Fusion Power Associates 35th Annual Meeting and Symposium
Fusion Energy: Recent Progress and The Road Ahead
December 16-17, 2014.
At Hyatt Regency Washington DC on Capitol Hill

The Magnetic Fusion Program in Japan

K. KURIHARA

Naka Fusion Institute
Sector of Fusion R&D
Japan Atomic Energy Agency

Magnetic Fusion R&D Program

Test Facility

JT-60

Core Plasma Research

Q=1.25

Ti(0)=45keV

Experimental Reactor

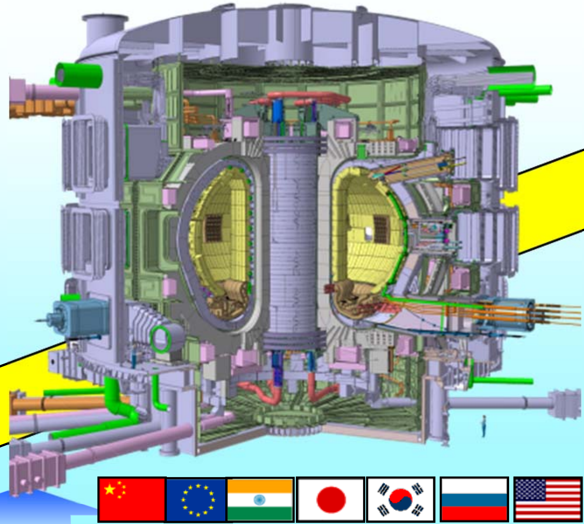
ITER 1

Fusion Power of 0.5GW

Q=10

DT Burning

@France



Demo Reactor

DEMO 6

Demonstration of Fusion Power Plant

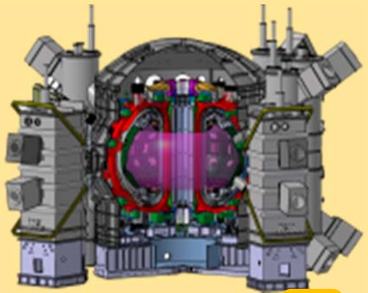
Fusion Power Plant

Supplement ITER toward DEMO

Support ITER

Broader Approach (BA) Activities

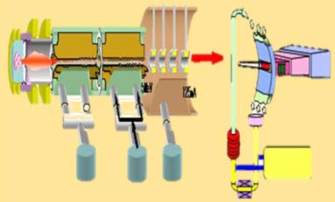
Establish Basis for DEMO



JT-60SA 2

@Naka

International Fusion Energy Research Center (IFERC) 4



IFMIF/EVEDA 3

@Rokkasho

Helical Device

5

LHD @Toki

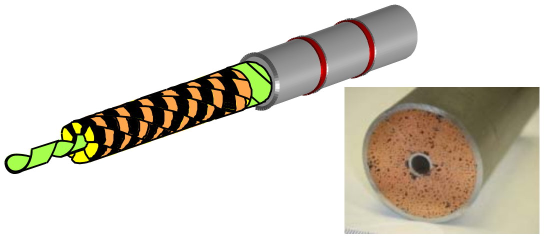
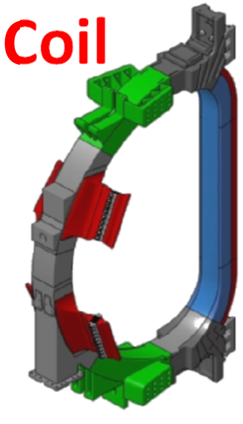
1

ITER Project
- In-Kind Procurement Activities -

Japanese Contribution in ITER In-Kind Procurement
Now Achieved 88% in Contracted Credit!

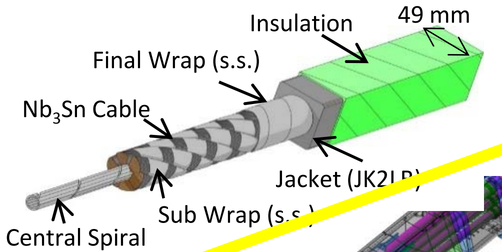
Toroidal Field (TF) Coil

TF Conductors: 25%
TF winding, assembly: 47%
TF Structures: 100%

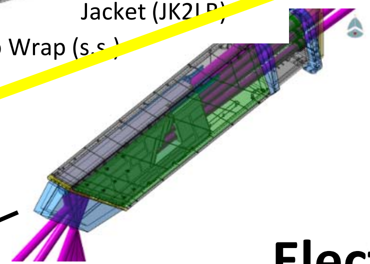
Central Solenoid (CS) Conductors

CS conductors: 100%

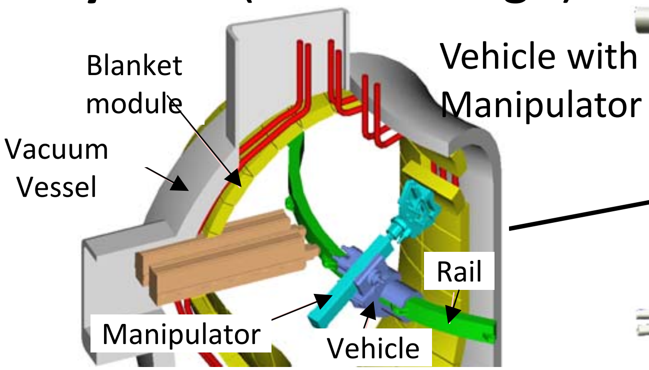



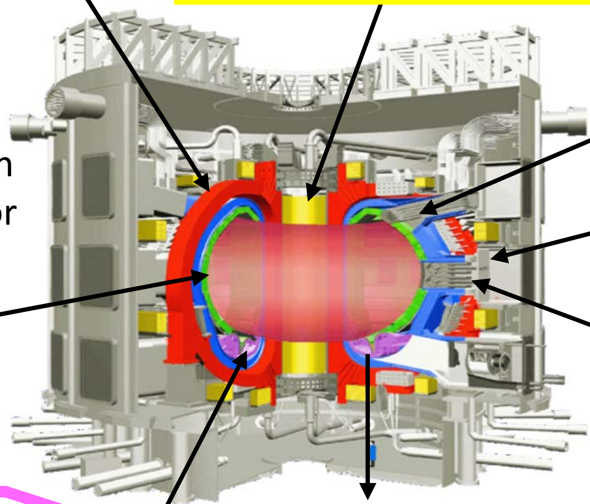
Diagnostics (under design)

Micro Fission Chamber
Poloidal Polarimeter
Edge Thomson Scattering
Divertor Impurity Monitor
IR Thermography
Thermocouples
Upper Port Integration
Lower Port Integration



Blanket Remote Handling System (under design)





Electron Cyclotron H&CD (under design)

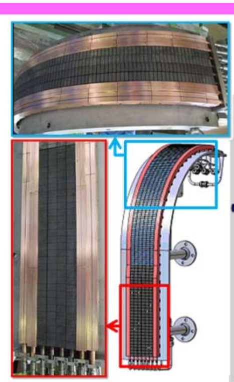
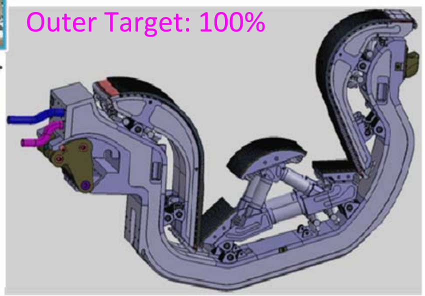
Gyrotron, Equatorial Launcher

Neutral Beam H&CD

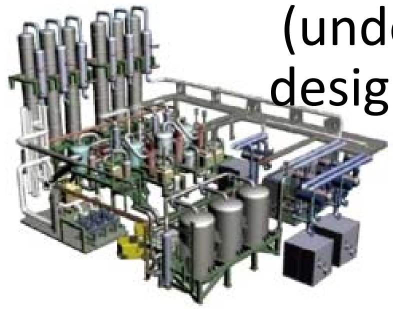
HV Bushing: 100%
1 MV Power Supply HV part: 100%)
1 MeV Accelerator: 33%

Divertor

Outer Target: 100%

Detritiation System (under design)



