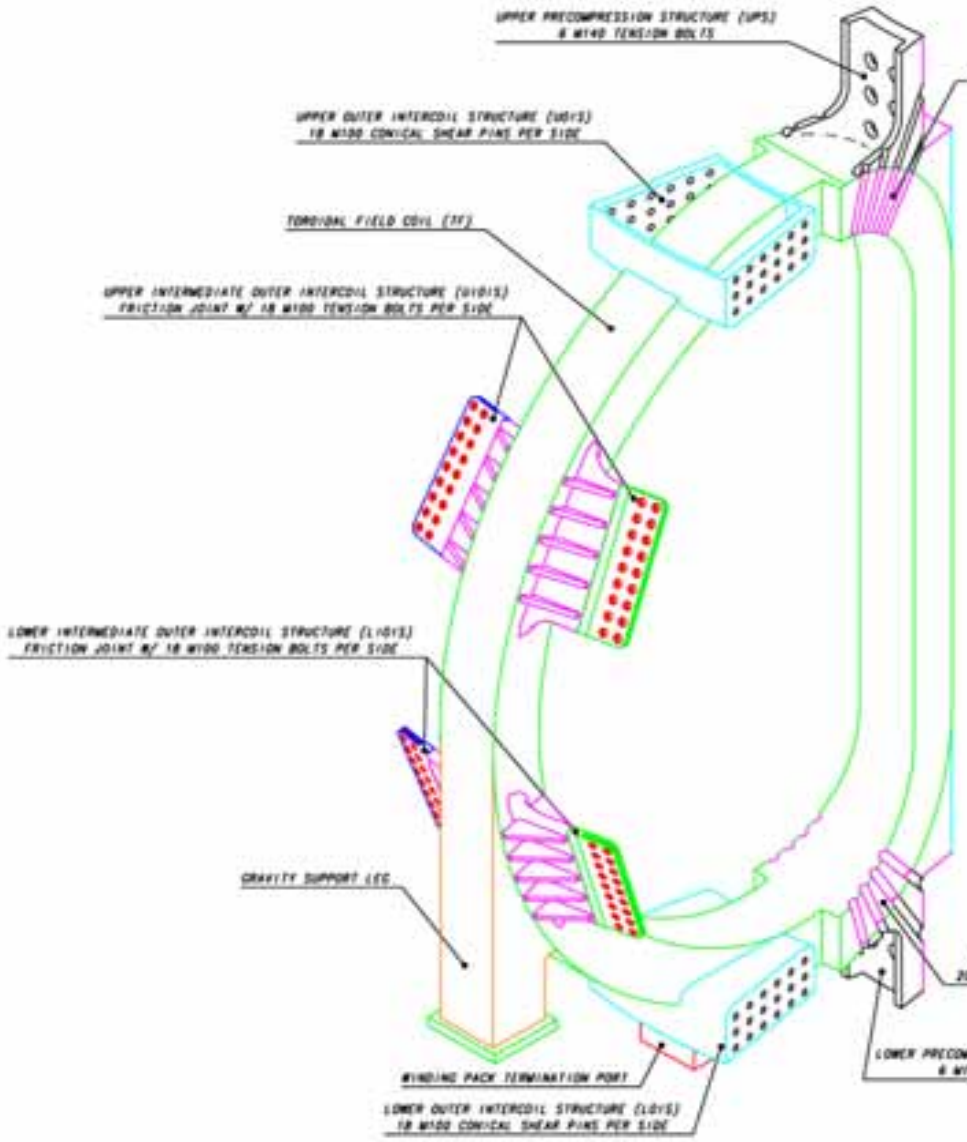
ITER coil assembly

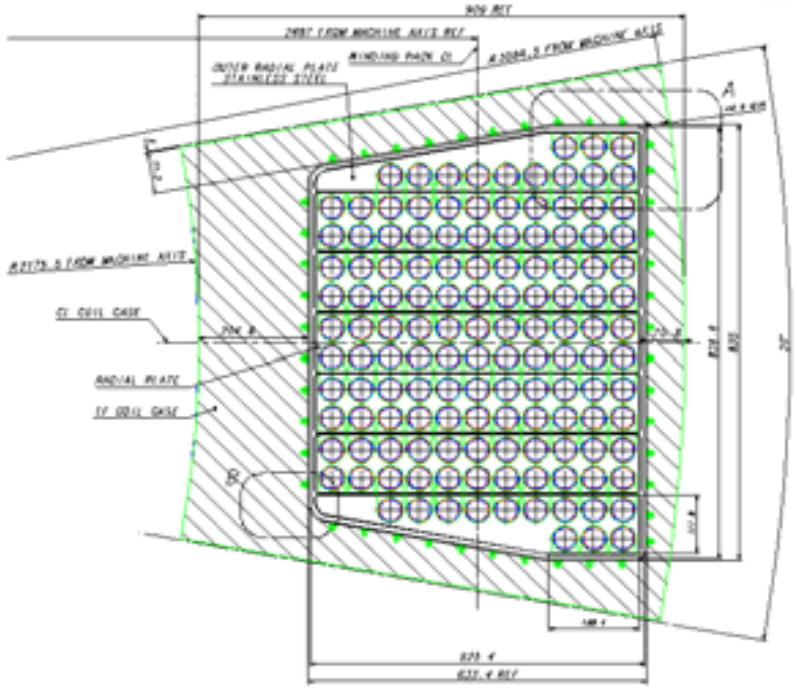
Overall Magnet System Parameters

Number of TF coils	18
Magnetic energy in TF coils (GJ)	~ 41
Maximum field in TF coils (T)	11.8
Centering force per TF coil (MN)	403
Vertical force per half TF coil (MN)	205
TF electrical discharge time constant (s)	11
CS peak field (T)	13.0
Total weight of magnet system (t)	~ 9,000



