Experimental Studies toward Long-Pulse Steady-State Operations in LHD

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Abstract. Stable discharges longer than one minute have been obtained in LHD with all the heating schemes including electron cyclotron heating (ECH). Plasma is sustained with neutral beam injection (NBI) or with ion cyclotron resonance frequency (ICRF) with 0.5 – 1 MW. Central plasma temperature is higher than 1.5 keV with a density of 1 - 2 x 10^{19} m^{-3} until the end of the pulse. Full installation of the carbon divertor has contributed to this achievement. This gives a sufficient base for physics and technology studies from the next campaign. The long pulse operation indicates new possibilities in diagnostics and in physics studies. Higher accuracy and reliability is obtained with diagnostics parameter scan, longer integration of signals or two-dimensional measurement. The mechanism of a slow oscillation called "breathing" is discussed. Hydrogen recycling analysis has been carried out and preliminary results are obtained. Based on these results, the future program is divided into two categories, that is, i) physics and technology experiments utilizing long-pulse discharges up to 5 minutes, and ii) extension of the pulse-length toward one hour.

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1. Introduction

The Large Helical Device (LHD) is a heliotron type fusion experimental device with superconducting coils [1]. It generates magnetic confinement configurations in a steady state without any current drive. A pair of helical coils is pool-cooled with 4.4 K liquid helium and generates the toroidal magnetic field up to 2.9 T. The vertical field is adjusted with three pairs of poloidal coils, which are force-cooled with supercritical helium at 4.5 K. Thus LHD has a big advantage for steady state operation, which is one of the major aims of the project [2]. In LHD, the aims of the long pulse experiments are to demonstrate the capability of maintaining high temperature plasmas in a steady state with a helical magnetic configuration, to utilize the long-pulse discharges for physics and technological investigations, and to accumulate a database, which could be useful for future reactors. The goal of the first step is set to achieve 3 MW, one-hour operation [3]. This paper describes the achievements and results in experimental campaigns in 1998 and 99 toward the long-pulse operations.

2. Overview of the Progress in Long Pulse Operations

Three heating systems have been under development to realize long pulse discharges, that is, Electron Cyclotron resonance Heating (ECH) [4], Neutral Beam Injection (NBI) heating [5], and heating with Ion Cyclotron Resonance Frequency (ICRF) [6-9].

In ECH, 84GHz gyrotrons are designed and utilized for the long pulse operations. Extension of the pulse length has been tried and a 2 minutes stable discharge was achieved in the end of the 1998 campaign [10]. Input power to the LHD vessel was 50 kW. Electron and ion temperatures were several hundreds eV, and the plasma well exceeded the radiation barrier of low Z impurities. However, electron density was as low as 4×10^{17} m^{-3} due to the low heating power level. The main problem is efficiency in the power- transmission between the gyrotron and a window at the LHD vacuum vessel, especially at a matching optics unit (MOU), which couples an output power of the gyrotron to a corrugated wave guide. More details are described in Ref. [10]

The NBI system consists of two beam lines [5], in which the co-injection line is designed to have the potential for the long-pulse operation. After the first experimental campaign, the electric power source for NBI was upgraded to provide two minutes pulses. A pulse length of 21 seconds was achieved in December 1998 [11]. The field strength at plasma axis was 1.5 T, the NB heating power was 0.6 MW in that campaign. In Fig. 1, progress in NBI pulse length is summarized. Shot numbers 6699 and 6709 correspond to this achievement. Two types of discharges are seen. One is a stable discharge with a density of 3×10^{18} m^{-3} (#6709), and the other an unstable one in which the density oscillates around 1×10^{19} m^{-3} (#6699). The density was controlled with a level of initial gas pressure with the pre-fill and determined by fuelling from the wall after the discharge starts. With a lower initial pressure, the density was low and in a steady state like #6709. But with a higher initial pressure, density was higher but unstable (#6699) with a slow oscillation named "breathing". The density operation range was limited by this "breathing" oscillation during the 1998 campaign.

