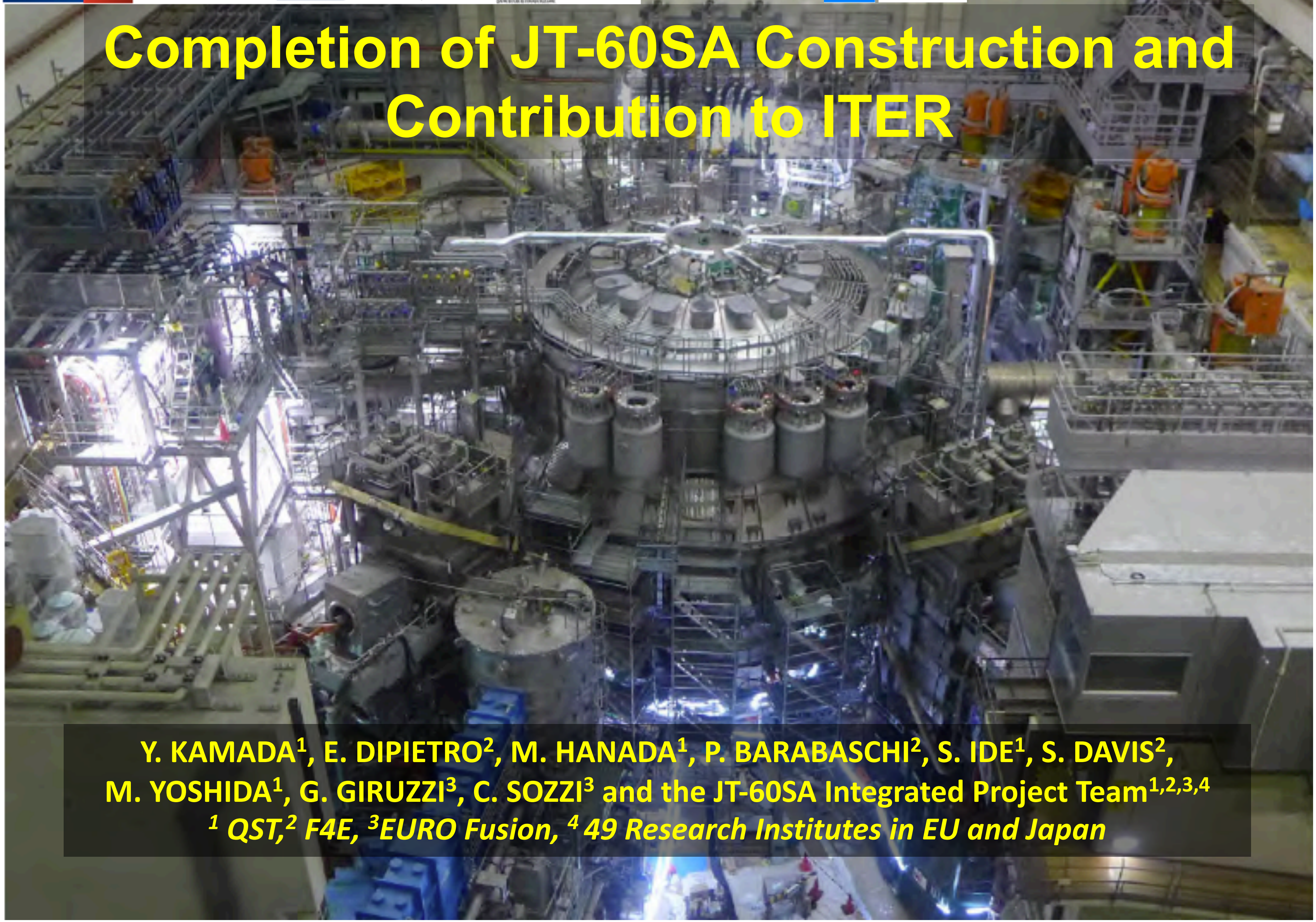
Completion of JT-60SA Construction and Contribution to ITER



Y. KAMADA[1], E. DIPIETRO[2], M. HANADA[1], P. BARABASCHI[2], S. IDE[1], S. DAVIS[2], M. YOSHIDA[1], G. GIRUZZI[3], C. SOZZI[3] and the JT-60SA Integrated Project Team[1,2,3,4]

[1] QST,[2] F4E, [3]EURO Fusion, [4] 49 Research Institutes in EU and Japan

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

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

1. Support ITER
using break-even-equivalent class high temperature D-plasmas lasting for a duration typically 100s.

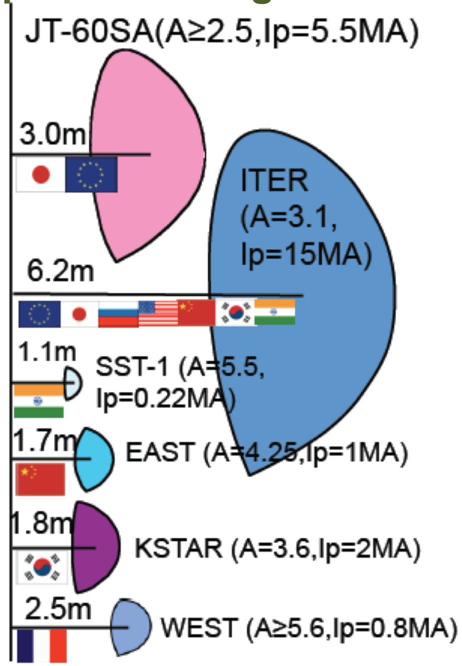
Engineering contribution to ITER as the largest superconducting tokamak system. (size ~ 10 – 15m, weight ~2300 t)

2. Supplement ITER toward DEMO
with long sustainment (~100s) of high pressure steady-state plasmas necessary in DEMO

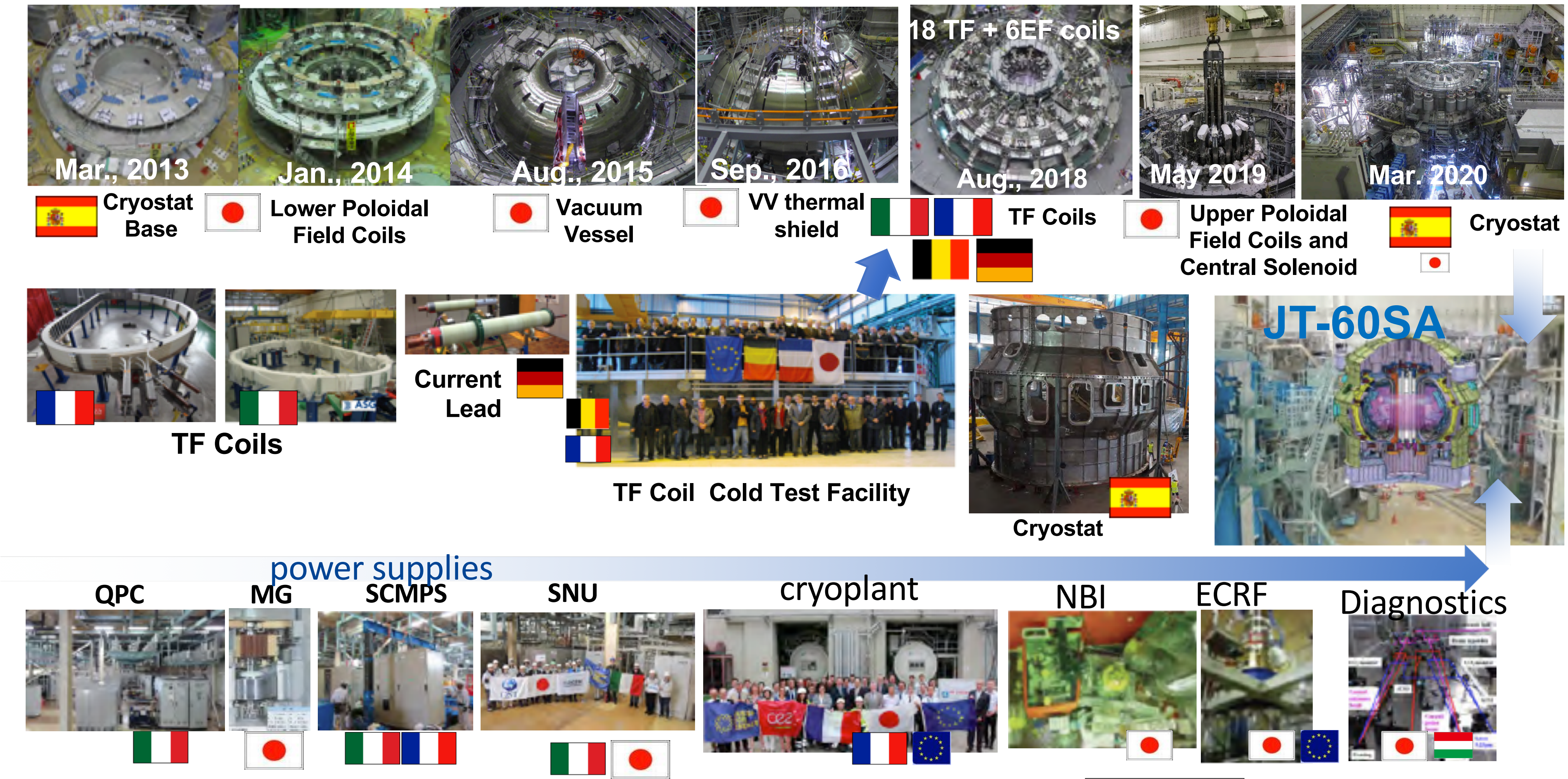
3. Foster Next Generation
playing leading roles in ITER & DEMO

