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Japanese perspective of fusion nuclear technology from ITER to DEMO

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ABSTRACT

The world fusion community is now launching the construction of ITER, the first nuclear-grade fusion machine in the world. In parallel with the ITER Program, Broader Approach (BA) activities also started this year with the collaboration of Japan and EURATOM, mainly at the Rokkasho BA site in Japan, as complementary activities toward DEMO.

The Atomic Energy Commission of Japan reviewed the ongoing 'Third Phase Basic Program of Fusion Research and Development', and then issued the results of the review, 'National Policy of Future Fusion Research and Development', in November 2005. In this report, it was anticipated that ITER will be made operational in a decade and that its programmatic objective can be met in the following seven or eight years. Under this assumption, the report presented a road map toward DEMO and beyond and identified R&D items in fusion nuclear technology that are indispensable for fusion energy utilization.

In the present paper, Japanese view and policy on fusion nuclear technology in ITER and beyond will be summarized, and an overview is given of a minimum set of R&D items in fusion nuclear technology toward DEMO that are essential for fusion energy utilization.

1. Introduction

In 1992, the Atomic Energy Commission of Japan laid down the 'Third Phase Basic Program of Fusion Research and Development' [1], whose central element was ITER. Over the next ten years, significant research progress was made; also, the world fusion program began shifting into a new stage. Taking into account these changes, in June 2003, the Atomic Energy Commission of Japan set up an ad hoc committee on basic issues on fusion research and development and charged it to check and review the progress of fusion R&D and to investigate future basic programs.

In response, the ad hoc committee thoroughly reviewed the ongoing activities and achievements obtained so far under the Third Phase Basic Program and discussed a possible road map and portfolio so as to enable Japan to initiate the Fourth Phase Basic Program, where construction and operation of DEMO will be the central element. The ad hoc committee issued in November 2005 a report entitled 'National Policy of Future Fusion Research and Development' [2], which was endorsed by the Atomic Energy Commission of Japan. In this report, it was anticipated that ITER will be made operational in a decade, and that its programmatic objective can be met in the following seven or eight years. Under this assumption, the report presented a road map toward the DEMO and identified R&D items on fusion nuclear technology indispensable for fusion energy utilization.

The ITER Organization Establishment Agreement and related documents were signed on 21 November 2006 and are expected to enter into force in the autumn of 2007. The BA Agreement also entered into force on 1 June 2007. As such, these two large international projects on fusion program will embark in the year 2007, and world fusion program is entering into a new 'ITER era'. These projects are central elements in the world fusion program along the pathway toward DEMO and essential for an early realization of fusion energy utilization.

The present paper provides an overview of the Japanese view and policy on fusion nuclear technology in ITER and beyond, and presents a minimum set of R&D items in fusion nuclear technology toward DEMO, which is essential for fusion energy utilization.

2. Fusion energy strategy from ITER to DEMO and beyond

Early realization of fusion energy utilization is important in order to contribute to the resolution of global environmental problems and provide energy security. In order to put fusion power into practical use, it is necessary to make fusion systems technically practical as a power generation system, as well as to be economically competitive against other energy systems. To this end, it is

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necessary to ensure economical competitiveness, and to demonstrate safety and operation reliability for the commercialization of the fusion energy.

Japan considers ITER a core program in the road map toward DEMO, in which the scientific and technological feasibility of fusion energy will be demonstrated, namely: demonstration of techniques for the control of extended burning plasmas; demonstration of essential reactor technologies in an integrated system; and proof-of-principle integrated performance of DEMO blankets through the ITER Test Blanket Program. Through active participation in the ITER Project, including the areas of component fabrication, construction and assembly, commissioning, operation, exploitation and decommissioning phases, the technology basis for the design and construction of DEMO will be established.

The next step beyond ITER is DEMO, whose mission is to simultaneously realize steady-state fusion core plasmas with high Q values and power generation on a practical scale. The economic aspect is understood to be an important factor in the development of DEMO, and should be duly taken into account. DEMO is intended to be the final integrated tokamak facility before the development of commercial fusion reactors, and will be upgraded during its operational phase so as to demonstrate to the utility industry and the public its attractiveness as a power generation system, mainly in terms of foreseeable economic competitiveness, safety, reliability and timeliness.

