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# Edge Minority Heating Experiment in Alcator C-Mod

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**Abstract.** An attempt was made to control global plasma confinement in the Alcator C-Mod tokamak by applying ICRH heating power to the plasma edge in order to deliberately create a minority ion tail loss. In theory, an edge fast ion loss could modify the edge electric field and so stabilize the edge turbulence, which might then reduce the H-mode power threshold or improve the H-mode barrier. However, the experimental result was that edge minority heating resulted in no improvement in the edge plasma parameters or global stored energy, at least at power levels of $P_{RF} \leq 5.5$ MW. Some analysis of these results is presented and some ideas for improvement are discussed.

**Keywords:** ICRH, H-mode, Alcator C-Mod, minority heating
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The present experiment was motivated by suggestions of Chang [1] and Perkins [2] that the plasma edge $E_r$ could be changed if a relatively small population of ICRH minority tail ions was created at the plasma edge and deliberately lost to the wall. For example, the radial ion loss current corresponding to 1 MW of tail ion loss at $T_{tail}$≈10 keV would be ≈ 100 A, i.e. comparable to the radial current needed to create H-modes in the biased limiter experiments [3]. If the edge electric field could be controlled in this way, it might be possible to reduce the H-mode power threshold or improve the H-mode barrier in future magnetic fusion devices.

This paper describes an attempt to use minority edge heating to control the edge electric field and H-mode transition in the Alcator C-Mod tokamak at MIT. Only the basic experimental results and conclusions are presented here; further details concerning the results, modeling, and references are elsewhere [4].

All the plasmas used in for these experiments had a major radius of R=0.67 m, a minor radius a=0.23 m, a plasma current of I=0.6 MA (except three at 0.4 MA), and central electron temperatures and densities typically $T_e(0) \approx 1$ keV and $n_e(0) \approx 1\text{x}10^{14}$

cm$^{-3}$. The initial ICRH edge heating experiments were done at 78 MHz with $P_{RF} \leq 2.3$ MW, and in a second set the ICRH power was increased up to $P_{RF} \leq 5.5$ MW by the addition of ICRH power at 80.0 and 80.5 MHz. All the plasmas were made with a deuterium majority (except one shot with a helium majority), and all had a ≈ 5% hydrogen minority concentration as measured by the $H_\alpha/D_\alpha$ line ratio.

The hydrogen minority resonance position was varied from the inner edge to the outer edge on a shot-to-shot basis by varying the toroidal magnetic field. At the lowest field of B=3.68 Tesla the ICRH resonance was at $R_H$ = 47.4 cm, i.e. 2 cm inboard of the inner separatrix at the midplane and 3.5 cm from the inner wall. At the highest field of B=6.75 Tesla the ICRH resonance was at $R_H$= 85.8 cm, i.e. 3.5 cm outboard of the outer separatrix and 4.5 cm from the outer ICRH antenna-protection limiter at the midplane. For both cases the resonant surfaces extended into the scrape-off layer above and below the midplane due to the curvature of the flux surfaces, and in the high field case the resonance intersected the RF antenna.

Figures 1(a) and (b) show the dependence of the total stored plasma energy on the resonance location and ICRH power for the magnetic field scan with 78 MHz only. For neither the inner nor the outer edge ICRH heating was there any significant increase in stored energy compared to the Ohmic plasma at these fields. In contrast, for the central heating cases at B=5-6 T the plasma stored energy increased by almost a factor of two with 1 MW of heating, corresponding to an H-mode transition (circled points). Fig. 1(c) shows that there was also no increase in the stored energy for inner edge heating cases when ICRH power level was increased to $P_{RF} \leq 5.5$ MW with combined 78 MHz, 80 MHz, and 80.5.

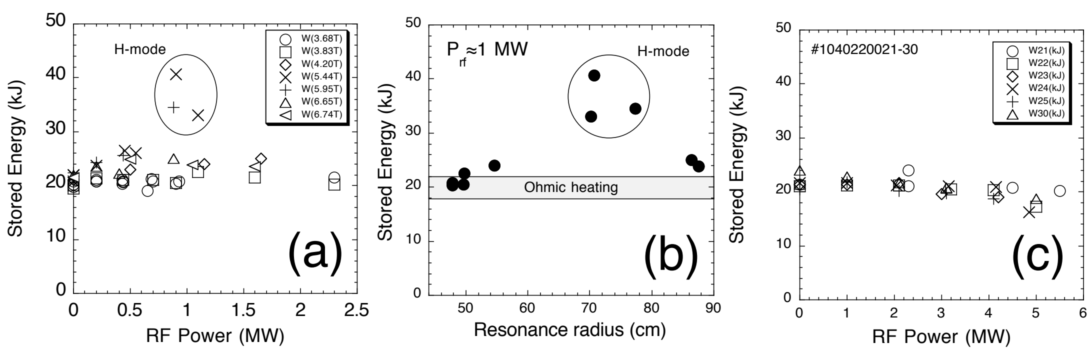


Fig. 1: The effect ICRH minority heating on the total plasma stored energy. The circled points are for central heating which created an H-mode, the others points are for inner or outer edge heating. Part (c) is a power scan for inner edge heating only.

Figure 2 shows the dependence of the edge plasma density and temperature on the ICRH resonance location during the scan of Figs. 1(a,b) based on the edge Thomson scattering data averaged over a 2 cm wide region just inside the separatrix. For neither the inner nor the outer edge heating there was there any significant increase in edge parameters compared to the Ohmic plasma just before the ICRH was applied (although there were slight increases for the outer edge heating case). In contrast, with central heating at B=5-6 T the plasma edge parameters increased as expected for an H-mode in C-Mod (circled points).