The ITER – JT-60SA collaboration arrangement signed in Nov. 2019 covers assembly, integrated commissioning and operation/experiments for risk mitigation and efficient implementation of ITER.

Superconducting tokamaks



JT-60SA Project: Started in 2007 between EU & Japan Construction & Research Planning



JT-60SA Research Plan

JT-60SA Research Unit
Started in 2010

Ver. 3.0 2011

Ver. 3.1 2013

Ver. 3.2 2015

Ver. 4.0 2018

by 416 co-authors (40 institutes)

Tokamak Assembly was completed on 31st March, 2020 after 13 years' effort from 2007.

All members of the EU-JA JT-60SA Integrated Project Team share the same clear target (and challenges !) of the Project.

G. Matsunaga, ID 822
Y. Shibama , ID 849

Assembly with High Accuracy

Central Solenoid

Cryostat Vessel Body

Cryostat Thermal Shield

Cryostat Top Lid

CS : 100t, 11m x 2.1m ϕ should be inserted into the central bore of the 18 TF coils keeping a quite narrow clearance less than 14mm.

Using laser tracker, insertion was carefully controlled by continuous adjustment => precise positioning of the magnetic axis within $\pm$1.4mm

Allowable Error Field ~ 10^{-4} of Bt:
Size of Device ~ 10m => Manufacture & assembly target accuracy ~ mm

G. Matsunaga, ID 822

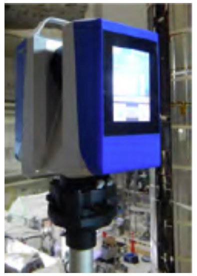
High assembly accuracy of mm order was realized

Good reference for ITER

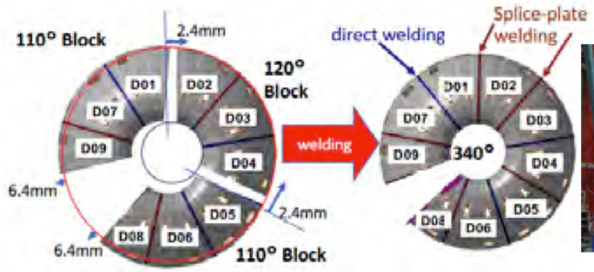
Y. Shibama, , ID 849

Laser Tracker

3D-Scanner

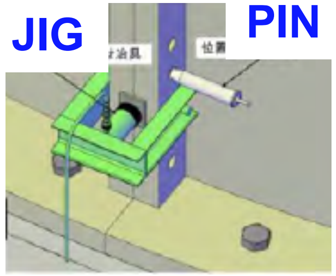


Expectation of shrinkage by welding

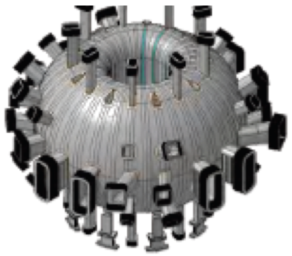


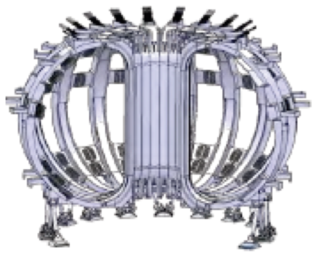
Pre-Assembly

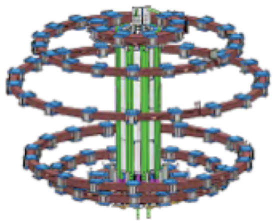
JIG **PIN**

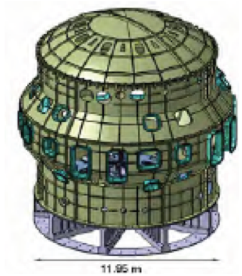


	Typical Size(m)	Weight (t)	Assembly Accuracy	
			Requirement(mm)	Achievement(mm)
Cryostat Base	diameter=12m	280t	≦ ±2mm	≦ ±2mm
VV	R=10m, H=6.7m	150t	≦ ±20mm	+6mm/-16mm
TF coils (18)	D shape 4.6m x 7.5m	387t total	≦ ±5mm	≦ ±1mm
EF coils (6)	diameter=4.4m -12m	114t total	≦ ±2mm	+1.6mm/-2.4mm
CS	Inner Dia./Outer Dia.: 1.3m/2m, Height: 11m	99t total	≦ 2mm	1.4mm horizontally
Cryostat Vessel	D= 13.5m, H=11m	220t total	≦ ±8mm	+7mm/-6mm
Cryostst Top Lid	D=11.5m	55t	≦ ±5mm	3mm/-4mm







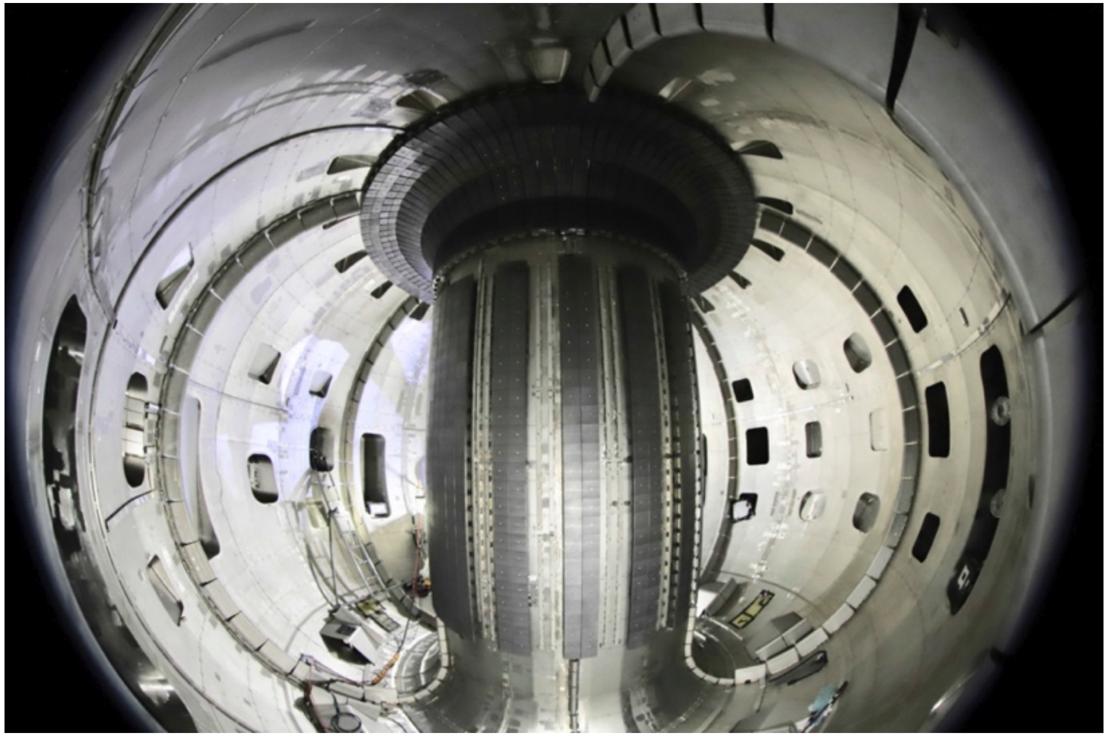


In Vessel : Accuracy of graphite tile alignment within +/-1mm

Machine status in the First Operation period:

the upper divertor plates (Carbon, inertial cooling) ,
partial (50%) coverage of the inner (high field side) first wall,
two Gyrotrons (1MW 110 GHz + 1MW 82/110/138GHz) with waveguide launchers,
power supply & cryoplant ready for the full-operation of the superconducting coils

Assembly of In-vessel components: Interfaces attached to the VV surface were precisely machined based on the VV surface measurements.

