Overview of Recent Japanese Activities in Fusion Technology

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16th TOFE
Madison, USA
September 2004

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Overview of Recent JapaneseActivities
in Fusion Technology

1. Introduction - Fusion Research Organization, Budget Situation
2. Blanket Technology
3. Tritium Technology
4. Superconducting Magnet Technology
5. Heating and Current Drive Technology
6. Summary
FUSION R&D BUDGET (1975 - 2003)
# RECENT FUSION R&D BUDGET

<table>
<thead>
<tr>
<th></th>
<th>FY2002</th>
<th>FY2003</th>
<th>FY2004</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL BUDGET</td>
<td>14,666</td>
<td>13,849</td>
<td>-</td>
</tr>
<tr>
<td>(Million Yen)</td>
<td>(12,800)</td>
<td>(11,989)</td>
<td>(14,101)</td>
</tr>
<tr>
<td>TOTAL BUDGET (except for national universities and attached institutes)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JAERI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JT-60</td>
<td>5,116</td>
<td>4,401</td>
<td>6,217</td>
</tr>
<tr>
<td>ITER</td>
<td>3,011</td>
<td>2,864</td>
<td>2,696</td>
</tr>
<tr>
<td>Others</td>
<td>1,715</td>
<td>987</td>
<td>828</td>
</tr>
<tr>
<td>National Laboratories</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National Institute for Materials Science</td>
<td>271</td>
<td>249</td>
<td>218</td>
</tr>
<tr>
<td>National Institute of Advanced Industrial Science and Technology</td>
<td>49</td>
<td>47</td>
<td>62</td>
</tr>
<tr>
<td>Universities</td>
<td>9,254</td>
<td>9,174</td>
<td>(7,643)</td>
</tr>
<tr>
<td>National Institute for Fusion Science (NIFS)</td>
<td>7,387</td>
<td>7,314</td>
<td>7,643</td>
</tr>
<tr>
<td>Institute of Laser Eng., Osaka Univ.</td>
<td>681</td>
<td>678</td>
<td>-</td>
</tr>
<tr>
<td>Research Institute for Applied Mechanics, Kyushu Univ.</td>
<td>418</td>
<td>417</td>
<td>-</td>
</tr>
<tr>
<td>Plasma Research Center, Univ. of Tsukuba</td>
<td>282</td>
<td>281</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>485</td>
<td>483</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>26</td>
<td>25</td>
<td>24</td>
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</tbody>
</table>

Budget for national universities and their attached institutes in FY2004 is not shown because they will become independent administrative institutions in the fiscal year.
Investigation on Fusion Research in Japanese Government

Covering all the domestic fusion research in Japan, the following future direction of national fusion research is suggested*:

(1) **Fusion research centralization**
   (tokamak, helical, reactor engineering, and laser)

(2) **Enhancement of the inter-university and inter-institutional research**

(3) **Education and training after centralization**

From report of the Working Group on Fusion Research in Japan set up under * the Council for Science and Technology, Subdivision on Science, Special Committee on Basic Issues. (dated 8 January 2003.)
Blanket Development in Japan

- The Fusion Council of Japan has established the long-term research and development program of the blanket in 1999.

- JAERI has been pursuing solid breeder blankets cooled by high pressure and high temperature water.

- Universities and NIFS have been developing advanced concepts: He-cooled, Li/V, molten salt, and LiPb for the module testing in ITER.

- Japan is looking for the possibility of testing all types of blankets under the TBWG framework.
(1) Demonstrative data of the integrated blanket structures: ITER TBM
(2) Material irradiation data: IFMIF

<table>
<thead>
<tr>
<th>Approximate calendar year</th>
<th>2015</th>
<th>2020</th>
<th>2030</th>
<th>2040</th>
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</thead>
<tbody>
<tr>
<td>Power Demonstration Plant</td>
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<tr>
<td>ITER</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Materials and Blanket System Development</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reference Material (RAFM) and System</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced Materials (V-alloy, Flibe, SiC/SiC --) and Systems</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>IFMIF</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blanket Module Testing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design ......Construction ...... Operation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Licencing)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(Blanket test)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irradiation Test, Materials Qualification and System Performance Test</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Staged construction and operation)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Reference Blanket (JAERI)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Advanced option (NIFS/Universities)</td>
<td></td>
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</tbody>
</table>
Neutronics / Tritium Production Rate Tests using 14 MeV Neutron Source (FNS)

Achievements
- Neutronics performance and Tritium Production Rate (TPR) was evaluated using 14 MeV neutrons with high accuracy, about 5% by simple mockups.

