C-Mod FY2010 campaign statistics and plans

presented by R. Granetz

Alcator C-Mod quarterly review
06 April 2010
C-Mod FY2010 operation

• Budgeted for 18 research run weeks (72 run days)
  — 5 weeks ARRA funded
  — 13 weeks base funded

• 14.7 research run weeks have already been completed to date

• ~1650 plasma discharges

• 43 different miniproposals received run time, with major emphasis on:
  — boundary layer heat transport in H-mode (joint facility milestone)
  — characterization and optimization of I-mode
  — optimization of mode conversion flow drive
C-Mod FY2010 run utilization to date (in run days)

<table>
<thead>
<tr>
<th>Topic/Group</th>
<th>Run Days</th>
</tr>
</thead>
<tbody>
<tr>
<td>H-mode Scenarios</td>
<td>3.50</td>
</tr>
<tr>
<td>MHD</td>
<td>2.03</td>
</tr>
<tr>
<td>Boundary</td>
<td>11.66</td>
</tr>
<tr>
<td>Transport</td>
<td>23.48</td>
</tr>
<tr>
<td>AT Scenarios</td>
<td>0.88</td>
</tr>
<tr>
<td>ICRF</td>
<td>15.38</td>
</tr>
<tr>
<td>Operations</td>
<td>1.00</td>
</tr>
<tr>
<td>Diagnostics</td>
<td>0.75</td>
</tr>
<tr>
<td>LH</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Total research days to date: 58.67 (14.67 weeks)

(DoE target for all of FY10 is 18 weeks.)
I-mode expands available pedestal collisionality space

\[ 3 < B_T < 6 \]
\[ 0.7 < I_{\rho,MA} < 1.3 \]

I-mode

L-mode

(pre I-mode)

typical EDA

\( T_{e,95} \) (eV)

Pedestal collisionality \( \nu^*_{95} \)
ICRF mode conversion flow drive

All 80 MHz data have $^3$He puff 100 ms to 150 ms and J-antenna at +90 degree (some data have D+E also), 1 MA and 1.2 MA.

8T/80 MHz data seem to follow Rice scaling, except the $\Delta V$ seems to be limited to 80 km/s: $\Delta W/I_p$ from 65- 110 kJ/MA, $\Delta V$ is kept between 70-80 km/s.

5.1T/50 MHz data are chosen from the same range of $I_p$ and density $\rightarrow$ a factor of 3 above Rice scaling.
ICRF mode conversion flow drive

Same data but plotted vs. $P_{rf}$.

8T/80 MHz data: Rotation linear vs. $P_{rf}$ in the entire data range. No saturation is seen.

5.1T/50 MHz rotation is higher, but less dramatically (as seen vs. Rice scaling).

$\Rightarrow P_{rf}$, but not $\Delta W$, that determines the rotation change in both 50 MHz and 80 MHz experiment.
C-Mod operations schedule for balance of FY2010

2010/03/27 (9 weeks) — up-to-air for manned access
  — Install new LH launcher
  — Maintenance/repair of W tiles, MSE, divertor TC’s, magnetics, etcetera
  — Repair of DNB (visit by Budker team)

2010/05/28 (6 weeks) — pumpdown, bake, plasma conditioning

2010/07/09 (4 weeks) — research operation
  — LH launcher evaluation; current profile control; AT regimes; hybrid scenarios; disruption runaways
  — boundary layer heat transport in H-mode (joint facility milestone)

2010/08/06 — additional FY2010 research operation? (budget and schedule dependent)
LH II Status

Alactor C-Mod
Quarter Review
April 6, 2010
Overview of LH II in-vessel components

- **Forward wave-guide made from WR187 Copper guide**
- **Coupler Assembly 304 L SS**
- **304 L SS shroud**
- **Coupler side support plates Inconel 625**
• On January 8, 2010 we found that the butt welding process coated the RF windows.
  – An error by our vendor of a critical e-beam setting coated many of the vacuum windows during one of the last welding operations
• This occurred in spite of our having qualified the process with extensive prototyping and successful welding of the first column and a 4-way splitter prototype
Picture showing the e-beam butt weld and the coated window

- Electron beam Butt weld
- Coated Ceramic Window
• We evaluated two methods to remove the coating off the windows. During this evaluation we performed a series of tests in order to select the best method.

