1. Purpose of Experiments

In support of an upcoming DoE Joint Facilities Milestone [1], a new set of heat-flux instruments was installed to diagnose C-Mod’s lower divertor. The purpose of the experiments described here is to test and optimize the performance of these diagnostics, with particular focus on diagnosing the heat-flux footprint around the outer divertor strike point.

2. Background

Physics-based plasma transport models that can accurately simulate the heat-flux power widths observed in the tokamak boundary are lacking at the present time. Yet this quantity is of fundamental importance for ITER and most critically important for DEMO, a reactor similar to ITER but with ~4 times the power exhaust. In order to improve our understanding, C-Mod, DIII-D and NSTX will aim experiments in FY10 towards characterizing the divertor ‘footprint’ and its connection to conditions ‘upstream’ in the boundary and core plasmas [1]. Standard IR-based heat-flux measurements are particularly difficult in C-Mod, due to its vertical-oriented divertor targets. To overcome this, a suite of embedded heat-flux sensor probes (tile thermocouples, calorimeters, surface thermocouples) combined with an improved IR thermography system was installed during the FY09 opening. In addition, a new divertor bolometer system was installed to assess radiative contributions to the divertor power balance (see Fig. 1).

The new embedded divertor sensors include 25 tile thermocouples, 14 calorimeters and a set of 10 unique surface-temperature thermocouple probes [2]. In previous experiments, the latter sensors have demonstrated the ability to measure surface temperature evolution with ~10 ms time response during a plasma discharge. A simple 1-D heat transport model can be used to infer surface heat fluxes as a function of time. In principle, with careful positioning of the strike point location, the heat-flux footprint across the outer divertor surface can be mapped out in some detail. Slower time-response
data from tile thermocouple and calorimeter sensors can provide independent measures of heat deposition profiles and allow the IR imaging system to be calibrated in-situ.

The instrumented tiles on the outer divertor consist of two columns of ‘ramped tiles’, which are tilted in the toroidal direction by ~2 degrees relative to standard tiles (Fig.2). This ensures that the tile surfaces will not be shadowed toroidally by...
misalignments in adjacent tiles. It also increases the thermal load to the local tile surface, improving signal-to-noise for IR and sensor-based diagnostics.

At a different toroidal location (F-port module), the divertor is instrumented with C-Mod’s standard set of 10 Langmuir probes, with similar poloidal spacing as the thermal sensors. These probes continuously record poloidal profiles of plasma density and electron temperature at the divertor surface (~ 5 ms per sample). Taken together with the thermal sensors, these data should allow plasma-sheath heat-flux transmission factors to be inferred – a fundamental quantity of plasma-sheath physics. In essence, the thermal sensor measurements will allow us to ‘calibrate’ the heat flux profiles and estimates of total power received by the outer divertor that were inferred previously by the Langmuir probe system.

At the present time, 6 (of 10) surface thermocouples and 11 (of 14) calorimeters are operational. These data, combined with the Langmuir probe data, are being stored on a new cPCI-based data acquisition system, which is has just recently come on-line. The divertor IR system is presently being calibrated and will be installed in the next few days. The divertor bolomtery will also be operational soon.

3. Approach

In order to prepare for heat-flux footprint physics experiments, debugging and conditioning of the boundary physics diagnostic set is required. In addition, some discharge optimization (plasma shape and positioning) is needed. For this, we would like to dial-up some standard lower-single null discharges with controlled inner/outer gaps but also with some control on the outer divertor strike point location. The latter may be accomplished by preprogramming the boundary shape. However, it is more desirable to implement a feedback control of the strike-point position, if possible.

We wish to take a series of nearly identical discharges with stationary or slow sweeps of the outer divertor strike-point, watching the behavior of the heat-flux sensors. A coarse density scan may be performed if things go well. Some cell access may be required to debug systems. We should start with 0.8 MA discharges, but then push to 1.0 MA to increase heat flux signals.

4. Resources

4.1 Machine and Plasma Parameters

Give values or range for:

- Toroidal Field: 5.4 tesla
- Plasma Current: 0.8 to 1.0 MA
- Working Gas Species: Deuterium
- Density: NL04 ~ 0.6 to 1.2x10^{20} m^{-2}
- Boronization Requested (if yes, specify whether overnight or between-shot, how recently needed, and any special conditions.): none
Equilibrium configuration (if possible, refer to database equilibria): Lower-single null with outer strike-point controlled.

4.2 Auxiliary Systems

ICRF Power, pulse length, phasing: none
LHCD Power, pulse length, phasing: none
Pellet Injection (species): none
Impurity blow-off injection: none
Diagnostic Neutral Beam: none
Special gas puffing: none, NINJA may piggyback
Cryopump: none
Non-axisymmetric Coils (Connections, Current); standard compensation.
Other:

4.3 Diagnostics

Desired: divertor heat-flux sensors, scanning probes (WASP, ASP, FSP), divertor IR thermography, core and divertor bolometry, Lyman-alpha, edge Thomson.

5. Experimental Plan

5.1 Run sequence Plan

We will make use of whatever piggy-back run time there is available to commission these boundary layer diagnostics. However, we need ~1 run day to vary the outer divertor strike point in a controlled way and to condition the scanning probes.

5.2 Shot sequence plan

Dial up some standard LSN discharges (5.4 tesla, 0.8-1.0 MA, NL04 ~ 0.6 to 1.2 ) with controlled gaps and controlled outer divertor strike point.

Scan WASP, ASP, and FSP probes to separatrix to condition them and to get basic information on upstream heat-flux widths.

Optimize outer divertor strike point location and sweep.

Vary density. Go to 1 MA.

6. Anticipated Results

This experiment should give us a good idea of what to expect from the new thermal diagnostics (both embedded and IR) and how best to utilize them for boundary-layer physics studies.
7. References

[1] Proposed US DoE Joint Facilities Milestone for FY10: “Conduct experiments on major fusion facilities to improve understanding of the heat transport in the tokamak scrape-off layer (SOL) plasma, strengthening the basis for projecting divertor conditions in ITER. In FY2010, FES will measure the divertor heat flux profiles and plasma characteristics in the tokamak scrape-off layer in multiple devices to investigate the underlying thermal transport processes. The unique characteristics of C-Mod, DIII-D, and NSTX will enable collection of data over a broad range of SOL and divertor parameters (e.g., collisionality, beta, parallel heat flux, and divertor geometry). Coordinated experiments using common analysis methods will generate a data set that will be compared with theory and simulation.”