Progress of ITER procurement in Japan
- Challenges in Science and Technology -

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Roadmap to Realize Fusion Energy

**Experiment Phase**
(Scientific Feasibility)
Achievement of High Temperature Plasma

**JT-60**
The highest fusion energy gain: 1.25
The highest ion temperature: 520M K

**Experimental Reactor Phase**
(Scientific and Technological Feasibility)
- 500 MW Fusion Power output
- Long pulse fusion burning

**ITER**
(International Thermonuclear Experimental Reactor)
The site is located at St Paul-Lez-Durance (Cadarache) in France

**BA Activities**
Development of:
- Technical basis for PROTOTYPE reactors
- ITER operation scenarios, etc.

**DEMO Reactor Phase**
(Technological Demonstration & Economic Feasibility)

**Prototype**
Demonstration of:
- Power generation,
- Economic prospect

**Support for ITER Project**
Technologies for DEMO, complementing ITER
Japanese Contribution to ITER

**Toroidal Field (TF) Coil**
- TF Conductors: 25%
- TF winding, assembly: 47%
- TF Structures: 100%

**Center Solenoid (CS) Coil**
- CS conductors: 100%
- Insulation
- Nb3Sn Cable
- Sub Wrap (s.s.)
- Jacket (JK2LB)
- Final Wrap (s.s.)

**Diagnostics**
(under design)
- Micro Fission Chamber
- Poloidal Polarimeter
- Edge Thomson Scattering
- Divertor Impurity Monitor
- IR Thermography
- Thermocouples
- Upper Port Integration
- Lower Port Integration

**Electron Cyclotron H&CD**
- Equatorial Launcher
- Gyrotron

**Neutral Beam H&CD**
- HV Bushing: 100%
- 1 MV Power Supply HV part: 100%
- 1 MeV Accelerator: 33%

**Detritiation System**
(ADS, under design)

**Divertor**
- Outer Target: 100%

**Blanket Remote Handling System**
(under design)
- Blanket module
- Vacuum Vessel

**Manipulator**
- Vehicle

**Vacuum Vessel**
- Rail

**Neutral Beam Handling System (under design)**

**Neutral Beam H&CD**
- HV Bushing: 100%
- 1 MV Power Supply HV part: 100%
- 1 MeV Accelerator: 33%
JADA has signed 12 PAs, corresponding to about 88% in credit value out of total Japanese contribution to the ITER in-kind procurement.
Coil winding

- 9 by JA/19 WPs
  - Bent conductor inserted in grooves of RP
- Stack of 7 DPs with insulation
- Double Pancake (DP)
- Winding Pack (WP)
- Case closed by welding, epoxy impregnation

Structure (coil case)

- 19 by JA/19 Coil cases
- Machining welding
- Subassembly
- Integration WP and Case
- Assembly

Conductor

- 33 by JA/133 conductors
  - Twisting and cabling
  - Jacketing

Coaxial cable:
- φ0.82mm
- Strand

Forged/Rolled material

- Segments

TF coil

- 14 m
- 9 m
Jackets (13m)

Manufacturing strands
(1 to 20km per strand)
Strand cross section (φ0.82mm)
Strands wound on bobbins
Total produced: 23,000 km (apprx 100 tons)

Manufacturing cables
Stranded conductor wound on a bobbin
Total produced: 760 m x 24
415 m x 9

Manufacturing of conductors
- 760 m (7.3 ton) x 24, 100% complete
- 415 m (4.0 ton) x 9, 100% complete

Conductor manufacturing facility
950 m

Jackets joint by butt welding and inspections

Lead-in of stranded conductor (<4 ton)
Compression molding bending

A finished conductor

Fabrication completed in 7 years, as scheduled (Dec. 2014 press release)
TF Coil Winding process (MHI)

Winding

Heat Treatment
18 DPs completed,

Transfer

Turn Insulation

RP

20 DPs completed,

11 DPs completed,

10 DPs completed,
TF Coil Winding process (MHI)

- CP Welding
- DP Insulation
- DP Impregnation
- DP Stacking

9 DPs completed,

First 7 DPs stacked for TF#1 in Dec. 2016.
TF coil winging line (Toshiba)
Conductor winding

- Precise measurement of conductor winding.
- Conductor length varies due to heat treatment.

