Overview of Recent DIII-D Experimental Results

by
P. Gohil

For the DIII-D team

Presented at the 53rd APS Meeting of the APS Division of Plasma Physics
Salt Lake City, Utah

November 14-18, 2011
DIII-D Research is Advancing the Physics Basis for Fusion Energy Production

ITER Research

Advanced Steady-State

Increased Scientific Understanding

DEMO

DIII-D

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DEMO
ITER Operational Scenarios: Achieved Stationary Conditions in Long Pulse ITER Baseline Discharges at Low Torque

- ITER shape
- ITER-like torque in steady state
- Broad EC Deposition near q=3/2
ELM Suppression Demonstrated in ITER Baseline Scenario

- ITER Shape, $q_{95} = 3.15$
- $\beta_N = 1.8$, $H_{89} = 1.8$
- Sustained for >1 s
  - Duration limited by available EC duration
- Achieved with single row $n=3$ I-coil RMP
- “ELMs” during $n=3$ associated with internal $n=1/m=1$ activity
Island-Like Displacements Observed During n=3 RMP Toroidal Phase Shifts

- Toroidal phase of n=3 RMP switched by 60° every 200 ms
- Thomson scattering density contours separate only in 0° phase
  - Suggestive of island formation
  - Localized near top of pedestal
- Similar structures seen for electron temperature

\[ \text{positive coil current = 0° phasing} \]
\[ \text{negative current = 60° phasing} \]
Nonresonant n=3 Magnetic Field Provides Additional Torque Maintaining Edge Rotational Shear for QH-mode

- QH-mode produced with reactor relevant level of co-\(I_p\) NBI torque
- Counter-rotation with co-\(I_p\) NBI torque

![Graph showing density, divertor flux, and NBI torque over time.]

Burrell, Friday 9:30
Garofalo, Thursday AM Posters
Nonresonant n=3 Magnetic Field Provides Additional Torque Maintaining Edge Rotational Shear for QH-mode

- With co-$I_p$ NBI torque, toroidal rotation is co-$I_p$ and edge rotational shear is small.

- For similar co-$I_p$ NBI torque, adding n=3 field maintains counter-$I_p$ rotation and larger edge rotational shear.

- Comparison made at similar density and NBI torque.

[Graph showing comparison of rotational shear with and without magnetic torque]
First Demonstration of ELM Pacing with 60 Hz Pellets: Substantial Reduction in ELM Size

- ELM pellet pacing at 5x the natural ELM frequency
- ITER shape, $\beta_N = 1.8$
- No significant change in energy confinement
High Resolution Data from Upgraded Thomson System Enables Detailed Studies of Pedestal Evolution

- Detailed profile evolution between ELMs
- Allows good comparisons with models

The EPED model predicts the observed evolution in the pressure gradient and the limit at the ELM crash

Snyder, Monday 4:00
Groebner, This Session
Disruptions: Runaway Electron Beam Control Allows for Safe Dissipation of Beam Energy

- RE beam position held stable with control system
- RE beam current can be ramped down with ohmic coil
- RE beam current can be dissipated by injection of high-Z gas
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DIII-D Neutral Beam Modified for Off-Axis Injection Provides up to 5 MW Heating for Support of Physics and AT Goals

Measured Fast Ion CXR Emission

Measured Difference in NBCD Agrees with Classical Model

M. VanZeeland, J.M. Park, This Session
Off-Axis NBI Produces Broad Current & Pressure Profiles with Sustained $q_{\text{min}}>2$ for Higher $\beta_N$ Stability Limits

- $q_{\text{min}}>2$ avoids 2/1 tearing modes
- Achieved $\beta_N=3.2$ limited by transport – needs further study
- Plasmas produced using off-axis NBI have higher predicted ideal-wall stability limits ($\beta_N \sim 4$)

Holcomb, This Session
Ferron, Thursday AM Poster
Turco, Friday 11:00
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National Fusion Facility
L-H Transition: High-resolution Measurements Demonstrate Turbulence-zonal Flow Dynamics Approaching Transition