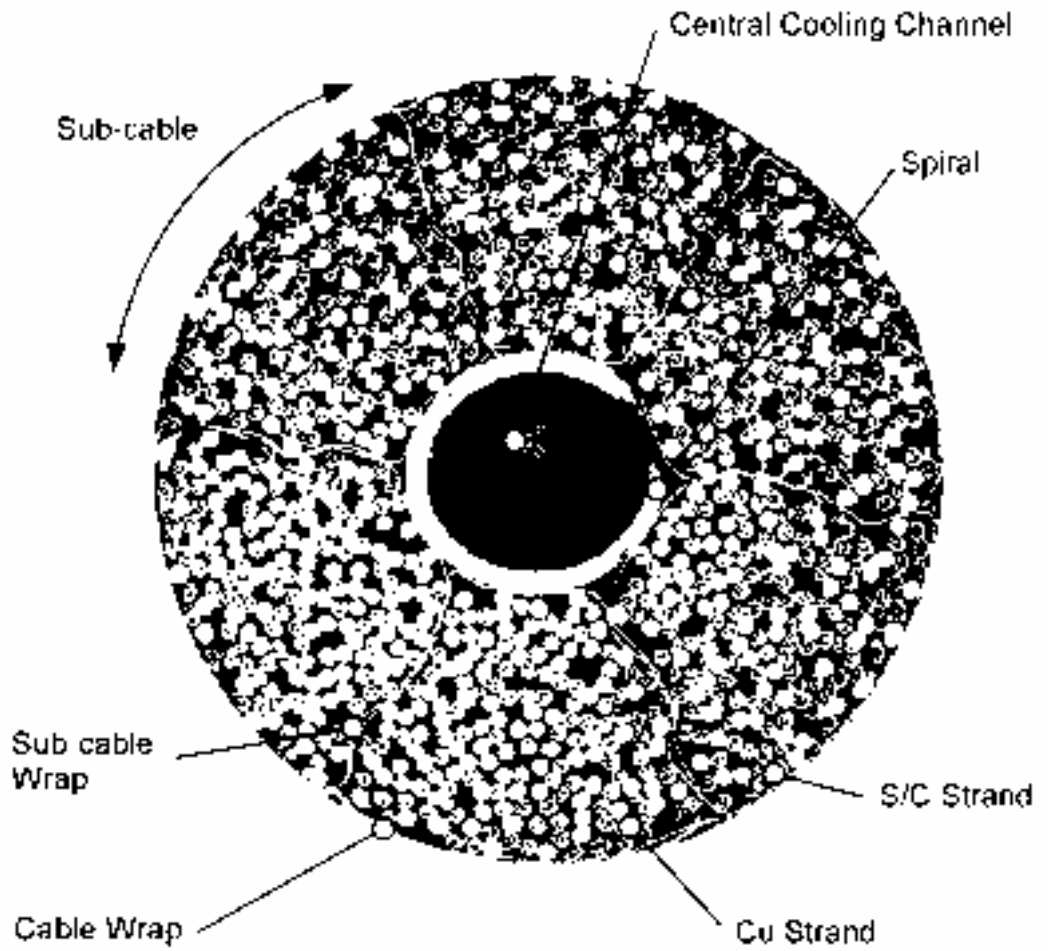
ITER Toroidal Field Magnets



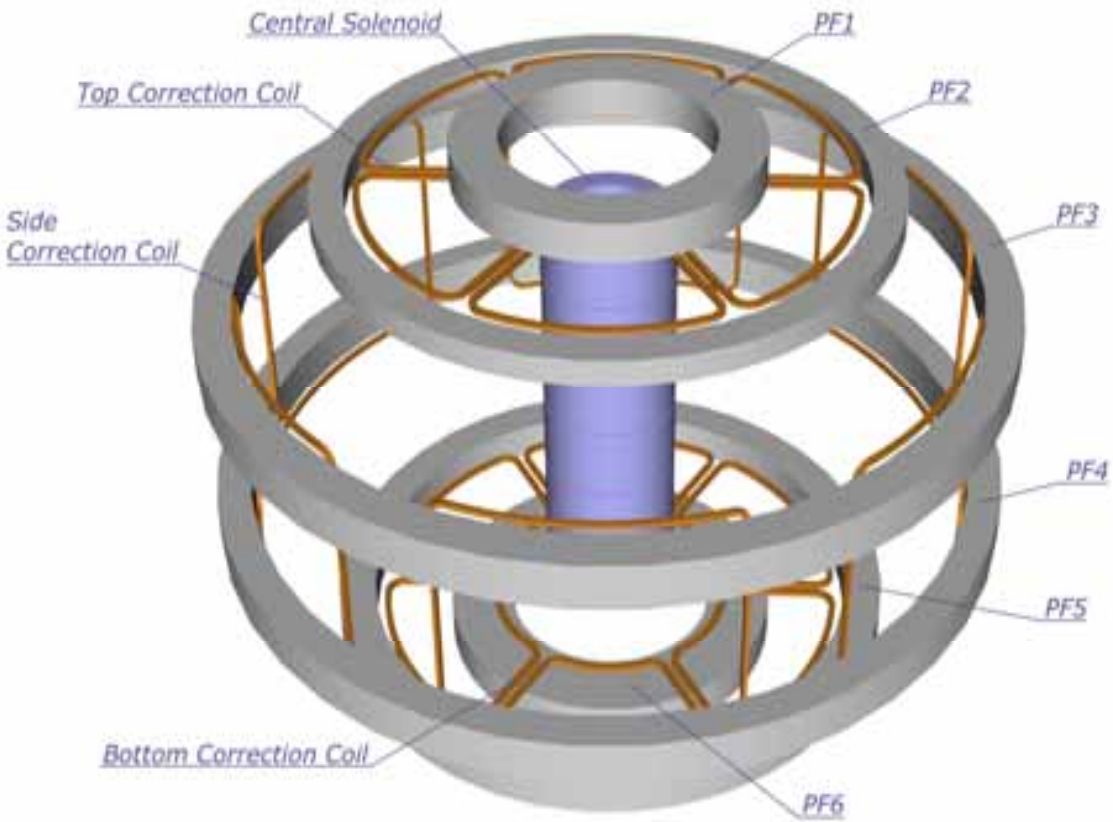


TF Cables

TF Cable unit lengths:
Sc prototype 401 m
Sc Cable R. DP 766 m
Sc Cable S. DP421 m

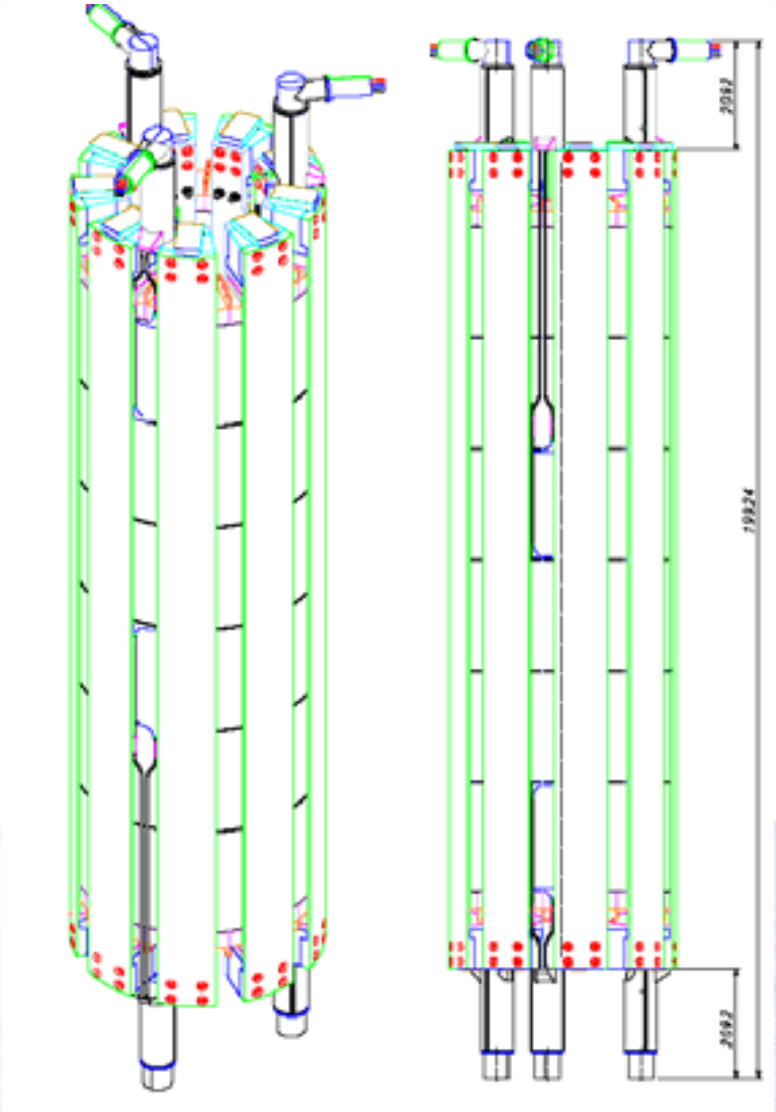


ITER CS and PF Coil System



PF3 and PF4 have 24 meter diameter

ITER CS Magnet System Assembly



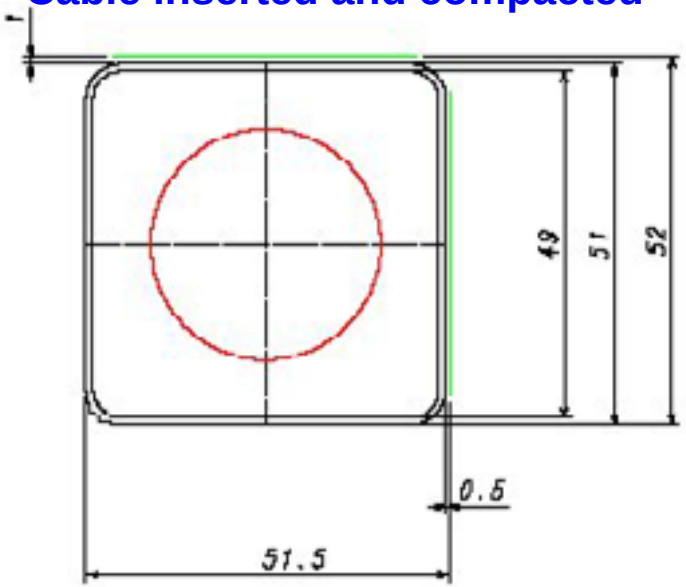
- **CS Assembly includes:**
  - 6 identical modules
  - Composite inter coil spacer Structures
  - Axial pre-compression system
  - Sets of axial upper and lower current and cryogen feeders
- **CS main interface is the TF System:**
  - CS mounts off the upper TF coil cases
  - TF in board sets the radial build constraint of CS but not the load path for electromagnetic forces

Central Solenoid Conductor

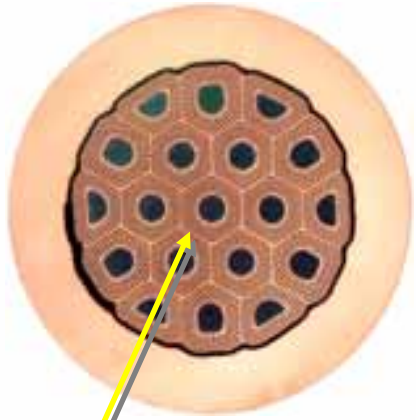
ITER selected JK2LB as Jacket Material

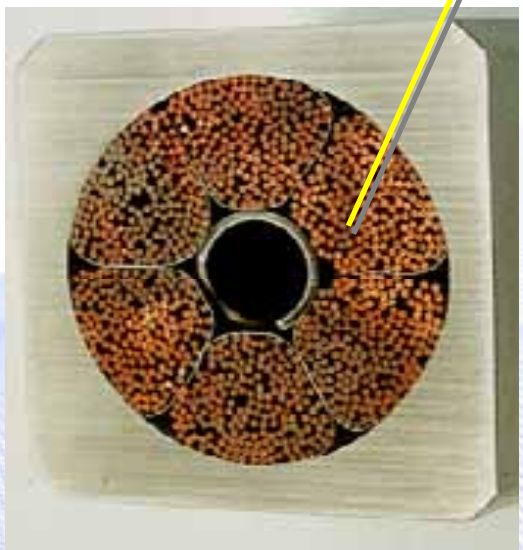
Procurement consists of:

- Nb_3Sn superconducting strand
- Pure copper strands
- Multi-stage cable including wraps and central spiral
- Jacket
  - Extruded segments 4-8m long
  - Butt welded/inspected
  - Cable inserted and compacted



Strand
(0.83 mm diameter)





CICC
(49 mm x 49mm)

