Transport and Turbulence TSG 5-year Plan and Diagnostic Prioritization

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On behalf of T&T TSG

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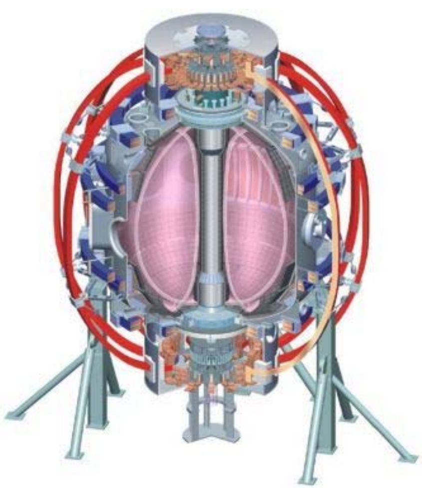

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Overview

- Need to develop T&T goals in the 5-year plan for FY14-18
  - The major goal of NSTX-U program is to explore ST as a viable concept for FNSF/Pilot
  - T&T TSG needs to develop predictive capability for the performance of FNSF/Pilot (both 0D and 1D)
- Need to prioritize related new diagnostics accordingly
  - BES upgrade (δn, δv_{pol})
  - UF-CHERS (fast δT_i and δv_{tor})
  - Doppler backscattering, DBS (δn, δv_{pol})
  - Radial polarimeter (δB)
  - Cross polarization scattering (δB)
  - Phase contrast imaging, PCI (δn)
  - GPI upgrade (δn, $\delta v_{\perp}$) (presentation)
  - New high-k (δn) (presentation)
  - FIReTIP upgrade (δn) (presentation)
  - Reflectometer upgrade (δn) (presentation)
  - ME-SXR (δT_e, δn - transport) (presentation)
  - Profile reflectometry ($n_{e,}$ transport)
  - CXIS ($T_{i,e}$, $v_{\theta,\varphi}$, transport)

Approach

- Two thrusts for the 5-year plan
  - Identify instabilities responsible for anomalous electron thermal, momentum, and particle/impurity transport in L and H mode plasmas
  - Establish and validate reduced transport models (0D and 1D) for NSTX-Upgrade plasmas
- Three spatial regions of concern in NSTX NBI H-modes relevant to NSTX-U and beyond
  - Core gradient region (r/a~0.4-0.9) – inside pedestal where significant gradients in thermal plasma exist (→microinstabilities predicted unstable) (also applies to L-mode plasmas)
  - Core flat region (r/a<~0.4) – approaching magnetic axis where thermal gradients become small (→microinstabilities predicted stable) but significant fast ion pressure ($P_{fast}/P_{tot} \leq 50\%$) (Alfvenic modes important)
  - Pedestal (r/a>0.9) - pedestal height plays an important role in global H-mode confinement (BP TSG)

Two thrusts to address core gradient region (for both L and H plasmas)

- Identify instabilities responsible for anomalous transport (thermal, momentum, and particle/impurity)
  - Measure scaling of local transport (χ_e, χ_φ, D_d, D_c) with relevant parameters (ν_e, I_p, B_T, γ_E, s, q, …)
    - Steady state analysis and perturbative experiments
  - Measure turbulence characteristics (δn_e, δB_r, …) and scaling with parameters
    - k_θ spectra (k_r~0) highest priority, most relatable to transport
    - Multi-scale spectrum of modes possible ($k_\theta \rho_s$=0.1-20+), would like complete k-space coverage
    - Focus on parameter regimes where instabilities are expected to be isolated
      - Use 2nd NB and 3D field coils as controlling tools
  - Compare with linear and non-linear predictions to discriminate theoretical modes
    - k spectra and transport fluxes
- Establish and validate reduced transport models for NSTX experiments
  - Validate existing 0D confinement scalings (ν_e, β_e, I_p, B_T, …) $\rightarrow$ distinguish W_{core} from W_{ped}
  - Measure 1D local transport scaling, develop profile database (for most relevant scenarios)
  - Develop transport models (for most relevant scenarios)
    - Start with analytic fits to linear and non-linear GK simulations (*a la* IFS-PPPL for ITG) for μ-tearing and ETG
    - Validate (and update as necessary) TGLF against gyrokinetics for NSTX/NSTX-U parameters
    - Validating neoclassical transport models seems important
  - Validate predictive transport simulations with 0D confinement scaling (empirical pedestal scaling? Overlap with Boundary Physics) for NSTX/NSTX-U/MAST
  - Validate predictive transport simulations with 1D profiles for NSTX/NSTX-U/MAST
  - Use predictive transport simulations for FNSF/Pilot

