Recent Progress of JT-60SA Project

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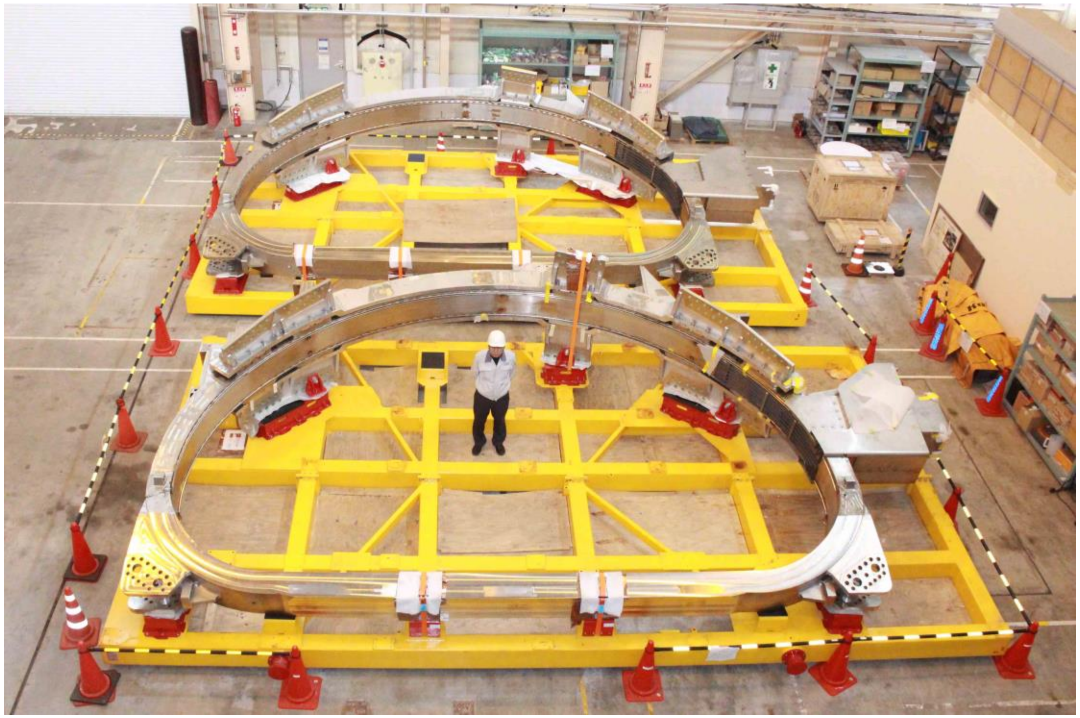
[1]JT-60SA Project Leader, [2]EU Project Manager, [3]JA Project Manager



IAEA Fusion Energy Conference 2016
17-22 October 2016
@Kyoto International Conference Center

JT-60SA (JT-60 Super Advanced) Project

JT-60SA Project is implemented under the Broader Approach (BA) Agreement between EU and Japan as well as the Japanese national fusion programme.

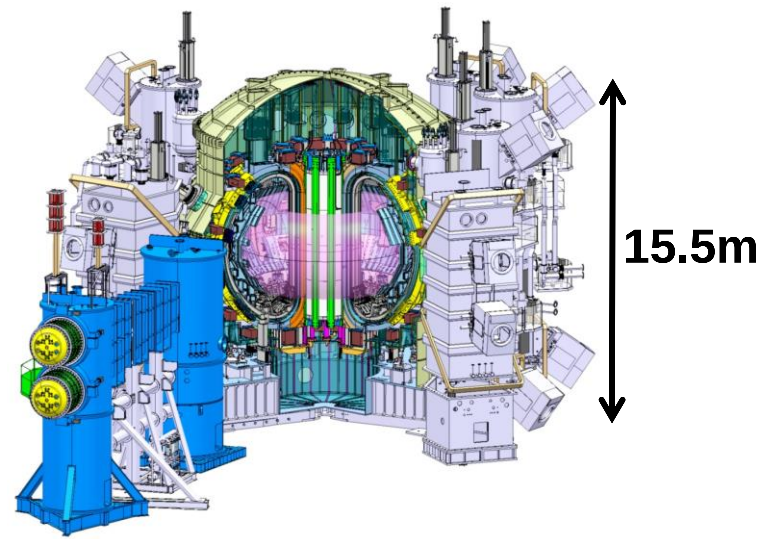
Mission:
Contribute to the early realization of fusion energy by addressing key physics and engineering issues for ITER and DEMO.

Major Objectives:

(1) Supportive Researches for ITER
JT-60SA starts operation in 2019
→ address ITER related issues in advance and optimize its operation scenarios under the break-even condition

(2) Complementary Researches for DEMO
study long sustainment of high integrated performance plasmas with high β_N value

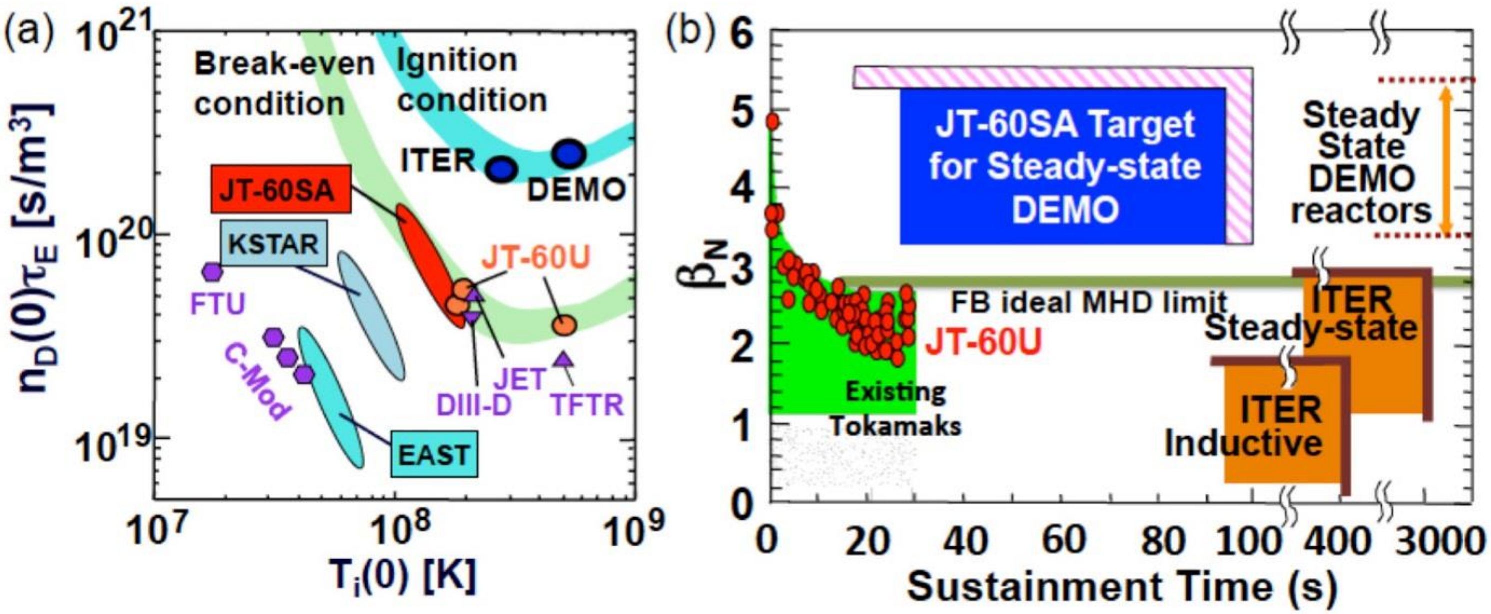
(3) Foster Next Generation
build up experience of young scientists and technicians who will play leading roles in ITER and DEMO.



