JT–60U Status and Plans

M. Kikuchi for the JT–60 Team
Japan Atomic Energy Research Institute
JAERI (Japan atomic Energy Research Institute) and JNC (Japan Nuclear Fuel Cycle–Development Institute) will be unified to form a new entity in Mid 2005. Present staff and budget of two institutes as of 2003 are as follows.

JAERI employs ~2,200 staff
budget ~ 94 billion Yen.

JNC employs ~2,300 staff
budget ~ 130 billion Yen.
Procedures for personal assignment

ITPA Joint experiments
US to JT–60U : LT IA Appendix A2 signed by E. Oktay and Visitor
EU to JT–60U : LT IA Appendix A2 signed by M. Watkins and Visitor
JT–60U to US : Personal assignment agreement (US–J) is required except PPPL and GA.
JT–60U to EU : Personal assignment agreement (EU–J) is required except JET.
National research collaboration

Research Theme structure for 2003–2004

Director of Department of Fusion Plasma Res.

Theme Leaders; (T. Fujita), S. Ide, H. Takeaga

Task

Extension of Discharge Duration (S. Ide)

Development of advanced tokamak (N. Sakamoto)

Confinement improvement at high density (H. Takenaga)

AMTEX (K. Tsuzuki)

Subject

Core Plasma (T. Takizuka)

H-mode Physics/ Pedestal (Prof. K. Toi (NIFS))

Modeling of ITB (Prof. A. Fukuyama (Kyoto U))

Current Hole (T. Fujita)

MHD/Energetic Particle / Disruption, (M. Takechi)

Current Drive (Prof. K. Hanada (Kyushu U))

Innovative operation (Prof. Y. Takase (U. of Tokyo))

Plasma Material Interaction (Prof. T. Tanabe (Nagoya U))

centralized joint research devices

Number of collaborator

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<th>Year</th>
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3. Organization of Fusion Research in JAERI

Board of Executive Directors
President : T. Okazaki
Vice President : S. Tanak, O. Tanaka
Executive Director : S. Matsuda

Office of Planning
Director : S. Okada
General Manager : S. Ishida

NAKA FUSION RESEARCH ESTABLISHMENT
Director General : M. Seki

Office of ITER Project Promotion
Director : Y. Okumura

DEPARTMENT OF FUSION
PLASMA RESEARCH
Director : H. Ninomiya
Deputy director : M. Kikuchi

- Tokamak Program Division
  General Manager : Y. Miura
- Plasma Analysis Division
  G. M. : T. Ozeki
- Large Tokamak Experiment and Diagnostics Division
  G. M. : Y. Kamada
- Plasma Theory Laboratory
  Head : Y. Kishimoto*
  *: Kyoto U.
- Experimental Plasma Physics Laboratory
  Head : Y. Kusama
- Reactor System Laboratory
  Head : K. Tobita

DEPARTMENT OF FUSION
FACILITIES
Director : M. Kuriyama
Deputy director : N. Hosogane

- JT-60 Administration Div.
  G. M. : Y. Terakado
- JT-60 Facilities Div. 1
  G. M. : K. Kurihara
- JT-60 Facilities Div. 2
  G. M. : N. Miya
- RF Facilities Div.
  G. M. : T. Fujii
- NBI Facilities Div.
  G. M. : T. Yamamoto
- JFT-2M Facilities Div.
  G. M. : T. Yamamoto

DEPARTMENT OF FUSION
ENGINEERING RESEARCH
Director : S. Seki
Deputy director : H. Takatsu

- Blanket Engineering Lab.
  Head : M. Akiba
- Superconducting Magnet Laboratory
  Head : K. Okuno
- Plasma Heating Lab.
  Head : K. Sakamoto
- Tritium Engineering Lab.
  Head : M. Nishi
- Office of Fusion Material Research Promotion
  Head : M. Sugimoto
- Fusion Neutronics Laboratory
  Head : T. Nishitani

DEPARTMENT OF ITER Project
Director : T. Tsunematsu
Deputy director : R. Yoshino

- Project Management Div.
  Head : M. Mori
- International Coordination Div.
  Head : T. Ando
- Tokamak Device Div.
  Head : K. Shibanuma
- Plant System Div.
  Head : T. Shoji
- Safety Design Div.
  Head : E. Tada

DEPARTMENT OF ADM. SERVICES
Director : I. Kikuchi
Deputy director : H. Kobayashi

- Administrative Service Div.
- Accounts Div.
- Utilities and Maintenance Div.
- Safety Div.