FY14 Goals

- BES is expected to be available; high-k is not likely to be available; 2nd NBI available; modest increase in Bt and Ip -> focus on low-k turbulence
- Implement high-k scattering in FY14
- Thrust 1:
  - Measure low-k turbulence in H-mode plasmas in lower ν^* regime with higher Bt and Ip with transport measurements and compare with low-k gyro-kinetic simulations and neo-classical transport calculations
    - Determine whether ion thermal transport is still neo-classical
    - Determine transport channels correlated with low-k turbulence
- Thrust 2:
  - Validate/establish 0D confinement scalings with higher Bt, Ip and lower ν^*

FY15 Goals

- High-k scattering system is available; expecting higher Bt and Ip (lower ν^*)
- Thrust 1:
  - Measure high-k turbulence and B_r fluctuations in H-mode plasmas a wide range of ν^* by varying B_T and I_p together with thermal transport measurements and compare with high-k gyro-kinetic simulations
    - Exploring the parametric ranges for the correlation between e-transport and high-k turbulence/Br fluctuations
- Thrust 2:
  - Validate 0D confinement scalings with even higher Bt, Ip and lower ν^*
  - Use validated 0D confinement scaling to predict 0D performance of FNSF/Pilot
  - Start analytic fits to linear and non-linear GK simulations (*a la* IFS-PPPL for ITG) for μ-tearing and ETG

FY16-17 Goals

- Expecting real-time current profile control
- Thrust 1:
  - Identify responsible k ranges for different transport channels in H-mode plasmas by correlating measured local transport trends (against ν_e, I_p, B_T, γ_E, s, q, …) with low-k and high-k measurements
  - Using Steady state transport analysis and perturbative experiments
  - Compare with gyrokinetic simulations to identify responsible instabilities
- Thrust 2:
  - Investigate flow shear scaling with Bt, Ip and lower ν*
  - Validate (and update as necessary) TGLF against gyrokinetics for NSTX/NSTX-U parameters
  - Validate predictive transport simulations with 0D/1D confinement scaling for NSTX/NSTX-U/MAST

FY18 Goals

- Expecting rotation feedback control
- Thrust 1:
  - Identify responsible k ranges for different transport channels in L-mode plasmas by correlating measured local transport trends (against ν_e, I_p, B_T, γ_E, s, q, …) with low-k and high-k measurements
  - Using Steady state transport analysis and perturbative experiments
  - Compare with gyrokinetic simulations to identify responsible instabilities
- Thrust 2:
  - Investigate confinement scaling with rotation feedback control
  - Investigate e-ITB scenario scaling utilizing real-time current profile control
  - Use predictive transport simulations for FNSF/Pilot

Turbulence – What diagnostic should be used to measure?

- ITG - χ_i, χ_e, χ_φ, D
  - driven by ∇T_i; suppressible by ∇n, E×B shear (ion thermal transport often neoclassical)
  - δn_e - $k_\theta \rho_s$ ~0.2, $k_r \rho_s$~0, isotropic eddies, L_θ~L_r~5-8 ρ_s (BES, high-k)
- TEM - χ_e, χ_φ, D
  - Driven by ∇T_e, ∇n_e; suppressible by E×B shear, reduced by collisionality
  - δn_e - Similar to ITG, maybe slightly higher $k_\theta \rho_s$~0.5+, especially electron heat transport (BES, high-k)
- KBM - χ_i, χ_e, χ_φ(?), D
  - Driven by $\beta' = \beta \cdot a/L_p$; suppressible by E×B shear
  - δn_e - ~similar to ITG, narrower k_θ spectrum (broader L_θ) (BES, high-k)
- **ETG** - χ_e
  - Driven by ∇T_e, low s/q; suppressible by ∇n_e, Z_{eff}, E×B shear; weak dependence on collisionality
  - δn_e - $k_\theta \rho_s$~10, $k_r \rho_s$~0, anisotropic, L_θ~3*L_r~0.5 ρ_s (high-k, …)
- **MT** - χ_e
  - Driven by ∇T_e, increasing s/q, sufficient β_e, peak around $Z_{eff} \nu_{ei} / \omega_{*e}$~5; suppressible by E×B shear
  - δn_e $k_\theta \rho_s$~0.2, $k_r \rho_s$ larger, anisotropy opposite to ETG **(maybe not BES, …)**
  - δB_r $k_\theta \rho_s$~0.2, $k_r \rho_s$~0, very broad, strongly ballooning, $\delta B/B_0$<1% **(polarimetry of some sort?)**

