ELSEVIER

Journal of Nuclear Materials 258–263 (1998) 1–6

journal of nuclear materials

Section 1. Plenary and invited papers

Fusion R&D strategy for Japan

A. Iiyoshi *

National Institute for Fusion Science, Oroshi, Toki, Gifu 509-5292, Japan

Abstract

The present status and the strategy of fusion R&D in Japan are outlined. Although the past fusion research subjects in Japan were strongly oriented to plasma confinement and related device technologies, activity in fusion engineering, especially materials engineering, is now growing. It is recognized that the development of radiation-resistant low activation materials is the key to the realization of fusion reactors. It is of vital importance to establish the sound research plan for materials development.

1. Introduction

Fusion R&D are carried out in Japan by a number of research organizations, including universities, national institutes and industries. Although the past fusion research subjects were strongly oriented to plasma confinement and related device technologies, activities in fusion engineering, especially materials engineering, has recently grown with the recognition that the development of the fusion engineering is the key to the realization of a fusion energy system. A comprehensive national plan for fusion development has been made by the Fusion Council, which is a part of the Long Term Program for Nuclear Power Development and Utilization under the Atomic Energy Commission of Japan. Growing emphasis is placed on the development of reactor technologies in the national plan.

In this paper, the status and the strategy of fusion R&D in Japan are outlined. Emphasis will be placed on the role of materials research in the fusion reactor development.

2. Fusion plasma research in Japan

Fusion research in Japan has been carried out mostly by JAERI (Japan Atomic Energy Research Institute) and universities. JAERI and the universities play different but complementary roles. In plasma confinement studies, research in JAERI is strongly oriented to Tokamak concept including JT-60U and JFT-2M operations and contribution to the ITER design activity.

Research in the universities, on the other hand, is directed mainly to alternative concepts and basic science. The National Institute for Fusion Science (NIFS), as an inter-university research institute, carries out research on helical concepts. The Large Helical Device (LHD), commencing its plasma operations at NIFS from April 1998, is the biggest project among the universities, and will be explained later.

Examples of the activities in the universities to explore the alternative or unique concepts are the laser system (Osaka University), the mirror system (Tsukuba University), the helical system (Kyoto University) and a high-field superconducting Tokamak (Kyushu University). NIFS is playing a role to coordinate the university research and to promote collaborations among the universities. Fig. 1 summarizes major universities with large fusion research devices. (It is to be noted that NIFS is also coordinating the joint project of universities with the USA, which will be explained later. The HFIR (High Flux Isotope Reactor), major facility for this project, is also shown in this figure.)

One of the other organizations conducting fusion plasma research is the Electric Technology Laboratory (ETL) which is pursuing the reversed-field pinch concept.

---

* Tel.: +81 572 58 2001; fax: +81 572 58 2600; e-mail: iiyoshi@nifs.ac.jp.

0022-3115/98/$19.00 © 1998 Elsevier Science B.V. All rights reserved.
PII: S0022-3115(98)00263-3