Before the 1999's campaign, commissioning of a full set of the helical divertor system was completed. One of the essential points of this system is that all the striking points are covered with carbon tiles. The breathing oscillation disappeared after the installation of the carbon divertor, and density limit was much improved in the 1999 campaign with the same field strength (1.5T) and heating power (<1MW) as those in the 1998 campaign. Radiation loss was significantly reduced and the density was controllable by helium gas-puffing during the discharge. The maximum density was 6×10^{19} m^{-3} with a heating power of 1MW.

In the 1999 campaign, most of the discharges were operated at 2.75 T, as opposed to 1.5 T in the 1998 campaign. The higher field strength enabled to enlarge the operation region of the

LHD plasmas in general, and to improve the plasma parameters. It was true in long pulse operations, too. In the middle of this campaign, a longer operation, 35 seconds, was achieved with NBI [12], which corresponds to shot number 11245 in Fig. 1. The NBI power source was supplied with a flywheel (FW) generator for most of the 1999 campaign, which limited the pulse length. In the later half of the 1999 campaign, the NBI operation with the commercial line became possible. The maximum pulse length reached 80 seconds at the end of the 1999 campaign [13]. The density trace is shown in Fig. 1 for the longest discharge #17311. Central electron temperature was around 1.8 keV at 80 s with a heating power of 0.5 MW and a density of 1.5 x 10^{19} m^{-3}. The density was controlled between 1.5 and 2.0 x 10^{19} m^{-3} by helium gas puffing until the end of the discharge.

It is worth noting that conditioning of the NBI injection port was improved smoothly and quickly. At the entrance of the beam into the vacuum vessel, a set of molybdenum cylindrical plates is placed to protect the wall of the porthole. This is not directly cooled at present, which results in significant temperature rise during the long-pulse injection. It leads to out gassing from the plates and occasionally uncontrollable density rise in the dis charge. One example is seen in Fig. 2 [14]. In the shot 17304, significant pressure rise was seen around the injection port and density increased slightly around 70 seconds. Shot 17311 is the next NBI shot, which corresponds to the 80 second discharge. The pressure rise was not seen any more, and the density was controllable until the end. This means that one conditioning shot is sufficient to extend the pulse length to 10 or 20 seconds longer.

In Tore Supra, uncontrollable density rise occurs with higher heating power in longer pulse operations than the present LHD. The cause of the density rise is attributed to outgas from surfaces heated by radiation during plasma discharge. It is indicated that the wall condition is quickly improved shot by shot, but a single disruption re-contaminates the cleaned surfaces, which revert the poor condition [15]. In LHD, a similar problem could occur with higher and longer heating in the future. But due to the lack of disruption, no re-contamination due to disruption is expected, which might give smoother progress in extension of the pulse length than in tokamaks.

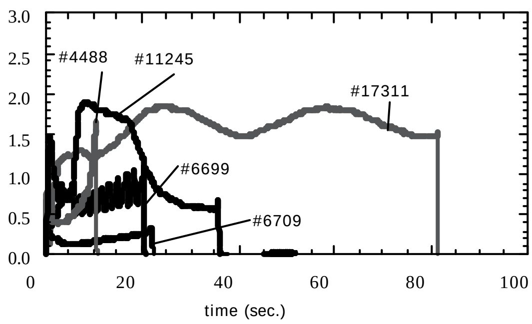

Fig.1 Line averaged electron density ($10^{19}/m^3$) with NBI heating

In the 1999 campaign, systematic operation of the ICRF heating started with magnetic field strength of 2.75 T and the frequency of 38.47 MHz. The major ion component was helium with a fraction of hydrogen ions. A series of experiments was carried out in order to optimize ICRF heating, scanning the magnetic field strength, the applied frequency and minority ion concentration. When the minority cyclotron resonance layer is shifted to the lower magnetic field position, the electron heating via a mode-conversion becomes dominant. On the other hand, when the cyclotron resonance is shifted near the magnetic axis, the ICRF heating power is dominantly absorbed by minority ions. The most efficient ICRF heating mode was

