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INITIAL H-MODE EXPERIMENTS IN DT PLASMAS ON TFTR

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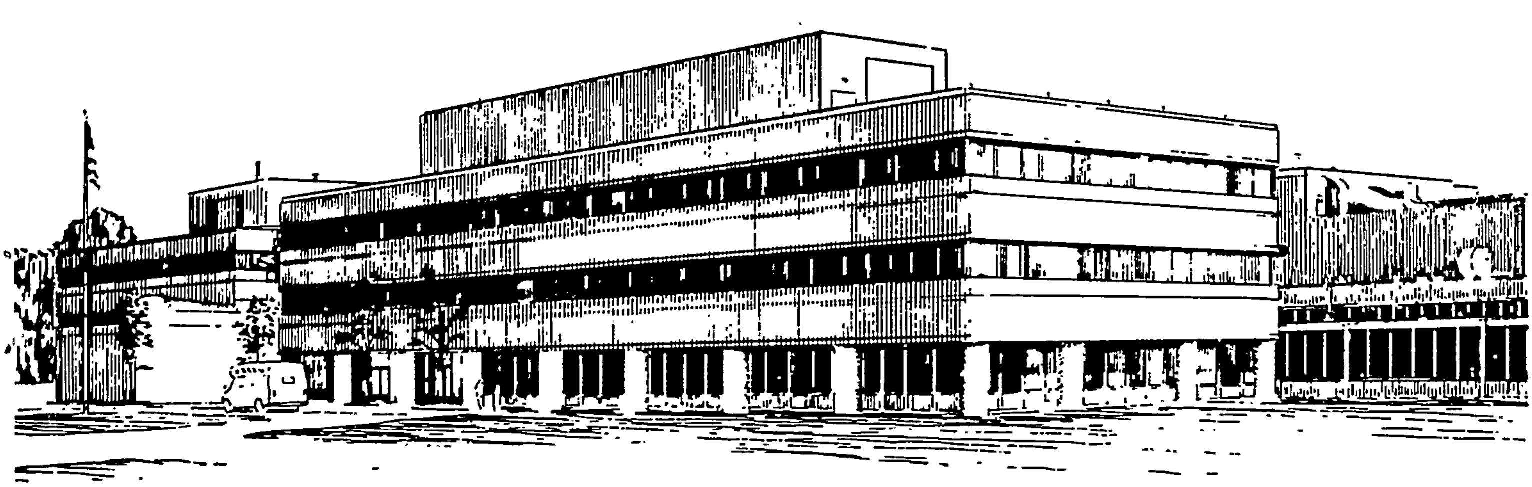

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ABSTRACT

H-modes have been obtained for the first time in high temperature, high poloidal beta plasmas with significant tritium concentrations in TFTR. Tritium is provided mainly through high power neutral beam injection (NBI) with powers up to 28 MW and beam energies of 90-110 keV. Transition to a circular limiter H-mode has been obtained following a rapid ramp down of the plasma current. Some of the highest values of τ_E have been achieved on TFTR during the ELM-free phase of these DT H-mode plasmas. τ_E enhancements greater than four times L-mode have been achieved.

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Abstract. H-modes have been obtained for the first time in high temperature, high poloidal beta plasmas with significant tritium concentrations in TFTR. Tritium is provided mainly through high power neutral beam injection (NBI) with powers up to 28 MW and beam energies of 90-110 keV. Transition to a circular limiter H-mode has been obtained following a rapid ramp down of the plasma current. Some of the highest values of τ_E have been achieved on TFTR during the ELM-free phase of these DT H-mode plasmas. τ_E enhancements greater than four times L-mode have been achieved.

1. Introduction

DT fueled limiter H-mode plasmas with high tritium concentrations have been obtained in TFTR. These plasmas are important because the effects of tritium on the transition, the H-mode confinement, and ELM behavior may be of interest to ITER. The H-mode data to date in TFTR operation have been obtained in high poloidal beta plasmas in which I_p is rapidly decreased (I_p ramp down) to improve global MHD stability [1]. Ramps from 1.65 to 0.85 MA and from 2.5 to 1.5 MA have been used in DT and DD comparison discharges. Beam powers from 9 to ~ 28 MW with voltages of 90-110 kV have been used. The tritium input to the plasma is predominantly through the heating beams, and the beam species mix can be varied from all D^o to all T^o sources. Most of the H-modes have been obtained with a very well conditioned graphite inner bumper limiter. Discharge cleaning is used to reduce deuterium recycling, followed by lithium pellet conditioning which reduces carbon influx [2].