Summary Table of Procurement Allocation

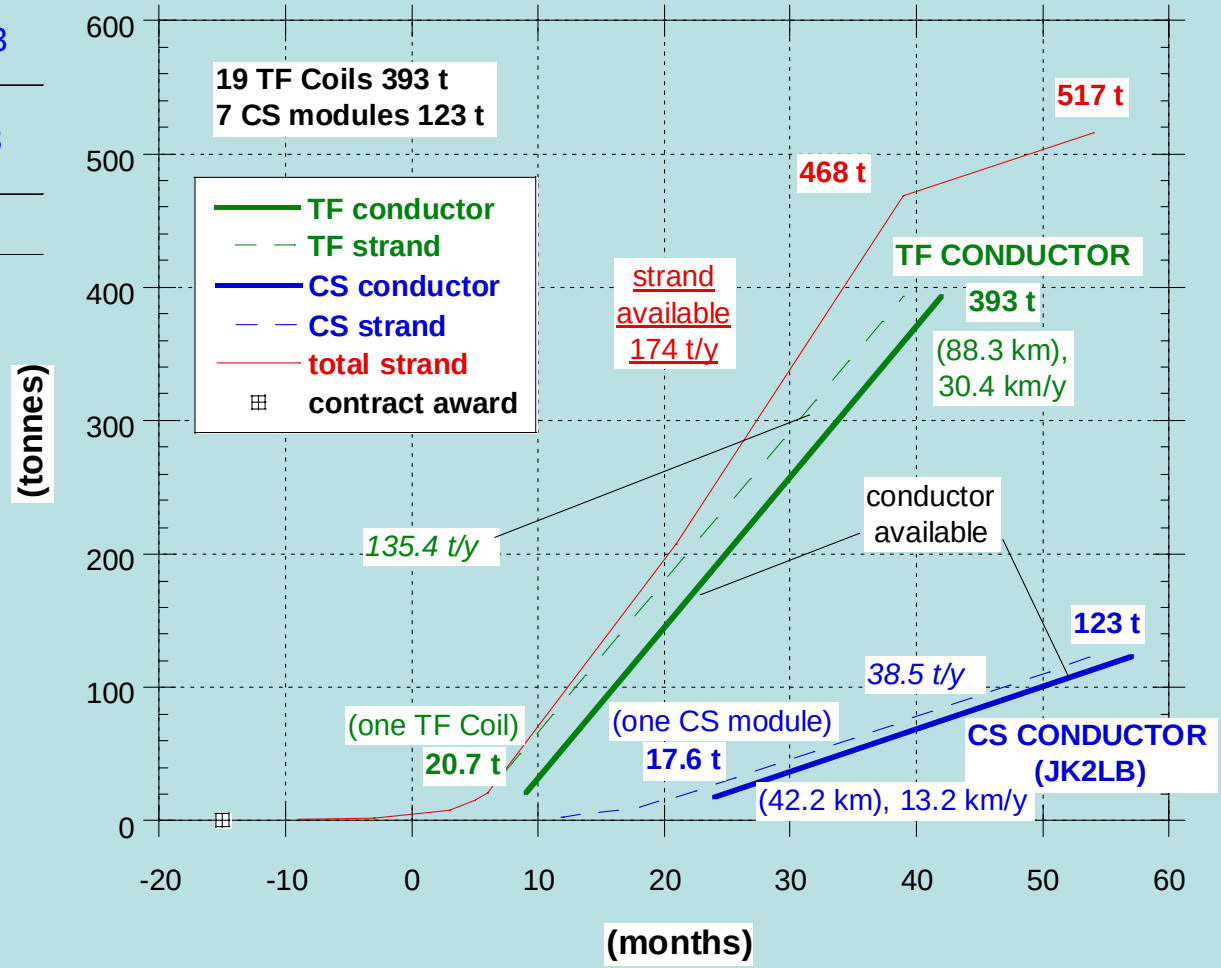
PACKAGE			kIUA	ALLOCATION	REMARKS
1.1 Magnet	Toroidal Field Magnet Windings	1A	85.2	EU=100%	1A for 10 TF (including 1 prototype) and 1B for 9 TF (including 2.5 kIUA for fabrication verification)
		1B	82.3	JA=100%	
	Toroidal Field Magnet Structures	2A	51.4	EU=10%, JA=90%	Fabrication of whole structures by JA and Pre-compression ring (0.6 kIUA) by EU. Final assembly of 10 TF coil cases by EU (10%)
		2B	47.7	JA=100%	
	Magnet Supports	2C	22.85	CN=100%	
	Poloidal Field Magnet 1 & 6	3A	13.6	EU=50%, RF=50%	PF1 by RF and PF6 by EU
	Poloidal Field Magnet 2 to 5	3B	33.6	EU=100%	
	Correction Coils	3C	2.6	CN=100%	
	Central Solenoid Magnet	4A+4 B	39.6	US=100%	
	Feeders	5A	26.15	CN=100%	
	Feeders Sensors	5B	18.05	FUND=100%	
	Toroidal Field Magnet Conductors	6A	215	EU=20%, JA=25%, RF=20%, CN=7%, KO=20%, US=8%	See Note-1
	Central Solenoid Magnet Conductors	6B	90	JA=100%	
	Poloidal Field Magnet Conductors	6C	74.25	EU=13%, RF=18%, CN=69%	

Nb_3Sn strand quantity requirements

Cr coated Nb3Sn strand (517 t) diam (mm)	TF 0.82	CS 0.83
Mass of strand in cable (t)	393	123
Production rate (t/y)	135	38

Note: Quantities reflect amount of strand in cable and do not include strand, cable, conductor, and coil fabrication losses

Total: 517 t + losses



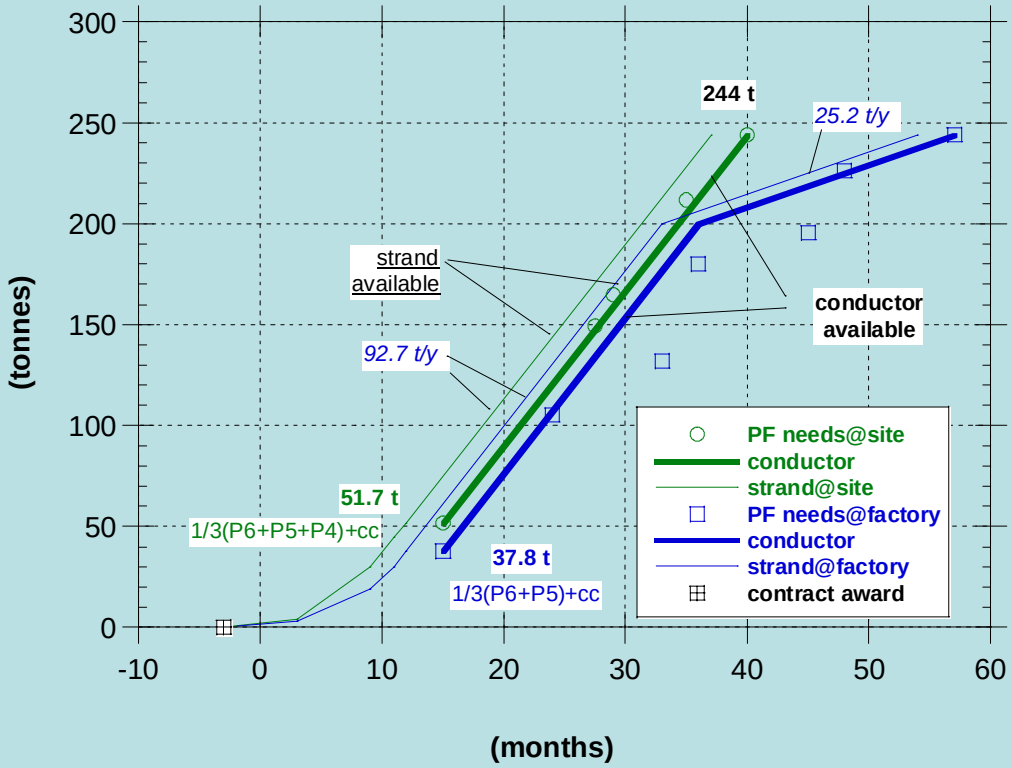
NbTi strand quantity requirements

Ni coated NbTi strand (244 t)	Mass of strand in cable (t)	Peak production rate (t/y)
PF2, 3&4 diam. 0.73 mm	87	93
PF5 diam. 0.72	105	
PF1&6 diam. 0.73	45	

+ 6-7 t for Correction Coils and feeders

Note: Quantities reflect amount of strand in cable and do not include strand, cable, conductor, and coil fabrication losses

Jc (A/mm^2) 5T, 4.2K	2900
fil. diam. (μm)	5
Ni plating (μm)	1-2
n value [0.1 – 1μV/m] 5T, 4.2K	20
RRR	150



Total: 244 t + losses

2 μm Ni coating to control the inter-strand resistance and to prevent oxidation (storage, handling)

Magnets R&D for ITER

Toroidal Field Model Coil (TFMC)

Central Solenoid Model Coil (CSMC)

Toroidal Field Coil Casing

HTSC Current Leads

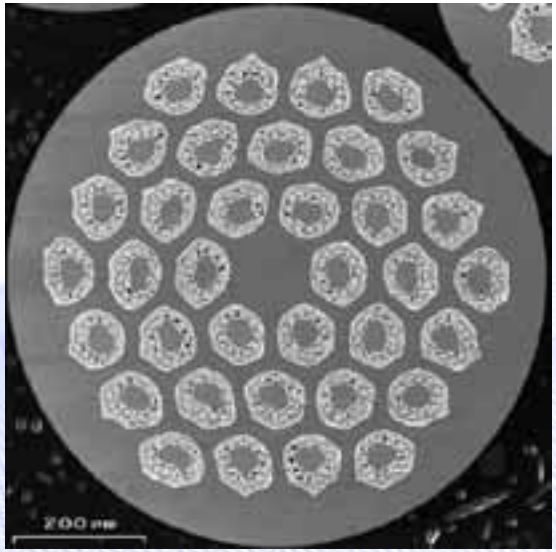
Advanced Performance Strand

Poloidal Field Conductor Insert (PFCI)

