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Future prospects of core-plasma research on the deuterium experiment in the Large Helical Device, LHD

大型ヘリカル装置LHDでの重水素実験によるこれからの炉心プラズマ研究

Yasuhiko Takeiri, LHD Experiment Group
竹入 康彦, LHD実験グループ

National Institute for Fusion Science, 322-6, Oroshi-cho, Toki-city, 509-5292, Japan
核融合科学研究所 〒509-5292 土岐市下石町322-6

Future prospects of core plasma research are discussed on the deuterium experiment to be conducted in the Large Helical Device, LHD. The achievements in LHD have provided the basis for deuterium experiments. The main objective of the deuterium experiment is to investigate the reactor-relevant plasmas by improving the plasma performance. The isotope effect, the mystery in fusion science, is highlighted as one of the physics issues to be elucidated for the burning plasmas.

1. Brief Overview on Achievements of LHD Experiments

The basic concept of the LHD project is to establish scientific bases for the reactor-relevant plasma performance in helical systems and to secure the design of a helical fusion reactor. To achieve it, the LHD plasmas should be investigated with the viewpoints of toroidal plasmas complementary to tokamak plasmas on scientific bases.

The plasma parameter regime of LHD has been steadily extended as summarized in Table I.

Parameter	Achieved	Target
T_{i0}	8.1 keV (1×10^{19} m^{-3})	10 keV (2×10^{19} m^{-3})
T_{e0}	13 keV (1×10^{19} m^{-3})	10 keV (2×10^{19} m^{-3})
n_{e0}	1.2×10^{21} m^{-3} (0.26 keV)	4×10^{20} m^{-3} (1.3 keV)
β	5.1 % (0.425 T)	5 % (1-2 T)
	3.7 % (1 T)	
discharge duration	54 min. (500 kW) 48 min. (1,200 kW)	1 hour (3000 kW)

Table I. Plasma parameters achieved in LHD compared to those target values.

The recent highlighted progress is extension of the parameter regime for the ion temperature (T_i) and steady-state operation, both of which are key issues towards a helical fusion reactor.

An increase in T_i has been realized, in addition to improvement of the ion heat confinement, by intense wall conditioning employing a series of the ICH-sustained discharges [1] to reduce the neutral density not only in the peripheral region but also in the core region [2]. It is beneficial to reduce the charge exchange loss of injected beam ions. Also, the resultant peaking of the electron density profile provides an increase in the ion heating efficiency in the core region.

A recent increase in the total ECH power (up to 4.6 MW) has been enabled to realize the electron ITB formation with the central T_e over 10 keV in the density range comparable to that for the ion ITB plasmas. Based on this reinforced heating capability, simultaneous high-temperature (T_i~T_e) plasma production has been pursued extensively by integration of the ion ITB and the electron ITB. Recent progress is shown by data points in Fig. 1, on the core T_i and T_e space. The hatched regime corresponds to the achieved parameters until FY2012.

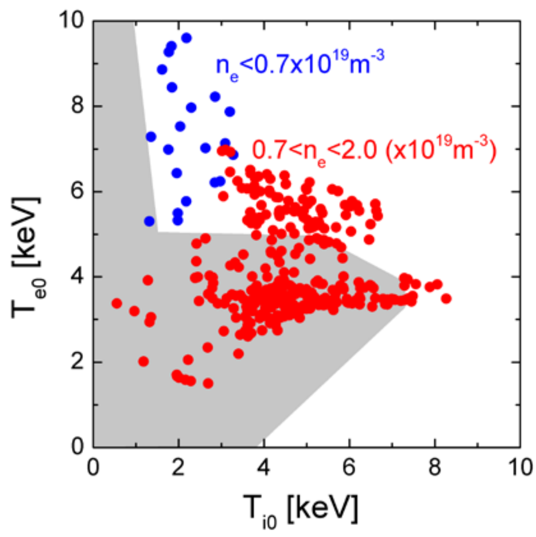

Figure 1. Parameter regime of core T_i and T_e, achieved in the LHD experiments.

The improvement of the ion heat confinement is recognized in the core region with positive radial electric field (electron root), and the temperature profile control (narrower electron ITB and wider ion ITB) is found to be a key for the integration of both ITBs [1].