Office of Fusion Material Research Promotion
Head : M. Sugimoto

Fusion Neutronics Laboratory
Head : T. Nishitani

JT-60 Administration Div.
G. M. : Y. Terakado

Superconducting Magnet Laboratory
Head : K. Okuno

Plasma Heating Lab.
Head : K. Sakamoto

Tritium Engineering Lab.
Head : M. Nishi

Office of Fusion Material Research Promotion
Head : M. Sugimoto

Fusion Neutronics Laboratory
Head : T. Nishitani
Introduction

JT-60U

Objectives

- ITER Physics R&D
- Advanced Tokamak Concepts for ITER & DEMO

Performance

ITER

DEMO Reactor

NCT
4. Status of JT-60U

**Recent trends of operation cycles**

- **FY2000**: 9 cycles, two shifts, 18 weeks of experiment
- **FY2001**: 6 cycles, two shifts, 12 weeks of experiment
- **FY2002**: 2 cycles, two shifts, 04 weeks of experiment
- **FY2003**: 2 cycles, one shift, 08 weeks of experiment
  - MG trouble in Feb. 2004, 3 EX weeks cancelled.
- **FY2004**: 2 cycles, one shift, 08 weeks of experiment (65s with reduced Bt capability)
- **FY2005**: 2 cycles, one shift, 08 weeks of experiment (65s)

Research plans are based on a two-year frame.

<table>
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- **FY 2002**
- **FY 2003** (MG trouble)
- **FY 2004**
- **FY 2005**

Electricity demand:
- **FY 2002**: 40MW
- **FY 2003**: 40MW
- **FY 2004**: 35MW
- **FY 2005**:
1. Modification for long pulse discharge

Max. pulse length of a discharge: 15s $\Rightarrow$ 65s. Modification on control systems in operation, Heating/CD and diagnostics, but not on major hardware.

- Control of NB: 30s, control of RF: 60s.
- PFC temperature is not actively cooled; carbon tiles (CFC for divertor), a small number of W tiles, and RF antennas.
- Vessel temperature is kept 150-300 degC; mostly 150 degC in 2003-04 campaign.

![Graph showing pulse length and magnetic field strength](image_url)
Improvement in NB systems (P-NB, N-NB)

Positive-ion NB (P-NB) (~85keV)
• 4 tangential (2 co + 2 ctr): 30 s
• 7 perpendicular: 10s(6u), 15 s(1u)

Negative-ion NB (N-NB) (~360keV)
• 2(1) co-tangential: 10 s (30s)

~2 MW/unit for long pulse operation.
350 MJ achieved with P-NB + N-NB
65 s discharge has been achieved

- Flux swing of transformer saved by NB+EC heating and EC breakdown assist.
- Long pulse LHCD will result in higher $I_p$.
- For 30 s, 1.4 MA ELMy H-mode was maintained.
Long sustainment of high $\beta_N$ in extended pulse operation

$\beta_N = 2.3$ sustained for 22.3s ($\sim 13.1\tau_R$)

$\tau_R = \frac{\mu_0 <\sigma_{NC}>}{m_a}a^2/12$

Long sustainment of high $f_{BS}$

- **Strong linkage of $j_{BS}(r)$, $j_{total}(r)$ and transport in high $f_{BS}$ plasmas,**

- **Previously, $f_{BS} \sim 80\%$ was maintained for 2.7 s ($\sim 0.6 \tau_R$)

- **Control must be demonstrated in longer sustainment ($\gg \tau_R$).**
  
  When ITB (c) changes=> p and $j_{BS}$ changes in $\tau_E$. But $j_{tot}$ changes in $\tau_R$. 

\[ \text{Pressure} \]
\[ \text{BS current} \]
\[ \text{Total current} \]

\[ \text{Current profile} \]
\[ \tau_E \]
\[ \tau_R \]

\[ \text{BS current transport (ITB)} \]
$\beta_p \approx 2.25$, $HH_{y2} \approx 1.7$ sustained for $\approx 7.4s$ ($\approx 2.7\tau_R$) under nearly full CD in RS plasma

Reversed shear ELMy H-mode ($3.4T$, $0.8MA$, $q_{95} \approx 8.6$, $\delta \approx 0.42$)

Non-inductive CD: Bootstrap dominant & $P_{NB}^{inj(co)} = 3.2MW$

Duration limited by NB injection.