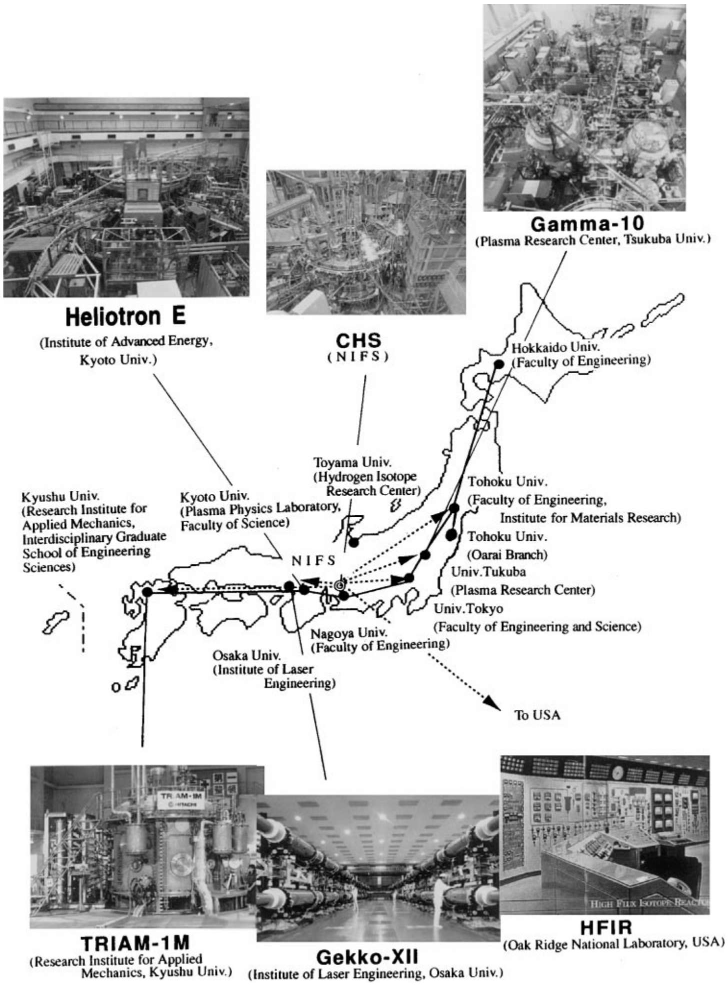

Fig. 1. Fusion research activities in Japanese universities.

3. Fusion engineering activity in Japan

JAERI's fusion engineering research is mainly oriented to issues and components critical to ITER, e.g. superconducting magnet, plasma-facing components, tritium and system safety. The research is also oriented to DEMO or beyond, such as R&D for SSTR and DREAM reactors and IFMIF design studies. NRIM (National Research Institute for Metals) performs fusion materials research such as fundamental radiation damage studies and fabrication of low activation materials.

The fusion engineering studies by the universities have been carried out in relatively individual manner without having specific large-scale facilities. For the purpose of enhancing communication among the universities and among the component technology people, the fusion engineering network system has been investigated since FY 1994 as a division of the fusion research network. Figs. 2 and 3 show the grouping of the fusion engineering network and the list of universities participating the network, respectively. It is one of the roles of the network system to coordinate collaborative research activities extending over different research fields.

It is also to be noted that industries are cooperating in fusion engineering research.

4. The LHD program and its contribution to fusion materials engineering

4.1. The LHD program

The Large Helical Device (LHD) program [1,2] studies the physics and technology of steady-state high temperature plasma confinement in the heliotron magnetic configuration. To demonstrate steady state operation in LHD, all magnets (double helix coils and

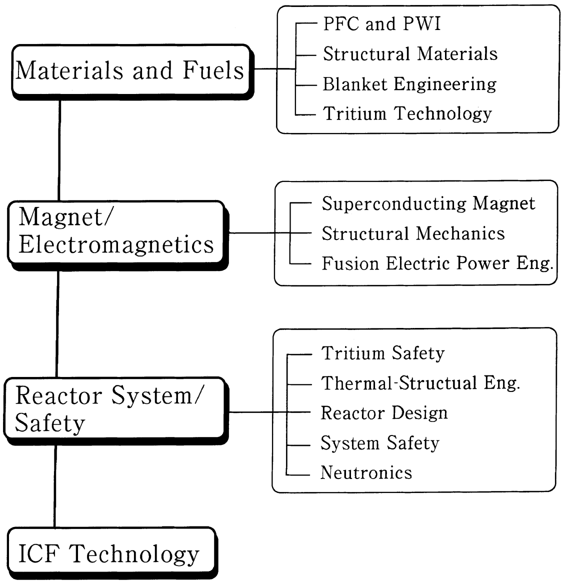

Fig. 2. Grouping of the fusion engineering network system in Japanese universities.

poloidal coils) are superconducting and the device is equipped with a built-in helical divertor. The worlds-largest 1GJ-level superconducting system of $R_c = 3.9$ m, $a_c = 0.975$ m, $B = 30$ kG (center of the torus) has been developed. The device (Fig. 4) was completed in March 1998 at a new site (Fig. 5). The various heating systems such as a 1 MW-level high power gyrotron (83 GHz and 166 GHz, CW) for ECH and a high voltage negative ion source (180 keV, 360 keV, MW) for neutral beam injection (NBI) have been developed. The first plasma production occurred on March 31, 1998.