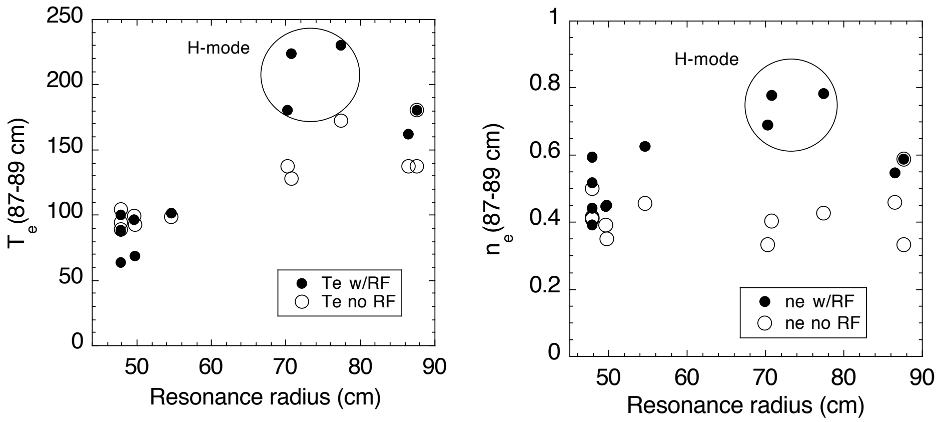


Fig. 2: The effect of ICRH minority heating on the edge electron temperature and density. The circled points are for central heating in which an H-mode was produced. The other points are for inner or outer edge heating (units are eV and $10^{14}$ $cm^{-3}$).

Several variations on this scenario were tried to improve these null results. The ICRH antenna phasing was varied from the co-current to the counter-current direction (instead of balanced as for Figs. 1 and 2), the plasma current was reduced from 0.6 MA to 0.4 MA, and a He majority plasma was tried instead of D majority (to vary the edge conditions). However, in all cases the stored energy slowly decreased with increasing ICRH power. Thus the experimental results were quite clear; namely, that edge heating caused no increase in the plasma confinement. The only effect of this edge heating was to slightly reduce the total stored energy, most likely due to recycling and/or impurity influx from the increased plasma-wall interaction.

Some modeling of this experiment was attempted using the TORIC ICRH code in TRANSP, with typical results shown in Fig. 3. For conditions of this experiment the code predicted that there would be a significant minority tail ion loss generated when the minority resonance was located at the inner (or outer) edge. In this 1.4 MW inner edge heating case the tail ion loss power was ≈350 kW at a peak tail ion temperature of ≈ 5 keV, corresponding to a calculated loss ion current of ≈ 60 Amps.

However, several potentially important effects were not modeled in this code, e.g. "parasitic" absorption of ICRF waves in the edge plasma, charge exchange of tail ions, and radial diffusion of tail ions in the edge. In particular, analytical estimates of the single-pass absorption of the ICRH in the edge showed that only a few percent of the ICRH power would be absorbed per pass since the edge ion temperature was so low. Thus any parasitic absorption at this level could significantly reduce the net power for creating a minority tail in the edge.

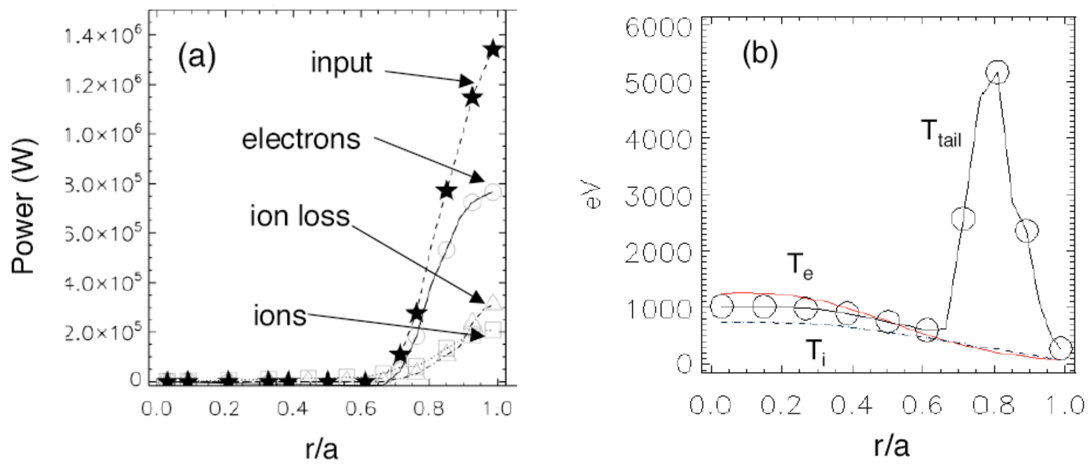


Fig. 3: Simulation of an inner edge minority heating case with the TORIC/TRANSP code. The code predicts an ion loss current of ≈ 60 Amps for this 1.4 MW case.

Unfortunately, it is not possible at this stage to make a quantitative comparison of the (null) experimental results with the theoretical modeling, since the modeling had such large uncertainties, and since there was no direct measurement of the ion loss or radial electric field in this experiment. It is quite possible that the tail ion loss was less than expected, and so the resulting change in $E_r$ was just not large enough to affect the plasma confinement.

The outcome of this experiment might be improved by reducing the edge density further to increase the tail ion energy, by increasing the edge ion temperature to improve the first-pass absorption of ICRH waves, or by reducing the SOL thickness to increase the fast ion orbit loss. The conditions would more easily occur in a device like JET, in which high edge ion temperatures have already been measured even without edge ion heating.

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