  – **Ultrasonic cleaning (UC)**
    • single waveguide & 4-way splitter successfully cleaned
    • Assembly of multiple waveguide could NOT be cleaned
    • We concluded that UC would require the disassembly of launcher, a risky and lengthy process.

  – **Dilute solution of Hydrochloric (HCL) acid**
    • Exposed coated test window surfaces in several ratios of HCL solution to distilled water, heated to different temperatures. These tests revealed that a ratio of 1 part HCL to 20 parts distilled water heated to 80 C was optimum.
    • Etching process permitted the cleaning of the fully assembled launcher, which we found to be less risky & time consuming.
Review of launcher windows cleaning process

• On March 10, 2010 we presented our finding to a review panel with participants from PPPL, GA, MIT Nuclear Dept., and PSFC personnel. The reviewers agreed that the ETCH process was the best approach.
Etching process

- We completed the etching process on March 1, 2010. Both borescopic evaluation and Low Power RF tests confirmed that the windows were clean.
Etching process

Dilute HCL solution poured from the top into the wave guides

Launcher support strap

Heater tank
Water heated to 80 C
LH II Launcher installed in Test Stand

- Launcher installed in test stand on 3-25-10.
  - Vacuum test of the launcher showed that all windows and o-ring gasket seals are leak tight. (leak rate measured to 1E-10 Torr-l/s.).
  - Vacuum leak tests were performed at room temperature and at ~150 C (bake temperature for C-Mod).
  - One Minor feed-thru leak found. Feed-thru is being removed and replaced, no effect on schedule.
LH II Schedule

- Complete all Test Stand tests including Low Power RF tests with waveguides at 25 psi by 4-9-10.
- Move Launcher to Cell by 4-12-10.
- Assemble launcher to Jungle Gym and complete phase shift calibration tests by 4-30-10.
- Install Launcher in C-Mod by 5-7-10.
- Launcher to be operational when C-Mod returns to operation.
C-Mod Status

DoE Quarterly Review
04/06/10
Outline

• C-Mod Status
• Facility Upgrade
• In-vessel/External work during Up-to-Air
• Short Term Plans
• Schedule
C-Mod Status

• We have completed 5 weeks of ARRA supported research
• We have completed 9.7 weeks of our 13 week base target
• Alcator C-Mod is up-to-air (~40 working days):
  – Installation of new lower hybrid launcher
  – Upgrades to diagnostics in support FY2010 Joint Research Milestone
  – Inspection and refurbishment of in-vessel components
  – New diagnostic installations and other upgrades
• Plasma operation will resume in June 2010
Major Facility Upgrade

- Improvements to alternator cooling system will be made during the up-to-air period
  - Eliminate dependence on Charles river cooling water
    - Eliminate EPA permitting issues
    - Eliminate possible impact of river water temperature on C-Mod operations during hot summer months (MA water temperature regulations)
  - MIT chilled water system will be tied into the alternator cooling system
    - MIT funded at the 840k level
      - Providing detailed design
      - Providing pumps, valves, heat exchangers, electrical
      - Providing manpower, contractors
Up-to-Air In-vessel List (as of 03/30/10)

- install lower hybrid launcher at C-Hor (Vieira, Dterry)
- work for Joint Facilities Milestone (LaBombard)
- diagnose/repair magnetics as possible (Granetz)
- inspect/document boron coatings (Wukitch, Blip, Whyte)
- repair lower halo Rogowski (Granetz)
- refurbish outer divertor W tiles (Vieira, Pierson, Blip)
- refurbish K limiter tiles (Pierson)
- K-Port limiter position change (Wukitch)
- Repair/upgrade MSE shutter (Scott, Mumgaard)
  - new automated MSE calibration
  - New housing/shutter assembly
- repair cryopump baffle (Pierson, LaBombard)
- upgrade to polar shutter (Irby, Leccacorvi)
- refurbish emissive probes (Ochoukov)
- install new probe stations on the AB-Limiter (Ochoukov)
- Bolometry upgrades and refurbishment (Reinke)
- Install new outer wall 2pi-diode (Reinke)
- reposition XTOMO array for clear view (avoid cryopump) (Reinke)
- K-Port GPI periscope calibration (Churchill)
- PCI in-vessel calibration (Ennever)
- HIREXSR ray-tracing calibration (Reinke)
- CNPA calibration (Bader)
- XEUS alignment (Reinke)
- Inspect/clean Z-Meter array mirror (Marmar)
- Install gate-valves on single chord HIREX ports at K-Hor and F-Hor (Reinke)
- VB Array calibrations (Marmar)
• Inspect magnet supplies
• Inspect/upgrade alternator systems
• Continue fabrication of the new advanced 4-strap antenna
• Continue work on Lower Hybrid Coupler- and Transmitter-Protection Systems (CPS, TPS)
• Continue refurbishment/upgrades to DNB as required to bring it back into operation
• Upgrades to vessel HEAT system (software/hardware)
  – Improve reliability
  – Develop temperature display map
• Complete installation of polarimeter
Advanced 4-Strap ICRF Antenna