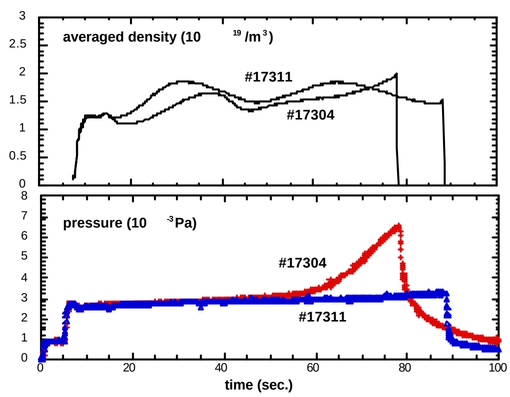

Fig.2 Average electron density ($10^{19}/m^3$) (top) and neutral pressure (10^{-3} Pa) at the injection port [14] (bottom) for successive two NBI shots, #17304 and #17311

obtained in the case that the minority cyclotron resonance is just located at the saddle point in the contour map of the magnetic configuration [16]. The longest discharge was 68 seconds [17], in which the density was maintained around 1.0 x 10^{19} m^{-3} by the helium gas puffing until the end of the discharge. The absorbed power was estimated to be 0.7 MW. The total radiation loss was constant around 0.2 MW until the end of the pulse, being well below the absorbed power. It is an important finding that the radiation loss is not significant. Central electron temperature was kept around 2.0 keV. Ion temperature was measured to be around 2 keV, too, by Doppler broadening of TiXXI using an X-ray crystal spectrometer [18].

It has been found that the primary power deposition from rf is dominated by ions in the condition of the discharge 17170, where electrons are heated through slowing down process of the energetic ions [16]. It is remarkable that the electron heating by fast ions is effective to maintain the electron temperature because the possible loss of the high-energy ions has been a concern in helical configurations, in particular, perpendicular heating with ICRF. The success in ICRF is particularly promising for extension of the pulse length in future because of its better efficiency in power consumption and cost compared to the NBI and the ECH systems.

3. Divertor and Vacuum Vessel

A divertor is an essential tool for heat and particle control in steady state fusion reactors. LHD has an intrinsic helical divertor configuration without any additional coil. A cross sectional view looks similar to a double-null divertor in tokamaks. But the divertor region rotates toroidally and poloidally with the same pitch as the helical coils, which forms a complex three-dimensional geometrical structure. A graphite armor tile is bolted to a copper heat sink fixed to a stainless steel pipe, in which cooling water flows. Tiles are arranged helically along the striking points. It has been confirmed by R&D experiments that heat removal efficiency is sufficient for 3 MW steady-state operations based on this design [19]. Installation has been completed in June 1999, and in full use in the 1999 campaign [20].

The vacuum vessel is also water-cooled [21]. U-shaped channels are directly welded to inside the vessel wall. Distance between two channels is 80 mm ~ 250 mm. First-wall panels, made of SS/Cu, are fixed on the channels by stainless steel bolts. According to the calculation, this structure removes heat load higher than 3 MW with a vessel temperature below 70 C.

A direct result of the divertor installation is a reduction in metal impurity radiations. Radiations from highly charged impurity ions, such as FeXXIII(13.287 nm), CrXXI(14.987nm) etc. reduced more than a factor 10 in the discharges with the carbon divertor compared with those with the stainless steel divertor [20]. Radiation profiles measured by bolometer array indicate that radiations from core region are reduced with the carbon divertor [22, 23]. "Breathing" oscillation did not occur after the installation of the carbon divertor.

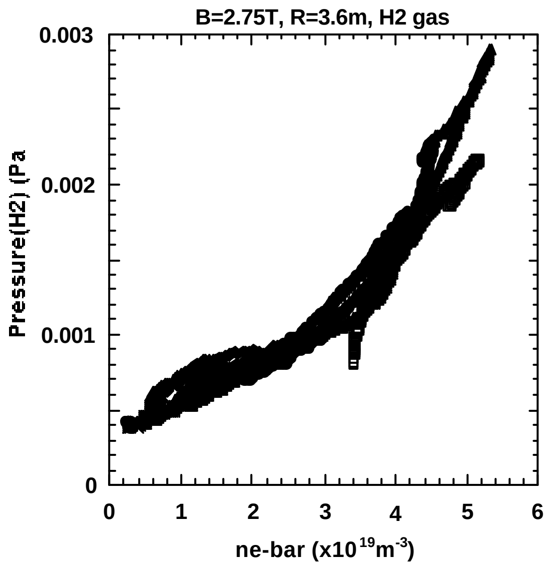

Fig.3 Density dependence of the neutral pressure around the divertor region.