2

JT-60SA Project

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

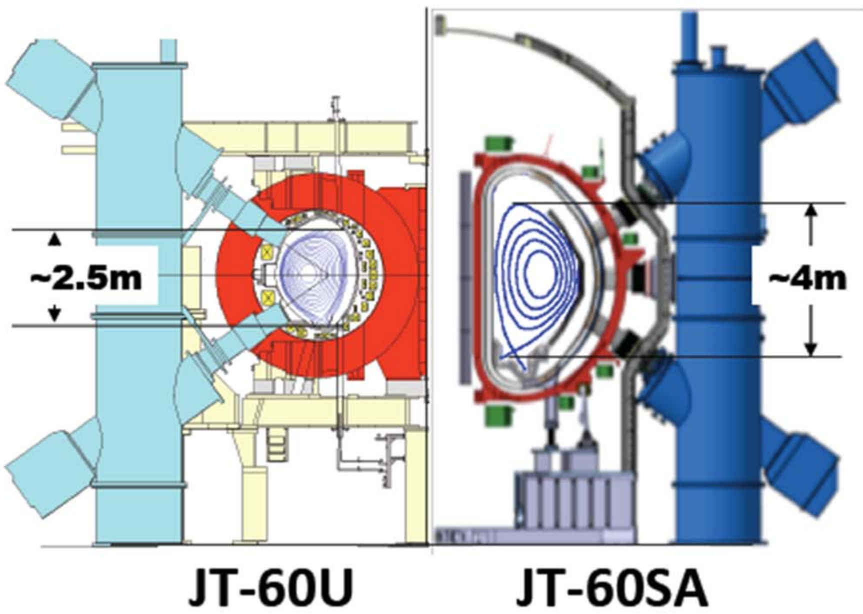
Mission

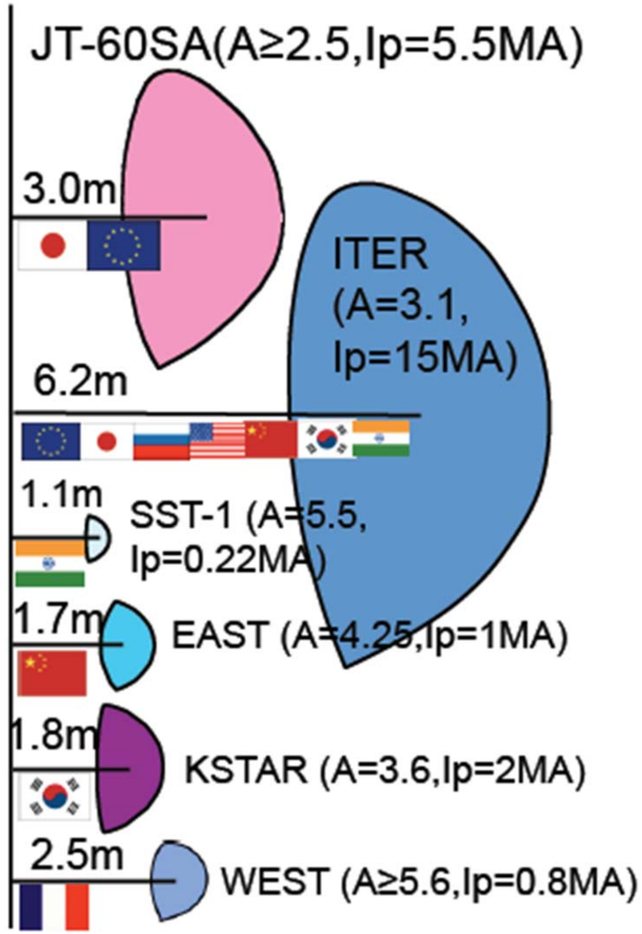
-support ITER: using break-even-equivalent class high-temperature deuterium plasmas lasting for a duration (typically 100 s) for optimization of ITER operation scenarios.

-supplement ITER toward DEMO: with long sustainment (100 s) of high pressure plasmas necessary in DEMO for establishment of DEMO operation scenarios.

24 PA's have been completed: 87% of the total.

The First Plasma is now planned in March 2019.

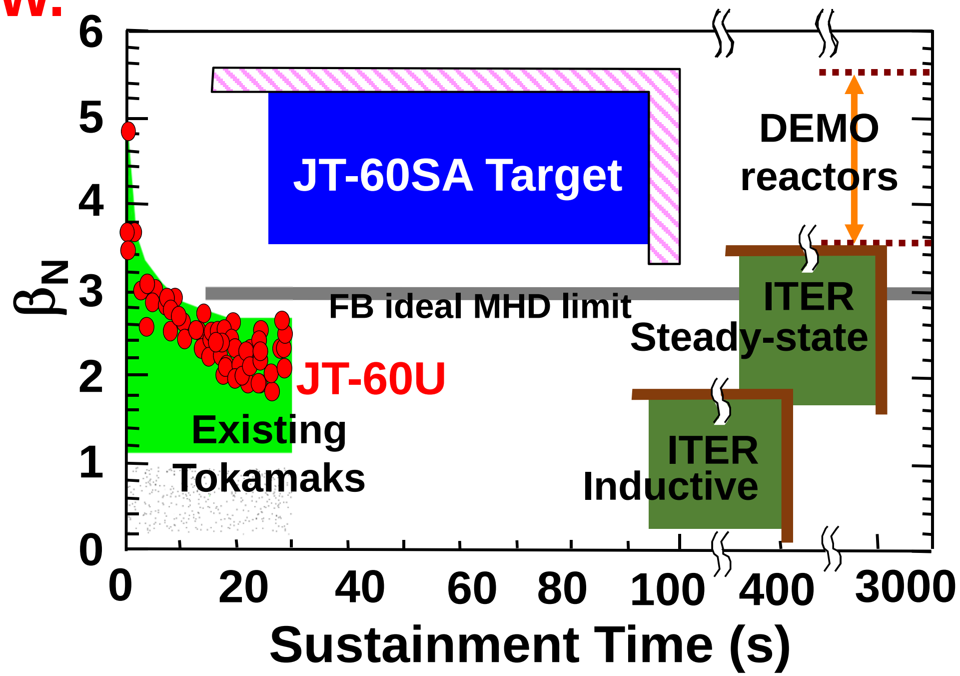




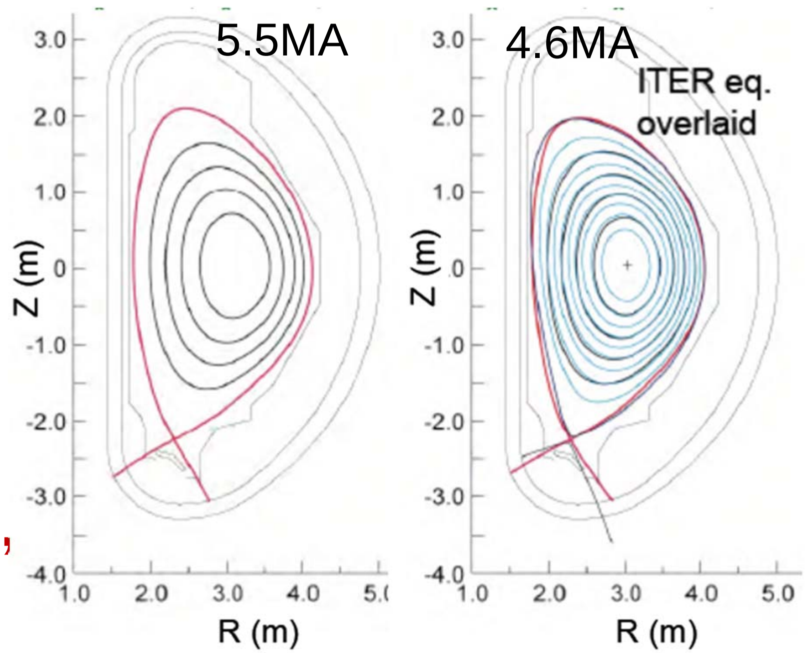
FUSION FOR ENERGY | cea | Ciemat | CONSORZIO RFX | ENEA C.R.FRASCATI- ITALY | KIT | SCK•CEN | JAEA

JT-60SA Target Plasma Design

JT-60SA: highly shaped ($S=q_{95}I_p/(aB_t)$ ~7, A~2.5) large superconducting tokamak confining deuterium plasmas (Ip-max=5.5 MA) lasting for a duration (typically 100s) longer than the timescales characterizing the key plasma processes such as current diffusion time, with high heating power 41MW.



	#2 Full Ip 41MW	#4-1 ITER-like Shape 34MW	#4-2 Advanced inductive 37MW	#5-1 High βN Full CD 37MW
I_p (MA)	5.5	4.6	3.5	2.3
B_T (T)	2.25	2.28	2.28	1.72
R_p (m)	2.96	2.93	2.93	2.97
A	2.5	2.6	2.6	2.7
κ95	1.72	1.7	1.72	1.83
δ95	0.4	0.33	0.34	0.42
q95	3.0	3.2	4.4	5.8
Pin (MW)	41	34	37	37
β_N	3.1	2.8	3.0	4.3
fBS	0.28	0.3	0.4	0.68



Utilizing the ITER- and DEMO-relevant plasma regimes and DEMO-equivalent plasma shapes, JT-60SA contributes to all the main issues of ITER and DEMO.