TFMC Assembly

TF Model Coil Conductor

- Current: 80 kA (4.5 K, 9.7 T)
- 316LN stainless steel jacket (Ø 40.7 mm) wound in radial plates
- Cable diameter: 37.5 mm
- 720 Nb_3Sn strands (1080 strands total)

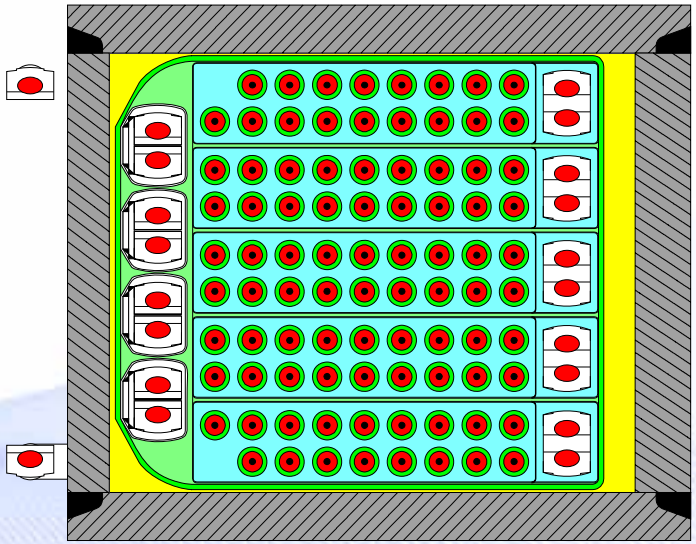


Strand Layout

TF Model Coil

Challenging Design: Radial Plates as Double Pancakes

Winding Pack of TFMC

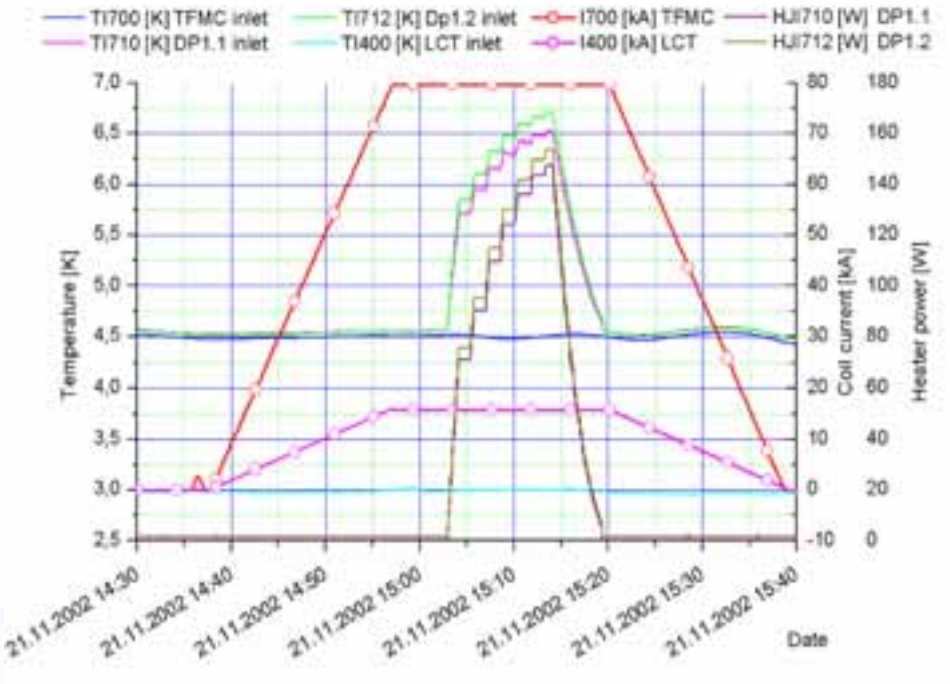


TFMC - Joints

Shaking hand joint: inner joint of double pancake 1

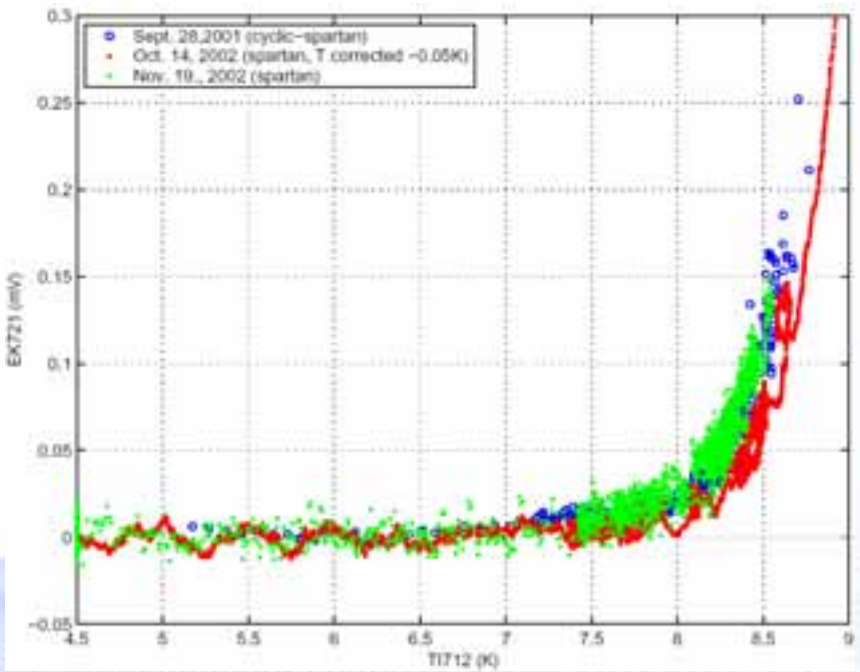
ITER - EFDA Magnets R&D
TF Model Coil

TFMC (80 kA) + LCT (16 kA)



TFMC exceeded design values

TFMC (80 kA)



No performance degradation

CSMC: 3 Coil Modules (25%EU)

CS Insert Coil (JA)