The significant reduction in metal impurities with the carbon divertor indicates that the plasma-wall interactions dominate at the divertor striking points and that the carbon target plates successfully covered most of them. On the divertor tiles, a clear footprint of the divertor leg is seen after the 1999 campaign was finished. It has been already confirmed that iron is a dominant element in the deposited layer of the footprint.

Particle controllability is determined by effective pumping speed and neutral pressure at the pumping duct in a divertor. The pressure is measured with a fast ion gauge [24]. Figure 3 shows the density dependence of the pressure in long-pulse NBI heated shots. It shows a nonlinear increase in high density region. But absolute pressure is as low as 3 x 10^{-3} Pa even at a density of 5 x 10^{19} m^{-3}. It means that the pressure in helical divertor of LHD is much lower than that in tokamaks at the location measured in the experiments. In a fusion reactor with 1 GW fusion power, helium removal rate of 1 Pa-m^3/s is required. If the effective pumping speed is assumed to be 200 m^3/s, helium pressure must be 5 x 10^{-3} Pa, which is factor 15 - 20 larger than the present value 3 x 10^{-4} Pa. Careful design of a closed type divertor is necessary to demonstrate particle removal capability in LHD. Maximum temperature rise at inboard target was around 150 C in the longest ICRF discharge, which indicates that active cooling of the divertor is effective.

4. New Possibilities in Diagnostics

A long pulse stable discharge opens new possibilities for various plasma diagnostics. A merit of long-pulse discharge is to provide a chance to a diagnostics to have the long time integration and/or slow scan of diagnostics parameters.

An example has been seen in a polarization measurement of electron cyclotron emission (ECE) in the 1999 campaign. In the LHD configuration, the polarization angle of the X-mode radiation changes with minor radius because of the rotational transform of the magnetic field. Theoretical calculation indicates that, if plasma density is high enough, the polarization rotates almost up to the edge of plasma. It means all frequencies exit the plasma under approximately the same angle. This was confirmed by measuring the polarization spectrum. For this purpose, polarization rotator was inserted between the plasma and the detector. By changing the polarization rotator angle, a different spectral polarization can be measured. During long-pulse LHD discharges, the rotator angle was changed and a complete polarization spectrum was obtained within one shot. The result is shown in Fig. 4 [25]. Peaks correspond to X-mode radiation, which represents the central electron temperature.

Another example is a tangential X-ray camera. Energy spectra of X-ray emission can be measured using a photon counting mode. From these spectra, two-dimensional profiles of electron temperature and impurity densities can be determined. In order to avoid pile-up, the X-ray intensity must be carefully optimized by crossing the appropriate thickness of Be filter. A proof-of-principle experiment has been done in Compact Helical System (CHS) in NIFS. Since the readout of the data from CCD is relatively slow to reduce the noise, the frame rate is only 0.3Hz (3 second). Moreover, because of the limitation of number of photon per frame, multi frames (typically more than 10 frames) are required to get enough statistics to derived electron temperature. In the CHS experiment, the data are accumulated for 10 identical shots to obtain the T_e profile with a sufficiently high accuracy [26]. Although the time duration required to derive two-dimensional electron temperature profiles using this type of X-ray camera is extremely long (~ 30 sec.), this

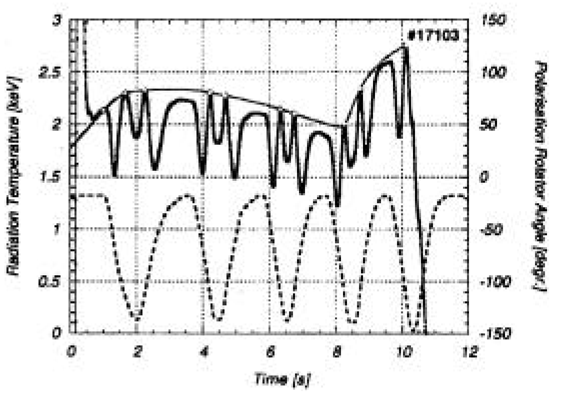

Fig.4 Spectorum of ECE at 148 GHz obtained in a long pulse discharge (thick solid curve) [25]. Angle of the polarization rotator is changed with time and plotted with a dotted curve. Peaks correspond to X-mode, namely central electron temperature, which is plotted with a thin solid line.