Status of JT-60SA Construction

JT-60SA Torus Assembly was started:

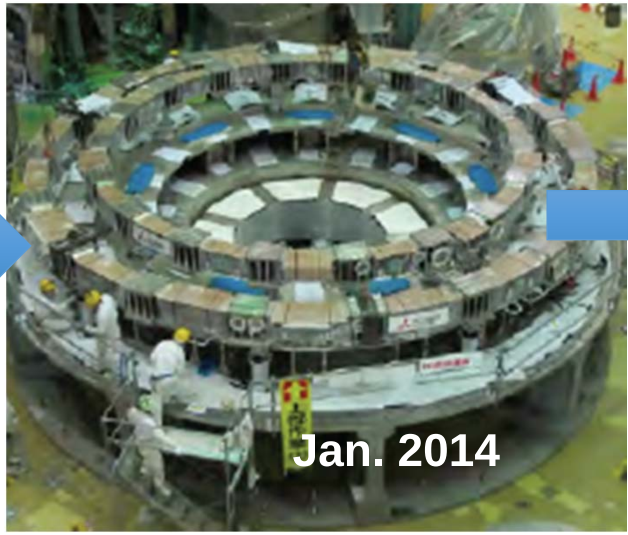
Temporary installation of EF4,5 & 6 on CB:

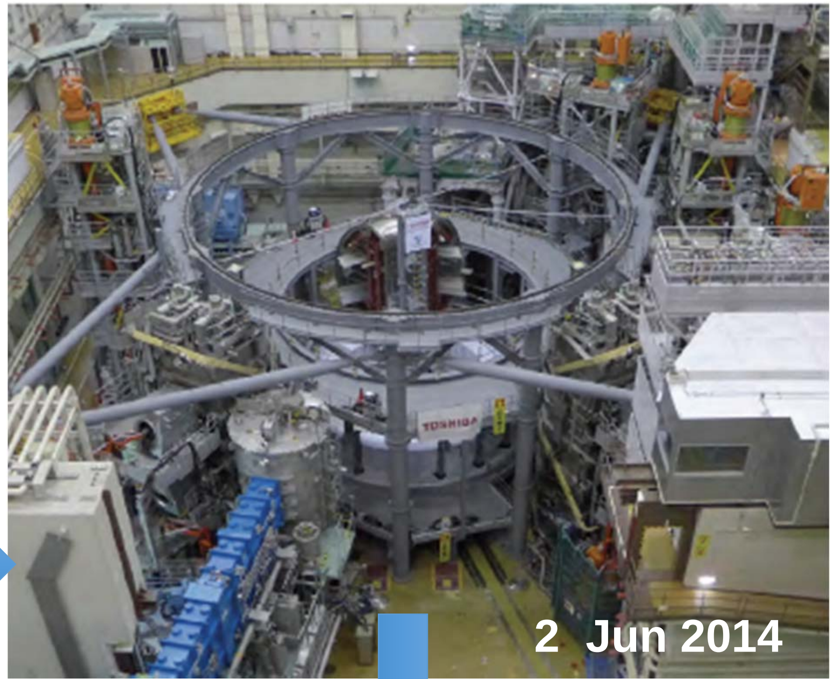
⇒Assembly Frame was set up.

⇒VV assembly was started in May 2014.

Cryostat Base

Lower 3 EF Coils

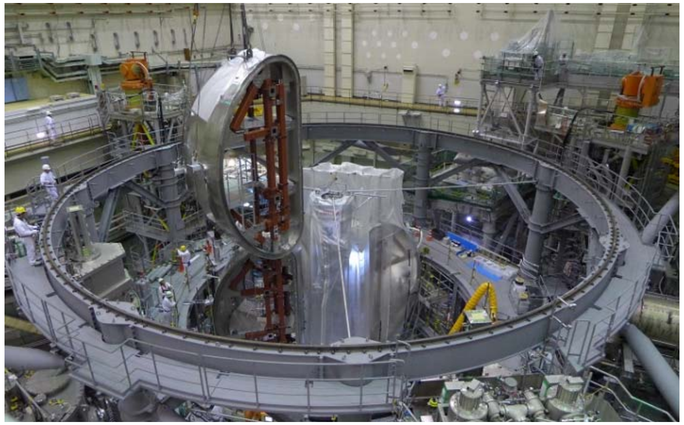




Vacuum Vessel →

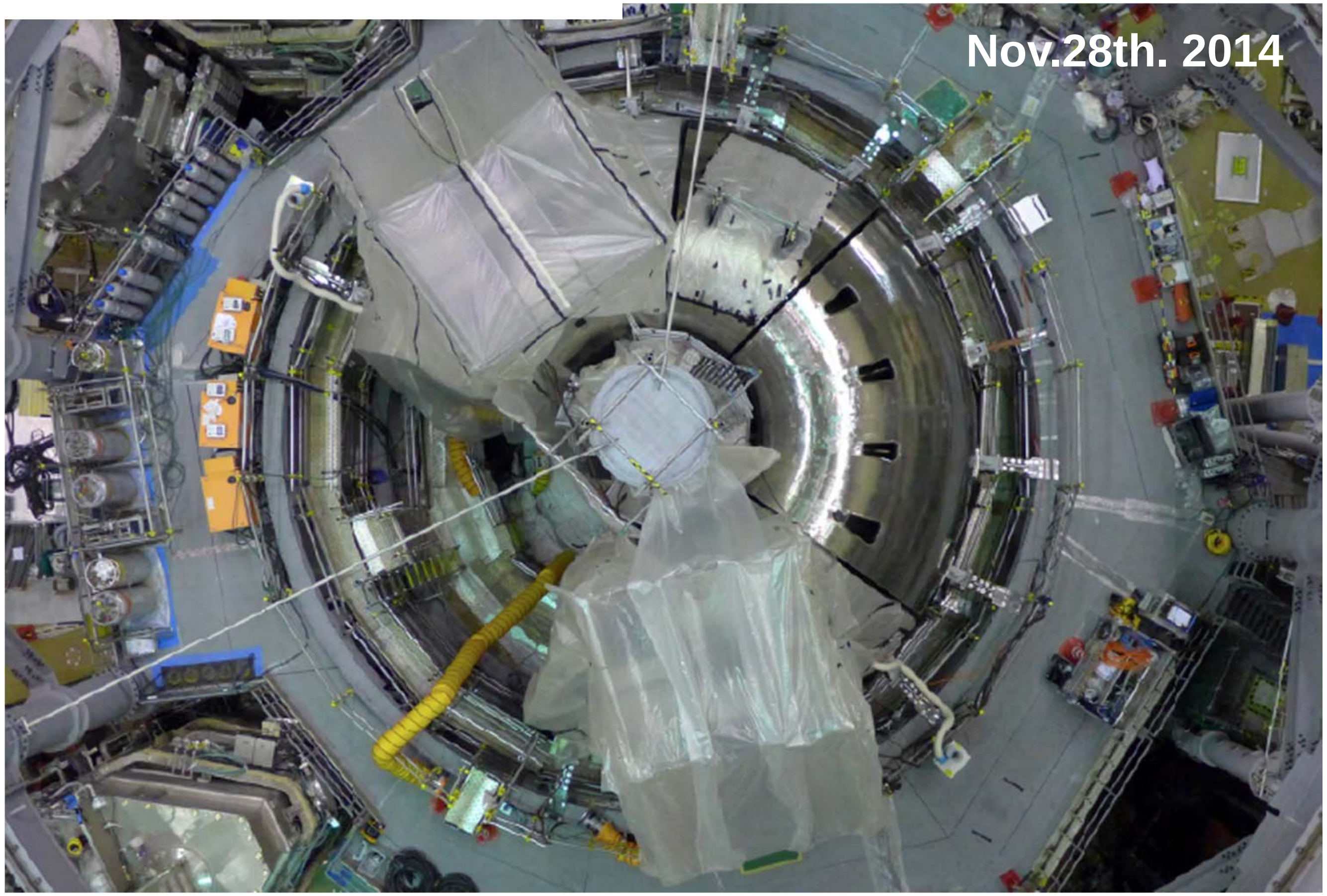
All sectors (40deg. X 7 + 30deg. X 2 + 20deg.) have been completed. on site.

40-deg. VV sectors will be assembled up to 340-deg. ready for the TFC installation.



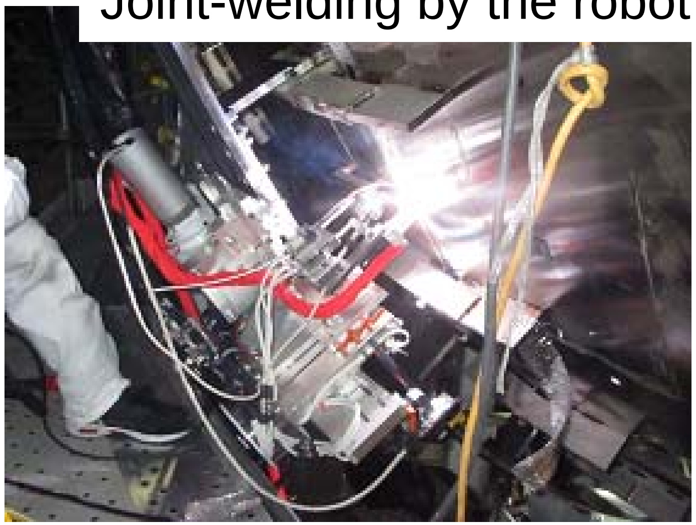
The third and fourth sectors on CB

The joint-welding of the first two 40-deg. VV sectors was started in July 2014, and will continue until the end of Sep. 2015 to form the 340-deg. VV torus.
The final 20-deg. sector will be set at the right position with the last TFC.

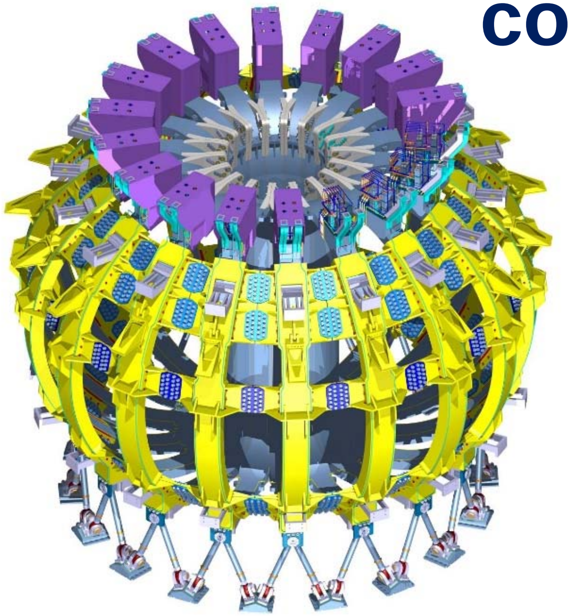


Now, seven 40-deg. sectors (= 280 deg.) have been placed on the cryostat base.

