Possible Pedestal Transport Theory Models And Modeling Tests

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Theses:

1) **Reminder of workshop impetus and objectives**
2) **There are 4 main pedestal transport issues**
3) **A suggested prioritization of issues**

Outline:

- **This workshop — impetus, objectives, testing approaches**
- **This synopsis — objectives, issues, prioritization considerations**
- **Suggested prioritization for key issues**

Impetus For "Pedestal Structure" Emphasis This Year

There is a year-long impetus and opportunity for critically modeling and testing theoretical models against recently obtained DIII-D experimental data and planning for the FY 2011 DIII-D Experimental Campaign:

1) An early draft of the FY 2011 Joint Research Target stated "The goal of the joint theory-experiment milestones is to understand the physics mechanisms responsible for the structure of the pedestal enabling the development of a predictive capability."

2) Pedestal plasma transport plays a significant role in determining the H-mode pedestal structure in transport quasi-equilibrium (just after an L-H transition or ELM) and perhaps the pedestal evolution into an ELM.

3) The HEP BE Princeton H-mode workshop paper (UW-CPTC 09-10, accessible from http://www.cptc.wisc.edu) presented estimates of the possible roles of many types of transport models in one DIII-D pedestal (98889) – but was inconclusive in many respects. Additional physics effects such as KBMs and ion orbit losses may also be important.

4) The present DIII-D experimental campaign will be concluding in April 2010, followed by a year in which DIII-D will not be operating; a new DIII-D Experimental Campaign will begin in early 2011.

WORKSHOP TIME FRAME: WHAT SHOULD WE DO THIS YEAR?

Workshop Objectives

- **General:**

  1) Discuss and identify critical pedestal plasma transport theory and modeling issues for comparisons with DIII-D pedestal structure experimental data over the next year.

  2) Identify measurements and experiments that could be made in the FY 2011 DIII-D Experimental Campaign to test critical physics issues in pedestal theories and models.

- **Critical "Pedestal Structure" Issues:**

  1) Pedestal height and width? — by transport? or other processes (e.g., KBM threshold)?, and what causes evolution to ELM peeling-balloning boundary?

  2) Pedestal density profile and plasma fueling? (ITER critical issue for plasma startup) — what causes the buildup?, and in particular how does top of pedestal get fueled?

- **Specific Transport Issues:**

  I: Fast quasi-saturation ($\sim$ 10 ms) of pedestal profiles $\rightarrow$ "pedestal structure"

  II: How does the density profile in the pedestal build up?

  III: Slow inward propagation of top of density pedestal (or other pedestal properties?)

  IV: Mechanism that causes precursor which precipitates ELM?

Approaches For Testing Theoretical Models

- **Levels and types of tests:**

  I: Conceptual theory — "back-of-the-envelope" estimate; is theory "in the ballpark?"

  II: Modeling — implement theory in a code and test against data from experiment.

  III: Experiment — "smoking guns" from critical tests of key theory phenomenologies (e.g., when a certain parameter is changed it should cause some specific fluctuations to grow in amplitude and cause a particular transport channel to increase).

  IV: Validation — "independent" scientist uses code to test against experimental database.

- **In this workshop we are interested in levels II and especially III.**

- **Some key pedestal experimental issues to develop tests for are:**

  1) What are the experimental signatures ("smoking guns") that indicate the transport mechanism(s) which determine the pedestal height and width (gradient scale length at middle of the pedestal $\simeq$ tanh profile fitting parameter).

  2) What key experimental tests could determine the cause(s) of the density profile in the pedestal, and the density at the top of pedestal and its inward propagation?

  3) What key plasma properties are evolving to precipitate ELMs, in addition to the peeling-ballooning instability boundary?

Objectives Of This Synopsis

1) Group theory models into categories of key pedestal transport issues.

2) Identify next steps in testing the various theory and modeling issues.

3) Identify key signatures and/or predicted parameter scaling of various models that can be tested against DIII-D data.

4) Recommend a theory and modeling-based prioritization of issues to be tested against DIII-D data and identify what needs to be done to develop meaningful experimental tests.

DESIRED WORKSHOP OUTCOME: a "consensus" on the most important studies (theory, modeling, experiment) to recommend to the DIII-D program for testing key aspects of relevant theory models of pedestal plasma transport this year.

Characteristics And Evolution Of DIII-D Pedestal

- **Characterizations of the profiles and evolution of pedestals in DIII-D have been documented in Groebner et al, NF 49, 045013 (2008), Beurskens, Osborne et al, PPCF 51, 124051 (2009), Callen et al, HEP BE H-mode workshop paper (UW-CPTC 09-10).**

- **The characteristics and evolution of pedestals in DIII-D that lead to long period Type I ELMs (e.g., in 98889 that HEP BE analyzed) and some key questions are:**

  1) Fast early stage ($\sim$ 10 ms) — pedestal density and temperature profiles evolve quickly, then "quasi-saturate" (causes?).

