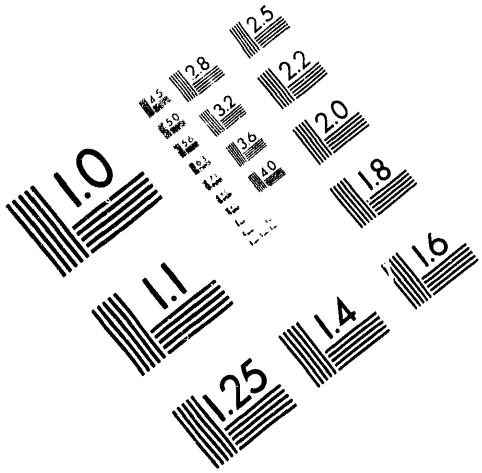

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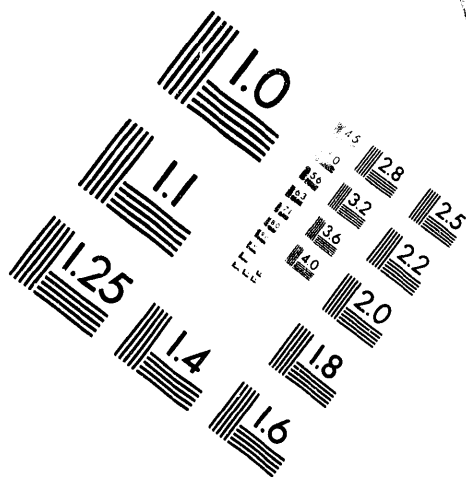

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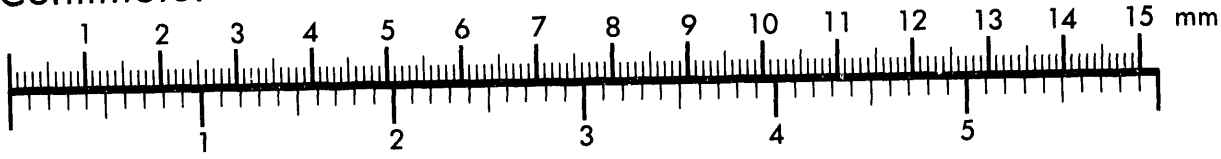

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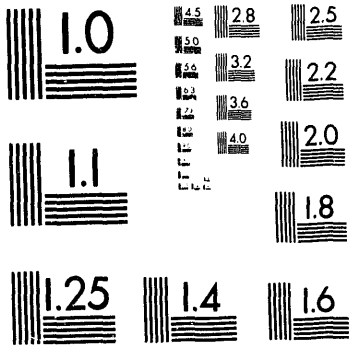

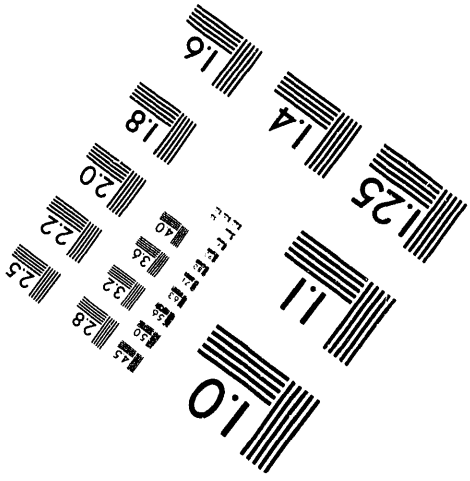

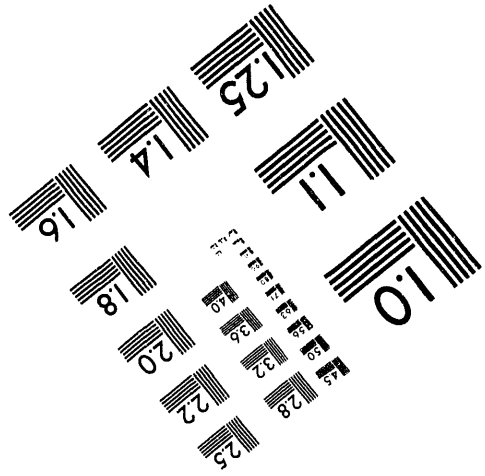

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DT Simulation of ICRF Heated Supershots in TFTR Using TRANSP*

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ABSTRACT

The principal goal of ion cyclotron range of frequency (ICRF) heating on the Tokamak Fusion Test Reactor (TFTR) is to enhance plasma performance during the deuterium-tritium (DT) physics phase of operations. Strongly centralized ICRF heating may play a critical role in obtaining high Q_{DT} and high β_α operation in TFTR, as well as in future fusion reactors. ICRF heating of a dilute minority species leads to the formation of an energetic ion population that, in turn, provides strong central electron heating. The corresponding rise in the central electron temperature translates into an increase in the slowing-down time of either neutral beam or alpha particles in the discharge. Preliminary DT simulations of the experimental results in deuterium-deuterium (DD) plasmas performed with the TRANSP code are presented in this paper.