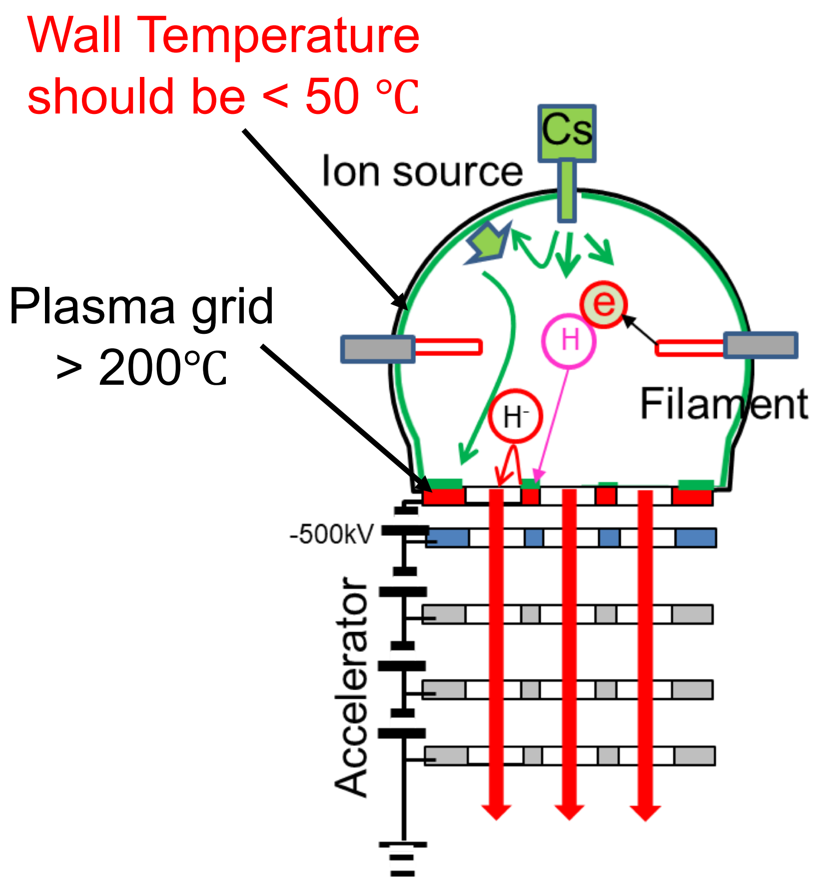


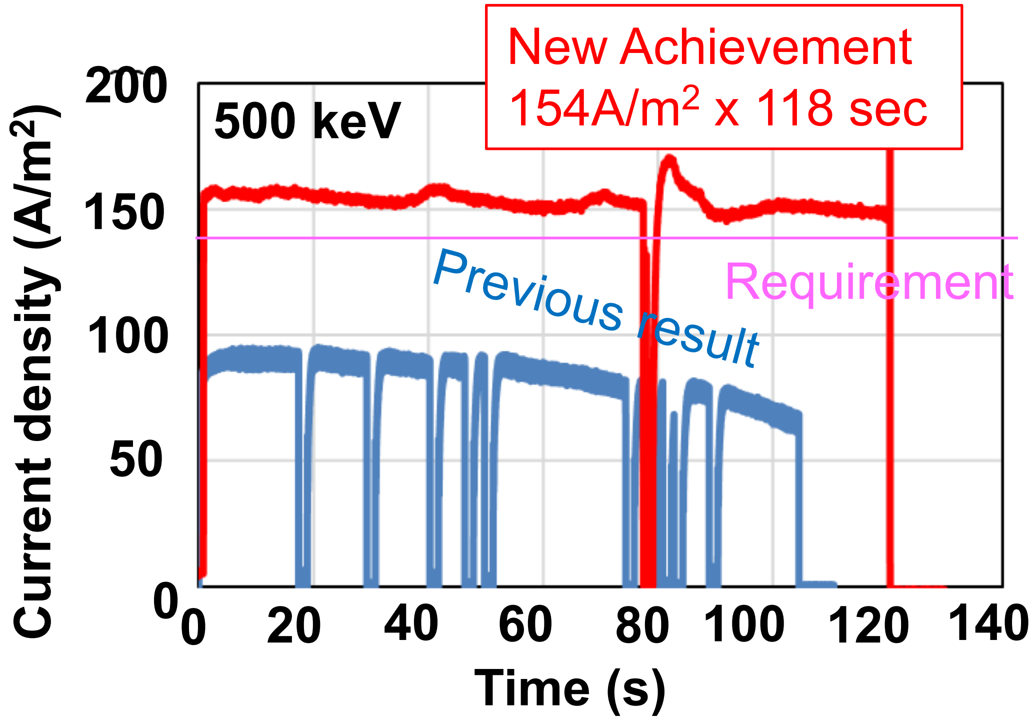
Accuracy of the graphite tile surface alignment < +/-1mm was achieved.

Stable 500 keV negative ion beam was achieved

For negative ion production, Condition of the Cs layer on the plasma grid is essential.

To control Cs, optimum balance of Cs absorption & desorption of the ion source wall was investigated. We found the balance is a clear function of the wall temperature based on simulation and measurement. **=> To ITER N-NBI**





Plasma Diagnostics installed for the first operation phase

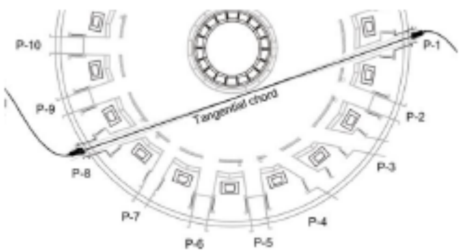
List of diagnostics

Diagnostics	Section	Port/Location
CO_2 Laser interferometer (tangential), Visible spectroscopy (tangential)	P1 and P8	Horizontal
Soft X-ray detector arrays	P14	Horizontal
Visible TV cameras (+ two light guide)	P15	Horizontal
EDICAM	P18	Horizontal
Langmuir probes	P2, P8 and P14	upper divertor

Magnetic sensors

- Rogowski coil: 2
- Diamagnetic loop: 1
- Flux loops: 27
- Magnetic probes: 17
- AT probe: 8