4.2. Materials R&D carried out for the construction of LHD

It should be noted that large amount of materials R&D were carried out for the construction of LHD. The research carried out at NIFS, as collaboration with Japanese universities, has also been enhancing the fusion engineering research activities of Japanese universities.

(1) *Superconducting magnet materials* [3,4]. For the helical coils of LHD, a pool-boiling type superconducting magnet was developed. It has Nb–Ti strands and a pure Al as a stabilizer. A pure Al stabilizer clad with Cu–2%Ni was developed to decrease the hall effect and

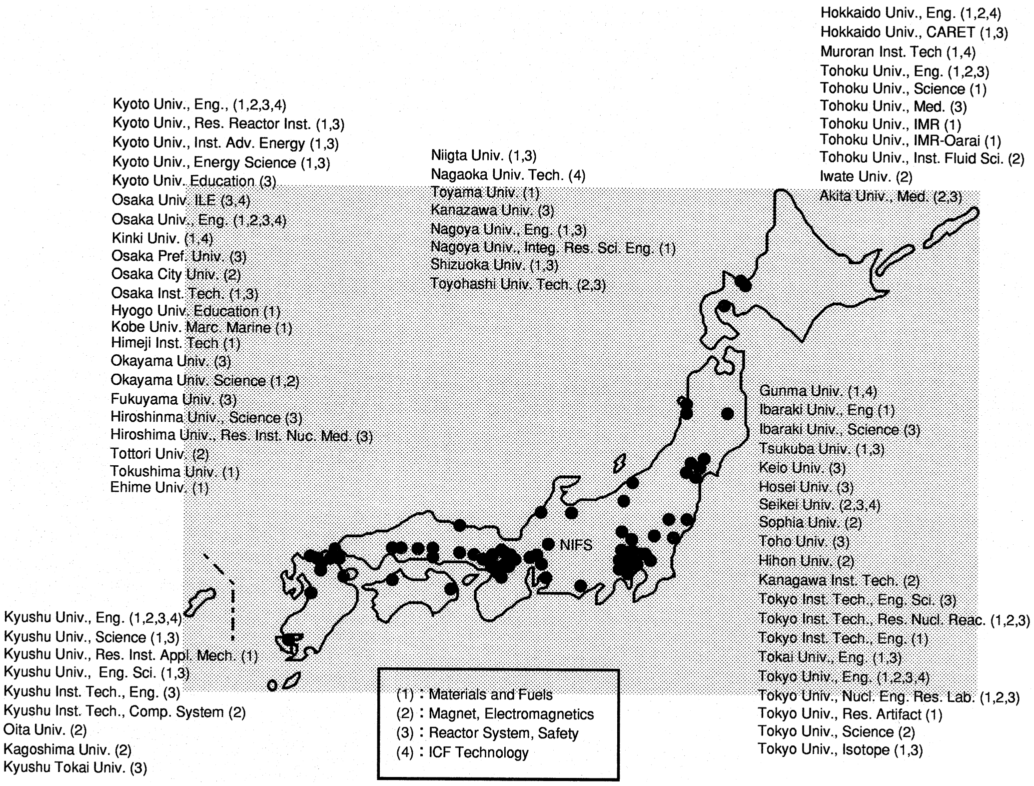

Fig. 3. Universities participating the fusion engineering network system.