INTRODUCTION

The main emphasis of the ICRF program on the TFTR is to enhance parameters in future DT experiments[1]. Strong central ICRF heating of supershots may play an important part in obtaining high Q and high β_α during the DT program in TFTR, as well as in future fusion devices, for the following reasons:

(1) The strong central heating that occurs with ICRF heating of supershot plasmas increases the central electron temperature. This causes an increase in the neutral beam and alpha slowing-down times and, hence, the density and beta of the alphas in the discharge.
(2) As neutral beam injection (NBI) power and the stored energy in the plasma increase, the plasma current must be increased to avoid MHD instability. At the highest currents, sawteeth appear. They may be able to be suppressed with the application of ICRF heating.

To investigate these issues, the TRANSP 1-1/2D time-dependent transport code[2,3] has been used to simulate the time evolution of ICRF and NBI heated supershot like plasmas in TFTR.

DT SIMULATIONS

The future DT experiments planned for TFTR are simulated with TRANSP using existing DD supershot data. In this simulation an equal mix of deuterium and tritium is substituted in the target deuterium plasma, as well as in the D^0 neutral beams, while the other measured beam and plasma parameters are unchanged. Thus, this conservative simulation neglects the effect that alpha heating enhances the plasma parameters or that confinement will increase with tritium. Also, TRANSP is not equipped at this time to predict second harmonic heating of the tritium ions; the heating of these ions would produce a hot tail in the distribution

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enhancing the fusion rate. In this paper we discuss the analysis of a pair of NBI supershot like plasmas that differ by the presence or absence of ICRF He^3 minority heating . DT equivalent simulations, as just described , are performed for each shot. The pair of shots, 66785/66680, differed primarily in that 66785 had 22-MW NBI with no ICRF and 66680 had 18-MW NBI with 4.5 MW of ICRF (Fig. 1).

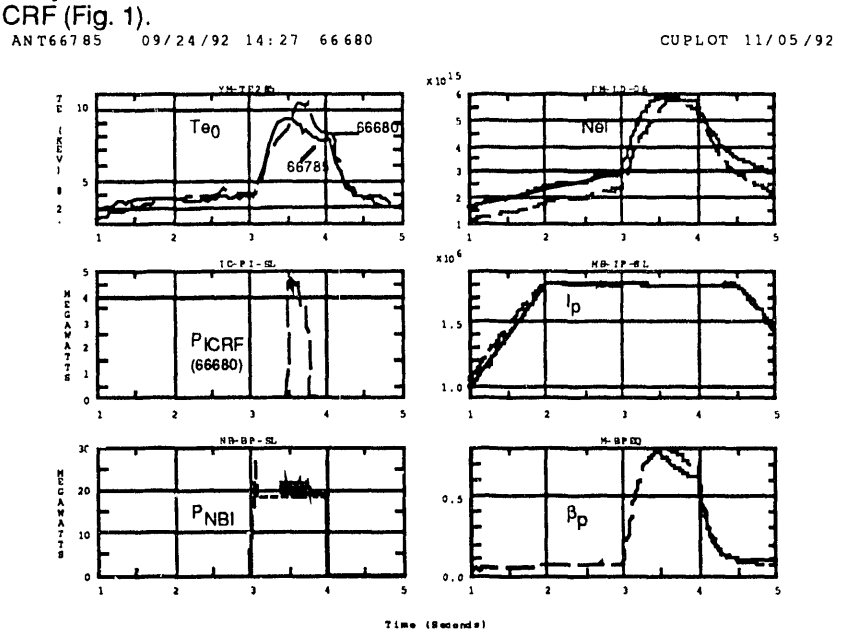

Fig. 1 Waveforms for TFTR shot 66785 (22 MW NBI) overlaid with 66680 (18-MW NBI + 4.5-MW ICRF). The DT equivalents of these two shots are discussed below.

Figure 2 shows heating from various sources in the DT equivalent shot, 66680. The heating rate by the 3.5-MeV alphas, as modeled by TRANSP, is ~5 x 10^5 W; thus the predicted Q_{DT} = (total fusion power)/(P_{NBI} + P_{ICRF}) = 0.12 for this shot.