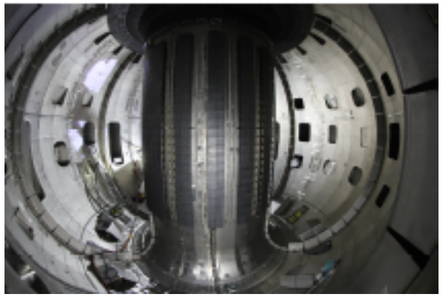
CO2 Laser interferometer



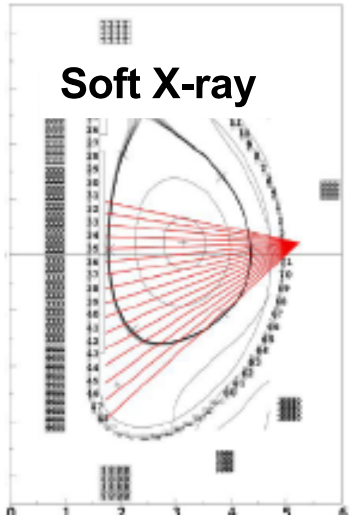
EDICAM

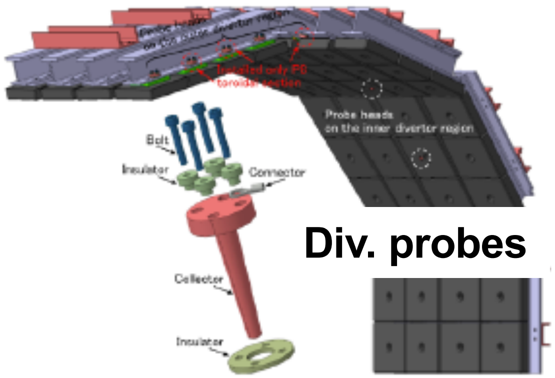
Centre for Energy Research

Visible camera



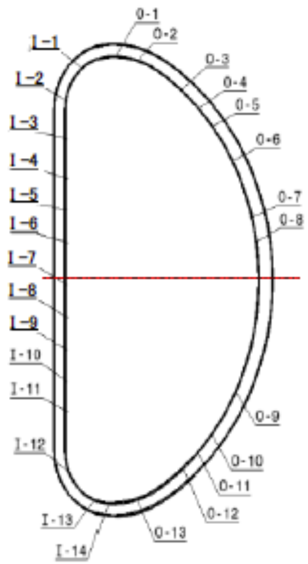
Soft X-ray



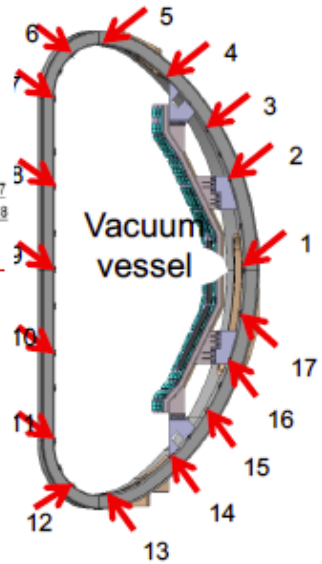


Div. probes

Flux loops



Magnetic probes

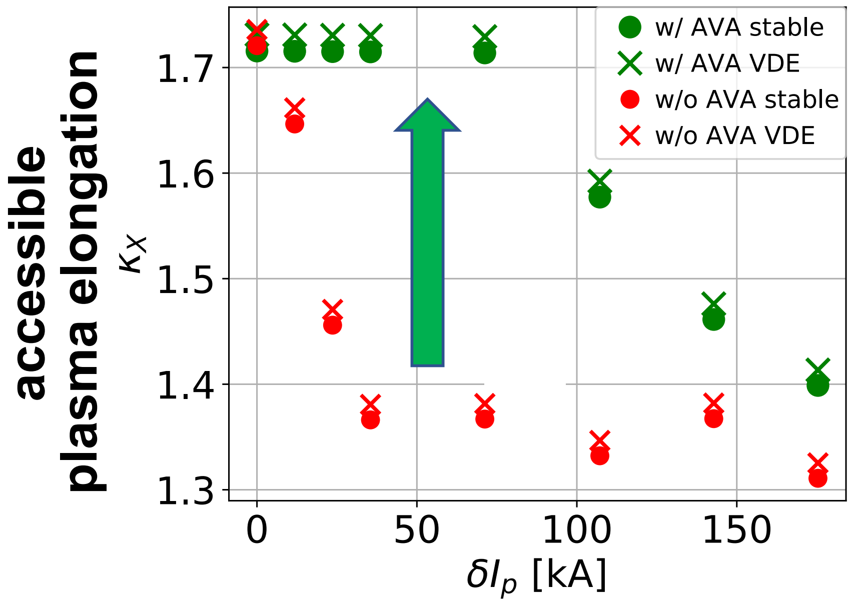


Advanced equilibrium control for plasma operation

A novel control scheme ‘adaptive voltage allocation (AVA)’ :
Feedback gains for both the position/shape and Ip controls are determined in real time adaptively within limits of PF coil power supply voltages.

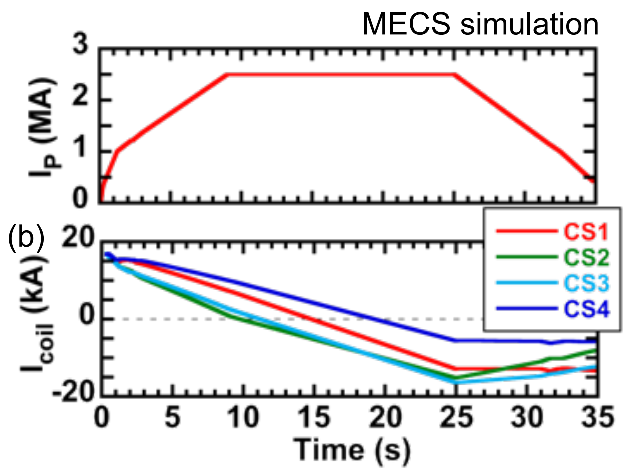
Partial collapse of Ip
=> vertical unstable depending on κ_X
Accessible κ_X is improved

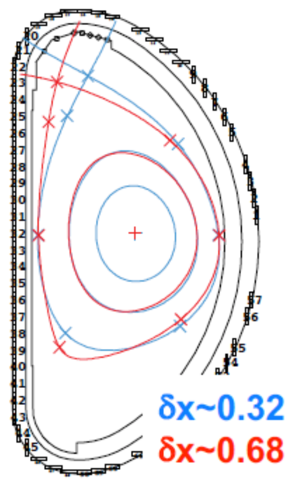
=> Contributes to position & shape control by super conducting coils in ITER & DEMO with limited PF controllability.



sudden drop of plasma current
(Ip = 2MA)

Example of the JT-60SA plasma scenario for the integrated commissioning





Individual Commissioning of cryogenic system established active control to mitigate heat load fluctuation

K. Hamada, ID 877

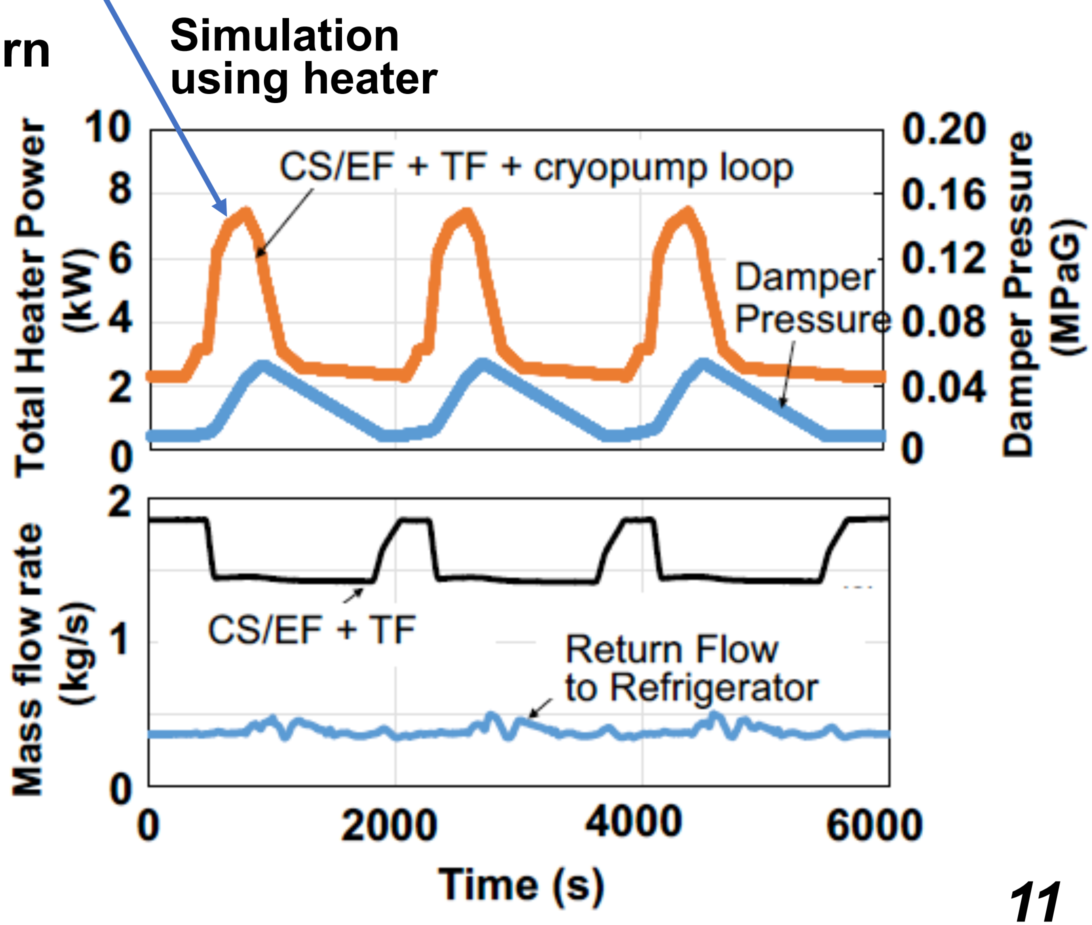
JT-60SA cryogenic system = 9.5kW at 4.5K : Commissioning completed