- **BES** and **high-k** are high priority for almost all modes (ITG/TEM/KBM/ETG) and are expected to be available
- **Not clear what will be useful for microtearing, both δn and δB_r**

Transport – What measurements are required to discriminate theoretical mechanisms?

- Local steady state transport coefficients vs. parameter scans
  - TS, CHERS, TRANSP analysis
- Local perturbative measurements, flux-gradient relationships
  - Impurity seeding, ME-SXR
  - Heat/cold pulse propagation, ME-SXR
  - n=3 braking and 2nd NBI, CHERS, UF-CHERS
  - SGI, reflectometery
- What diagnostics are needed to validate transport models?
- Seems like biggest new diagnostic priority is identifying modes present through turbulence measurements
- What more transport tools do we need?

Same two thrusts for core flat region

- Identify instabilities responsible for anomalous transport (thermal, momentum, and particle/impurity)
  - Fast δn_e (δT_e, δB ?) diagnostics for NSTX-U, > 2MHz required?
  - Test predicted transport with direct measurements of pert. transport
  - Upgraded reflectometry: can it access core in NSTX-U H-modes?
  - BES: SNR in core of NSTX-U, any capability to increase bandwidth?
  - Any potential for 1-2MHz+ fluctuation diagnostics other than δn_e
- Establish and validate reduced transport models for NSTX experiments
  - Belova HYM model to predict instabilities, validate mode structure with diagnostics, model predicted modes for NSTX-U, FSNF
  - Gorelenkov ORBIT model uses *AE eigenmodes to predict transport
  - α–driven instabilities may play a transport role in next-step devices, how do we model these?
  - Will conventional turbulence become important in core NSTX-U H-modes?

Core gradient region – diagnostic priorities

EXPECTING

- Profile and transport diagnostics: TS, CHERS, etc…., TRANSP

Diagnostics for measuring turbulence, fast profile changes for direct perturbative transport measurements

- ME-SXR/Interferometry/Reflectometry(upgraded)
- BES
- High-k

NEW DIAGNOSTIC PRIORITIES

- Measure δB_r perturbations on outboard side ($k_\theta \rho_s$~0.05-1, $k_r \rho_s$~0+)
- Measuring continuous range of k_θ density spectra, $0.1<k_\theta \rho_s<30$ (k_r~0+)

- For *AE studies, δn_e, δT_e, δB with sufficient bandwidth for radial/poloidal mode structures
- If conventional turbulence becomes important for r/a < 0.4, same fluctuation diagnostics needed as the outer plasma: high density, NBI attenuation may be an issue on NSTX-U

Same two thrusts for pedestal region (overlap with Boundary Physics)

- Identify instabilities responsible for anomalous transport (thermal, momentum, and particle/impurity)
  - 3D GPI
  - Doppler backscattering
  - Langmuir and magnetic probes
  - …
  - Theory – drift waves, P/B, paleoclassical

- Establish and validate reduced transport models for NSTX experiments
  - Traditional drift modes - ITG/TEM/KBM/MT/ETG (?)
  - Peeling/ballooning (Snyder tests)
  - Paleoclassical (Callen tests)

<u>Overlap with Boundary Physics</u>

- SOL physics - Midplane and divertor turbulence, zonal flows, L-H transition
- III-1. Measure and interpret **energy and particle transport and turbulence in the Scrape-Off-Layer (SOL), and understand the** linkage between SOL parameters and the peak heat flux to the divertor to develop means for **heat-flux mitigation and control.**
- III-3. Measure and understand **boundary plasma response to applied 3D magnetic field perturbations and other perturbations** designed to control edge plasma transport and stability.