Conductor must fit within grooves of RP:
- a few mm over 14-m height and 9-m width.
- \( \approx 0.02\% \) tolerance in dimensions.

Rectangular flange is machined so that the conductor fits within the RP groove.
- Full-size prototypes have been manufactured for optimization of manufacturing technologies, such as suppression of welding deformation.

Data of welding deformation and its suppression procedures have been accumulated for fabrication of ITER TF Coils.
TF Coil Structures

Outboard Sub-assembly
(consisting of 4 Basic Segments before welding B1+B2 and B3+B4)

Inboard Sub-assembly (consisting of 3 Basic Segments)

The sub-assemblies have been welded within required tolerance.
ITER NB system is required to generate 40 A of D⁻ ions at 1 MeV for 3,600 s, which is much more than performance of existing NB systems (22 A, D⁻ at 0.5 MeV for 10 s).

The ITER Council decided to build the NB test facility at Padua Italy, which has identical design to the ITER NB system, to fulfill all the requirement in advance.

Most of the 1 MV PS have been already manufactured by Hitachi Ltd.
A ceremony has been held at Padua celebrating the arrival of Japanese components and the start of on-site construction work, on 11th Dec. 2015. Dignitaries including Mr. Itakura (MEXT), Mr. Bigot (DG of the ITER Organization), Mr. Garribba (European Commission), Mr. Barabaschi (F4E), Mr. Gnezott (RFX) and Mr. Miel (Ministry of education, Italy) were in attendance.
Almost all components have been manufactured, and 80% of them have been already installed at NBTF site.
HV bushing for HNB injector

ITER NB Injector
16.5 MW D⁰ at 1 MeV for 1 hour

1 MV Transmission Line

HV bushing

- Pressure/vacuum boundary between PS and BS.
- Feedthrough for bus bars and water pipes
- Double layers: ceramic and FRP
- Five rings in series for 1 MV insulation.

Manufacturing and 1 MV insulation were unavoidable challenges to realize the ITER NB system.
Development of HV Bushing

Large bore ceramic ring R&D

Joint R&D with Kyocera

Joint R&D with Hitachi Power Devices

Brazing R&D

Small scale R&D

Mockup Bushing Test

2009 Brazing of Kovar with Large ceramic

2006 A half-size R&D

Brazing joint

2005

240 kV/single stage for 2 hours (120% of rated voltage)
(2) 480 kV/two stages for 1 hour also confirmed.
Series production of ceramic rings and brazing in progress
✓ Major requirement of ITER Gyrotron already achieved (1 MW for 1,000 s, efficiency > 50%, 5 kHz modulations, etc.).
✓ PA signed in Sep. 2013 (eight Gyrotrons).
✓ Manufacturing of ITER Gyrotron #1 & #2 started from Jan. 2016.
✓ First Gyrotron for ITER has been delivered to QST Naka in December 2016 (on schedule). The gyrotron is to be shipped to ITER site after high power test at Naka.
Summary

• In order to manufacture the full-scale ITER components, following challenges were required.
  ✓ Control and precise measurement of conductor winding in D-shape and subsequent precise machining/welding of Radial Plate,
  ✓ Welding technologies for TF Coil Structure, to fulfill the tight tolerances suppressing the welding deformation,
  ✓ 1 MV insulation in air, oil and SF6 in a large capacity 1 MV dc power supply,
  ✓ Development of large bore ceramic ring and its brazing with Kovar for HV bushing of NB injector, together with 1 MV insulation technology in vacuum,
• First 170 GHz 1 MW Gyrotron has been delivered.
• Thus Japan has developed manufacturing technology for full-scale ITER components and their procurement is in progress together with industries.
• For other procurements, such as Blanket Remote Handling, Diagnostics, Atmospheric Detritiation System as well as the Test Blanket System, design activities are in progress to launch manufacturing toward the ITER First Plasma in 2025.