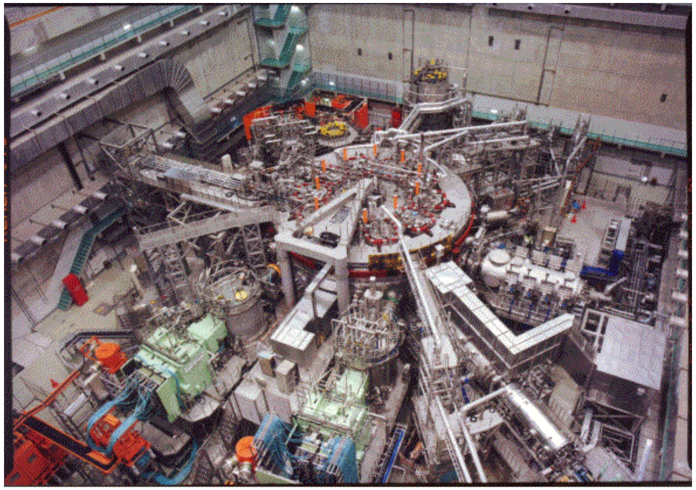
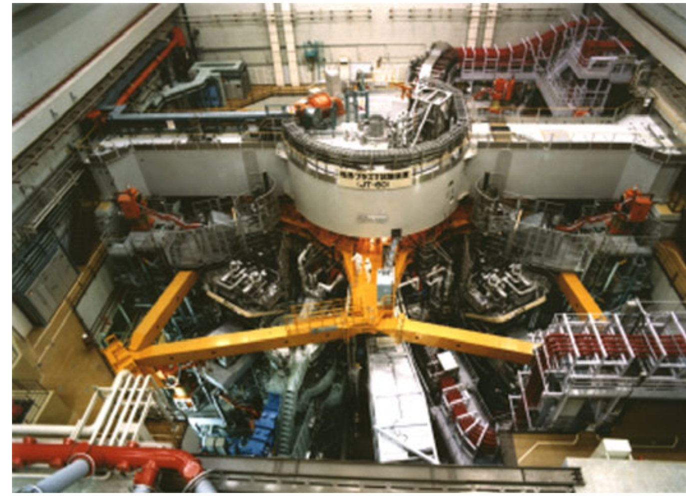
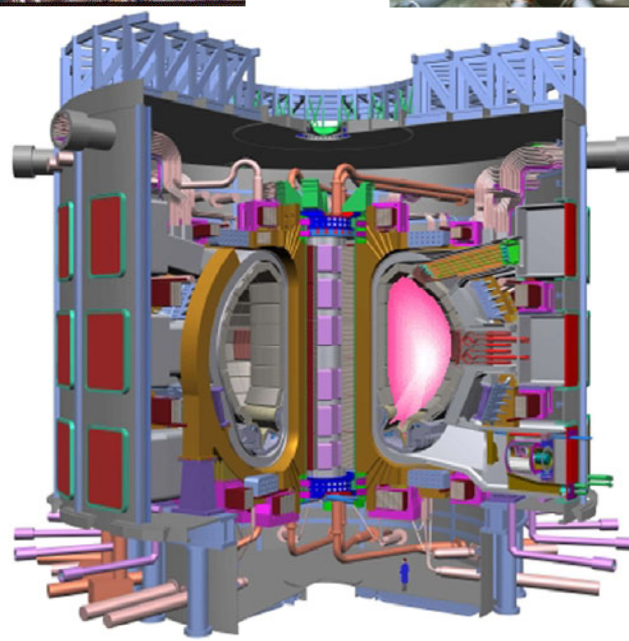
Overview of Recent Japanese Activities in Fusion Technology







16th TOFE
Madison, USA
September 2004

Masahiro SEKI
JAERI Naka
Fusion Engineering Division
AESJ

Overview of Recent Japanese Activities in Fusion Technology

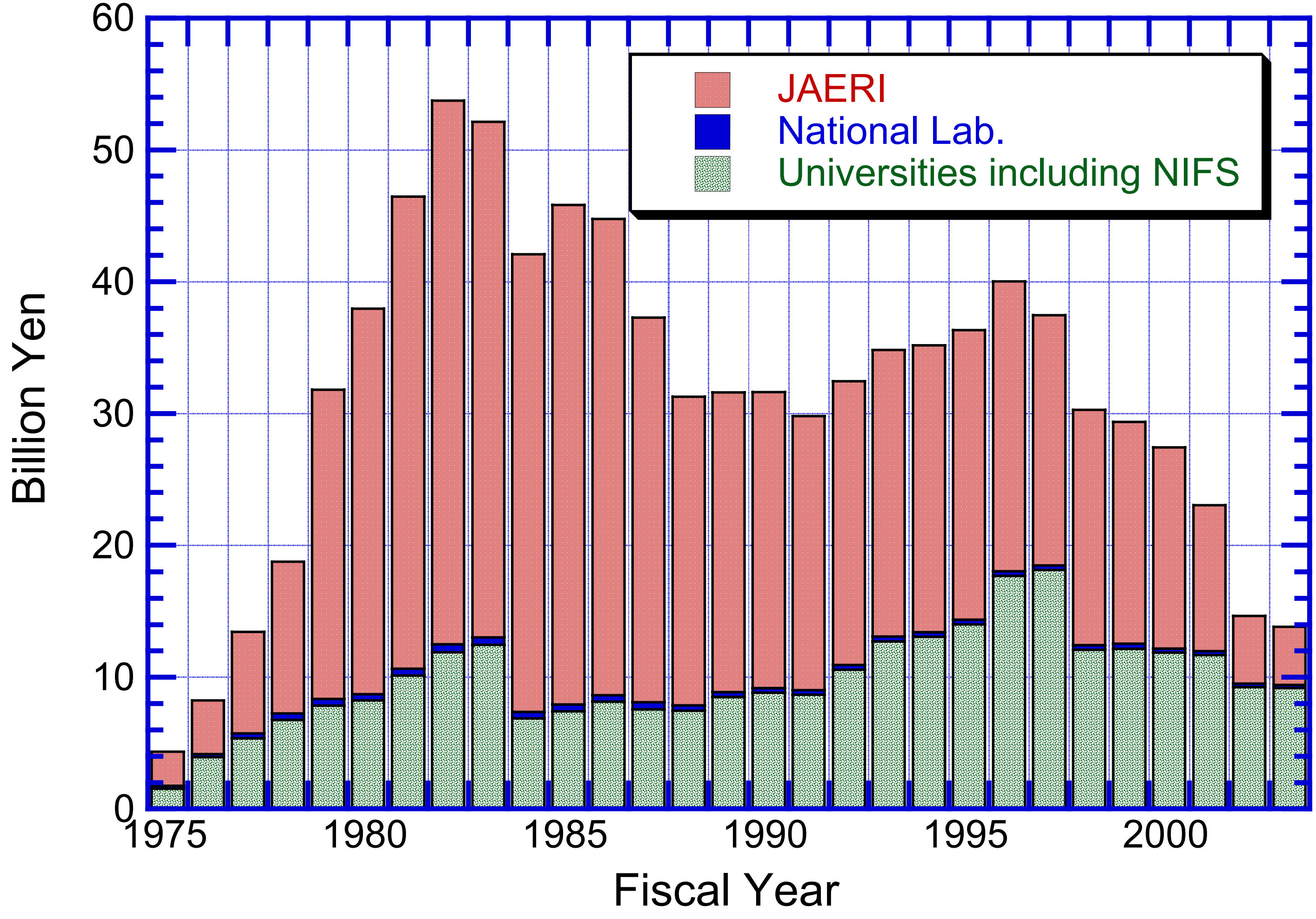
1. Introduction - Fusion Research Organization, Budget Situation
2. Blanket Technology
3. Tritium Technology
4. Superconducting Magnet Technology
5. Heating and Current Drive Technology
6. Summary

Organization of Fusion Research & Development

September 2004

- Ministry of Education, Culture, Sports, Science and Technology
  - National Institutes of Natural Sciences (National Institute for Fusion Science)
  - National Universities (Osaka Univ., Kyusyu Univ., Tsukuba Univ., etc.)
  - Japan Atomic Energy Research Institute
  - National Institute for Materials Science
- Ministry of Economy, Trade and Industry
  - National Institute of Advanced Industrial Science and Technology

FUSION R&D BUDGET (1975 - 2003)



RECENT FUSION R&D BUDGET

(Million Yen)

	FY2002	FY2003	FY2004
TOTAL BUDGET TOTAL BUDGET (except for national universities and attached institutes)	14,666 (12,800)	13,849 (11,989)	- (14,101)
JAERI	5,116	4,401	6,217
JT-60	3,011	2,864	2,696
ITER	391	550	2,693
Others	1,715	987	828
National Laboratories	271	249	218
National Institute for Materials Science	49	47	62
National Institute of Advanced Industrial Science and Technology	222	203	155
Universities	9,254	9,174	(7,643)
National Institute for Fusion Science (NIFS)	7,387	7,314	7,643
Institute of Laser Eng., Osaka Univ.	681	678	-
Research Institute for Applied Mechanics, Kyushu Univ.	418	417	-
Plasma Research Center, Univ. of Tsukuba	282	281	-
Others	485	483	-
Others	26	25	24

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.