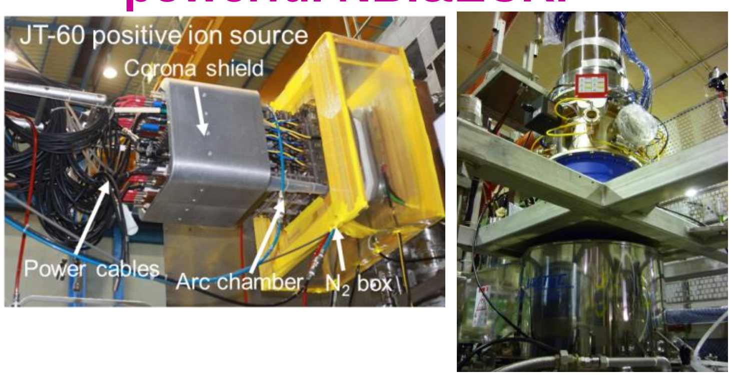
(full current inductive mode)

Plasma Current	5.5 MA
Toroidal Field	2.25 T
Major Radius	2.96 m
Minor Radius	1.18 m
Elongation, κ_X	1.87
Triangularity, δ_X	0.50
Safety factor, q_{95}	3.0
Plasma Volume	131 m^3
Heating Power	41 MW
Normalized beta, β_N	3.1

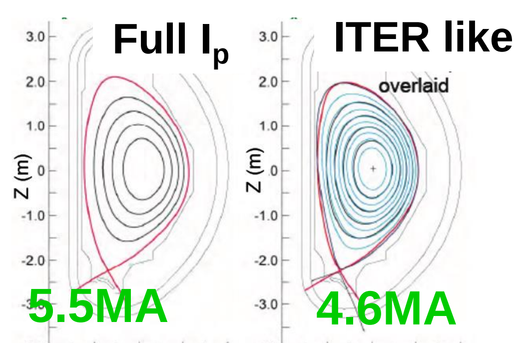
JT-60SA target region in relation to ITER and DEMO



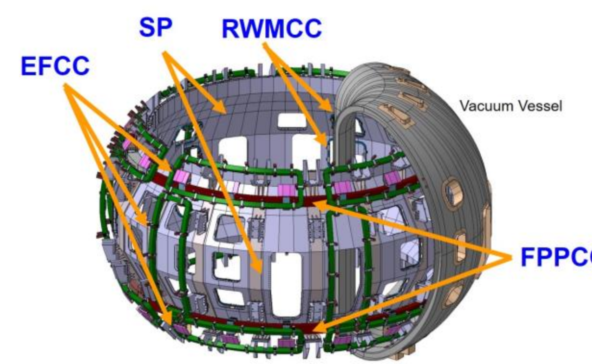
powerful NBI&ECRF



flexible shaping

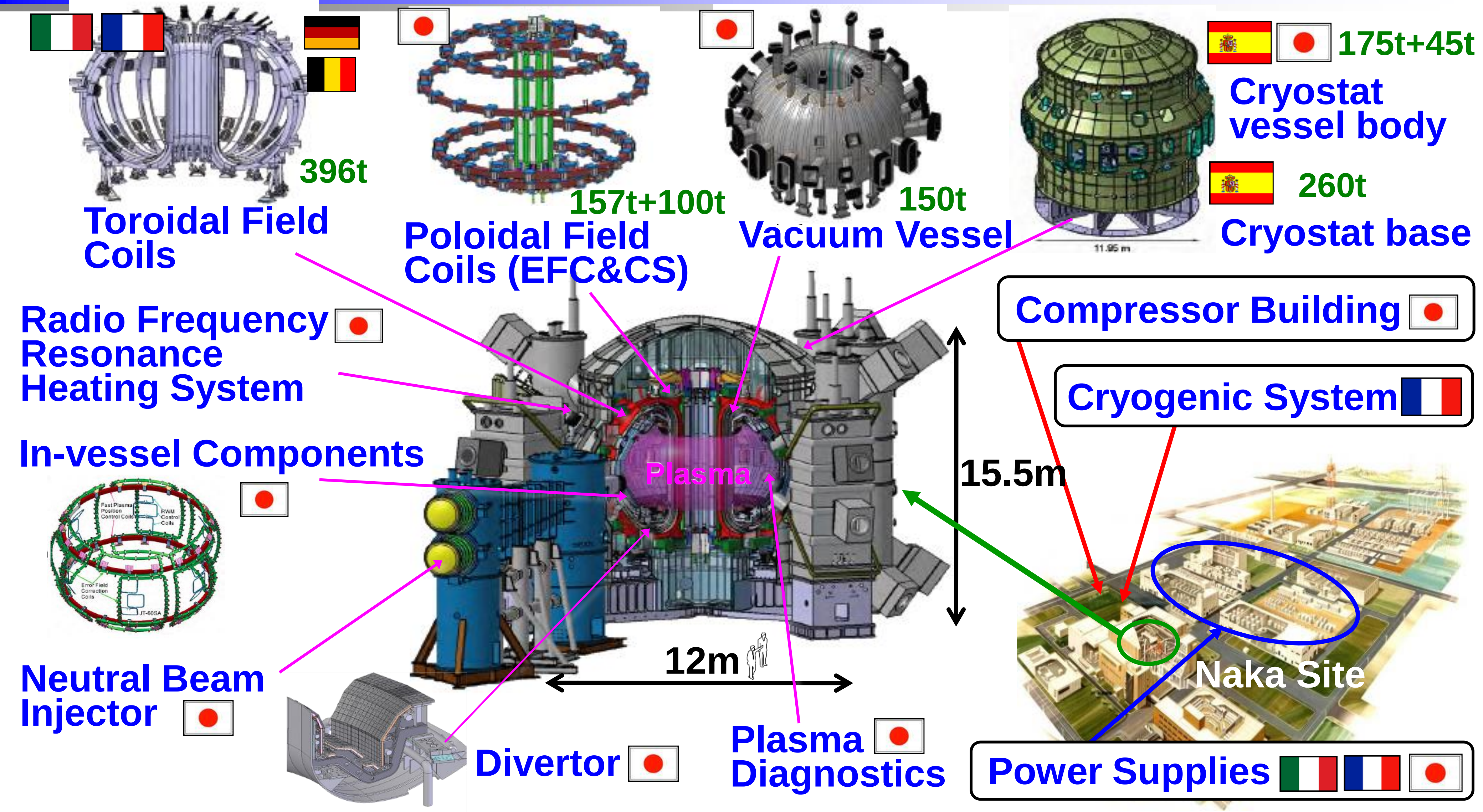


in-vessel coils



Long sustainment of high integrated performance plasmas with high β_N value for DEMO will be investigated by making the best use of (1) powerful and versatile NBI&ECRF system, (2) flexible plasma shaping, (3) various kinds of in-vessel coils, and so forth.

Share of JT-60SA Components and Systems (remarkable progress since the last IAEA FEC)



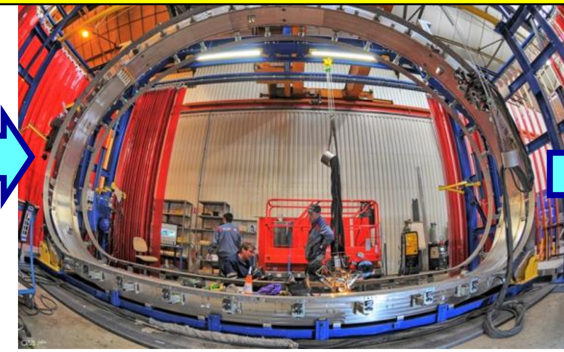
Existing JT-60 facilities (e.g. transformer substation, motor generators, etc.) are also reused as much as possible to reduce overall project cost.

Toroidal Field Coils (NbTi)