2. Experimental Results

The greatest energy confinement enhancement following an H-mode transition on TFTR [3] (whether DD or DT fueled) has been obtained in a DT fueled discharge. Waveforms for this plasma are shown in Fig. 1. Shown for comparison are parameters for an equivalent DD plasma (i.e., with similar beam power, power deposition, I_p ramp, and NBI heating scenarios). Figure 1(a) shows I_p ramping down from 1.85 to 1.2 MA. NBI heating of 13 MW starts at 2.4 sec, increasing to 23 MW at 2.7 sec, just after I_p reaches 1.2 MA. The initial heating of ~ 13 MW of co-only NBI is applied, from 2.4 to 2.7 sec, in both cases before full heating power is applied. The H-mode transition for both is indicated by a small, but rapid, drop in D_α light as shown in Fig. 1(c). In the DD plasma, the D_α signal remains relatively constant following the initial perturbation at t = 2.94 sec until the beginning of the ELMs. However, for the DT plasma, the initial change in D_α occurs at ~ 2.86 sec, and the rate of decrease accelerates between 2.9 to 2.96 secs. The quiescent phase following the transition onset is, in general, longer in DT than in DD; 130 ms vs 100 ms in the cases shown. The ELM frequency is lower in the DT case or, ~ 40 Hz compared to 100 Hz for DD. However, for this pair of discharges, the ELM amplitude is greatest for the DT plasma

A dramatic increase in τ_E for the DT plasma is evident in Fig. 1(b), this is in contrast to the small change in τ_E for the DD comparison plasma (the change is not always as small for DD). τ_E increased from 160 ms before the transition to ~ 232 ms just before the onset of ELMs. This is a gain of 72 ms or an increase in τ_E of 45%, due mostly to the dE/dt term. At the peak in τ_E, the enhancement is greater than four times ITER89-P scaling [4]. At peak τ_E, $\beta_{N\text{-}dia}$ is relatively high at 2.7. This plasma was obtained using nearly balanced NBI with 12.6 MW co + 10.4 MW ctr power. During the main heating phase nearly 13.7 MW of power (60% of total) was provided by T° beams. The DT neutron rate reached a peak value of ~ 1.6×10^{18} neutrons/sec during the H-mode phase, equivalent to 4.2 MW of fusion power. High enhancement factors, ≥ 4, and a fusion power of 5.6 MW have also been obtained in plasmas with an I_p ramp down from 2.5 to a 1.5 MA plateau.

In general in TFTR, the characteristics of the DT H-mode are essentially the same as found in DD H-modes [5-7] and are similar to those obtained through L- to H-mode transitions on other tokamaks. An initial observation is that the main difference in DD and DT H-modes on TFTR appears to be that the gain in τ_E can be somewhat higher in DT, and the ELM frequency and amplitude are slightly different. As found during earlier DD operation, changes in edge T_e, T_i, V_φ, and n_e are observed; the change in D_α can be very subtle and slow at the H-mode transition in TFTR. Usually at the transition, changes in magnetic fluctuations and poloidal rotation, indicated by a shift in the microwave scattering spectra toward the electron diamagnetic drift direction, are also observed.

Figures 1(d) and 1(e) show the time variation of the edge T_i and T_e for the two plasmas. Just before the transition, the T_i and T_e profiles for the DD and DT cases are essentially the same for R > 275 cm. At ~ 5 cm just inside the plasma edge (R_{edge} ~ 325 cm), T_e ~ 610 eV and T_i ~ 3000 eV in both cases. The center T_i and T_e were higher for the DD plasma before the transition. In the quiescent H-mode phase at the time of τ_{Emax}, T_i is significantly greater for DT than DD across the entire profile, with a difference of 7 keV at the center and 700 eV at the edge. The difference in T_e is much smaller, ~ 130 eV for the edge plasma. The edge T_e and T_i values at the H-mode transition for a variety of discharges were found to be the same as those of Fig.1. The large gain in τ_E in the DT case is due to the large increase in T_i. For DT, the central T_i increased by ~ 14 keV while for DD, the increase was ~ 5.5 keV. Corresponding to the increase in τ_E, the high frequency magnetic fluctuations in the range 250-350 kHz decreased during the quiescent phase of the H-mode, with the decrease for DT being somewhat greater than for DD. TRANSP analysis of the experimental data for the DT case shows that the ion conductivity is reduced significantly during the ELM-free H-mode phase compared to the pre-transition value. This is shown in Fig. 2, which is a plot of χ_{itot} vs r/a for a time just before the H-mode transition and the time during the H-mode at which τ_E is a maximum. χ_{itot} includes both convective and conductive fluxes. At r/a = 0.7, the decrease is by a factor of 3. The change in χ_{etot} was much more modest. The changes in χ_{etot} and χ_{itot} between two similar times for the DD H-mode were also rather modest. Based on the comparison of experimental data for the DD and DT plasmas of Fig. 1 and the TRANSP analysis results of Fig. 2, there is an apparent species effect on the H-mode confinement and on ELM behavior. Further quantitative evidence is shown in Fig. 3 which is a plot of τ_{E_max} vs I_p/P_b for DD and DT H-mode plasmas obtained during the DT run. From the figure it is clear that τ_E is consistently higher for DT H-modes. (Similarly, the gain in τ_E during the quiescent H-mode phase vs I_p/P_b shows the values for DT plasmas to be higher.) This would indicate that there is a larger gain in τ_E with the transition to the H-mode for DT plasmas than for DD. To date, the gain in τ_E is relatively transient and is usually