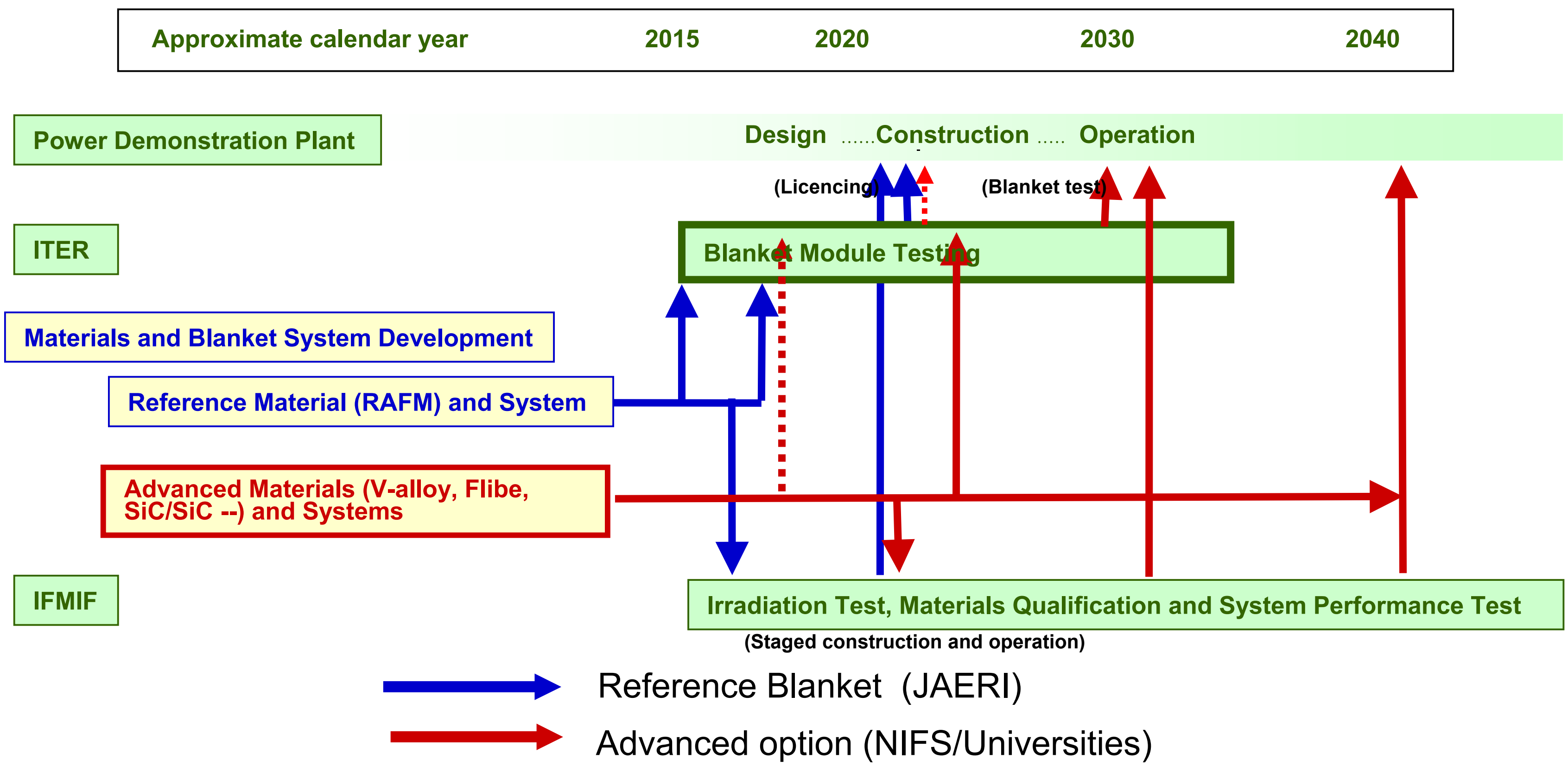
- JAERI has been pursuing solid breeder blankets cooled by high pressure and high temperature water.

- 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.

Materials and Blanket Development

(1) Demonstrative data of the integrated blanket structures : ITER TBM
(2) Material irradiation data : IFMIF



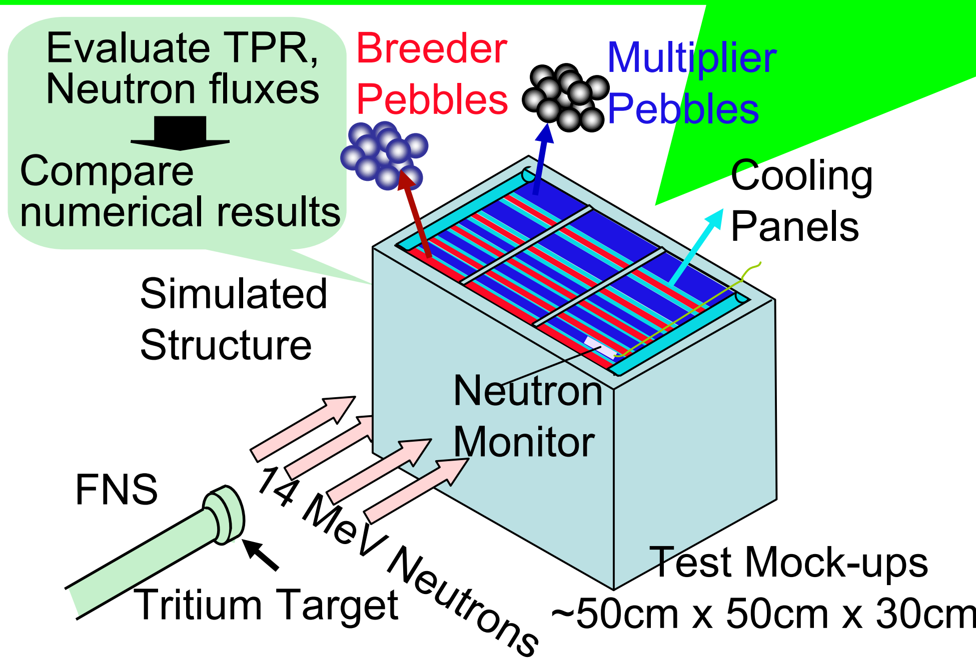
Neutronics / Tritium Production Rate Tests using 14 MeV Neutron Source (FNS)

Achievements

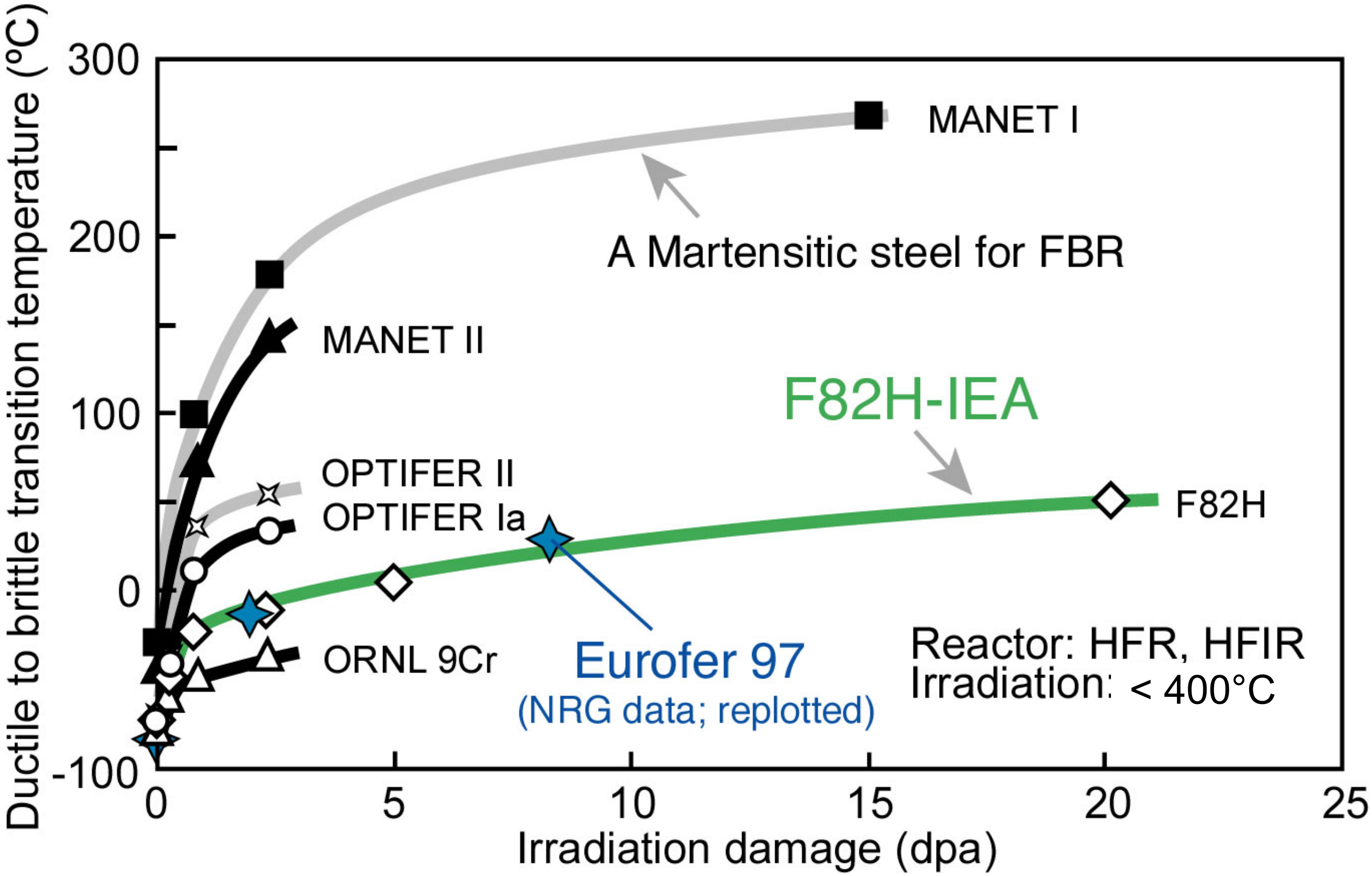
- Neutronics performance and **Tritium Production Rate (TPR) was evaluated using 14 MeV neutrons** with high accuracy, about 5% by simple mockups.