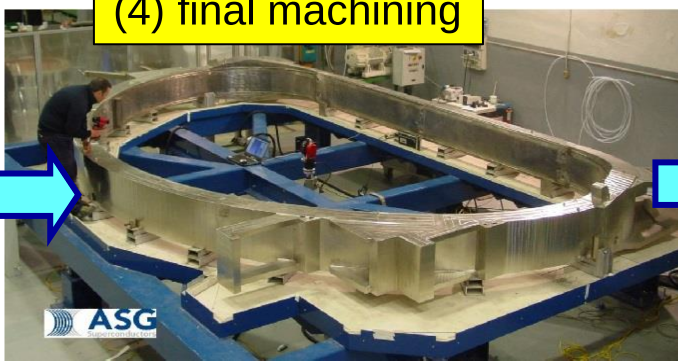
(1) winding pack (WP) fabrication

(2) impregnation of WP

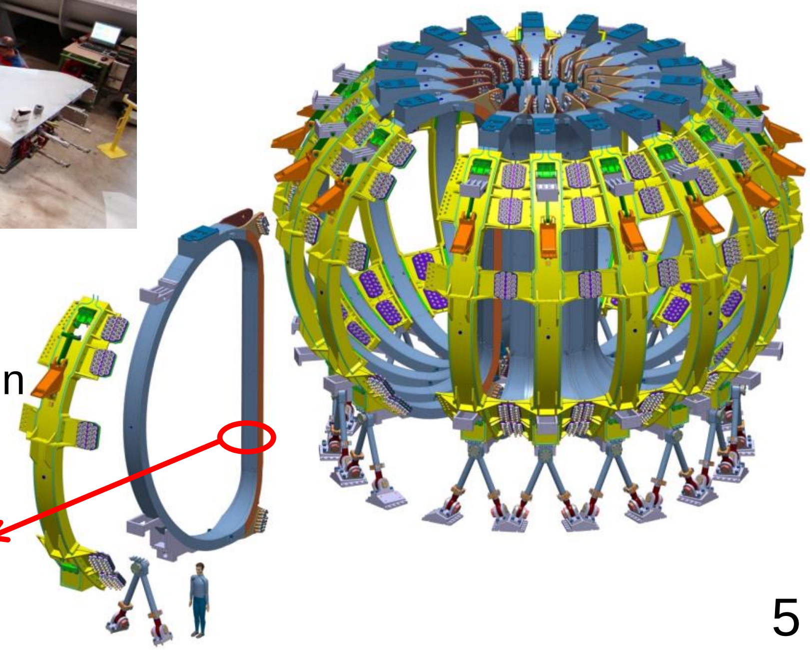
(3) WP enclosed in coil casing

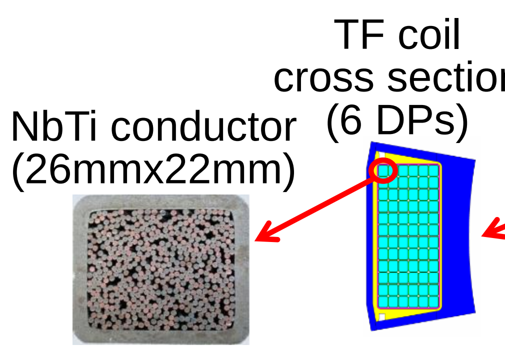


(4) final machining



(5) completed TF coil



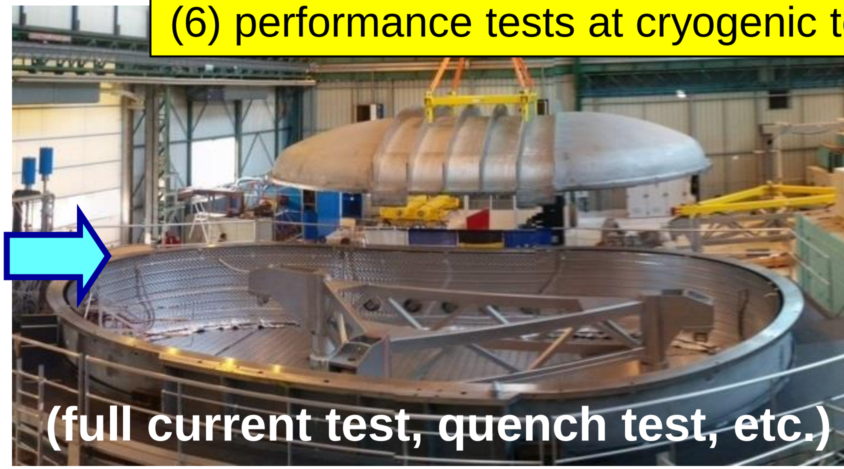


18 TF coils plus 2 spare TF coils are being fabricated in France and Italy.

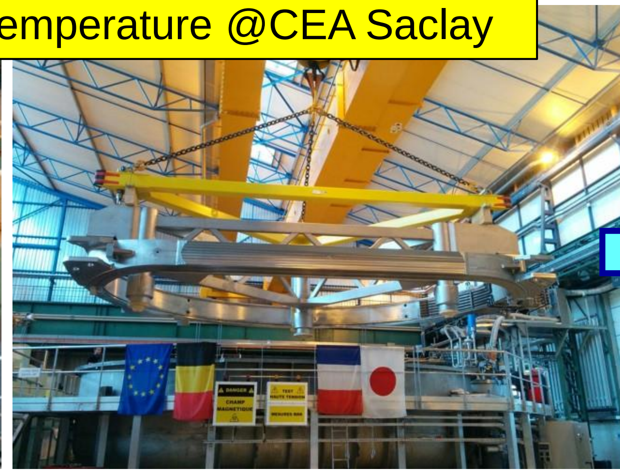
JT-60SA Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

Two TF coils now in Naka Site

(6) performance tests at cryogenic temperature @CEA Saclay

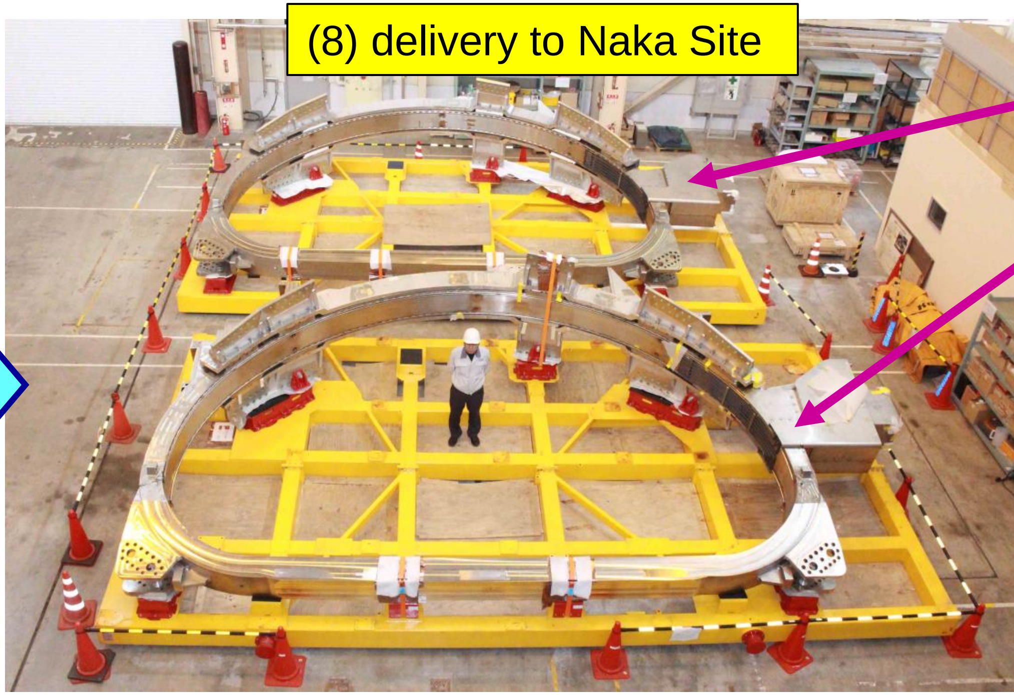


(full current test, quench test, etc.)



(7) OIS preassembly

(8) delivery to Naka Site



2nd coil "Brigitte"

1st coil "Annie"

3rd coil "Roberta"

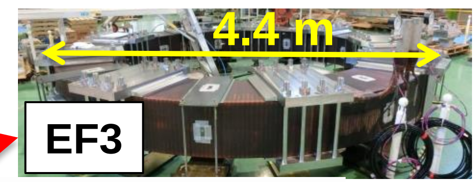
coming on the Pacific Ocean

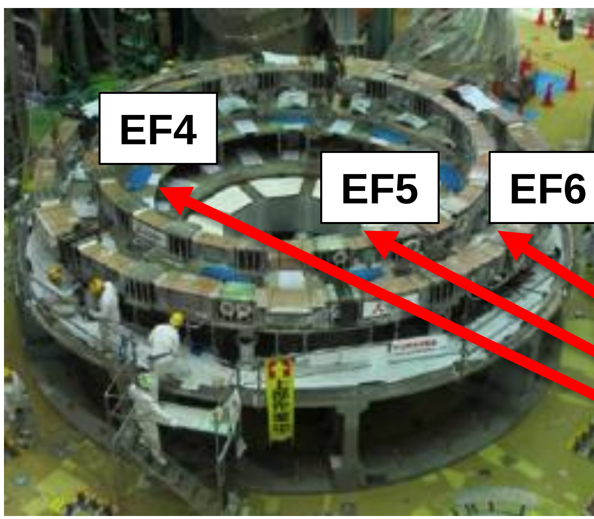
TF coil assembly around the vacuum vessel will start in December 2016.

Equilibrium Field Coils (NbTi)

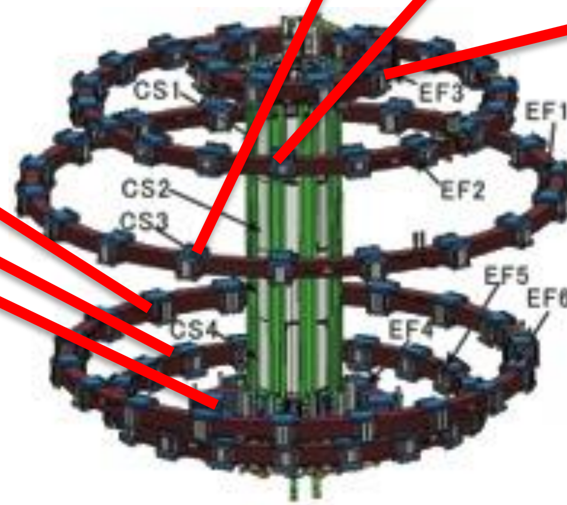
All EF coils were manufactured with excellent accuracy in the circularity for minimizing error field.

