Alcator C-MOD

Mini-Proposal

Subject: Scrape-off Layer Transport Studies


Date: 15-JAN-1999

Approved by: ____________________________ Date Approved: ________________

1. Purpose of Experiments

Include immediate goal of the experiments, scientific importance and/or programmatic relevance.

Refer to any relevant program milestones or ITER R&D commitments.

The purpose of these experiments is to continue and extend the systematic mapping of density/temperature profiles and energy/particle fluxes in the scrape-off layer and divertor over the wide range of operation conditions and confinement regimes available to C-Mod including: ohmic and ICRF heated L-mode, ELM-free H-mode, and EDA H-mode regimes. The ultimate goal of this activity is to develop and refine empirical and physics-based models of heat and particle transport processes in the tokamak boundary plasma.

2. Background

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

The motivation for this work is two-fold: (1) Basic Science - The physics of anomalous transport processes in the boundary layers of high temperature magnetically confined plasmas is an interesting problem that remains to be fully explained. (2) Research and Development - Accurate, physics-based models of cross-field transport in both the scrape-off layer and divertor plasma regions are needed in order to extrapolate the performance of the divertor to full-scale fusion reactor conditions and to optimize plasma conditions in present research facilities.

Divertor and SOL transport studies in C-Mod typically rely on data simultaneously recorded by probes in the divertor and by fast-scanning probe systems outside the divertor region. With these data, interpretive analysis tools such as the EDGEOFIT code [1] can be used to infer effective cross-field diffusivity profiles in the SOL on many discharges. In this way, scaling relationships between discharge parameters and the magnitude of local heat transport can be examined.
Significant progress has been made in characterizing the scrape-off layer conditions in Alcator C-Mod [2] and elsewhere (e.g. [3]). Empirical scaling relationships have been investigated using the database of C-Mod ohmic L-mode data [1,2]. The ohmic L-mode database for C-Mod is fairly extensive covering a factor of 2.5 variation in magnetic field and a factor of 5 variation in core plasma density. These data have been used to test various physics-based models of anomalous plasma transport [4]. On the other hand, most of the operational space available on Alcator C-Mod remains to be explored.

Although the edge database presently has over 500 “good” ohmic L-mode slices, there are less than 100 corresponding H-mode slices. The H-mode data set is even more sparse than it first appears considering that H-mode comes in a number of varieties (ELM-free, ELMy, EDA,..) which should be treated as separate discharge types. In addition, with the recently installed “divertor flapper” system, C-Mod has the unique opportunity to sort out the effect of divertor neutral bypass on scrape-off layer plasma profiles and anomalous transport in the various confinement regimes.

The current deficiency in the edge scrape-off layer transport database is due to a number of factors: (1) In the past, ohmic discharges were more frequent and we focused on them initially, (2) data recorded from the F-bottom scanning probe has continued (despite some recent progress) to be corrupted during ICRF heating by RF sheath rectification effects and/or noise, and (3) one must be very careful in poking a Langmuir probe into a high power-density H-mode discharge!

Some recent developments should help this situation: (1) The A-port horizontal probe system has been refurbished with a high-power handling Mach probe head for SOL profile measurements. The vacuum interlock on this system will allow damaged probe heads to be replaced. Also, based on the work of Jim Reardon [5], this location should be less susceptible to RF effects during operation of the D and E antennas. (2) The helium gas-puff diagnostic (C.S. Pitcher) will be available to record SOL density and temperature profiles at the midplane. (3) Improvements to the A-port reflectometry system are being made (Y. Lin, J. Irby). (4) A prototype tangential two-color interferometer (J. Irby) is being installed to record plasma densities near the separatrix. (5) The technique of programming a B-toroidal ramp to spatially scan the ECE has proven quite useful to map out the edge electron temperature profile across the separatrix.

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 near-term focus of scrape-off layer transport experiments are on low-power ICRF-heated H-Modes and comparison of ohmic L-mode transport with the divertor bypass open and closed. The longer term objectives are to obtain data at varied magnetic fields (3.5, 8 tesla) and for ICRF powers greater than 2 MW. A complete set of well diagnosed discharges would fill in the following matrix of control parameters:

Plasma current: Ip = 0.8, 1.0, 1.2 MA
Magnetic field: $B_t = 3.5$ (60 MHz ICRF), 5.3 (forward/reversed), 8.0 T
ICRF Power: 1.0, 2.0, 3.0 MW
Plasma density: scan full density range
Divertor bypass flapper: open/closed

In principle, a lot of this could be done in a piggy-back mode. But, in order to do this, the session leader must accommodate the vertical and horizontal scanning probe diagnostics by allowing tweaks to the LCFS target and, most importantly, allowing for some repeated shots. The latter request is often ignored since it can slow down parameter scans. When (if) non-probe SOL diagnostics take over the work load, things should get a lot easier.