The isotope effect on such a high-temperature regime is one of the high-priority issues to be investigated in deuterium experiments. Discharge scenario development and the establishment of the hydrogen and/or helium plasma database have been progressing prior to the deuterium experiment.

The steady-state operation has also been successfully progressed to demonstrate 47 minutes 39 seconds duration of plasmas with T_i~T_e~2 keV and the electron density of about 1.2×10^{19} m^{-3}, sustained by the combination of 1 MW-ICH and 0.2 MW-ECH. The total injected energy reaches 3.36 GJ, which broke the LHD's own previous world record of 1.6 GJ. This has been made possible by the ensured stable heating capability and reliable real-time density control. The termination of the discharge was due to the radiation collapse induced by impurity contents (such as carbon) in the plasma. The detailed study has been progressing in close considerations to the plasma-wall interaction [3].

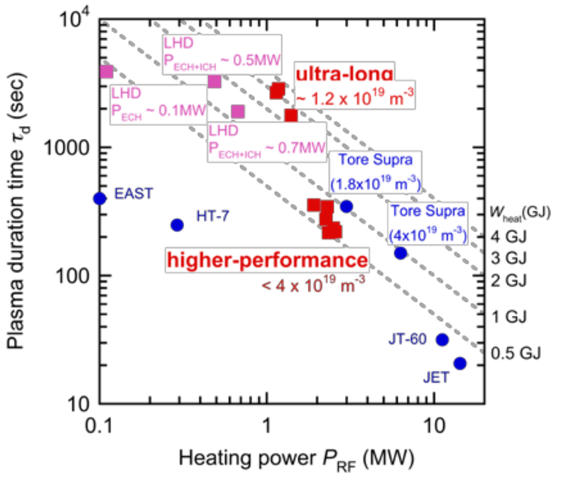

Figure 2. Operational regime of steady-state plasmas in LHD, and its comparison to achievements in several tokamaks.

2. Objectives and Main Subjects of LHD Deuterium Experiment

Considering the concepts of the LHD project, the objectives of the LHD deuterium experiment are summarized as follows;

1. Realization of high-performance plasmas by confinement improvement and to provide a wide range of plasma parameter space relevant to the reactor plasmas. As a consequence, scientific research area will be expanded.
2. Clarification of the isotope effect in the plasma confinement, and establishing the firm scientific basis for the burning plasmas.
3. Demonstration of the energetic ion confinement capability to be relevant to burning plasmas in helical systems.

The LHD deuterium experiment is anticipated to provide a wide variety of research opportunities which are relevant to burning plasma physics and reactor scenario development. Among them the followings are main subjects to achieve the objectives;

1. <u>Confinement improvement and relevant physics</u>
   The isotope effects on the plasma confinement and the related confinement improvement in the deuterium experiments, towards systematic understanding of the toroidal burning plasmas.
2. <u>Improvement of MHD stability and expansion of high-β regime</u>
   MHD equilibrium and stability in high-β regime in collisionless plasmas to be realized by the confinement improvement and the increase in the heating power in the deuterium experiment.
3. <u>Confinement of energetic ions</u>
   Confinement of energetic ions, such as ones accelerated by the ICRF D(H) heating scheme to be diagnosed by means of high-accuracy diagnostics.
4. <u>Divertor optimization</u>
   Particle and heat control in the peripheral plasma with the closed helical divertor and the improvement of steady state plasma performance.
5. <u>Plasma-wall interaction</u>
   Increasing understandings on the impacts of plasma-wall interaction including the fuel recycling on the plasma confinement improvement, to be extrapolated to burning plasmas.
6. <u>Expansion of experimental scenario</u>
   Ion heating experiments by the ICRF heating schemes of H-minority/D-majority and ^{3}He-minority/D-majority.

For enhancing the experimental capabilities on such main subjects, reinforcement and optimization of the heating devices, installation of the closed helical divertor, and installation of the diagnostics for energetic particles and neutrons, and so on, have been conducted. Details will be described in the presentation.

These main subjects and other important issues should be tackled by all efforts of the research community, and the integrated understandings should be elucidated towards burning plasmas.

References

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[2] K. Fujii et al., Rev. Sci. Instrum., **85** (2014) 023502.

[3] H. Kasahara et al., EX/7-3, 25th IAEA Fusion Energy Conference, St.Petersburg, Oct. 2014.