Active control of heat load fluctuation, essential for dynamic operation in tokamaks, has been established in a large scale cryogenic system. => ITER

JT-60SA: heat load changes: 2.3kW -> 7.4 kW quickly during plasma operation

In order to avoid sudden hot He return from the magnet to the refrigerator,

- **Temporary absorption of the heat by the liquid He damper.**
- **Active reduction of the flow rate of supercritical helium after plasma discharge**

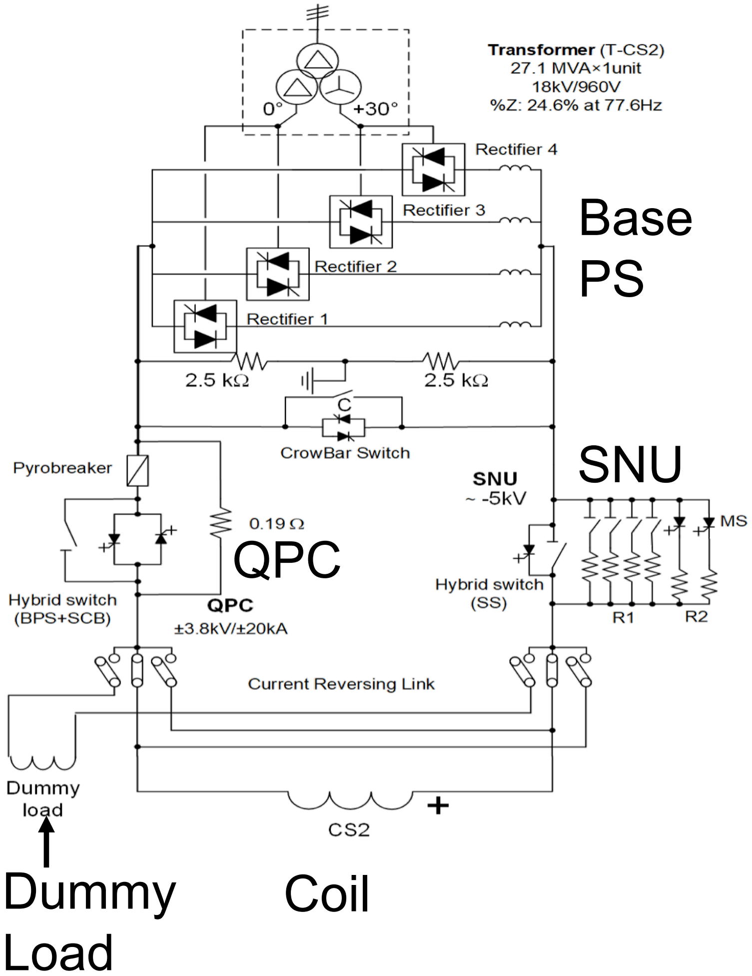


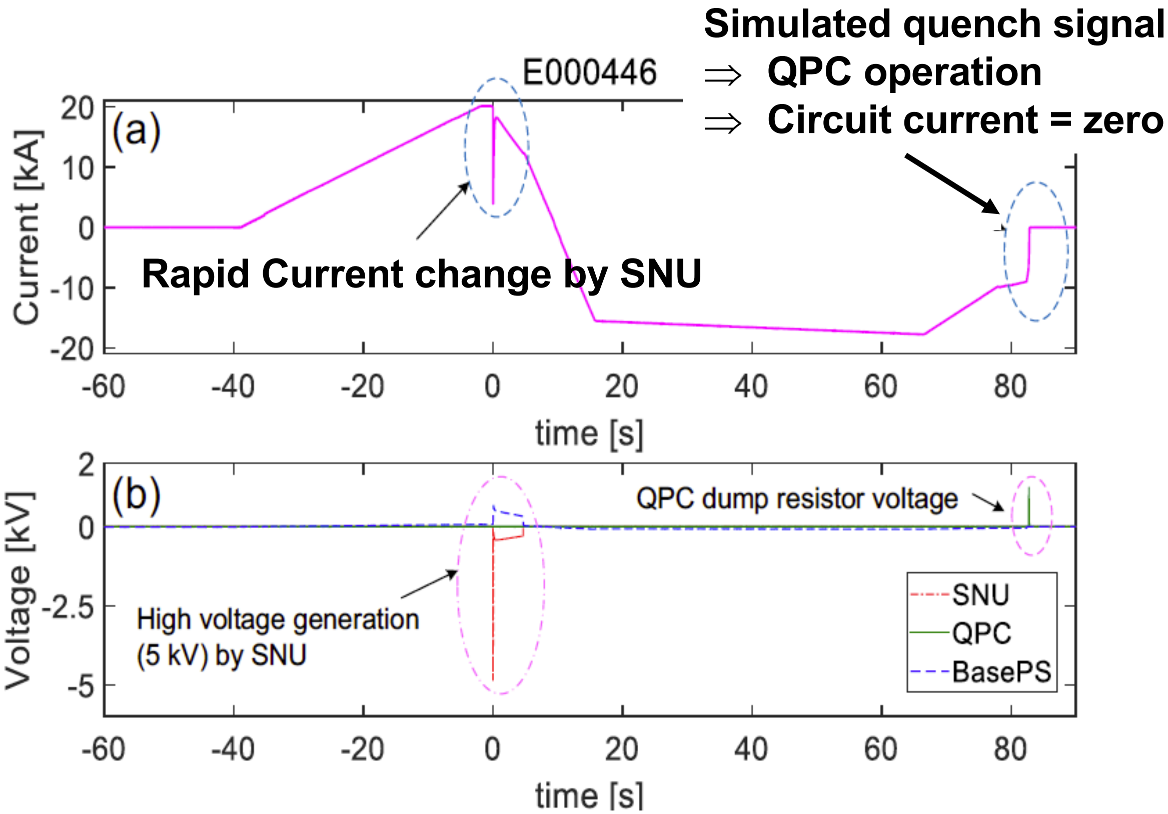
K. Shimada, ID 751

Commissioning of the power supplies completed with dummy load

Integrated operation among Base PS, Switching Network Unit (SNU), Quench Protection Circuit (QPC) , and Booster PS for PFC was completed successfully.

SNU produces high voltage for PF coils at the Plasma start up = used in ITER.





