Advanced Tokamak Research in JT-60U and JT-60SA

A. Isayama on behalf of the JT-60 team

Japan Atomic Energy Agency, 801-1, Mukoyama, Naka, Ibaraki 311-0193, Japan

isayama.akihiko@jaea.go.jp

Steady-state sustainment of high integrated performance is essential for a fusion reactor, where simultaneous achievement of high values of the normalized beta (β_N), confinement enhancement factor ($H_{H98(y,2)}$), non-inductive current drive fraction (f_{NI}) and so on is required. For example, in one of the advanced scenarios in ITER, so called the Hybrid Scenario, $\beta_N \sim 2$-2.5, $H_{H98(y,2)} \sim 1$-1.2 and $f_{NI} \sim 0.5$ are assumed to obtain the fusion gain $Q \sim 5$ with the discharge duration of longer than 1000 s. To develop the scenario of the advanced tokamak operation and clarify physics issues and their solution, advanced tokamak research has been extensively performed in JT-60U by fully utilizing its capability. Typical example of a long-pulse high-beta discharge is shown in Fig. 1(a)-(c),where $\beta_N \sim 2.6$, $H_{H98(y,2)} = 1.0$-1.1, bootstrap current fraction = 0.43-0.46 are sustained for 25 s. Current profile, whose diffusion time is about 1.8 s, is fully relaxed , and at the same time peaked pressure profile is also sustained stationary. Onset of neoclassical tearing modes (NTMs), which limit the stationary sustainment, is successfully avoided throughout the discharge. Progress in the stationary high-beta plasma development is shown in Fig. 1(d), where β_N is plotted against sustained duration. As shown in this figure, operational regime of high beta has been successfully extended in this experimental campaign. In a higher beta regime, active control of NTM becomes important. In JT-60U, an NTM with the poloidal and toroidal mode numbers are 2 and 1, respectively, was successfully suppressed by electron cyclotron (EC) current drive by modulating the injected EC wave at ~5 kHz in synchronization with the mode rotation. Onset of a resistive wall mode, which appears at a high-beta regime above the beta limit without conducting wall ('no-wall limit'), was controlled by changing rotation profile. In addition, advanced feedback control system has been developed, and simultaneous control of pressure gradient and current profile was successfully demonstrated.

The operation of JT-60U was concluded with great success in August 2008. A superconducting tokamak, JT-60SA (Super Advanced), is being constructed to take over and drive forward the advanced tokamak research as a part of the Broader Approach in collaboration with EU. The JT-60SA device has 18 toroidal coils and 6 poloidal coils with superconducting magnets. Toroidal magnetic field and plasma current are ≤ 2.25 T and ≤ 5.5 MA, respectively. Auxiliary heating and current drive are done by positive-ion based neutral beams, negative-ion based neutral beams and electron cyclotron waves. In addition to engineering design, physics assessment such as MHD stability, divertor heat load etc. is in progress.

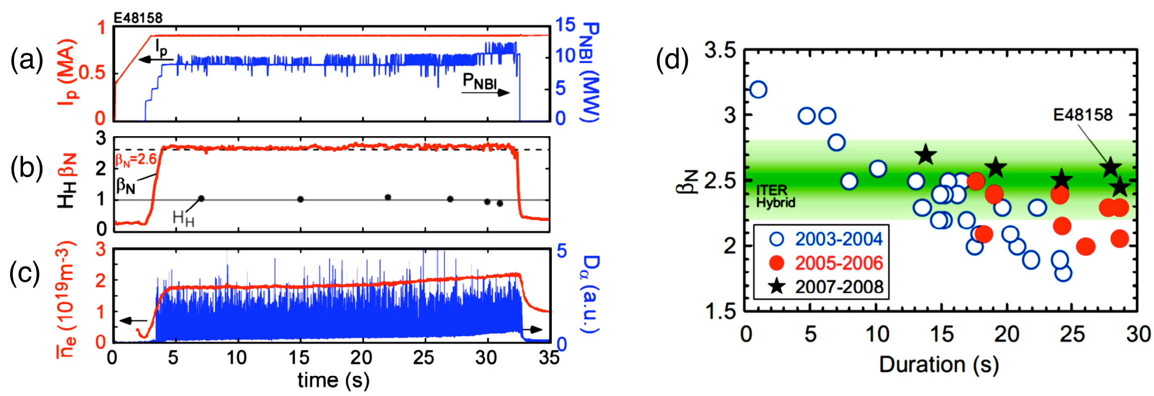

Fig. 1: Typical discharge of long-duration, high-beta plasma. (a) Plasma current and neutral beam power, (b) normalized beta and confinement enhancement factor and (c) line-averaged electron density and Dα intensity. (d) Progress in β_N and sustained period.