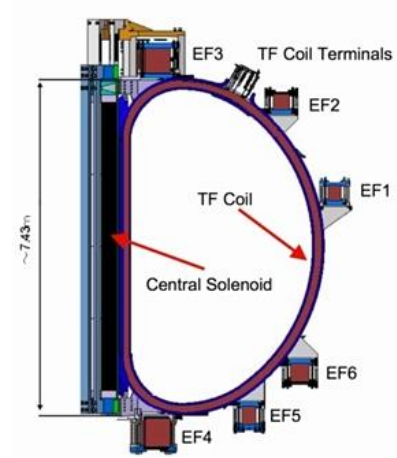
	Diameter	Circularity	Requirement	fabrication
EF1	12.0 m	0.3 mm	≤8 mm	Aug. 2016
EF2	9.6 m	0.4 mm	≤7 mm	
EF3	4.4 m	0.2 mm	≤6 mm	
EF4	4.4 m	0.6 mm	≤6 mm	Feb. 2013
EF5	8.1 m	0.6 mm	≤7 mm	Jan. 2014
EF6	10.5 m	1.3 mm	≤8 mm	





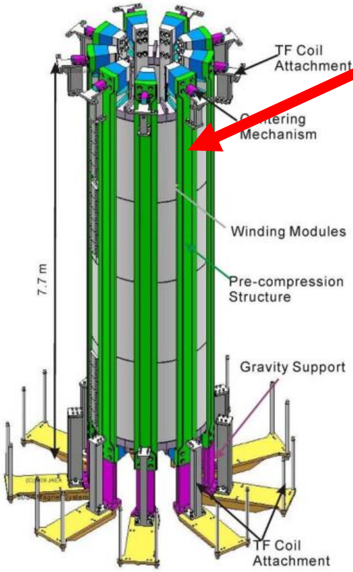
EF4, EF5 and EF6 are temporally placed on the Cryostat Base.





Central Solenoid (Nb_3Sn)

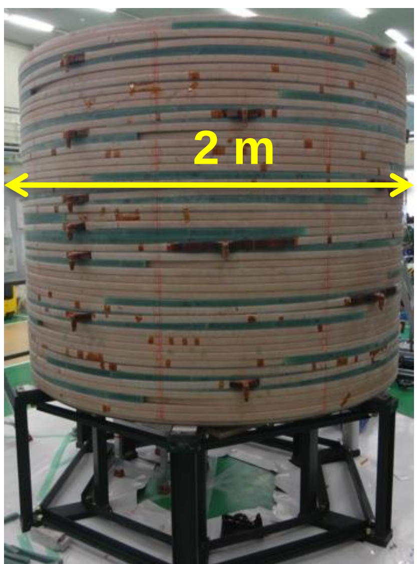
JT-60SA has 4 identical Central Solenoids (CS)



(1) winding of conductor

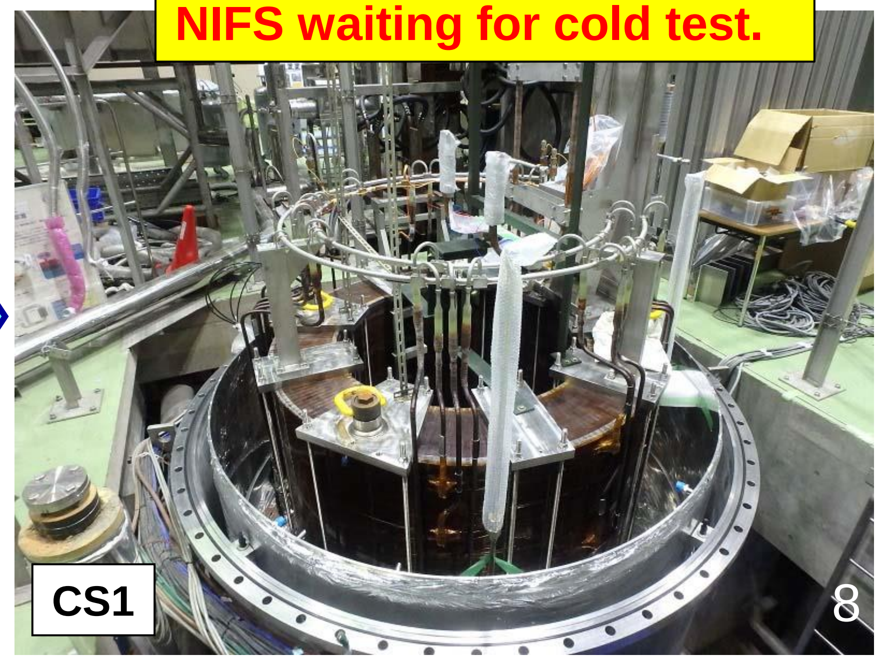
One CS module is composed of 7 pancakes (6 OP and 1 QP).

(2) insulation and stacking



(3) impregnation

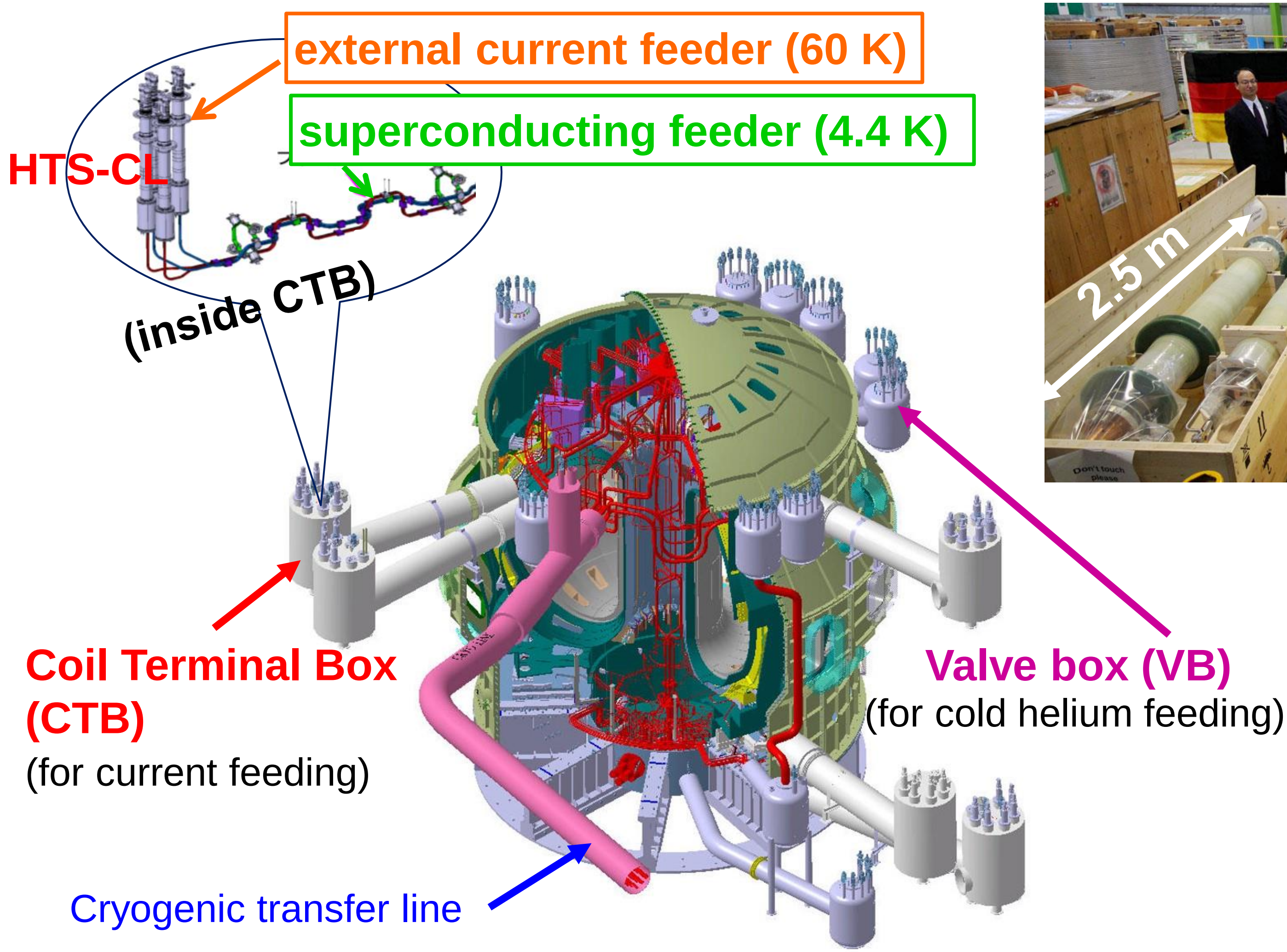
(4) 1st CS module is now in NIFS waiting for cold test.



High Temperature Superconductor Current Leads, Coil Terminal Boxes and Valve Boxes

High Temperature Superconductor Current Leads (HTS-CLs) using bismuth alloy (Bi-2223/AgAu) saves cooling power of the cryogenic system.

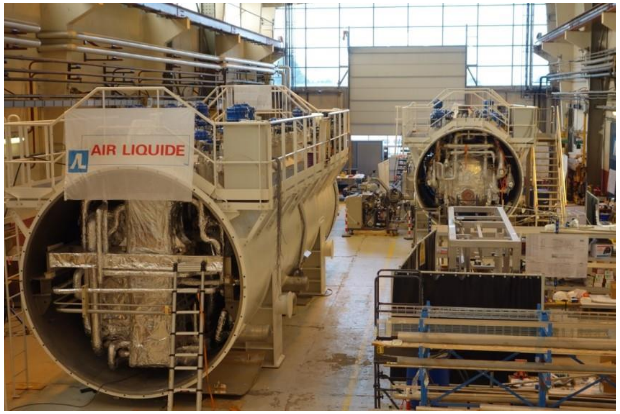
(6 HTS-CLs (25.7kA) for TF coils, 20 HTS-CLs (20kA) for EF coils and CS)



(test facility CuLTKa in KIT)

Cryogenic Plant has been newly constructed in the Naka Site.