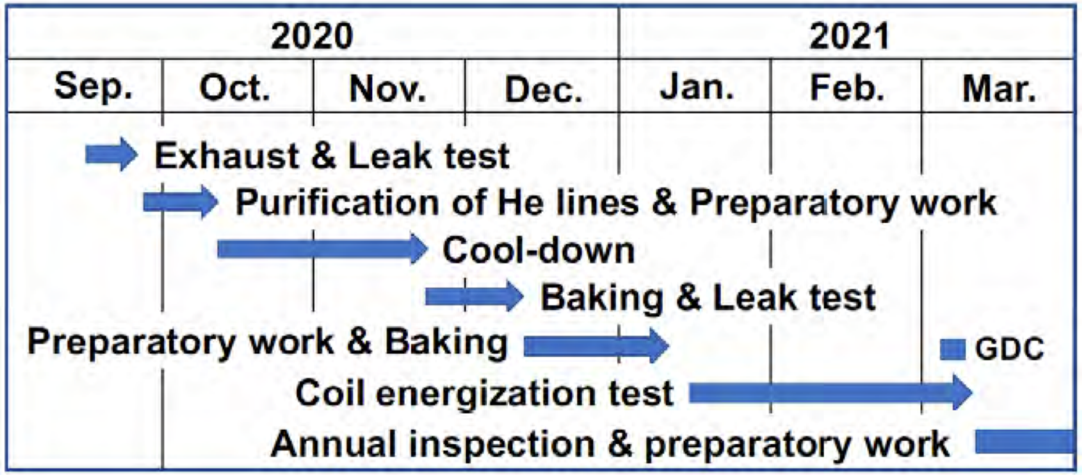

Base PS


SNU


QPC

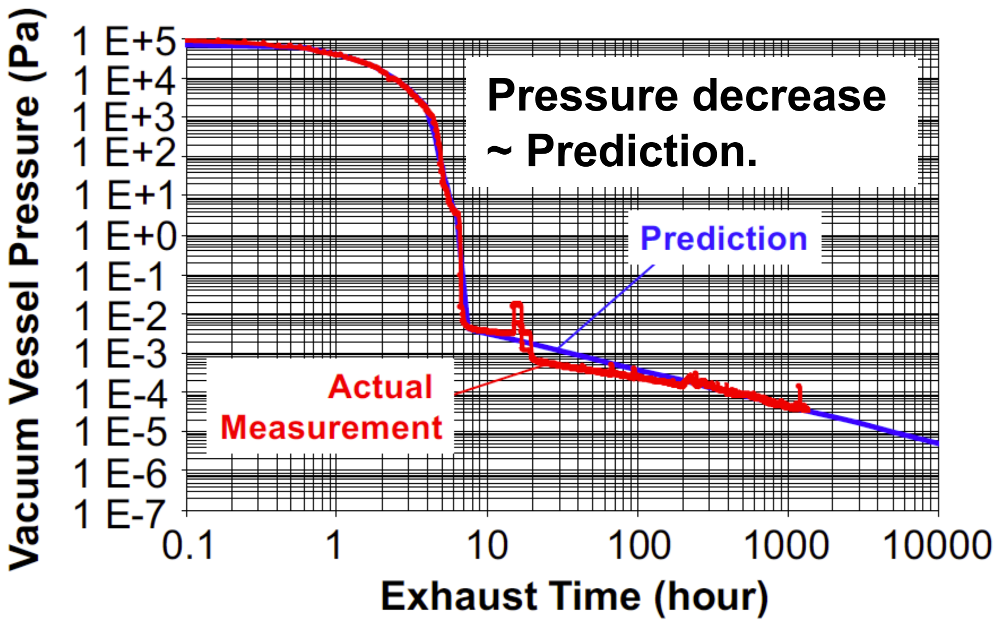

Booster PS

Integrated Commissioning (IC) : smooth cool-down



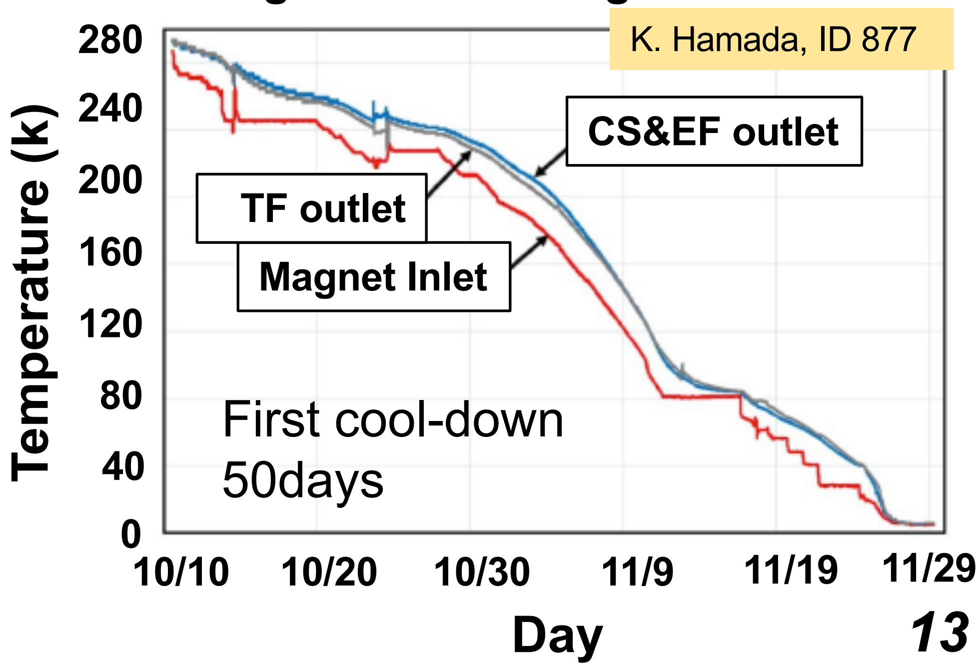
IC: tight EU-JA collaboration using data & screen sharing, video meeting almost every day. Participation from ITER.

Evacuation : VV & CV started middle Sep.
Expected vacuum tightness confirmed.
VV Temp. : 50ºC ⟷ Baking 200ºC



Cool-down Inside CV, 760t of items

Control of Temperature difference
inlet and outlet: <35K
among TF coil windings: <10K



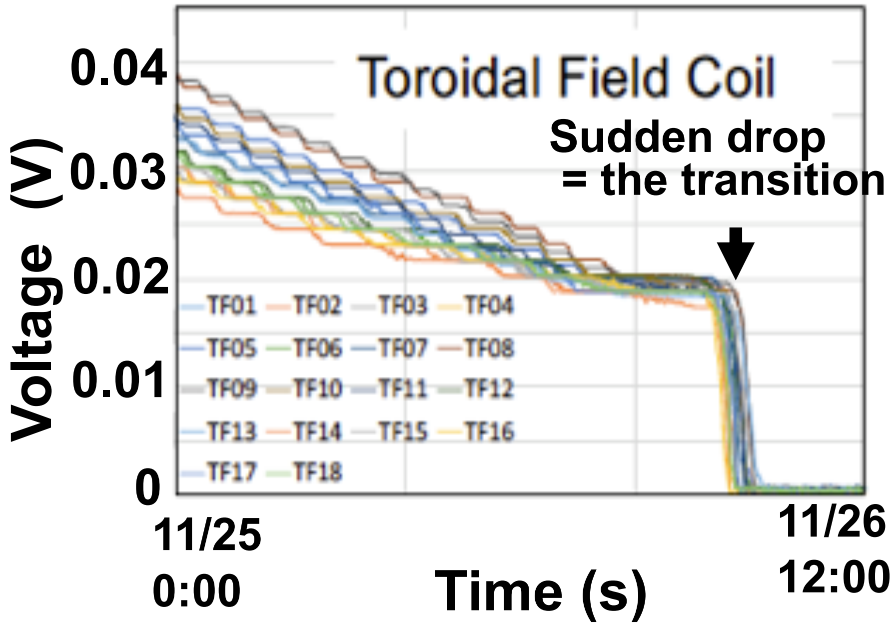
Super-conducting state confirmed for all TF, EF and CS coils
TF coil current reached the nominal value