Joint-welding by the robot



EU Procurements for JT-60SA devices are smoothly conducted and delivered to Naka on schedule.

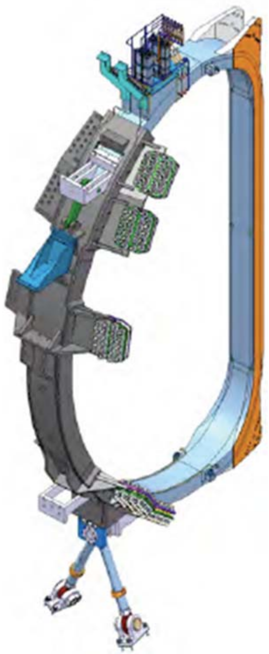


18 (+1 spare)

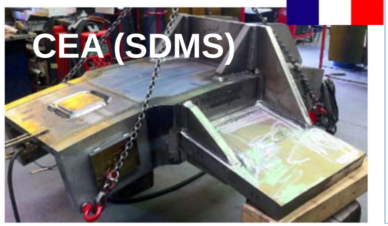
TF coils & their related components manufacture are running well in France and Italy.

TF (Toroidal Field) Coil Winding started

(CEA, ENEA)



Outer Intercoil Structures



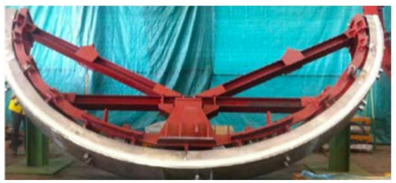
Manufacture of structural components are also going well.

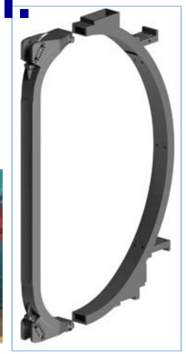
Gravity supports

CEA
Alstom

Casings

ENEA(Walter Tosto)

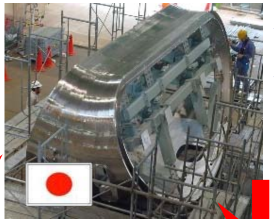




JT-60SA: Manufacture on schedule in both EU and JA

JT-60U Disassembly Completed in Oct. 2012

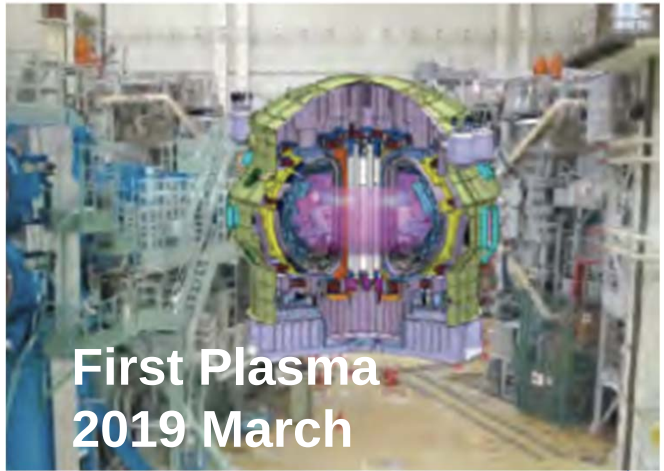
Lower 3 EF Coils



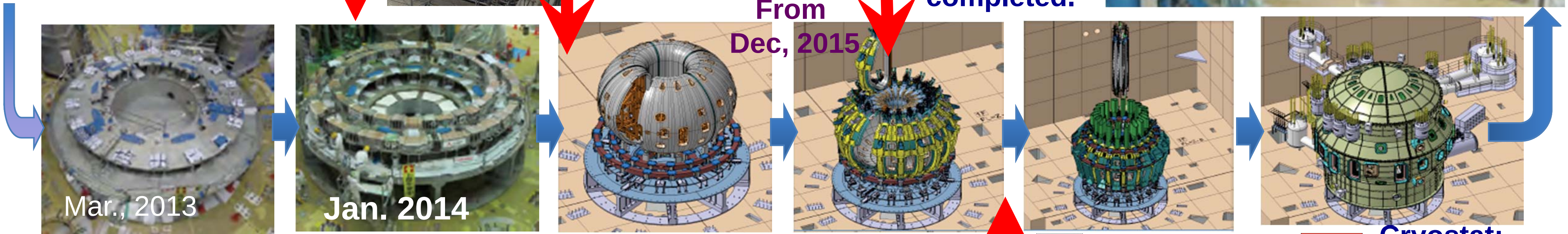
Vacuum Vessel Sectors

Toroidal Field Coils Winding started.

TF coil test facility has been almost completed.



From Dec, 2015



Cryostat Base (260 tons)

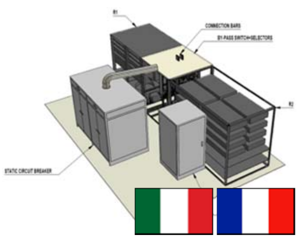
Tokamak Assembly started in Jan. 2013 by installing the cryostat base.

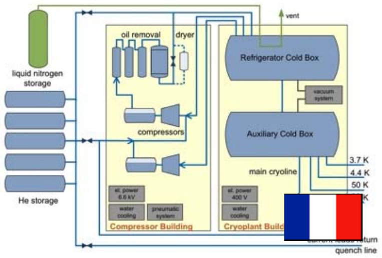
HTS Current Lead

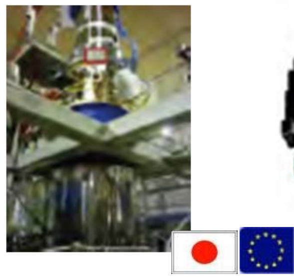
Upper 3 EF Coils & CS

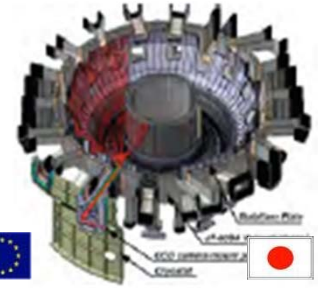
Cryostat: Manufacture started.

power supplies, cryoplant, NBI, ECH, diagnostics, etc









QPC: Sep. 2014

Mar. 2015

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

Examples of Test Items in Physics

(a) H-mode operations towards Q=10 (H, He, D)

L-H transition, Pedestal Structure

H-mode confinement (incl. compatibility with radiative divertor, RMP, etc.)

Local Ripple & TBM Test

(b) ELM mitigation (RMP, pellet, …)

(c) Disruption avoidance & mitigation (Intensive Gas, impurity pellet)

(d) Divertor heat load reduction

(e) Integrated operation scenario optimization with SC PF coils.

(operation scenarios, plasma actuators, diagnostics …)

(f) High energy particle physics using 10MW 500keV N-NB

NB Current Drive studies (incl. off-axis NBCD),

AE mode stability & effects on fast-ion transport,

Interactions between high energy ions and MHD instabilities

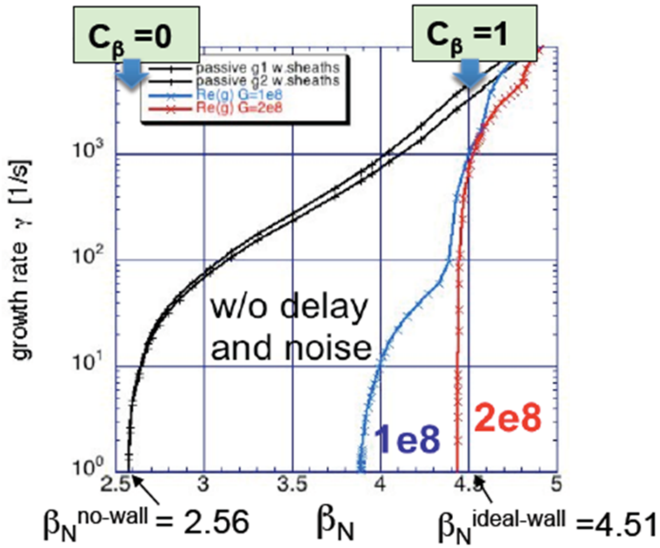
➔ JT-60SA Research Plan updated to Ver.3.1 (Dec. 2013)