$\beta_N \approx 1.7$, $\beta_p \approx 2.25$ by FB control

Nearly full CD

$H_{89} \approx 3$, $HH_{y2} \approx 1.7$

No strong impurity accumulation

$Z_{eff}$: constant ($\approx 3$)
$f_{BS} \sim 75\%$ sustained for $\sim 7.4s \ (\sim 2.7\tau_R)$

- BS current peaked at the ITB.
- $f_{BS} \sim 75\%, \ f_{BD} \sim 20\%, \ f_{CD} \sim 95\%$
- Well-aligned BS current
- $j(r)$ and $p(r)$ reached stationary conditions.

\[
\begin{align*}
E43046 & \quad I_p \\
0 & \quad 1 \\
4 & \quad 6 \\
8 & \quad 10 \\
12 & \quad 7.4 \text{ s} \\
\end{align*}
\]

$f_{BS} = 75\%$

\[
\begin{align*}
q_{\text{min}} & \quad q_{\text{min}} \\
0.2 & \quad 0.4 \\
0.6 & \quad 0.8 \\
1.0 & \quad 1.2 \\
2.0 & \quad 2.2 \\
4.0 & \quad 4.2 \\
6.0 & \quad 6.2 \\
8.0 & \quad 8.2 \\
10.0 & \quad 10.2 \\
12.0 & \quad 12.2 \\
\end{align*}
\]

Well-aligned BS current peaked at the ITB.

Well-aligned $j(r)$ and $p(r)$ reached stationary conditions.
Long sustainment of nearly full CD plasmas

- Achieved region of ~ full CD with large $f_{BS}$ has been significantly extended.
- $j(r)$ approached stationary conditions.
- Controllability of $j(r)$ and $p(r)$ must be studied in a long time scale.

![Graph](image_url)

- Double symbol: ~Full CD
- SSTR
- ITER
- Steady State
- Weak shear
- Rev. shear
- $f_{CD} > 90\%$
- $p^* \approx 0.006$
- $n^* \approx 0.06$
- $\tau_R > 2$
Divertor heat load is reduced by a factor of 10 during grassy ELM than during type I ELM.

- $\Delta W_{\text{ELM}}$ is reduced by a factor of 10 during grassy ELM.
- Narrower radial extent.
- Low $n_e^*$ region ($n_e^* \leq 0.15$).

$q_{95} \approx 6.1$
$d \approx 0.46$
Inter-machine comparison between C-Mod EDA and JFT-2M HRS regimes

JFT-2M has found a “High Recycling Steady” (HRS) H-mode. These features are qualitatively similar to C-Mod EDA regime. ITPA Inter-machine collaboration was proposed (PEP-12).

Questions: Is this the same regime as EDA? If so, how do access conditions and fluctuations scale and compare?
National Centralized Tokamak Program

- **Objectives:** to realize high-beta steady-state operation with the use of reduced radio-activation ferritic steel in a collision-less regime.

- **Planning:** For further progress in the high beta steady state research, the modification of JT–60 is regarded as “National centralized tokamak facility program”. Detailed design work is ongoing in collaboration with universities, institutes and industries in Japan.

![Diagram of Tokamak Facility Program](image-url)
Summary

- Long pulse operation is successfully performed.
  - 65 second discharge
  - 30 second H-mode
  - 24 second sustainment of $\beta_N \sim 1.9$
- Region of sustained high beta has been extended.
  - Stationary RS ELMy H-mode plasma with $f_{BS} \sim 75\%$ has been sustained for 7.4s under near full CD
- NCT is being promoted.
  - DOE–JAERI technical planning of tokamak experiments(WS)
- US–Japan cooperation is always productive.
  - C–MOD/JT–60U joint experiments