X-ray CCD camera would be useful diagnostics for a long pulse discharge in the steady state operations in LHD (see Fig.1). This new diagnostic has been set up in LHD, successfully used to measure Shafranov shift with high accuracy in the imaging mode [27], and ready for use with the photon counting mode.Wavelength calibration is sometimes laborious and time consuming for a grazing incidence spectrometer in the vacuum ultra violet (VUV) region. Wavelength scan has been tried by utilizing a long pulse steady discharge. It was successful and such a discharge was found to be very useful for the calibration. The measurement of the two dimensional space distribution of impurity radiation is also planned with another UV spectrometer during a single shot of long-pulse discharge [28].

5. Physics Studies

Physics and technological studies are one of the aims of the long-pulse experiment. Several studies have been growing during these two years. Two examples are summarized here.

The first example is so called "breathing" oscillation. It is characterized with a low frequency oscillation in NBI heated discharges [11]. Most of the plasma parameters oscillate with the same frequency between 0.5 and 1.5 Hz. Total radiation loss P_{rad} is measured by a set of bolometer array. The ECE signals, correlating to local electron temperatures, decrease at first with increase in radiation P_{rad} in spite of constant density. When the temperature decreases to a certain low level, low Z impurity radiation such as CIII and OV increases, which causes a further decrease in the temperature. A few hundreds of seconds later, the temperatures start to recover. Increase in P_{rad} follows it with further delay.

The physics mechanism has been intensively discussed and published [11,22,23,29-32]. According to the radiation profile measurement with the bolometer array, the increasing phase of P_{rad} is dominated by radiation around ρ =0.4, where ρ is averaged minor radius. It indicates that the radiation is mainly contributed not by low Z but by metal impurities. As mentioned earlier, "breathing" did not happen with the graphite divertor. These two facts indicate that energy loss through metal impurity radiation is playing an important role in this phase of the oscillation [29,30]. In the later phase, the low Z radiation intensity increases. The radiation profile measurement indicates that the radiation is localized at plasma periphery. Finally this results in detachment of the divertor plasma from divertor plates, which has been observed by Langmuir probes at the divertor plate [29]. Metal impurity influx from the divertor, which is not directly measured, is reduced during the detachment, which causes a reduction in metal impurity in the core plasma. Energy balance improves, and core and edge plasmas are heated again. Metal impurity emission restarts due to recovery of the temperature in front of the divertor plates, then core radiation increases again, which returns the plasma to the initial condition. It is pointed out that radiation loss by metal impurity radiations is not sufficient to cause the detachment. Low Z impurity radiations are playing the main role of edge cooling just before the detachment [31]. Another argument should be mentioned here, where a change in transport is playing a key role in the oscillation [32]. Discussion on the detail of the mechanism is still continued.

Secondly, a more essential problem for steady-state operation is particle balance. As mentioned earlier, gas-puffing is necessary even at the end of the 80 second NBI discharge. It means that the wall is not fully saturated and the recycling rate is lower than unity.