Refrigerator Cold Box & Auxiliary Cold Box



Naka Site on 7 April 2015

Helium Storage vessels

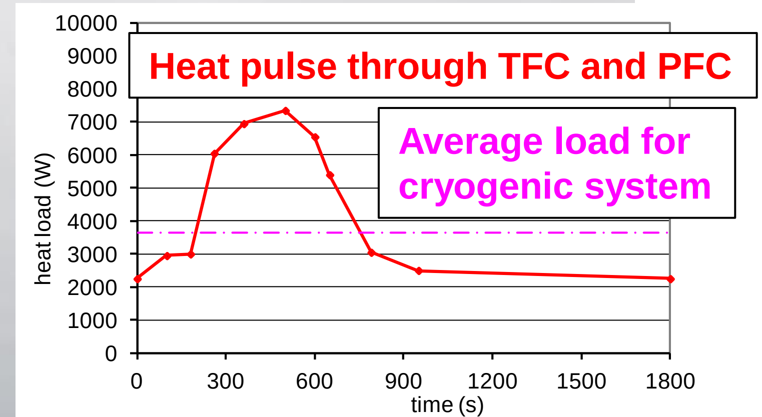
Naka Site on 27 May 2015

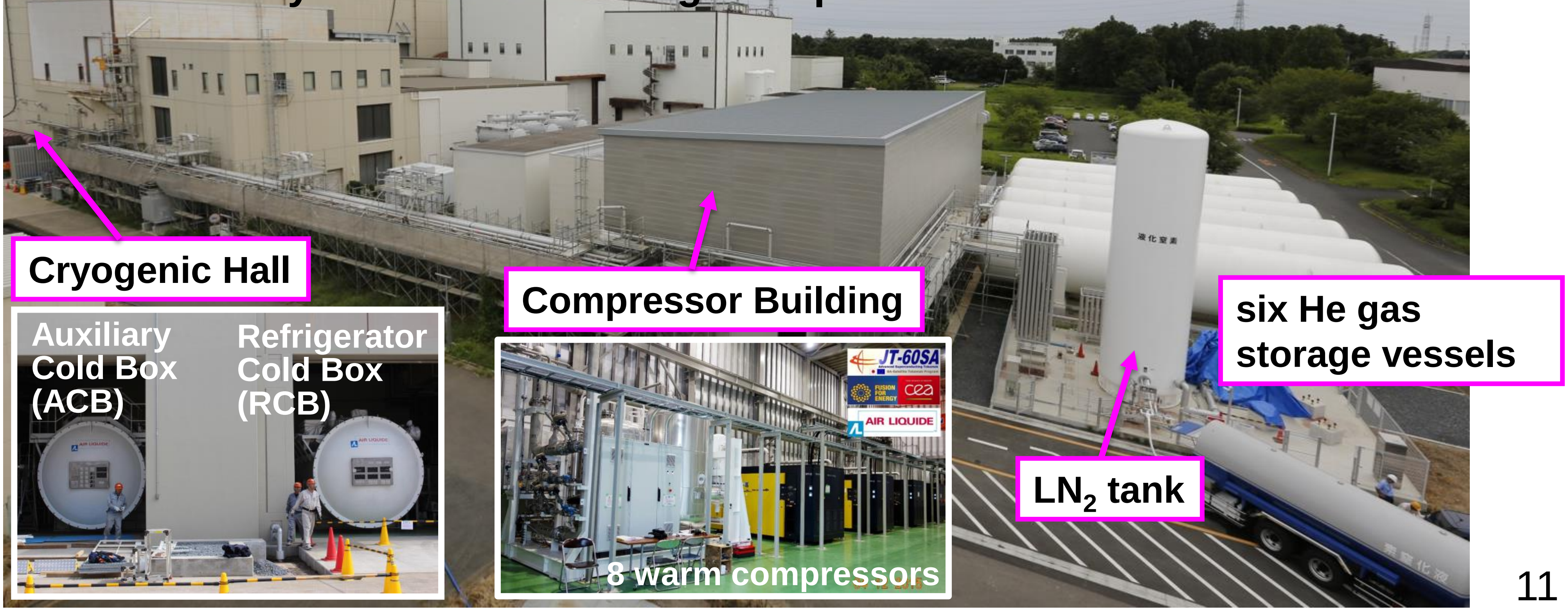
Warm Compressors

Construction Work in Naka Site

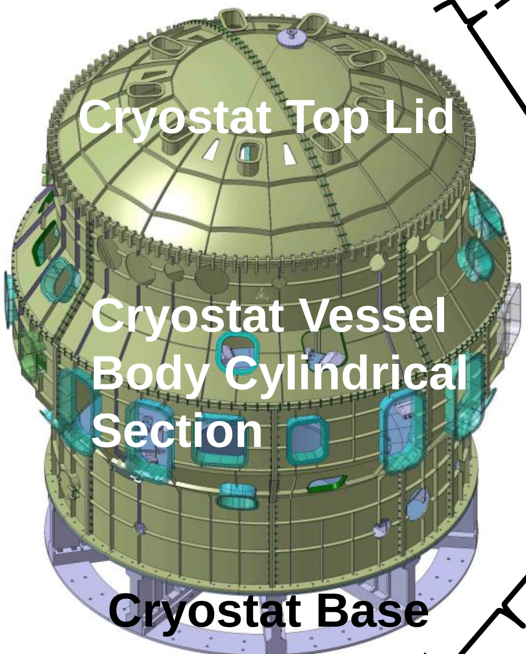
Commissioning of the Cryogenic System was successfully completed.

- The total power equivalent at 4.5K is about 9kW. (world largest class refrigerator for a fusion plant before ITER)
- Adoption of Auxiliary Cold Box facilitates heat load smoothing.
- Actual operational condition were tested and validated by the commissioning in Sep. 2016.