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



Dose dependence of DBTT shift of F82H



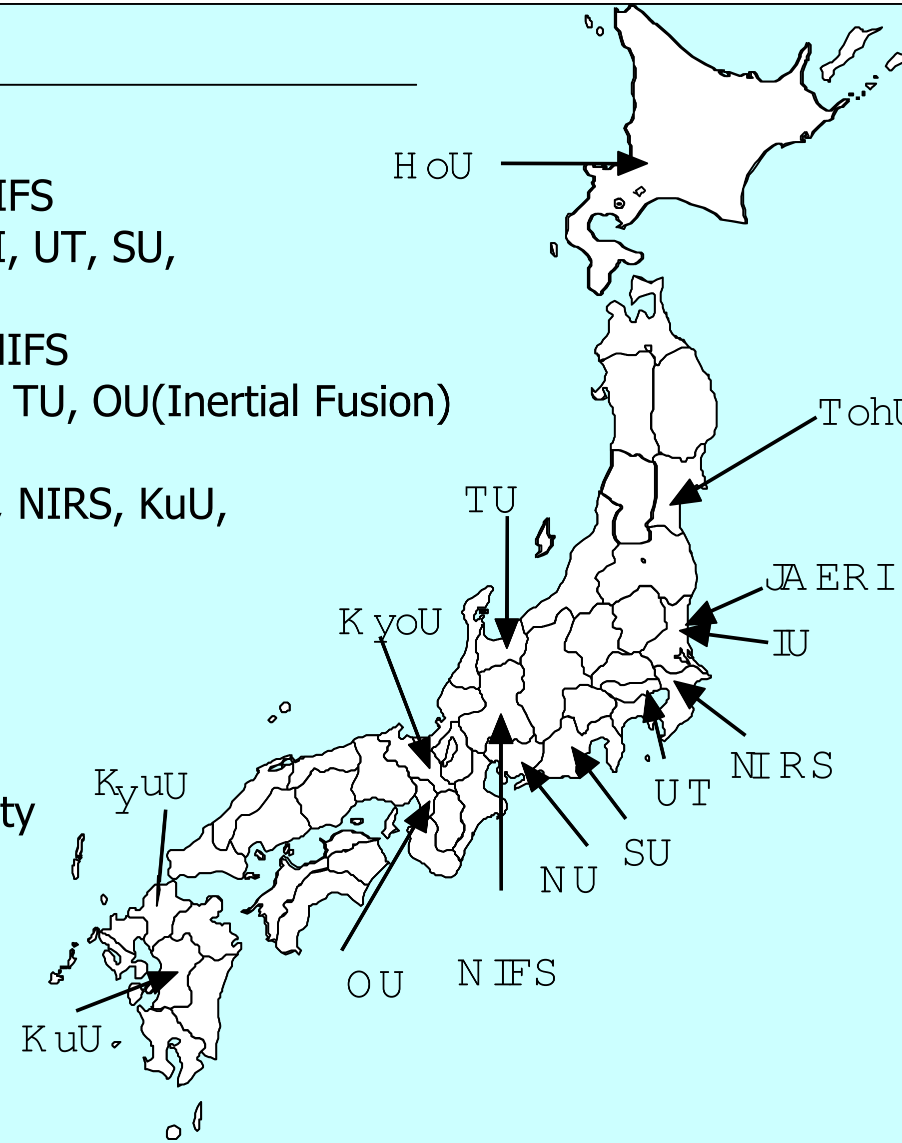
DBTT also tends to saturate with dose, as far as He level is not high

R&D Activities on Tritium in Japan

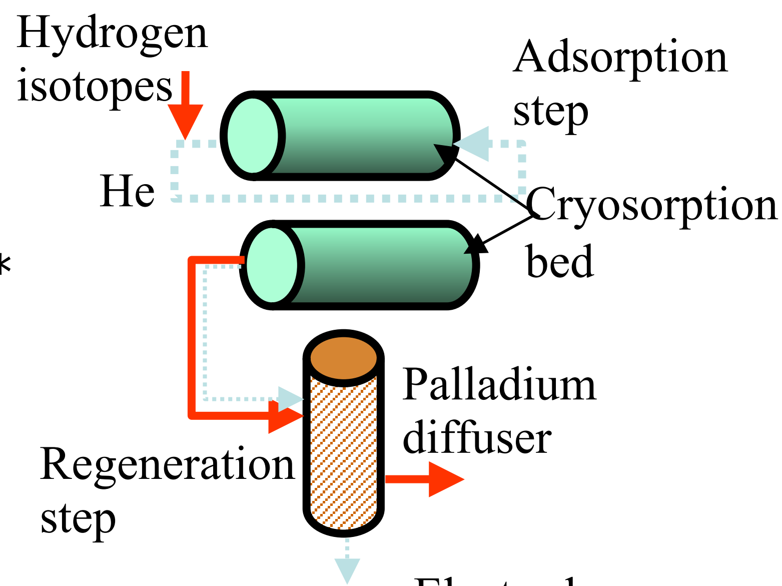
Subjects **Organization**

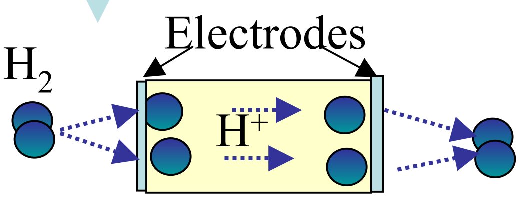
Tritium processing : JAERI, NIFS, NU
Tritium Behavior in Blanket : KyuU, UT, SU,TU, NIFS
Interaction between Tritium and Materials : JAERI, UT, SU, NU, TU, KyuU, KyoU, HoU, OU
Decontamination and Safety : JAERI, UT, KyuU, NIFS
Analysis of Tritium and Tritium in Inertial Fusion : TU, OU(Inertial Fusion)
Fundamental Studies of Tritium : TohU, SU
Tritium Behavior in Environment and Biology : IU, NIRS, KuU, KyoU, NIFS

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

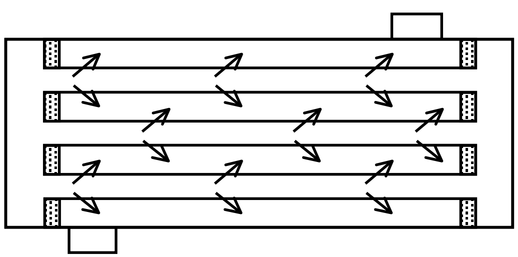


Tritium Processing in Blanket, fuel cycle, and confinement system





Protonic conductor


Polyimide membranes
(Hollow-fiber type)

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

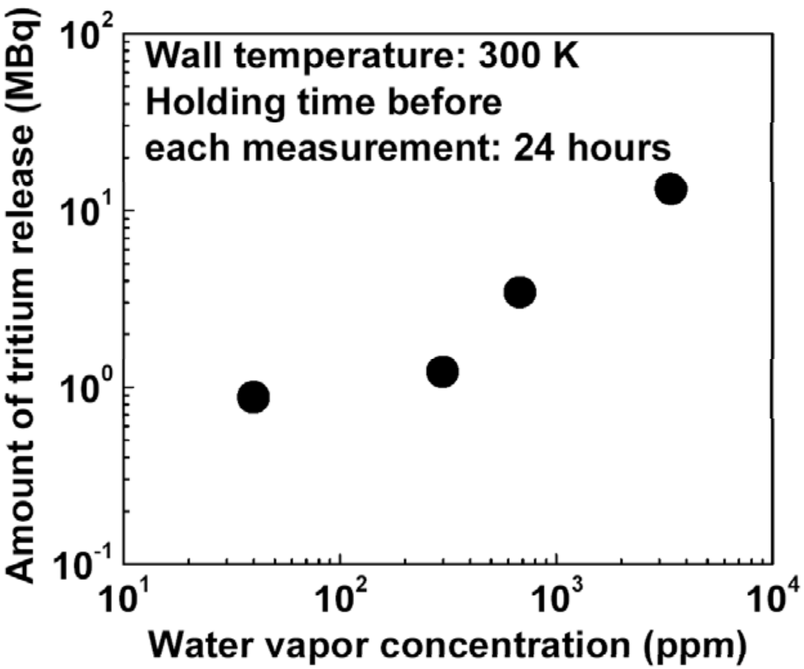
*Advanced tritium recovery system using proton conductor (electrochemical hydrogen pump): JAERI, National Institute for Fusion Science (NIFS), Nagoya University

