Overview of the 2000 DIII–D Experimental Campaign

by

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DIII–D Mission: To establish the scientific basis for the optimization of the tokamak approach to fusion energy production

DIII–D Focus: Advanced Tokamak (AT) research
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DIII–D Focus: Advanced Tokamak (AT) research

- Areas of focus on DIII–D have been defined as THRUSTS
- Year 2000 Research Areas

A.T. Divertor

EC
Electron Cyclotron

RWM
Resistive Wall Mode

ITB
Internal Transport Barrier

A.T. Thrust - High bootstrap fraction scenario
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A.T. Thrust - High bootstrap fraction scenario

Topical Science Areas
Develop scientific understanding for Thrusts and general tokamak physics

Boundary
Confinement
Stability
Heating & CD
ADVANCED TOKAMAK PROGRESS
LONG PULSE, STEADY, ELMing H-MODE
$\beta_N H_{89P} \sim 7 \tau/\tau_E \sim 35$

- NBI power is feedback controlled on plasma beta at $\beta_N = 2.7$
- Density is controlled with divertor pumping
- Luce MO1.002
- Wade CI2.001

Normalized Beta $\beta_N = 2.7$

Plasma Current Flattop 6.3 s

Density $= 3.6 \times 10^{19} \text{ m}^{-3}$
DIVERTOR-2000 CONTROLS DENSITY AND IMPURITY LEVEL

- Accurately contoured band of carbon tiles
- Accurate tile alignment prevents hot spots
- Reduced carbon

Old

New

1 mm

2.5 mm

0.1 mm

0.62 mm
DIVERTOR-2000 CONTROLS DENSITY AND IMPURITY LEVEL — 50 MJ INPUT

- Density feedback regulated with divertor pumping
- Heat Input (MJ)
- Peak Tile Temperature (°C)
- Z_{eff} < 2

Old
- 1 mm
- 2.5 mm

New
- 0.1 mm
- 0.62 mm

Lasnier MO1.013
Isler MO1.014
REAL-TIME STRIKE POINT AND SHAPE CONTROL ACHIEVED FOR DIVERTOR PUMPING

- Outer strike point sweep to control pumping

- Density exhaust depends sensitively on strike point locations

Graph showing sweep outer strike point and inner strike point fixed, with line-avg density (10^19/m^3) over time (ms) for unpumped and pumped conditions.
PROGRESS IN FEEDBACK STABILIZATION OF THE RWM

- Strait MO1.003
- Garofalo MO1.004
- Okabayashi GI1.005

MODELING AGREES WITH EXPERIMENT

HIGHER $\beta_N$ WITH INTERNAL SENSORS, FUTURE UPGRADED C–COIL

FEEDBACK TURN-ON TIME

NO-WALL LIMIT (approx.)

RWM AMPLITUDE

MODE CONTROL + DERIV. GAIN

NO FEEDBACK

PLASMA TOROIDAL ROTATION

$\rho \sim 0.5$

Time (ms)

1100 1200 1300 1400 1500

101953 101956

G

Modeling agrees with experiment

Higher $\beta_N$ with internal sensors, future upgraded C–coil
HIGH POWER EC SYSTEMS (110 GHz) FOR AT PROFILE CONTROL COMING ONLINE

- J. Lohr MO1.005
  New Diamond Window Gyrotron

- 1 MW Class Gyrotrons

- 2000 Experiments with 2-3 gyrotrons

- 2001 Experiments with up to 6 gyrotrons

- PPPL articulating launcher invaluable for physics productivity – necessary to exploit EC as an AT tool

- CPI Gyrotron
- Mirror Interface Unit
- GA Dummy Load
- Cryomagnetics Magnet
- PPPL / GA Support Tank

Independently rotatable toroidally
EC RESULTS INDICATE AN EFFECTIVE A.T. CONTROL TOOL

- Localized, off-axis, current drive in ELMing H–mode discharges

  R. Prater MO1.006
  Y.R. Lin-Liu MI1.003
  L.L. Lao NP1.079
  C.C. Petty NP1.080

\[ \delta J = \delta \nabla \times B / \mu_0 \]

ECCD Profile Prediction (Toray-GA)
EC RESULTS INDICATE AN EFFECTIVE A.T. CONTROL TOOL

- Localized, off-axis, current drive in ELMing H–mode discharges
  R. Prater MO1.006
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- Complete suppression of neoclassical tearing mode (NTM) with Co-ECCD

- Precise localization of ECCD required for NTM stabilization
  T. Strait MO1.003
EC HEATING DRIVES ELECTRON ITB

- Prater MO1.006
- Doyle MO1.007
- Greenfield GP1.112

- 0.8 MW ECH applied at $\rho \sim 0.4$; no NBI
- Co–ECCD in this case; counter and radial ECH also drive ITB

$T_e$ (keV) vs. $t$ (ms) graph showing large $T_e$ gradient for ECE channels.
ITB THRUST USES COUNTER NBI - DISCOVERS NEW OPERATING MODE
QUIESCENT DOUBLE BARRIER (QDB)
TWO BARRIERS, NO SAWTEETH, NO ELMs (QH-MODE EDGE)

\[ P_{\text{NBI}} (\text{MW}), \quad P_{\text{rad}} (\text{MW}) \]

\[ \beta_N H_{89} \sim 7 \]

\[ q_0 > 1 \]

\[ \langle n_e \rangle (10^{19} \text{ m}^{-3}) \]

\[ ELM-free \]

\[ I_p (\text{MA}), \quad \Rightarrow \text{Counter NBI} \]

\[ \text{Time (s)} \]

\[ \text{Doyle MO1.007, Burrell BI1.002, Greenfield GP1.112} \]
## OTHER EXPERIMENTS DONE IN THE TOPICAL SCIENCE AREAS

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Edge flow reversal may hold key to old mystery of power threshold being lower with ion $\nabla B$ drift toward X–point

L–Mode discharges, 1 MA, 2.1 T, NBI = 1.9 MW
three turbulence diagnostics observe flow reversal in target discharge

Midplane Langmuir probe also sees flow reversal (R. Moyer, UCSD)
L–MODE CONFINEMENT DEGRADES WITH ELONGATION, H–MODE IMPROVES

Confinement TSA experiment - dimensionally similar discharges
Each pair has same l, B, n, R, a, T(ρ) (Heating power varied)

Larger $\kappa$ => more NBI
Larger $\kappa$ => less NBI
OVERVIEW OF THE 2000 DIII–D EXPERIMENTAL CAMPAIGN

- AT Thrust: control tools lead to $\beta_N H_{89p} \sim 7$ for $> 30\tau_E$
  - AT divertor pumping
    - $\beta$ feedback controlled
      - Stationary discharge

- EC
  - Off axis ECCD in ELMing H–mode
  - ECH generated $T_e$ barriers
  - NTM suppression with co–ECCD

- Progress in active RWM stabilization

- New QDB mode of operation

- Topical science area experiments
ADDITIONAL TOOLS FOR THE 2001 CAMPAIGN

- Increase to 6 gyrotrons
- Internal sensor loops to enhance RWM feedback control
- Edge J diagnostic  Snider NP1.099