R&D Target by 2010
- To demonstrate neutronics performance and TPR of simulated TBM mockups with higher accuracy, < 5%, using 14 MeV neutrons
- To develop neutron monitors for TBM

Evaluate TPR, Neutron fluxes
Compare numerical results

Evaluate TPR, Neutron fluxes
Compare numerical results
Dose dependence of DBTT shift of F82H

DBTT also tends to saturate with dose, as far as He level is not high.
## R&D Activities on Tritium in Japan

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Organization</th>
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</thead>
<tbody>
<tr>
<td>Tritium processing: JAERI, NIFS, NU</td>
<td></td>
</tr>
<tr>
<td>Tritium Behavior in Blanket: KyuU, UT, SU, TU, NIFS</td>
<td></td>
</tr>
<tr>
<td>Interaction between Tritium and Materials: JAERI, UT, SU, NU, TU, KyuU, KyoU, HoU, OU</td>
<td></td>
</tr>
<tr>
<td>Decontamination and Safety: JAERI, UT, KyuU, NIFS</td>
<td></td>
</tr>
<tr>
<td>Analysis of Tritium and Tritium in Inertial Fusion: TU, OU(Inertial Fusion)</td>
<td></td>
</tr>
<tr>
<td>Fundamental Studies of Tritium: TohU, SU</td>
<td></td>
</tr>
<tr>
<td>Tritium Behavior in Environment and Biology: IU, NIRS, KuU, KyoU, NIFS</td>
<td></td>
</tr>
</tbody>
</table>

JAERI: Japan Atomic Energy Research Institute  
NIFS: National Institute for Fusion Science  
NIRS: National Institute of Radiological Science  
HoU: Hokkaidou University, TohU: Tohoku University  
IU: Ibaraki University, TU: Toyama University, UT: University of Tokyo, SU: Shizuoka University,  
NU: Nagoya University, KyoU: Kyoto University, OU: Osaka University, KyuU: Kyushu University,  
KuU: Kumamoto University
**Tritium Processing in Blanket, fuel cycle, and confinement system**

**Tritium Processing in Blanket and fuel cycle**
*Integration tests of blanket tritium recovery system of cryosorption and fuel cycle system: Japan Atomic Energy Research Institute (JAERI),*
*Demonstration of recovery of tritium in He sweep gas by the integrated system*
*Advanced tritium recovery system using proton conductor (electrochemical hydrogen pump): JAERI, National Institute for Fusion Science (NIFS), Nagoya University*
*Adsorption and chemical exchange techniques for tritium recovery from cooling water: JAERI, NIFS, Nagoya University*

**Tritium Processing in Confinement system**
*Polyimide membrane system for tritium removal from atmosphere: NIFS, Shizuoka University*
Tritium and Materials
*Tritium in JT-60 first wall: JAERI, Nagoya (imaging plate technique), Kyushu, Hokkaido, Toyama Universities, University of Tokyo
Effectiveness of addition of water vapor
*Basic studies on the interaction between tritium and Materials:
SiC: University of Tokyo; ZrNi, V-Ti: Toyama University; SiC, Boron, graphite, solid blanket materials: Shizuoka University

Decontamination and Safety
*Tritium behavior in cement: JAERI and Kyushu University
*Behavior of tritium vapor in a room: JAERI
*Basic studies for the behavior of the tritium vapor on construction materials: Toyama University, University of Tokyo.
*Remove of tritium on a carbon/hydrogen co-deposited layer by excimer laser: JAERI

Dependence of tritium release amount on vapor concentration in the air introduced to JT-60.
Analysis and others

* Tritium analysis by β-ray induced X-ray (BIXS): Toyama University, Good linear relation between an amount of tritium and the intensity of X-ray
* Tritium studies related to inertial fusion: Osaka University

Environment and Biology

* Model for tritium behavior in environment and biology: National Institute of Radiological Sciences
* Start the project “Environmental Radionuclides Movement Analysis (ERMA) from 2003
* Fundamental studies, oxidation of atmospheric tritium by soil microbes, and biological risk of low dose tritium: Ibaraki University

* Measurement of concentrations and chemical forms of tritium in environment (atmosphere and rain): Kumamoto University.
* No significant effect of human activities was observed for the tritium concentration in rain in Japan.
Achievements in ITER Magnet Development

- High performance Nb$_3$Sn strands have been developed and qualified in industrial scale (25 t in total).
- Large-current Nb$_3$Sn CIC conductor technology has been established (5.6 km in total).
- Coil Fabrication technology has been developed.

Ready for ITER construction
There are two options in terms of the maximum field of the TF coil in DEMO. 

<table>
<thead>
<tr>
<th>Field</th>
<th>16 T</th>
<th>20 T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Nb₃Al</td>
<td>HTS</td>
</tr>
</tbody>
</table>
Further Development of Nb₃Al Strand

Present status of RHQT Nb₃Al

• Current density of around 1000 A/mm² at 16 T.
• Unit length of 300 m.