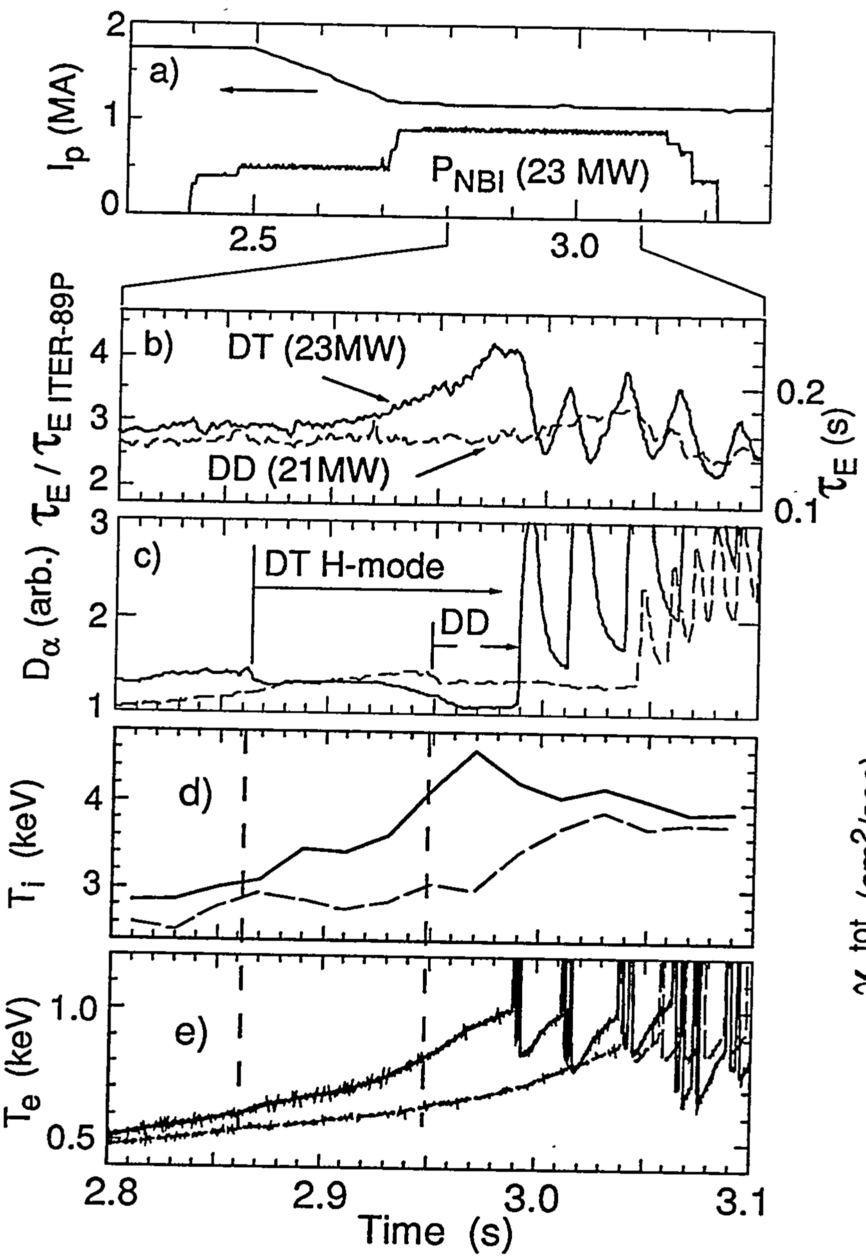

Fig. 1 Time variation of parameters for comparable DD and DT H-modes. Shown are I_p, P_b, τ_E, D_α, T_i(edge), and T_e(edge).