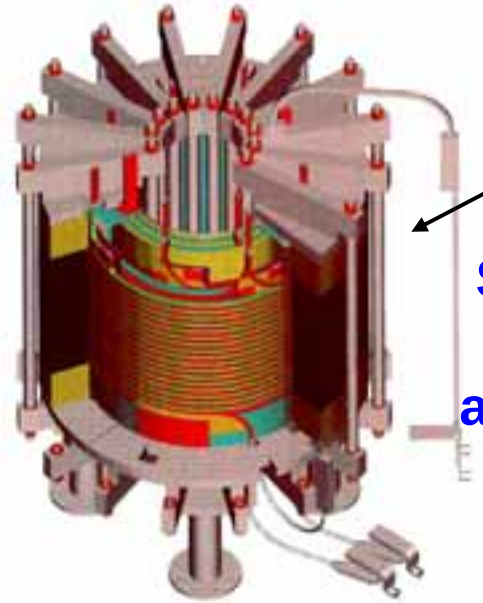
+

+

JA Outer Coil Module

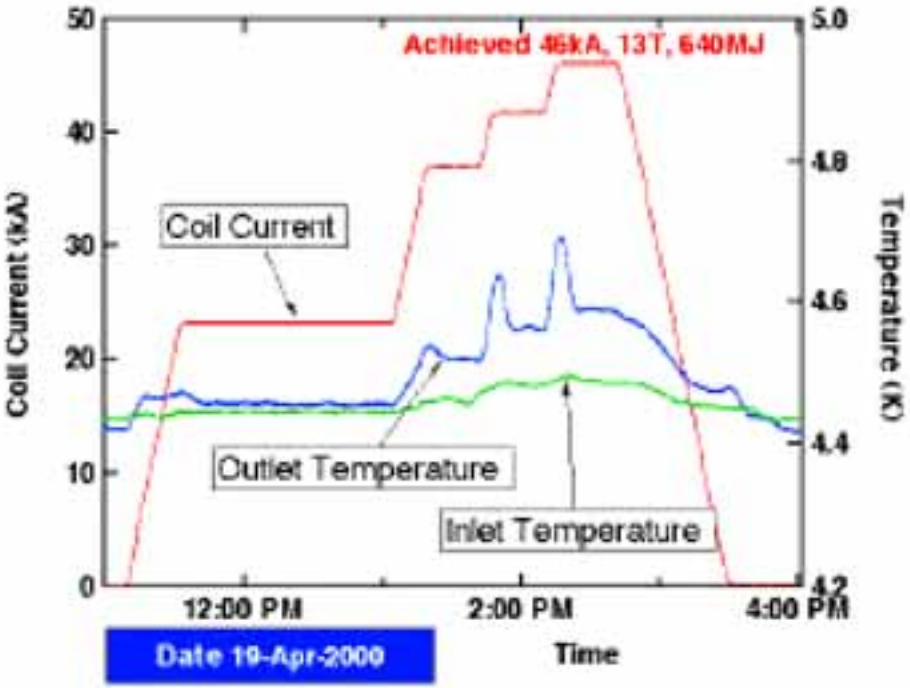
=

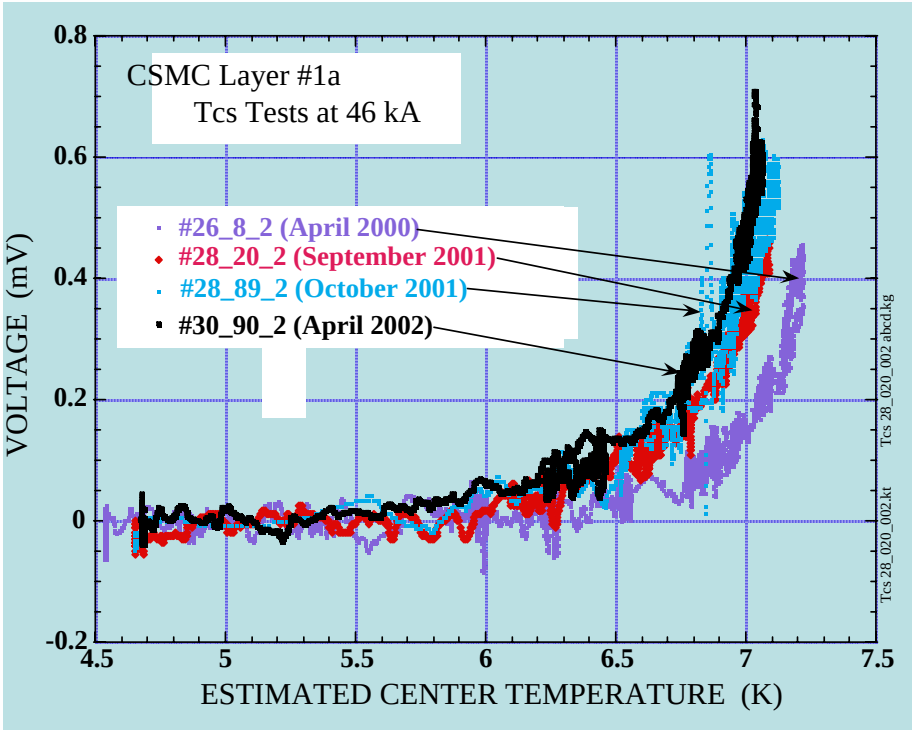
Coil Assembly in Test Facility



Schematic Assembly
of CSMC
and Support Structure

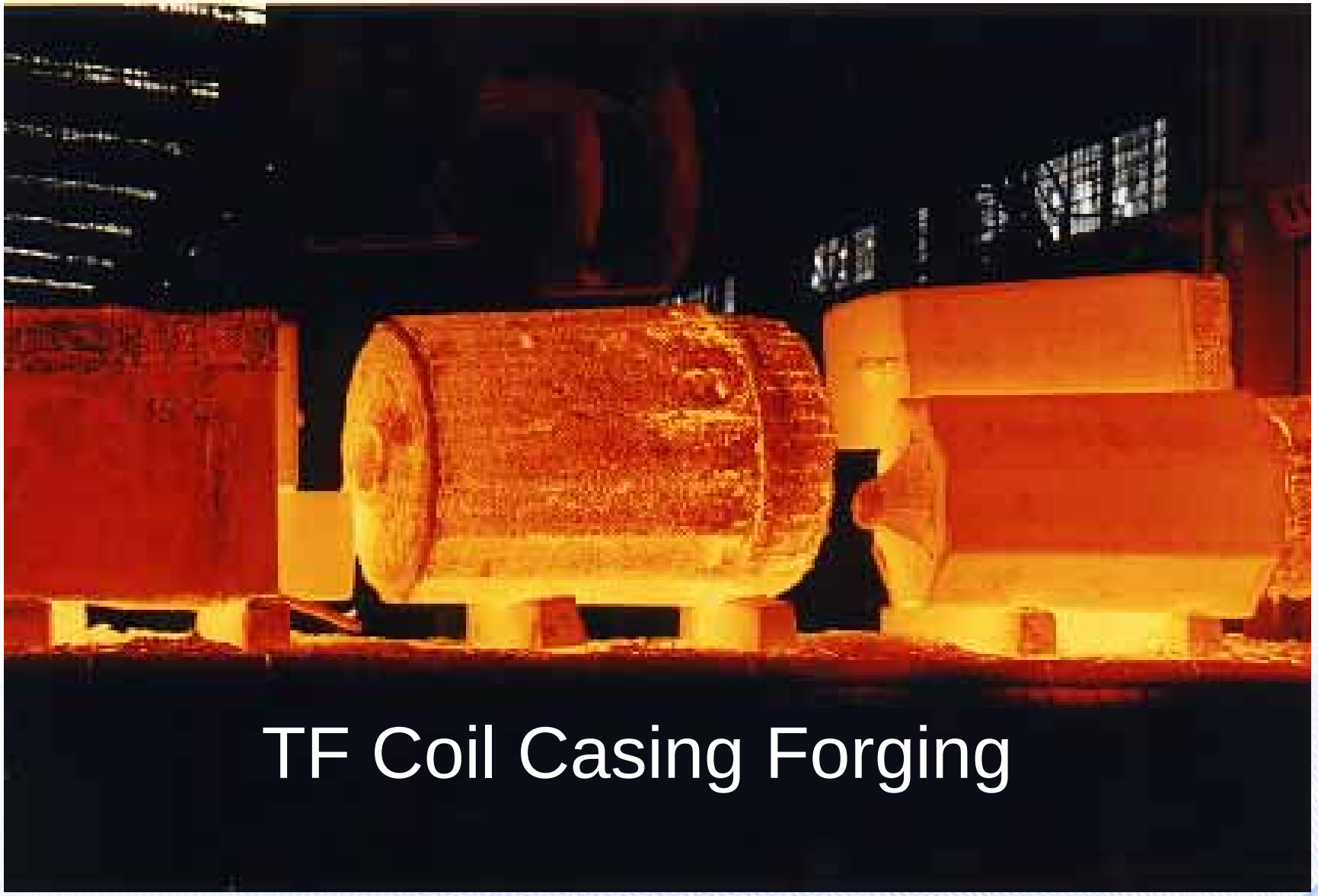
CS Model Coil:Test results





CSMC successfully achieved design values

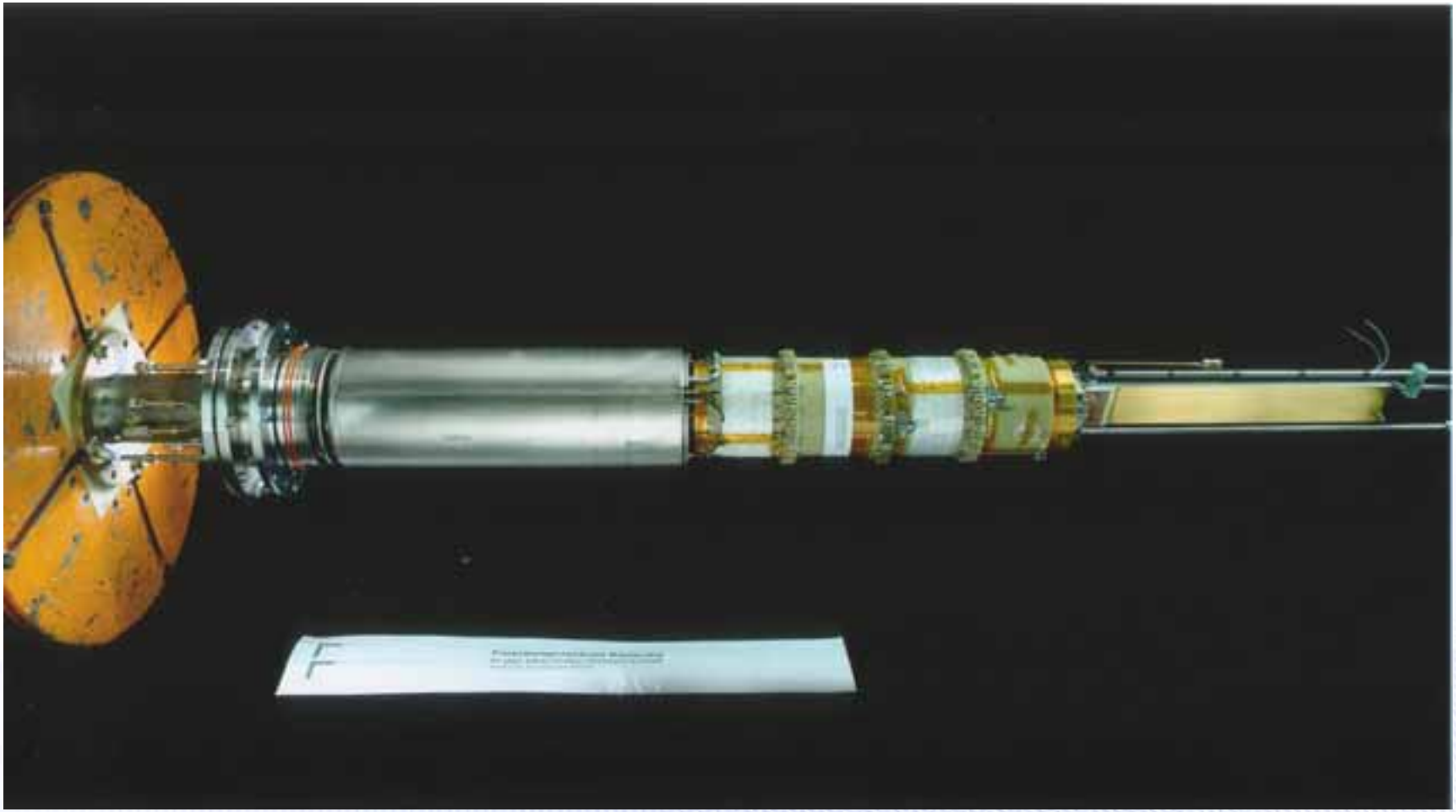
Small degradation (0.1 to 0.2 K) saturated after few cycles