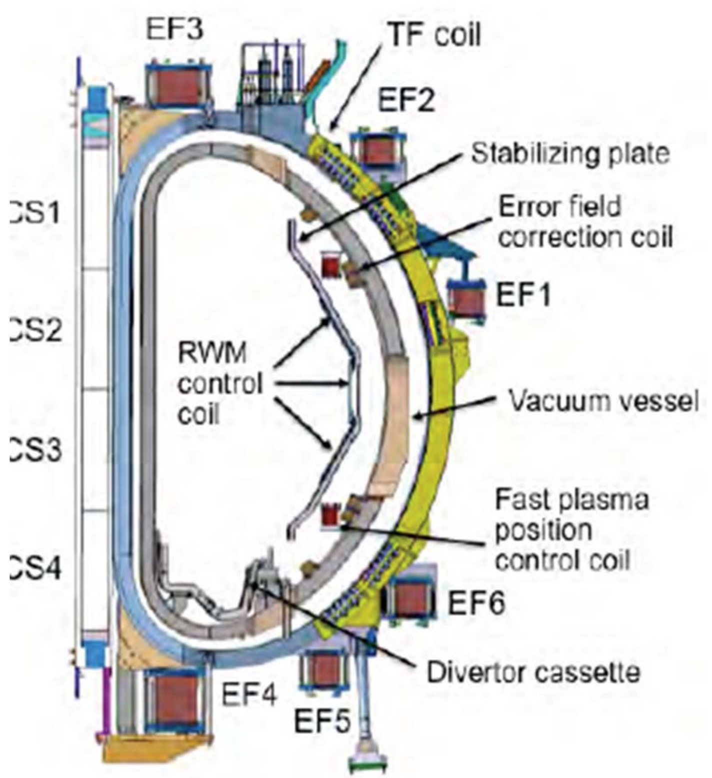
MHD stability control (as an example)

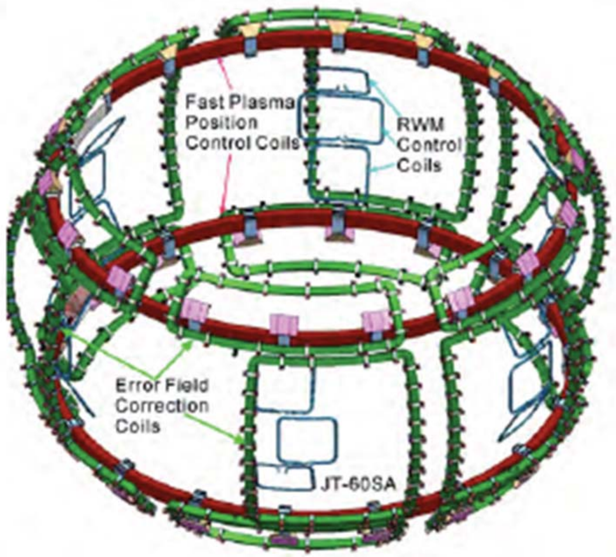
- Stabilizing Wall
- Fast Plasma Position Control coil
- Error Field Correction (EFC) coil
- **RWM Control coil: 18 coils. on the plasma side.**
  + ECCD (NTM), rotation control

RWM control

β_N = 4.1 (C_β =0.8) with effects of conductor sheath, noise (2G), and latency (150 ms).







JT-60SA Research Plan by EU and JA

"Research items and Strategy for JT-60SA" to solve critical issues in ITER and DEMO.

JT-60SA Research Plan updated to Ver.3.1 in 2013, Dec.

Co-authors: 331 persons

- Japan: 150 (76 from JAEA, 74 from 15 Univ.)
- EU: 176 (10 countries, 24 institutes)
- Project Team: 5

=> Objectives: Encourage collaborative studies, and Optimize hardware. (Revised towards the first plasma)

Expected experiment participants: JA: 250-300, EU: 200-250

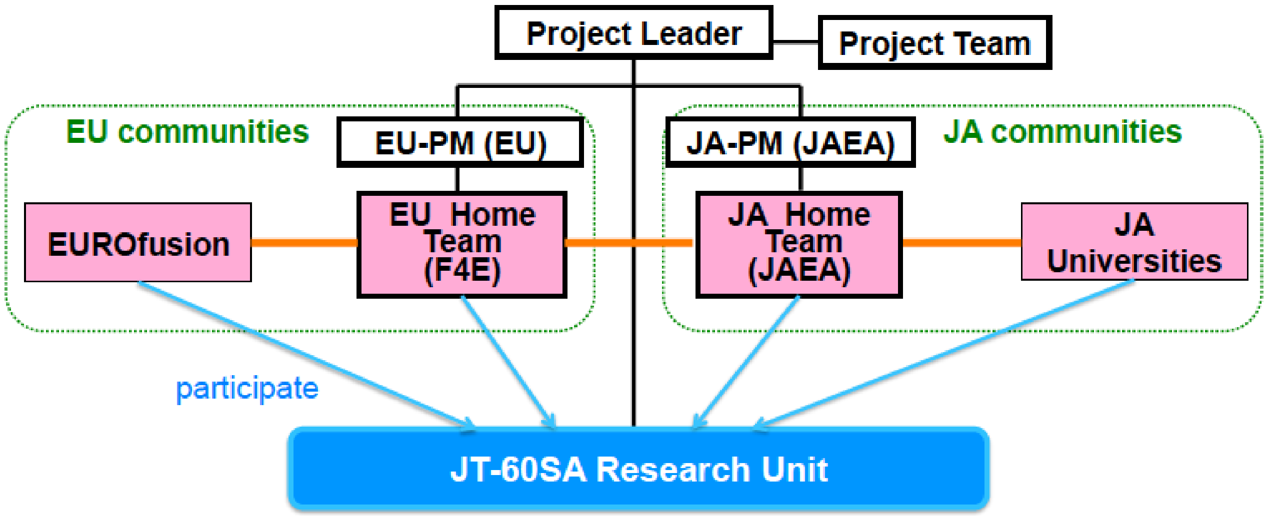

JT-60SA Research Plan

= Research Objectives and Strategy =

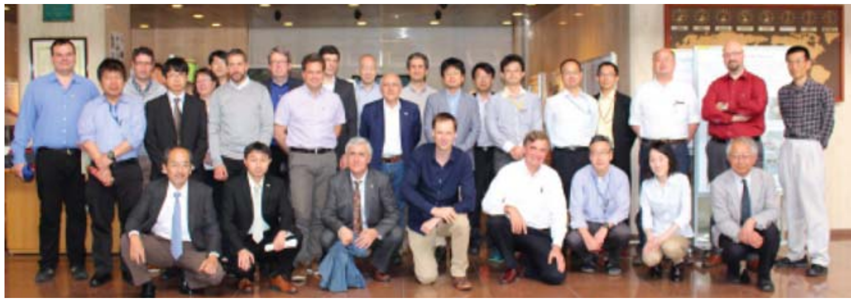
Version 3.1

2013, December

JT-60SA Research Unit



Coordinators: M. Yoshida (JA), G. Giruzzi (EU)



3rd. Research Coordination Meeting (Naka, May.,2014)

Please visit➔ JT-60SA Research Plan: http://www.jt60sa.org/b/index_nav_3.htm?n3/operation.htm

3

IFMIF/EVEDA Project

IFMIF/EVEDA (Engineering Validation and Engineering Design Activity of International Fusion Material Irradiation Facility)

Three facilities to be validated

Accelerator facility

Linear IFMIF Prototype Accelerator (LIPAc) @ JAEA Rokkasho

Li Target Facility

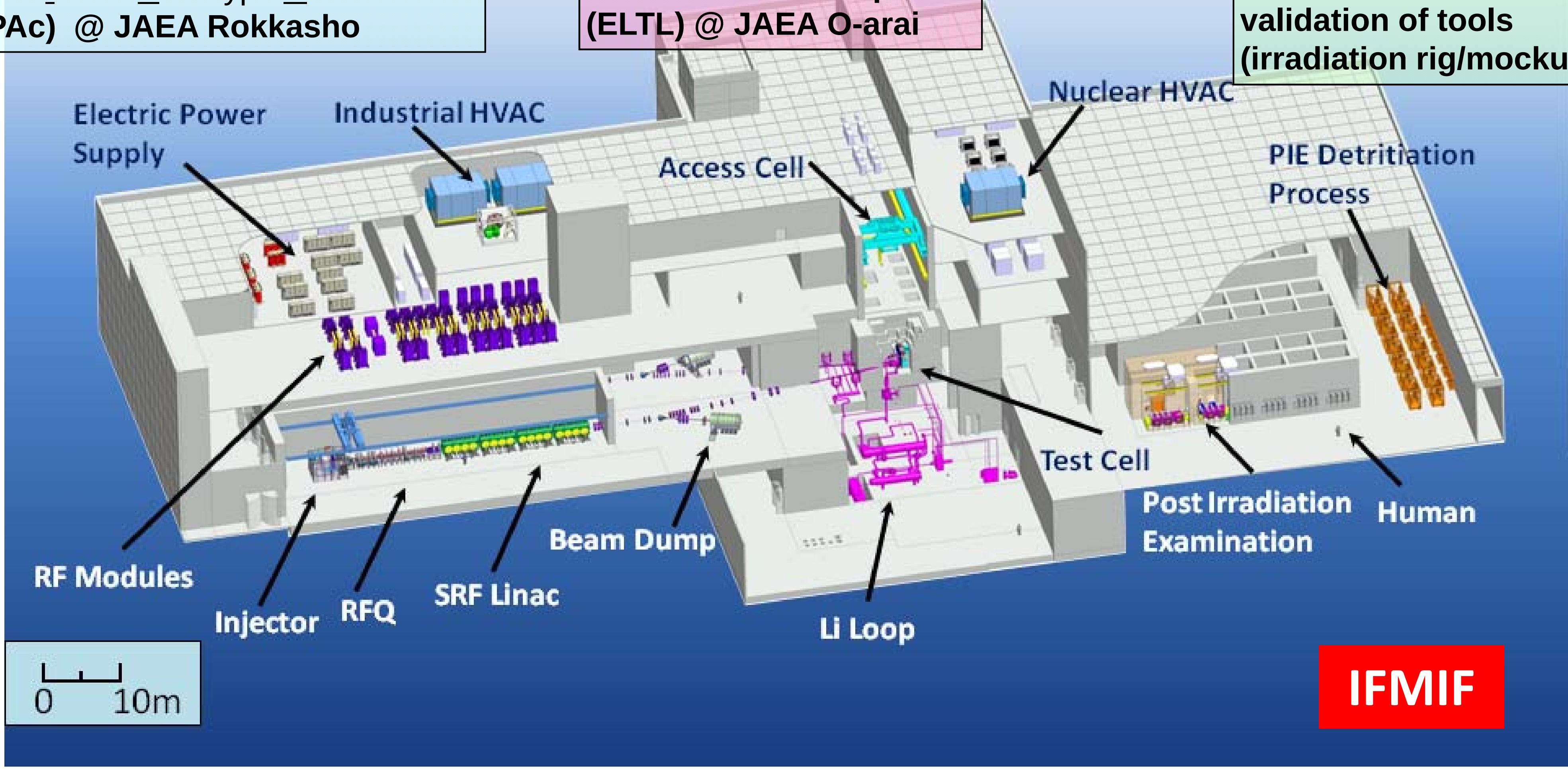
liquid Li screen flowing at 15 m/s to stand $1 GW/m^2$ D+ beam load