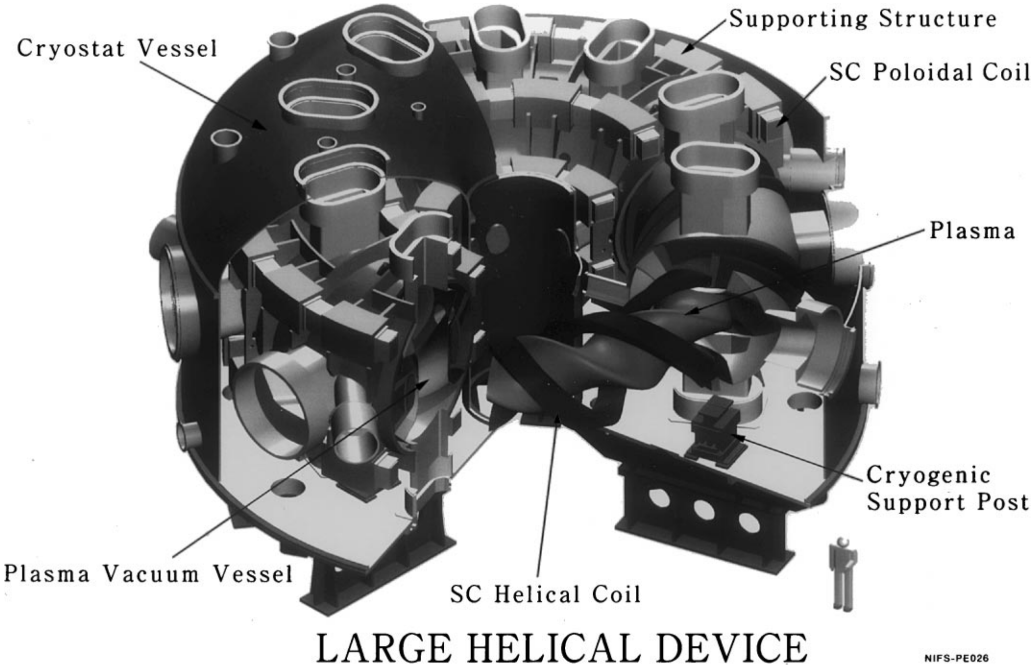

Fig. 4. The large helical device (LHD).

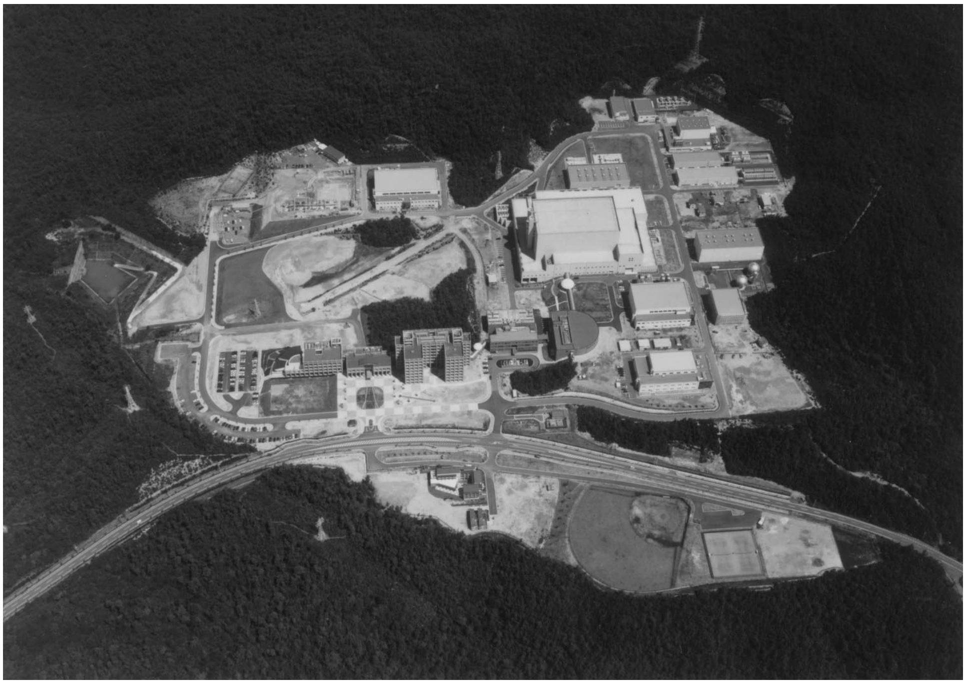

Fig. 5. New site for NIFS (Toki-city, Gifu-prefecture).

to increase the superconducting stability. For the poloidal field coil, a forced-flow cooling with Nb–Ti conductors concept was developed. A bare copper surface was applied to the superconductor to keep current sharing uniform and to increase a quench current. The deformation properties of the coil packs of both the helical and poloidal coils were evaluated under simulated electromagnetic force in the liquid helium.

