The Magnetic Fusion Program in Japan

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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
Fusion Power of 0.5GW
Q=10
DT Burning
@France

Demo Reactor

DEMO
Demonstration of Fusion Power Plant
Support ITER toward DEMO

Support ITER
Broader Approach (BA) Activities
Establish Basis for DEMO

Helical Device

LHD @Toki

JT-60SA @Naka
International Fusion Energy Research Center (IFERC)

IFMIF/EVEDA @Rokkasho
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%

Blanket Remote Handling System (under design)
- Vehicle with Manipulator
- Vacuum Vessel
- Manipulator
- Vehicle
- Rail

Divertor
- Outer Target: 100%

Detritiation 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%

Diagnostics (under design)
- Micro Fission Chamber
- Poloidal Polarimeter
- Edge Thomson Scattering
- Divertor Impurity Monitor
- IR Thermography
- Thermocouples
- Upper Port Integration
- Lower Port Integration
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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.
JT-60SA: highly shaped ($S=q_{95}I_p/(aB_t) \sim 7$, $A \sim 2.5$) large superconducting tokamak confining deuterium plasmas ($I_{p\text{max}}=5.5$ 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.

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

Jan. 2014

2 Jun 2014

Mar., 2013

Lower 3 EF Coils

Vacuum Vessel ➔

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

4th Jun 2014
40-deg. VV sectors will be assembled up to 340-deg. ready for the TFC installation.

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.

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

TF (Toroidal Field) Coil Winding started
(CEA, ENEA)

Manufacture of structural components are also going well.

Outer Intercoil Structures
CEA (SDMS)

Gravity supports
CEA Alstom

Casings
ENEA (Walter Tosto)
JT-60SA: Manufacture on schedule in both EU and JA


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

Cryostat Base (260 tons)

Toroidal Field Coils Winding started.

Vacuum Vessel Sectors

UF coil test facility has been almost completed.

First Plasma 2019 March

TF coil test facility has been almost completed.

Upper 3 EF Coils & CS

Cryostat: Manufacture started.

HTS Current Lead

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

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

\[ \beta_N = 4.1 \ (C_\beta = 0.8) \] 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


Please visit
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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 1GW/m² 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)

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

- 70 kV and 40 mA
International Fusion Energy Research Center (IFERC) Project
Remarkable progress seen in each activity with efficient joint work of EU and JA

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
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

- 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
- Several-month-long operation, 17 times since 1998
- Operational time of He compressor: 76,400 hours
- 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

Engineering Base
- Duty > 99%

A large number of opportunities for diversified collaboration on physics.
Achieved plasma parameters encourage the further next step.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Achieved</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>(T_{i0})</td>
<td>8.1 keV ((1 \times 10^{19}\ \text{m}^{-3}))</td>
<td>10 keV ((2 \times 10^{19}\ \text{m}^{-3}))</td>
</tr>
<tr>
<td>(T_{e0})</td>
<td>13 keV ((1 \times 10^{19}\ \text{m}^{-3}))</td>
<td>10 keV ((2 \times 10^{19}\ \text{m}^{-3}))</td>
</tr>
<tr>
<td>(n_{e0})</td>
<td>1.2( \times 10^{21}\ \text{m}^{-3}) ((0.26\ \text{keV}))</td>
<td>4( \times 10^{20}\ \text{m}^{-3}) ((1.3\ \text{keV}))</td>
</tr>
<tr>
<td>(\beta)</td>
<td>5.1 % ((0.425\ \text{T}))</td>
<td>5 % ((1-2\ \text{T}))</td>
</tr>
<tr>
<td>Discharge duration</td>
<td>54 min. ((500\ \text{kW})) \textbf{48 min. ((1,200\ \text{kW}))}</td>
<td>1 hour ((3,000\ \text{kW}))</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>FY2013</th>
<th>FY2014</th>
<th>FY2015</th>
<th>FY2016 – FY2024</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation for D-exp. (3 years)</td>
<td>H-Exp.</td>
<td>H-Exp.</td>
<td>Deuterium Experiments (9 years)</td>
</tr>
<tr>
<td>Upgrade for Heating System (NBI, ECH, ICRF)</td>
<td>Upgrade for Diagnostics System (Neutron diagnostics, etc.)</td>
<td>Remodeling of Building and Facilities</td>
<td>Preliminary Experiments for Neutron Diagnostics</td>
</tr>
<tr>
<td>Installation of Safety Equipments (Tritium removal system, etc.)</td>
<td></td>
<td></td>
<td>Calibration Experiments for Neutron Diagnostics</td>
</tr>
</tbody>
</table>

#### Target in D-Exp.

- $T_i = 10\text{keV}$ at $2 \times 10^{19}$ m$^{-3}$
- $W_p = 3.8\text{MJ}$ at $1 \times 10^{20}$ m$^{-3}$
- $\langle \beta \rangle \sim 3\%$ at $T(0)\sim 5\text{keV}$
- $nT\tau \sim 1.4 \times 10^{20}$ m$^{-3}\text{keV s}$
- 3MW Heating for 1 hour

**Agreements for D-exp.**
- Legal License

**Deuterium Experiments**
- Closed Helical Divertor with Pumping System
  - NBI: 18MW (60–80keV, 2sec)
  - 14MW (180keV, 2sec)
  - ECH: 6MW–3sec, 1MW–CW (77GHz & 154GHz)
  - ICRF: 6MW–5sec, 2–3MW–CW

**Neutron Diagnostics**
- High-Energy Particle Measurement
- 3-Dimensional Measurement
- High-Accuracy Measurement
- Divertor Diagnostics
- Steady-State Data Acquisition
- PWI Laboratory
DEMO Design Activities in Japan
Fusion Community for DEMO Design in Japan

Joint Core Team (organized 2013-14)

- JAEA, NIFS, Universities, etc.
- Industry
- Academic Societies, Associations (AESJ, JSME, CSSJ, JPSF, etc.)
- Codes & standards
- Policy
- Government (MEXT, CSTP)
- WG for Fusion Research Council for Science and Technology, MEXT
- Fusion Energy Forum of Japan Fusion Network
- Japan Atomic Industrial Forum Inc.
- Industry soundness, Manufacture, Economy
- R&D Program
- Int’l Relation, & Roadmap
- EU, USA, China, Korea, IAEA

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

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)

Discussion towards DEMO Development Roadmap
by Working Group on Fusion Research
Council for Science and Technology, MEXT

Taskforce for Grand Strategy of Technology Bases for Development of DEMO

Optimization of grand strategy and management based on comprehensive overlooking of technology

Evaluation
Guidance

Report and approval of overall policy

Strengthening cooperation

Related Academic Societies

Provision of information, Facilitation of new involvement

Ad hoc Team of Conceptual Design of DEMO

General Coordination Group

Information sharing, Request

Superconducting coil
Divertor
Blanket
Heating & current-drive system
Theory and computational simulation
Fusion-relevant plasma
Diagnostics & control
Fusion fuel system & establishment of codes and standards
Fusion materials & establishment of codes and standards
Safety of fusion reactor and safety research
Availability & maintenance

Joint-Core Team

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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.).

2. **In BA Activities**
   - **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 towards 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.