  2) Slowly evolving stage ($>$ 10 ms $\rightarrow$ ELM) — mainly top of pedestal (density mainly?) slowly increases and moves inward (cause?).

  3) Final stage (ELM crash) — eventually an ELM occurs (? on "precursor" that precipitates ELM).

- **While not all DIII-D pedestals have this multi-stage character, we concentrate on this depiction because it seems plasma transport plays important roles in its various phases and the near-steady conditions in the slowly evolving phase facilitate transport analyses.**

Key Pedestal Transport ISSUES

I. PEDESTAL WIDTH?

II. DENSITY BUILDUP?

III. SLOW INWARD GROWTH OF PEDESTAL?

IV. ELM "PRECURSOR?"

Criteria For Prioritization Of Issues To Address

- **Importance to:**

  a) 2011 Joint Research Target (pedestal structure, predictive capability),

  b) DIII-D programmatic objectives (pedestal height and control, amelioration of ELMs and their effects), and/or

  c) ITER (pedestal height and width, ELM control, density buildup and control).

- **Feasibility:**

  a) Testable theory or modeling hypothesis with quantifiable key parameter(s),

  b) Diagnostics with sufficient spatial and temporal resolution, and

  c) Experimental tools (NBI, ECH, ...) that can be used to vary key parameters.

- **Commitment of sufficient resources:**

  a) theory — development of key criteria and responsiveness to questions that arise,

  b) modeling — relevant codes available and commitment to run relevant cases,

  c) experiments — machine time with key diagnostics measuring responses to changes in critical parameters, and

  d) data consolidation (for assessing results and modeling studies) — people time of key experimentalists.

Suggested Prioritization Of Studies For Issues I–IV

I. PEDESTAL WIDTH? — What physical process(es) cause the pedestal to "saturate" in $\sim$ 10 ms? In particular, what determines the "pedestal width," i.e., gradient scale length near the mid-point ($\rho_N \sim 0.98$, $T_e < 400$ eV) of the pedestal from the tanh fit, of that initial pedestal structure?

1) KBMs? — are KBM-type fluctuations observed (with BES?, DBS?) $\sim$ 10 ms after an ELM or L-H transition and do they cause threshold-type transport or intermittency in pedestal pressure profile evolution to the initial "quasi-saturation;" need TGYRO, TGLF etc. predictions of KBM instability thresholds and nonlinear saturation and effects; then, use fluctuation diagnostics to look for predicted KBM fluctuations ($n \sim 30$?, $\sim$ coherent structures?, fast de-correlation rate?) with BES and DBS diagnostics.

2) Paleoclassical transport? — are the paleoclassical predictions for the pedestal width parameters L_{Te}/a and L_{ne}/a borne out (as minima) in magnitude and scaling? Test by decreasing resistivity and hence magnetic field diffusivity [via decreasing $Z_{\rm eff}$ or increasing T_e at constant n_eT_e and $P_e(1)$?] to see if L_{Te}/a increases as paleoclassical model predicts.

3) Other fluctuations? — need compelling case from theory (TGLF etc.) and/or diagnostics (BES?, DBS?) that some other fluctuations grow up in $\sim$ 10 ms AND cause sufficient transport to "saturate" pedestal profile in steepest gradient region ($\rho_N \sim 0.98$).

4) Next step would be two mechanism model in which a preceding mechanism determines the pedestal steepest gradient region, but plasma transitions to a different mechanism (ETG, ITG, DTEM or ?) at the pedestal top going into core plasma $\rightarrow$ profile curvature.

Suggested Prioritization Of Studies For Issues I–IV (cont'd)

II. DENSITY BUILDUP? — What process(es) govern the buildup (in $\lesssim$ 10 ms) of the density profile structure in the pedestal region? Explore by measuring (via reflectometry) the pedestal density buildup just after an L-H transition (or an ELM?) and use modeling codes to test various models.

1) Density pinch? — is the density buildup as fast as pinch-type models imply? (i.e., faster than via the neutral recycling source?); need good well-characterized density profile evolution (via reflectometry) after an L-H transition (or perhaps an ELM) and good determination of the neutral recycling into the pedestal region; will need detailed dynamic modeling (via modeling codes run predictively) of the $\sim$ 10 ms density buildup.

2) Neutral fueling alone? — challenges to this model are how to explain the often observed density "ears" at the top of pedestal and why H-mode plasmas absorb almost all neutrals recycled into them (dominantly plasma effect not edge source issue?); probe with variety of fueling techniques (gas puffing, edge pellet injection), perhaps by comparisons with C-Mod and NSTX.

3) Density and temperature of neutrals in pedestal? — need (new, e.g., LIF) measurements of density and temperature of neutrals in the pedestal region plus divertor region plasma and neutral diagnostic results for specific discharges made available to modeling codes (GTEDGE, SOLPS, UEDGE) so they can properly quantify the neutral source.