*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

Interaction between Tritium and Materials, Decontamination and Safety



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

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

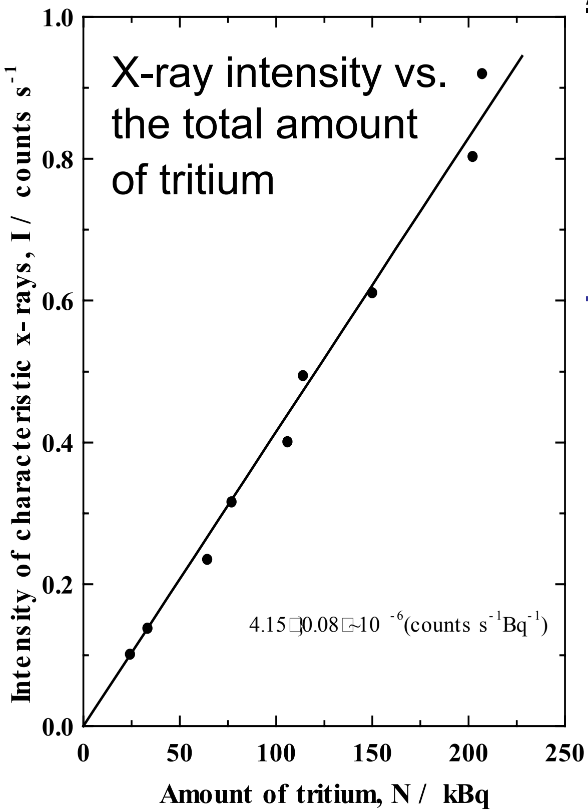
*Tritium behavior in cement: JAERI and Kyushu University

*Behavior of tritium vapor in a room: JAERI

*Basic studies for the behavior of the tritium vapor on construction materilas: Toyama University, University of Tokyo.

*Remove of tritium on a carbon/hydrogen co-deposited layer by excimer laser: JAERI

Analysis, others, Environment and Biology



Analysis and others

*Tritium analysis by b-ray induced X-ray (BIXS): Toyama University, Good linear relation between an amount of tritium and the intensity of X-ray

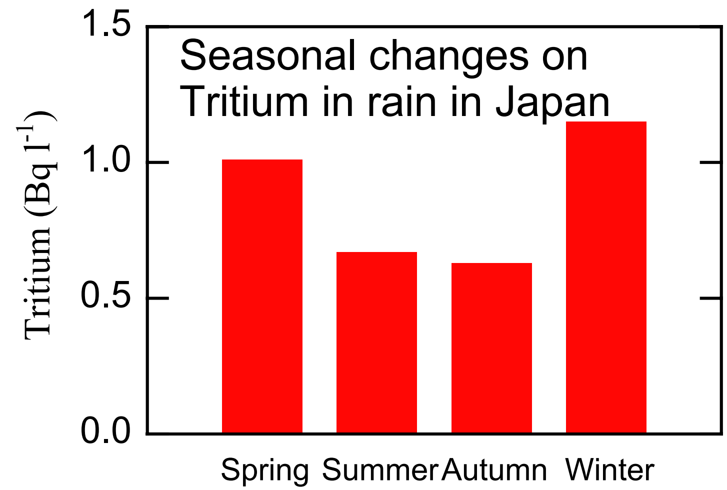
*Tritium studies related to inertial fusion: Osaka University

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

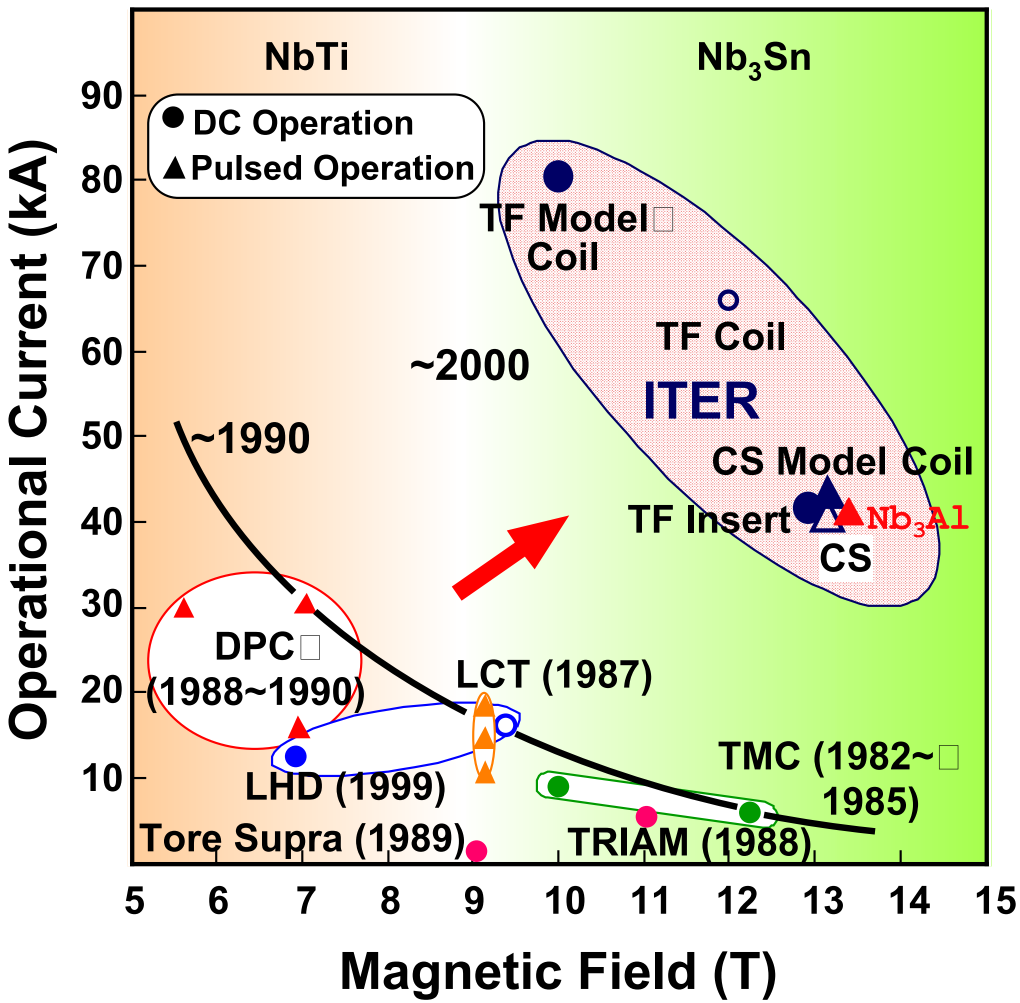
*Fundamental studies, oxidation of atmospheric tritium by soil microbes, and biological risk of low dose tritium: Ibaraki University



*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_3Sn strands have been developed and qualified in industrial scale (25 t in total).
- Large-current Nb_3Sn CIC conductor technology has been established (5.6 km in total).
- Coil Fabrication technology has been developed.