According to static inventory measurement with a small scale ion beam experiment, it is said that saturation is reached with a fluence in the order of $10^{17}/cm^2$ for carbon and stainless steel. Divertor flux was measured by a Langmuir probe and is typically on the order of $10^{18}/cm^2s$ [33]. Then one second is enough to reach saturation at the divertor if the above mentioned understanding for static inventory is true. At the first wall, charge-exchange neutral flux dominates. If you assume the flux intensity as $10^{15}/cm^2s$, more than 100 seconds is necessary to reach static equilibrium. In this sense, it is not surprising that the saturation is not seen during 80 seconds discharge. But continuous wall pumping is seen in much longer discharges. One example is a tokamak discharge in TRAM-1M. Time variation of the recycling coefficient is shown in Ref. [34], where the rate is close to but below unity at the end of a low density, three minutes discharge. Recycling rate below unity is often observed in even longer discharges in TRIAM-1M [35]. Another example is a glow discharge in a small experimental device named SUT [36]. Hydrogen behavior is carefully investigated with boron-coated stainless steel. Flux and energy from hydrogen glow discharge is on the order of $10^{14}/cm^2s$ and 200 - 300 eV, respectively, being comparable to the charge-exchange neutral flux in tokamaks. It is clearly seen that wall pumping continues for 10 hours. To understand this long-lasting wall pumping, a concept of "dynamic retention" is employed [36]. During bombardment of energetic particles, a significant fraction of trapped hydrogen atoms is released to be mobile. Most of them are reemitted from the surface, but a finite fraction of them moves toward the inside of the bulk materials, which causes the continuous wall pumping. Such a concept of dynamic inventory is required for understanding the recycling and inventory during the discharge.

As the first step to approach this problem, careful analysis of the particle balance is started using long-pulse discharges in LHD [23]. A systematic analysis of the particle balance was carried out with a set of 10 second hydrogen discharges. Wall inventory is estimated using a set of particle balance equations. Apparent particle confinement time τ_p* is estimated based on multi-shot analysis. It is clearly seen that the time τ_p* increases with integrated hydrogen flux, but is still finite within this experimental range. For longer discharges, the gas-puffing system was manually controlled and it was unable to know the fuelling rate quantitatively. The analysis in longer discharges and comparison between modeling with and without dynamic retention is necessary. It will be done in the next campaign.

Refferences

[1] MOTOJIMA, O., et al., "Progress Summary of LHD Engineering Design and Constructions", Nucl. Fusion 40 (2000) 599.

[2] IIYOSHI, A., et al., "Design Study for the Large Helical Device", Fusion Technology 17 (1990) 169.

[3] NODA, N., et al., "Research Plan for Long-Pulse/Steady-State Experiments in LHD", J.of Plasma and Fusion Research SERIES Vol., 1 (1998) 130.

[4] SHIMOZUMA T., et al., in Fusion Technology 1996 (Proc. 19th Symp. Lisboa, 1996) Elsevier Amsterdam and New York (1996) 553.

[5] KANEKO, O., et al., Fusion Energy 1996 (Proc. 16th Int. Conf. Montreal,1996), IAEA,Vienna (1997) 539.

[6] MUTOH, T. et al., "Steady State Tests of High Voltage Ceramic Feedthroughs for ICRF Heating System of Large Helical Device", Fusion Technol. 35 (1999) 297.

[7] SEKI, T., "Hardware of Steady State ICRF Heating for LHD", presented in ITC-10 on Physics and Technology for Steady State Plasmas, Toki, 2000.

[8] KUMAZAWA, R. et al., Rev. Sci. Instrum. 70 (1999) 555.

[9] MUTOH, T., et al., Fusion Engineering and Design 26 (1999)387.

[10] SHIMOZUMA, T., et al., "ECH Sysytem and Its Application to Long Pulse Discharge in LHD", to be publishrd in Proc. IAEA-TCM on ECRH Physics and Technology, Oh-arai, 1999.

[11] TAKEIRI, Y., et al., "Plasma Characteristics of Long-Pulse Discharges Heated by Neutral Beam Injection in the Large Helical Device" Plasma Phys. Contr. Fusion 42 (2000) 147.

[12] FUJIWARA, M. et al., "Overview of Long Pulse Operation in the Large Helical Device ", Nucl. Fusion 40 (2000) 1157.

