Subject: Improved Detached Divertor H-Modes  MP No. 250
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1. Purpose of Experiments
Include immediate goal of the experiments, scientific importance and/or programatic relevance. Refer to any relevant program milestones or ITER R&D commitments.

A tokamak fusion reactor will likely operate a scenario that combines the detached divertor condition with H-mode confinement and a clean core plasma. In this Mini-Proposal the detached divertor, high \( q_\parallel \) H-mode operational regime already achieved in Alcator C-Mod [1,2] will be investigated further and hopefully improved. The goals of this Mini-Proposal will be:

(1) to optimize the H-factor in the detached divertor regime,
(2) to improve the feedback scenario used to achieve a dissipative divertor,
(3) to demonstrate the ability of the divertor to handle 7MW of input power,
(4) to investigate the physics of detachment.

2. Background
Discuss Physics basis of the proposed research, Prior results at Alcator or elsewhere, and any related work being carried out separately.

A detached divertor, high \( q_\parallel \) H-mode has been achieved in Alcator C-Mod (Mini-Proposal #163 - Run 980213)[2]. This mode of operation combined a clean core plasma, \( Z_{eff} \sim 1.4 \), and good core confinement, \( H_{ITER89P} \sim 1.6 \), with large power flows, \( q_\parallel \sim 0.5 GW m^{-2} \), and a detached divertor, \( P_{plate} \sim 0.05 \times P_{SOL} \). This achieved \( Z_{eff} \) is acceptable for maintaining a burning plasma. However, the energy enhancement factor achieved needs to be improved to meet the requirements for a burning plasma. In Alcator C-Mod there is a linear relation between the edge temperature and global confinement[3]. If the edge temperature is enhanced by better wall-conditioning, better tailoring of the impurity puff, using different impurities, or improving the screening of impurities from the core plasma, a better H-factor should result. However, in any scenario, the power flowing to the divertor must be kept at an acceptable level.
A number of the essential features of the detachment process have been explored in these discharges. Volume recombination in the divertor, although measurable, is not significant in these dissipative H-mode plasmas. This indicates that the loss in ion current to the plates is a result of other processes, most likely the reduction of the ion source. There is a significant difference in the ion and neutral flow velocities measured in the divertor under detached conditions. The friction from ion-neutral collisions arising from this parallel flow differential is consistent with the observed electron pressure loss along field lines. Neutral power losses in the divertor have been measured. It is seen that \( \sim 10\% \) of the total divertor radiated power losses are due to the charge-exchange process. Screening, compression, and enrichment of argon are reduced a factor of about two after divertor detachment.

3. Approach
Describe the methodology to be employed; explain the rationale for the choice of parameters, etc. Describe the analysis techniques to be employed in interpreting the data, if applicable. If the approach is standard or otherwise self-evident, this section may be absorbed into the Experimental Plan.

The approach for these studies is to create a high \( q_{\parallel} \), lower single null diverted H-mode plasma. To detach the divertor plasma from the plates, an impurity gas, \( e.g. N_2 \), will be puffed into the divertor region through a piezoelectric valve located in a lower vertical port. First, attempts will be made to optimize the H-factor under the same conditions as on 980213. This will be done by changing the requested level of edge radiation and thus varying the degree of detachment. Second, the input power will be increased in some number of steps to the maximum available and attempts will be made to detach the divertor. The effects on the core plasma, \( e.g. Z_{eff} \) and H-factor, will be monitored and compared for all these operational scenarios.