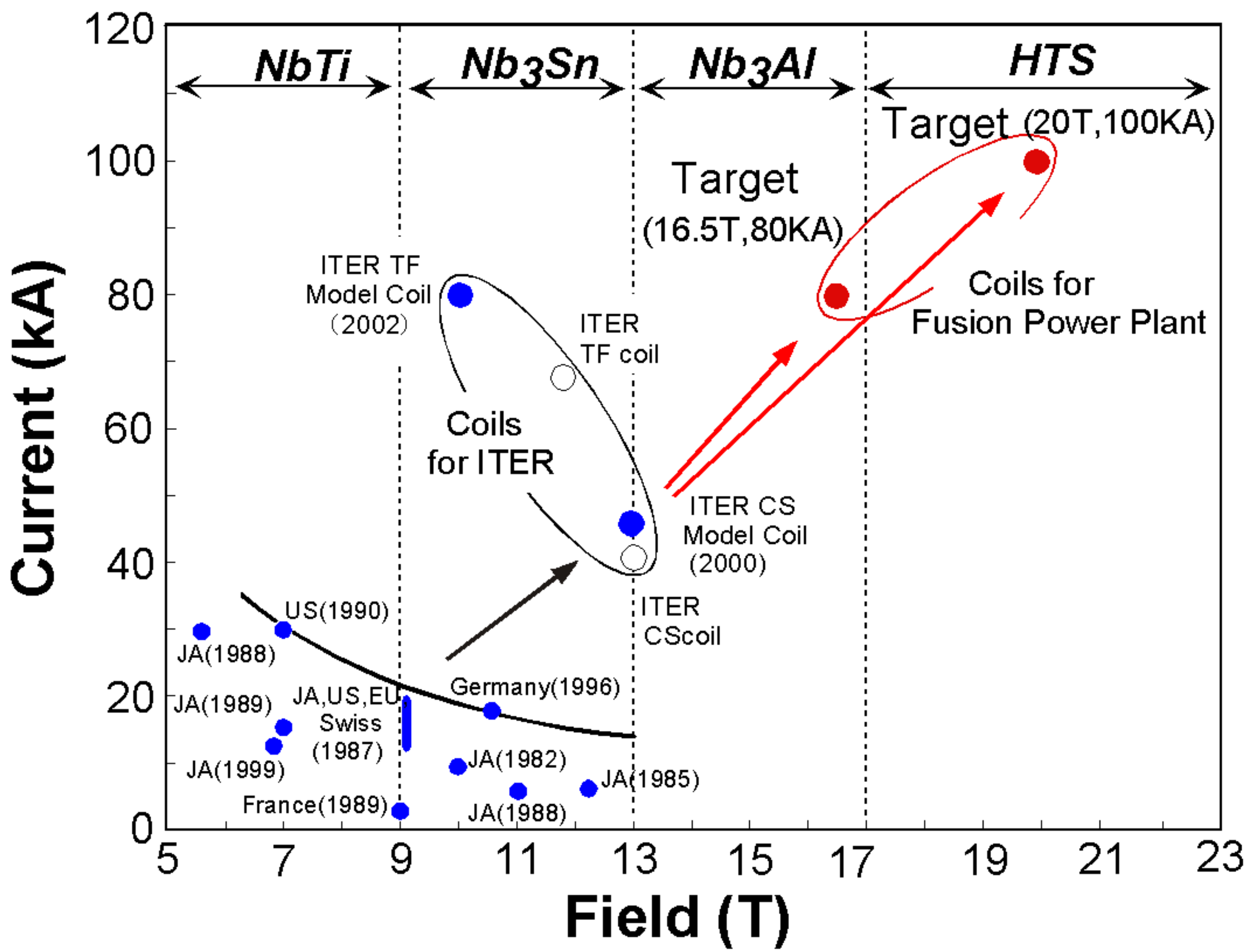
↓

Ready for ITER construction

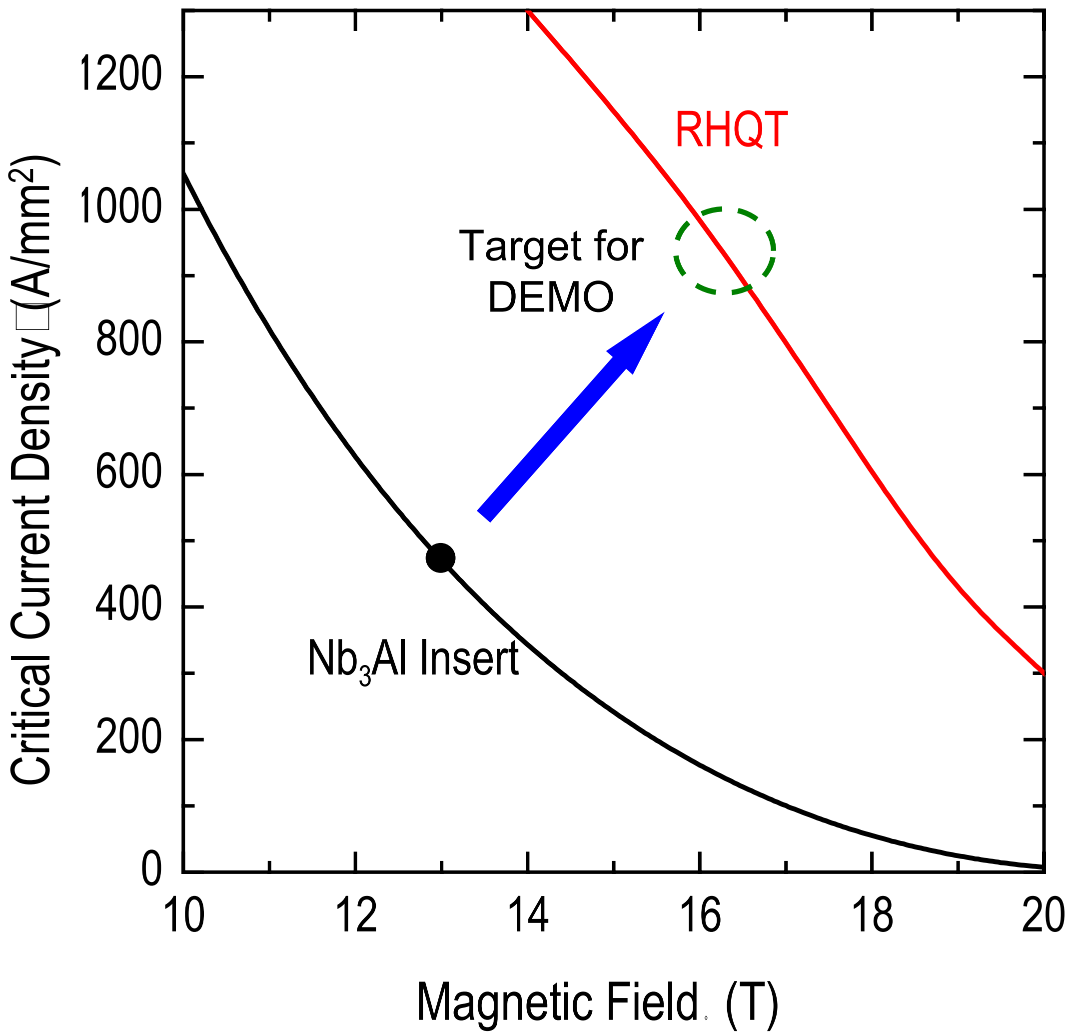
Development Target of SC Magnets

There are two options in terms of the maximum field of the TF coil in DEMO.

Field	16 T	20 T
Material	Nb_3Al	HTS



Further Development of Nb_3Al Strand

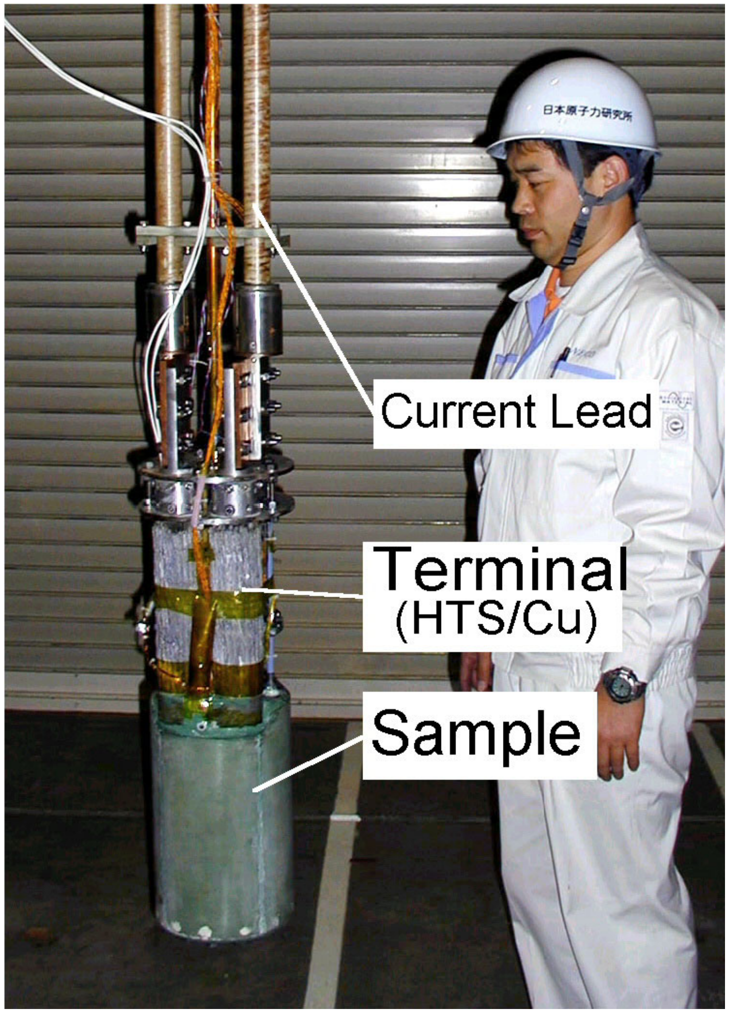


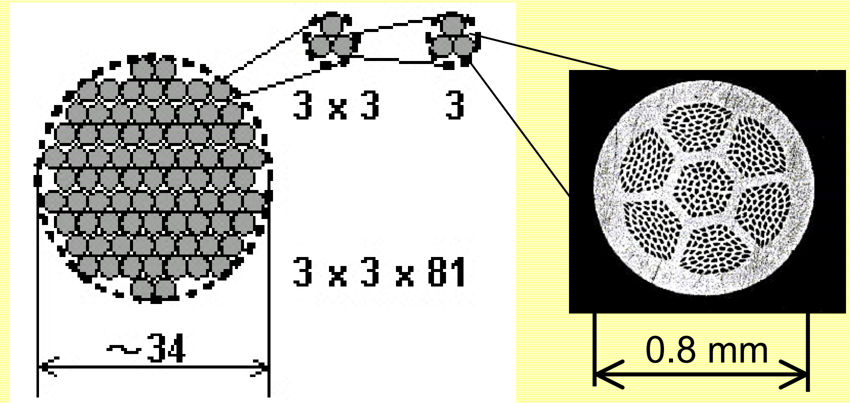
Present status of RHQT Nb_3Al

- Current density of around 1000 A/mm^2 at 16 T.
- Unit length of 300 m.