• Underlying cause of impurity generation is thought to be generation of \( E_{||} \).
• Rotate antenna structure \( 10^\circ \) to be perpendicular to total B field.
  – Minimize integrated \( E_{||} \) through symmetry (reduced by factors of 3-10).
  – Power density is increased (\( \sim 10 \text{ MW/m}^2 \) @2 MW).

• Antenna construction progress:
  – Four new feedthrus are in house and leak checked.
    • Power testing is planned to be completed by end of April.
  – Reduced size strap has been manufactured.
    • Wire EDM process has been established to cut twisted antenna strap.
• Ready for installation January ’11.

• Remaining major steps towards construction:
  • Finalize antenna strap and manufacture full size strap
  • Finalize and manufacture back plate and strip-lines
  • Manufacture antenna straps
  • Faraday screen manufacturing
Lower Hybrid Control

- Transmitter Protection System Upgrade (available late summer 2010)
  - TPS design done as Phase I and II of SBIR grant
  - Improved protection of both equipment and personnel
  - Fiber optic links will replace many hardwire connections
  - Remotely programmable set-points and monitoring for each klystron cart
  - Klystron collector over-temperature protection will provide safer long pulse operation
- Coupler Protection System Upgrade (available next run period)
  - Improved protection and safety for new launcher
  - Remote programmability of fault trip levels
  - Protects against high reflected power, power imbalance, over power, and rapid power changes
  - CPS parameters written directly to MDS+
  - Commercially available cPCI based digitizer and FPGA provide hardware base
  - CPS is installed and has undergone extensive testing with high power klystrons
Polarimeter

- Lower optical table installed
- FIR lasers installed and operated during plasma discharge
- Fields, vibration levels, FIR phase variation measured during plasma discharge

- Currently completing enclosure/gas purge system and installing optical components
- Upgrade number of chords with ARRA funds late 2010

ARRA Funded 2.45 THz Detector
Operations Plan and Schedule
Operations Plan

• Up-to-air from 4/5/2010 to late May 2010
• Complete remaining FY2010 physics operation
  – LH launcher brought on-line
  – Joint milestone
• Extend FY2010 as possible (within funding and schedule constraints) to continue using new LH tools and address high priority physics goals
• Begin FY2011 campaign (October 2010)
• Up-to-Air in early calendar year 2011 to install new advanced 4-strap antenna
# Operations Schedule