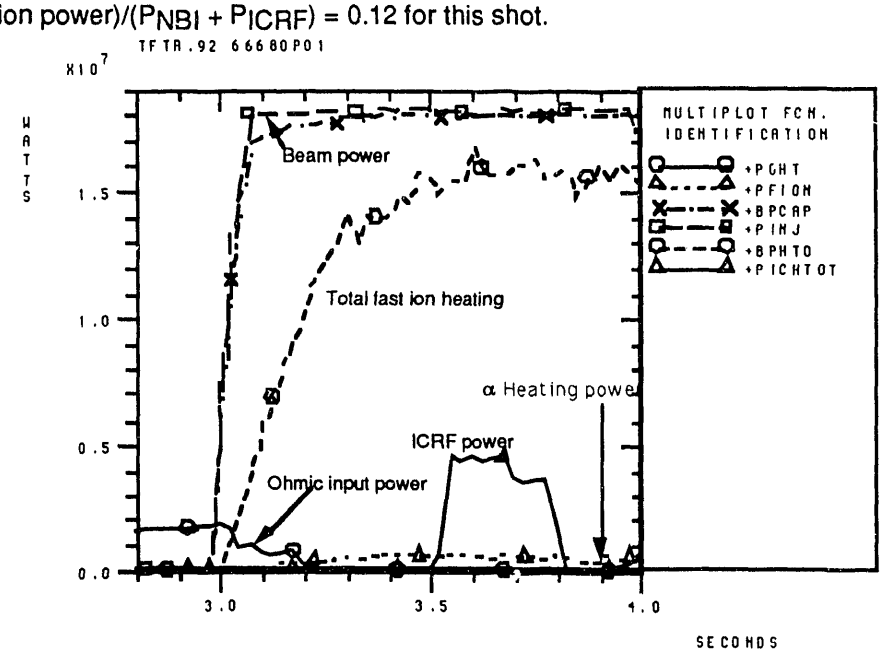

Fig. 2 Various heating terms in the DT equivalent shot, 66680p01 (NBI + ICRF).

The volume integrated heating powers are shown in Fig. 3. The beam fast ions heat mainly thermal ions, whereas the 3.5-MeV alpha particles mainly heat electrons, because the alpha energy is >> E_{crit}~14.8T. This alpha heating is overshadowed by the NBI during the NBI phase.

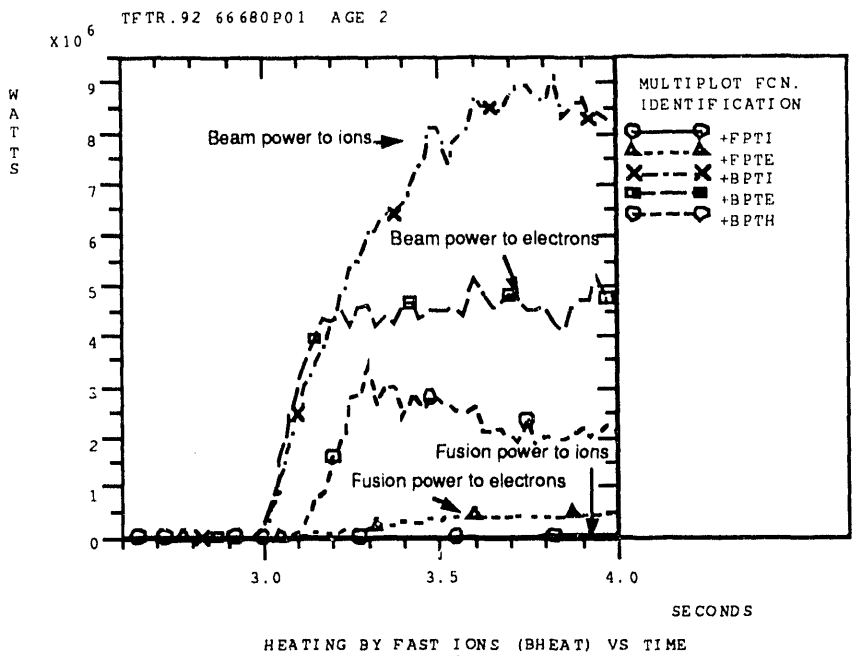

Fig. 3 66680p01(NBI + ICRF) Volume Integrated heating powers.

Figure 4 shows the alpha slowing-down time, volume averaged from r = 0 to r/a = 0.25. A rise of ~7% is seen in the ICRF shot, 66680, mainly due to the rise in the central electron temperature. This increase in the slowing-down time will lead to an increase in the density and β of the alpha particles, as seen in Fig. 5.

