N3 Fusion Energy Development Strategy and the ITER Program
核融合エネルギーの開発戦略と ITER 計画

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Fusion energy is one of possible options of future energy sources for humankind. The fusion energy has intrinsic advantages over other future energy options. And it is scientifically challenging since it requires to confine and to sustain high temperature plasma of a few 100 million degree far exceeding the temperature of the center of the Sun. The ITER is right now a most important step towards the fusion energy development in which control of burning plasma is addressed. Flexible and well-thought strategy for fusion energy development is required for early contribution to the energy market and stabilization of atmospheric CO_2 concentration.

1. Introduction

The Sun is a mother of all living on the Earth. Source of the energy of the Sun is fusion reaction as discovered by Hans Bethe in 1939. Fusion research was started at around 1950 as an exciting challenge of the human kind to realize a Sun on the Earth. Confinement of high temperature plasma is needed to realize a Sun on the Earth. The plasma is a fourth state of matter and was not familiar for physicists and engineers although 99% of the universe was made of plasma. It took about 45 years for fusion researchers to realize equivalent break-even (break-even: ratio of fusion power to net input power is 1) plasma with a strong support by the people and the people's government. Human being now knows how to produce high temperature plasma up to 520 million degree in large tokamaks such as JT-60 [1].

Scientific knowledge during 55 years of fusion research enabled us to design and construct a fusion experimental reactor, the ITER. We have good confidence to achieve technical objectives of ITER [2]. Fusion research is a long-term scientific activities never experienced by the Human being. It requires strong will to fulfill long-term scientific program for realizing a Sun on the Earth. Fusion DEMO next to ITER will be a last step before the commercialization of fusion energy following so-called "Fast Track" approach to Fusion Energy [3]. This two-step approach to fusion energy becomes possible with a strong accompanying program such as continued concept improvement of tokamak configuration and also fusion technology development.

This year (2005) is named as "Einstein Year" since hundred years has passed since his discovery of $E=mc^2$ relation in 1905. And this year it is timely to discuss fusion research in which energy is produced through his famous relation.

2. The ITER

The programmatic objective of ITER is to demonstrate scientific and technical feasibility of fusion energy. It is important to understand that feasibility of fusion energy depends on the outcome of ITER. If ITER is successful enough, technical feasibility of fusion energy becomes firm as documented by the report of the Subcommittee of the Fusion Council for Fusion Development Strategy [3].

The technical objectives of ITER is set to demonstrate key elements of the control of self-sustained fusion burn, namely to sustain $Q \geqq 10$ for 400 seconds without precluding $Q=\infty$, to aim at $Q \geqq 5$ non-inductive steady-state operation, integral demonstration of number of essential reactor technologies, component test for a future reactor such as divertor heat and power control, and test of tritium breeding module concepts [2].

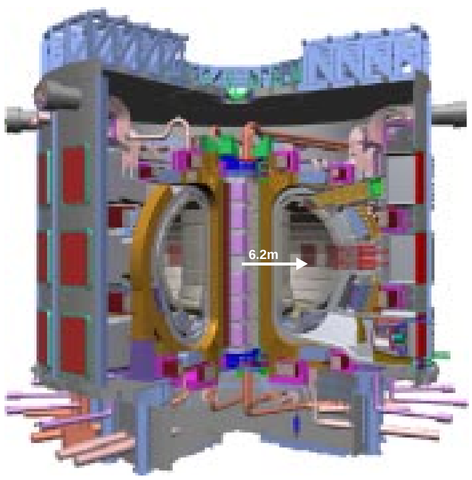

Fig. 1 Bird's eye view of the ITER

Impact of ITER technical objectives on the development path towards fusion energy was discussed in ITER SWG report #2 [4]. The ITER represents a demonstration of fusion technologies under power-plant-relevant conditions: super-conducting magnets, additional heating, fuel handling and vacuum pumping systems, plasma facing components. The ITER also provides the opportunity to explore the compatibility of improved tokamak modes and profile control in regimes of strong self-heating and steady-state operation as a test for tokamak power plant operation.

In order to proceed to a demonstration power plant (DEMO), ITER should address many physics and physics-technology issues such as,

- steady-state burning plasma with current driven profile control and a high bootstrap current fraction.
- A high performance core with an effective divertor, including high heat-flux steady-state components
- Test of tritium-producing blankets and of structural materials

Steady-state operation with $Q \geqq 5$ will be an important Japanese milestone for ITER. It is also quite important to develop “soft” divertor plasma with which divertor plates could withstand high heat and particle fluxes for year-long operation in DEMO. Moreover, higher beta operation is needed for the DEMO reactor since it becomes a prototype of company-led 1st generation commercial reactor. For such test operations in ITER, further proof of non-inductive steady-state operation and also exploration of high beta operation is required in accompanying program before the test in ITER.

3. Program in parallel with ITER

Since ITER is an international program, any test program in ITER requires agreement among participating parties. So unproven experiments under non-DT facilities have a difficulty for adoption, especially in case that it needs some investment. In this respect, domestic program giving a confidence for such a test in ITER plays an important role in leading and maximizing productivity of ITER research.

If such a domestic program has unique feature that could not be realized in ITER, it will contribute to expand a possible design window of DEMO, not limited to ITER configuration. The working group for fusion research under council for science and technologies identified such a feature as high beta steady-state operation with shape, aspect ratio, and feedback control enhancement that significantly contributes to the economical viability of fusion energy that was originally planned to be demonstrate in Prototype fusion reactor after DEMO before the appearance of “Fast Track” approach [3].

It is also quite important to develop fusion reactor materials through irradiation tests of likely candidate materials such as reduced activation ferritic steel by 14MeV neutron source such as IFMIF to validate applicability of such materials and also obtain irradiation data for design and improvements of components as endorsed by the working group on fusion research [5]. Efforts should also be made on development of high temperature blanket system that is essential for the DEMO reactor.

Also development of safer and environmentally acceptable (with respect to waste management) reactor concept is important for better public acceptance.

4. Discussion

Above-mentioned research items are quite essential for a decision of construction of DEMO. DEMO could be constructed if the extrapolated COE (cost of electricity) to 1st commercial reactor meets the user requirement, and if the extrapolated safety features to 1st commercial reactor meet the public needs, and if the extrapolated operational reliability meets the user requirement, etc. Assessment of breakeven price was made by K. Tokimatsu that gives good long-term target for fusion economy[6]. Also, recent analysis by K. Tobita showed that significant reduction of fusion rad-waste is possible with proper selection of radial build and materials [7]. Fusion development strategy should be well-thought and be flexible to allow adoption of improvements in various fields into a core program. It is quite important to balance various issues according to a progress of research accomplishments for early realization of fusion energy.

References

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