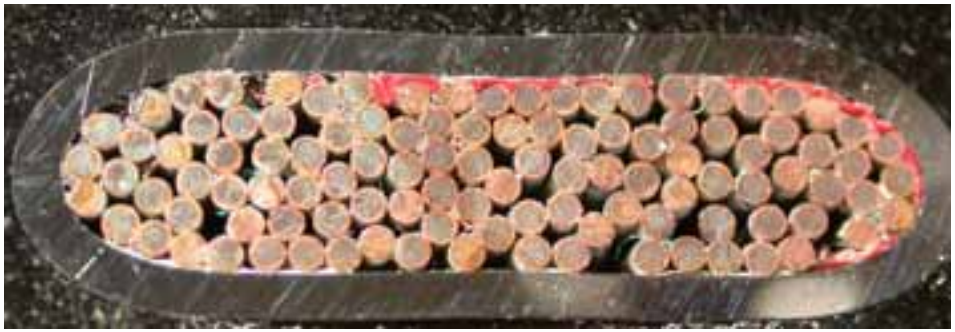
TF Coil Casing Forging

TF Casing Model 1

70 KA HTSC Current Lead



Sub size conductor with ITER advanced strand



Strand Parameters

- OST strand, internal-tin
- J_c > 1100 A/mm^2 (12 T, 4.2 K)
- non-Cu losses: 900 kJ/m^3
- Strand Ø: 0.81 mm
- Cu:non-Cu ratio: 1

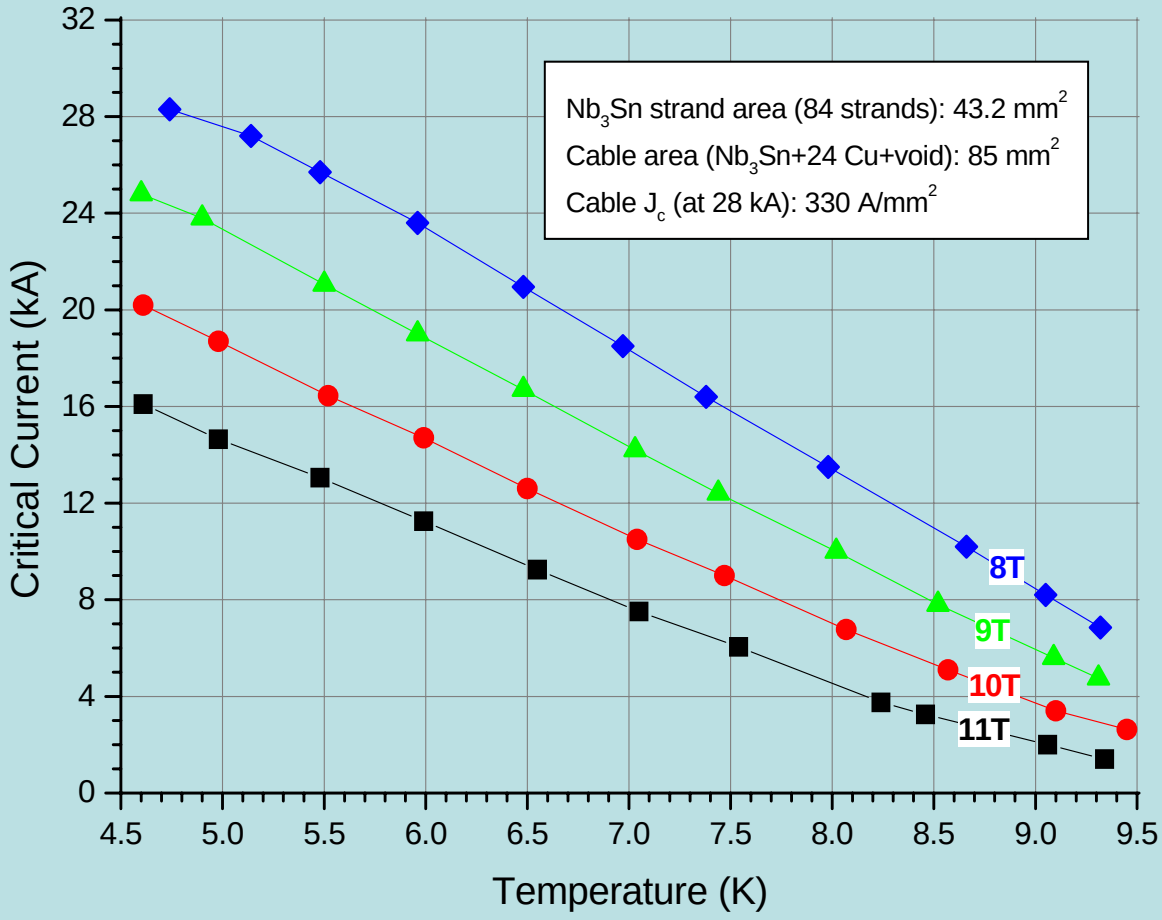
Cable Parameters

- Conductor dimensions: 7.5x18.2 mm
- Jacket thickness: 1 mm
- Cabling pattern: 3x3x3x4
- 84 sc + 24 copper strands
- Twist pitch: 58/95/139/213 mm
- Strand area: 56.76 mm^2 (cosθ = 0.98)
- Void fraction: 35 % (calculated)

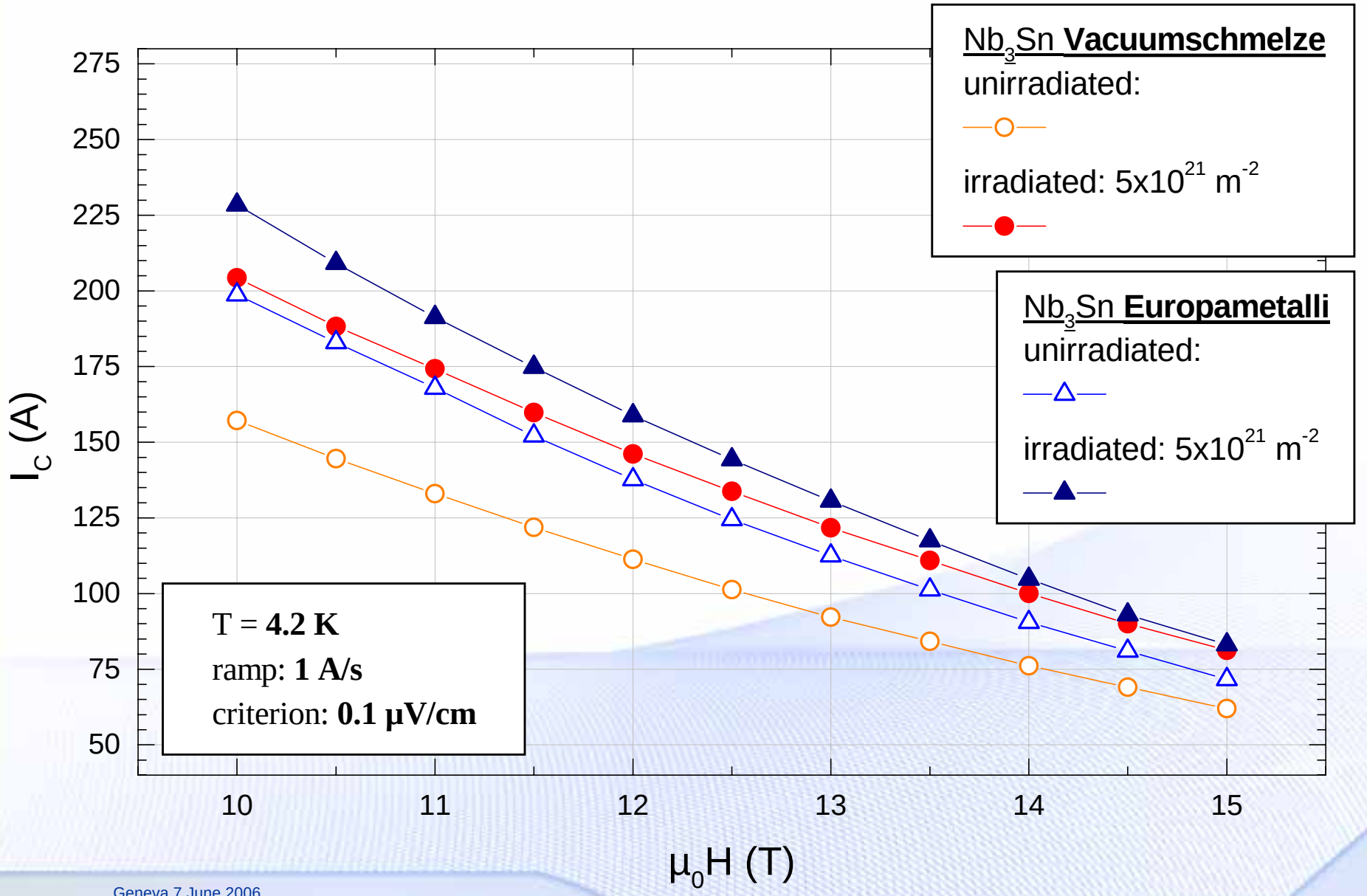
Sub size conductor with ITER advanced strand