4. Resources

4.1 Machine and Plasma Parameters
Give values or range for:

Toroidal Field: 5.5 T (with \( B_T \) wiggles if desired by ECE)

Plasma Current: 1.0 MA

Working gas species: \( D_2 \)

Density: \( \bar{n}_e = 2.5 \times 10^{20} m^{-3} \) \((nl04 = 1.5 \times 10^{20} m^{-2}) \) before H-mode

Equilibrium configuration (if possible, refer to database equilibria): Lower SN diverted equilibria with acceptable gaps for both the RF and EDGE groups, \( e.g. \), shot 980213015

Pulse length, typical current & density waveforms, etc. Refer to database or sketch desired waveforms: see shot 980213015
4.2 Auxiliary Systems

**RF Power, pulse length, phasing**: maximum available (for high SOL power) from 0.5 to 1.0 sec, at least $6 - 7 MW$ for half of the run day

**Pellet Injection (species)**: None

**Impurity blow-off injection**: where appropriate for impurity transport studies

**Special gas puffing**: Nitrogen puffing, divertor capillary puffing

**Other**: Boronized walls

4.3 Diagnostics

List required diagnostics, and any special setup or configuration, e.g. non-standard digitization rate.

All core temperature and density diagnostics; Divertor probe array; Bolometer arrays; Fast scanning probe; Visible bremsstrahlung; OMA spectrometer viewing divertor, setup for flow measurements; Chromex; Molybdenum monitor; McPherson spectrometer looking at nitrogen; All reticon arrays with $H\alpha$ filters; Ratiomatic pressure gauges; Divertor pressure gauges

4.4 Neutron Budget

Estimate the neutron dose rate at the site boundary. Give basis for estimate. (Once some experience has been gained a standard formula will be provided for estimating dose rates.)

$$R_{DD} = 1 \times 10^{14} \text{sec}^{-1} \text{ for 0.5 sec per shot}$$

5. Experimental Plan

5.1 Run sequence plan

Specify total number of runs required, and any special requirements, such as consecutive days, no Monday runs, extended run period (10 hours maximum), etc.

Two runs will be required if all systems are working well, including RF capabilities of $6 - 7 MW$. The algorithm for impurity puffing feedback with the AXUV diodes as the control parameter should be checked out during piggyback conditions before this run proceeds. The piezoelectric valve located in J-port (vertical bottom) should be operational.

5.2 Shot sequence plan

For each run day, give detailed specification for proposed shot sequence: number of shots at each condition, specific parameters and auxiliary systems requirements, etc. Include contingency plans, if appropriate.

(1) Obtain an H-mode plasma acceptable to both the EDGE and RF groups, starting from shot 980213015 (5 shots). This plasma should have gaps $\approx 2$cm and SSEP $> 1.6$cm. The amount of injected RF power should $\sim 2.7 MW$. 

(2) Improve the H-factor in dissipative divertor H-modes. Set the radiation level with feedback and determine if operating near the detachment threshold is beneficial to maintaining a high H-factor while keeping the power loading of the divertor at an acceptable level (10 shots).

(3) Deepen detachment and try to find recombination. Set the radiation level with feedback to deepen the detachment, that is make the pressure deficit very large, and use the Chronex and McPherson to look for signatures of recombination (10 shots).

(4) Obtain a dissipative divertor with maximum power available from the RF heating system. Step up the RF power from the beginning level of $\sim 2.7\, MW$ to $\sim 5\, MW$ and then $\sim 7\, MW$ and create a dissipative divertor such that the divertor power load is acceptable (15 shots).

For all of the above points, it would be desirable to make flow measurements in the divertor, radiated power measurements, and high resolution edge temperature measurements.

6. Anticipated Results

Discuss possible experimental outcomes and implications. Indicate if the program may be expected to lead to publications, milestone completions, improved operating techniques, etc. Indicate if the experiments are intended to contribute to a joint research effort, or an external database.

The results of this Mini-Proposal will help develop a high $q_\parallel$ H-mode plasma in which the power flowing to the divertor plates is minimized to acceptable levels and the performance (H-factor, central $Z_{eff}$, etc.) is maintained. The results from this run should contribute to understanding the physics of detachment and power handling.

7. References

Include references both to external and internal literature or communications which bear on this proposal. See Section 2.