- Limit-cycle oscillations between L & H-mode show interplay between zonal flow (predator) and turbulence (prey)

- Poloidal velocity spectra (from BES) evolves from geodesic acoustic mode (GAM) dominated to zonal flow dominated close to transition

- Zonal flow measured by fast reynolds stress probe increases just prior to transition
Enhanced Diagnostics Reveal New Physics Insights

- New measurement of $C^{2+}$ flows
- Strong flows towards inner and outer strikes points due to drag by main ion flows (Weber this session)

- Fitting thermal $D_\alpha$ emission spectra
- Differences in $v_\phi$ between main ions, carbon and neoclassical predictions (Grierson Wed. 11:30)
Assessed the Effect of Divertor Geometry on Divertor Conditions

Preliminary results for H-mode plasmas:

- $\uparrow L_\parallel \rightarrow \uparrow n_{\text{osp}} \& \downarrow T_{\text{osp}}$ — as expected
  
  ($L_\parallel$ = parallel connection length)
Assessed the Effect of Divertor Geometry on Divertor Conditions

Preliminary results for H-mode plasmas:

- \( \uparrow L_{\parallel} \rightarrow \uparrow n_{\text{osp}} \) & \( \downarrow T_{\text{osp}} \) — as expected
  
  \( L_{\parallel} \) = parallel connection length

- \( \uparrow R_{\text{osp}} \rightarrow \downarrow n_{\text{osp}} \) & \( \uparrow T_{\text{osp}} \) — against expectation
  
  - neutral trapping plays a critical role
  
  (preliminary SOLPS analysis)
Talks in this Session Present DIII-D Research Supporting ITER, Steady-State High Performance and Fusion Plasmas

**Providing solutions to key ITER issues**
- R. Groebner  
  GO4.05:  Testing Pedestal Models for Joint Research Target on DIII-D
- L. Zeng  
  GO4.07:  Effects of Resonant Magnetic Field Perturbations on Density Profiles, Particle Transport, and Turbulence in DIII-D
- J. Callen  
  GO4.08:  RMP Effects on Pedestal Structure and ELMs
- P. Stangeby  
  GO4.09:  The relation between upstream radial widths of $n_e$ and $T_e$ and outer target power width for H-mode discharges in DIII-D
- T. Weber  
  GO4.10:  $C^2+$ Flow Measurement in DIII-D Using Coherence Imaging Spectro-Polarimetry
- J. Wesley  
  GO4.14:  Attributes of argon pellet fast shutdowns in DIII-D

**Developing physics basis for steady-state operation**
- M. Van Zeeland  
  GO4.02:  Initial Off-Axis Neutral Beam Checkout and Physics Experiments on DIII-D
- J.M. Park  
  GO4.03:  Off-Axis NBCD Experiments in DIII-D
- C. Holcomb  
  GO4.04:  High $q_{min}$ Steady State Scenario Development Using Off-axis Neutral Beam Injection on DIII-D
- W. Solomon  
  GO4.15:  Advanced Inductive Plasmas with Low Torque Startup

**Advancing fundamental understanding of fusion plasmas**
- Z. Yan  
  GO4.06:  The Dynamics of Turbulence and Shear Flow Approaching the L-H Transition
- R. Pinsker  
  GO4.11:  Comparison of 3-D Modeling with Experimental Results on Fast Wave Antenna Loading in DIII-D
- G. Kramer  
  GO4.12:  Simulation of Observed EGAM Induced Beam-ion Losses in DIII-D
- J. Hanson  
  GO4.13:  Measuring Kinetic Contributions to Resistive Wall Mode Stability Using Active MHD Spectroscopy
DIII-D Program Much More Extensive Than Can Be Described Here – See Invited and ITER Talks Plus Two Poster Sessions

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Invited & Tutorial

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DIII-D Poster Sessions: Thursday Morning and Thursday Afternoon