Excellent performance (only -0.6 % strain for strand extrapolation required)

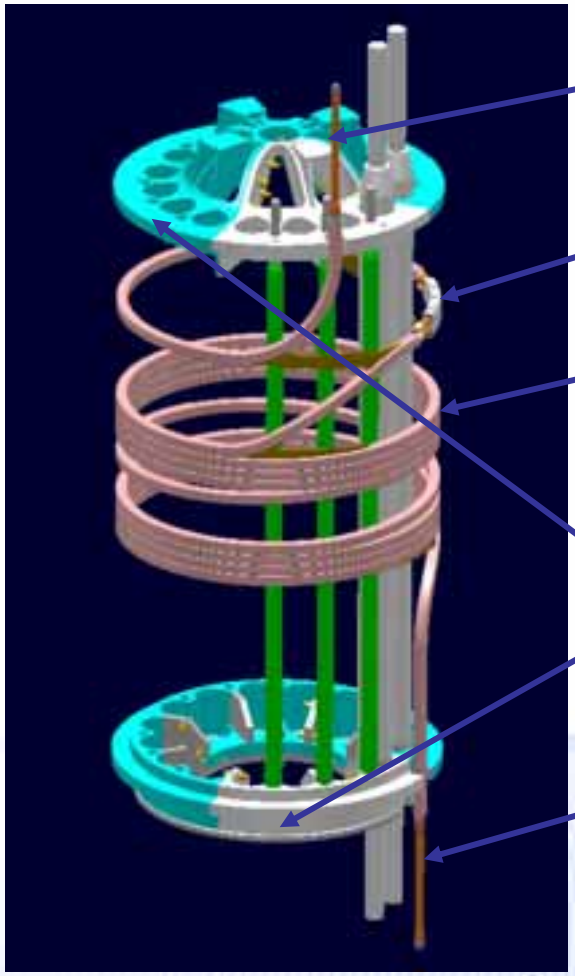
Almost no I_c degradation after cycling (< 3 %)



Sc irradiation Ic



ITER PF Insert Coil (EU 90%)



Coil Design Parameters

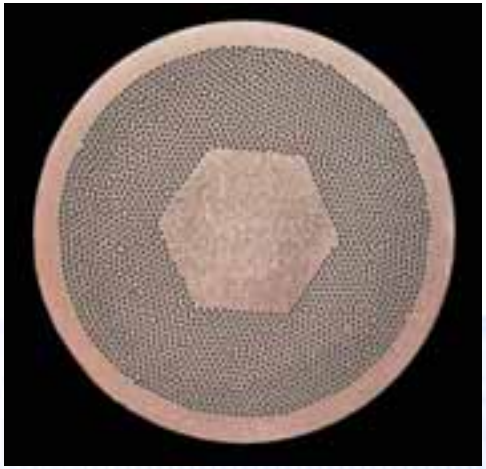
		PFI
Maximum Field		6.3 T
Maximum Operating Current		50 kA
Maximum Field Change		2 T/s
Conductor length		49.50 m
Main Winding Envelope	Outer Diameter	1.57 m
	Inner Diameter	1.39 m
	Height	1.40 m
Height		1.40 m
Weight		6 t

PFCI

Prototype Joint

PF Insert Coil: Conductor

- Current: **50 kA** (4.5 K, 6.3 T)
- 316LN stainless steel jacket (51×51 mm^2)
- Cable Ø: 38.7 mm
- 1440 **NbTi** strands



Strand Parameters

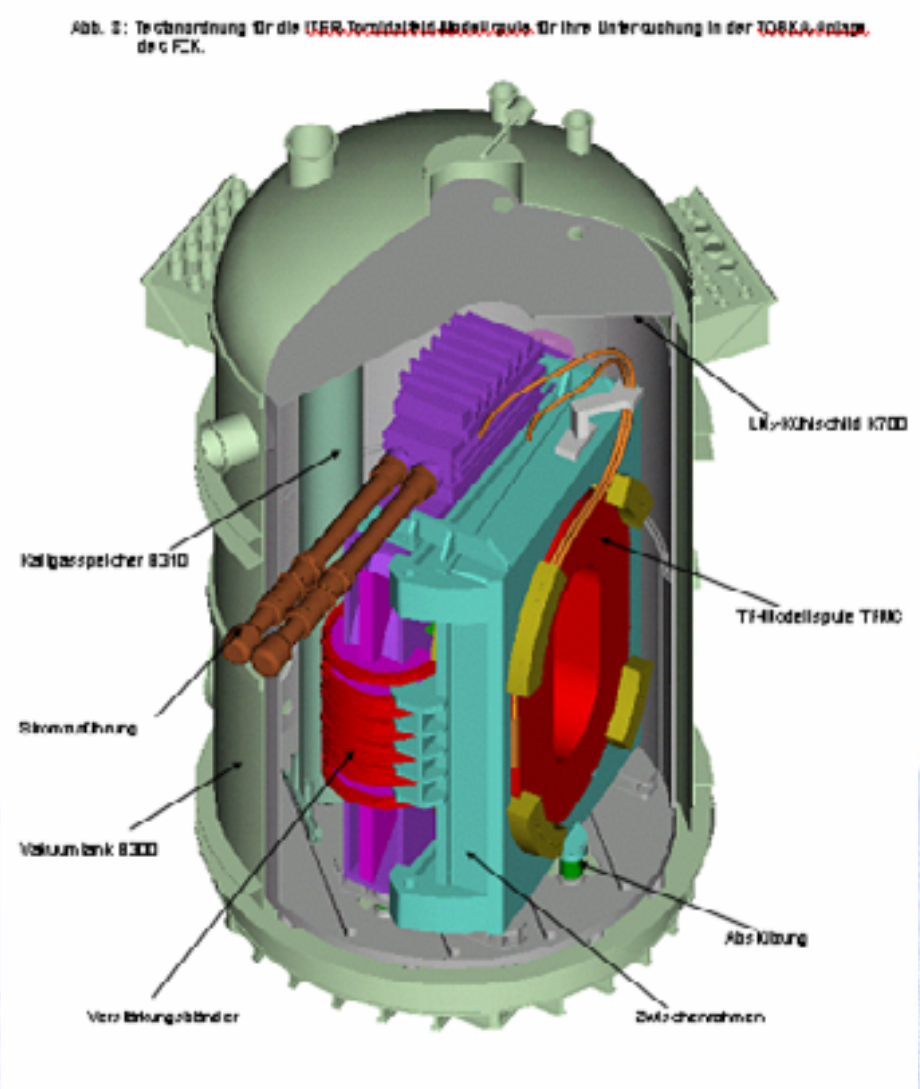
- J_c > 2700 A/mm^2 (5 T, 4.2 K)
- Strand Ø: 0.73 mm
- Cu:non-Cu ratio: 1.4
- Filament Ø: 9.8 µm
- Number of filaments: 2346