Critical Current Density (A/mm²) vs. Magnetic Field (T)

Target for DEMO

RHQT
Rapid-Heating, Quenching and Transformation (RHQT) method
Heat treatment at 1800 °C for 0.1s is used for Nb3Al formation.
Trial fabrication of 10 kA HTS conductor

Current Lead

Terminal (HTS/Cu)

Sample

Conductor

Bi-2212 strand

0.8 mm

~34

Measured Critical Current at 12 T

Critical Current (kA) at 1µV/cm

Expected Ic from strand data

Measured at 12T

Critical Current (kA)

Temperature (K)

10 15

20 25 30

10 15 20 25 30
60-kA HTS Current Lead

**Terminal at Room Temp.**

**Copper Part**

**HTS Part**

**Terminal at Cryogenic Temp.**

### Major parameters

<table>
<thead>
<tr>
<th>Current lead</th>
<th>60 kA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated current</td>
<td></td>
</tr>
<tr>
<td>Overall effective length</td>
<td>1550 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HTS part</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Effective length</td>
<td>300 mm</td>
</tr>
<tr>
<td>Outer diameter</td>
<td>153 mm</td>
</tr>
<tr>
<td>Cooling method</td>
<td>Conduction (in vacuum)</td>
</tr>
</tbody>
</table>

**HTS material**
- Ag-10at%Au sheathed Bi-2223 tape

**Elements**
- Stack of 6 tapes
- 6.5mm x 2.7mm

**Conductor**
- 48 elements in a cylindrical array

**Copper part**
- Effective length: 750 mm
- Outer diameter: 140 mm
- Conductor material: Copper (RRR:100)
- Conductor configuration: Bundle
- Current density: 10 A/mm²
- Cooling method: Forced-flow He at 20K, 3.2g/s
SC Magnet Development

**Through the Technology R&D up to now:**

- Technologies to build ITER magnet system has been established by the extensive international collaboration among ITER parties.

- The magnet system will provide the maximum field of 13 T with toroidal filed of 5.3 T on plasma axis and major radius of 6.2 m.

- High performance Nb$_3$Sn superconductor has become available in industrial scale.

**Future Development towards Advanced Performance:**

- Nb$_3$Al and High Temperature Superconductor have excellent properties. A long-term, extensive development is required for fusion magnet application.
The primary feature on the engineering aspect of LHD is using superconducting coils for magnetic confinement: two pool boiling helical coils (H1, H2) and three pairs of forced-flow poloidal coils (IV, IS, OV).

**SC Helical Coils**
A numerically controlled winding machine has been developed for ±2 mm of high accuracy positioning.

**SC Poloidal Coils**
The poloidal coils wound with cable-in-conduit conductors (CICC) have the feature of high stability and low AC loss.

**Supporting Structure**
The SC coils are assembled to the supporting structure which sustains large electromagnetic forces.

**SC Bus-Lines**
SC coils are connected to the power supplies by superconducting bus-lines with the nominal current of 31.3 kA.

**He Refrigerator**
Cooling capacity:
- 5.65 kW at 4.4 K
- 20.6 kW at 80 K
- 650 L/h liquefaction
Cold mass: 820 t

**National Institute for Fusion Science**
Operational History of LHD

- LHD has been used for extensive plasma experiments since 1998 with 8 months operation period in each year. Seven cycles of experimental campaigns have been performed in four years.
- Operation time of the cryogenic system: 31,963 hrs
  Coil excitation No.: 804, Plasma shot No.: 48,721
Progress in NBI Development
- MeV accelerator -

H⁻ ion current density increasing progressively, since improvement of the voltage holding in vacuum insulated accelerator.

- The R&D in progress to increase the negative ion current density up to the ITER requirement.
- Recently, the beam dump replaced to swirl tubes: CHF at 140 A/m², 1 MeV
- Power supply of the facility: ≤ 1A.
Beam Power History of LHD N-NBI
Summary of Recent Progress

Performance of Gyrotron

- JA/170GHz
- RF/170GHz
- EU/140GHz
- JA/110GHz
- RF/140GHz
- US/110GHz

In Progress
Reduction of stray Radiation in gyrotron
Now 10% ~100kW)
<2%

Pulse extension by reduction of inner power deposition

For 170GHz/1MW CW(>400sec)
ECH System for LHD 7th Experimental Cycle

8 set of Gyrotrons, Transmission Lines, Antennas are operated.
4-168GHz (Toshiba), 2-84GHz CPD (GYCOM), 2-82.7GHz non CPD (GYCOM)
1-84GHz CPD (GYCOM) 200kW 1000 s (diamond window)
2- evacuated 1.25 inch corrugated waveguide system.
6-non-evacuated 3.5 inch corrugated waveguide system.
Total injection power to the LHD exceeds 2.1 MW at maximum in 6th cycle experimental campaign.
Summary (Long pulse experiments)

- 766 sec, 72 kW injected into LHD
  - Plasma is maintained for 756 sec
    - $n_e = 2.4 \times 10^{17} \text{m}^{-3}$, $T_{\text{rad,ECE}} = 240 \text{ eV}$
  - Plasma parameters are limited by the injection power.
    - Repetitive gas-puff is controlled not to cause radiation collapse.
  - Even with such low plasma parameters, change in the recycling during pulse is observed.
Summary

1. Inter-university and inter-institutional collaboration have been actively performed in many technology fields.
2. International collaboration has been an excellent vehicle to promote R&Ds in these stringent circumstances.
3. Japanese technology R&Ds tend to aim at a power demonstration plant. Many still aim at ITER.
4. ITER : We work hard to site ITER in Japan.
We are hoping Rokkasho as ITER site

Japan has good relations with US in fusion research as well as in baseball.