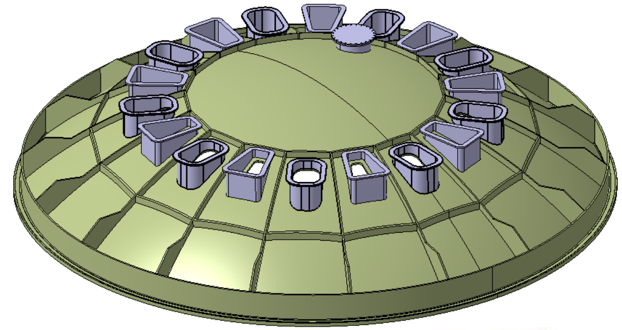




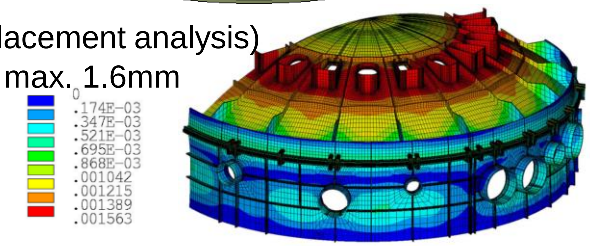
Fabrication of three cryostat parts



45 ton, 11.6 mø

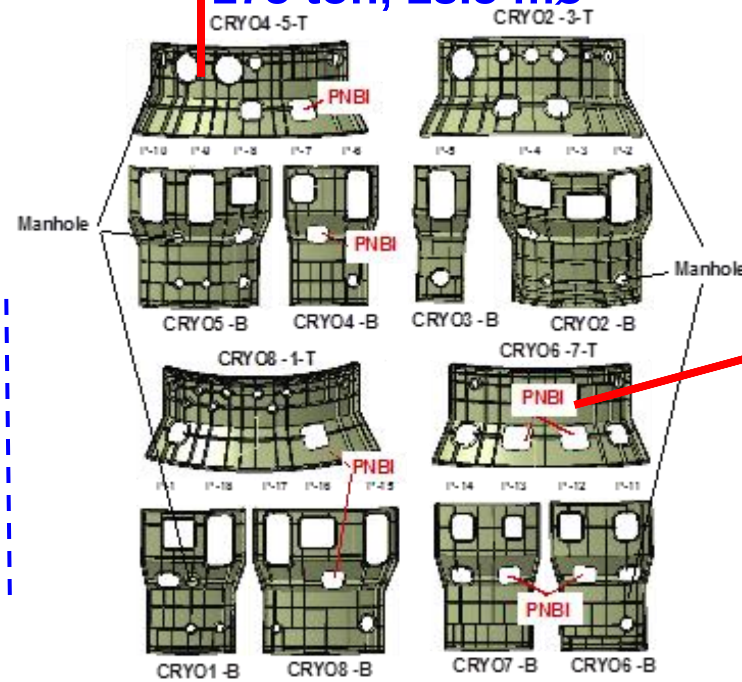


(displacement analysis)
max. 1.6mm



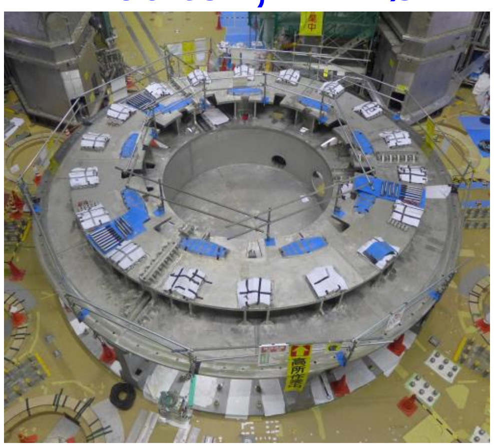
detailed design completed

175 ton, 13.5 mø



under fabrication

260 ton, 12 mø



assembled in March 2013

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Advanced Superconducting Tokamak
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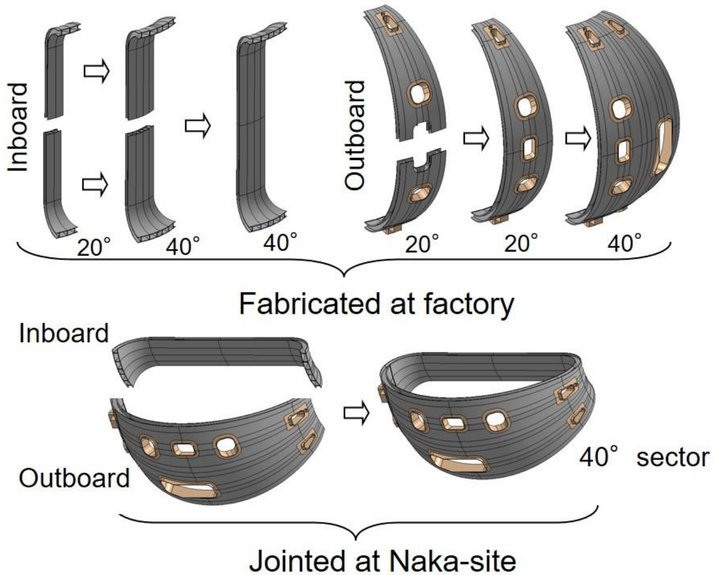
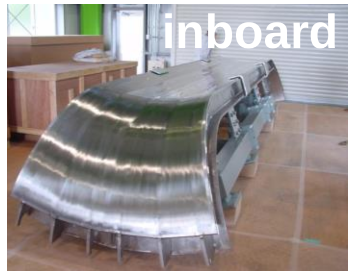
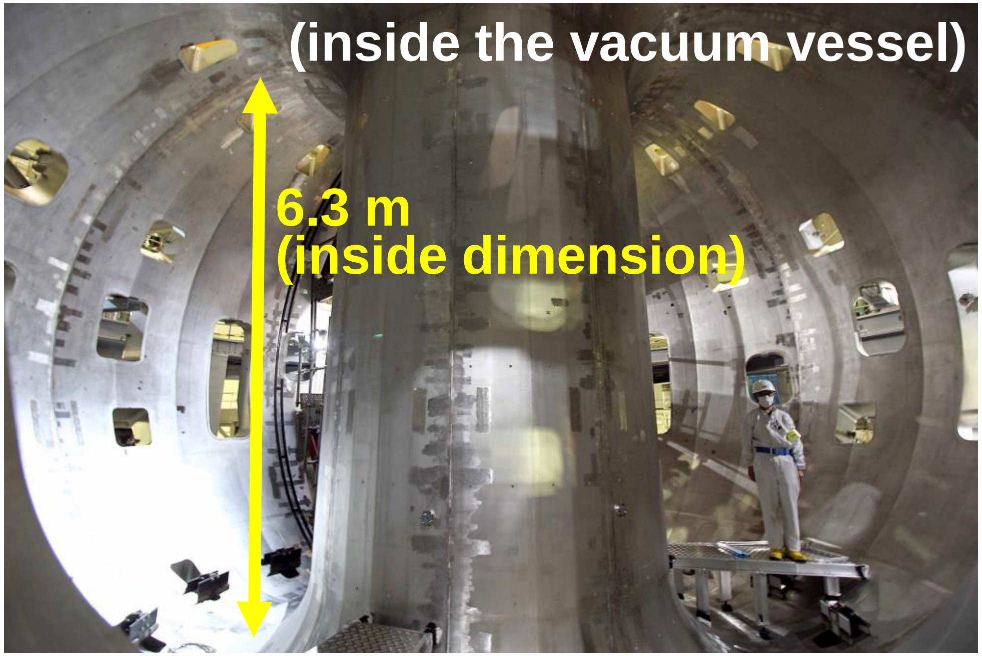
340° Vacuum Vessel was completed





First delivery of 40° inboard sector in Apr. 2011

Thermal Shields are being installed.



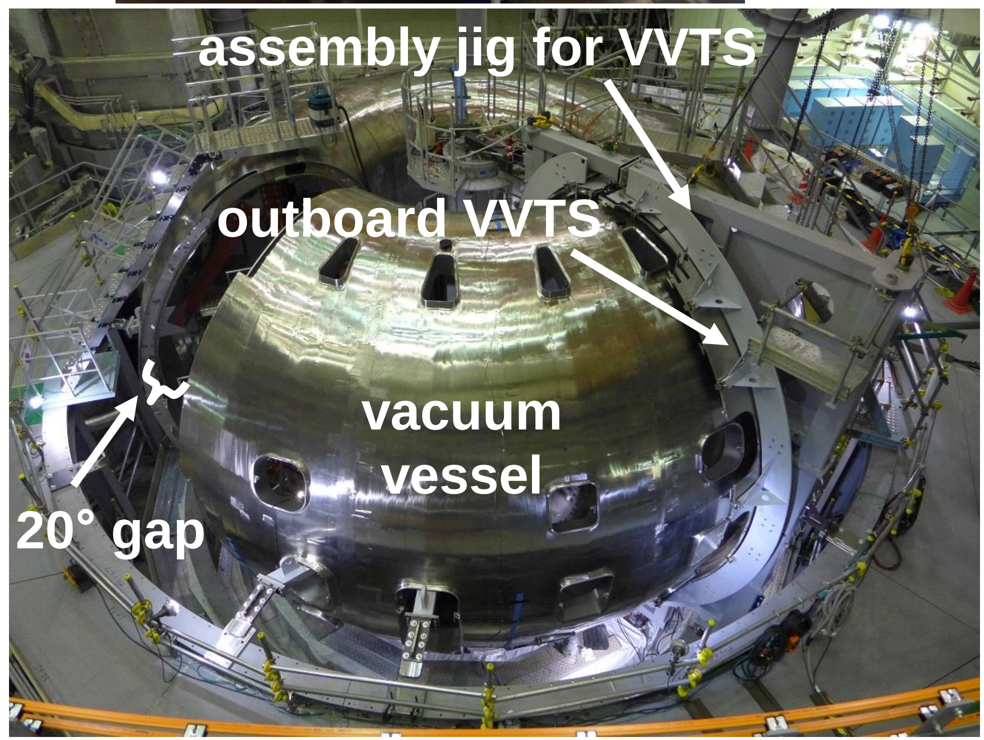
40° VVTS

in the VVTS manufacturer

High dimensional accuracy was achieved by careful welding work.

	actual	Requirement
horizontal	±5 mm	±30 mm
vertical	-4 mm	+6/-4 mm

(Welding shrinkage in the torus direction was adjusted by welding with splice plates.)



VVTS assembly will be completed in Nov. 2016.

Power Supply System

SCMPS (Superconducting Magnet PS)

Base PS to provide DC current to the SC coils

PS for EF2~EF5 and TF coils

delivered to Naka in June 2016

PS for CS1-4 modules, EF1,EF6 coils

to be delivered in 2017

SNU (Switching Network Unit)

Booster PS to provide high voltage for plasma breakdown and current ramp-up

delivered to Naka in Oct 2016

QPC (Quench Protection Circuit)

Protection of SC coils when quench or PS failure occur

10 units for EF coils and CS modules

3 units for TF coils,

Commissioning in June 2015

Motor Generator (reused facility)

Provide power for P-NBI, N-NBI, EF&CS PS

H-MG: 18kV/400MVA, 2.6GJ

T-MG: 18kV/215MVA, 4.0GJ

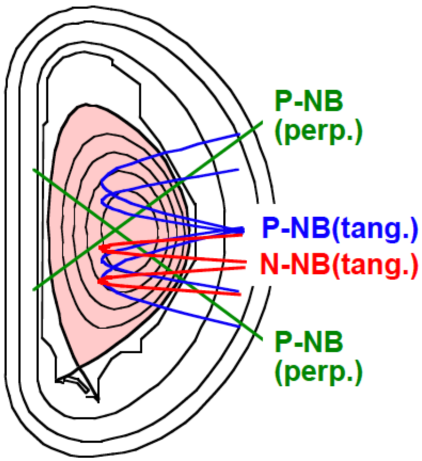
Overhaul of H-MG was carried out in 2015