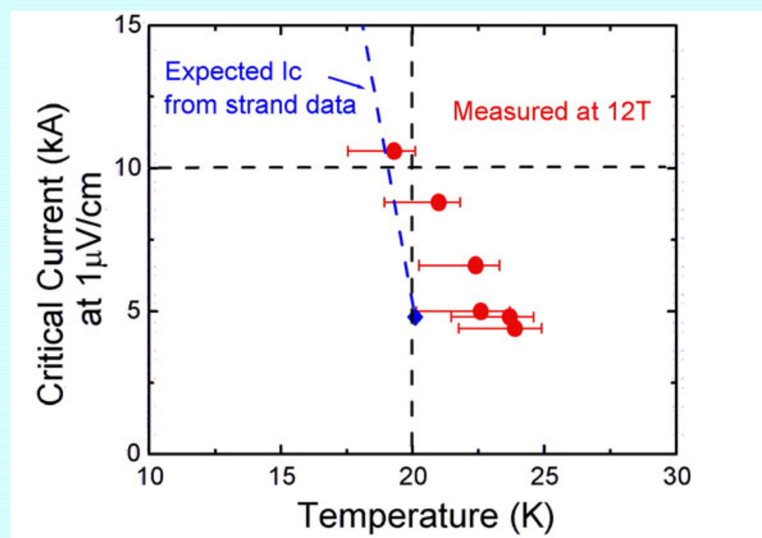
RHQT
Rapid-Heating, Quenching and Transformation (RHQT) method
Heat treatment at 1800°C for 0.1s is used for Nb3Al formation.

Trial fabrication of 10 kA HTS conductor

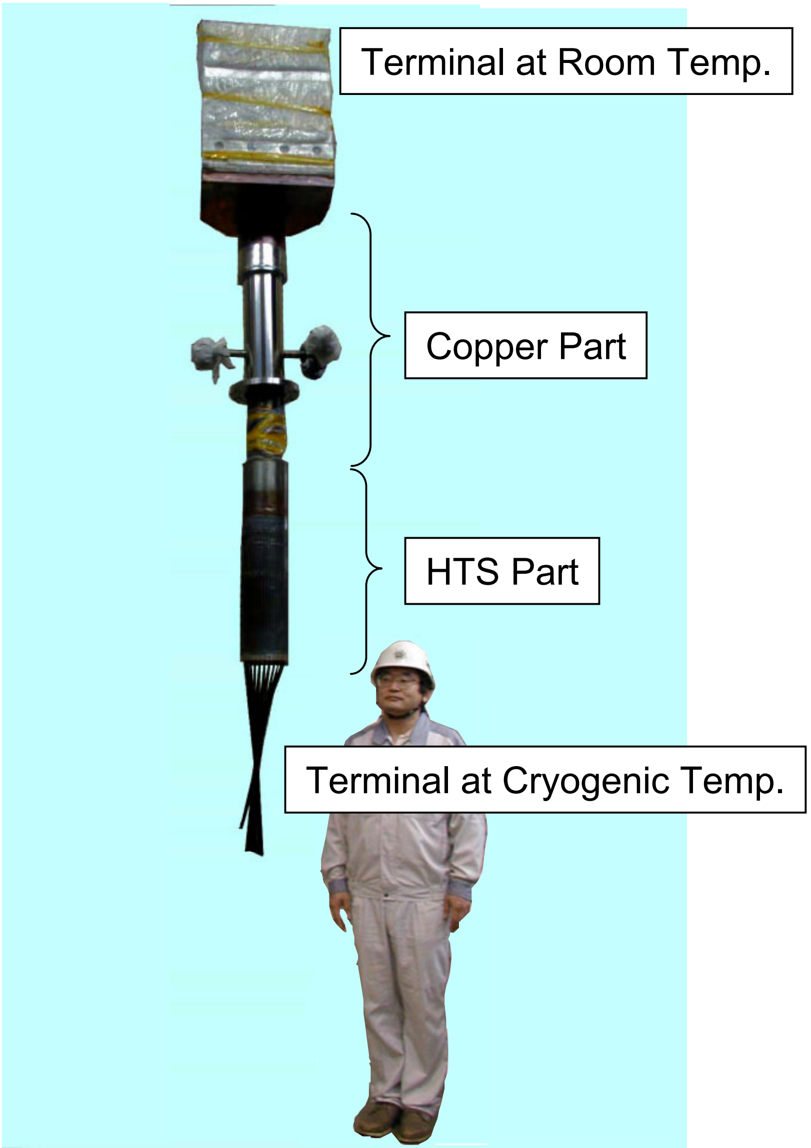




Measured Critical Current at 12 T

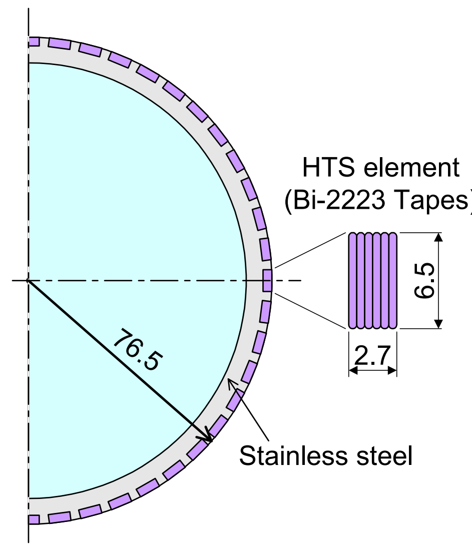


60-kA HTS Current Lead



Major parameters

Current lead	
Rated current	60 kA
Overall effective length	1550 mm
HTS part	
Effective length	300 mm
Outer diameter	153 mm
Cooling method	Conduction (in vacuum)



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/mm^2
Cooling method	Forced-flow He at 20K, 3.2g/s

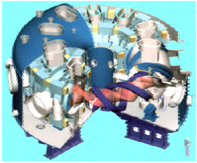
SC Magnet Development

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_3Sn** superconductor has become available in industrial scale.

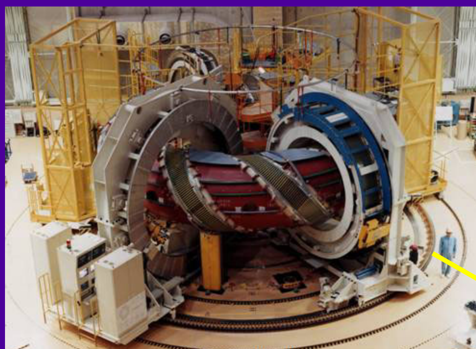
Future Development towards Advanced Performance:

- **Nb_3Al** and **High Temperature Superconductor** have excellent properties. A long-term, extensive development is required for fusion magnet application.



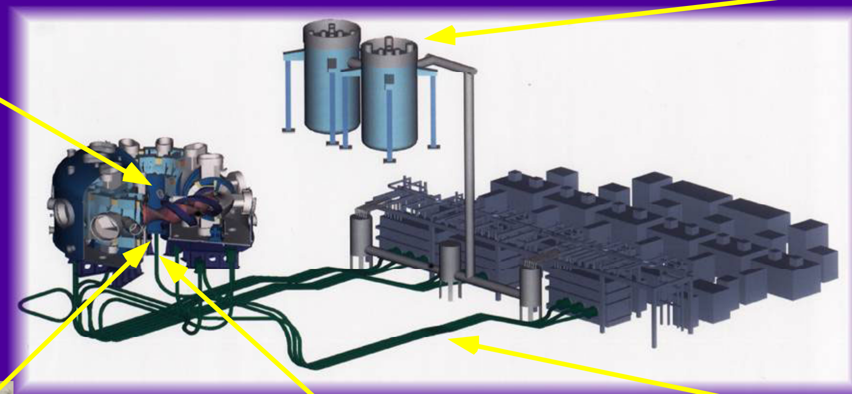
LHD Superconducting System

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.



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

SC Poloidal Coils

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

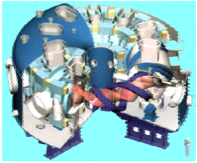
Supporting Structure

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

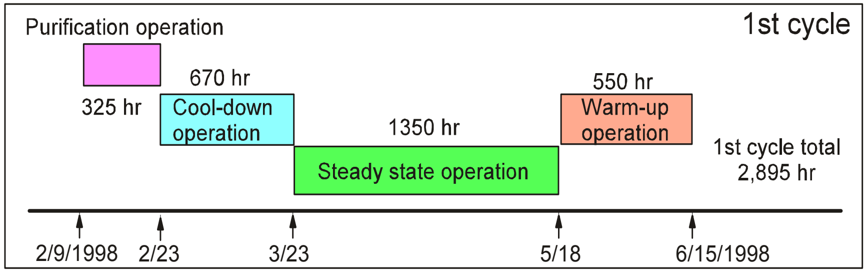
SC Bus-Lines

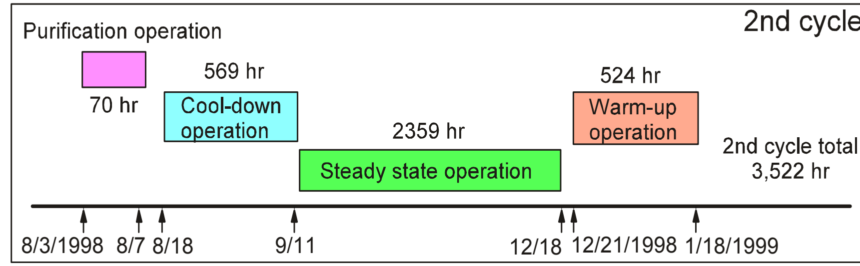
SC coils are connected to the power supplies by superconducting bus-lines with the nominal current of 31.3 kA.