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
<th>Qtr 2, 2010</th>
<th>Qtr 3, 2010</th>
<th>Qtr 4, 2010</th>
<th>Qtr 1, 2011</th>
<th>Qtr 2, 2011</th>
<th>Qtr 3, 2011</th>
<th>Qtr 4, 2011</th>
<th>Qtr 1, 2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>up-to-Air (LH, refurb, edge diag)</td>
<td>40 days</td>
<td>Mon 4/5/10</td>
<td>Fri 5/28/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>pumpdown</td>
<td>0 days</td>
<td>Fri 5/28/10</td>
<td>Fri 5/28/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>bake/ecdc</td>
<td>10 days</td>
<td>Sat 5/29/10</td>
<td>Mon 6/7/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>plasma condition</td>
<td>19 days</td>
<td>Tue 6/8/10</td>
<td>Thu 7/8/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>physics operation (fy10 part 4)</td>
<td>17 days</td>
<td>Fri 7/9/10</td>
<td>Fri 8/6/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>fy10 operation complete</td>
<td>0 days</td>
<td>Fri 8/6/10</td>
<td>Fri 8/6/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>maintenance</td>
<td>10 days</td>
<td>Mon 8/9/10</td>
<td>Fri 8/20/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>extended plasma operation (fy10)?</td>
<td>8 days</td>
<td>Tue 8/24/10</td>
<td>Fri 9/3/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>maintenance</td>
<td>20 days</td>
<td>Mon 9/6/10</td>
<td>Fri 10/1/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>physics operation (fy11 part 1)</td>
<td>21 days</td>
<td>Tue 10/5/10</td>
<td>Tue 11/9/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>maintenance</td>
<td>10 days</td>
<td>Wed 11/10/10</td>
<td>Tue 11/23/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>physics operation (fy11 part 2)</td>
<td>18 days</td>
<td>Wed 11/24/10</td>
<td>Thu 12/23/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>warm up</td>
<td>10 days</td>
<td>Fri 12/24/10</td>
<td>Sun 1/2/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Up-to-Air (4-strap installation)</td>
<td>60 days</td>
<td>Mon 1/3/11</td>
<td>Fri 3/25/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>pumpdown</td>
<td>0 days</td>
<td>Fri 3/25/11</td>
<td>Fri 3/25/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>bake/ecdc</td>
<td>10 days</td>
<td>Sat 3/26/11</td>
<td>Mon 4/4/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>plasma condition</td>
<td>19 days</td>
<td>Tue 4/5/11</td>
<td>Fri 4/28/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>physics operation (fy11 part 3)</td>
<td>17 days</td>
<td>Mon 5/2/11</td>
<td>Tue 5/24/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>maintenance</td>
<td>10 days</td>
<td>Wed 5/25/11</td>
<td>Wed 6/7/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>physics operation (fy11 part 4)</td>
<td>19 days</td>
<td>Wed 6/9/11</td>
<td>Mon 7/4/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>fy11 operation complete</td>
<td>0 days</td>
<td>Mon 7/4/11</td>
<td>Mon 7/4/11</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>TTF</td>
<td>4 days?</td>
<td>Tue 4/13/10</td>
<td>Fri 4/16/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>HTPD</td>
<td>4 days?</td>
<td>Mon 5/17/10</td>
<td>Thu 5/20/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>PSI</td>
<td>5 days?</td>
<td>Mon 5/24/10</td>
<td>Fri 5/28/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>EPS</td>
<td>5 days?</td>
<td>Mon 6/21/10</td>
<td>Fri 6/25/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>2010 IAEA</td>
<td>6 days</td>
<td>Mon 10/11/10</td>
<td>Sat 10/16/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>2010 DPP APS</td>
<td>5 days</td>
<td>Mon 11/15/10</td>
<td>Fri 11/19/10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
EOT
FY2010 Joint Facilities Research: Boundary Layer Heat Transport

Outline:
- Status of joint experiments
- Divertor heat flux tools
- Initial physics results
- Plans

Quarterly Progress Report
Presented by B. LaBombard
for the Boundary Heat-Flux Team:
  Jim Terry, Dan Brunner,
  Josh Payne, Matt Reinke, ...

April 6, 2010
JFR Targets Achieved for 1st and 2nd Quarters

FY2010 DoE Joint Facilities Research Milestone:

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. The divertor heat flux profiles and plasma characteristics in the tokamak SOL will be measured 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 data that will be compared with theory and simulation.

<table>
<thead>
<tr>
<th>1st Quarter Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Develop a preliminary research plan coordinated among the three facilities, in order</td>
</tr>
<tr>
<td>to accomplish the required experiments measuring scrape-off layer characteristics</td>
</tr>
<tr>
<td>and divertor heat flux, towards the goal of understanding divertor conditions</td>
</tr>
<tr>
<td>projected for ITER.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2nd Quarter Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial planned experiments will have been carried out on at least one of the three</td>
</tr>
<tr>
<td>facilities.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3rd Quarter Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiments will have been carried out at multiple facilities. Experimental analysis</td>
</tr>
<tr>
<td>and preliminary interpretive modeling of results from multiple facilities will be</td>
</tr>
<tr>
<td>in progress. An initial evaluation of the data set will be performed and research</td>
</tr>
<tr>
<td>plans adjusted as appropriate.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4th Quarter Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Complete necessary experiments, data analysis and associated interpretive modeling.</td>
</tr>
<tr>
<td>Prepare a joint report on the empirical understanding gained, the connections to</td>
</tr>
<tr>
<td>edge transport models, and the opportunities for more detailed and extensive</td>
</tr>
<tr>
<td>comparisons to theory and simulation. Identify critical research areas to improve</td>
</tr>
<tr>
<td>extrapolation to ITER.</td>
</tr>
</tbody>
</table>
In coordination with NSTX (R. Maingi) and DIII-D (C. Lasnier) Teams:

January 21 -- Mini-proposal developed for DIII-D similarity experiments
February 5 -- Conference call: DIII-D & C-Mod similarity experiment plans
February 9 & 11 -- DIII-D similarity experiments (MP 2010-62-02)
February 12 -- C-Mod similarity experiments (MP 591, day 1)
February 23 & 24 -- C-Mod EDA H-mode experiments (MP 591, day 2 & 3)
March 3, -- C-Mod EDA H-mode experiments (MP 591, day 4)
March 4 -- Conference call: experimental status and data needs for modeling
March 10 -- C-Mod EDA H-mode experiments (MP 591, day 5)
April 6 -- Draft of experimental summary for ECC meeting at TTF
C-Mod Research

Two mini-proposals are the primary vehicle for C-Mod’s Boundary Layer Heat Transport Experiments:

**Ohmic+ ICRH heated L-Modes:**
MP#570, “Boundary layer heat transport experiments in L-mode plasmas”
- Probes+Edge Thomson: map midplane ‘heat-flux’ widths to divertor footprints
- Vary edge collisionality, current, field (similar to edge ‘phase-space’ studies)
  - 4 runs completed in FY10 fall campaign, used to commission diagnostics

**Stationary H-Mode regimes (EDA):**
MP#591, “Boundary layer heat transport experiments in H-mode plasmas”
- EDA H-Modes: power and collisionality dependence of divertor footprint, vary current to affect pedestal width
- Dimensionless identity experiments with DIII-D, shape similarity with NSTX
- Edge Thomson + IR thermography: map midplane ‘heat-flux’ widths to divertor footprints
- Vary edge current, field, SOL power (ICRF); identify empirical scalings
- Heat channel width scaling: dependence on major radius?
- Power balance: Can we account for integrated heat fluxes to divertors?
- 5 runs completed in FY10 winter campaign, with focus on IR ‘footprints’

Dimensionless similarity match with DIII-D discharges attained

Current, power, field and topology variations begun

Good progress on developing IR imaging and thermal analysis tools to infer heat flux footprints
• Stationary EDA discharges attained
• Outer boundary shape ~matched with DIII-D
• ICRF power and density varied to scan pedestal and SOL conditions
Pedestal conditions of previous C-Mod similarity discharge (1000626017) attained
(Unfortunately, DIII-D’s Thomson scattering diagnostic had a technical problem in the
companion discharges, accounting for the lower than expected scaled temperatures...)

Higher scaled SOL density values are obtained in C-Mod versus DIII-D
=> evidence that atomic physics breaks similarity match in SOL?
Significant progress in IR imaging and thermal analysis tools -- a top priority during the winter campaign

New Divertor Heat-Flux Instrumentation Installed in FY09

An extensive suite of analysis tools has since been assembled:
- 3D virtual model of J-divertor, ramped tiles and sensors
- Between-shot image stabilization and spatial registration
- In-situ temperature calibration algorithms, background light subtraction
- Energy deposition models for limiter and divertor structures
- 2D heat transport modeling of ramped tiles…
IR Thermography on C-Mod presents significant challenges, relevant to the ITER environment

C-Mod Challenges:
- closed, vertical target plate
- oblique observation angles
- shiny, low emissivity refractory target
- extremely high peak heat fluxes
- low-Z surface films, changing with time

Important Capabilities Developed:
- between-shot image stabilization
  {IDL source code sent to DIII-D and TCV}
- image registration, defining “regions-of-interest” for analysis
- in-situ pixel-by-pixel & post-shot calibration using imbedded TCs
- 2D thermal model of divertor target with between-shot analysis
- compensation for surface films in thermal analysis
IR Thermography on C-Mod presents significant challenges, relevant to the ITER environment

C-Mod Challenges:
- closed, vertical target plate
- oblique observation angles
- shiny, low emissivity refractory target
- extremely high peak heat fluxes
- low-Z surface films, changing with time