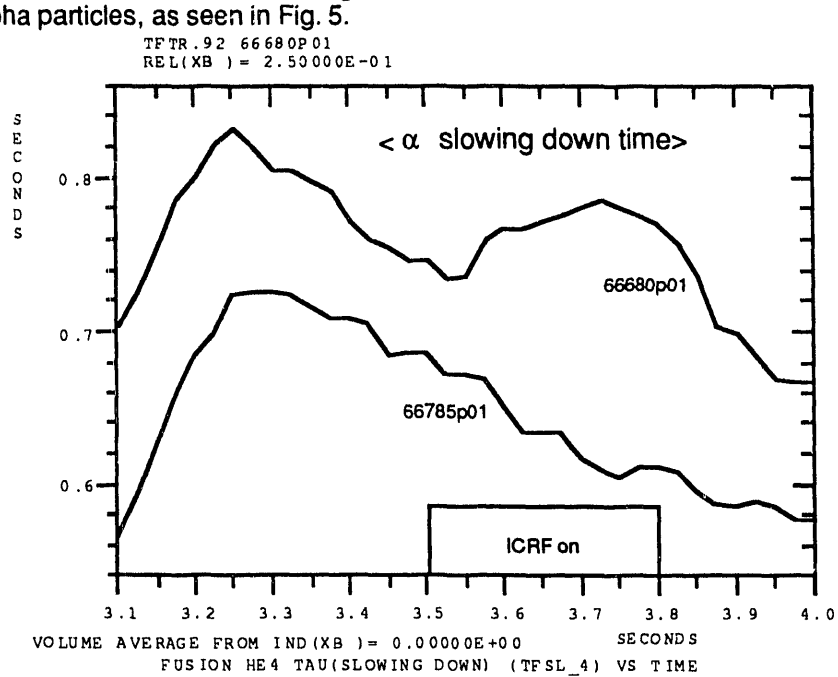

Fig. 4 Volume average, from r = 0 to r/a = 0.25, of the alpha slowing-down time; note that it increases significantly in 66680p01 as T_e increases with the onset of ICRF (see Fig. 1).

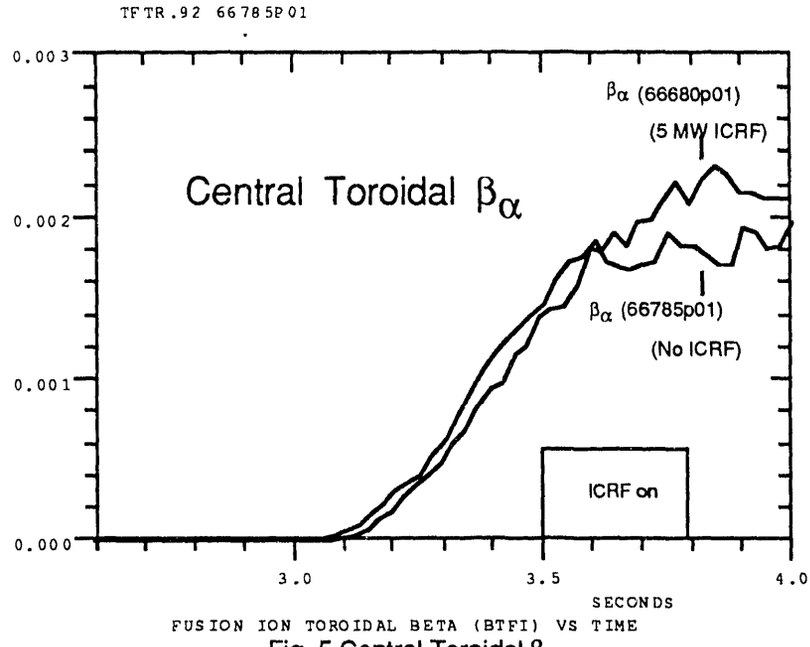

Fig. 5 Central Toroidal β_α

SUMMARY

Strong central electron heating is observed with ICRF in TFTR supershot 66680 [Te(0) increases ~2 KeV over the non-ICRF companion shot]. The higher Te is predicted to lead to higher β_α during DT operation in TFTR, due to the increase in the alpha slowing-down time. Because the alphas are born at energies far above the critical energy, the alphas will slow down primarily on the electrons. This increase in the slowing-down time will be approximately in the ratio of $Te^{3/2}/Ne$ (Spitzer slowing-down time).

DT equivalent simulations were performed with the TRANSP code for these discharges in which half the deuterium was replaced with tritium in the neutral beams and target plasmas. In the 66680 DT simulation, Q_{DT} is 0.12, and the central β_α increases over the non-RF companion by ~35% to β_α = 0.23% . The higher electron temperature due to the ICRF heating causes the alpha slowing down time to increase from 0.73 sec to 0.78 sec.

These DT simulations are conservative: alpha heating effects and isotopic improvement in confinement are neglected. Also, TRANSP is not equipped to handle second harmonic tritium heating yet. Heating of the tritium fast beam ions would also enhance the fusion rate. Therefore, actual DT plasma performance in TFTR for the same parameters might be better than indicated here.

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