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Current and Future States of the Key Technologies to Realize Fusion Reactor –a View of Technology Maturity Assessment by Young Researchers
核融合炉実用化のためのキーテクノロジーの現在と将来 —若手による技術成熟度評価活動から見えてきたもの—

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The Young Scientists Special Interest Group on Fusion Reactor Realization is an active volunteer group which consists of the spirited young researchers beyond the frame of organizations or specialties who has a burning ambition to realize fusion reactors in their lifetime. To accelerate the R&D of fusion reactors, the possible bottle-neck technology should be clearly stated and recognized by the research specialists. Also an appropriate technological communication tool is necessary to highlight the key technologies and to obtain the supports from societies. In this study we adopted and tested a technology readiness level (TRL) methodology to evaluate the current status of key technologies for fusion reactor. The obtained results should be further discussed but clearly show that the bottle-neck technologies exist in the boundary area between specialists.

1. Introduction

"It takes 30 years before the fusion reactor can be commercialized". This is a famous phrase that was also described in the everlasting excellent book "Challenge to Fusion Energy" [1], which has been giving a grand dream and hope to young people as well as to the society suffering energy problems. Though budget constraints may have been significantly severer than initially expected by scientists, it is also inferred from the book that technical issues lurking in the great success of scientific researches of nuclear fusion has prevented the commercialization of the fusion reactor.

Off course, our privilege as "young" researchers living in their future as 30 years later is not to condemn the past but is to utilize the past experience with a sincere effort. Now we should emphasize that it is important to clarify the strategy of technological development that can be tolerated by the society (or government) as an investor. However this is a tough work for the researchers who always write academic papers, reports and proposals with various professional terminologies and parameters. Even for the fusion research specialists (probably not only young researchers but also senior researchers), an understanding of the whole picture of the integrated fusion science and technology is becoming difficult. In order to manage the various engineering subjects (or risk) appropriately towards the commercialization of fusion reactors, some useful tools for the researchers in different fields, the government, and society to evaluate the present condition of technical subjects rationally and quantitatively, and are required to carry out their decision-making and consensus building.

Recently, the Young Scientists Special Interest Group on Fusion Reactor Realization has been assessed the technical maturity of fusion reactors based on the evaluation of technology readiness levels (TRLs). This is a systematic evaluation method which has been used to support the evaluation and comparison of maturity for new technology developments in various projects of NASA [2] can provide a common understanding of the degree of progress of technology and its risk management. Until now, our group is successfully analyzing the present view of TRL of various fusion reactor technologies. Through this work, it is succeeding to reveal the critical common subjects and to share the obtained knowledge. In this paper, the TRLs for fusion reactor evaluated by the newest knowledge of the *spirited* young researchers beyond the frame of organizations or specialties are shown. Based on the TRL evaluation, the prospects towards the fusion reactor commercialization are also introduced.

2. Technology Readiness Level (TRL)

A summary of the TRLs in NASA is shown in Table 1 [2]. The 9 set of specific "exit criteria" shown is applied in conducting the technology readiness assessment. The NASA's TRL and its similar concepts are widely used for measuring technology readiness of various technologies and comparing maturity between different types of technology. However, they sometimes fail to give negative aspects when the TRL is used for the risk management of two or more projects advanced simultaneously. Note that the TRL indicates *NOT* the potential but the status of the technology development. The comparison of TRL between different technologies must be performed carefully to avoid the misleading and misunderstanding of the project which contains a "hidden treasure" beyond the risk to be overcame.

Table 1 NASA definitions of the TRLs [2]

TRL1	Basic principles observed and reported.
TRL2	Technology concept and/or application formulated.
TRL3	Analytical and experimental critical function and/or characteristic proof-of-concept.
TRL4	Component and/or breadboard validation in laboratory environment.
TRL5	Component and/or breadboard validation in relevant environment.
TRL6	System/subsystem model or prototype demonstration in a relevant environment (ground or space).
TRL7	System prototype demonstration in a space environment.
TRL8	Actual system completed and "flight qualified" through test and demonstration (ground or space).
TRL9	Actual system "flight proven" through successful mission operations

3. A brief example of TRL evaluation on fusion reactor technologies

The TRL setup which we propose for fusion reactor developments is shown in Fig. 1. Currently, it is obvious that the items of TRL 1-3 is still left behind to the tokamak, helical, laser system and their common technologies. In order to put a fusion reactor in practical use in 30 years, the achievement of TRL4 and more (i.e., engineering design phase) supported by target-oriented teams is required immediately.

The TRL assessment on the Tokamak type reactor has been performed by assuming the two scales of the net electricity output as 0.3 or 1 GW. As a result, the TRL was in the stage of 2 to 3 for both scales as a fusion reactor power plant. For the large-sized (low beta) system having a high TRL for the reactor core plasma, however, it was shown that the TRL evaluation as the whole reactor system falls down due to the technical subject by enlargement of TF coil and so on.

The TRL of a helical prototype nuclear reactor development is considered to be in the stage 3. The achievement of TRL4 is expected through R&D in a present progressive and also TRL6 is expected in the knowledge obtained from other equipment, such as LHD with deuterium experiment, a large-sized engineering test facility, and ITER.

The laser fusion is verging on their ignition and burn. However it was pointed out that a technical gap exists between FIREX/NIF of a single shot and a reactor. Cooperative R&D with a broad organization is required in order to shift to reactor engineering from plasma science.

The above-evaluations still need further discussion and re-evaluation. The detailed evaluation of TRLs broken down into engineering components of fusion reactor concepts will be reported in the conference. Finally, it is recommended to examine the TRL for your research and development. This is an aim of this paper to just give an opportunity of your argument.

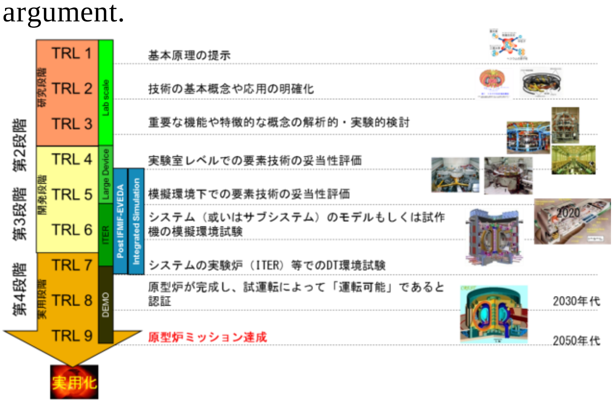

Fig.1. A setup of TRL for fusion reactor development.

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