Important Capabilities Developed:
- between-shot image stabilization
  {IDL source code sent to DIII-D and TCV}
- image registration, defining “regions-of-interest” for analysis
- in-situ pixel-by-pixel & post-shot calibration using imbedded TCs
- 2D thermal model of divertor target with between-shot analysis
- compensation for surface films in thermal analysis
2D thermal model of outer divertor has been developed...  
...to infer heat flux profiles from IR surface temperatures

QFLUX_2D -- surface heat flux analysis
- finite element, transient heat transport model of ramped tiles and back plate
- surface films modeled using a novel Fourier analysis technique, imposing a non-negative surface heat flux constraint
- automatic between-shot analysis has recently been implemented
2D thermal model of outer divertor has been developed... 
...to cross-check IR-inferred energy deposition against TCs

**QFLUX_2D -- verification of IR-inferred heat deposition**
- IR surface temperatures are imposed only for plasma pulse time
- 2D heat transport model is continued for ~30 seconds after pulse
- computed tile temperature rise is compared to measured values
  
  \[
  \text{Output} \quad \text{Tile \& Calorimeter Temperatures} 
  \]
  
  => discrepancies point to potential problems with IR/heat flux model
- similar cross-checks will be performed using individual calorimeters...
New limiter, divertor and IR heat measurements...
- allows full accounting of energy loss to first-wall components
- provides rough cross-check of energy input/output
- can be used to follow systematic trends...

Discharge energy balance can now be assessed with new thermal diagnostics and analysis tools

Energy Balance: 1100212024

Energy In

Energy Out

E_{\text{out}}/E_{\text{in}}: 0.91

Surprise -- Inner Divertor takes a similar amount of energy as Outer Divertor! (preliminary, work in progress...
Initial Footprint Observations:
C-Mod heat flux channels are narrow with ‘tail’ features

Footprint taken from similarity discharge, 1.325 s

- Narrow with ‘tail’ feature
Initial Footprint Observations:
C-Mod heat flux channels are narrow with ‘tail’ features

- Narrow with ‘tail’ feature
- ‘tail’ consistent with LP data

Footprint taken from similarity discharge, 1.325 s
Initial Footprint Observations:
C-Mod heat flux width challenges ITER empirical scalings

\[ \lambda_q \text{ scaling from JET [Kirnev, et al., PPCF 49 (2007) 689-701] is basis for ITER heat flux width scaling:} \]

\[ \lambda_q^{cond} \propto B^{-1}_\phi P_{sol}^{-0.5} n_{e,u}^{0.25} q_{95} R^2 \]

...predicts integral \( \lambda_q \) for C-Mod shot#1100212024: \( \lambda_q^{cond} \sim 0.55 \text{ mm!} \)

\( \Rightarrow \) C-Mod data are already providing a valuable ‘anchor’ for \( R \) and \( B \) dependences...

- FWHM \( \sim 1.85 \text{ mm} \)
- Integral \( \lambda_q \sim 2.7 \text{ mm} \) ('tail' is problematic here)
- 1/e distance \( \sim 1.3 \text{ mm} \)
Plans: 2\textsuperscript{nd} half of FY10

April-June -- Manned vessel access
\begin{itemize}
\item Replace Ramped Tiles in strike-point region (repair Tungsten tiles)
\item New & improved set of Calorimeters, Surface TCs and Tile TCs sensors/cables
\item Repair damaged Langmuir probes on outer and upper divertors
\item New Langmuir probe array on Ramped Tiles
\item Clean IR periscopes, install ‘landmark’ tiles in divertor view
\item Bundle data for modeling studies
\end{itemize}

May -- PSI Meeting, San Diego

July-September -- Summer run campaign
\begin{itemize}
\item Revisit L-Mode heat flux footprints (MP#570)
\item Continue H-Mode footprint studies (MP#591)
\item Assemble empirical scalings, connections to ‘upstream’ measurements
\item Joint Facilities Research final report
\end{itemize}

FY11 --
\begin{itemize}
\item Continued boundary heat transport studies…
\end{itemize}
Plans: April-June Manned Vessel Access

- Install new set of Surface TCs
  - improved cabling
  - eliminate EMF from divertor currents
- Install faster time-response Tile and Calorimeter TCs
- Extend ramp shelf for LP array
- Install ‘ramp-down’ tiles for background light view
- Install new LP array (7 probes)