Japan's planned Tokamak type DEMO will have a core dimension similar to that of ITER with a power generation capability on the gigawatt (GW) scale. DEMO needs to operate continuously for about one year with high plant efficiency, high output stability at the transmission end, and with an overall tritium breeding ratio greater than 1. Major technical requirements for DEMO are outlined below:

1. For the fusion core plasma, high plasma pressure operation is required to increase fusion power density to several times that of ITER, so as to realize thermal output of 3–4 GW. It also requires non-inductive, steady-state operation and the control of heat and particles to enable continuous operation over at least one year.
2. The first wall and blanket structure must withstand a neutron fluence of about 10–20 MW/m^2 and heat flux of 1 MW/m^2. The blanket must achieve tritium fuel self-sufficiency with high reliability. The divertor must withstand higher heat and particle fluxes than the first wall, and it must accommodate these load conditions and stay operational for several years. Scheduled maintenance of the first wall and divertor is expected once per three to five years, and down-time for maintenance should be minimized so as not to jeopardize plant availability. Continuous and reliable operation of the heating and current drive system up to one year should be established.
3. DEMO is the first plant system which supplies its own tritium fuel by means of an in situ tritium-breeding blanket and which drives a high-temperature and high-pressure medium containing tritium. Safe and reliable systems to process, handle and monitor a large amount of tritium fuel should be incorporated in DEMO.
4. In view of the economic competitiveness of fusion power generation system, construction cost of DEMO should be suppressed to an acceptable level, taking future commercialization into account.

Two types of DEMO designs are under development in Japan: the SlimCS, led by JAEA, and the Demo-CREST, by CRIEPI (Central Research Institute of Electric Power Industry). The SlimCS features a low-aspect-ratio ($A = 2.6$) design with a reduced-size central solenoid and a thin toroidal field coil system, resulting in a reduced weight of the machine and eventually a minimizing construction cost [3]. In addition, the low aspect ratio has the merits of achieving vertical stability for high elongation and high normalized-beta plasma, which leads to a high power density device with reasonable physics requirements. The Demo-CREST design envisages two-staged operations: a demonstration and a development phases. In the first phase, the design will operate with plasma performances extrapolated from the early stages of ITER operation; will be constructed using materials and technologies proven on, or extrapolated from, ITER, and will demonstrate power generation up to 500 MW. In the latter phase, it will show the possibility for economic competitiveness by introducing advanced plasma performances and high performance blankets [4].

It should be underlined that, in the process of fusion energy system development, collaborations with fission areas are becoming more important. The expertise and knowledge available in the fission areas are deemed of significant value in the development of fusion nuclear systems, such as safety and licensing, treatment and disposal of radwaste, neutron irradiation damage of materials, nuclear data, computational science, and so on. Therefore, these collaborations should be further strengthened.

3. Roles of ITER project

3.1. Construction

Much R&D progress has been made during the ITER Engineering Design Phase by the Japanese ITER Implementing Agency (IA), the former JAERI (now re-structured as JAEA) in collaboration with domestic universities and industries, particularly in the areas of fabrication technologies development for key ITER components, and in demonstrating of their performance. On the basis of these achievements, JAEA, now the Japanese ITER Domestic Agency (DA), is partly responsible for procurement, during the construction phase, of the following critical fusion technology components: superconducting magnets; in-vessel components (blanket/first wall and divertor); heating/current drive systems; blanket remote handling system; tritium safety system; and diagnostics system. Procurement activities will be launched shortly for some long-lead-time components such as the magnet, while procurement of the other components will follow, subject to the ITER project schedule. These procurement activities are essential to construct a technology knowledge base within the domestic research body and industries for the design and fabrication of DEMO components.

3.2. Operation

Commissioning of the ITER facility is planned to start in the year 2014 and first plasma is planned for 2016. The Japanese DA plans to engage heavily during the commissioning and operation phases to contribute to the successful operations of ITER. It is understood that performance of the ITER components and their safe and reliable operation will be evaluated, demonstrated, and enhanced step-by-step during the commissioning and operation phases proceeding from hydrogen to full non-inductive current drive high duty DT phase. Operational experiences and knowledge gained during these phases are essential to the construction of a technology basis for a fusion reactor and for the design of DEMO.

In these phases, technologies essential to a fusion reactor will be demonstrated in an integrated fashion under real fusion environments. In this sense, the following aspects are deemed of high importance: (1) demonstration of superconducting magnet performance under plasma discharges and radiation environments; (2) demonstration and improvements of remote maintenance technologies for components which exposed to radiation environments and subjected to operational deformations; (3) demonstration of