[13] TAKEIRI, Y., et al., “Long-Pulse NB-Heated Discharges in LHD”, presented in ITC-10 on Physics and Technology for Steady State Plasmas, Toki, 2000.
[14] OKA, Y., et al, “Operation of the Negative ion-Based Neutral Beam Injection System during Large Helical Device Experimental Campaign”, presented in 21th Symposium on Fusion Technol. (2000) Madrid.
[15] GRISOLIA C. et al., “Plasma Wall Interaction during Long Pulse Operation in Tore Supra”, J. Nucl. Mater. 266-269 (1999) 146.
[16] SAITO, K., et al., “Ion and Electron Heating in ICRF Heating Experiments on LHD” submitted to Nucl. Fusion.
[17] KUMAZAWA, R., et al., “Long Pulse ICRF Heating Experiment on the LHD”, presented in ITC-10 on Physics and Technology for Steady State Plasmas, Toki, 2000.
[18] MORITA, S., et al., in Proc. 14th European Physical Society Conference on Controlled Fusion and Plasma Physics (1987) Abstracts Vo IID. Part III (1987) p. 874.
[19] KUBOTA, Y., et al., in Fusion Technology (Proc. 20th Symp. Marseille, 1998) Vol.1, Assoc. Euratom-CEA, Cadarache (1998) 241.
[20] NODA, N., et al., “LHD Helical Divertor and Its Performance in the First Experiments” presented in ITC-10 on Physics and Technology for Steady State Plasmas, Toki, 2000.
[21] INOUE, N., et al., “Design and Construction of the LHD Plasma Vacuum Vessel”, Fusion Eng. Design. 41 (1998) 331.
[22] PETERSON, B. J. et al., “The Effect of Divertor Tile Material on Radiation Profile in LHD”, presented in 14th Int. Conf. on Plasma Surface Interactions, Rosenheim, 2000.
[23] NAKAMURA, Y. et al., “Particle and Power Balance Study in Long Pulse Discharge on LHD”, presented in 14th Int. Conf. on Plasma Surface Interactions, Rosenheim, 2000.
[24] SUZUKI, H., et al., “Plasma Stailess Steel Wall Interaction of the LHD”, presented in ITC-10 on Physics and Technology for Steady State Plasmas, Toki, 2000.
[25] DE VRIES, P. C. et al., “The Polarization of Electron Cyclotron Emission Spectre in the Large Helical Device”, Physics of Plasmas 7 (2000) 3707.
[26] LIANG, Y., IDA, K., et al., “Energy and Spatial Resolved Measurement of Soft X-Ray Emission with Photon Counting X-Ray CCD Camera in CHS”, submitted to Rev. Sci. Instrum.
[27] LIANG, Y., et al., “Measurement of Soft X-Ray Imaging by Using CCD Camera for Long Pulse Discharge”, presented in ITC-10 on Physics and Technology for Steady State Plasmas, Toki, 2000.
[28] MORITA, S., National Institute for Fusion Science, personal communication, 2000.
[29] PETERSON, B. J., “Bolometric Measurements of Radiated Power Profiles from Initial NBI Heated Plasmas in the Large Helical Device”, presented in 26th European Physical Society Conference on Controlled Fusion and Plasma Physics (Maastricht, 1999).
[30] PETERSON, B. J., “Modeling of Impurity Radiation and Transport during Long Pulse “Breathing” Plasmas in LHD”, presented in ITC-10 on Physics and Technology for Steady State Plasmas, Toki, 2000.
[31] TOKAR, M. Z., et al., “A possible Nature of “Breathing” Plasmas”, Physics of Plasmas (in print).
[32] ITOH, K., et al., “Modeling of Density Limit Phenomena in Toroidal Helical Plasma”, NIFS-627, 2000.
[33] MASUZAKI, S., “First Experimental Results of PSI studies in the Large Helical Device”, presented in 14th Int. Conf. on Plasma Surface Interactions, Rosenheim, 2000.
[34] ITOH, S., et al., Fusion Energy 1998 (Proc. 17th Int. Conf. Yokohama,1998), IAEA,Vienna (1999) Vol. 1, p.99.
[35] ITOH, S., and SAKAMOTO, M., Research Institute for Applied Mechanics, Kyusyu University, personal information, 2000.
[36] TSUZUKI, K., et al., “Dynamic Behavior of Hydrogen Atoms with a Boronized Wall”, J. Nucl. Mater. 241-243 (1997) 1055.