At least three run days should be set aside for filling in “holes” in parameter space (see section 5). Perhaps this could be done late in the run period when the “holes” become most apparent, although last time with the shorten run campaign we never got to do the experiments. At this time, the planning for the dedicated runs focuses on low power-density, 5.3 tesla H-modes to make best use of the probe diagnostics and to make sure that at least we get these data. The discharge parameters listed in sections 4 and 5 reflect this initial focus. However, if some or all of these data are collected in a piggy-back mode, then the discharge specifications will be appropriately changed to fill in the rest of the “holes” in the database.

H-modes with high power ICRF might best be studied in a piggy-back mode. Runs for some of the H-mode power threshold and pedestal profile studies might be ideal for this. It is very important that we run some 3.5 and 8 tesla discharges to study the B-field dependence of H-mode SOL transport. Again, if the 5.3 tesla data set becomes filled in from piggy-back experiments, then the run plan below will be changed to ask for 3.5 and/or 8 tesla data.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

**Toroidal Field:** 5.3 tesla (possibly 3.5 and/or 8.0 tesla for modified run plan)

**Plasma Current:** 0.8, 1.0 MA (1.2 MA for modified run plan)

**Working gas species:** Deuterium with hydrogen as needed for RF coupling.

**Density:** NL04 program ranging from 0.6 to $1.4 \times 10^{20} \text{m}^{-2}$

**Equilibrium configuration** (if possible, refer to database equilibria): Standard lower divertor with strikepoints on the vertical sections of the divertor plates.

**Pulse length, typical current & density waveforms, etc.** Refer to database or sketch desired waveforms: current flat-top lasting to 1.1 seconds
Equilibria will be selected from recent runs and appropriately customized. The discharges will have a flat-top ohmic phase from 0.5 to 0.7 seconds followed by a two step RF-heated phase (1MW from 0.7 to 0.9 sec, 2.0 MW from 0.9 to 1.1 sec). Depending on target density, the RF-heated phase will give access to different confinement regimes (ELM-free, ELMy, EDA H-modes,..). The equilibria will be tuned as needed for optimal fast-scanning probe target position. A toroidal B-field ramp will be programmed to allow full electron temperature profile measurements with ECE systems.

4.2 Auxiliary Systems

**RF Power, pulse length:** 1.0 MW of RF power from 0.7 to 0.9 sec, 2.0 MW from 0.9 to 1.1 sec.

**Pellet Injection (species):** none

**Impurity blow-off injection:** none

**Special gas puffing:** none

**Other:** none

4.3 Diagnostics

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

Particular focus will be on SOL diagnostics including: F-port and A-port fast-scanning probes, divertor probes, helium puff diagnostic, reflectometer, tangential TCI, divertor bolometers, visible cameras. The scanning probes will be set to reach maximum insertion at 0.6, 0.8 and 1.0 sec.

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.)

Less than $10^{14}$ 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.

The experiments will require at least three full run days of reproducible RF heated plasmas.

These runs should be scheduled only when good quality, reproducible H-mode plasmas are available.

2 run days:
Density, current, RF power scans (ohmic L, ELM-free, EDA, ICRF L-mode phases)
Initial plan: 0.8 MA and 1.0 MA, 5.3 T, 1.0 to 2.0 MW ICRF
Modified plan: 1.2 MA, 3.5 and/or 8.0 T
divertor flapper open/closed

1 run day (covered by MP# 205 and not listed in the shot sequence plan below):
reversed field - Density, current, RF power scans (ohmic L, ELM-free, EDA, ICRF L)
0.8 MA and 1.0 MA, 5.3 T, 1.0 to 2.0 MW ICRF
divertor flapper open/closed

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.

Day 1: 0.8 MA, 5.3 T (subject to change)

Shot#1-5
NL04: 1.0x10^{20} m^{-2}
Setup equilibrium and FSP/ASP target.

Shot#6-31
Density scan NL04: 0.6, 0.8, 1.2, 1.4x10^{20} m^{-2}
Alternate shots with flappers open/closed
Provide for three tries at each density and flapper setting to optimize probe insertion, ICRF operation, and H-mode quality.

Day 2: 1.0 MA, 5.3 T (subject to change)

Shot#1-5
NL04: 1.0x10^{20} m^{-2}
Setup equilibrium and FSP/ASP target.

Shot#6-31
Density scan NL04: 0.6, 0.8, 1.2, 1.4x10^{20} m^{-2}
Alternate shots with flappers open/closed
Provide for three tries at each density and flapper setting to optimize probe insertion, ICRF operation, and H-mode quality.
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.

These experiments will expand the edge transport database to include a wider range of discharge parameters. Most importantly, they will provide critically needed data on ICRF heated L-mode, ELM-free H-mode, and EDA H-mode regimes, and enable a direct comparison of SOL transport with the divertor bypass open and closed. These results should allow us to refine empirical and physics-based models of heat and particle transport processes in the tokamak boundary plasma.

7. References

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