(2) *Cryogenic structural materials* [5]. The cryogenic support structure for LHD was designed to sustain huge electromagnetic forces during operation at 4.4 K. Optimization of the composition, especially C and N contents, was carried out to satisfy the yield strength and fracture toughness at 4.4 K requirements. The weldability as thick plates was also investigated. Welding wires and electrodes for thick-section welding were developed. Welding procedures were developed to obtain better joint strength and to minimize the residual deformation after the welding.

(3) *Divertor component materials* [6,7]. Comparative studies of the heat flux capability of graphite/Cu joint components were carried out using an electron beam. Because LHD is designed as a steady operation machine, steady heat loading effects have been intensively investigated. Surface coating studies such as in situ boronization were also carried out for the purpose of applying a surface modification of the LHD vessel.

5. International collaboration in fusion engineering

In addition to ITER and IFMIF design activities, Japan is promoting international collaboration in many fields of fusion science and engineering, including bilateral programs and those under the IEA framework. Here, some examples in fusion materials engineering are introduced.

Neutron irradiation effects on materials have been investigated using reactors in the USA in the framework of the Japan–USA fusion cooperation program. Japanese research on fusion structural materials has been enhanced by this collaborations. The major subject of JAERI's collaboration with the USA (HFIR/ORR project) has been the effects of helium on the properties of ITER candidate austenitic steels. More fundamental studies have been carried out in the university/USA collaboration. The first phase (RTNS-II project, FY1982–1986) and the second phase (FFTF/MOTA project, FY1987–1994) focused on radiation damage by 14 MeV neutrons and high-fluence neutron irradiation effects, respectively. The subject of the present phase (JUPITER project, FY1995–2000) is the dynamic and variable effect of neutron irradiation. Recent experiments in the JUPITER program are reported in this conference [8–10].

Among other international projects relating with the fusion materials engineering are BEATRIX-II and TEXTOR experiments. Irradiation of blanket materials was carried out under BEATRIX-II program. In Japan, JAERI was in charge of this collaboration. The joint experiment with TEXTOR using high Z limiters has motivated the development of high Z metallic Plasma Facing Component materials.

Japan is acting as the key country in plasma and fusion research in Asia. In 1996, Asian Plasma and Fusion Association (APFA) was established by plasma and fusion-related societies and institutions in China, Korea and Japan. This activity covers both the plasma science and the fusion engineering fields.

6. Japanese strategy for the fusion reactor development

A national plan for fusion development was made in 1992 by the Fusion Council as the "Third Phase Basic Program of Fusion Research and Development". This was accepted by the Atomic Energy Commission of Japan. In this plan, although the Tokamak concept is the main course of the reactor development, alternative concepts were also suggested to be explored further. Fig. 6 is an illustration of Japanese strategy for the magnetic fusion reactor development.

In the national plan, emphasis was also placed on the development of the reactor technologies. Development of radiation-resistant low activation structural materials and compilation of materials irradiation data were pointed out as important research to be enhanced further.

Japanese research strategy for the fusion materials development has been discussed in the Research Committee for Nuclear Fusion under the Science Council of Japan and Research Planning Subcommittee of the Fusion Council. In 1996, the former committee presented proposals for establishing research core centers for fusion engineering in Japanese universities [11]. The importance of a core center for the fusion reactor materials study was emphasized in the proposal. A report concerning the national fusion materials research program is expected in 1998 from the Fusion Council. The definition of the role of JAERI and universities in fusion materials research is one of the subjects under discussion in the committee. The fundamental approach to fusion materials development carried out by Japanese university will continue to play an important complementary role to the other more engineering-oriented activities of JAERI and industry. The fundamental approach is especially important in seeking breakthroughs and innovation in materials development.