EVEDA Li Test Loop (ELTL) @ JAEA O-arai

Test Facility

Handling the irradiation material samples and acquisition of material data

Design, manufacturing and validation of tools (irradiation rig/mockup)



IFMIF EVEDA Project

Linear IFMIF Prototype Accelerator - **LIPAc**

IFMIF vs LIPAc : D$^+$ accelerator

125 mA : LIPAc 9MeV (IFMIF 40MeV)

Injector+ LEBT
CEA Saclay

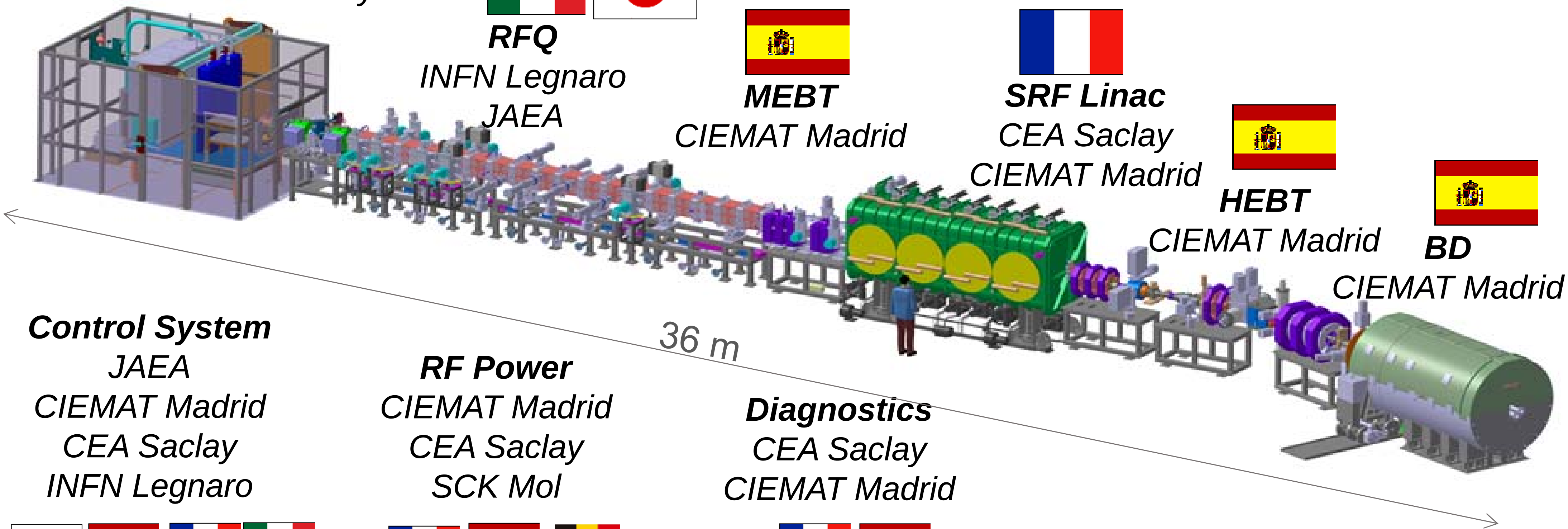
RFQ
INFN Legnaro
JAEA

MEBT
CIEMAT Madrid

SRF Linac
CEA Saclay
CIEMAT Madrid

HEBT
CIEMAT Madrid

BD
CIEMAT Madrid



Control System
JAEA
CIEMAT Madrid
CEA Saclay
INFN Legnaro

RF Power
CIEMAT Madrid
CEA Saclay
SCK Mol

Diagnostics
CEA Saclay
CIEMAT Madrid

LEBT: Low Energy Beam Transport line
RFQ: Radio Frequency Quadrupole
MEBT: Medium Energy Beam Transport

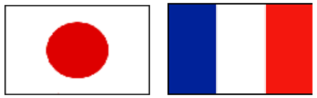
SRF Linac: Superconducting Radio Frequency LINAC

HEBT: High Energy Beam Transport lines

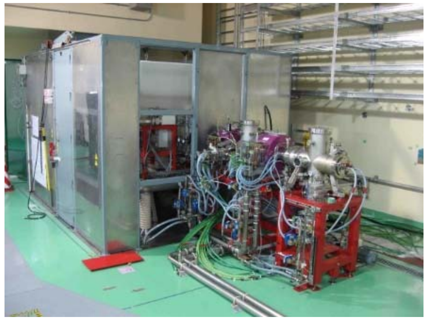
➔ **IFMIF/EVEDA project will be presented by Dr. Okumura.**

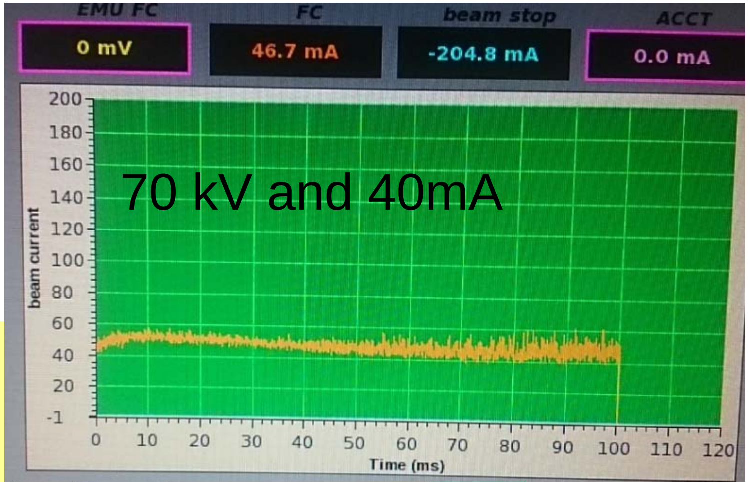
Status of IFMIF/EVEDA

Installation of Injector for the Linear IFMIF Prototype Accelerator (LIPAc) was completed.
Beam tests have been initiated by JAEA, CEA and IFMIF/EVEDA Project Team.

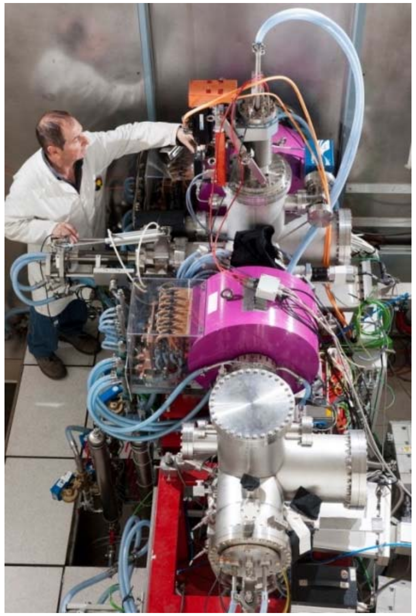


Installation of the Injector in the Accelerator Vault





LIPAc injector 1st beam was achieved on Nov. 4, 2014



4

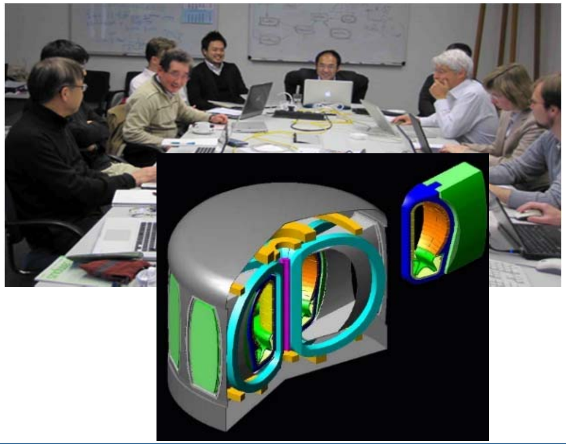
International Fusion Energy Research Center (IFERC) Project