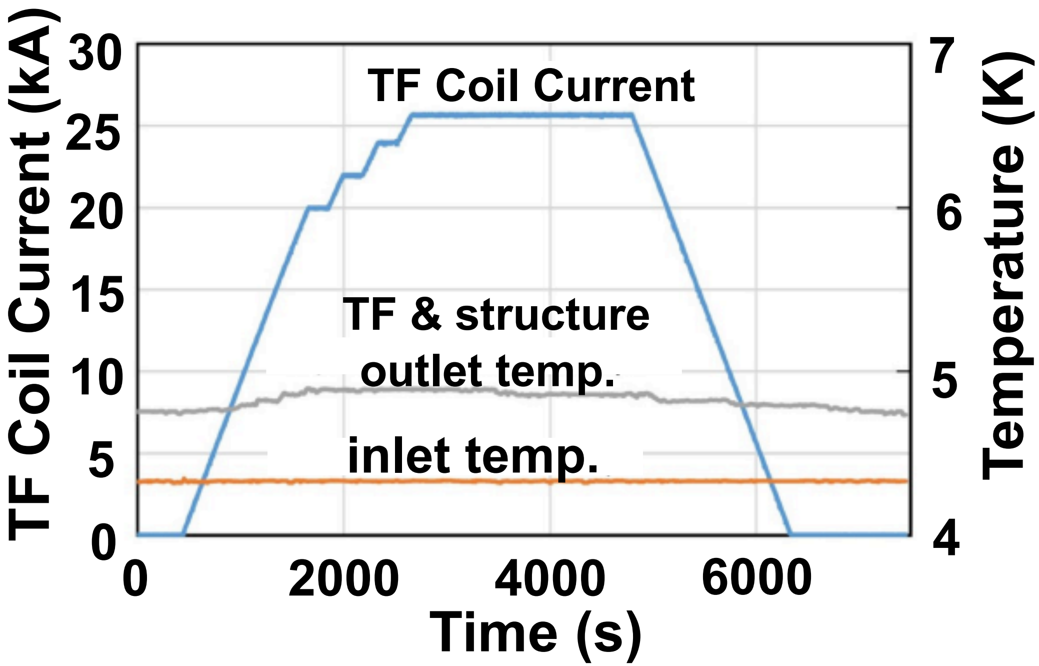
by flowing 20A to the coils and measuring voltages to keep this current.

TF coil current reached
25.7kA (nominal value) = 2.25T of Bt

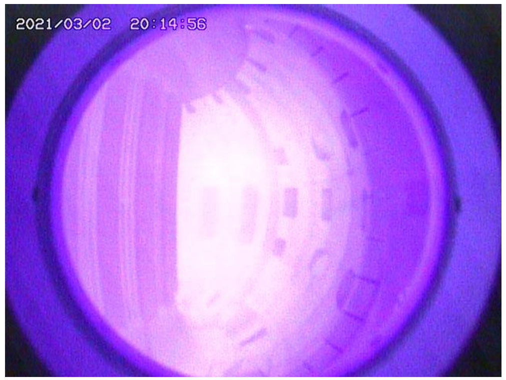
Almost Uniform displacement of 18 TFCs
6.8 mm – 8.3 mm (ave. 7.65mm)

EF coils and CS tested up to 5kA (25% to the full current of 20kA).





ECRF (82GHz , 760kW) plasma



Integrated Commissioning suspended by EF1 Incident

At the last shot of excitation test of a PF coil (EF1) (9th March),

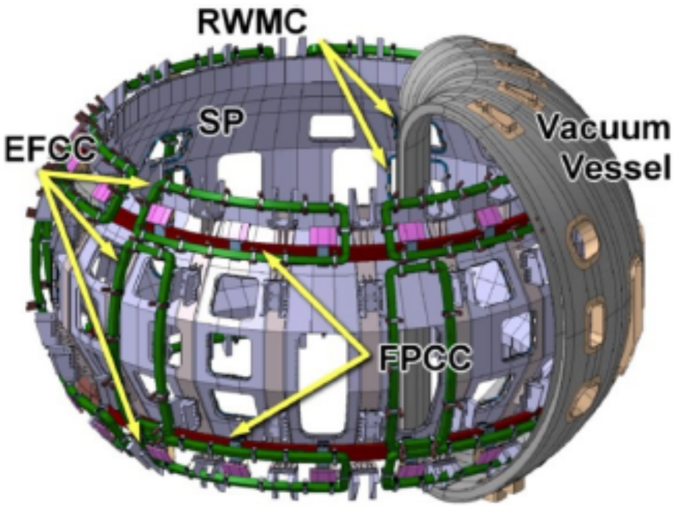
Upon repetitive application of 5-7kV, rapid rise in the coil current occurred.
Power Supply immediately stopped by interlock of over-current.
Discharge continued within a short time, discharging the coil current.
The cryostat pressure increased (7000Pa next day).

Inspection inside the cryostat (from 8th April)
Melted spots: observed at the terminal joints of the coil with He cooling channel.
No damage to the coil itself.
It seems to be due to insufficient voltage holding capability at the joint.
The pressure rise was caused by the He leakage through the melted spots.

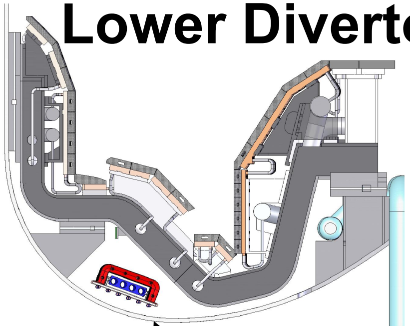
The root cause analysis is underway,
in order to repair the damaged parts effectively & to make sure this will not happen in other similar areas.
The Key will also be to later widely disseminate such analysis to support the consolidation of knowledge necessary for any future superconducting tokamak.
JT-60SA supports ITER, DEMO and fusion also in this way.

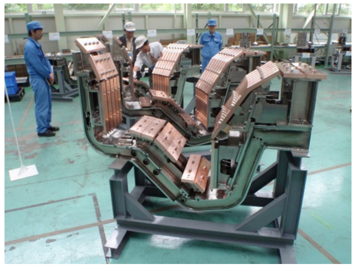
Future Enhancement: design & manufacture ongoing