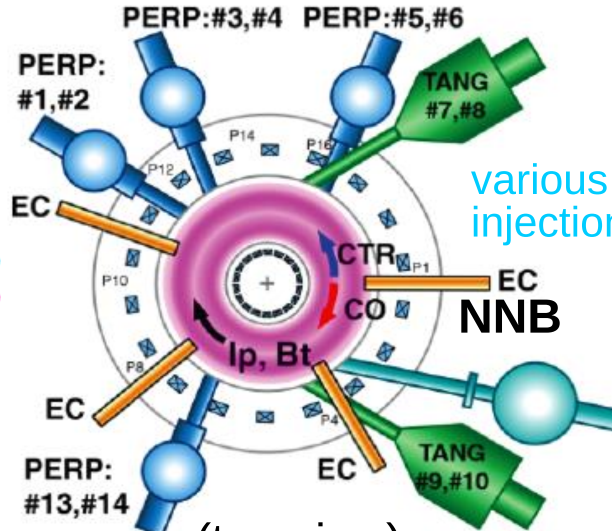
Powerful and versatile heating/CD by NBI and ECRF (41MW in total)

JT-60SA Advanced Superconducting Tokamak
BA-Satellite Tokamak Program

NBI system

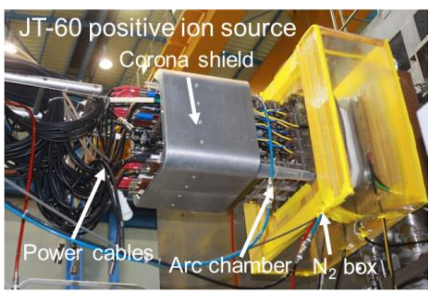
- P-NBI, 85keV, 12units × 2MW=24MW, 100s
  tangential 4u (CO:2u, CTR:2u), Perpendicular: 8u
- N-NBI, 500keV, 2units×5MW=*10MW*, 100s
  tangential, off-axis





(top view)

various beam injection angle



(P-NBI ion source)

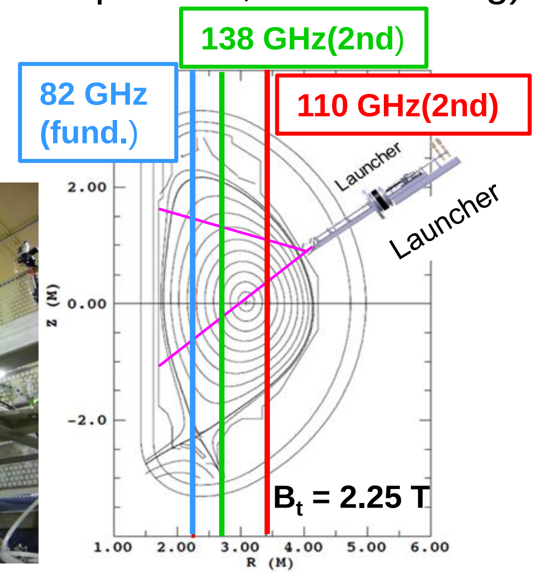
Beam acceleration of 85 keV was successfully demonstrated for 100s (P-NBI).

Heating, current-drive and momentum-input profiles can be flexibly controlled.

ECRF system

- 9 Gyrotrons, 4 Launchers
  7MW in total
  <5kHz power modulation
- movable mirror at launcher
- multi-frequency gyrotron
  110GHz(2nd) (1MW,100s) +
  138GHz(2nd) (1MW,100s) +
  82GHz(fund.) (1MW, 1s)
  (start-up assist, wall cleaning)

(gyrotron)



(launcher)

JT-60SA Advanced Superconducting Tokamak BA-Satellite Tokamak Program

Overall Progress of JT-60SA Project

Research Phases of JT-60SA

- JT-60SA research phase starts with Hydrogen operation to conduct full commissioning.
- JT-60SA is upgraded step by step.

(power/duration of P-NBI&ECRF, divertor target material, remote handling availability)

	Phase	Expected Duration		Annual Neutron Limit	Remote Handling	Divertor	P-NB 85keV	N-NB 500keV	ECRF 110 GHz & 138GHz	Max Power	Power x Time
Initial Research Phase	phase I	1-2y	H	-	R&D	LSN partial-monoblock Carbon Div.Pumping	10MW		1.5MW x100s + 1.5MW x5s	23MW	NB: 20MW x 100s 30MW x 60s duty = 1/30 ECRF: 100s
	phase II	2-3y	D	4E19			Perp. 13MW Tang. 7MW			33MW	
Integrated Research Phase	phase I	2-3y	D	4E20		LSN full-monoblock Carbon Div. Pumping		10MW	7MW	37MW	
	phase II	>2y	D	1E21							
Extended Research Phase		>5y	D	1.5E21	Use	DN/SN full-monoblock Metal or Carbon Advanced Structure	24MW			41MW	41MW x 100s

ITER H / He operation phase

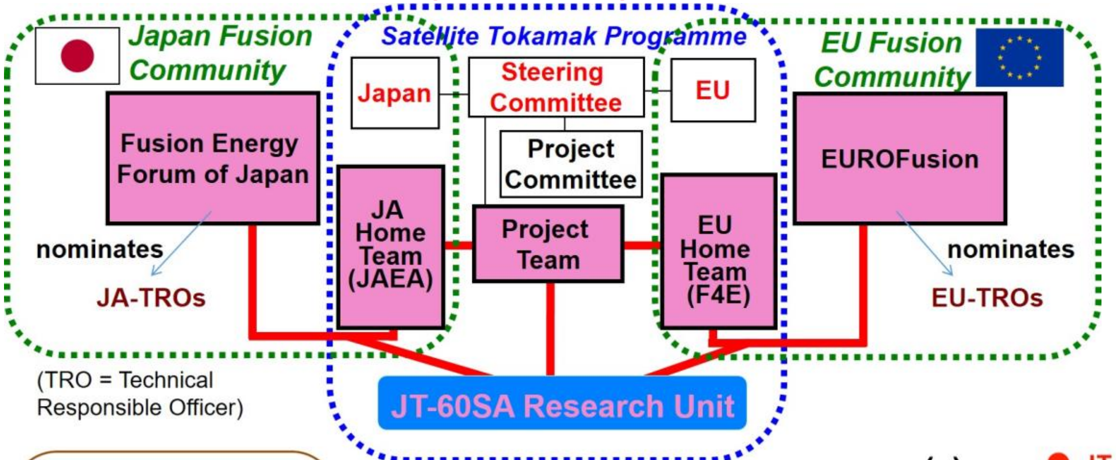
Possibility of W-coated full monoblock CFC (partially bulk W) divertor + full W-coated first wall + fully water-cooled

Partially W (or W-coated CFC) divertor tiles

(address compatibility of metallic divertor with integrated high performance plasmas)

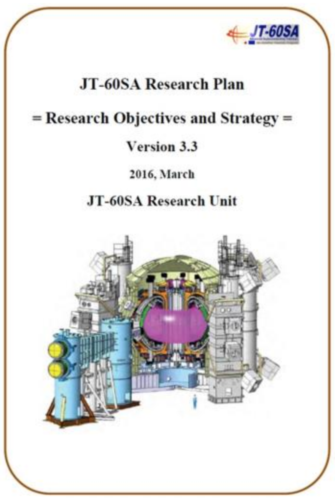
EU/JA Research Collaboration on JT-60SA Project

- **Research collaboration on JT-60SA Project is strongly promoted.**
- **EU and JA fusion community members join "JT-60SA Research Unit" to study key physics and engineering issues of ITER and DEMO.**



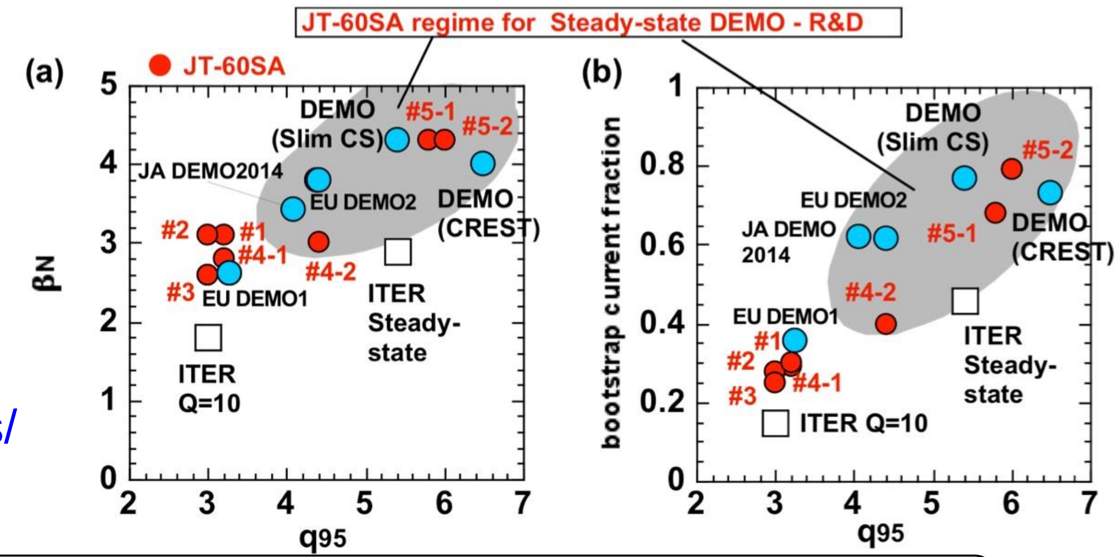
(TRO = Technical Responsible Officer)

5th. EU&JA Research Coordination Meeting (May 2016, Naka)



JT-60SA Research Plan (ver. 3.3) written by 378 authors from EU/JA was open to public in March 2016.

http://www.jt60sa.org/pdfs/JT-60SA_Res_Plan.pdf



JT-60SA target region covers ITER target and **DEMO target**.
Thus their acceptable parameters will be investigated by JT-60SA operation.