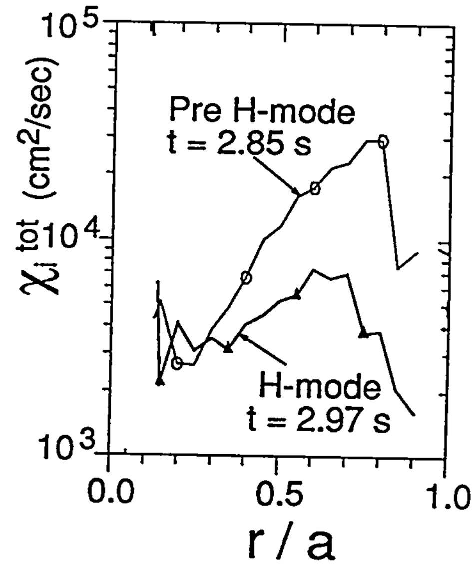

Fig. 2 Total diffusivity, χ_{itot} from TRANSP, as a function of r/a for the DT plasma of Fig.1; at times before and during H-mode.

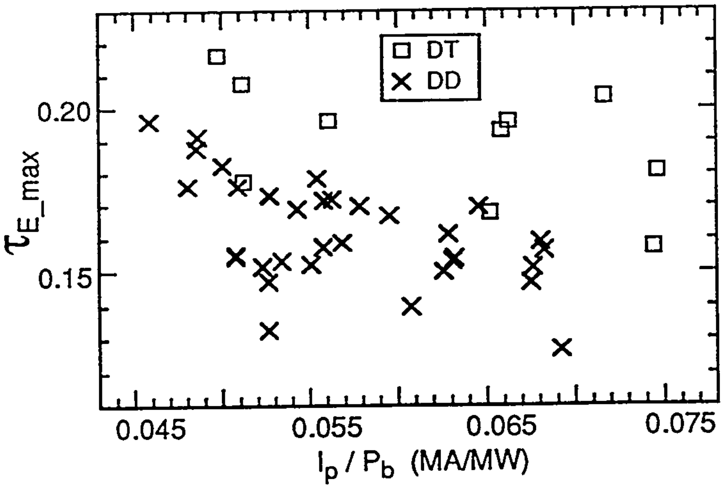

Fig. 3 Variation of the value of τ_E just before ELMs with the ratio I_p/P_b for both DD and DT plasmas studied since the beginning of DT operation.

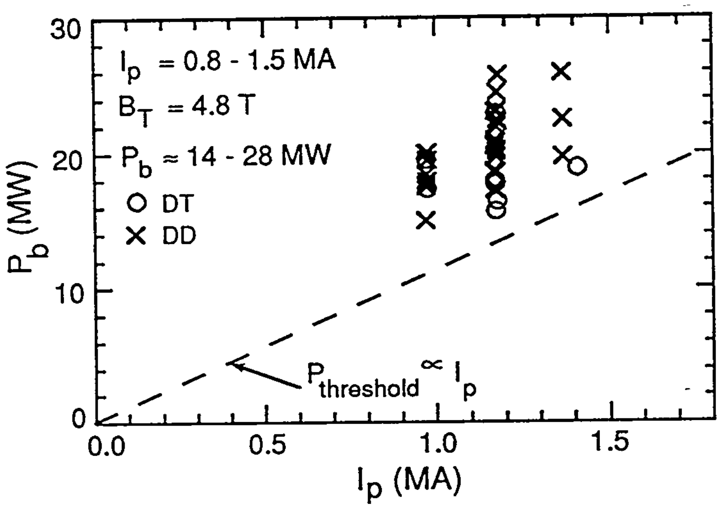

Fig. 4 Comparison of recent DD and DT data to the threshold power scaling from earlier TFTR DD operation.

terminated by the onset of ELMs. Larger gains might be possible if the ELM-free period could be extended.

In general, for operational purposes, the threshold power scaling for H-mode transitions in DD was found to scale linearly with plasma current, such that $P_{th}(MW) \sim 1.1 \times I_p(MA)$ [3]. A plot of P_b vs I_p for DD and DT H-mode plasmas obtained during the present run is shown in Fig. 4. Qualitatively, the I_p dependence of P_{th} for DT appears to be similar to that for DD, with higher power required for plasmas with I_p ramps of 2.5 down to 1.5 MA compared to ramps from 1.85 down to 1.2 MA. The scaling found earlier for DD operation is indicated in the plot. The data is insufficient to determine whether the threshold is lower for DT than for DD; since beginning DT operation, the NBI power has been well above the threshold. Experiments aimed at determining the threshold scaling for DT and for taking advantage of the apparent favorable isotope effects on H-mode confinement and behavior (Figs. 1 - 3) are planned for future TFTR operation.

Acknowledgments

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