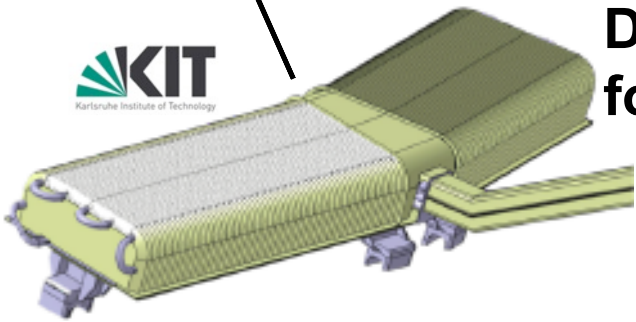
Stabilizing wall, In-vessel coils



Lower Divertor

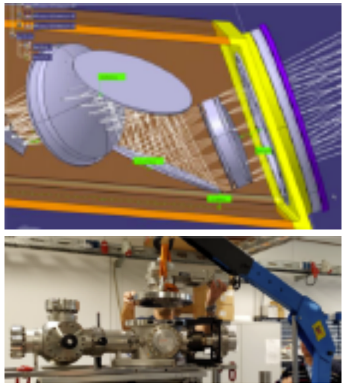






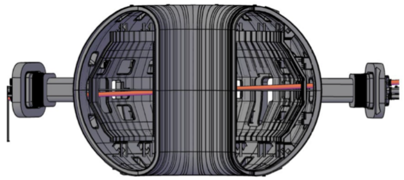
Divertor Cryopump for divertor control

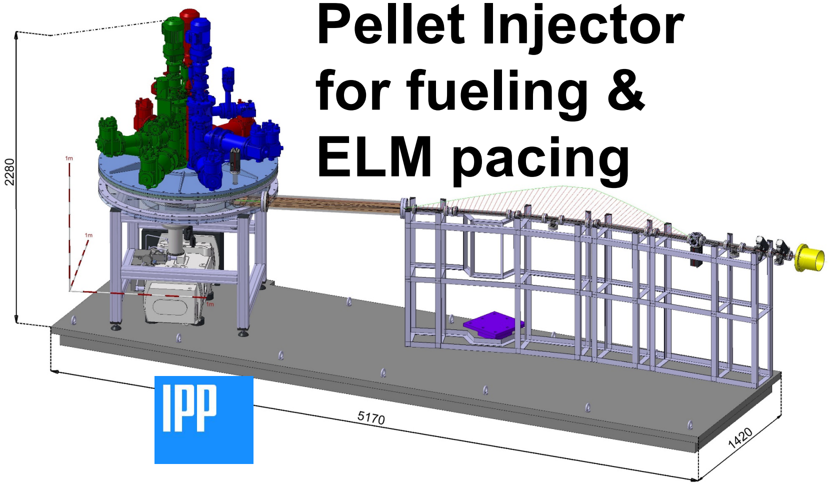
Diagnostics: many



Incl. innovative proposals

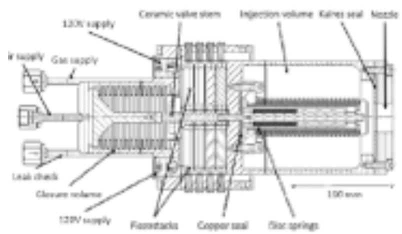
PCI S.Coda, ID1012

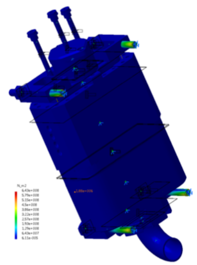




Pellet Injector for fueling & ELM pacing

MGI for disruption mitigation





Coherent physics studies with advanced modelling

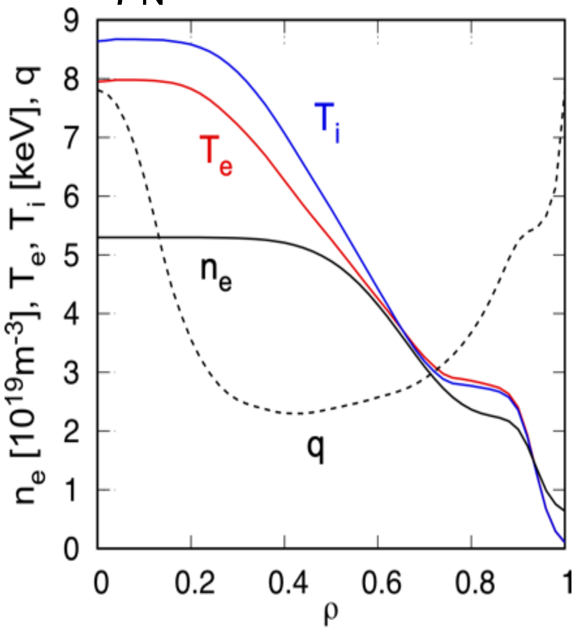
preparing a sound basis for the scientific exploitation of JT-60SA

Performance Prediction: GOTRESS+
Scenario Development : CRONOS for hybrid scenario , METIS for H-mode scenario
MHD stability : MARS-K & CarMa for RWM, FAR3D for N-NBI on resistive ballooning
Edge and Divertor : SOLEDGE2D , SOLPS-ITER , SONIC, EMC3-EIRENE
ELM pacing: JOREK

GOTRESS+

M. Honda, ID 710

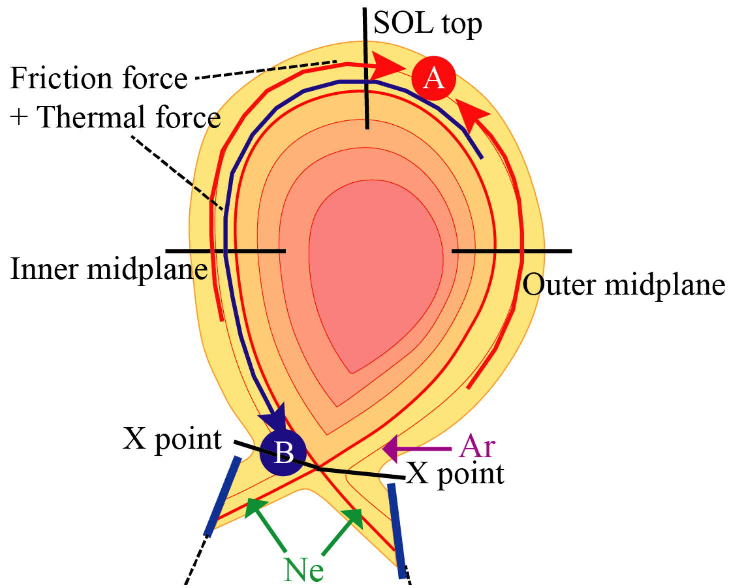
stable profiles for high-β steady-state with β_N=4.31



SONIC

S. Yamoto, ID 725

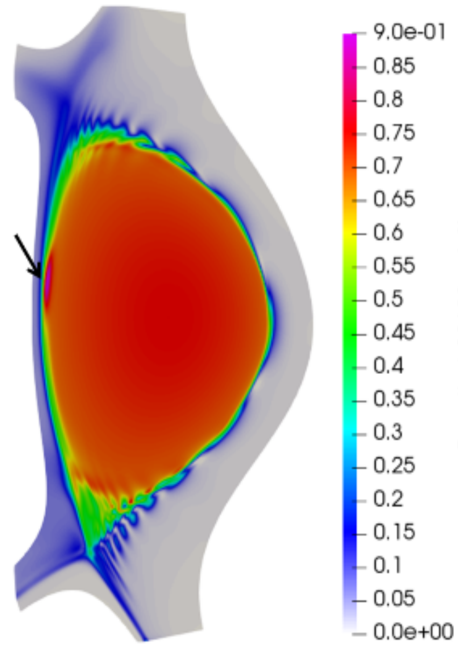
A: Ar-only : Ar trapped at the top SOL due to thermal force, leading to core Ar increase.
B: Ar+Ne : Ar transported to inner div.due to friction force



JOREK

S. Futatani, ID 1049

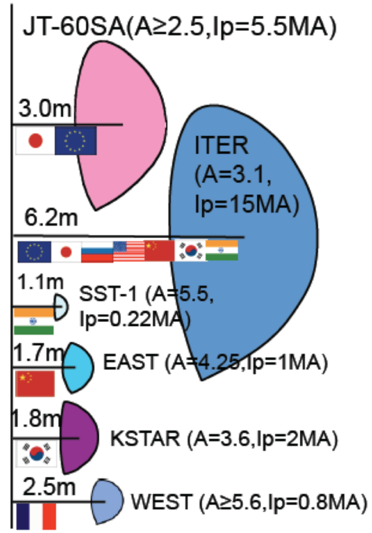
pellet with 470 m/s
density perturbation spreads with filaments due to ballooning mode structures



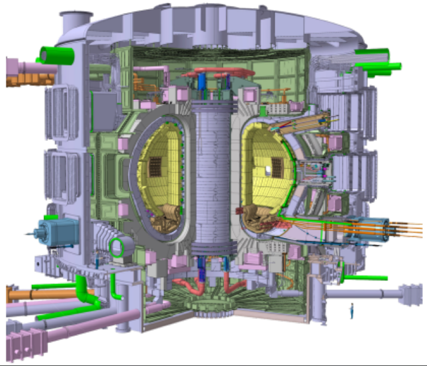
density contour plot

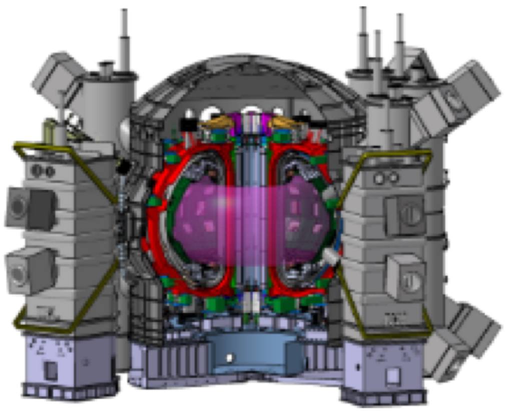
JT-60SA enhances International Collaborations

Assembly & Commissioning
Tokamak Operation & Experiment
Modeling Validation
Fusion Engineering



ITER





JT-60SA

Summary

Construction of JT-60SA tokamak was completed in March 2020

All the main components: Manufacture and assembly satisfied requirements.

Heating, Diagnostics : also going well

Tokamak operation control systems: completed, and
Plasma discharge scenarios for IC: established.

Integrated Commissioning (IC) started:
- Vacuum pumping => Cool-down => Coil excitation
- Transition to the super-conducting state: confirmed for all TF, EF,CS
- TF coil current reached 25.7kA (nominal value)

Analyses of the EF coil incident are under way for recovery.

Importance of JT-60SA plasma research was confirmed with advanced modellings.