4) Other possible models? — poloidal flux transient effects? (explore possible magnitude via current ramps and transient modeling); intermittency in the rate of density buildup? (indicative of an instability hovering near its threshold conditions?).

Suggested Prioritization Of Studies For Issues I–IV (cont'd)

III. SLOW INWARD GROWTH OF PEDESTAL? — What causes the continuing slow ($\gg$ 10 ms) growth in the pedestal pressure (mainly density?) at the top of the pedestal and its propagation further into the core plasma?

1) Possible "simple" processes — experimentally identify if this is caused by core NBI fueling (vary mix of NBI, ECH?), a pinch effect (vary T_e and $Z_{\rm eff}$ at top of pedestal to vary paleoclassical pinch, explore trace impurity pinches), or current profile evolution (use current ramps or ECCD to change current profile evolution at $\rho_N \sim 0.85$?); need corresponding modeling studies for quantitative tests of models, preferably before attempting experimental tests. Should distinguish between density and temperature evolution.

2) Flux-gradient landscape — need to develop "'S-curves" of the heat and particle fluxes versus their temperature and density drives (like Hubbard work on C-Mod but with temperature and density simultaneously); add peeling-ballooning boundaries?; probe via increasing/decreasing core heat and particle sources, and following the gradient responses from L-H transitions through slow pedestal growth and on to an H-L back transition; hysteresis in this curve would be indicative of interplay of fast (core), slow (pedestal) transport mechanisms and is of generic interest; does pedestal front grow inward at a rate proportional to (normalized drive)$^{1/2}$ $(D_{\rm resid}\, t)^{1/2}$ as one-fluid theory predicts?

3) KBMs — do these instabilities continue to "mold" the pressure profile as the core plasma heating and (NBI) particle sources continue to "pump up" the core plasma? are KBM-type fluctuations observed (via BES, DBS) in the top of the pedestal and do they cause the pressure profile to grow and propagate further inward?

Suggested Prioritization Of Studies For Issues I–IV (cont'd)

IV. ELM "PRECURSOR?" — What key phenomena cause the pedestal to evolve to the peeling-ballooning boundary to precipitate Type I ELMs?

1) KBMs? — are KBM-type fluctuations observed (with BES?, DBS?) and do they cause threshold-type transport or intermittency to mold pedestal pressure profile evolution in slowly evolving stage?; need TGYRO/TGLF (or other?) predictions of difference between peeling-ballooning boundary, and KBM instability thresholds and nonlinear behavior; then, use fluctuation diagnostics to look for predicted KBM fluctuations ($n \sim 30$?, $\sim$ coherent structures?, fast de-correlation rate?) with BES and DBS diagnostics.

2) Slow profile evolution into peeling-ballooning instability? — does ELM precursor (observe with DBS) increase during its growth as $\sim e^{(t/\tau)^{3/2}}$ with $\tau \sim (\tau_A^2 \tau_{\rm evolution})^{1/3}$, as in Phys. Plasmas 6, 2963 (1999)?; determine (experimentally via up/down current ramps or ECCD? via Li beam measurements?, or via modeling?) if current profile evolution is likely to be dominant and if so, what region ($\rho_N \lesssim 0.9$?) of current profile is critical?

3) Ultimate nonlinear stage of ELMs — What is role of reconnection via island overlap of high order current sheets in latter stages?; does it produce the ultimate "disruption" in the ELM collapse?, need more understanding of BOUT (and M3D, NIMROD) simulations at higher Lundquist number plus nonideal MHD effects, and comparison with higher density more resistive ELMs (e.g., Type III ELMs and EDAs in C-Mod).

Next Tier Issues Of Lower Priority — Not Ordered

Ion orbit losses — need detailed code calculations (CPES, TEMPEST?) of carbon charge exchange spectra outside separatrix to explore these effects.

Ion heat transport — it seems lower (by factor $\sim$ 3) than interpretive experimentally inferred value; need detailed modeling evaluations with wider range of pedestals; could paleoclassical pinch reduce discrepancy?

ELM "shock" — how long after an ELM must one wait before a transport analysis becomes appropriate; use magnetics, reflectometry and DBS to determine how long it takes the plasma to "settle down;" BOUT++ and M3D, NIMROD simulations could provide physics insights about key processes and for how long they are extant.

Top of T_e pedestal — is it determined by where ETG and paleo χ_e are equal (for T_e)?; need measurements of ETG fluctuations (DBS?) at top of pedestal region as T_e changes there (is η_e a critical parameter inducing intermittency in n_e, T_e profiles?); need good scaling formula (from TGLF?) for ETG χ_e plus better paleo module in ONETWO.

Top of T_i pedestal — is it determined by where ExB flow shear stabilizes low k (ITG) turbulence (for T_i probably, ? on n_e, T_e)?; need experimental tests varying flow shear at top of pedestal (via co/counter NBI?, NRMF NTV effects?); TGLF calculations before experiment would be helpful.

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