IFERC Project

International Fusion Energy Research Center

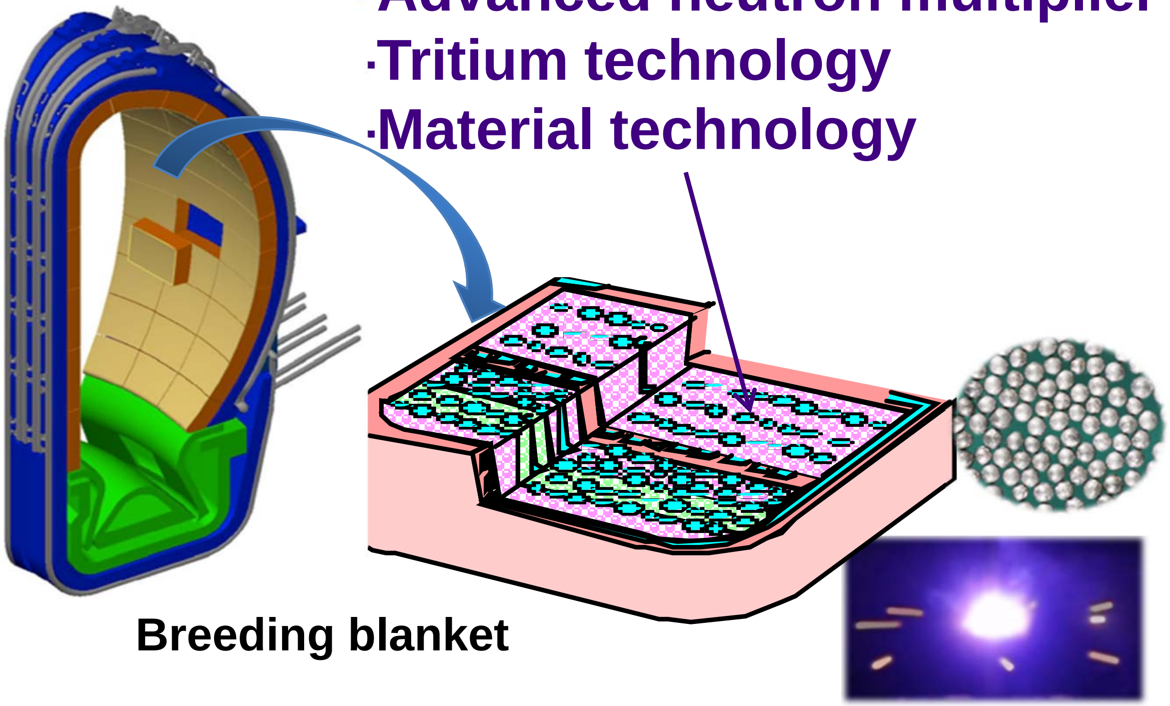
DEMO Design

Joint work to design feasible DEMO concepts
➔revisit later



DEMO R&D

- **Advanced tritium breeder**
- **Advanced neutron multiplier**
- **·Tritium technology**
- **·Material technology**



Breeding blanket

Computer Simulation Center

Large-scale simulation for magnetic confinement fusion

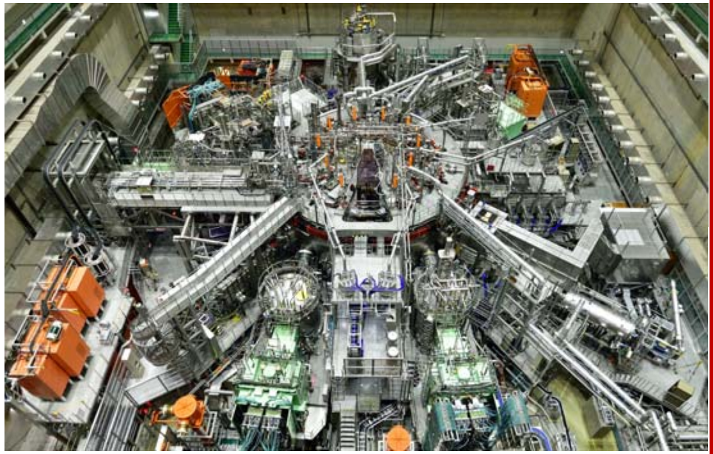
- **Linpack performance: 1.23 Pflops (as of June 2014, world 30th fastest)**
- **Maintain extremely high availability (> 98%) and running rate (> 85 %)**
- **Highly contributed to research: 275 publications and 847 presentations**

Remarkable progress seen in each activity with efficient joint work of EU and JA

5

Large Helical Device (LHD) Project

Large Helical Device (LHD) Project



- The world-largest helical system, and the world-largest SC fusion machine at present.
- Intrinsic advantage and engineering capability of steady-state operation
- Complementary/alternative role to tokamak approach

The goal of the project

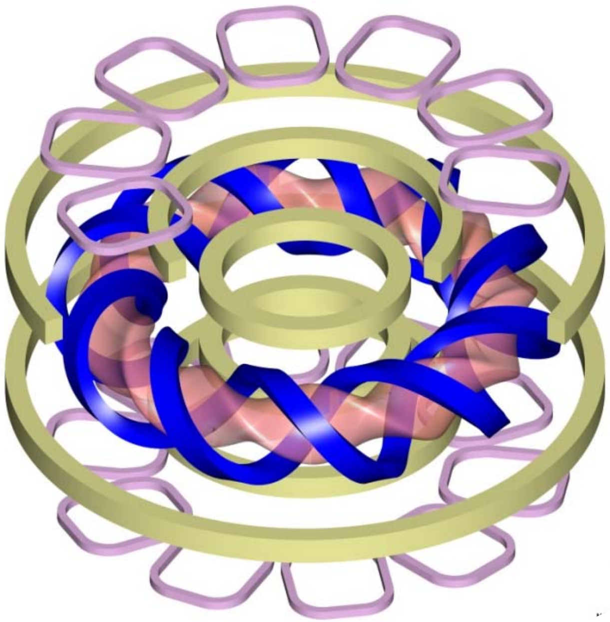
- **Establish scientific basement for a helical fusion reactor**
- **Comprehend physics of toroidal plasmas**

In-Vessel View of LHD

- **Outer diameter 13.5 m**
- **Cold mass 820 ton**
- **Total weight 1500 ton**
- **Magnetic field 3 T**
- **Magnetic energy 0.77 GJ**
- **Operation for 16 years since 1998** ➔ Engineering Base
- **Several-month-long operation, 17 times since 1998**
- Operational time of He compressor:76,400 hours ➔ Duty > 99 %
- Coil excitation number 1,580 times
- Plasma discharges: 125,000 shots (Plasma pulse every 3 min)

Heating capability

NBI	28	MW
ECH	4.6	MW
ICH	3.5	MW



A large number of opportunities for diversified collaboration on physics.

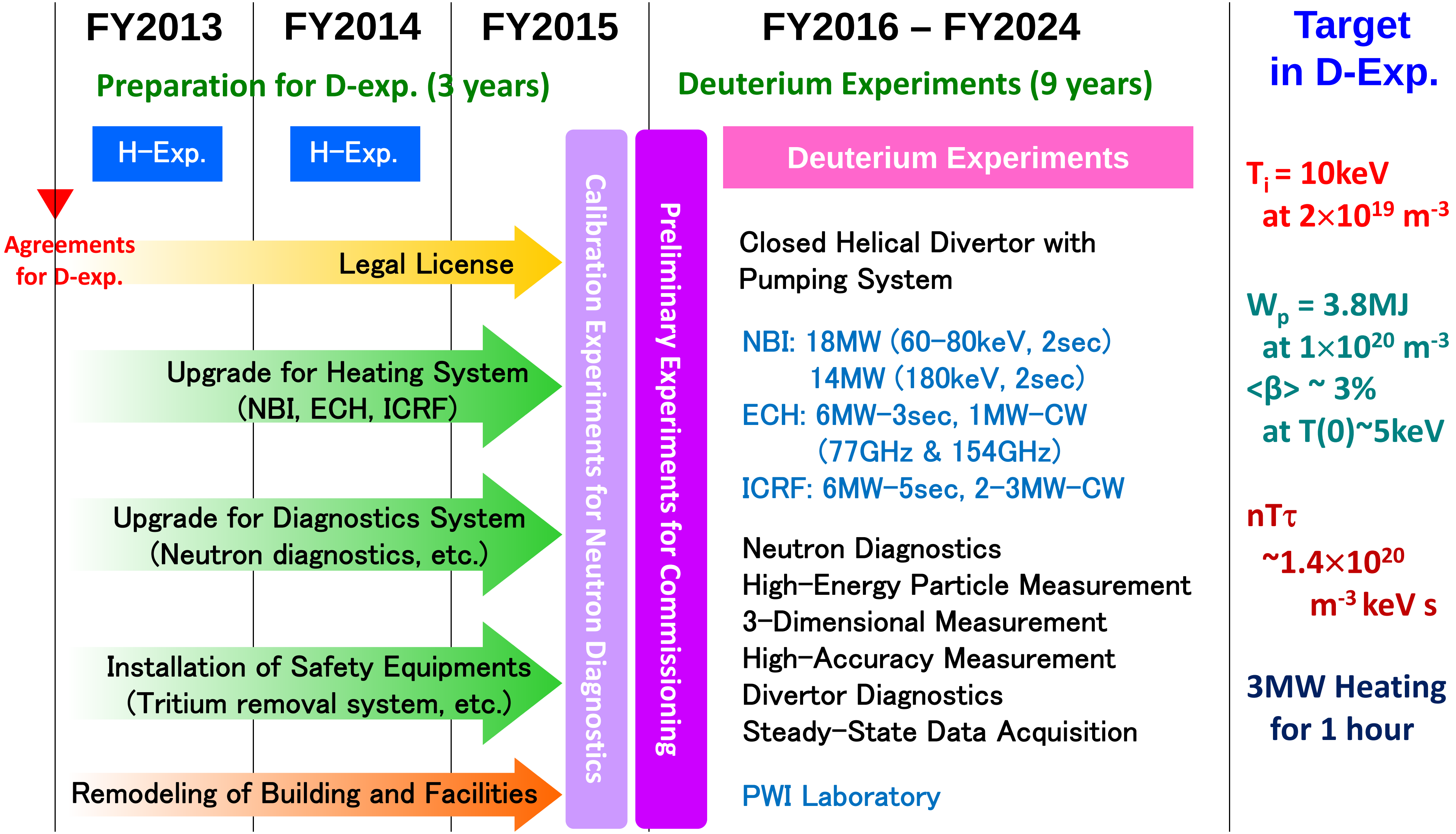
Achieved plasma parameters encourage the further next step.