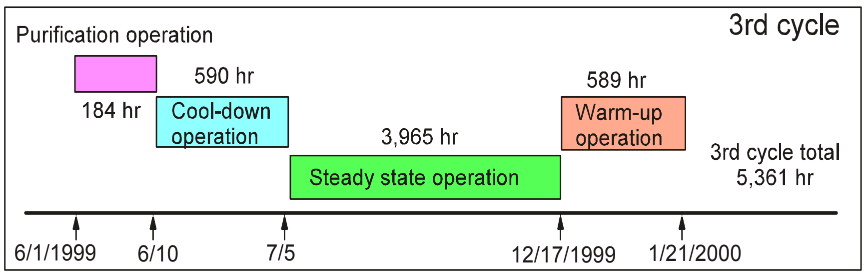
NIFS National Institute for Fusion Science

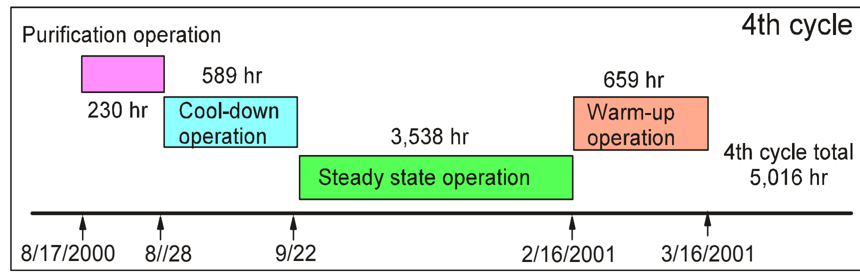


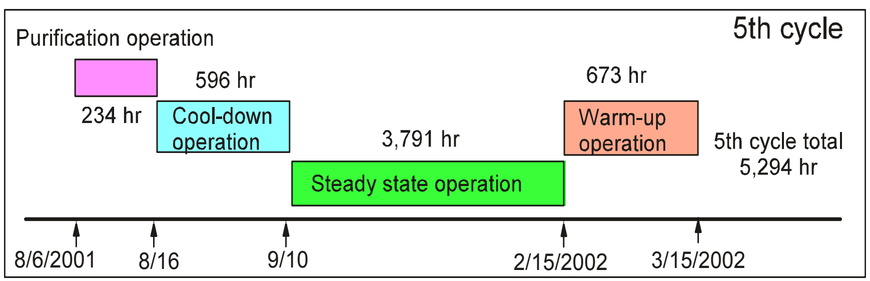
Operational History of LHD

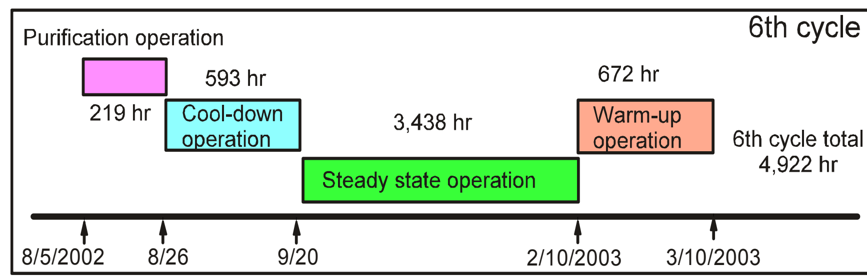


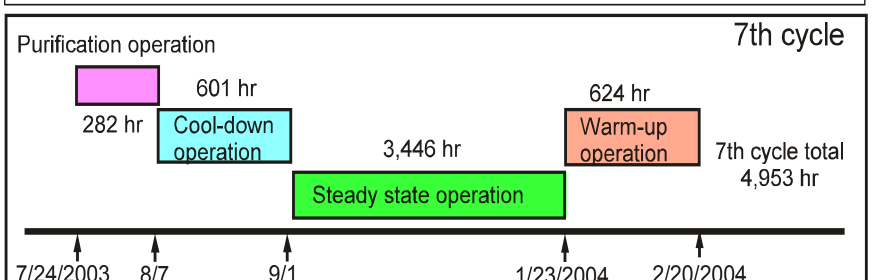






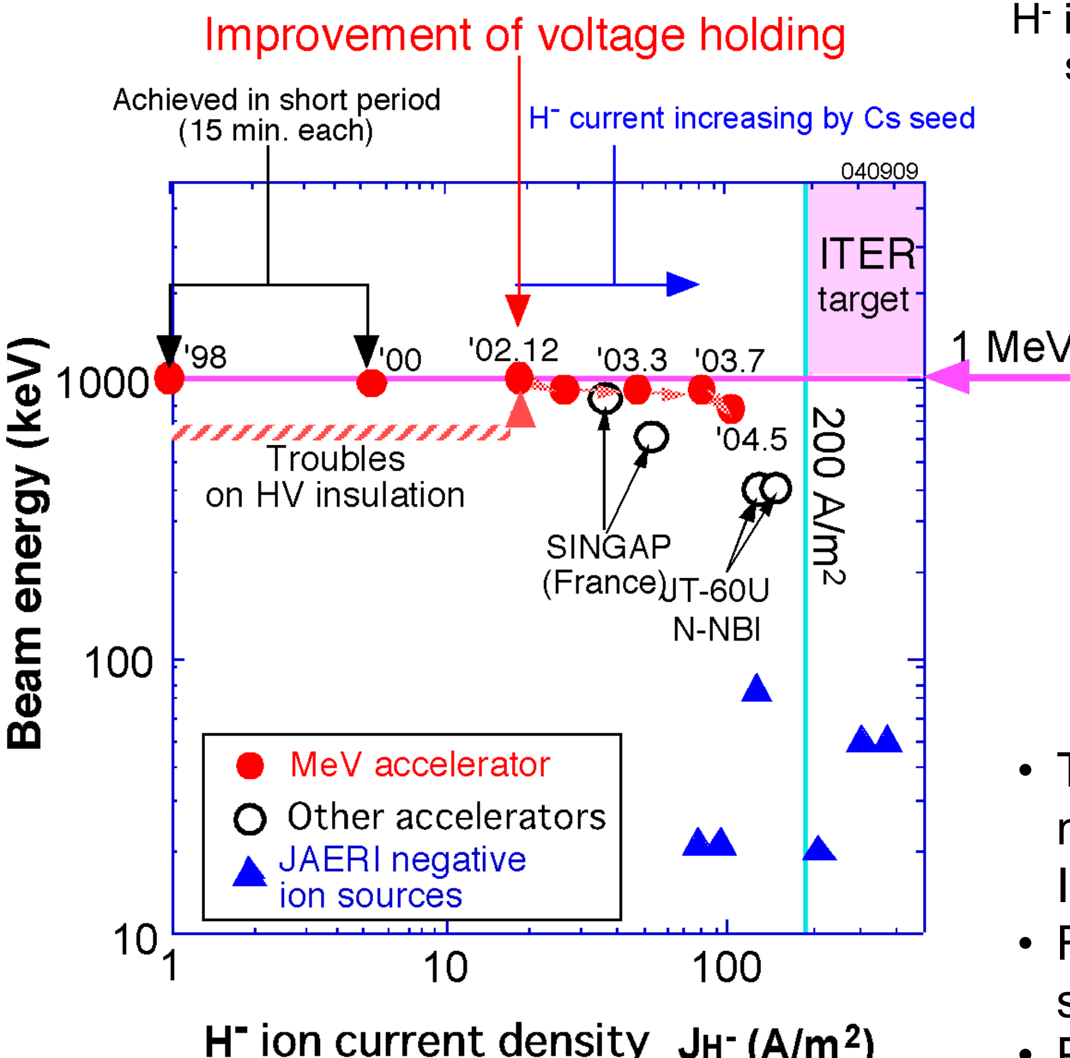






- LHD has been used for extensive plasma experiments since 1998 with 8 months operation period in each year. Seven cycles of experimental campaigns have been performed in four years.
- Operation time of the cryogenic system: 31,963 hrs
  Coil excitation No.: 804, Plasma shot No.: 48,721