7. Toward the materials development for fusion reactors

With the progress in plasma confinement studies, it is widely recognized that the development of materials is the key to the realization of fusion reactors. The design and construction of plasma devices have also enhanced the materials development studies as shown in Section 4.2.

However, materials R&D independent from the plasma research is necessary particularly for neutron-interactive components. A typical example is the

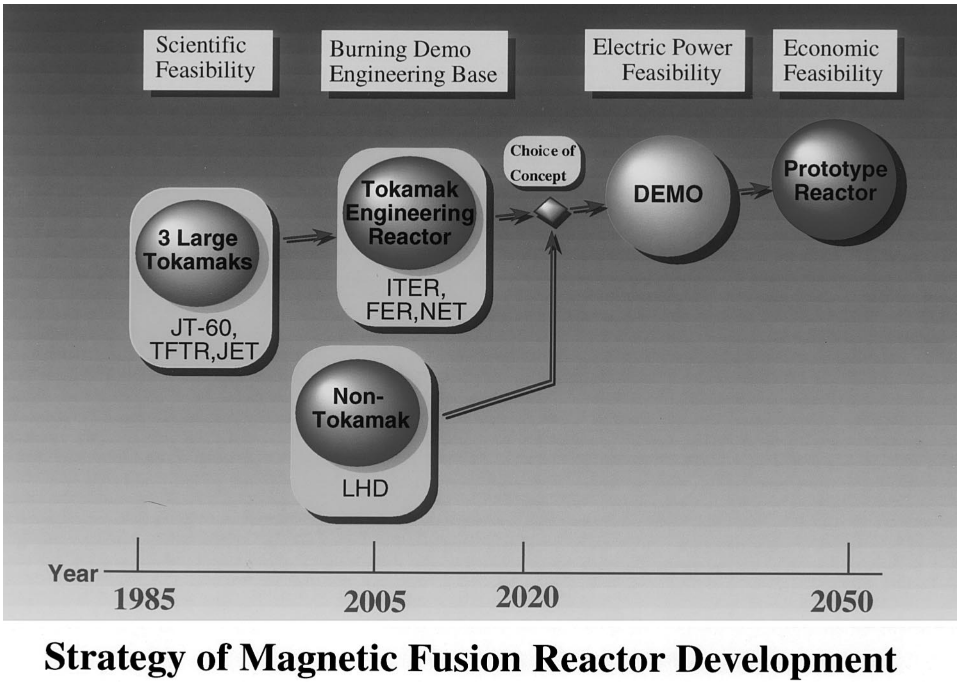

Fig. 6. Japanese strategy for magnetic fusion reactor development.

development of radiation-resistant low activation structural materials. Since any plasma device, including ITER, is insufficient as a tool for developing these materials, establishment of a sound research strategy and definition of indispensable research tools are of vital importance.

It should be noted that the uncertainty in materials development brings uncertainty in fusion reactor development itself. Once the sound plan for the materials development in national fusion program is established, investments of the necessary facilities in the materials development studies should be justified.

References

[1] A. Iiyoshi, M. Fujiwara et al., Fusion Technol. 17 (1990) 169.

[2] M. Fujiwara et al., Plasma Phys. Control. Fusion 39 (1997) A261.

[3] O. Motojima, N. Yanagi, A. Nishimura, these Proceedings.

[4] N. Yanagi et al., these Proceedings.

[5] A. Nishimura et al., IEEE Trans. Magn. 32 (1996) 2941.

[6] Y. Kubota, N. Noda, A. Sagara, O. Motojima, Vacuum 47 (1996) 955.

[7] A. Sagara et al., J. Nucl. Mater. 241–243 (1997) 972.

[8] K. Abe, A. Kohyama, C. Namba, F.W. Wiffen, R.H. Jones, these Proceedings.

[9] T. Shikama, S.J. Zinkle, K. Shiiyama, L.L. Snead, E.H. Farnum, these Proceedings.

[10] T. Muroga, S. Ohnuki, F.A. Garner, S.J. Zinkle, these Proceedings.

[11] On the establishment of research core centers in fusion reactor engineering, Report by the Research Committee for Nuclear Fusion under the Science Council of Japan, June 1996 (in Japanese).