Parameter	Achieved	Target
T_{i0}	**8.1 keV** (1×10^{19} m^{-3})	10 keV (2×10^{19} m^{-3})
T_{e0}	13 keV (1×10^{19} m^{-3})	10 keV (2×10^{19} m^{-3})
n_{e0}	1.2×10^{21} m^{-3} (0.26 keV)	4×10^{20} m^{-3} (1.3 keV)
β	5.1 % (0.425 T) 3.7 % (1 T)	5 % (1-2 T)
Discharge duration	54 min. (500 kW) **48 min. (1,200 kW)**	1 hour (3,000 kW)

Red: achieved in FY2013

Schedule for LHD deuterium experiment (tentative)

- Concluding the Agreements for the LHD deuterium experiment with local government bodies on March 28, 2013.
- Deuterium experiment will start in 2016, and during the planned 9-years' experiments, 10keV of the T_i should be achieved.



6

DEMO Design Activities in Japan

Fusion Community for DEMO Design in Japan

Industry

Industrial soundness, Manufacture, Economy

Japan Atomic Industrial Forum Inc.

JAEA, NIFS, Universities, etc.

R&D Program

Fusion Energy Forum of Japan
Fusion Network

Joint Core Team (organized 2013-14)

Int'l Relation, & Roadmap

EU, USA, China, Korea, IAEA

Academic Societies, Associations AESJ, JSME, CSSJ, JPSF, etc.

Codes & standards

WG for Fusion Research
Council for Science and Technology, MEXT

Policy

Government MEXT, CSTP

The joint core team should discuss and show the grand strategy to DEMO which is cooperated with fusion community in Japan.

The Joint Core Team Submitted a Special Report in July 2014

Report by the Joint-Core Team
for the Establishment of Technology Bases
Required for the Development of a Demonstration Fusion Reactor

18 July 2014 [in Japanese] ***English version will be released in Jan. 2015***

1. Introduction

2. On the Concept of DEMO Premised for Investigation

- 2-1. Change of Energy Situation and Social Requirement
- 2-2. Fundamental Strategy
- 2-3. Development Strategy
- 2-4. Basic Concept Required for DEMO
- 2-5. Points of View for Changeover to DEMO Phase and Assessment of Transition Conditions

3. Technological Issues of Elements of DEMO

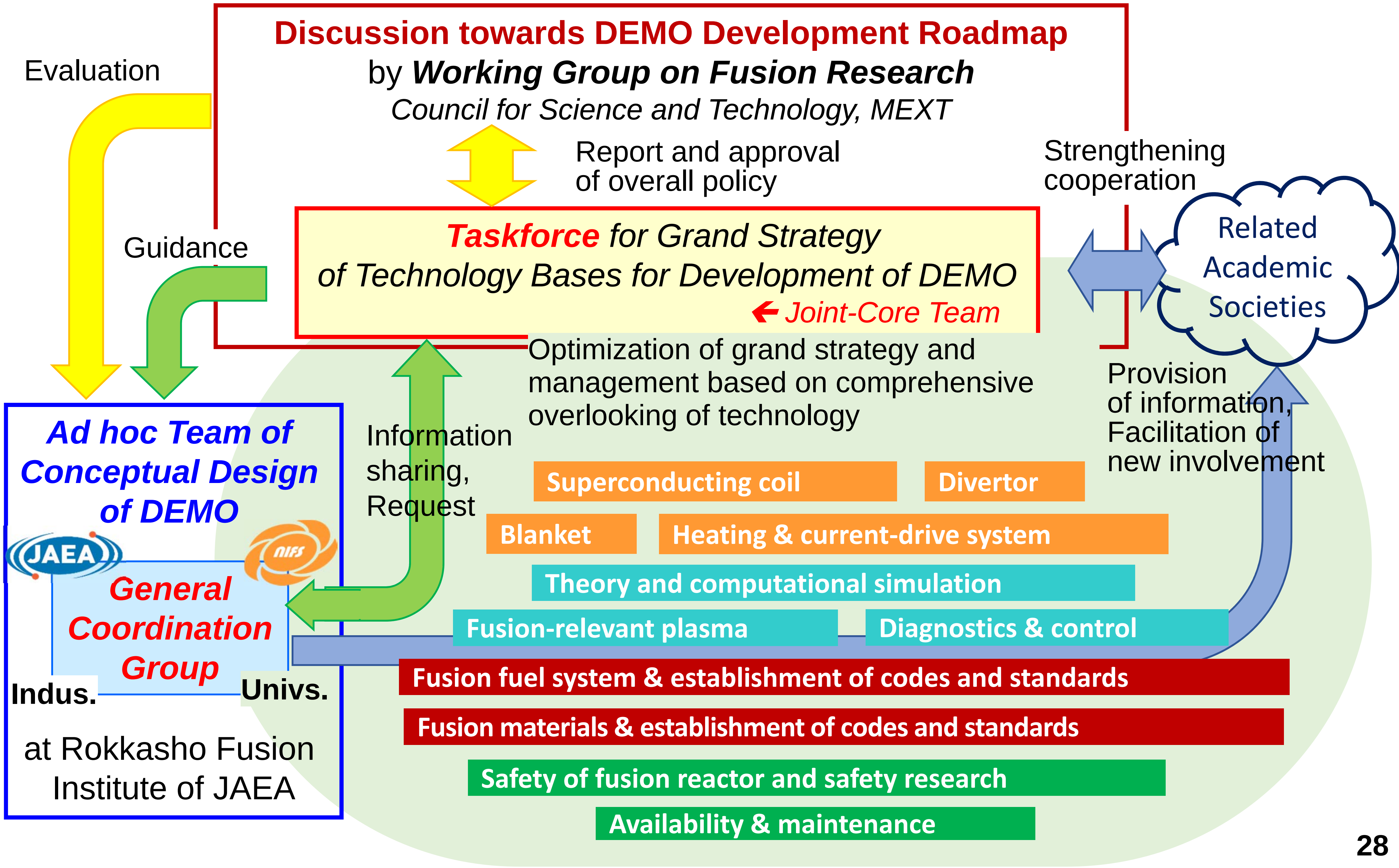
- 3-1. Superconducting Coils 3-2. Blanket
- 3-3. Divertor 3-4. Heating and Current Drive Systems
- 3-5. Theory and Numerical Simulation Research
- 3-6. Reactor Plasma Research 3-7. Fuel Systems
- 3-8. Material Development and Standards / Criteria
- 3-9. Safety of DEMO Reactor and Safety Research
- 3-10. Availability and Maintainability 3-11. Diagnostics and Control Systems
- 3-12. Newly Required Facilities and Platforms

4. Points of Reactor Design Activity

5. International Cooperation and Collaboration

6. Summary - Development of Grand Strategy towards Future Establishment of Technological Bases for DEMO -

Organized Framework for Implementation throughout Japan towards Establishment of Technology Bases for DEMO (in plan)



Summary

Toward the earlier realization of a Magnetic Fusion DEMO reactor, ITER Project and BA Activities are intensively being promoted in Japan.

1 ***In ITER Project:*** **In-kind procurement activities have come to a peak of manufacturing processes at the factory in Japan (TFC, CS, etc.).**

In BA Activities

2 **JT-60SA Project: Manufacture is running well on schedule by EU & JA:**
- **VV assembly was started in May 2014.**
- **Research Plan Ver3.1 was released in 2013 (*available on the website*)**

3 **IFMIF/EVEDA Project:**
- **The injector for the Linear IFMIF Prototype Accelerator was installed.**
- **The first beam of the injector has achieved in last Nov. 2014.**
- **The other components are ready for installation.**

4 **IFERC Project (DEMO Design, DEMO R&D, Computer Simulation Center, ITER Remote Experiment Center) is producing many results on each field.**

5 ***The alternative to a tokamak*: LHD will start Deuterium experiment in 2016**

6 **DEMO Design Activities:**
- **Joint Core Team discussing the grand strategy submitted a Special Report to MEXT, in July 2014. (*English version soon available*)**
- **General Coordination Group for DEMO CDA will be newly organized soon.**

Roadmap towawd Fusion Energy

- The first plasma and Q>10 in ITER will be possibly the trigger points to DEMO EDA and its construction, respectively.
- BA will reach the assumed period in 2019 (JT-60SA), and 2017 (the other projects). Post BA activities are under discussion.
- DEMO is expected to go into operation in a middle of 2040s.