Progress in NBI Development
- MeV accelerator -

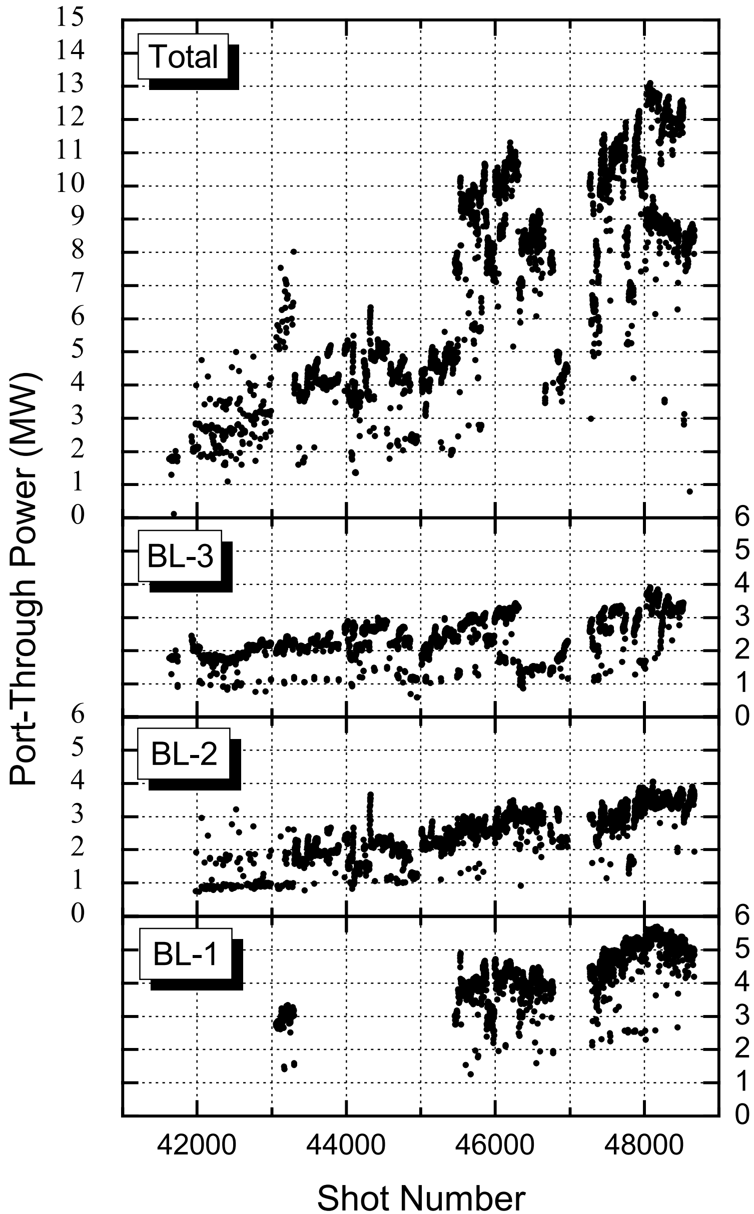


H^- ion current density increasing progressively, since improvement of the voltage holding in vacuum insulated accelerator.

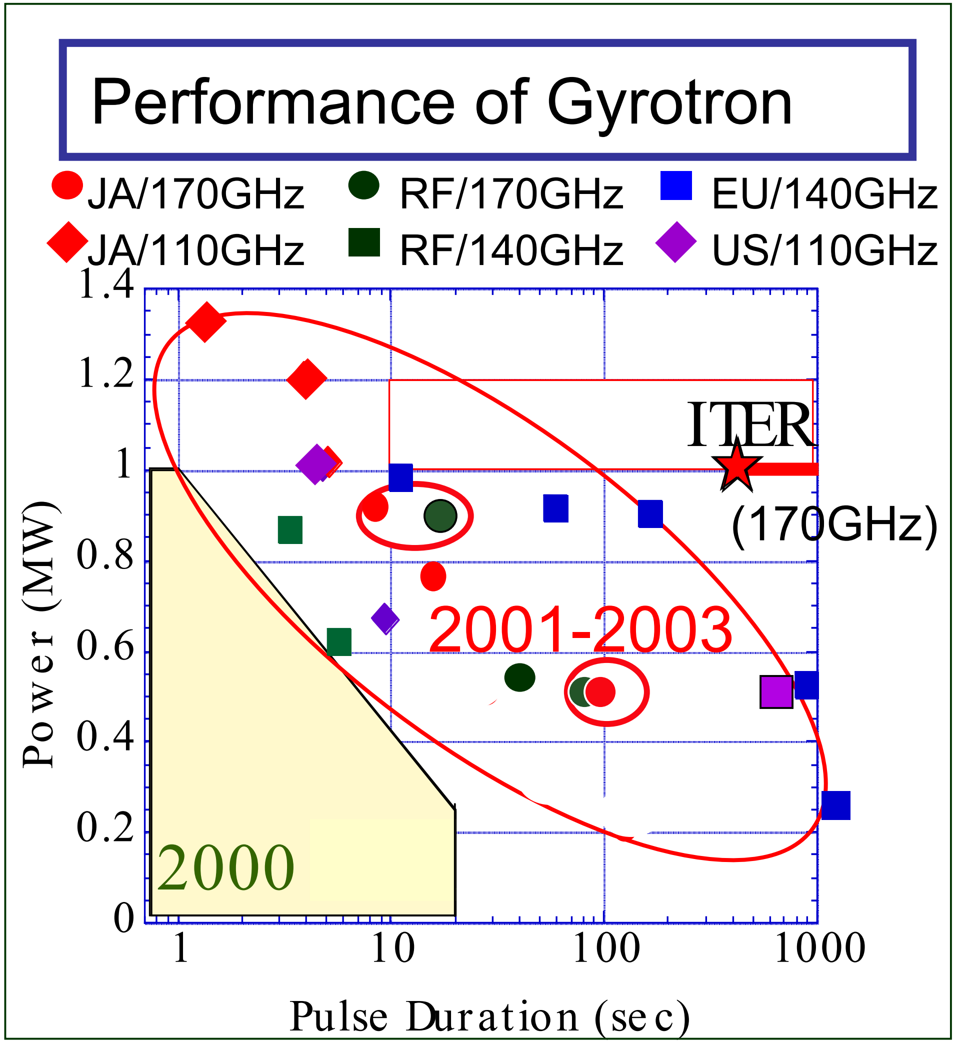
Beam energy	Negative ion current	Negative ion current density
ITER		
1 MeV	40 A	200 A/m^2
MeV accelerator	**(Achieved)**	
1 MeV	0.07 A	18 A/m^2
0.9 MeV	0.11 A	80 A/m^2
0.8 MeV	0.14 A	102 A/m^2

- 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/m^2, 1 MeV
- Power supply of the facility: $\leq$ 1A.

Beam Power History of LHD N-NBI



Summary of Recent Progress



In Progress

Reduction of stray Radiation in gyrotron

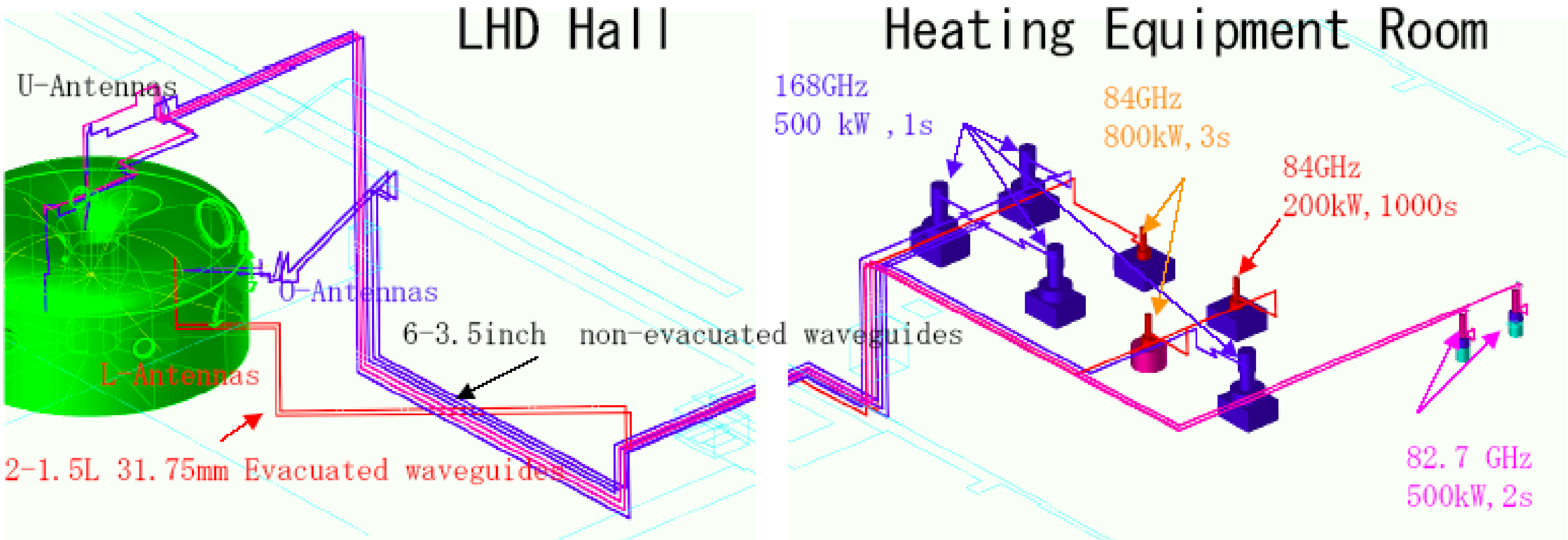
Now10%□~100kW)

□ <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.

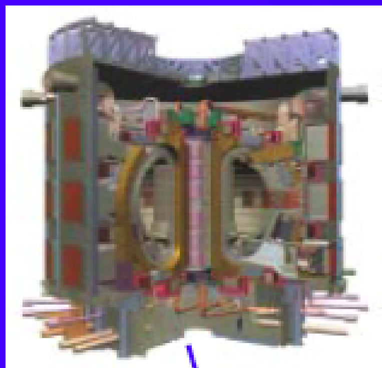
Summary (Long pulse experiments)

- 766 sec , 72 kW injected into LHD
  - Plasma is maintained for 756 sec
    - n_e= 2.4x$10^{17}$$m^{-3}$, $T_{rad,ECE}$=240 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.