PFCI Manufacturing Status

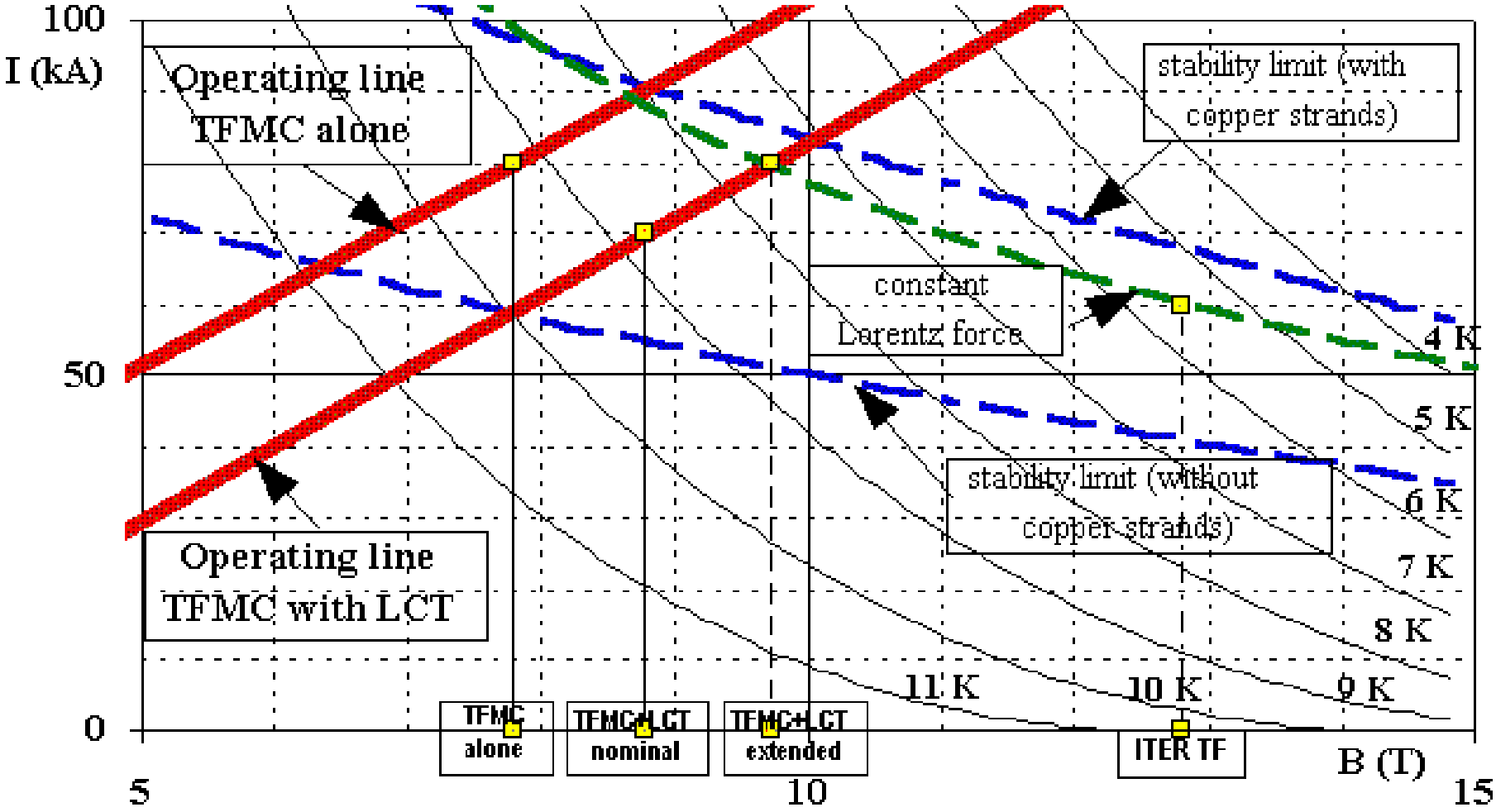
CONCLUSIONS

- The ITER Magnets feasibility has been demonstrated
- The optimization of the design is required to incorporate the latest R&D results
- Strand procurement can start
- Procurement allocation needs attention

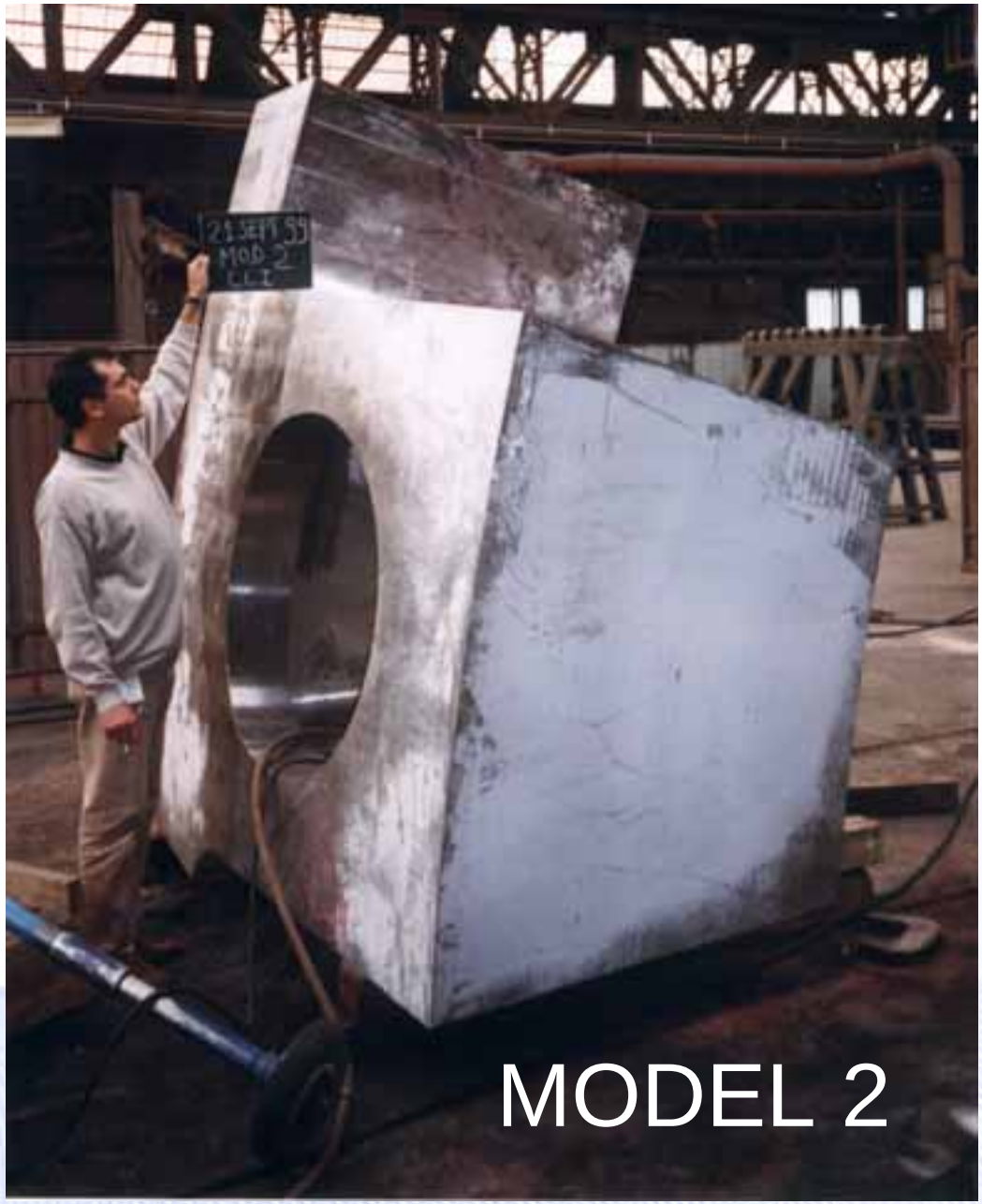
Test of ITER Toroidal Field Model Coil in TOSKA, FZK, Germany (EU 100%)



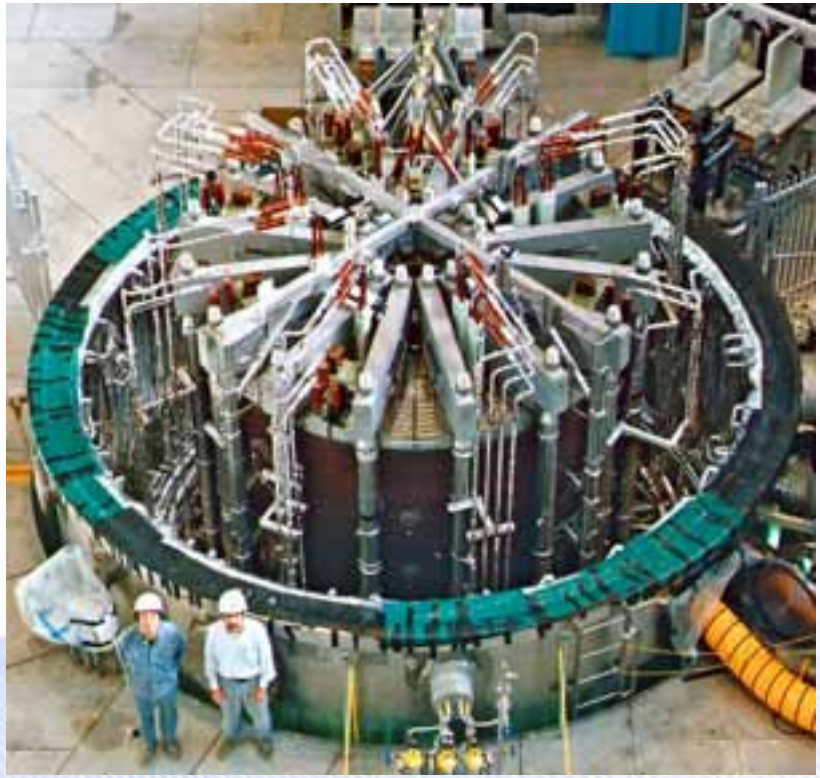
TFMC Operating Diagram



TF Intercoil Structure Casting

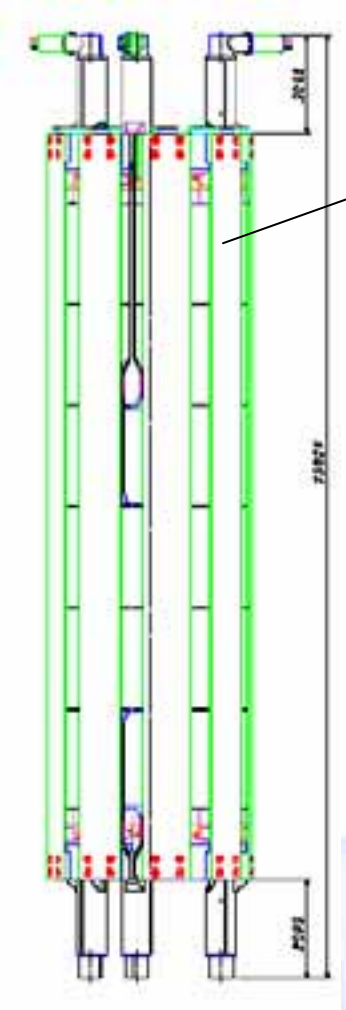


Model Coil Test Facility (JAERI, Naka, Japan)



Coils assembled in the Vacuum Vessel

CS Magnet System Scale



Each Module is slightly larger than the complete CS Model Coil