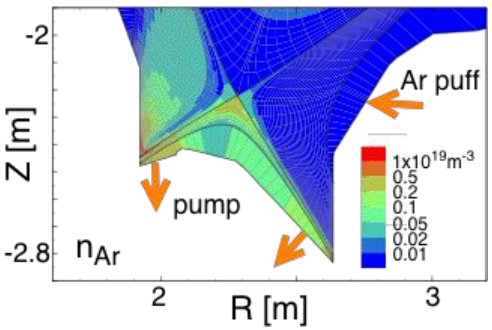
JT-60SA as a flexible 'Test Stand' for ITER

- **ITER like operation environment**
  - ITER like non-dimensional parameters, small-torque input
  - Electron heating dominant plasma (by N-NBI, ECRF)
  - Large fraction of energetic particle (500 keV N-NB)
  - Operation scenario optimization with superconducting coils.
- **High Plasma Performance**
  - H-mode operation (H, He, D) study (I_p ~ 5.5 MA) towards Q=10
    - L-H transition, Pedestal Structure, Confinement Improvement
    - H-mode compatibility with radiative divertor, RMP, etc.
    - Confinement in high n_{GW} regime
    - Effect of Local Ripple, Error Field / noise on confinement
  - Improved H-mode (Hybrid) operation with ITER-like shape (I_p ~ 4.6 MA)
- **Divertor Integrity**
  - ELM mitigation (RMP, pellet pacing, etc.) & small / no ELM regime at low ν^*
  - Divertor Heat Load reduction (radiative divertor, ITER-like divertor config.)
  - Disruption avoidance & mitigation at high I_p (MGI, etc.)
- **High β_N plasma**
  - MHD instability suppression at small~zero rotation condition

Research and Development for tokamak operation

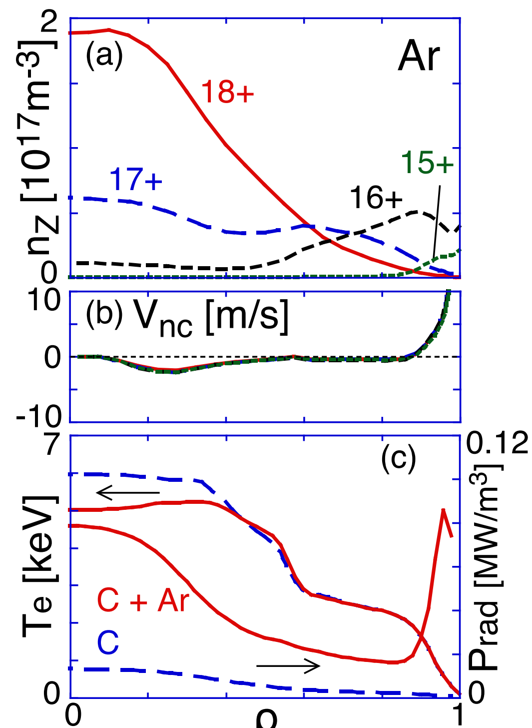
TH/P2-19 (N. Hayashi) [Tue.]

Core-edge coupled predictive modeling of JT-60SA high-beta steady-state plasma with impurity accumulation has been studied.



← Ar density profile calculated by SONIC

1.5D core transport solver (TOPICS) + IMPACT using SONIC Ar edge densities →

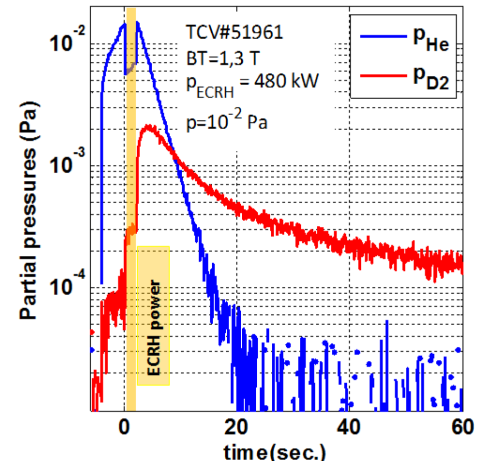


Ar seeding is effective for reduction of divertor heat load below 10 MW/m². Ar^{16-18+} accumulation in core causes slight decrease of temperature, which is fully recoverable by additional core heating.

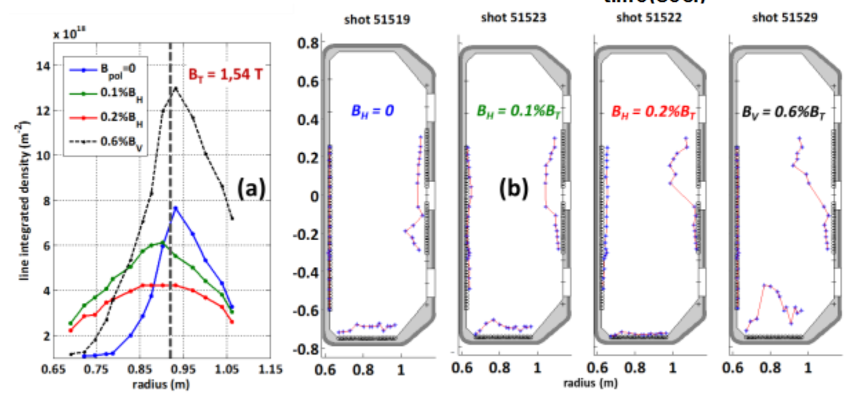
EX/P8-31 (D. Douai) [Fri.]

EC Wall Conditioning (ECWC) experiments to support JT-60SA operation have been performed by TCV.

ECWC efficiency assessed from amount of released D_2 fuel →



Ion saturation current profile changes with B_H and B_V . ↓



Optimized combination of B_H and B_V are required for effective wall conditioning.

see more in EX/P8-40 (G. Giruzzi, M. Yoshida) [Fri.]

JT-60SA Advanced Superconducting Tokamak BA-Satellite Tokamak Program

Summary of JT-60SA Project

1. Fabrication, installation and commissioning of JT-60SA components and systems procured by EU and Japan are steadily progressing. TF coil assembly around the vacuum vessel will start soon. JT-60SA starts operation in 2019.
2. Powerful and versatile NBI/ECRF system, flexible plasma shaping, various kinds of in-vessel coils are advantage of JT-60SA for plasma control.
3. JT-60SA will explore ITER and DEMO relevant parameter region in advance for the purpose of optimization of their operational scenarios, especially in high β_N (~5) region.
4. Close research collaboration between EU and Japan has been promoted. JT-60SA Research Plan v.3.3 by 378 researchers from EU and Japan released in March 2016 elaborates on key physics and engineering issues to be addressed for ITER and DEMO.

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JT-60SA related presentations in this conference

18 Oct (Tue)

FIP/1-3Ra (J. Hiratsuka)	Long-pulse acceleration of 1MeV negative ion beams toward ITER and JT-60SA neutral beam injectors & towards powerful negative ion beams at the test facility ELISE for the ITER and DEMO NBI system
TH/P1-18 (T. Bolzonella)	Securing high β_N JT-60SA operational space by MHD stability and active control modelling
TH/P2-19 (N. Hayashi)	Core-edge coupled predictive modeling of JT-60SA high-beta steady-state plasma with impurity accumulation
TH/P2-20 (M. Romanelli)	Investigation of Sustainable Reduced-Power non-inductive Scenarios on JT-60SA

19 Oct (Wed)

FIP/P4-42 (C. Day)	Assessment of the operational window for JT-60SA divertor pumping under consideration of the effects from neutral-neutral collisions

20 Oct (Thu)

TH/P6-24 (R. Zagorski)	Numerical analyses of baseline JT-60SA design concepts with the COREDIV code

21 Oct (Fri)

FIP/P7-37 (J.-C. Vallet)	Towards the completion of the CEA Contributions to the Broader Approach Projects
EX/P8-31 (D. Douai)	Development of Helium Electron Cyclotron Wall Conditioning on TCV for the operation of JT-60SA
EX/P8-40 (G. Giruzzi)	Physics and operation oriented activities in preparation of the JT-60SA tokamak exploitation
FIP/4-1Ra (Y. Shibama)	Assembly Technologies of the Superconducting Tokamak on JT-60SA
FIP/4-1Rb (P. Decool)	JT-60SA TF Coil Manufacture, Test and Preassembly by CEA